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Air pollution mapping over a city – virtual stations and morphological indicators

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Abstract

Air quality is a major concern in many large cities of the world, where people and sources of pollution are concentrated in the same place. Most cities have acquired a surveillance network of air pollution. But the cost of these networks is high and limits the knowledge of pollutant concentration to specific points of the town. Presently practitioners generate maps of concentration in pollutants by mean of interpolating and extrapolation methods, such as thin plate or kriging methods. Those methods are familiar and their quality depends on the number of input parameters. Others tools by modeling pollutant dispersion exist but turn to be insufficient and are not validated yet. Based on a multi-sources approach, this paper presents a methodology for the mapping of pollutant concentrations over the city of Strasbourg and its vicinity. Sources related to air pollution and urban shapes and morphology are exploited to densify the number of pollution data used for a mapping by interpolation. Several terms are introduced: "identity card of a measuring station", "morphological indicators", "pseudostation" and "virtual station".

Introduction

Nowadays most large cities in Europe have acquired a surveillance network for air quality. Such a network is composed of static measuring stations, which allow a continuous surveillance of air pollution on station location. Pollution data are collected in near real time and used to compute an atmospheric pollution indicator (ATMO). This indicator aims at informing local authorities, as well as the population, of the atmospheric air quality. In answer to a high rating of the ATMO indicator, public authorities are able to take restrictive measures with car traffic and with some air polluting companies.

Car traffic is continuously increasing. Atmospheric pollution hampers human breathing and impacts on life quality. Furthermore it becomes a critical factor of anticipated deaths, which concerns ambient air quality as well as air quality in houses and places of work. Studies suggest that current levels of particulate pollution in urban air associated not only with short-term, but also long-term increases in cardio respiratory morbidity and mortality (Nevalainen & Pekkanen 1998). However the real exposure of persons to ambient pollution cannot be estimated with the present network. The costs of a measuring station and its maintenance limit the knowledge to specific points of the town.

To evaluate the exposition to atmospheric pollution, an accurate knowledge of the spatial distribution of pollutants over the city is required. Several tools exist. Most of them provide maps of pollutant concentrations but over a regional scale with a grid of 1 km, which is insufficient. The first section offers a state-of-the-art showing the limitation of present tools. Actually, no accurate knowledge of the spatial distribution of atmospheric pollutants over a city is currently available. To overcome this problem, a methodology using remotely sensed data and geographical data sources is presented. It leads to define the notion of "*virtual station*". Previous study (Ung *et al.* 2001) has shown its benefits and its limitations. The application to the city of Strasbourg and a solution under analysis is shown to reader. The last section deals with a discussion of the results and the future works.

1. State-of-the-art

The aim of air quality monitoring is to get an estimate of pollutant concentrations in time and space. Several models exist and provide a map of pollutant concentrations by modeling its transport, deposition and/or transformation processes in the atmosphere. Those models are classified with regard to the scales of atmospheric processes. Spatial scales may range from the very local scale (e.g. street level, direct surroundings of a chimney) to the global scale (up to 100 km); time scale may range from minutes (estimation of peak concentrations) up to days (estimation of trends). Those models can be distinguished on the treatment of the transport equations (Eulerian, Lagrangian models) and on the complexity of various processes (chemistry, wet and dry deposition). Further descriptions of those models are given in a report of the European Topic Center on Air Quality (Moussiopoulos 1996).

To evaluate the population exposition to air pollution, a mesoscale (urban scale) model is required. Existing models differ with regard to the structure of the computational domain, the utilized parameterizations, the method of initialization, the imposed boundary conditions and the applied numerical techniques. Such models require as input considerable meteorological, geographical information, and emission data. Hence they require numerical simulations, often in conflict with the limited data processing resources, and not enough accurate yet. Those model evaluations are impossible without appropriate experimental data at proper locations in Europe.

