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Remote Sensing and Air Quality in Urban Areas

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Abstract: This paper aims at showing the potentialities of the Earth observation (EO) data for the knowledge of the atmospheric pollutants concentration field over metropolitans areas. At present, deterministic modeling and decision support systems only use pollutants maps obtained with mathematical methods. But, given the few scattered stations measuring the pollutants concentrations, an accurate map of the spatial distribution is almost impossible with standard methods. We found a strong correlation between the black smoke (BS) concentrations and data from sensor TM6 of the Landsat satellite. The map derived from the EO data gives errors close to those obtained by standards methods. The representation is nevertheless closer to the real urban environment. In a near future, EO derived products could be treated in near real time in conjunction with pollutants measurements to provide accurate information to decision maker.

1 Introduction

In the western Europe more than two thirds of the population live in urban areas and urbanization is still continuing [1]. It is found that transport is the main source of atmospheric pollution in cities and the number of personal car is still growing [2]. Furthermore, the air pollution can be exacerbated by local weather conditions and wind patterns leading to phenomena such that heat (or cold) islands which influence the chemical transformation of pollutants. Hence the urban air pollution is a very complex phenomenon involving a lot of parameters and processes (physics, chemistry, meteorology, geography, and other environmental sciences) and links between them are not fully understood.

It is obvious that good air is a prerequisite for the health and the well-being of human. Several studies demonstrated that in France the atmospheric pollution leads to an increase of 4% in the risk of anticipated deaths, and that 265 deaths/year may be directly attributable to air pollution [3]. A survey conducted by the World Health Organization (WHO) shown that, in the world, transport pollution would cause 80 000 anticipated deaths/year [4]. We can also mention that WHO has estimated, for a European standard city, that life expectancy decreases in one year, and that 14 millions of Europeans have a decrease in the vital capacity of 5% [5]. Medical studies tend to demonstrate that breathing diseases may be linked to pollution peaks and that elderly people and young children are the most affected [6], [7], [8]. But the links that might exist between atmospheric pollution and increasing of allergy troubles are still misunderstood and further studies requiring more measurements of pollutants concentrations are needed [9]. Consequently the study of atmospheric pollution problems in metropolitans areas is gaining more and more interest, and is a growing issue among the scientific and medical community in Europe. Moreover urban air pollution becomes a critical question which rightly concerns the citizens.

Urban planners and public policy makers need tools for a comprehensive knowledge of the urban environment, for the forecasting of the air pollution and for the population information. Since 1996, in France, mayors in charge of large cities of over 100 000 inhabitants must install a measuring network. This network is managed by local organization and it is composed of several static measuring stations linked to a central computer via the phone lines thus pollution data are collected in near real time (Fig. 1 shows an example of a network structure). Recently, some network have been equipped with a laboratory van which can measure the pollution in area without stations or around static stations in order to study the representiveness of the measurement. Collected data are then used to compute an atmospheric pollution indicator (ATMO) aiming at informing the local authorities as well as inform the population of atmospheric air quality. This indicator is calculated from the NO2, SO2, O3, and particulates concentrations. The air quality network is very useful because it allows an accurate knowledge of pollutants concentration in a specific point of the town, and it is therefore a good means to warn the population of pollution danger. At present, the alert system consist in a board with a map of the area under concern showing the station location with light. If pollution data measured by a station exceed a threshold then the light turn to red indicating the place where a pollution peak happen. But given the few measuring stations which are scarcely distributed, an accurate knowledge of the spatial distribution of the atmospheric pollutants is currently impossible. However air quality organizations strongly stress that the mapping of the atmospheric pollution over a city is sorely needed.

After presenting the study area and discussing what is currently done with pollutants data for obtaining map of concentration field, we will propose a new method making use of Earth Observation data.

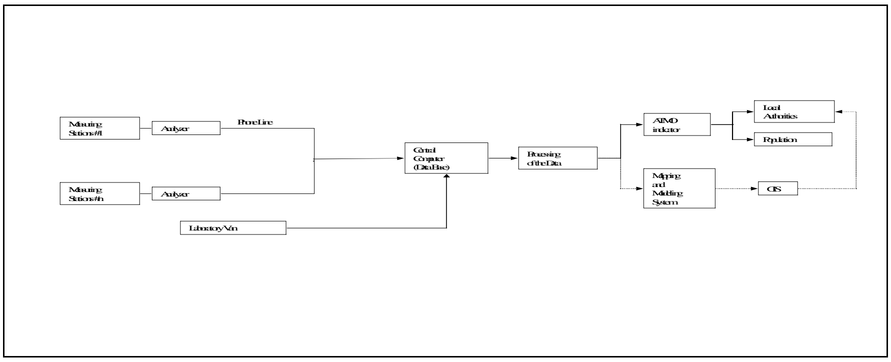

Fig. 1. Structure of a current (minimal) air quality networks. In dotted line are the non-fully operational tasks.

