Modelling vehicle-generated atmospheric pollution in a *quartier* of Lyon using the model SIRANE

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1 Introduction

Urban air pollution is usually measured by a few fixed point samplers, which provide relatively high resolution of the temporal evolution of pollutant concentrations, but very poor spatial resolution. There are many practical applications, however, which require a much more detailed knowledge of the spatial variations in pollutant concentrations within individual streets and in the areas between the measurement stations. Examples of such applications include calculations to estimate overall urban air quality, the exposure of the urban population to atmospheric pollution or the likely effects of modifications to urban infrastructure. The only practical way of increasing the representativity of the data from point measurements is to couple the data with computational models of the transport and dispersion of pollutants in the urban canopy. One approach that has been widely adopted to model concentrations in a single street is the street canyon model (Johnson *et al*, 1973, Yamartino & Wiegand, 1986, Berkowicz *et al*, 1997, Soulhac *et al*, 1998*a*). This type of model can give useful results for a single, isolated street, but it is difficult to apply it to a whole district, because it does not account for the exchange of pollutants between streets, at intersections. We have therefore developed a simple model – SIRANE – for a network of streets. The aim of the work presented here is to use this model to compute atmospheric pollution in one of the arrondissements of Lyon, and to compare the results with data from the monitoring network. The model is then used to evaluate the representativity of the samplers, and the exposure of the urban population to atmospheric pollution.

2 The model

The model SIRANE is based on the concept of a network of streets (Soulhac *et al*, 1998*b*). The network is constructed from a set of street segments, joined at nodes which represent the intersections; this is compatible with the description typically used in GIS-based systems for computing traffic flows in urban environments. The mean wind flow within each street segment is calculated from the characteristics of the external wind field. The pollutant concentrations are calculated by representing each segment as a box, and computing the mass balance for pollutants entering and leaving the volume. The exchange of pollutants between the street and the overlying urban canopy is modelled using a gradient-diffusion approach, specially developed for the model. The exchange of pollutants between connected streets at street intersections is computed from a model specifically developed from detailed studies of idealised configurations, which takes into account the concentrations in neighbouring streets and the mean and fluctuating wind above the streets. The transport and dispersion of pollutants in the urban canopy above the roofs is modelled using a Gaussian calculation; the resulting plumes can contribute significantly to the pollution in downwind streets. Finally, a simplified chemistry model is included to represent the transformation NO-NO_2-NO_3 within the streets. The model was initially validated by comparison with results of 3D numerical simulations of flow and dispersion in idealised street networks, using the atmospheric boundary layer code MERCURE.

