Air quality mapping in urban areas: bridging the gap between background and near road pollution

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Abstract Mapping atmospheric pollutants in urban areas is a growing requirement from municipalities, because of obvious health-related issues. Such mapping frequently relies on a limited monitoring network that might be combined with physicochemical models. Classical interpolation approaches are usually based on background measurements only, due to significantly higher spatial variability of near road pollution; ignoring the highest concentration levels in the produced maps has several drawbacks: tricky communication, inability to provide relevant estimates for population exposure. On the other hand, numerical models are pushed towards local scales, leading to intensive computation needs. The presented approach allows integrating both background and nearby roads data in the same modeling approach. It might also be used to optimize the numerical model meshing. Both aspects are illustrated on two real cases.

1 Introduction

Mapping atmospheric pollutants in urban areas frequently relies on a number of air quality measurements. Measurements are described as “near road” when they aim at providing air quality close to pollution sources (industries, traffic roads) and “background” measurements (urban, rural) when they are designed to characterize the average atmospheric pollution over these areas [1]. Background and near road measurements correspond to different statistical populations, both in terms of concentration levels and spatial representativeness, justifying that they are usually processed separately.

In this context, a classical approach consists in mapping background urban pollution from background measurement sites, ignoring nearby roads (proximity) measurements. Proximity phenomenon being of importance for pollutants like nitrogen dioxide or benzene, ignoring this information restricts the use of such

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mapping, in particular for characterizing air pollution nearby roads and evaluating the potential exposure of populations.

Concentration levels along roads can be predicted thanks to numerical models such as STREET [2], ADMS-Roads [3] or SIRANE [4]. Indeed, using different parameters (emissions, axis typology, meteorology...), these road models estimate pollutant concentrations along the main axis [5].

In this context, geostatistics may provide appropriate methods to bridge the gap between background and near road pollution during air quality mapping. Modeled concentrations over the network need to be consistently combined with air quality measurements.

Also, at the urban scale, physicochemical models commonly simulate the concentrations of chemical compounds on a regular grid which is refined along the road network. The outcome of the numerical simulation is usually linearly interpolated on a regular grid corresponding to the final mapping scale. This post-processing creates artifacts around the road network, due to the distribution of the simulation nodes. An efficient interpolation using the preceding approach allows reducing the number of simulation nodes (and consequently the computation time) required to guarantee the quality of the physicochemical model output.

Both cases are illustrated on real examples coming from several French cities.

2 Methodology

Based on pollutant measurements and a physicochemical road model, the proposed methodology consists in several steps which are detailed in the following paragraphs:

- mapping background pollution from background measurements and emission inventory, using classical geostatistical techniques [6, 7, 8],
- correcting potential bias between measured and modeled concentrations nearby roads,
- spatializing the corrected concentrations known on the traffic network consistently with the information available upon the type of decrease and the distance of impact.

Estimating the background pollution

The cartography of the background pollution is obtained by the application of classical geostatistical techniques to the available background measurements: kriging or cokriging integrating auxiliary variables such as for instance an emission inventory. At this stage, measurements impacted by the road proximity are discarded from the dataset.

Estimating concentrations over the traffic network

Having a background pollution cartography and near road sites removed from its construction, the objective is now to combine this information with the one linked to the road information: road model, road emissions or just the network geometry, in order to obtain a relevant cartography which integrates both background and near road pollution.

The consistency between the road model and the available data is first checked: for instance, modeled concentration nearby roads should be higher than the background pollution; also, near road information (measured and modeled concentrations) nearby roads should be correlated.

The concentrations coming from the road model are available in the form of lines corresponding to the different sections of the modeled road network. In order to spatialize them, these lines are discretized in regular points covering the entire road network.

Spatializing traffic over-concentrations

Near road concentrations, exclusively known on the network, have then to be spatialized. Several studies have found that pollutants such as nitrogen dioxide show an exponential decrease of the pollution levels along the road axis [1, 9]. In addition, the surrounding urban network is crucial to determine the impact distance of the road, equal to 100m maximum in a close urban area (important roughness, except "canyon-type" roads), and 200m maximum in an open environment (national roads and highways). Soil occupation allows distinguishing these two cases.

