OZONE SPATIALIZATION IN URBAN AND HINTERLAND AREAS *

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Abstract

Despite the air-quality monitoring networks run by approved organizations, large numbers of areas in France suffer from a lack of information about air pollution levels. Pollutant modeling enables such information gaps to be filled, albeit with certain limits. The approach used in this article to model average ozone concentrations in the city of Nice is based on environmental regression. The variables used refer to urban morphology, topography and weather conditions. The resulting model allows 70% of spatial variations in ozone pollution in Nice to be explained.

Keywords: atmospheric pollution, modeling, multiple regression.

Introduction

A large number of epidemiological studies carried out at a variety of spatial and temporal scales in recent years have shown the detrimental effects of air pollution on human health. Since 1990, for instance, the *Evaluation des Risques de la Pollution Urbaine sur la Santé* program (ERPURS: Assessment of Urban Pollution Risks on Health) has long focused on the short-term health effects of urban air pollution. This type of program, if it is to be properly carried out, requires that exposure to different pollutants be quantified at micro-level. In France, despite the development of the *Réseau National des Associations Agréées pour la Surveillance de la Qualité de l'Air* (AASQA: National Network of Approved Air Quality Monitoring Associations), there remains a very large number of poorly monitored areas, especially in densely populated city centers. Measurement of exposure in such areas, with their high concentrations of polluting emissions sources is therefore unsatisfactory.

AASQA is aware of these shortcomings and of the technical and financial limits to raising the number of monitoring sites, and is increasingly resorting to the modeling of urban air pollution in order to quantify the mean pollutant concentrations to which residents are exposed district by district and even street by street (Airpaca, 2009). The most common approach used is deterministic. The aim is to use models with ever more precise resolutions in order to show as accurately as possible the pollution levels to which each citizen is exposed. Numerical models incorporate equations from atmospheric physics and chemistry and require large initial databases such as emissions inventory of air pollutant emissions and meteorological data (e.g., ADMS-Urban). This type of deductive method is cumbersome to set up, however, and does not allow street-by-street outputs to be modeled. The various AASQA platforms have needed long measurement periods in order to adjust and validate models (Airpaca, 2009). The success of such an approach thus partly depends on a

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considerable amount of fieldwork to enable often significant spatial variations in air pollutants resulting from highly localized mechanisms to be recorded.

The present article aims to propose the spatialization of ozone concentrations in the city of Nice with a resolution of 50m à based on itinerant measurement campaigns using an inductive method based on multiple regression. It is an approach not directly based on the physics or chemistry of the phenomena measured like the one above, but has the advantage of being easier to set up. It requires the set of variables to be determined by multiple regression tests, since urban environments are heterogeneous, with irregular patterns of buildings, streets and wooded areas (Derbez *et al.*, 2001), and urban morphology has a strong influence on the dispersion of air pollutants (Maignant, 2007). The predictors selected to explain spatial variations in ozone concentrations are thus closely linked to the city's form and topography, as well as to weather conditions in the lower layers of the atmosphere.

1. Approach to the spatialization of tropospheric ozone

The empirical, or inductive, method is based on observation of the phenomenon to be modelized. Measurements made at selected points build up the model, whose aim is to provide data for each mesh of a pre-established grid. There can be several variants of the method according to the phenomenon's spatial dependence: is it autocorrelated in space? In order to find this out, calculation of the semivariogram reveals whether a spatial pattern is present or not. When there is spatial autocorrelation between measurement points, the interpolation will affect a specific value to the phenomenon according to the one observed in the immediate vicinity; this is the actual principle of kriging, which fixes the value of a spatial variable being studied at a non-sampled site by the linear combination of adjacent specific data. Ozone concentrations are not autocorrelated in space, however, in urban and hinterland environments, where there are too many factors affecting non-linear mechanisms (notably those linked to ozone chemistry's extreme complexity; *Académie des sciences*, 1993).

The environmental characteristics of observation points are used as explanatory variables of a phenomenon in the absence of spatial autocorrelation. This method lies at the interface between a purely deterministic approach and a purely spatial one, since the choice of environmental variables is not random but is justified by the intensity of the statistical relationship between the data and the phenomenon to be modeled. The physical – and in the case of ozone, chemical – mechanisms are thus implicitly included in the regression model. The pertinence of this type of approach is evaluated mainly by putting aside a certain number of observation points before calculating the model; they will be used to validate the results.

2. Methods: ozone concentrations, topography, urban morphology and pollutant dispersion

A multiple regression model enables a variable (e.g., ozone) to be calculated from explanatory variables, also called predictors, as described below.