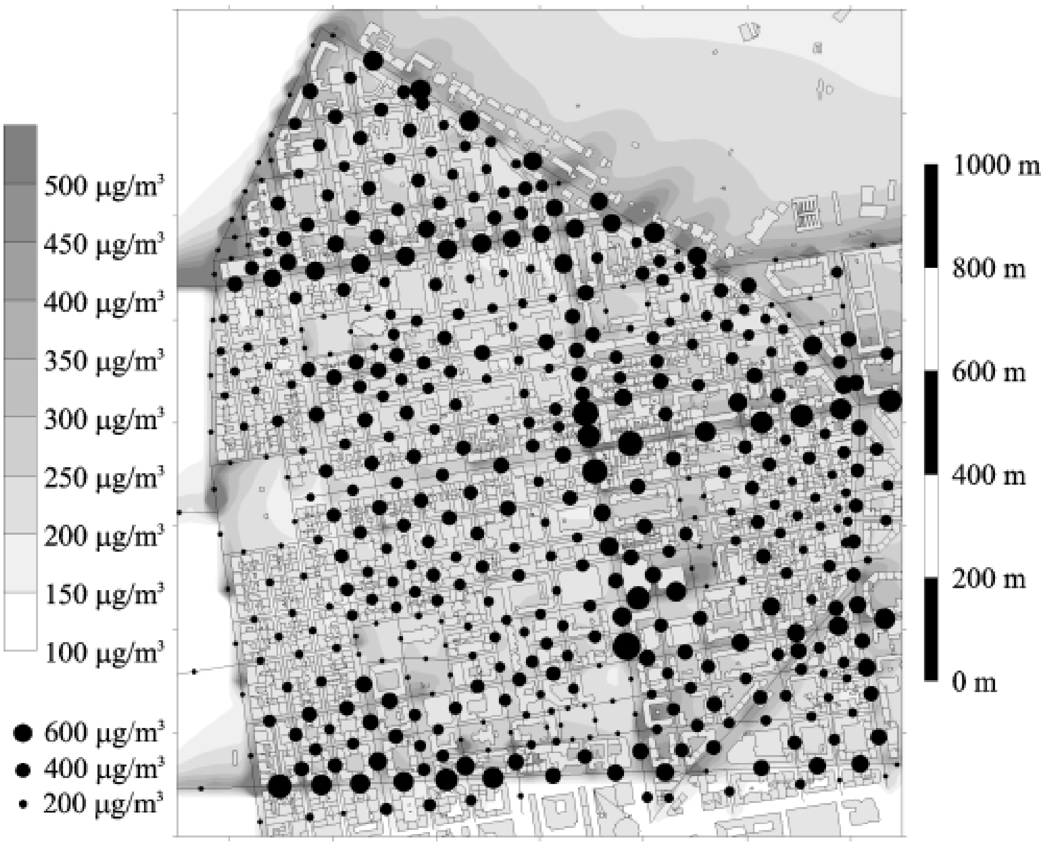

Figure 1 Instantaneous concentrations of NO_X in the 6th *arrondissement* of Lyon. The solid circles represent the average concentrations within the streets. The grey-scale field gives the concentration field at roof level.

3 Simulation of an *arrondissement* in Lyon

A full validation of the model SIRANE in real conditions would require a campaign of field measurements to provide a detailed description of the spatial and temporal evolution of the pollution within the streets. Unfortunately, this sort of data base does not yet exist, since most of the field studies that have been performed to date have been concerned with pollution variations within a single street. In order to provide this sort of data, the COPARLY intends to carry out a series of field measurements in the 6th *arrondissement* of Lyon, and the simulations presented here have been performed to help in the preparation of this campaign.

The *arrondissement* is relatively flat, measures about 1.5km by 1.5km, and consists of a fairly regular network of about 450 street segments (see figure 1). The aspect ratio of the streets (height/width) varies between 1 and 2, and the average segment length is of the order of 100m. The traffic flows for this network were obtained from simulations performed using the traffic model DAVIS, for a standard weekday rush hour, modified by daily and weekly weighting functions to account for deviations from rush hour conditions. The traffic flows were then used to estimate vehicle emissions, using the COPERT II methodology. Meteorological data (wind speed and direction) were estimated from hourly measurements at the meteorological station at Bron, about 7 km from the *arrondissement* (the terrain between the two sites can be considered relatively flat and uniform).

The simulations were carried out for a 12-month period in 1996-97; hourly concentrations of NO_X were computed using the model SIRANE, and these concentrations were then adjusted to take account of long term variations in the background NO_X concentration. These were estimated from the concentration of NO_X measured at 3am each day (when the traffic flows were effectively zero) by a monitor located in the 6th *arrondissement*.

The results of the simulations are shown in figure 1. The model computes both the average concentration inside each segment in the network, and the concentration field at roof level. In order to evaluate the quality of the computed concentrations we have compared them with the concentrations actually measured, during the same period, by a fixed sampler located in one of the streets close to the centre of the *arrondissement*. The predicted and observed concentrations, over a typically week, are shown in figure 2, which shows that the correlation between the two data sets is generally very good. This is confirmed by a plot of predicted hourly concentrations as a function of the corresponding measured concentrations (figure 3) and an estimate of the principal statistical properties of the two data sets (table 1). The correlation coefficient for the two data sets is 0.83, but there are some situations in which the difference between predicted and measured concentrations exceeds a factor of 2 (figure 3). This is particularly evident for situations in which the model tends to over-predict the concentrations – the difference between observed and predicted concentrations is generally much smaller when the model under-predicts the concentration.

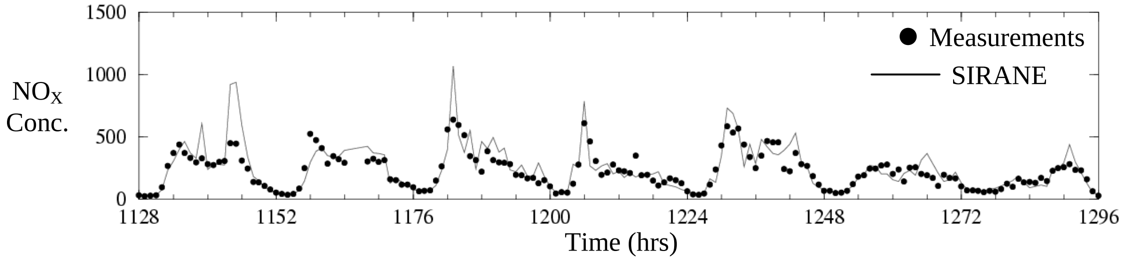

Figure 2 NO_X concentrations – a comparison between SIRANE and measured data for the period 17-23 June 1996.