The near road over-concentrations known along the road network are spatialized using simple kriging with an exponential variogram model whose the range is taken equal to the impact distance of the roads (figure 1).

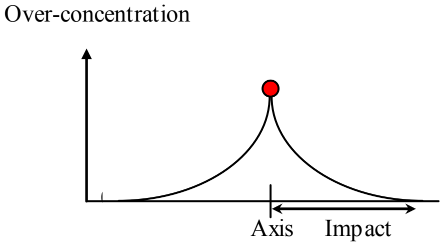

Figure 1 Illustration of how concentrations modeled along the traffic network are spatialized using simple kriging. The distance of impact ("Impact") of the road on the neighboring air quality classically varies between 100m and 200m depending on the known density of urban fabric.

If the road network leading to significant concentrations levels is exhaustively modeled, the expected mean of over-concentrations outside of this network is simply equal to 0.

Final estimation

The final pollutant map is computed by adding together the background pollution map and the near road over-concentrations cartography. By construction, the map obtained in this way honors the measured data, takes into account the available background information (emissions) and integrates the modeled pollution levels near roads.

3 First example: integrated background – near road pollution over Toulon (France)

Material

This first example aims at mapping annual nitrogen dioxide (NO_2) concentrations over the city of Toulon (South East of France). NO_2 annual concentrations have been measured at 73 are background sites and 30 near road sites.

A NO_2 emission inventory is available over the area of interest. Soil occupation is known at a 50m resolution. The road model STREET [2] has been applied to model the NO_2 concentrations on the main network of the conurbation.

Mapping of the NO_2 background pollution

NO_2 mapping classically integrates an emission inventory because of their correlation. The inventory is usually first transformed (smoothing and logarithm transform) in order to improve this correlation. Figures 2 and 3 illustrate the resulting transformed inventory and the correlation between transformed emissions and NO_2 background concentrations.

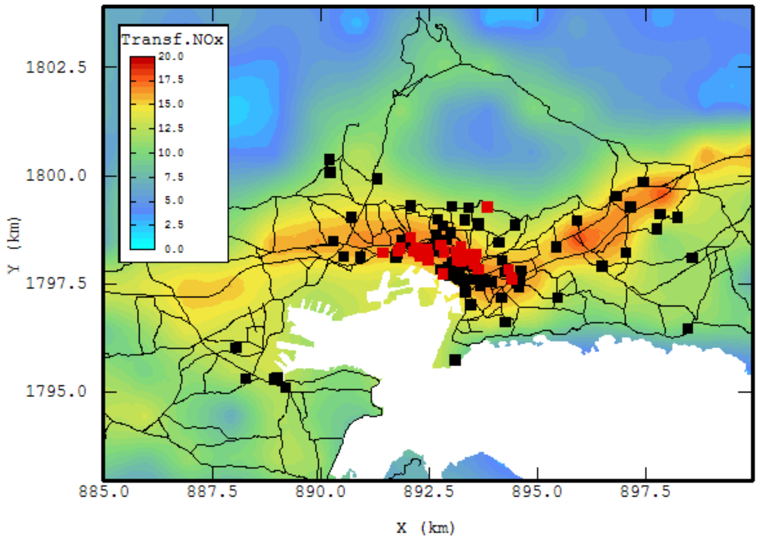

Figure 2 Transformed nitrogen oxides emissions, location of NO_2 background (black squares) and proximity (red squares) measurements. Traffic network modeled by the road model STREET (thin black lines).

The analysis of the 73 background sites led to remove 7 of them because of concentrations higher than the nearby background sites, due to the proximity of the road network. The final cartography of the background pollution is obtained by kriging of NO_2 background data with the transformed inventory as external drift (figure 4).

