H14-167

FLUXSAP 2010 EXPERIMENTAL CAMPAIGN OVER AN HETEROGENEOUS URBAN ZONE, PART 2: QUANTIFICATION OF PLUME VERTICAL DISPERSION DURING A GAS TRACER EXPERIMENT USING A MAST AND A SMALL TETHERED BALLOON

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Abstract: FluxSAP 2010 is the first of two experimental campaigns aiming at quantitatively assessing the contribution of urban vegetation in the sensible heat and water vapour fluxes, over a heterogeneous area including buildings, semi-impervious surfaces, low and high vegetation. In this framework, we have performed a gas tracer experiment to quantify the vertical expansion of a plume, using a mast and a small tethered balloon as carriers for the tracer samplers. The first goal of this experiment is a better understanding and quantification of plume vertical dispersion in an urban area as a function of the atmospheric turbulence. The second objective is to assess atmospheric dispersion models and footprint models in urban areas.

Key words: *Urban environment, atmospheric dispersion, experimental campaign.*

INTRODUCTION

With about fifteen partners, the IRSTV is coordinating a large federative research program - VegDUD (2010-2013) funded by the French National Research Agency - on the assessment of the role of vegetation in the sustainable urban development. In the framework of the experimental part of this program, called FluxSAP (Mestayer *et al.*, 2011), a gas tracer experiment was performed, from 18 to 27 of May 2010, in a suburban district of the city of Nantes (France). The first objective of this experiment is to better understand and quantify the plume vertical dispersion in an urban area as a function of the atmospheric turbulence. The second objective is to assess atmospheric dispersion models and footprint models in urban areas. For that purpose, 30 releases of tracer gas (SF_6) have been performed from several emission points that were chosen depending on the wind direction. The various atmospheric stability conditions (from neutral to convective) encountered during the campaign allow documenting the influence of the distance from the release point and of the urban density on the plume dispersion. The data are analysed and compared with three Gaussian models, two from the first generation (Briggs, 1973; Doury, 1976) and one from the second generation, ADMS 4.0 (CERC, 2009).

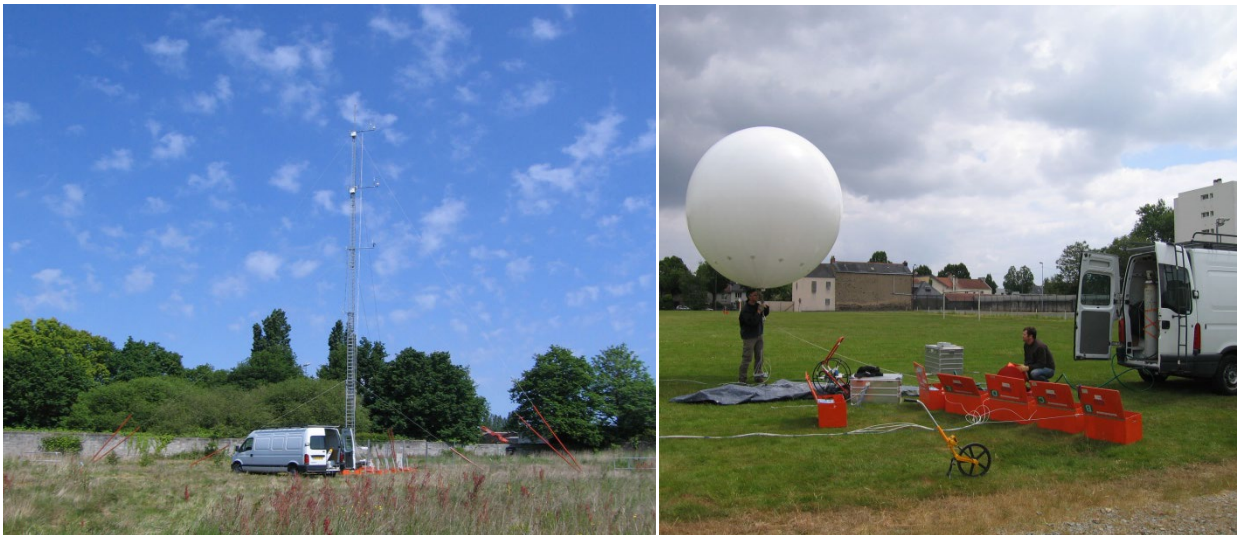
This paper presents the experimental set-up, the first results, and the preliminary conclusions on the measurement feasibility over an urban heterogeneous district.