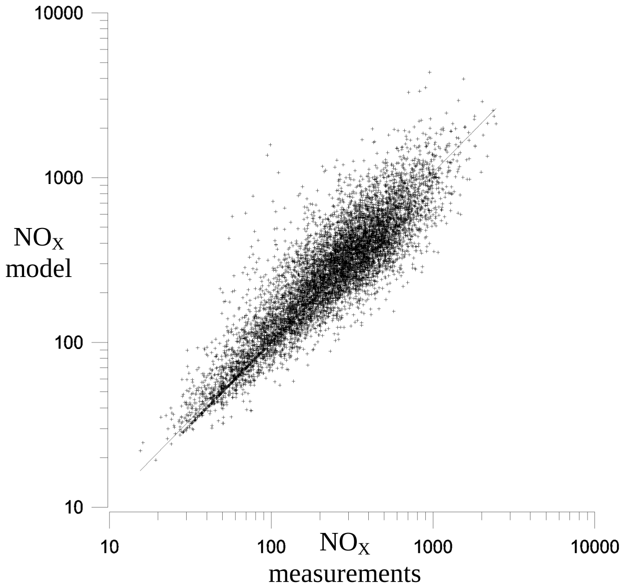

Figure 3 A comparison between the predicted and measured concentrations of NO_X (in μg/m3) for a 12 month period 1996-97.

NOX concentration (μg/m^3)	COPARLY Measur.	SIRANE model
Annual average	305	338
50 percentile	250	274
98 percentile	958	1165

Table 1 Principal statistical properties of the predicted and measured concentrations for a 12-month period 1996-97

In order to explain this difference, we have examined all the situations in which the predicted and observed concentrations differ by a factor of at least 2.5. These events are not distributed evenly throughout the year, but, as figure 4 clearly shows, tend to be concentrated around public holidays (bank holidays, school holidays etc). The most probable explanation for this is that the traffic model (which was developed to simulate rush hour traffic on a typical working day) cannot be easily adapted to simulate periods of exceptionally low traffic flows, and consequently over-estimates the vehicle flows compared with the real situation. This also explains why the greatest differences between predicted and observed concentrations occur when the model over-predicts the concentrations.

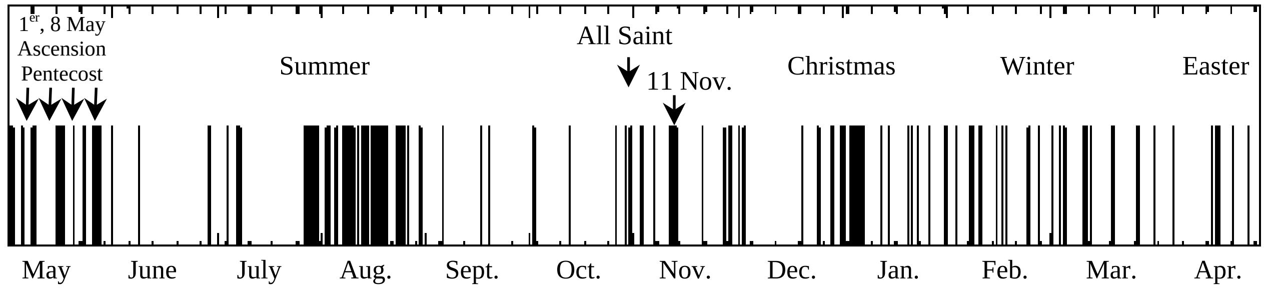

Figure 4 Temporal location of significant differences between predicted and observed concentrations. Each line corresponds to one data point, for which the ratio of predicted to observed concentrations is greater that 2.5 or less than 0.4.

