Spatial representativeness of an air quality monitoring station. Delimitation of exceedances areas

Maxime Beauchamp[1], Laure Malherbe[1], Laurent Letinois[1]

1. Institut National de l'Environnement Industriel et des Risques (INERIS)

Direction des risques chroniques, Parc Technologique Alata, 60550 Verneuil-en-Halatte, France

maxime.beauchamp@ineris.fr

Chantal de Fouquet[2]

2. Equipe géostatistique, centre de géosciences, Mines ParisTech

35 rue Saint Honoré, 77305 Fontainebleau, France

Abstract

Spatial representativeness of a monitoring station and spatial extent of an exceedance zone in case of non-compliance with environmental objectives are notions appearing in the European legislation on ambient air quality. No specific approach is prescribed to delimit such areas. We developed a probabilistic methodology based on a preliminary kriging estimate of atmospheric concentrations at each point of the domain.

In the proposed definition, a point is considered as belonging to the area of representativeness of a station if its concentration differs from the station measurement by less than a given threshold. Additional criteria related to distance or environmental characteristics may also be introduced. The standard deviation of the estimation error is then used, to select the points, at a fixed risk, where the difference of concentration with respect to the station is below the threshold and to provide the probability of overshooting a limit value.

Stability in time and sensitivity to the selected criteria are first tested with NO_2 annual concentration data produced by combining surface monitoring observations and outputs from the CHIMERE chemistry transport model.

On the local scale, data from passive sampling surveys and high resolution auxiliary variables are used to provide a more precise estimate of background pollution. Traffic related pollution can also be accounted for in the map with help of additional information such as distance to the road, traffic-related NOx emissions, or road traffic counts. The methodology is applied to NO_2 experimental datasets for different French cities to assess the spatial representativeness of stations and delimit areas of exceedance of the NO_2 annual limit value.

Keywords: geostatistics; kriging; air pollution; spatial representativeness; exceedances of air quality limit values

1 Introduction

Local agencies in charge of air quality monitoring are concerned with assessing the geographical areas in which concentrations may be assumed similar to those measured by monitoring stations. They also have to provide an estimation of the surface and population exposed to the observed exceedances.

Spatial representativeness of a monitoring site is a recurrent notion that appears in European regulatory requirements on air quality but has not been precisely defined so far. A definition is proposed and its practical implementation leads to the production of maps to characterize areas represented by the stations.

The approach is also used to identify exceedances areas, regardless of the representativeness issue.

Application of the method for the background pollution [1] is presented and results concerning limit value exceedances are presented in the case where a traffic-related pollution model is considered.

2 Materials and Methods

2.1 Representativeness

First, let $Z(x)$ denote the concentration at location x, $Z^*(x)$ its estimate from kriging and $\sigma_K(x)$ the kriging standard deviation.

A first approach to define the area of representativeness of a monitoring station S_0 located in x_0 is to consider all the sites where the concentrations are sufficiently close to the station measurement, which implies the introduction of a threshold notion [2][3][4]:

$$|Z(x) - Z(x_0)| < \delta \tag{1}$$

Let us take the estimation error $\epsilon(x)$ into account, conventionally assumed to be a Gaussian process with zero mean and a standard deviation equal to $\sigma_k(x)$: $\epsilon(x) = \sigma_k(x).T$ where $T \hookrightarrow \mathcal{N}(0,1)$. We don't take the measurement error at the station into account. The condition (1) can be written :

$$|Z^*(x) + \epsilon(x) - Z(x_0)| < \delta \tag{2}$$

We introduce the statistical risk that the concentration of a point considered in the area of representativeness of S_0 differs from the station measurement by more than the given threshold δ:

$$\mathbb{P}[|\epsilon(x)| \geq \delta - |Z^*(x) - Z(x_0)|] < \eta \tag{3}$$

Then, making a Gaussian hypothesis on the error distribution, the standard deviation of the estimation error is used to select the points in the area of representativeness:

$$|Z^*(x) - Z(x_0)| < \delta - \sigma_k(x) * q_{1-\frac{\eta}{2}} \tag{4}$$

In this approach, a point can be considered as belonging to several areas of representativeness. So, additional criteria related to distance, minimal deviation of concentration, or environmental features are introduced to make a point belong to a unique station.

2.2 Exceedances

Let LV designate the considered limit value. LV = 40 μg/m^3 for NO_2 annual mean concentrations [5].

We do not consider the correlation between the kriging estimation and its error, then evaluating whether Z(x) exceeds the limit value can be written as follows:

$$Z(x) > LV \Leftrightarrow Z^*(x) + \sigma_k(x).T > LV \Leftrightarrow T > \frac{LV - Z^*(x)}{\sigma_k(x)} \tag{5}$$

In the proposed method, non-exceedance and exceedance areas are delimited from inequality (5), considering a non-detection probability threshold, which is the risk of x belonging to a non-exceedance zone whereas Z(x) is above the limit value, and a false detection probability threshold, which is the risk of x belonging to an exceedance zone whereas Z(x) is below the limit value. If the priority is to keep the number of exceedance points wrongly included in the non-exceedance area as small as possible, then α should be set to a low value whereas a higher value may be allowed for β. Cori [3] suggests that α be given the classical value of 5 while β could empirically be set to 1/3 to have a moderate risk of false detection.

