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AN APPROACH FOR DETERMINING URBAN CONCENTRATION INCREMENTS

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Abstract:A simple approach for accurately estimating an urban concentration increment on top of the regional background for urban areas in Europe is presented. The method operates by establishing a functional relationship between the concentration increment and the local meteorological situation, the city characteristics, the urban emissions and background concentrations.This approach builds on earlier attempts to provide estimates of the urban increment for various pollutants, by improving key aspects concerning the treatment of the meteorological parameters. The application of the method in the framework of the current study has been carried out for PM_{10} and NO_2 based on concentration measurements from 16 cities in order to fix the functional relationship parameters using multiple regression. Pollutant concentrations needed for the multiple regression process can also be derived from high resolution urban scale model results. The functional relationship was then validated by estimating urban increments for the same pollutants in 7 additional urban conglomerations. The results demonstrate the capability of this simple approach to reproduce the urban increment with satisfactory accuracy, thus providing a tool for fast but still reliable quantitative assessments of urban air quality that can subsequently be used in calculations of exposure and health impact assessment. The method can be potentially applied to a wider range of pollutants, including $PM_{2.5}$ and CO, depending on the availability of emission and regional background concentration data. Additionally, scenario calculations for the urban increments can be based on scenario emissions and respective modelled regional background concentrations, a feature that will be particularly useful for air quality forecasts for megacities. Definitely, further and more vigorous validation will be required in order to verify the applicability of the method in more diverse situations, including the use of input data obtained from regional scale models instead of measurements.

***Keywords**: Urban air quality, urban increments, functional relationships, MEGAPOLI*

INTRODUCTION

The use of computational methods is essentialfor a better insight into the complicated and multivariate nature ofthelocal emissions contribution to the urban pollution levels.The simple methodology presented in this studyaims at the determination of an urban concentration increment on top of the regional scale background, for urban areas in the entire European region. This is especially relevant for the purposes of health impact assessment of various pollutants, but will be demonstrated here for PM_{10} and NO_2.

The methodology attempts to define a functional relationship between local meteorological parameters, city characteristics and urban emissions on the basis of measured increments on sample locations. The functional relationship can then be applied on arbitrary locations (urban areas) throughout Europe.Special care was taken during the selection of sampling locations so as to ensure geographical representativeness and adequate data availability.

METHODOLOGY& RESULTS

The overall procedure for determining the urban increment can be described as a sequence of three main processing stages:

1. **Spatial sampling**: selection of representative rural-urban measurement station pairs across Europe.

2. **Multiple regression analysis** for determining a functional relationship.

3. **Generalisation**: estimation of urban increments for other European cities.

In order to extract concentration increments, several station pairs consisting of one rural and one urban background station were selected. The search initially focused on 20 cities that have been studied before in the framework of various projects (e.g. the MERLIN project, URL1), namely Antwerp, Athens, Barcelona, Berlin, Brussels, Budapest, Copenhagen, Gdansk, Graz, Helsinki, Katowice, Lisbon, London, Marseille, Milan, Paris, Prague, Rome, Stuttgart and Thessaloniki.

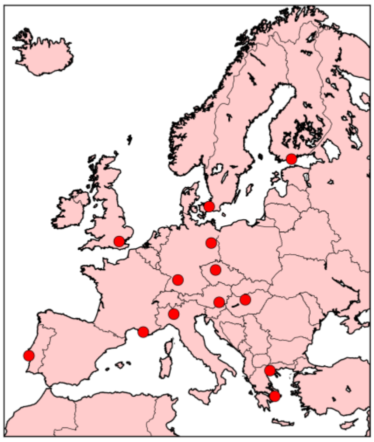
Data associated with the main meteorological parameters were available for the year 2003 from the regional model PARLAM-PS (Bjørge, D. and R. Skålin, 1995). Therefore, it was decided to use the AirBase (Airbase, 2008) datasets for this particular year throughout the calculationsprocedure. The next step was the selection of appropriate station pairs, satisfying the following criteria:

- The two stations of the pair should be categorised explicitly as rural (or suburban) background and urban background, respectively. Station categorisation was based on the AirBase metadata entries.

- Both stations should have better than 90% (for NO_2) or 75% (for PM_{10}) data completeness for the reference year (as reported in AirBase).

- The two stations should be located close enough, preferably within the same 50×50 km^2 PARLAM-PS cell.

