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# ADDING VIRTUAL MEASURING STATIONS TO A NETWORK FOR URBAN AIR POLLUTION MAPPING

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## ABSTRACT

Generating maps of pollutants concentration is made by means of interpolating and extrapolating methods. The quality of the results depends mainly of the number of input concentration values issued from the measuring ground network i.e, from the number of stations. This paper deals with a method for the virtual densification of this network. "Virtual measuring stations" are created. They are determined by the means of a classification method combined with hashcoding tools. Discriminating elements are pollutants emission classes, land cover types and urban morphological indicators created to this purpose. A first implementation was done for particulate matter (PM). This method aims at improving the quality of interpolation by increasing the number of concentration data.

**Key Words:** Pollution Map, Virtual Measuring Station, Morphological Indicators

## 1. INTRODUCTION

Many large cities in Europe have acquired a measuring network in order to monitor and analyze air quality. Monitoring and studying air pollution are made by agencies created to this aim. Local authorities rely on these studies to take decisions and to inform the population in order to reduce health impact caused by air pollution. European policies in this domain involve space-time knowledge of individual or collective exposure to pollutants. Therefore it is becoming more and more essential to know the spatial distribution of pollutants concentration at any time and any place in the city in order to map pollution at very local scale.

To answer this need, agencies in charge of studying air pollution are using two different methods. Either they map pollutants concentration with numerical models, either they interpolate concentrations values issued from measuring ground network. Combination of both methods may occur. Interpolation methods are mostly used. Modeling pollution variability at local scale involves to solve very complex phenomena and needs many input parameters such as meteorological parameters, emissions parameters, boundary conditions. Many models are used to map pollutants concentrations at larger scale (country scale). Others such as STREET and ADMS can model pollution dispersion at very local scale (street scale); they turn to be insufficient because they are often dedicated to emissions due to traffic and do not represent the background pollution over the whole city. It results that they give no accurate knowledge of the spatial distribution of pollutants over the whole city. Moreover such models require many input parameters to be optimal and parameters are often not available. For all these reasons, practitioners presently generate maps of concentrations by means of interpolation and extrapolation methods. Among those, the most used is the kriging method.

The accuracy of the results of the interpolation depends mainly on the number of known measurements. Majority of cities have a monitoring network composed by an insufficient number of measuring stations. Indeed, according to Stalker & Dickerson (1962), a network of conventional ground measurements requires at least four sampling stations of $SO_2$ by surface of 2.5 km² to estimate the actual concentration at ± 20 %. For the city of Strasbourg, which is our study area, and whose surface is 306 km², a network of approximately 120 stations instead of the 32 current ones would be needed. Increasing the number of ground measuring stations requires important material means and is extremely expensive. Furthermore, maintenance has a considerable cost.

To overcome these problems, we propose a method for mapping concentrations of pollutants. It consists in a virtual densification of the network. Our study is based on the work of Ung (2003), Ung *et al.* (2001, 2002), who introduced the concept of "virtual stations". The first part of this paper presents the method. In the second part, an application of the methodology to the city of Strasbourg is shown. In the third part, results are discussed. The last section is a conclusion; future work is sketched.

## 2. METHOD

The starting point of the concept of "virtual station" comes from observations made by agencies in charge of air quality monitoring. These agencies (such as ASPA in Strasbourg) observed that there are places in the city, which present properties similar to those of the measuring stations (Weber *et al*. 2002). From this, we made the assumption that a place having the same morphological features with respect to air flow and belonging to the same emission class than an actual measuring station, will have the same behavior regarding pollutants circulation and therefore, the same concentration.

Accordingly, if we can identify these features in an automatic way, we will identify virtual stations. As features, we selected morphological indicators (Miller and Gravelius), emission register and land cover.

Morphological indicators describe the shape of the space surrounding the station. Individual buildings, their height, orientation and their arrangement influence wind flows and thus spatial distribution of the pollutants (Turbelin 2000). We have selected two indicators to characterize the space surrounding the station.