The other ways to reconstruct the signal are models by means of interpolation and extrapolation of measurements. The problem is to reconstruct the spatial distribution of the pollutant considered within a geographical area, given limited values. Some scientists use the kriging method (Frangi *et al.* 1996, Carletti *et al.* 2000); some others recommend the use of the thin plates interpolation method (Ionescu *et al.* 1996). The quality of the maps can be judged by comparing predictions and appropriate measurements. But the validity and accuracy of such approach depend on the number of measurements. It results that no accurate knowledge of the spatial distribution of pollutants, over a city, is accessible.

Air pollution in cities is a complex phenomenon involving local topography, local wind flows and microclimates. For its better description and understanding, the study of its space-time variability should include different data sources related to urban morphological and environmental features. In this context, satellite images are certainly a valuable help in getting urban polluting features. Satellite imagery improves the monitoring of cities in a wide range of applications, e.g., mapping roads and streets (Couloigner 1998), mapping urban demarcation (Weber 1995), mapping of physic parameters such as albedo and heat fluxes (Parlow 1998), and also mapping urban air pollution (Basly 2000). Several studies have shown the possible relationships between satellite data and air pollution (Finzi & Lechi 1991, Brivio *et al.* 1995, Sifakis *et al.* 1998, Retalis *et al.* 1999, Wald & Baleynaud 1999, Basly 2000).

2. Approach

The proposed methodology combines point measurements and different data sources such as geographical database BDTOPO®IGN© and remotely sensed data provided by the Landsat Thematic Mapper (TM) sensor. The methodology allows the definition of virtual stations, which provide additional measurements that are used for densifying the input parameters of interpolating methods. For a better understanding, it can be separated into 3 steps.

Step 1: Characterization of measuring stations and of pseudostations
The urban area is divided into cells by a regular grid. The cell size defines the spatial resolution of the mapping. A cell size less than 100 meters is required for a city mapping. The methodology makes use of measuring stations and others data to locate places of the city, which have the same environmental, morphological and polluting features than a real measuring station. Such places are defined as *"pseudostations"*. Their location can be performed using the notion of "*identity card*" of a cell. Actually cells are characterized by a list of parameters (its identity card) and pseudostations are cells having a same identity card as a real station. Using remotely sensed data, those cells are materialized by pixels of the satellite image. The spatial resolution of the mapping of pollution and the spatial resolution of the satellite image are the same: 30m for the Landsat TM. It follows that digital numbers outputs from the satellite are parameters of the identity of a cell.

Step 2: Estimation of pollution - virtual stations
Pseudostations are places in the city where static measuring stations could be installed to increase the surveillance network. To make use of those pseudostations for the air pollution mapping, a relation between satellite data and ground measurements must be derived. This relation aims to predict pollutant concentrations in those pseudostations. A strong correlation was found with some pollutants. For example, Wald and Baleynaud (1999) focused their studies on the correlation between black particulate concentration and digital numbers output from the infrared thermal band TM6. A linear regression is a first approximation of the relation between satellite data and ground-based measurements. We define "*virtual stations*" as pseudostations for which concentrations of pollutants can be predicted with the model. So virtual stations are operational stations that companies in charge of the air quality measuring in the city will have, in the case of an unlimited budget. They form a subset of the pseudostations set.

Step 3: mapping by interpolation and extrapolation using virtual stations
The mapping is performed using an interpolating and/or extrapolating model: thin plates, polynomial, co-kriging or Hsieh-Clough-Tocher. The accuracy is controlled with the help of correlation, error and mean square error between the estimated and the observed data.

Previous works (Basly 2000, Ung *et al.* 2001) have shown that mapping pollutant concentration is possible using remotely sensed data and ground measurements. They demonstrate the benefits of pseudostations and virtual stations. Such stations allow a better accuracy of the mapping of black particulates over the city.

