Satellite data for the air pollution mapping over a city – The use of virtual stations

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Satellite data for air pollution mapping over a city – Virtual stations

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ABSTRACT: Atmospheric pollution becomes a critical factor of anticipated deaths, which concerns ambient air quality as well as air quality in houses and places of work. For the well being of human and for the population information, we need to evaluate the actual exposure of persons to ambient pollution. One way to perform it is to evaluate the space time budget of air pollution exposition. Hence an information on the spatial distribution of pollutant concentrations 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. Measuring stations, scarcely distributed in the city, provide a complete surveillance but their costs limit the knowledge of pollutant concentration to specific points of the city. To overcome this problem, several notions are defined: "identity card of a measuring station", "pseudostation" and "virtual station". Based on a multi-sources approach, this paper presents a methodology using remotely sensed data for the mapping of pollutant concentrations over a city.

1 INTRODUCTION

Nowadays most large cities in Europe have acquired a surveillance network for air quality. 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 increasing continuously. 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 1998). However the real exposure of persons to ambient pollution cannot be estimated with the present network. The costs of a measuring station and of 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 to perform it. 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 other data sources is presented. It leads to define the notion of "*virtual station*". Then an application of this methodology to the city of Nantes is shown to reader. The last section deals with on a discussion of the results obtained and the future works.

2 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 modelling 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 Centre 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 utilised parameterisations, the method of initialisation, the imposed boundary conditions and the applied numerical techniques. Such models require at 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 mapping 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 atmospheric pollutants, over a city, is currently 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., the detection of urban changing, mapping roads and streets (Blanc 1999, 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, Sifakis 1992, Poli *et al.* 1994, Brivio *et al.* 1995, Sifakis *et al.* 1998, Retalis *et al.* 1999, Wald & Baleynaud 1999, Basly 2000). According to those studies, a methodology for the mapping is developed.

3 THE METHODOLOGY

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. It allows a definition of virtual stations, which provide additional measurements that are used for densifying the input parameters of interpolating and extrapolating methods. For a better understanding, it could be separated into 3 steps.

3.1 *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 could be performs using the notion of "*identity card*" of a cell. Actually cells are characterised 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 materialised 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.

3.2 *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 mapping of air pollution, a relation between satellite data and ground measurements must be derived. This relation aims at predicting pollutant concentrations in those pseudostations. We define "*virtual stations*" as pseudostations for which concentrations of pollutants can be predicted. So virtual stations are operational stations that companies in charge of measuring air quality in the city will have, in the case of an unlimited budget. They form a subset of the set of pseudostations.

3.3 *Step 3: mapping by interpolation and extrapolation using virtual stations*

The mapping is performed using an interpolating and/or extrapolating model: thin plates, polynomial, linear 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.

4 APPLICATION AND DISCUSSION

The study area is the city of Nantes. The objectives of this first application to the city are twofold. The application of the methodology to the city of Nantes illustrates the benefits of Earth observation data for the knowledge of the atmospheric pollutant distribution. For lack of morphological indicator, only satellite data and ground measurements are used to define the identity card of a cell and to estimate its pollution. Therefore the set of pseudostations identify with the set of virtual stations. It will be shown that mapping pollutant concentration is possible using remotely sensed data and virtual stations. The results demonstrate the benefits of virtual stations.

4.1 *The study area and data used*

The city of Nantes is located in Western France at 54 km from the Atlantic Ocean. Geographical coordinates are 47.23° latitude North and 1.55° longitude West. That location explains the oceanic climate, which is mildly. Except for an oil refinery 20 km to the west, Nantes has no polluting industry. Atmospheric pollution is mostly due to motor vehicles. The local organization in charge of the air quality network in the city and vicinity is Air Pays de la Loire.

The studied day (22 May 1992) is a sunny day with clear sky and light wind from NorthEast. Pollution level was below critical levels. A Landsat satellite image was acquired on that day at 1017 UT. A portion of this image is represented in Figure 1. This size is 15.36*15.36 km, with a pixel size of 30*30 m. The channel TM4 (at 0.8 µm) reveals the patterns of the streets and roads in the city (in dark tones).