The Miller indicator $\mathbf{I_M}$ characterizes the circularity of this space. It varies from 0 for a linear shape to 1 for a perfectly circular shape (eq. 1):

$$I_M = \frac{4\pi S}{P^2} \tag{1}$$

where S is the surface of the area and P is the perimeter of the area.
The Gravelius indicator $\mathbf{I_G}$ is an indicator of compacity. It compares the perimeter of the visibility surface to a perimeter of a disk having the same area (eq. 2):

$$I_G = \frac{P}{2\sqrt{\pi S}} \tag{2}$$

The visibility surface S characterizes the open space around the station. It is computed by a rays throw technique by taking into account the buildings position around the station. It is expressed as follow (eq. 3):

$$S = \sum_{i=1}^{N_{rayon}} S_{angle}(i) \tag{3}$$

where $S_{angle}(i)$, is a sector in the direction $i$ (eq. 4):

$$S_{angle}(i) = \frac{\pi D^2_{angle}(i)}{N_{angle}} \tag{4}$$

with $D_{angle}(i)$, the visibility distance computed in the direction $i$.

The emission register informs about the quantity of pollutants (in tons) emitted per year per squared kilometer.

The land cover plays an important role in the pollutants dispersion. Changes in land cover (e.g., buildings compared to trees) imply changes in aerodynamic roughness lengh, which in turn modify air flow by creating turbulences (Tennekes & Lumley 1972). The method is made of two steps: determining virtual stations and mapping by an interpolation / extrapolation method.

Prior to the determination of virtual stations and their localizations, the urban area is divided into cells by a regular grid. The cell size defines the spatial resolution. For each cell, the Miller and the Gravelius indicators, the emission class and the land cover type are computed or already known. Each cell containing a measuring station is compared to all others. Only are kept those cells whose features are similar to those of the station; they are “virtual stations” for this measuring station and they are precisely localized in the city. The method uses spectral analysis tools, namely hashcoding tools (Albuisson 1995).

## 3. APPLICATION TO THE CITY OF STRASBOURG

### 3.1 Study area

The city of Strasbourg is located in Eastern France, separated from Germany by the Rhine river. Geographical coordinates are: 48.33° and 7.38°. Strasbourg is the permanent seat of the European Parliament. ASPA is the local agency in charge of the air quality measuring network in the city of Strasbourg and vicinity. Fig. 1 displays a map of the measuring network in the city of Strasbourg and vicinity. There are 12 stations, 5 of them measure ($PM_{10}$, $_{13}$, $_{2.5}$). There is no heavily polluting industries in this area and the local traffic of motor vehicles plays an important role. Wind is blowing mostly from North or South and does not bring significant pollution clouds from abroad (REKLIP 1995).

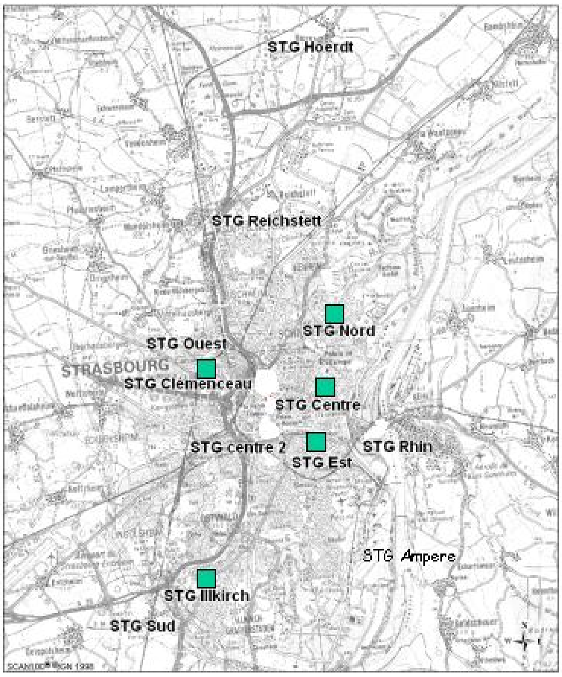


Figure 1. Stations of the air quality measuring network in the city of Strasbourg. Square denoted the stations measuring PM. The width of the map represents a distance of approximately 20 km.