METHOD: EXPERIMENTAL SET-UP

The SF_6 was chosen as the tracer gas because it is exclusively human-induced and is present in the atmosphere at very low concentration (about 8 ppt). During our experiment, the generation rate was between 0.1 and 5.9 g per second for each of the thirty emissions. The release system comprised a SF_6 bottle (Messer, France) connected to a mass flow meter (Sierra GFM 67). A tube was used to generate the gas release at 1.5 m above ground. A fan was also used in front of the release tube to homogenize the gas in the atmosphere. It was imperative to check the release rate all through the release process, as this rate would be specifically used to normalize the results and calculate the Atmospheric Transfer Coefficient, ATC (see after equation 1). During this measurement campaign, we released SF_6 between 3 and 6 times a day, for duration of 10 minutes.
The vertical distribution of the gas concentration has been obtained by setting the sampling points along a 27 m meteorological mast and under a 100 m high small tethered balloon (Figure 1). To collect air samples, small tubes have been placed at 5 levels along the mast and the halyard of the tethered balloon and connected to a specific device (DIAPEG) including a pump and a specific bag. The precise location of the balloon was given by GPS in the horizontal coordinates and by difference of pressure in the vertical direction (z axis). The sampling time varied between 10 and 30 minutes and the transit time of the plume was determined by real time measurements of SF_6 (each 2 minutes).

SF_6 analyses were conducted by Gas Chromatography with Electron Capture Detector (GC-ECD). Analytical instrumentation consisted of an AUTOTRAC 101 Tracer Gas Monitor (Lagus Applied Technology Inc., TRACERTECH). The limit of detection is 30 ppt and the accuracy of the measurement is generally 3%. The time required to analyse one sample was 2 minutes. About 50 samples were analysed during each release experiment, with calibration before and after analyses, between 30 ppt and 100 ppb. All analytical instrumentation was placed in a laboratory truck located near the mast or the balloon. Analyses were carried out immediately after sampling, providing results about 2 hours after the experimental release.

The micrometeorological measurements were done with two sonic anemometers (Metek USA-1) located on the mast at 21 m and 26 m high.



(a) (b)

Figure 1: Meteorological mast (a) and tethered balloon (b).

RESULTS AND DISCUSSION

Experimental conditions during the campaign

The experimental campaign took place over two weeks in spring 2010. The campaign started with anticyclonic conditions (May 18) and ended with a depression system (May 27). These meteorological conditions imposed the locations of the SF_6 emissions at the north-east of the measurement site during the first week and at the south-west during the second week (Figure 2). Among the 30 emissions, only 25 are exploitable because the plume has not been detected in the experimental field for 5 of them (measurements were below the detection limit). During this campaign we have done 14 flights with the tethered balloon. The minimum and maximum distances between the emission point and the mast or the balloon was 20 m and 1150 m respectively with an average distance of 356 m (Table 1).

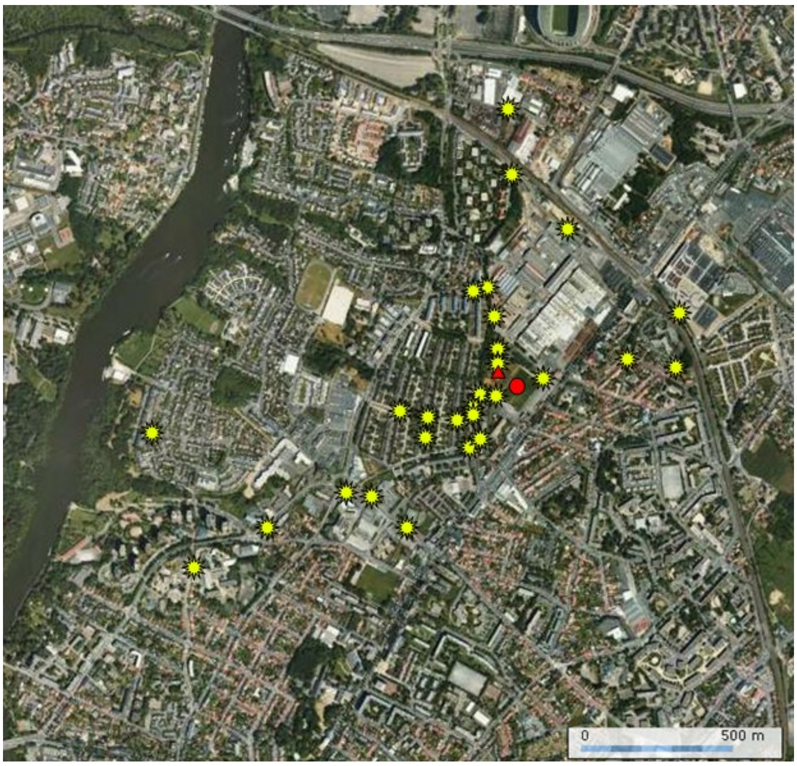


Figure 2: Location of the 30 emission points (stars), the mast (triangle) and the balloon (circle).