Applying this set of criteria, 51 stations for NO_2 and 26 stations for PM_{10} were selected. The spatial distribution of the cities corresponding to these station pairs is presented in Figure 1. As it can be deduced from this Figure, in many cases, different station pairs had to be selected for NO_2 and PM_{10} measurements.Having established a sufficient sample of station pairs, timeseries of concentration differences were obtained from each station pair, meant to provide an estimate of the urban increment.



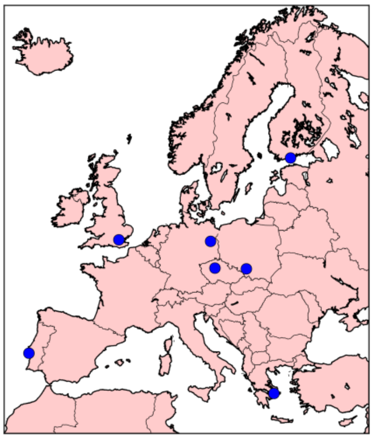


Figure 1. Locations of the cities with sufficient measurement data for the estimation of NO_2 (left) and PM_{10} (right) urban increments.

At the second stage of the methodology, the urban background increments were determined through a piecewise functional relationship which is established on the basis of certain variables that are known to be important (Amann et al., 2007). These variables include the level of emissions within the urban area, the size/area of the urban entity, the urban and regional background concentrations, as well as the wind speed and the atmospheric stability.

A novel element of the current approach, as compared to previous similar attempts, consists of several improvements with respect to the part of the meteorological input, firstly with the use of an advanced interpolator for meteorological parameters at the sub-grid level and, secondly, with the incorporation of atmospheric stability as an important factor contributing to the profile of the urban increments. In order to obtain the relationship between the urban increment and the variables mentioned above, a multiple regression analysis was carried out, using the following formulation:

$$C_{i\ urban} = \omega_i + \phi_i \frac{E_{iUE}}{A_{UE} \cdot u_{avg}} + \gamma_i\ C_{i\ rural}$$

Where:

$C_{i\ urban}$ = Urban increment of pollutant *i*.

E_{iUE} = Total emission of pollutant *i* within an urban entity in tons.

A_{UE}= Urban area in km^2.

u_{avg}= Urban entity average wind speed in m/s.

$C_{i\ rural}$= Rural background concentration of pollutant *i* in $\mu g/m^3$.

ω_i, ϕ_i, and γ_i = Multiple-regression parameters for pollutant *i*.

The regression analysis is performed on the cities identified during the station pair selection process. A separate version of the above formulation is extracted for each of the seven Pasquill-Gifford stability classes (S_C=1...7), thus taking into account the dependence of concentrations on atmospheric stability. Values of all the variables were averaged over the periods identified through the stability categorisation. Regarding the data that were used in the multiple regression analysis, the urban areas were defined on the basis of land use as provided by the European 1km resolution land use map of the CORINE Land Cover 2000 (CLC2000) project (Büttner et al., 2004). Besides, it was also assumed that only primary emissions released from low sources increase concentrations within the cities (Amann et al., 2007). Estimates of the urban emissions for each city were based on the MEGAPOLI European Gridded Emission Inventory (Kuenen et al., 2010), which is a version of the TNO emissions data-set, available for the whole of Europe in a resolution of $0.0625° \times 0.125°$ (latitude×longtitude) (Figure 2).

The average 10-metres wind speed was estimated using the “Meteorology Generator” tool and the 2003 PARLAM-PS dataset. The “Meteorology Generator” tool utilizes the CONDOR diagnostic model (Moussiopoulos et al., 1988; Flassak, Th. andN. Moussiopoulos, 1989) for the calculation of local wind fields ensuring that the effects of local topography are taken into account during the spatial interpolation. Wind speeds for the 20 preselected cities are shown in Figure 3.