### 3.2 Data used

The morphological indicators Miller and Gravelius were computed for the whole city of Strasbourg (fig. 2). They are computed from scripts of Arcview 3.2, Geographical Information System (GIS) software applying to a geographical database of the French Institute of Geography (BD TOPO®). The database is georeferenced and contains a 3D description of the city for buildings. Each building is described by a polygon and each polygon has attributes such as height (minimum, maximum, mean), area and perimeter… The computation provides two images of Strasbourg whose pixels contain the values of the Miller and Gravelius indicators. The computing time requested was very large (several days). All data used are input to a GIS. The size of the elementary cell is set to 10 m.

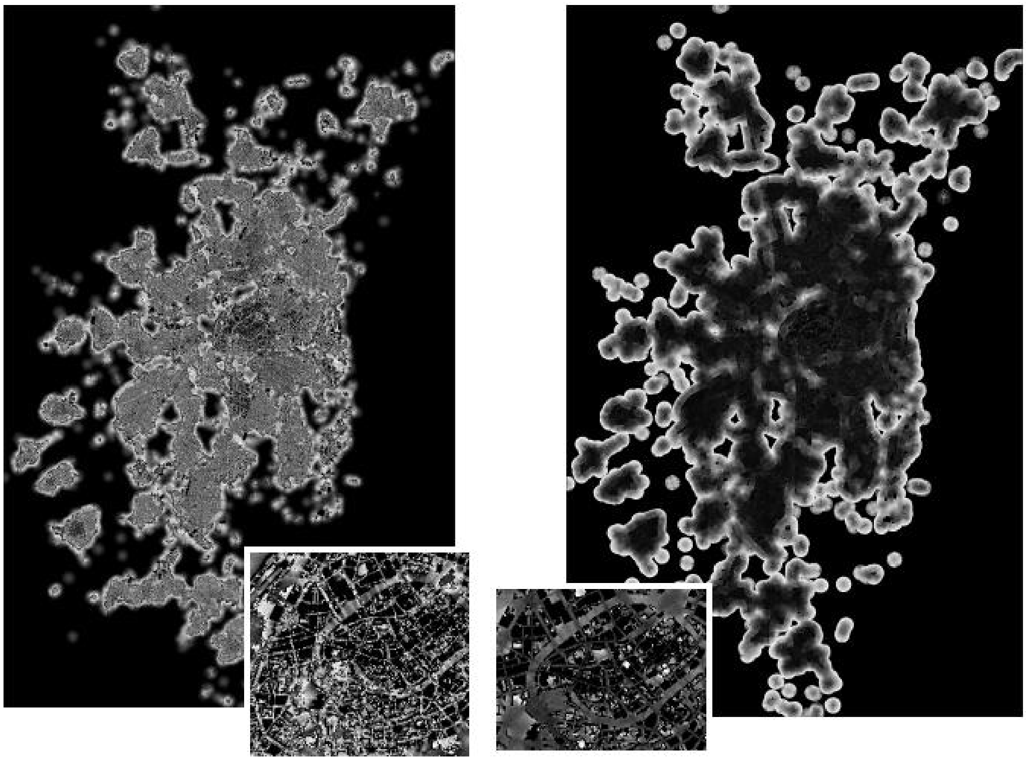

Figure 2. Images of Gravelius (left) and Miller (right) for the city of Strasbourg. Images at bottom, display zooms of the city center for each indicator.

