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Vertical and horizontal concentration profiles from a tracer experiment in a heterogeneous urban area

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ABSTRACT

An atmospheric tracer dispersion study was conducted in a heterogeneous district of the city of Nantes, France, in May 2010 and June 2012 during the measurement campaigns FluxSAP. Vertical (0–100 m) and horizontal (≈300 m) profiles were measured at distances of 20 to 1200 m from the tracer gas release location. The vertical profiles show vertical mixing occurring progressively with distance: the 0–100 m air column is homogenous beyond 600 m, whereas at shorter distances a maximum of concentration is observed, either at ground level for distances less than 200 m, or at altitude for intermediate distances. Our measurements are compared with the Briggs-urban model which may be used in emergency situations: the model gives coherent results with our measurements in terms of vertical and horizontal dispersion parameters but we observe concentration differences up to an order of magnitude between model and measurements. Based on our results we propose new relationships for the horizontal and vertical dispersion parameters for distances from 0 to 1 km. For emission–measurement distances above 1 km, differences appear between the trends deduced from our measurements and those of the Briggs-urban model: it will be necessary to acquire data at greater distances, 2000 m and more, to verify and validate these trends.

1. Introduction

To qualify existing atmospheric dispersion models, numerous experimental campaigns have been conducted in relatively simple dispersion conditions, mainly in rural, flat or slightly hilly environments ("Prairie grass", "BNL", "TVA" campaigns; Barad (1958), Carpenter et al. (1971), Briggs (1973), Gifford (1976)). However, more than half of the population in the world currently lives in urban environments and nearly 5 billion people (i.e. 60% of the population) will live in urban areas in 2030 (UN, 2007). In the event of a chemical or nuclear accident or terrorist attack near an urban centre, it is necessary to predict correctly the dispersion of a pollutant in specific heterogeneous environments. It is probable that conventional fast operational models, validated in flat uniform landscapes, are not well adapted to urban environments, while more sophisticated models are not adapted to provide a rapid response in emergency situations when impact forecasts need to be predicted in a short time with poorly documented input data. For this reason, it is useful to conduct experimental campaigns that provide information on the behaviour of pollutant releases in urban landscapes.

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In addition, although it is logical to think that studies on flat ground are reproducible from one area to another, each urban environment has its unique particularities depending on the close environment, the overall configuration of the city and the situation within the city (downtown, semi-urban, street canyons …). Urban environments thus vary from one district to the next and even more so from one city to the next. Pollutant dispersion is dependent on the local wind and turbulence conditions. The need for the acquisition of urban atmospheric dispersion data sets has been recognized by the scientific community since a few years and several field campaigns have been completed in the United States and Europe: Urban 2000 in Salt Lake City (Allwine et al., 2002), Barrio Logan in San Diego (Venkatram et al., 2004), Oklahoma City (Allwine et al., 2004; Flaherty et al., 2007), BUBBLE in Basel, Switzerland (Rotach et al., 2004), CAPITOUL in Toulouse, France (Lac et al., 2008), and DAPPLE in London, U.K. (Martin et al., 2010a, b).

Despite these recent campaigns, it still appears useful to carry out field experiments to be able to estimate dispersion in different types of urban environments or complex terrain (Laiti et al., 2013). Moreover, none of these studies provided data on vertical dispersion, with the exception of Flaherty et al. (2007) for Joint Urban 2003 in Oklahoma City. This is due to the considerable efforts required by an experimental programme in an urban environment (Allwine et al., 2002), especially to deploy measurement systems at altitude to document vertical dispersion.

Two dispersion measurement exercises were conducted in May 2010 and June 2012 during the FluxSAP 2010 and 2012 experimental campaigns (Mestayer et al., 2011a,b). Our objectives were: 1) to conduct experimental tracer releases to study the horizontal and vertical mixing of a tracer in an urban area, 2) to compare our data with the output of an operational Gaussian model used in emergencies, and 3) to acquire an urban dispersion dataset to test the crisis models of IRSN (French Institute of Nuclear Safety). In this study, we place the accent on vertical dispersion. In this paper we present the FluxSAP experimental set-up, the instrumental layout, the tracer experiments, the meteorological conditions, and we analyse our horizontal and vertical dispersion results by comparison to the Briggs-urban Gaussian model (Briggs, 1973, 1985).