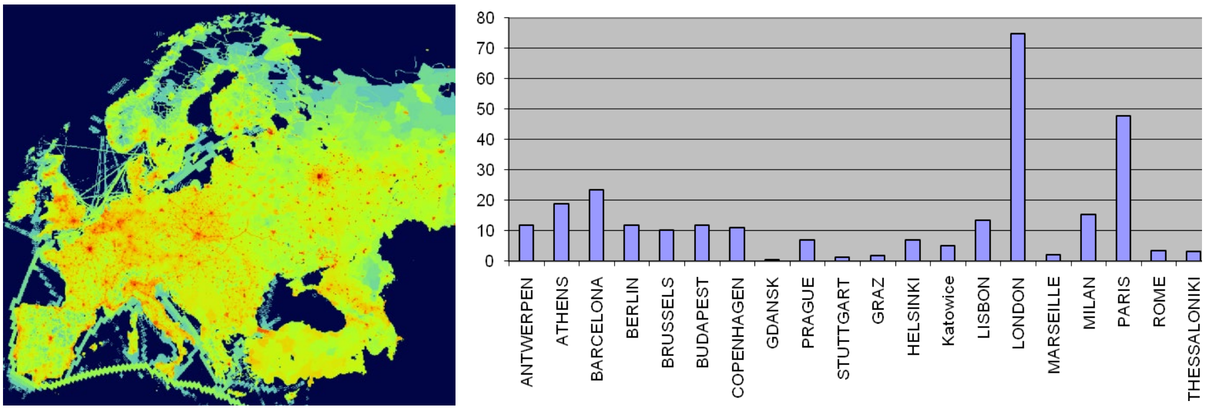


Figure 2. European yearly emissions map in thousands of tons (CO) based on the TNO emissions dataset (left) and urban emission estimates in tons for NO_x based on the TNO emissions dataset and CORINE land use (right).

The final stage of the calculations involved the application of the piecewise functional relationship extracted in the previous step to an additional set of urban areas around Europe in order to calculate urban increments.Figures 4 and 5 depict the urban concentration increments as they were calculated on the basis of measurements (bars) but also using the functional relationships (diamonds) of the proposed methodology.

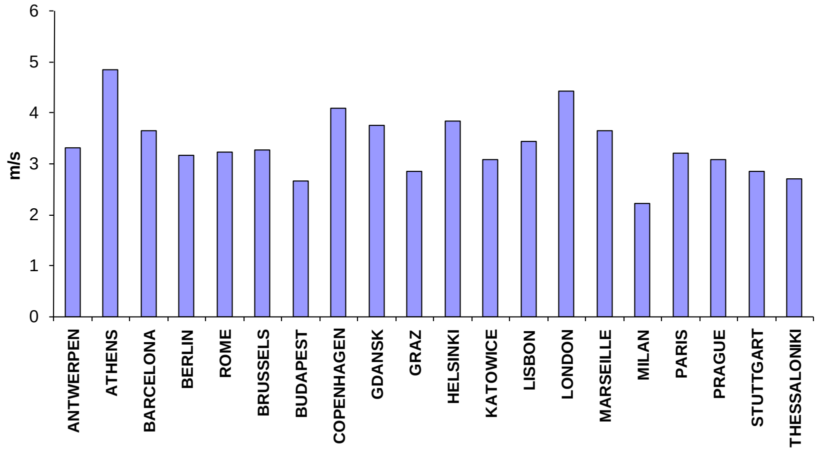


Figure 3. Mean annual 10-m wind speed for the 20 preselected cities as calculated with the aid of the "Meteorology Generator".

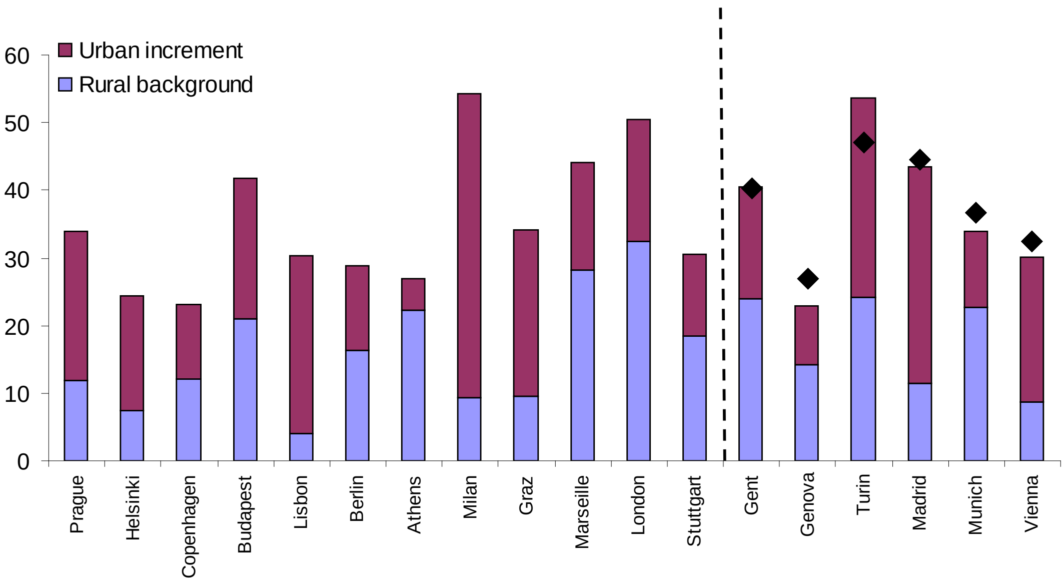


Figure 4. Urban increments in μg/m^3 for NO_2 in calibration and validation urban areas (to the left and right of the dashed line, respectively). Diamonds indicate urban concentrations predicted by the UI methodology.