The horizontal wind speed varied between 2.3 and 5.2 m s^{-1} (average 3.5 m s^{-1}). The micrometeorological parameters, friction velocity (u_*) and sensible heat flux (H) were respectively in average 0.6 m s^{-1} and 154 W m^{-2}. During the period the Pasquill stability class varied between B and D.

Table 1: Experimental conditions during the campaign (min: minimum, ave: average, max: maximum).

Distance from emission (m) (min/ave/max)	U (m s^{-1}) (min/ave/max)	u_* (m s^{-1}) (min/ave/max)	H (W m^{-2}) (min/ave/max)	Pasquill stability class (number of occurrence)
20/356/1150	2.3/3.5/5.2	0.3/0.6/0.9	17/154/299	B(9), C(9), D(7)

Comparisons with Gaussian models

Comparisons have been made between the measurements at different levels and the results of three Gaussian models: Briggs-urban (Briggs, 1973), Doury (1976) and ADMS 4.0 (CERC, 2009).

The Atmospheric Transfer Coefficient (ATC) is computed according to equation (1):

$$ATC = \frac{\int_{t0}^{t1} X(M,t).dt}{\int_{t'0}^{t'1} q(t).dt} \qquad (1)$$

- X(M,t): SF_6 concentration (m^3 m^{-3}), at point M;
- q(t): SF_6 release rate (m^3 s^{-1});
- t'_0, t'_1: time of beginning and end of source emission;
- t_0, t_1: time of beginning and end of measurement at M.

The comparisons of the ATC values obtained from models and measurement are presented in Figures 3, 4 and 5 for respectively Briggs-urban, Doury and ADMS 4.0.

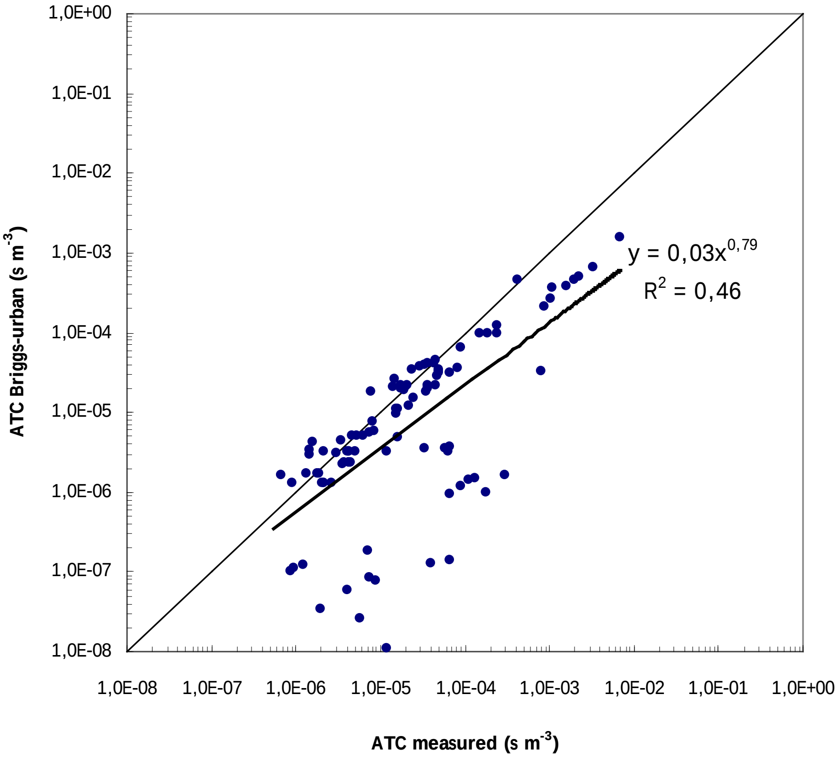


Figure 3: ATC Briggs-urban versus ATC measured (bold line: power fit).