2. Site and campaign description

The study was conducted in the city of Nantes, a town of around 500 km^2, with a population of some 580,000 inhabitants, on the mouth of the river Loire about 75 km far from the Atlantic ocean. The atmospheric tracing experiments were carried out in the “Pin Sec” district, situated between the city centre and the ring road (Figs. 1, 2). This “Pin Sec” district is the heart of the Nantes observatory of urban environments (ONEVU), which is the long-term multidisciplinary urban observatory of IRSTV (Ruban et al., 2010). The land use is heterogeneous alternating commercial and industrial zones and individual and collective housing areas with a mean building height varying from 7 to 14 m above ground. A permanent 30 m meteorological mast (Goss soccer field, 47.24582°N, −1.52757°W) constitutes the centre of our tracing experiment campaigns and provides the main meteorological data including temperature, wind speed and direction, and heat fluxes (Fig. 3). The land use in a circle of 1 km around the mast includes 43.7% of vegetated areas (private gardens, squares, public parks), 21.2% of buildings, 18.3% of roads and 16.8% of undefined surfaces. We performed 30 tracer releases during FluxSAP 2010 from May 18–29, 2010, all in daytime, and 20 daytime and 6 night-time releases during FluxSAP 2012 between May 30 and June 5, 2012. Only 20 releases of FluxSAP 2010 and 26 of FluxSAP 2012 were retained for analysis after elimination of the emissions that led to undetectable SF_6 concentrations or values very close to the detection limit due to poor positioning or bad timing. For 25 tracer releases, samples were taken at 5 heights from 1 to 100 m under a tethered balloon, while for 21 other releases, samples were taken along the meteorological mast at heights from 1 to 25 m. Transverse dispersion was documented with 7 sampling systems at ground level up to 100–200 m on each side of the expected plume centre. Fig. 2 shows the positions of the sampling site (green dot) and tracer release points (red dots, FluxSAP 2010; white dots, FluxSAP 2012). The sampling systems at ground level and at altitude were always positioned at the same site whereas the emission position was adjusted as a function of the wind direction.

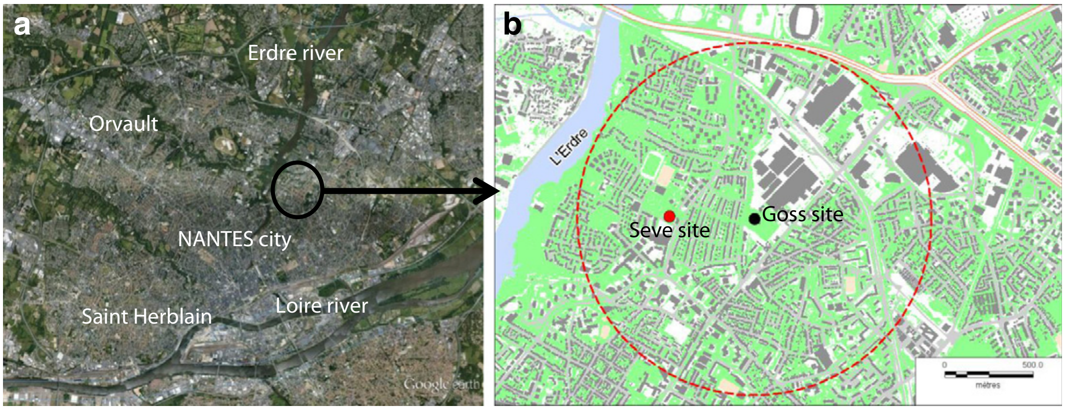

Fig. 1. (a) Aerial photograph of Nantes, showing the experimental dispersion study area (black circle), (b) position of Seve (red dot, 47.2456°N, −1.5339°W) and Goss (black dot, 47.2458°N, −1.5272°W) sites in the area (the red circle around Goss site is 1000 m in diameter).