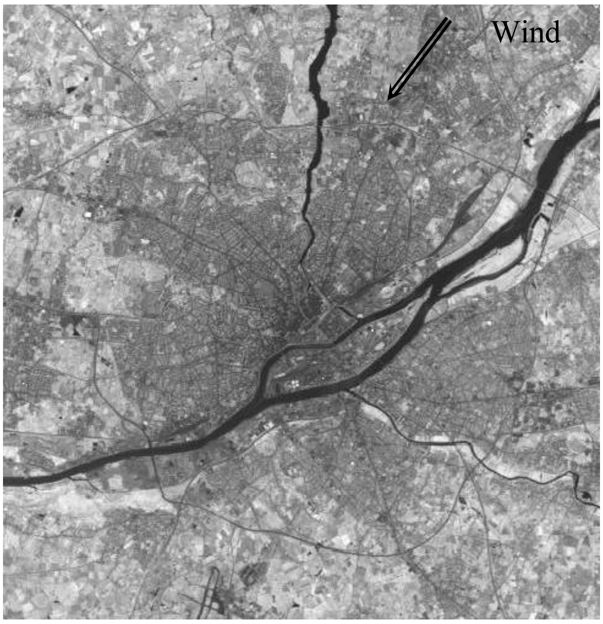

Figure 1. Sample of an image of the city of Nantes, acquired by satellite Landsat (TM4, at 0.8 µm), for May 22, 1992. The network of streets is seen fairly well in dark tones, as well as the Loire River and the airport in the south. ©Eurimage, reproduced with permission.

4.2 *Application to the city of Nantes*

Digital numbers output from satellite images are used to define the identity card of a pixel. In that case, pseudostations are pixels having same digital numbers as a measuring station in several combinations of satellite bands. For the day under concern, 12 measuring stations were operating. A strong correlation was found with some pollutants. To evaluate the accuracy of the method we only use 6 points out of 12. We apply the method and compare outputs to the remaining 6 stations.

Poli *et al.* (1994) studied the relationship between a map of apparent temperature of Rome (Italy) and the total particulate matter suspended in the air in the winter season. The particulate matter is assumed to be a significant tracer of the atmospheric pollution, as well as a good indicator of the air quality. Wald and Baleynaud (1999) focussed their studies on the correlation between black particulate concentration and digital numbers output from the infrared thermal band TM6. According to their studies, a linear regression is applied on pseudostations, as being a first approximation of the relation between satellite data and ground-based measurements. That defines virtual stations.

4.3 *Results*

Figure 2 presents an example of map of concentration in black particulates obtained with the thin plate method applied to 6 measurements.

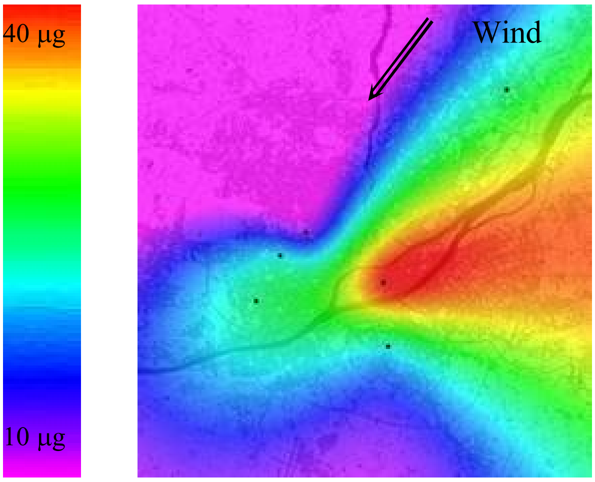

Figure 2. Extract of a map of concentration in black particulates over the city of Nantes for May 22, 1992 obtained from thin plates interpolation of the 6 measurements – in black dots.

In Figure 2, we can see that a veil of black particulate smoke is dispersing in the opposite direction of the wind. That certainly does not reflect the reality of polluting situation. This image could be compared to the image of Figure 3.

Figure 3 is a map of concentrations in black particulates obtained with the proposed methodology. The combination of satellite band, used to define the pseudostations, is the combination [1,2,3,4]. 43 pseudostations are located. Virtual stations (including real stations) were derived by a linear regression. Virtual stations are homogeneously located over the city of Nantes. In figure 3, virtual stations provide a better spatialisation of the studied phenomenon.

The resulting image, in figure 3, is obtained with the same thin plate method applied to the 43 virtual stations. Compared to figure 2, this image gives a more realistic view of the distribution of pollutants over the city. Actually zones of high and low levels of air pollution appear in the map. The veil of black particulate smoke is dispersing in the same direction than the wind direction. 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.