This leads to the following definitions:
- **non-exceedance zone:** x / $\mathbb{P}[Z(x) > LV] < \alpha$

$$\begin{aligned} \mathbb{P}[T > \frac{LV - Z^*(x)}{\sigma_k(x)}] < \alpha \quad &\Leftrightarrow \quad Z^*(x) < LV - q_{1-\alpha} * \sigma_k(x) \\ &\Leftrightarrow \quad Z^*(x) < LV - 1.65 * \sigma_k(x) \text{ for } \alpha = 5\% \end{aligned} \tag{6}$$

- **exceedance zone:** x / $\mathbb{P}[Z(x) \leq LV] < \beta$

$$\begin{aligned} \mathbb{P}[T \leq \frac{LV - Z^*(x)}{\sigma_k(x)}] < \beta \quad &\Leftrightarrow \quad Z^*(x) > LV - q_\beta * \sigma_k(x) \\ &\Leftrightarrow \quad Z^*(x) > LV + 0.41 * \sigma_k(x) \text{ for } \beta = 34\% \end{aligned} \tag{7}$$

$q_{1-\alpha}$ and q_β are the (1-α) and β-quantiles from the standard normal distribution.

The locations satisfying none of those conditions make the "uncertainty zone".

3 Results

To illustrate the results of the methodology, passive sampling data provided by an extensive campaign carried out in in the French city of Montpellier by the local agency Air Languedoc-Roussillon are used. The sampling dataset includes eight 14-day periods of measurement at background and traffic sites.

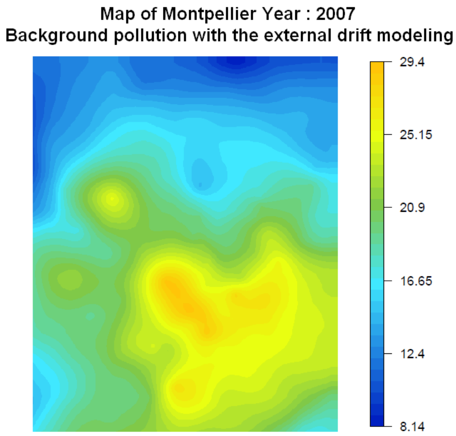

Figure 1: Map of the NO_2 background annual mean in Montpellier during the year 2007

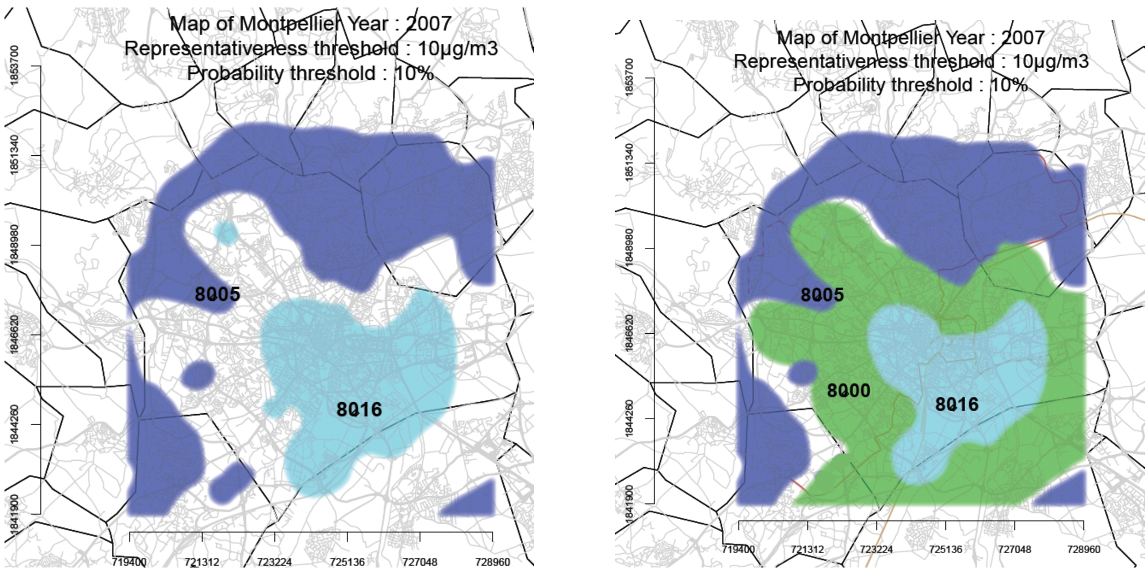

Figure 2: Areas of representativeness of the background monitoring sites for the French city of Montpellier in 2007, for a threshold of $10\mu g/m^3$ and a risk fixed at 10%

Figure 2 shows the areas of representativeness on the background pollution for a threshold of $10\mu g/m^3$ and a statistical risk fixed at 10%. Two areas of representativeness can be obtained: a first one for the downtown pollution and a second one for the suburb pollution.

