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Significance of Canyon Effect in Condensation of Traffic Related Air Pollution in Cities

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Abstract. Ambient air pollution is still a hot and rather challenging topic of environmental management in Europe. Growing demand of transportation hinders lessening pollution levels in cities. Small scale resolution spatiotemporal measurement data are hardly available on actual levels of pollutants, therefore adequate models are needed to follow intra-city distribution of pollutants. Diverse models are available to approximate and predict transmission of the main pollutants. Inclusion of influence of city geometry such as canyon effect offers more accurate forecast, but requires more parameters and or initial data. In this paper we investigate the question how much influence does the real 3D structure of the city on spatial distribution of pollutants and hereby personal expositions. We performed in situ measurements in a real canyon-like street, in an intersection and along different roads and a roundabout in a middle-sized central European city, Győr. NO_x was chosen as air quality indicator, since it is an important ozone-precursor and mostly originates from road traffic. Correlations with actual traffic was also investigated based on detailed manual traffic counting data. Our field measurements underpin, that there are significant differences among locations even on a very small spatial scale, hence inclusion of 3D and canyon modelling are highly relevant and desirable for reliable predictions needed for environmental management of the city.

Keywords: air pollution, NOx, canyon effect, field measurement, model validation

1. Introduction

Air pollution has been a concern in several cities all around the world, as it is associated with significant adverse effects of public health. It is the top environmental risk factor of premature death in Europe. The effects of poor air quality have been felt most strongly in two main areas: harmful effects on urban populations and on ecosystems. At present, particulate matter (PM) and ground-level ozone (O_3) are the most problematic pollutants in Europe in terms of effect to human health, followed by polycyclic aromatic hydrocarbons (PAHs) and nitrogen dioxide (NO_2). In terms of damage to ecosystems, the most harmful air pollutants are O_3, ammonia (NH_3) and nitrogen oxides (NO_X). [1]

In Hungary and other central European countries overall air pollution has been decreasing in the last decade according to industrial changes started in the 1990's, and later technological changes in order to fulfil standards of the European Union. As industrial pollution decreased, traffic plays more important role in determining air condition in urban areas of Hungary. Despite that introduction of emission control ('Euro 4' [2], 'Euro IV and V'[3-4]) and technological improvements of engines and fuels lead to reduction of individual emission of vehicles, increase of number of vehicles and travelled distances continuous to retard reduction of air pollution.

Similarly to other EU countries, Hungarian Government has established a network of automatic urban air pollution monitoring sites in the second part of the 1990's. These sites provide high precision, long term data of concentrations of main pollutants and basic meteorological data (wind speed and direction, temperature, air pressure) in a 5 minutes time resolution. Data of Hungarian Air Quality Network is freely available at [5].

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More than a decade of monitoring data about main pollutants of the major European cities provide sufficient temporal data for analysis [6], however a single monitoring site for a city or a few for bigger cities are far from sufficient spatial resolution required to make reliable estimates of personal exposure. Modelling approaches are widely used to follow and predict intraurban distribution of traffic related air pollution. They are applied mainly on two different special scales. Street canyon models are aiming to describe emission and dispersion processes in a single section of a road or an intersection, including several details (e. g. wind direction, street geometry) [7, 8]. On city level more complex, but less detailed models are applied by connecting traffic simulations and emission modelling to air pollution models [9]. Complexity of the models has a primary constrains on the number of descriptive parameters and initial data needed and the computational time consumed.

Validation of models are mostly based on monitoring data or satellite measurements [10], or wind tunnel experiments [11, 12]. Real fine scale field studies (articulated sampling of a street canyon or an intersection) are rarely available. Passive samplers are widely used for collecting fine scale data (of PM and nitrogen-oxides), however this method offers limited temporal resolution (weeks). Low cost air quality monitoring devices would promise a solution to reach both high spatial and temporal resolution, but they currently fail to match the reliability of data of standard monitoring devices [13].

In this paper we propose the question of the need and reliability of 3D geometry based complex air pollution models on city level. We investigate how real street geometry and meteorological field conditions effect the level of air pollution pedestrians are exposed to. A series of measurements were performed in a middle-sized central European city to compare levels of a selected air pollution indicator (NO_x) on two spatial scales: inside a single crossing and along main roads. Daily profile of traffic and pollution level were investigated in parallel. For experimental measurements the same chemiluminescence based devices were used as the standard monitoring sites have in order to evaluate range of applicability of monitoring data in fine scale modelling.