2.1. Itinerant ozone measurements

Ozone is a special type of air pollutant, as it is not emitted by a source, but produced in the troposphere from precursor gases called primary pollutants, the latter originating from both anthropogenic sources (manufacturing, energy transformation, road transportation, etc.) as well as from biological sources (coniferous forests). In conditions of intense ultraviolet radiation (from April to September at temperate Northern Hemisphere latitudes), the mixture of primary pollutants produces ozone during episodes of anticyclonic fine weather (Durand, 2004). The Nice area is regularly affected by episodes of ozone pollution in summer, due to its location on heavily-used traffic routes with their high emissions of precursor gases, and its very high sunshine rates (Martin, 2008).

A large number of ozone measurement campaigns were carried out between April and September 2007 by following the same itinerary in Nice and its surrounding area (Martin, 2009). Measurements made over 85 days enabled mean ozone concentration behavior to be evaluated for 779 measurement points during the stability period in mid-afternoon (with levels close to the daily maximum) (figure 1).

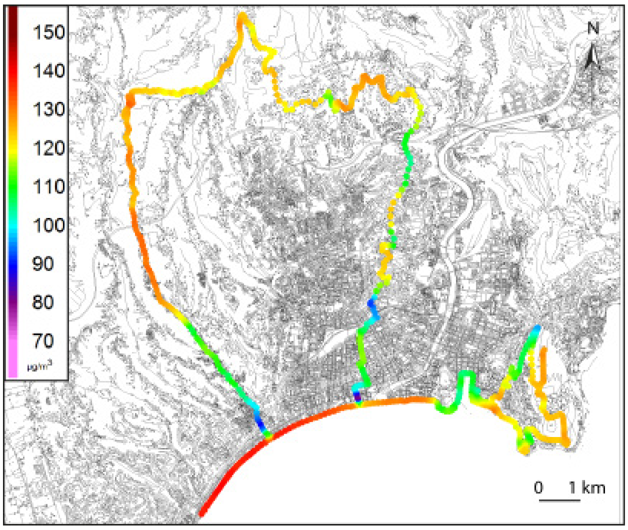

Figure 1. Mean ozone concentrations measured in Nice, April - September 2007, location of roads and buildings.

2.2. Topographical variables

The dynamics of the planetary boundary layer (PBL), whose thickness varies with the weather, are closely linked to the underlying topography. The entire set of meteorological variables is affected by this, and thus the dispersion and transportation of air pollutants. As a secondary pollutant, ozone is even more dependent on the influence of topography on aerological conditions. For example, the most distinct ozone-concentration spatial gradients can frequently be observed between talwegs and peaks. Air movement at the bottom of steep-sided valleys is generally less favorable to intense mingling of air masses. As a particularly reactive gas, ozone tends to be destroyed on contact with ground by dry deposition, and this is less common in well-aired places such as hilltops (Toupance, 1988).

In addition to altitude, other variables also depend on DEM, in particular the narrowness, steepness and exposure (slope orientation) of valleys. Another relevant characteristic for explaining ozone's spatial variations is distance from the sea; passing from a smooth surface to a rugged one constrains the movement of air masses and thus the mingling of pollutants. Since part of our sampling itinerary followed the shoreline, we were able to test the link between ozone and distance from the coast. Ruggedness does not evolve in a strictly linear fashion as one penetrates inland, so calculating the standard deviation of altitudes in differently sized windows enabled the correlation coefficients with the 779 points where ozone was measured to be calculated as well. Finally, the relative position of each ozone sampling point provided an opportunity to quantify the impact of a valley's being closed in or, in contrast, open and airy, on observed pollution levels.

Six topographical variables were therefore included in the spatialization model: altitude, slope, exposure, distance from the sea, rugosity as defined by the standard deviation of altitudes, and relative closedness/openness (*i.e.*, in a valley bottom or, on the contrary, at the top of a ridge). Several versions of the last three variables were tested by modifying the size of the spatial window by which they were defined (for example: rugosity measured over 200, 500 and 1000 meters).

2.3. Urban morphology

The alternation of buildings of different shapes and heights with roads of varying widths partly conditions air-pollutant dispersion intensity in urban and hinterland areas at any given time. Street morphology affects the volume of air in which pollutants emitted by road traffic are diluted. Hence, the wider an avenue and the lower the surrounding buildings, the greater the pollutant-dispersion potential, and vice versa. The Landsberg Building Index of the ratio between the height of buildings and the width of streets provides a partial, small-scale synthesis of city morphology, allowing dispersion potential to be taken into account. The IGN (*Institut National de l'Information Géographique et Forestière*) cartographic database gives the location and height of both buildings and roads (figure 1).

2.4. Dispersion of air pollutants

Weather conditions within the PBL, especially those in the mixed layer, partly regulate air pollutant concentrations by acting on post-emission dilution. Vertical stability in the atmosphere's lower layers and wind speed are two core parameters for understanding recorded pollution levels. As weather stations are not much more densely located around Nice than are pollution sensors, it was necessary to have recourse to a meteorological model. The RAMS (Regional Atmospheric Modeling System) deterministic model, designed for applications at meso-level, or indeed at much smaller scales (a spatial resolution of 500m was used here), provided weather information for the itinerary followed during ozone field campaigns from April to September 2007 (Martin, 2008). Four meteorological parameters were selected: wind speed and relative humidity at ground level, PLB height, and turbulent kinetic energy (TKE), a variable describing the blusteriness of an air mass).