The land cover map is a CORINE Land Cover (2000) with an initial resolution of 100 m. This map contains 44 different types of land cover. It was oversampled to a grid cell of 10 m using a nearest neighbor technique (Fig.3, left). The emission register is a map in a vector format, whose each polygon represents 1 km² area. The quantity of pollutants was recoded into a limited number of classes (10).The map was then oversampled to 10 m using a nearest neighbor technique. A polluting source has an influence over a surrounding area (Hewitt & Jackson 2003). A spatial filter of Gaussian type was applied to take such influence into account. The resulting image is no longer the emission register but more a map of annual background pollution (Fig. 3, right).

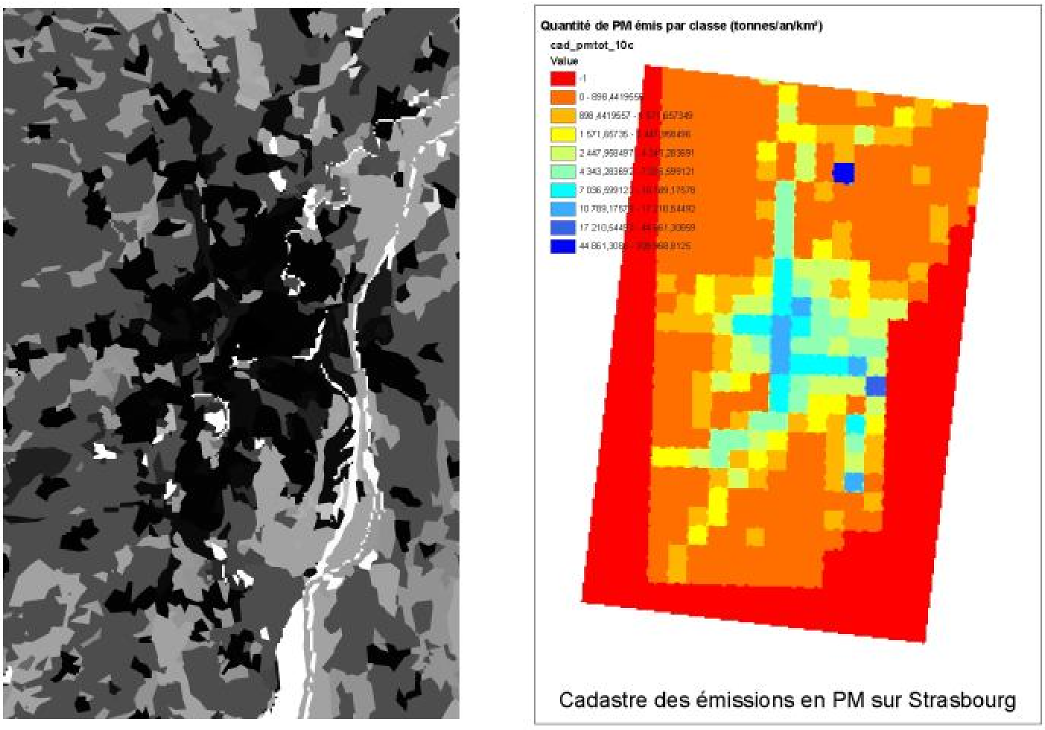


Figure 3. Images of the land cover map (left) and the emission register for PM for 2004 (right).

## 4. RESULTS AND DISCUSSION

Table 1 reports on the number of virtual stations found for each of the five stations measuring PM. These virtual stations are mapped in Fig. 4.

Table 1. Number of virtual stations for each real measuring station

| Real station name | Number of virtual stations |
|---|---|
| STG Illkirch | 361 |
| STG Centre | 727 |
| STG Nord | 710 |
| STG Clemenceau | 16 |
| STG Est | 11 |