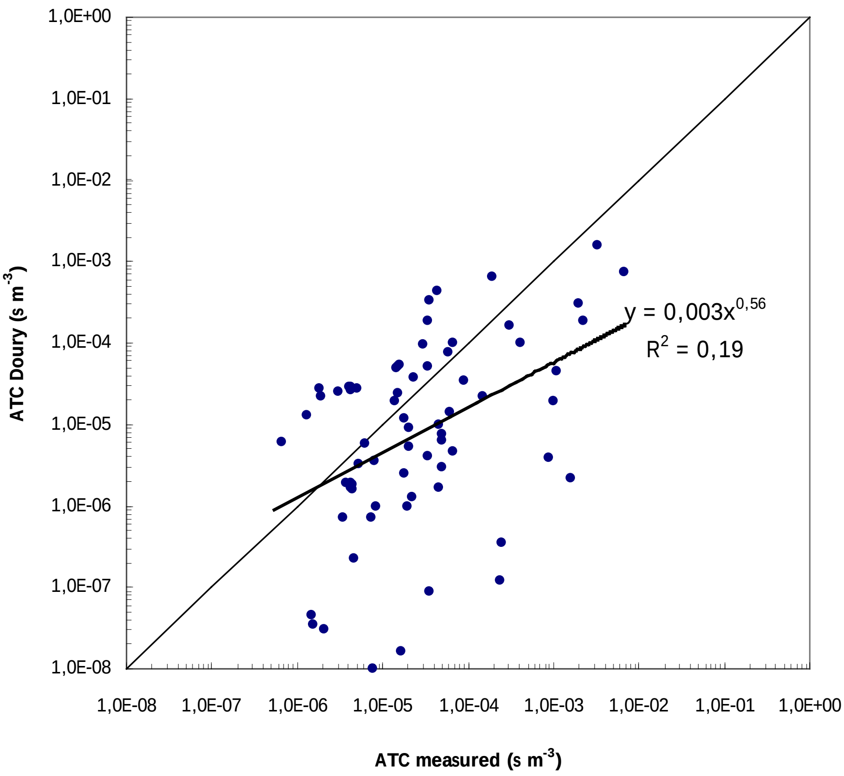


Figure 4: ATC Doury versus ATC measured (bold line: power fit).

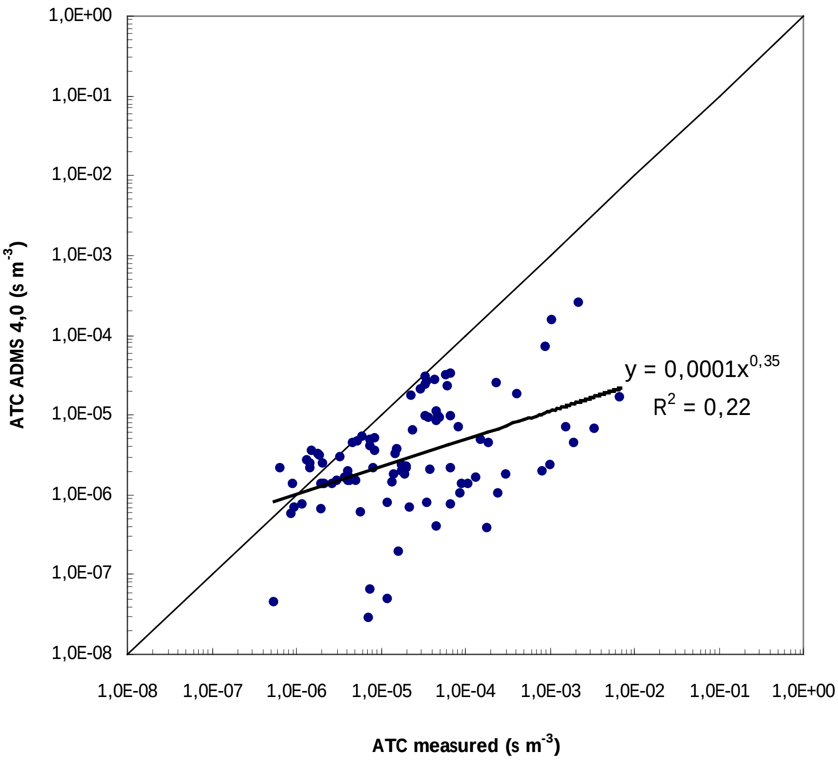


Figure 5: ATC ADMS 4.0 versus ATC measured (bold line: power fit).

The best fit between model results and experimental data is obtained with the Briggs-urban model. Large discrepancies between measurements and Doury or ADMS 4.0 models are observed with highly scattered values. The number of measured data above the detection threshold of our device (ATC > 10^{-8} s m^{-3}) is 107 (including all the sensors located along the mast or under the balloon). Briggs-urban and ADMS 4.0 models predict a number of ATC values greater than the threshold value in quite good agreement with measurements (99) while the Doury model underestimates this number (69) (Table 2). This can be explained by the fact that the Doury model predicts a too narrow plume compared to the reality.