3. Strasbourg case study

The city of Strasbourg is located in Eastern France, separated from Germany by the Rhine. Geographical coordinates are 48.33° latitude North and 7.38° longitude West. Strasbourg was chosen as the Headquarter of the Council of Europe and then later as the permanent Headquarter of the European Parliament and the European Court of Human Rights. L' Association pour la Surveillance et l'étude de la Pollution Atmosphérique en Alsace (ASPA) is the local organization in charge of the air quality measuring network in the city of Strasbourg and vicinity. Atmospheric pollution is mostly due to motor vehicles.
The methodology is applied to the city of Strasbourg with the concentration in suspended particulates PM_{10}. All spectral bands except the thermal band TM6 are used for the location of pseudostations. The noise of the instruments (4 percent of the mean of the observed radiance) is taking account. From 3 actual stations, 301 pseudostations are derived. Then, to predict concentration in PM_{10} a linear model is derived using ground measurements and Landsat thermal infrared data TM6 for 3 different dates.

4. Results and discussion

Figure 1 presents the map of concentration in suspended particulates PM_{10} for March 31 1998 obtained from thin plates interpolation of the 3 measurements. The map size is 25.8*33.6 km^2, with a pixel size of 30*30m^2. Zones of high and low levels of air pollution appear in the map. For a better visualization of the studied area, a Landsat satellite image in band TM4 is incrusted in background. This channel (at 0.8 μm) reveals the patterns of the streets, roads in the city and the Rhine river. For the date under concerned, there were only 3 measuring stations (black dots) for particulates PM_{10}. It results in an impossibility to obtain a reliable map by present methods.

When applying our method, 301 virtual stations are obtained (see black dots in figure 2). Pseudostations are homogeneously located over the city of Strasbourg and its vicinity. An thin plates interpolation is applied on the 301 virtual stations and a map is obtained (figure 2). Compared to figure 1, this map gives a more realistic view of the distribution of pollutants over the city. The authors are aware of the limitations of such a map and stress that there is currently not validated map of air pollution to compare to.

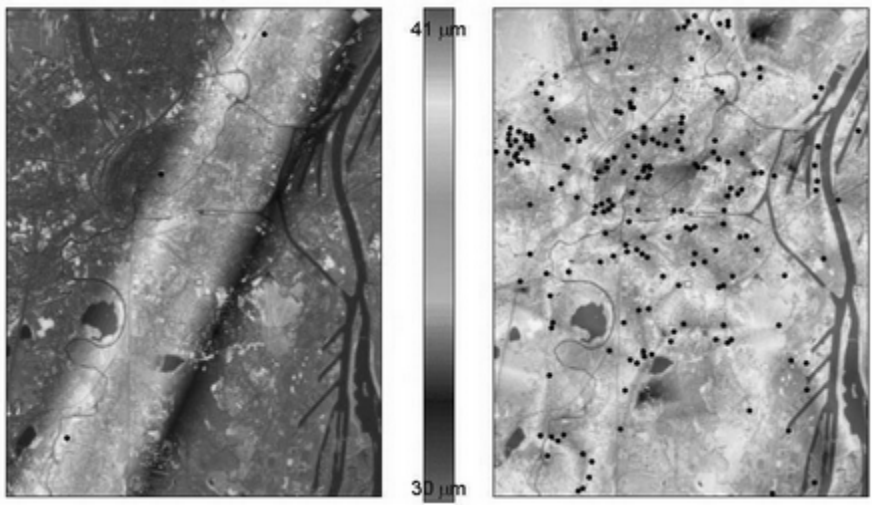


Figure 1. With out virtual stations *Figure 2. . With virtual stations*
Extracts of a map of PM_{10} in Strasbourg derived from Landsat TM6 data by thin plates interpolation of the present and virtual stations (black dots).

This illustrates the benefits of the proposed methodology. However a detailed study performed on several different Landsat images taken at different dates show that the location coordinates of pseudostations depend on the day (Ung *et al.* 2001). Pseudostations are places of the city having same morphological, environmental and polluting features as a real fixed station. Their location should

not be variable. It results that further studies are required for a better description of stations, through the notion of their identity card. The aspect missing in this application on the city of Strasbourg is certainly the lack of geographical and physical properties of the site and its neighborhood to describe the identity card.