2. Field measurements

2.1. Study sites

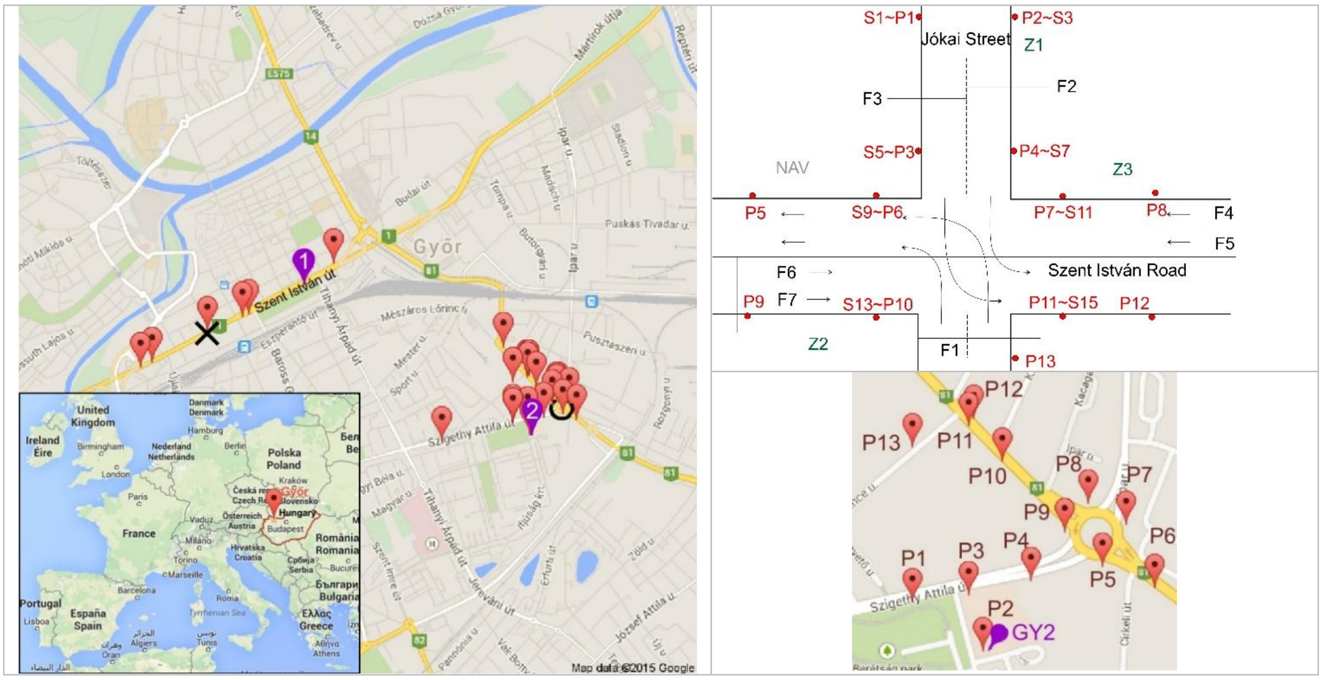

Fig. 1: Location of measurement sites (red drops), the investigated street canyon (black X, upper right map) and the roundabout (black O, detailed in lower right map). Regular monitoring containers are signed by purple drops.

City of Győr, a well-developed industrial city with about 130,000 inhabitants, located in the western part of Hungary in 100 km proximity to Budapest, Vienna and Bratislava. Emissions of nitrogen-oxides originates mainly from road traffic. Other sources are heating, which is relevant only in the cold seasons (usually from October to March) and industrial sources located at the north-eastern end of the city, which have rarely significant effect on air quality of the city through dominant north-west winds blowing away.

Air sampling points were selected along main roads. Szent István Road is the main road of the city leading to Budapest (East) and Vienna (West). The intersection with a busy one-way street (Jókai Street) was selected for canyon studies (X in Fig. 1). Szigethy Attila Road and Fehérvári Road are joining in a roundabout, they bear most of the traffic between the city and the industrial park. Although there is a bypass highway around the city these main roads are having considerable traffic.

2.2. Methods

Air samples were collected during September in 2013 and 2014 from 49 locations of pedestrian areas. Each sampling day 8 minutes long (1 l/min) air samples were taken to Tedlar bags beginning at 5:30, 7:30, 11:30,15:30, 18:00 and 22:50 to follow daily profile of the NO_x level. Manual traffic counting was conducted from 5:00 to 23:00 in quarter-hour time resolution differentiating 6 vehicle categories. Actual traffic during the 8-minutes air sampling period was recorded separately. Noise measurements were also taken. Levels of NO_x was studied at three system of locations.

- (A) Canyon study: Szent István Road – Jókai Street intersection surrounded by 5-6 storied buildings, 2x8 locations (S1-16), 1.5 m and 3 m elevations in Sept. 2013 and 13+1 (control further on Szent István Road) locations (P1-P14) at 1.5 m in 2014 Sept. (see Fig. 1 upper right map and Google street view [14]);
- (B) 3 main road study: Szent István Road, Szigethy Road and Fehérvári Road at 2013 Sept. and
- (C) Roundabout with two main roads: Szigethy Road and Fehérvári Road at 2014 Sept. (Fig. 1 lower right map and Google satellite image [15]).