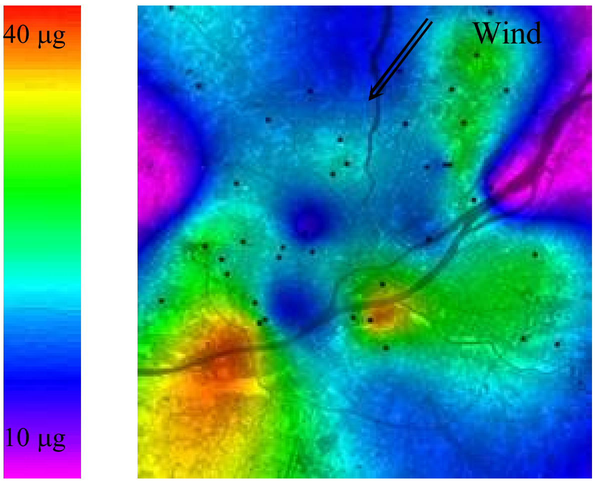

Figure 3. Extract of a map of black particulates over Nantes for May 22, 1992 obtained from thin plates interpolation of the 43 virtual stations – in black dots.

The discrepancies between the estimated concentrations and real measuring concentrations in black particulates are evaluated using the 6 remaining stations (table 1).

	correlation	error %	RMSE %
without virtual stations	0,47	-76	89
with virtual stations	0,7	-32	54

Table 1. Correlation, bias and RMSE (Root Mean Square Error) in percentage between estimated and real black particulate concentration over the city of Nantes for May 22, 1992.

The table 1 points out that virtual stations allow a better accuracy of the mapping of black particulates over the city of Nantes. Positive correlation is found between estimated and observed data for the 6 remaining stations and the use of virtual stations increase this correlation.

4.4 *Limitations*

The results show a great influence of the choice of the combinations of satellite bands of the generalized vector on the number and on the location of the virtual stations (table 2). The greater the number of spectral bands, the lower the number of virtual stations. In addition, the validation results (correlation, error and RMSE) depend on initial set of measuring stations.

combination	n_virtual stations
[1,2,3]	385
[1,2,3,4]	43
[1,2,3,5]	30
[1,2,3,7]	48

Table 2. Numbers of virtual stations (including real station) located in the city of Nantes.

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.

Previous works have shown that a fairly accurate linear relationship exists between satellite outputs and concentrations in black particulates. Further studies are needed to prove the significance of a relationship between satellite data and the other pollutants.

5 CONCLUSION AND PERSPECTIVE

This first application of the methodology for the mapping of the concentration in black particulates illustrates the potentialities of Earth observation data for the mapping of pollutant concentration. It shows that the mapping of concentration of black particulates is possible using the thermal band TM6 image of the Landsat satellite. The use of remotely sensed data for the mapping of pollutants over a city brings a better spatialisation of the phenomena under study. The notion of virtual stations improves the mapping. This encourages us to continue our investigation.

Further studies are needed to fully understand the links between the pollutant measurements and satellite data. Next investigation will focus on a better analyze of measuring stations and its neighborhood to improve the definition of an identity card of a station, of pseudostations and of virtual stations. The research will include a geographical data source: the BDTOPO®IGN© (figure 4) containing physical and morphological properties of the site (building heights, positions of roads…).

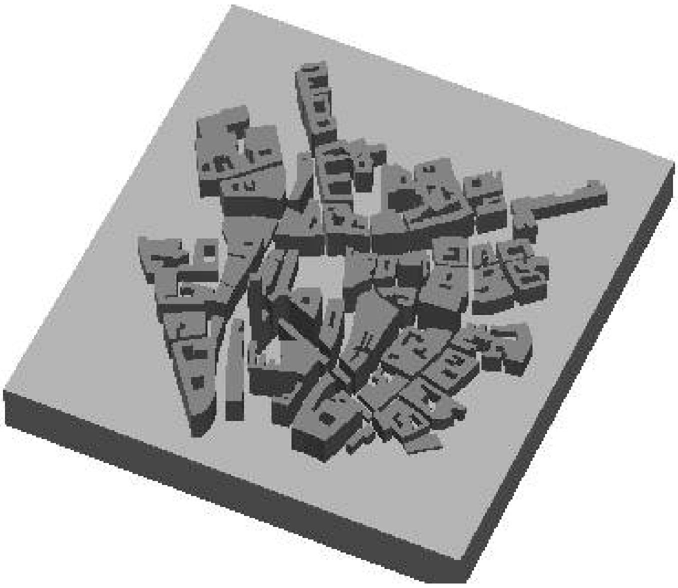

Figure 4. 3D dimension view on a location in the city of Strasbourg (France). An example of BDTOPO®IGN©, 1989.

This data source will allow

- a georeferencing of satellite images for a better localisation of stations.
- a better definition of the identity card of a stations

Morphological indicators for "distance to the road", "rate of building" or "wind exposition" will be defined.

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