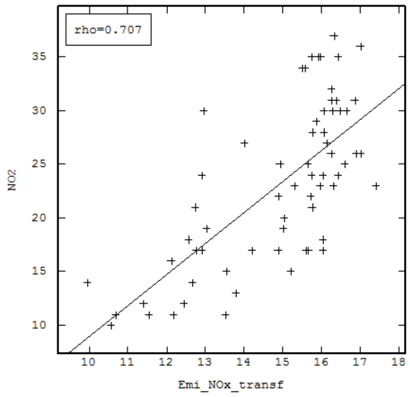

Figure 3 Scatter diagram between transformed nitrogen oxides emissions and measured background NO_2 concentrations. Linear regression line and correlation coefficient indicated.

Spatialization of near road over-concentrations and final mapping

The concentrations modeled by STREET, discretized every 20m, are overlaid on the cartography represented on the figure 4. Their average correlation with the near-road measures leads to correct them by kriging with external drift: the global behavior of the STREET model is kept, but the concentrations levels are corrected in order to be consistent with near road data. The corrected over-concentrations modeled by STREET are spatialized by simple kriging with 0 mean using an exponential variogram model. The variogram range is equal to 100m in dense urban areas (defined by a proportion of constructions higher than 50%) and 200m in open environment (constructions lower than 50%). The final NO_2 map over Toulon, obtained by addition of the background mapping and the one of near-road over-concentrations, is illustrated on figure 5.

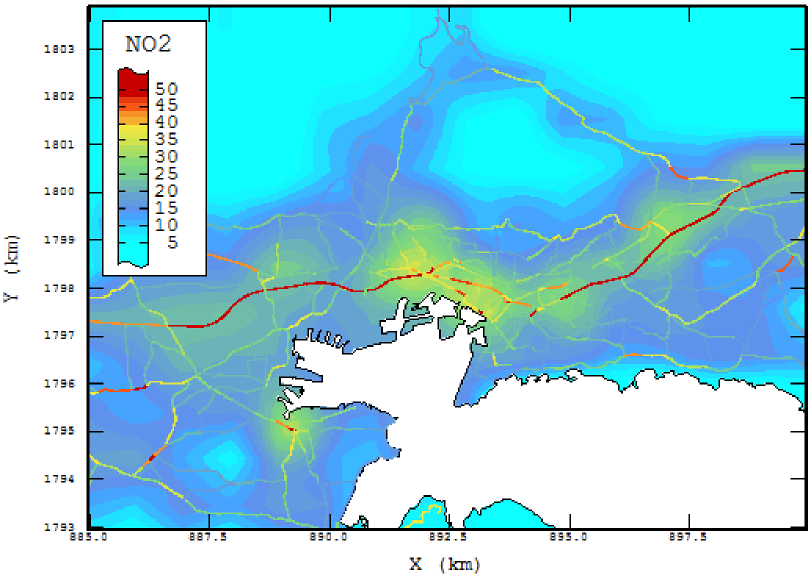

Figure 4 Background annual NO_2 concentration map ($\mu g/m^3$). NO_2 concentrations provided by the road model STREET are overlaid with the same color scale.