3. The multiple regression model of ozone concentrations in Nice

After a number of tests were carried out to improve the regression model, seven variables were finally adopted. Building height and road width were part of the final model and showed close linear relationships with ozone (with correlation coefficients of -0.77 and -0.63 respectively). From among topographical-geographical variables, only altitude and distance from the sea were selected (correlations of 0.22 et 0.2 respectively with ozone). Finally, three of the four meteorological variables from the RAMS model were also included, with low-level correlations of between 0.2 and 0.26 in absolute value (table 1).

Variables	Correlation coefficient	Coefficient of determination
Building height	-0.77	0.59
Road width	-0.63	0.64
Relative humidity	-0.23	0.66
Wind speed	-0.24	0.67
Turbulent kinetic energy	0.26	0.68
Altitude	0.22	0.69
Distance from the sea	0.20	0.7

Table 1. Intensity of linear relationships between ozone and each explanatory variable, and evolution by successive inclusion of variables of the coefficient of determination.

Thus, apart from the descriptive variables of urban morphology, the role of the other predictors may seem secondary. Their influence is nevertheless masked by the two predictors statistically the most closely linked to ozone, and including them helps improve the quality of spatialization significantly. This is because the morphology of buildings and streets indirectly reflects concentrations of primary pollutants (in particular the nitrogen monoxide – emitted by motor vehicles – which destroys ozone as soon as its concentration exceeds a few µg/m^3). In the city center ozone chemistry predominates and reduces the influence of other factors affecting ozone levels.

The robustness of the adopted solution was tested during a validation stage. Fifty of the initial 779 ozone observations were eliminated at random, enabling the differences between the model and observation to be calculated. The test was repeated 10 times in order to ensure its solidity. The mean adjusted multiple correlation coefficient was thus 0.84 and the adjusted coefficient of determination (the correction taking into account the number of explanatory variables) 0.7; finally, the mean difference between modelized ozone concentrations and the 50 observation points excluded from the regression model was 5.6 µg/m^3.

The final ozone concentration map clearly shows lower ozone levels in urban areas, particularly Nice city center, where tall buildings and heavy traffic thoroughfares result in high primary pollution with significant ozone breakdown; higher ozone concentrations can be observed on the outskirts of the city. Over the sea and along a narrow coastal band, there are also high ozone levels due to the thinness of the PBL, which does not allow ozone to be mixed with a large volume of air (figure 2).

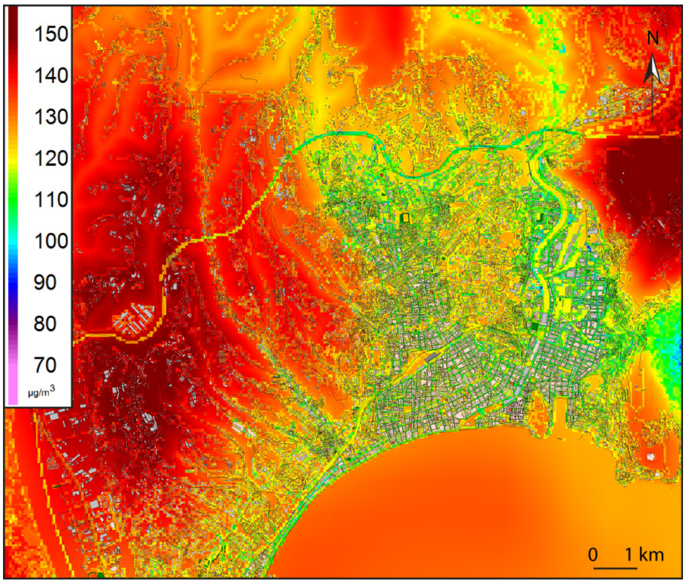

Figure 2. 50m-resolution map of mean ozone concentrations in Nice, April - September 2007.

Conclusion

The present study associated empirical and deterministic approaches in order to put forward a micro-scaled mean spatial configuration of ozone pollution. By combining a multiple-regression statistical method and a considerable database of mean ozone concentrations with urban morphology and weather conditions, we were able to spatialize ozone pollution for the entire city of Nice with a resolution of 50 m and a low margin of error. Depending on their location, people can thus know the mean ozone levels to which they are exposed in the open air in mid-afternoon from April to September. There is, however, a significant limit to this apparently satisfactory result: the regression model based on 2007 measurements has a limited lifespan, and is perhaps no longer valid. Ozone-precursor emissions are tending to fall as European Emission Standards are tightened for motor-vehicles; such regulations apparently led to a fall in ozone concentrations in Alpes-Maritimes department (where Nice is located) between 1998 and 2009 (Martin, 2010). New measurements may therefore need to be made in the near future in order to update the database.

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