Table 2: Benchmarking models (Briggs-urban, Doury and ADMS 4.0).

Model	Number of ATC values above 10^{-8} s m^{-3}	Average ratio (measurement / prediction)	FAC 2 (%)	FAC 5 (%)
Briggs-urban	99	35	57	77
Doury	69	91	16	43
ADMS 4.0	99	51	29	55

The average ratio between the measurements and the model results indicates that Briggs-urban model is still the most suitable. The statistical indicators FAC2 and FAC5 can also be used to analyse model results (Hanna *et al.*, 1993):

$$FAC2: \frac{1}{2} \leq \frac{C_p}{C_0} \leq 2 \qquad (2)$$

$$FAC5: \frac{1}{5} \leq \frac{C_p}{C_0} \leq 5 \qquad (3)$$

where C_p and C_0 are respectively the predicted and the observed concentrations. The factor FAC2 (or FAC5) corresponds to the fraction (in %) of C_p values that are within a factor 2 (or 5) compared with C_0. Once again, the Briggs-urban model gives the best results while the ADMS 4.0 model seems better suited to our configuration than the Doury model.

PERSPECTIVES

The analysis of the results shows that this kind of tracer experimental campaign is useful to assess and improves simple atmospheric dispersion models. In order to obtain more comprehensive information about the dispersion processes occurring in this complex urban area, the next step will be to perform detailed simulations of some release episodes using the large-eddy simulation model ARPS (Xue *et al.*, 2000). This atmospheric code has been modified to represent the unsteady dynamics of the flow inside the urban canopy and the main transfer processes with the atmosphere above (Maché *et al.*, 2010). From the turbulent flow computed by ARPS, it is possible to estimate both the concentration of pollutant and the scalar fluxes within and above the canopy. Since the footprint concept refers to the relative contribution of each element of the surface area to the locally measured quantities such as the concentration or the scalar fluxes (Vesala, 2008), our results will also be used to develop a footprint model specifically adapted to the area of interest. The footprint model will be utilized as the basis of interpretation of humidity and heat fluxes measured during the FluxSAP 2010 in order to estimate the role of the vegetation on the urban microclimate. In 2012, a new experimental campaign (FluxSAP 2012) will be conducted in Nantes.

REFERENCES

Briggs G.A, 1973: Diffusion estimation of small emissions. Contribution No.79. Atmopsheric Turbulence and Diffusion Laboratory, Oak Ridge,TN.

CERC, 2009: ADMS 4.0 4 User Guide. Cambridge Environmental Research Consultants (CERC).

Doury A, 1976: Une méthode de calcul pratique et générale pour la prévision numérique des pollutions véhiculées par l'atmosphère, Commissariat à l'énergie atomique, Rapport CEA R 4280 (Rev 1), Saclay, France, 37pp.

Hanna S.R., Chang, J.C. and Strimaitis D.G, 1993: Hazardous gas model evaluation with field observations, *Atmospheric Environment*, **27A**, 2265-2285.

Maché M., I. Calmet, J.-F. Sini, 2010: Analysis of the dynamical interactions between atmosphere and urban canopies of different densities using a drag force approach, 13th International Conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes (HARMO13), 1-4 june, Paris, France, 668-672.

Mestayer P., Chancibault K., Lebouc L., Letellier L., Mosini M.L., Rodriguez F., Rouaud J.M., Bagga I., Calmet I., Fontanilles G., Gaudin D., Lee J.H., Piquet T., Rosant J.M., Sabre M., Tétard Y., Brut A., Selves J.L., Solignac P.A., Dayau S., Irvine M., Lagouarde J.P., Kassouk Z., Launeau P., Connan O., Defenouillère P., Goriaux M., Hébert D., Letellier B., Maro D., Najjar G., Nerry F., Quentin C., Biron R., Cohard J.M., Galvez J. and Klein P, 2011: Fluxsap2010 experimental campaign over an heterogeneous urban zone, part 1: heat and vapour flux assessment, HARMO 14, 2-6 Oct. 2011, Kos Island, Greece. This issue.

Vesala T., Kljun N., Rannik U., Rinne J., Sogachev A., Markkanen T., Sabelfeld K., Foken T. and Leclerc M., 2008: Flux and concentration footprint modelling: State of the art, *Environmental Pollution*, **152**, no. 3, 653 – 666.

Xue M., K. K. Droegmeier & V. Wong, 2000: The Advanced Regional Prediction System (ARPS): A multi-scale nonhydrostatic atmospheric simulation and prediction model. Part I: Model dynamics and verification, Meteorology and *Atmospheric Physics*, **75**, 161-193.