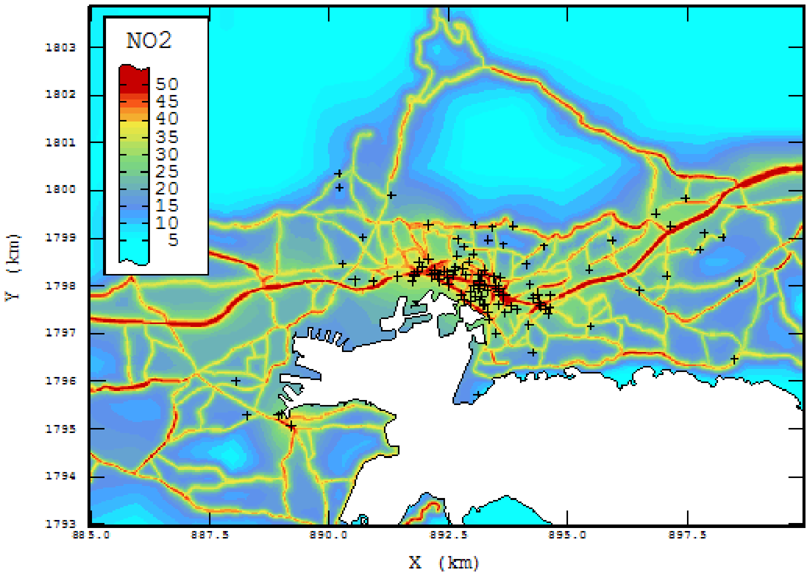

Figure 5 Final NO_2 map ($\mu g/m^3$), obtained from the summation of the background map and of the spatialized concentrations provided by the road model, corrected in order to be consistent with near road measurements.

4 Second example: post-processing of a physicochemical model over Nancy (France)

This second example illustrates the post-processing of a physicochemical model over Nancy (East of France). The development of an adapted interpolation methodology allows improving significantly the post-processing of the physicochemical model.

Initial sampling

The output of the physicochemical model ADMS [3] is made up of a first regular grid (with a resolution of 300m that could be refined in urban areas) and a second sampling along the road axis using regular transects of 4 points.

Usually, the visualization of the modeled concentrations requires as post-processing an interpolation on a final regular grid. A crude re-interpolation usually generates artifacts as illustrated on figure 6.

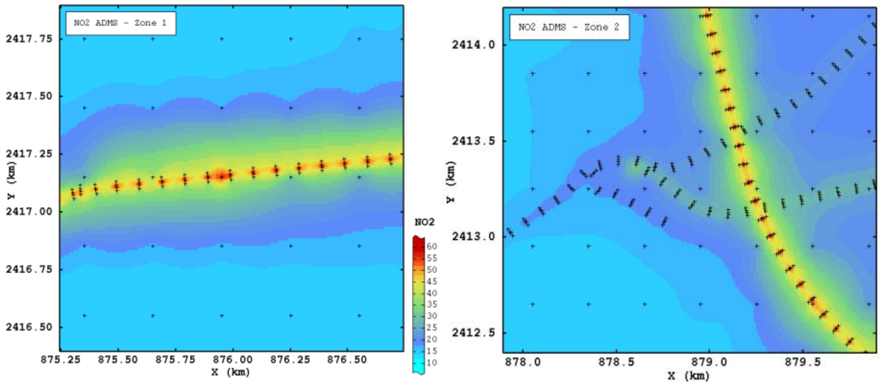

Figure 6 Kriging (with a default linear variogram model) of NO_2 modeled concentrations (ADMS) in µg/m3 on two test-zones over Nancy.

Interpolation approach

The objective of this work consists in improving the post-processing of the modeled concentrations. Two solutions have been considered: (i) during the interpolation by kriging, local anisotropy parameters are used in order to improve the interpolation continuity along the road axis and to reduce artifacts in these areas [10], (ii) separate background and proximity mapping.

The first approach consists in directly working with modeled concentrations on all the simulated points. Firstly, from the knowledge of the road network, the direction and the importance of the anisotropy are locally determined. The anisotropy factor specifies the highest continuity of concentrations along the road axis against the perpendicular direction. This factor is high along a single axis oriented in a unique direction. It is lower in areas of crossroads and it could be equal to 1 if there is no road axis (isotropic case). These different parameters are then used during the re-interpolation by kriging. Figure 7 illustrates the result of this method applied on the two previous test-zones. The improvement is obvious in the case of simple axis, despite of some artifacts due to the kriging neighborhood, but creates more significant artifacts in case of crossroads and of axis with bends.

The second approach is based on the same idea as the one applied over the first example of Toulon. The first step consists in mapping the background pollution. A near-road buffer is defined from the knowledge of the road network. An arbitrary distance of 500m on each side of the axis is here considered. The re-interpolation of background concentrations is then achieved from the ADMS regular sampling removing points within the near road buffer. Then, over-concentrations are calculated within the near road buffer and are spatialized using simple kriging with an exponential variogram model and a range equal to the distance of impact.