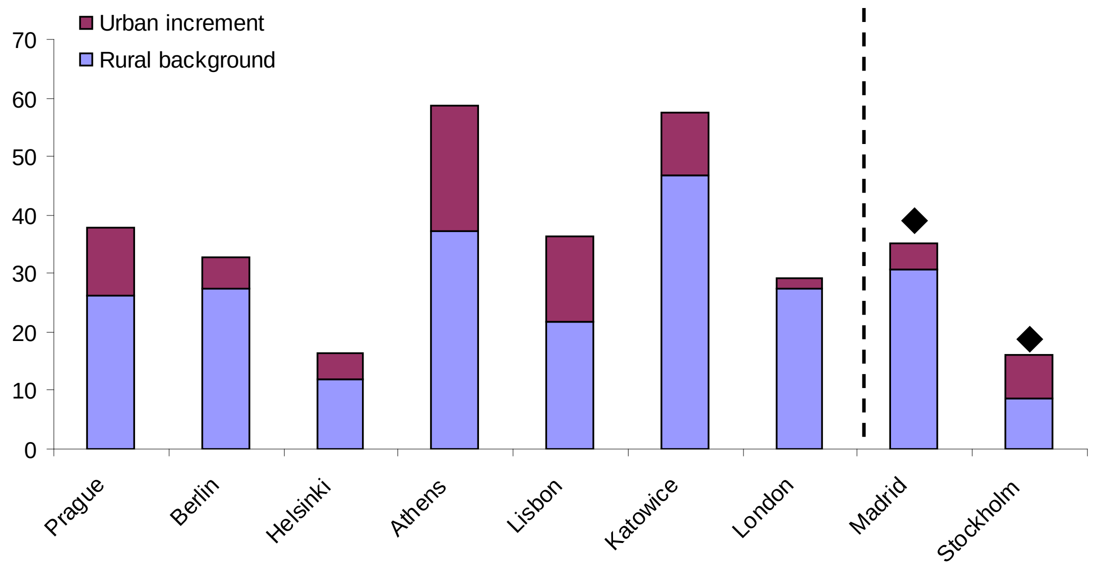


Figure 5. Urban increments in μg/m^3 for PM_{10} in calibration and validation urban areas (to the left and right of the dashed line, respectively). Diamonds indicate urban concentrations predicted by the UI methodology.

Urban concentrations needed to extract the increment described in the first step of the methodology can as well be derived from high resolution urban scale model results. Exploring this idea, a pilot application of the methodology was carried out using modelled concentrations originating fromCityDelta (Cuvelier et al., 2007) results, for 8 European cities for the year 1999. In order to extract the sample increments and the functional relationship, model results for a central point and averaged concentrations at eight peripheral points were used for each city. Figure 6 depicts the nine points used for the calculation of the urban increment in the city of Paris, as well as the yearly mean PM_{10} concentration map produced by the CHIMERE model.