Air samples were taken into Tedlar bags were transported to the laboratory of the North Transdanubian Regional Environmental Protection and Nature Conservation Inspectorate and analysed on chemiluminescence based gas analysers (Thermo Environmental Instruments M-42C and Thermo Scientific M 42i).

Results were analysed graphically and spatial differences were tested statistically. Our measurements were compared with the data of regular monitoring and our traffic data from manual counting.

3. Results

Some results of the first year measurements have been published in [16]. Significant differences could be demonstrated statistically between the two sides of the canyon (Jókai Street) and among the 3 main roads (B). However, lack of significance of the elevation between 1.5 m and 3 m was also remarkable. The later explains the changes in canyon study's measurement-setup in 2014. Here we focus within-crossing differences and comparison of canyon-like and open space situations.

In case of canyon study we could detect significant concentration on the leeward side of the Jókai Street (perpendicular to the Szent Istvan Road (Fig. 1), which was acting as street canyon in North-Western wind we were having during both sampling (Fig. 2). However airflow along the canyon were less obvious.

Differences in the amount of traffic flow and congestion could be visible on measured data. We could measure higher concentrations under similar traffic flows in the pedestrian area along streets bordered both sides by building even if they were one-storey houses. Reliability of regular container data proved to be very good only in 50 m radius in open sites (Fig. 3, P1-3 in Fig. 1 lower right map). Traffic lights have shown also visible effect on concentration of air pollution, most significantly in the rush hours.

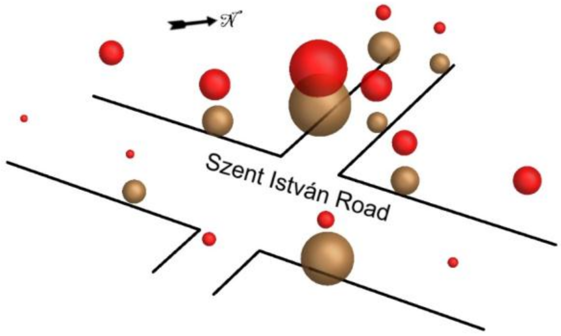

Fig. 2: Daily average of NO_x in the intersection on the two sampling days projected over the sampling sites. Upper red spheres represents data from 23/09/2014 and lower bronze spheres from 10/09/2013.

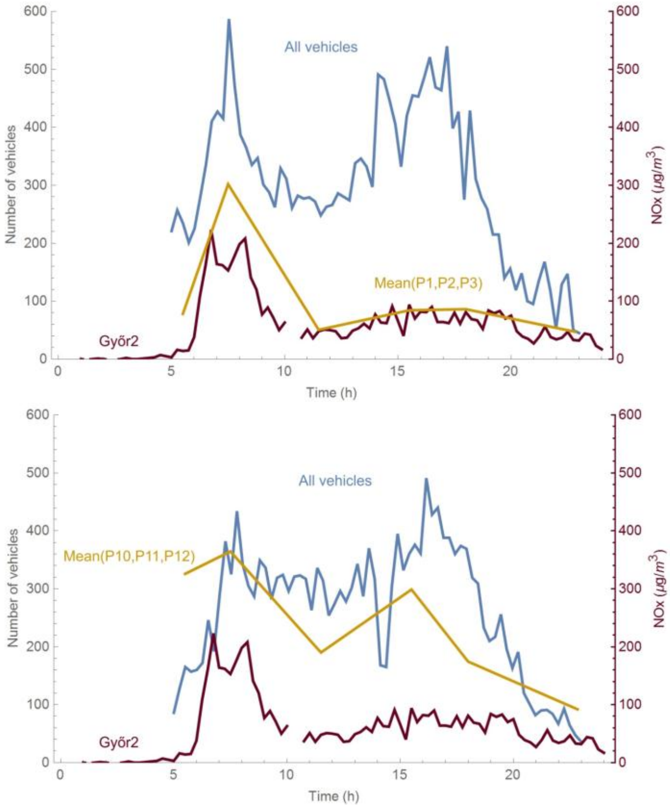

Fig. 3: Comparison of monitoring data to measurements along roads and traffic volume. Upper: Sampling points in range of 50 m of the monitoring container open space (i.e. no buildings next to the pedestrian area). Lower: Sampling point 250-300 m from container along road boarded both side by houses. Sampling points are shown in Fig. 1 lower map on the right.

4. Conclusions

Our field measurements underpin the importance of canyon effects, and resulted similar patterns as wind tunnel experiments [12]. Our results suggest that direction of traffic flow and position of traffic lights can also have visible effects on pollution levels. Our measurements also draw attention to that monitoring site's data cannot be used as average or approximation in built-up streets and canyon like street geometries. Detailed simulation models including 3D street geometry, accurate traffic flow data or models and inclusion of traffic lights are important indeed for accurate prediction of pedestrian's exposure. These results are applied in the 3DAirQC model we are developing at the Széchenyi István University [17].

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