2 The Study Area and Dataset

The city of Nantes is located in Western France at 54 km from the Atlantic ocean. Air Pays de la Loire (formerly Loirestu'Air) is the local organization in charge of the air quality network in the city of Nantes and vicinity. Having an image taken by the satellite Landsat the 05/20/92 at 10:17 UT, we have used pollution data corresponding to the overpass of the satellite. In May 1992, fourteen stations were located within the urban area, twelve of which were inside the city. It has been shown that the higher the air pollution, the higher the aerosols concentration [10]. So we have focused the study on that pollutant. The day of May 20 was a sunny day with clear sky and light wind from North-East. The pollution level was below the critical levels.

3 The Current Mapping of BS

People working with air quality networks use interpolation/extrapolation techniques in order to evaluate the pollutant spatial distribution. Some scientists use the kriging method [11], some others recommend the use of the thin plates interpolation method [12] (Fig. 2 displays an example of a BS map obtained with the thin plates method). Concerning the accuracy of the map obtained, firstly it depends on the accuracy of the measuring stations, secondly it depends on the representativeness of the measurement in its neighborhood. In fact, concentration value can highly vary depending on the side of the street it had been measured [13]. Thirdly, according to Sifakis [14], for a reasonable accuracy, that is an error probability of 5%, a conventional air quality network ought to have 4 stations per 2,5 km² to find concentration values with an error of 20%. In our case the city of Nantes and vicinity should have 65 stations! The cost of a station is very expensive, so quality network use passive tubes to increase the number of data but not all the pollutants can be measured with this means.

Air quality organizations point out that an accurate mapping will allow:

- the monitoring of the whole urban area periodically,
- the localisation of the main pollution sources as well as their extension,
- the indication of areas where anti-pollution efforts have to be carried out,
- the establishing of the links between the distribution of the pollution and the local morphology as well as the street network,
- the optimisation of the sitting of the measuring-stations,
- the validation of the numerical models dealing with the local/regional pollution,
- the integration of pollution maps into a GIS which will allow the assessment and the prediction of environmental policies, as well as the simulation of scenarios.

In order to enhance the mapping of air pollutants we propose a new method making use of EO data.

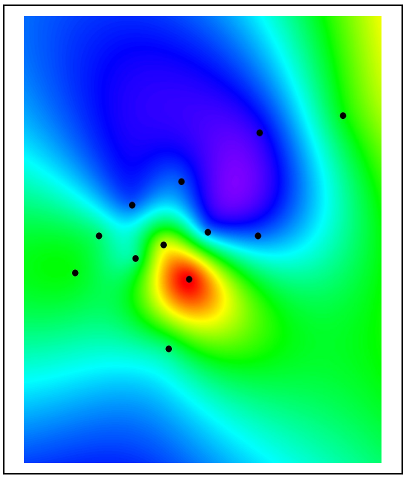

Fig. 2. BS concentration field obtained with the thin plate interpolation method making use of the 12 available measurements.

4 The Mapping of BS Using EO Data

The expected benefits of using EO data relative to current practices have also economic and social dimensions.

Concerning the economic dimension: establishing maps will be cost-saving; making use of maps for the sizing, the design and the implementation of the monitoring network will be cost-efficient; furthermore, the fighting against pollution will be improved by pin-pointing the most polluted areas with some impacts on cost-saving in preventing health troubles.

Concerning the social dimension: maps will serve to assess the efficiency of political measures for the prevention of pollution and mitigation of its effects, and as a consequence, maps will help to preserve a better quality of life for the citizen.

Several studies have shown the possible relationships between satellite data and air pollution [14],[15], [16], [17], [18], [19], [20]. We propose the use of the thermal infrared image (Landsat TM6) for which a strong correlation was found with some pollutants and more particularly with BS. After a least-squares regression, a linear relationship was found between 6 of the 12 pollution data and the corresponding digital count (radiance) of the TM6 image. The 6 remaining pollution data have served to evaluate the accuracy of the map. The relative rms error is about 80% which is fairly high but less than interpolation rmse. This relation was applied to each pixel of the image in order to derive a spatial distribution of BS over Nantes and vicinity (Fig. 3 shows a BS map obtained with EO data).