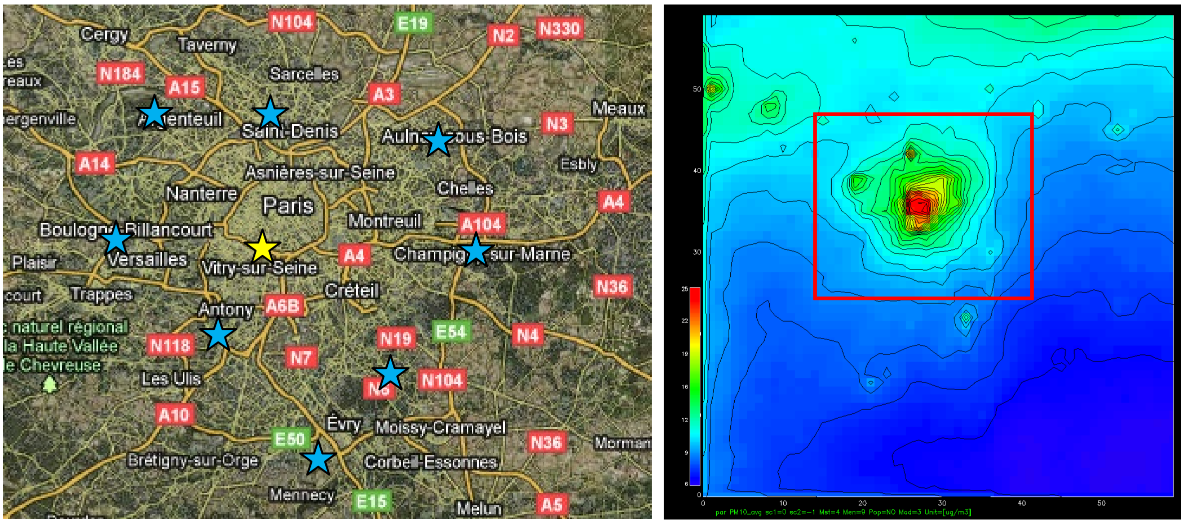


Figure 6. Locations of the central point (yellow) and the eight peripheral points (blue) used for the city of Paris (left) and spatial distribution of the PM_{10} mean annual concentration calculated by the CHIMERE model.

The calculated concentrations using the model simulations data were then evaluated against measurement data and the "station pairs" approach results. This comparison relies upon the essential assumption that although the CityDelta model applications refer to the year 1999, they nevertheless represent an adequate approximation of the concentration differences between the periphery and the urban background of each city. This validation indicates that the results of the methodology using data originating from urban models (CityDelta) are in fairly good agreement with those calculated using observed data. Nevertheless, additional research has to take place for verifying that model results can replace measurement data in urban increment calculations without any quality loss in the calculated results. Figure 7 presents the validation of the approach for PM_{10} and NO_2 as regards six European cities.

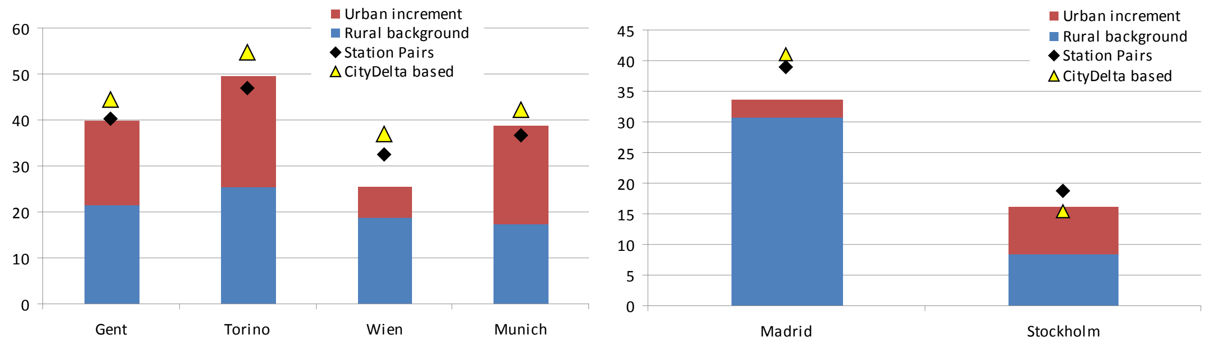


Figure 7. Evaluation of the CityDelta based results, against results based on station pairs and measured concentration increments of NO_2 (left) and PM_{10} (right).

CONCLUSIONS

An urban increment was determined based on a functional relationship scheme, allowing for a correction of regional background concentrations inside areas with significant urban density by establishing an operational correlation between the concentration increment originating from measurement data and the local meteorological situation, the city characteristics, the urban emissions and background concentrations. In addition, an alternative version of the methodology was utilized in order to test its performance in the case that concentrations originating from urban models (CityDelta) are used for the calculation of the urban increment instead of observed data.

The methodology is not intended to be used as an all-encompassing methodology that can be applied regardless of further considerations, but is rather proposed in order to demonstrate the functionality of simple approaches to provide the means to perform fast but still reliable estimations of urban air quality that can then be used incalculations of exposure or health impact assessment.

The methodology can potentially be applied to a wider range of pollutants, including $PM_{2.5}$and CO, with the condition thatcorresponding emissions and regional scale concentrations data are available. In addition, scenario calculations for the urban increments could be based on scenario emissions and respective modelled regional scale concentrations. Finally, the methodology could acquire the form of a module or sub-model that can be used on top of regional scale model calculations.

ACKNOWLEDGEMENTS

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