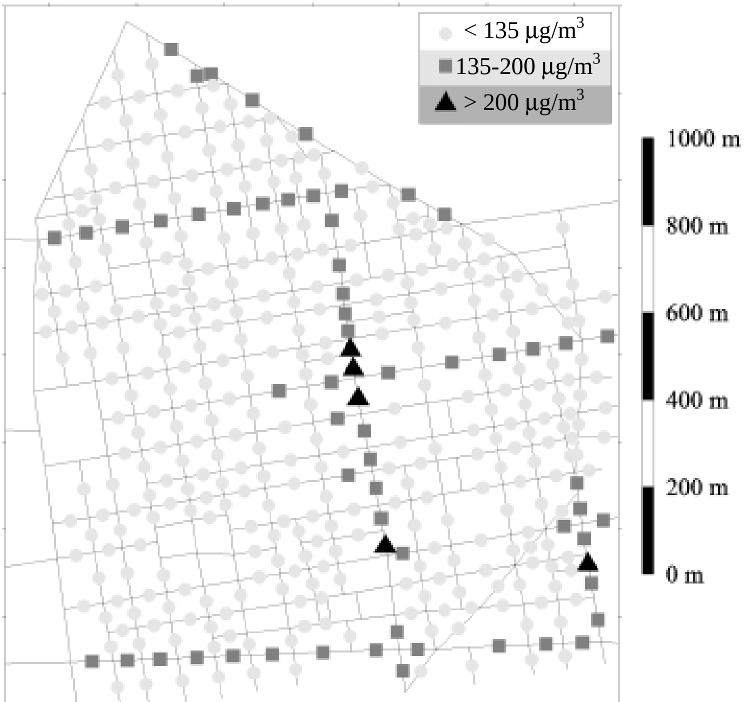

Figure 5 The 98th percentile for NO_2. The threshold values have been taken as the guide value (135 µg/m3) and the maximum value (200 µg/m3) as specified by current legislation.

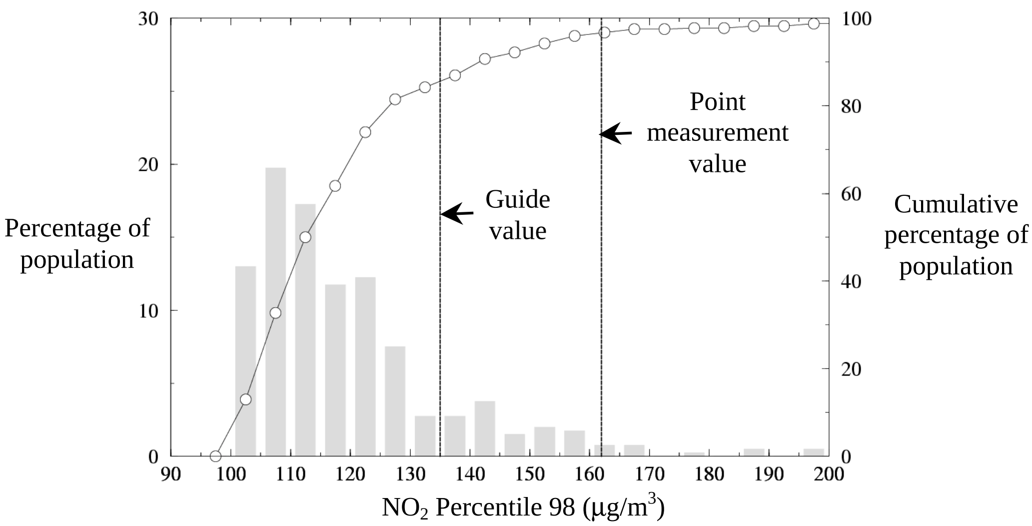

Figure 6 Population exposure and the representativity of the pollution sampler within the 6th *arrondissement*.

The results from this preliminary study have enabled us to determine some of the principal characteristics of the site, and to plan the field experiments in detail. The calculations of the concentration field will be used to determine where to locate the different measurement devices, and the sensitivity of the calculations to the hourly traffic flows has emphasised the importance of acquiring detailed measurements of temporal and spatial variations in traffic flows, throughout the duration of the campaign.

4 Application of the model

This type of model also enables us to investigate questions of wider, more general interest. For example, we have used it to provide an initial estimation of the exposure of the population to different levels of pollution, over a 12-month period. The results shown in figure 5 show those areas in which the annual average exposure exceeds certain regulatory thresholds. These calculations have been combined with data on population density to estimate the percentage of the population exposed to different pollution levels (figure 6). This analysis suggests that about 15% of the population in the 6th *arrondissement* are exposed to levels in excess of the guide value. The same graph shows that the average concentration measured by the pollution monitor is not very representative of the pollution levels experienced by the inhabitants of the *arrondissement* – it over-estimates the pollution levels to the extent that only a few percent of the inhabitants actually breathe air as polluted as that measured by the sampler.

5 Acknowledgements

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6 References

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