Results can be helpful in providing some recommendations for setting up new fixed monitoring sites. In this case, sampling passive data can be used to find an appropriate site where the concentration of NO_2 is representative of the missing information, taking into account some criteria such as the decreasing of the kriging variance for instance.

Concerning the exceedances issue, the areas where NO_2 background concentrations overshoot the annual limit value (40 $\mu g/m^3$) are very small since NO_2 exceedances mostly occur at traffic-related sites. Figure 3 shows the probability map for the NO_2 background annual mean in Montpellier to overshoot the threshold of 32 $\mu g/m^3$ (that corresponds to the upper assessment threshold [5]) during the year 2007.

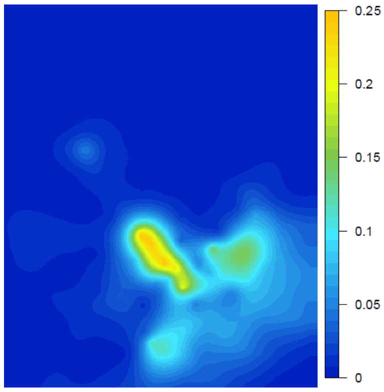

Figure 3: Probability for the NO_2 annual mean in Montpellier to overshoot the threshold of 32 $\mu g/m^3$ during the year 2007

On local scale, detailed concentration maps accounting for both background and roadside pollution can be established from passive sampling surveys, using high resolution auxiliary variables and additional information about traffic emissions and distance to the roads [6].
Figures 4 and 5 shows the results obtained for the French city of Troyes, where a passive sampling campaign was carried out in 2009 by the local agency Atmo Champagne-Ardennes.

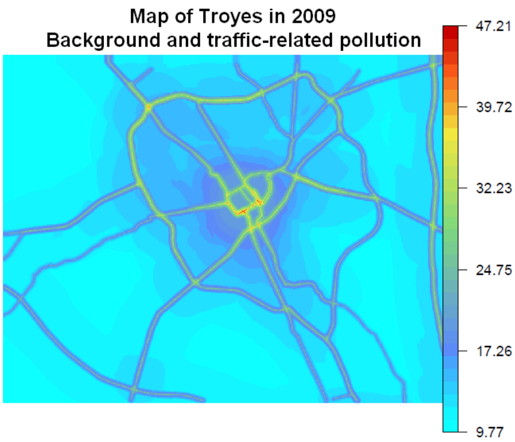

Figure 4: Map of the background and roadside pollution in the French city of Troyes in 2009

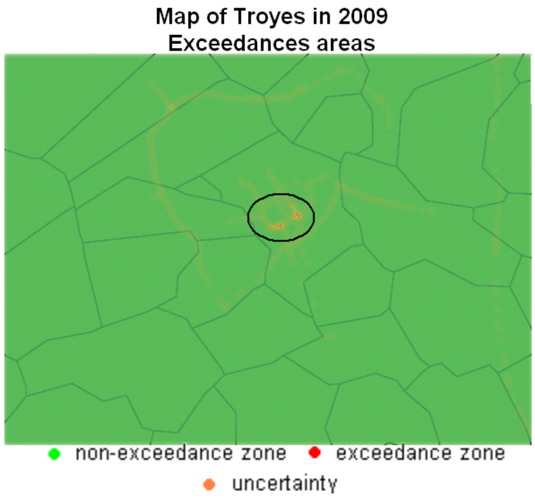

Figure 5: Exceedances areas of the NO_2 annual limit value ($40 \mu g/m^3$) in the French city of Troyes in 2009

4 Concluding remarks

Application of the method for the representativeness of background pollution measurements using analyzed data of NO_2 annual concentrations produced on national scale shows its sensitivity to the criterion selected to remove intersections between representativeness areas. Stability in time of the areas is also related to variations of concentrations on the domain.

The notion of exceedance and non-exceedance was formalized making some conventional assumptions due to operational constraints. It distinguishes the non-detection and false detection probability thresholds which can be adjusted according to the objectives of the study.
Exceedances areas are consistent with observed exceedances but traffic-related exceedances identified by the method strongly depends on the quality of the roadside pollution modeling.

In the end the method is able to provide areas of representativeness for background pollution measurements. The relevance of defining an area for traffic measurements is still in discussion. As regards the spatial extent of an exceedance, authorities and decision makers will rather have a single figure for the exceedances issue than an interval of values. Therefore, a remaining issue is the way of addressing the uncertainty area. Among envisaged solutions are its inclusion in the exceedance area or the refining of the uncertainty area, considering a criterion based on the temporal evolution of concentrations.

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