The authors are aware of the limitations of such a map and stress that not only the aerosols in the atmosphere influence the satellite measurement but also the nature of the landscape.

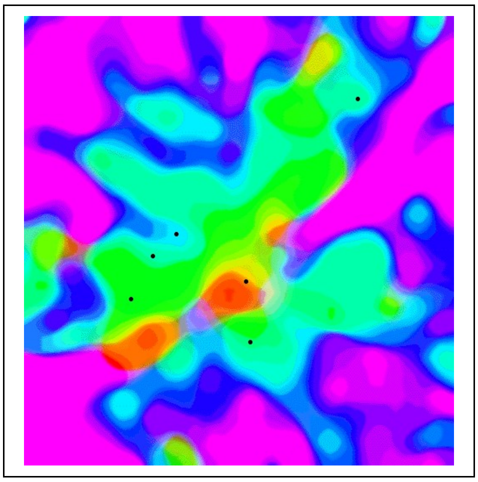

Fig. 3. Spatial distribution of BS over Nantes and vicinity derived from Landsat TM6 data on 20 May 1992 10:17 UT. The six points denote the sites used in combination with EO data.

5 Conclusions

This first attempt of mapping BS with Landsat TM6 data encourages us to continue our investigations. The results are promising, errors are similar to that found with standard methods, but the map derived with EO data provide further information concerning the urban features and morphology.

Further studies are needed to fully understand the links between the pollutants measurements and satellite data. Next investigations will focus on the establishment of more elaborated relationships by looking for areas which are similar in many aspects to the measuring sites. These aspects include the geographical and physical properties of the site and its neighborhood, which may be expressed by the spectral signature sensed by the satellite. Then we will be able to build a library of models linking the EO and pollution data as a function of several parameters including the meteorological conditions. Problem of very cloudy or rainy days, during which the satellite cannot observe the ground, are to be solved. This library models the spatial distribution of the pollutants. In an operational phase, measurements are collected by the processing center. An analysis is made of these data and external parameters. A spatial distribution model is constructed from the library and fused with measurements to produce in near real time an accurate map of concentration field of the pollutants.

The future urban network will operationally integrate external data such as satellite and aerial images or even drone images (Fig. 1). All the available satellite images taken over the area will be used (Landsat, SPOT, ENVISAT, etc.). The lack in data will be completed by campaign making use of airplane, and also drone if needed (e.g. when pollution peaks occur). All these data will be used in conjunction with pollution data collected by measuring stations, laboratory van, Sodar, Lidar (laser detection of pollutants), and even pedestrians volunteers, in order to increase the accuracy of the spatial distribution of pollutants. EO derived products, such as 2-D and 3-D maps, will also serve as input to numerical model of pollutants dispersion. The whole data will be managed through a SIG which will allow the pollution risk assessment, the simulation of scenarios in near real time.

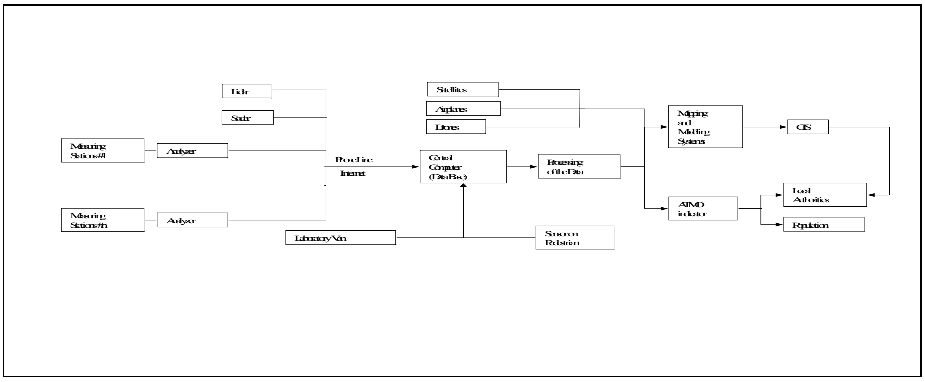

Fig. 4. What could be, in a near future, the structure of an air quality network integrating remote sensing data from satellites, airplanes or even from drones. At this time of integration, modeling and mapping system will be fully operational as well as fully integrated in a GIS.

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