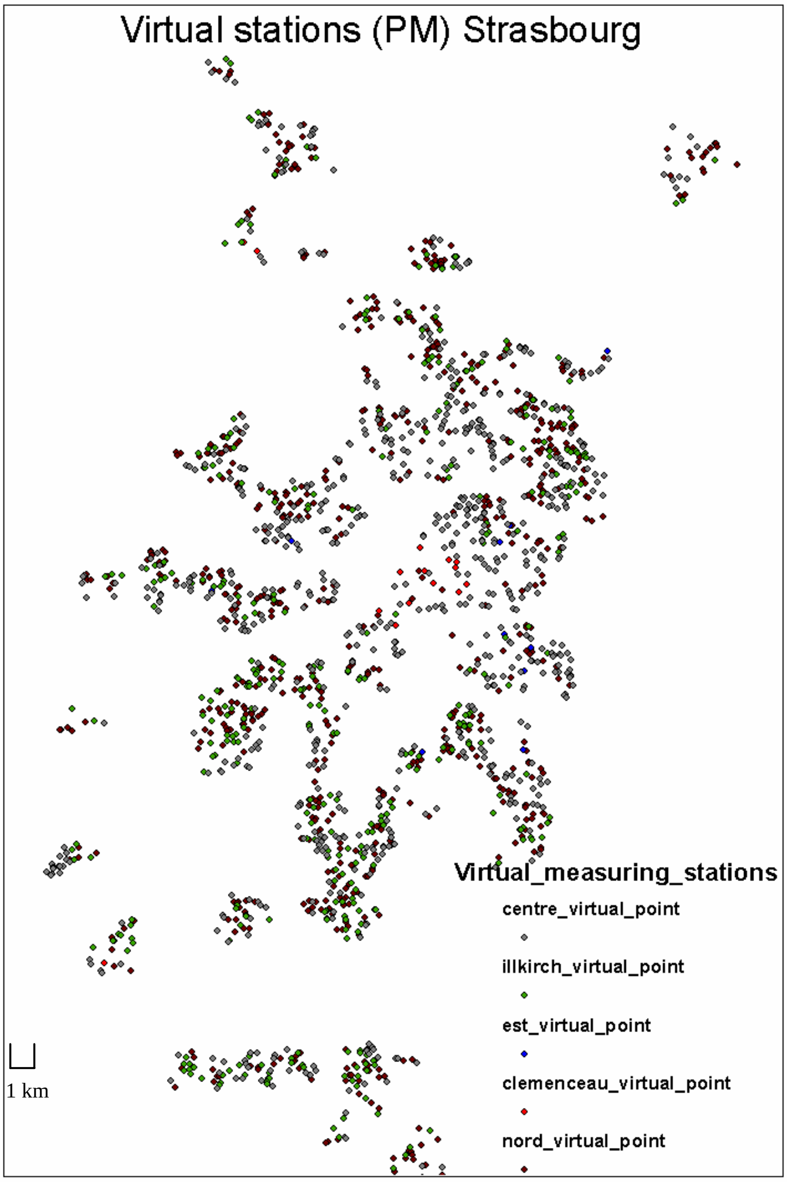


Figure 4. Localization of virtual stations for each real measuring station.

The total number of virtual stations is quite high: 1825. They are scattered all over the city, which is a real advantage for interpolation method. Compared to the initial 5 stations, one may easily understand the benefit of the virtual densification.

However, we are puzzled in this first application of the method by the very large number of virtual stations for the three first stations. It may mean that many places in the city have the same features than the measuring sites. Conversely, the number of virtual stations is quite low for STG Clemenceau and STG Est. It means that the discriminating elements are sufficiently discriminating in the last case and maybe not in the first one. A detailed analysis is underway to assess this hypothesis.

Mapping the PM concentration from this set of virtual stations has not been performed yet. However previous works in our laboratory (Ung *et al.* 2002), show the interest of virtual stations for mapping. The set of virtual stations they used was determined with a different method and different data sets: from satellite images, but the idea is similar. Figure 5 (left) shows a $PM_{10}$ concentration map. It is obtained by the "thin plates spline" method from three actual measuring stations (black dots). The area is approximately 26 x 34 km² with a spatial resolution of 30 m. A map of Strasbourg was laid in the background for better readability.