In order to reproduce the good continuity of the concentrations over the traffic network itself, the over-concentrations are first re-estimated at regular intervals of 10m along the network. The final cartography is obtained by the addition of the over-concentration and of the background maps. The result of this approach is illustrated on figure 8. It shows a better continuity of the concentrations and less artifacts due to crossroads or to the roads geometry.

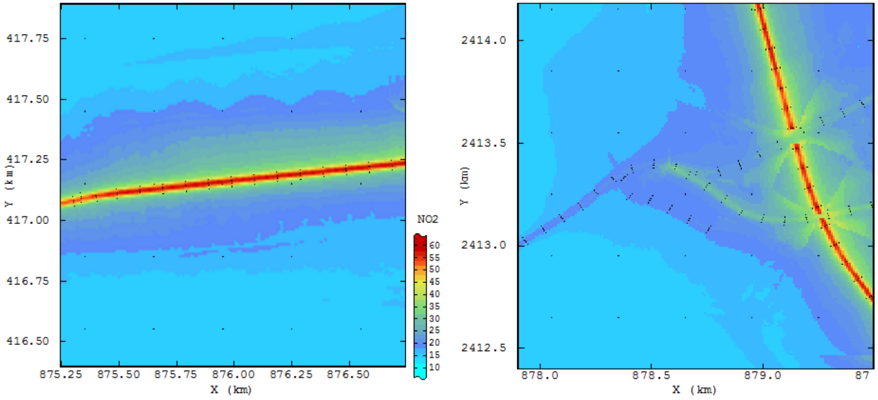

Figure 7 Spatialization by kriging with local parameters of NO_2 modeled concentrations (ADMS) in µg/m3 on two test-zones over Nancy.

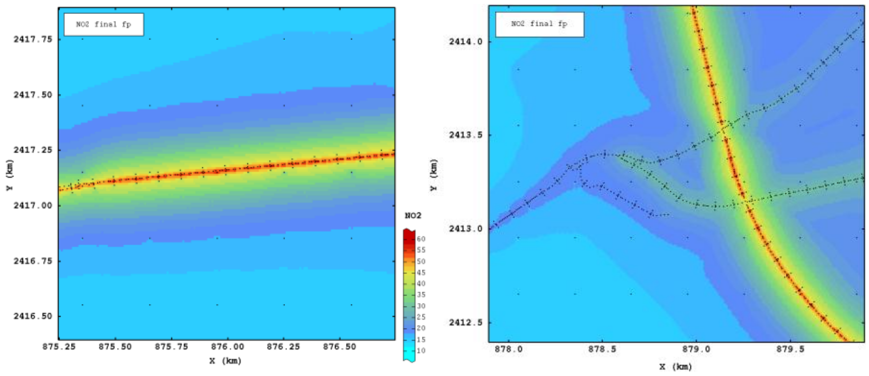

Figure 8 Final NO_2 map (µg/m3), obtained from the summation of the background map and of the spatialized over-concentrations.

Finally, this method allows optimizing the model meshing in order to reduce its computation time.

5 Conclusion

The presented methodology allows combining, in a flexible and pragmatic way, air quality information related to both background and near road phenomenon.

Several perspectives remain. Obviously, distinguishing background and near road data is sometimes arbitrary and difficult, especially when the typology of the monitoring sites is changing due to modifications of the traffic network; preliminary exploratory data quality control is therefore recommended. Also, uncertainty assessment is not straightforward as the approach involves two independent steps. Estimation variances might be combined but with some assumptions. Finally, the approach is assuming that the significant part of the traffic network has been exhaustively modeled, which is sometimes not the case.

Nevertheless, the approach has been applied successfully on various contexts for pollutants largely influenced by traffic (nitrogen dioxide, benzene). It helped solving communication issues and providing realistic maps.

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