5. Solution under analysis

To overcome this problem, the research focuses presently on a better analysis of measuring stations and its neighborhood to improve the definition of the identity card of a station, of pseudostation and of virtual station. It includes a geographical database BDTOPO©IGN. Each building is described by the location coordinates (x,y) and the z value (height). Figure 3 presents an extract of a 3D representation of a measurement area: “Place Kléber” of the old city of Strasbourg (center of the image).

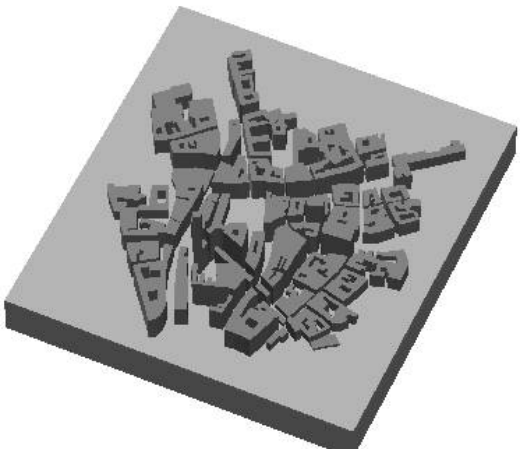


Figure 3
A 3D dimension view on “Place Kléber” located in the old city of Strasbourg (France). An extract of BDTOPO®IGN©

This database allows a georeferencing of satellite images for a better location of stations. It is exploited for the extraction of morphological indicators to improve the definition of the identity card of stations. Croxford and Penn (1998) showed the influence of the meteorological and morphological conditions on the measured pollutant concentrations. The position of buildings impacts on the pollutant dispersion (Morawska *et al.* 1999). Therefore possible morphological indicators related to pollutant dispersion are under analysis. The capabilities of the Geographical Information System (Arcview© 3D analyst) allow to construct images representing the distance to the first building in a direction. Figure 4 presents an extract of those indicators calculated for the area of the old city of Strasbourg: the distance to the first building at 135°. “Place Kléber” is in the center of the image. Distances greater than 200 m appear in red, and short distance in blue. Streets orientated at 135° appear in red, and buildings in pink. Such indicators can be computed to obtain further indicators such as visible area of a station. Their construction will allow a better description of the identity card of a station and a better location of virtual stations.

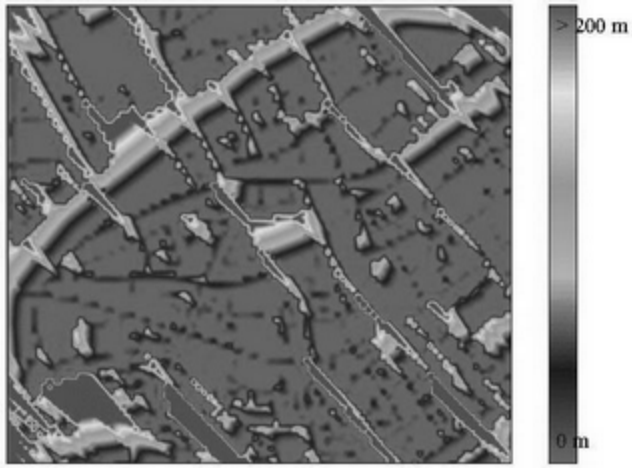


Figure 4
An extract of morphological indicators : distance to the first building at 135° in the old city of Strasbourg

Conclusion

The application of the methodology for the mapping of concentration in suspended particulates PM_{10} illustrates the potentialities of Earth observation data for the mapping of pollutant concentration. The work can be performed in every city having an operational surveillance network. The use of remotely sensed data for the mapping of pollutants over a city brings a better spatialisation of the phenomena under study. It allows a first definition of the identity card of a station and of virtual stations. Those stations improve the mapping, but their locations are not precisely defined. To overcome this problem, a solution using geographical database and morphological indicators of the local area is presented. Resulting images of indicators reflect a reality of urban shapes in a specific configuration. This encourages us to continue our investigation.
Next investigation will focus on a better analysis of morphological indicators and their influence on the location of virtual stations. The validation of this approach will be achieved through the ground-truth campaign within and inter regional research project of the INTERREG 3 program in June 2002.

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