The low number of measuring points yields to a very uniform pollution map, which does not represent the reality. Figure 5 (right) is a pollution map obtained thanks to virtual stations for the same date. 301 virtual stations were found. Compared to the figure on the left, the map based on virtual stations shows a more realistic pollution distribution. This map has not been fully validated though a measuring campaign in June 2003 indicates that several virtual stations spotted by Ung *et al.* (2002) were actually behaving like the real stations as expected (Ung 2003; Puissant 2003). In a similar approach, in a study on the city of Nantes (France), Basly (2000) found that using virtual stations for the mapping improved result quality. The root mean square error (RMSE) decreased from 80 % (for a map interpolated without virtual stations) to 50 % (for a map interpolated with virtual stations), for the case of black smokes.
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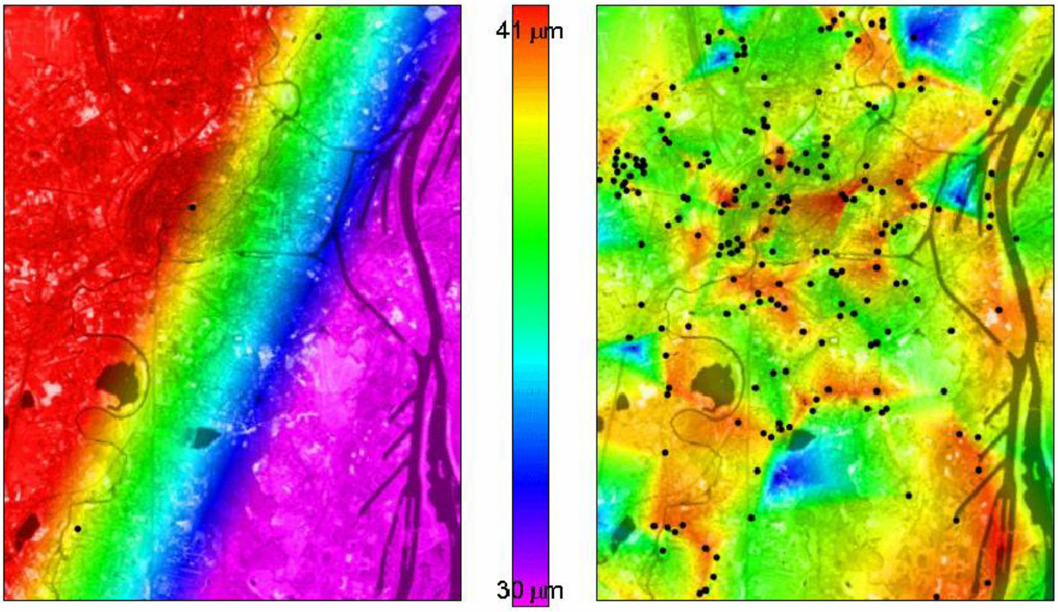


Figure 5. $PM_{10}$ concentration maps over Strasbourg obtained by interpolation of real measuring stations only (left) and of both real and virtual measuring stations (right).

## 3. CONCLUSION

In this paper, we present a method to make denser the pollution measuring network and thus to increase the concentration measurements in order to improve the pollution mapping by interpolation. Making denser consists in virtually adding new measuring stations. "Virtual stations" are places of a city exhibiting features similar to those of measuring stations. Features are linked to pollution sources (emission register) and aerodynamical properties of the considered place (morphological indicators, land cover). The first implementation of the method was done for particulates (PM) and for the case study of the city of Strasbourg.

From the 5 PM measuring stations initially, we obtained 1825 virtual stations homogeneously spread over the area. Among the virtual stations, several of them are likely to be wrong because the selected features are not discriminating enough. Our further work will consist in finding additional features to improve the determination of virtual stations. It will also consist in validating the virtual stations obtained and then in interpolating estimations to obtain a particulates pollution map.

Technically, the method is easily feasible by practitioners since it involves well-known tools and it uses data they already have. It is promising to map pollution with high accuracy and thus to represent the pollution distribution variability.

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