**H13-216**

# AIR QUALITY MODELLING SYSTEM FOR TRAFFIC SCENARIO ANALYSIS IN FLORENCE: MODEL VALIDATION AND IDENTIFICATION OF CRITICAL ISSUES

*Paolo Giambini[1], Pietro Salizzoni[2], Lionel Soulhac[2] and Andrea Corti[3]*

[1]Dipartimento Energetica “Sergio Stecco”, Università degli Studi di Firenze, Firenze, Italy
[2]Ecole Centrale de Lyon, Lyon, France
[3]Dipartimento di Ingegneria dell’Informazione, Università degli Studi di Siena, Siena, Italy

**Abstract**: Nowadays, a major pollutant source within a city is traffic emissions and this leads to interactions between the mobility, the air quality and the regulation of vehicles in the urban areas. In order to evaluate the effects of different traffic scenarios and the validity of emission reduction strategies, it is fundamental to reliably study pollutant dispersion inside the urban canopy, where the effects on human health are most significant because of the proximity between the emission sources (vehicles) and the potential receptors (population). A possible way to evaluate the air quality impacts in the hotspot located in complex environment is to use dispersion models that include modules for the simulation of the small scale effects (e.g. street canyon and intersection modelling). The aim of this study is to evaluate the performance of a multi-scale model for simulating and evaluating traffic scenarios of $PM_{10}$, $NO_x$, $NO_2$ and CO in the city of Florence. SIRANE, a modelling system based on nested models of different types (a combination of a Gaussian plume and a box model) was applied to the study area. A detailed validation of the air quality modelling system against measurements from permanent monitoring stations of the city of Florence (including a wide range of traffic levels and different street geometries) has been carried out. Both long term averages (annual averages) as well as short term averages (hourly) were considered. The evaluation study includes a sensitivity analysis of the most relevant data input: emissions (different fleets of cars), urban background (measurements from monitoring stations or model estimations) and street geometry (considered or not); this analysis permitted to identify the most critical input data requirements. The validation study provides a robust basis for the evaluation and the improvement of the model and permits to obtain insight and knowledge on specific differences between the parts of the modeling system that perform well or poorly.

***Key words:*** *Urban air quality, model evaluation, sensitivity, scenario analysis.*

## INTRODUCTION

In the last years, modelling pollutant dispersion at the urban scale assumed an increasing importance in the air quality management process; one of the main interests of the urban scale modelling is to be able to assess responsibility for existing air pollution levels in urban areas. Nowadays, the most important pollutant source within cities is traffic emissions; reliably simulating pollutant dispersion deriving from traffic emissions is fundamental to understand the effects on human health caused by the proximity between the vehicles and the potential receptors (population). One of the ways to evaluate the air quality impacts in complex environments and the consequences of long-term policies like transport planning is to use dispersion models that include nested models for the simulation of the small scale effects (e.g. street canyon and intersection modelling). This approach is used in this work.

The objective of this work is to develop an air quality modelling system based on nested models which can be reliably used by administrators and policy makers in order to understand the effects of different traffic scenarios and the validity of emission reduction strategies that could be adopted to ensure compliance with the air quality limits. With this aim, this study included several long-term (1-year long) dispersion modeling applications aimed at evaluating emission scenarios of $PM_{10}$, $NO_2$, $NO_X$ and CO in the city of Florence and a detailed evaluation study (sensitivity analysis and validation).

## URBAN AIR QUALITY MODELLING

The simulations were carried out using SIRANE **(**Soulhac *et al.* 2001**)**, a multi-scale model developed by the Ecole Centrale de Lyon and based on a combination of a Gaussian plume model and a box model. The study area includes the entire territory of the municipal district of Florence and it is 11×6 km$^2$ sized.

The full year 2002 time period was chosen, using a 1-hour time step, thereby all models were applied in a long-term mode. Measurements from the meteorological station of Firenze-Ximeniano, were used as input; it has the most complete hourly time series data of wind velocity and direction, temperature, global and net solar radiation and it is located in the central position of the study area.

Traffic emissions of the year 2002 were carried out using Corinair methodology (EEA 2007) in combination with the traffic volume data carried out by the application of the mobility model VISUM 10 (both spatial distribution inside the street network and hour-by-hour time disaggregation, see also USSMAF 2009) and the fleet of cars deriving from annual inventory of Italian Automobile Club (ACI). $PM_{10}$ (primary only, both deriving from exhaust and non-exhaust emissions), $NO_X$, $NO_2$ and CO were the chosen pollutant species. All the simulations were realized without considering chemistry mechanisms, except for NO2. The urban background concentrations were included in the simulations using the results of ADMS-URBAN simulations carried out for the MODIVASET-2 project (see Giambini *et al.*, 2008) and, alternatively, using the monitored concentrations of the background site of Firenze-Boboli (FI-BOBOLI, site acknowledged by the administration as the reference urban background).

For all the applications, the receptors were located both on a 50×50 m$^2$ computational grid and on an intelligent grid in correspondence of the streets at a height of 3 m; the grid so elaborated allows to obtain very detailed concentration maps (see for example figure 1). Concentrations were also evaluated at additional receptors located in correspondence of the monitoring stations within the study area.

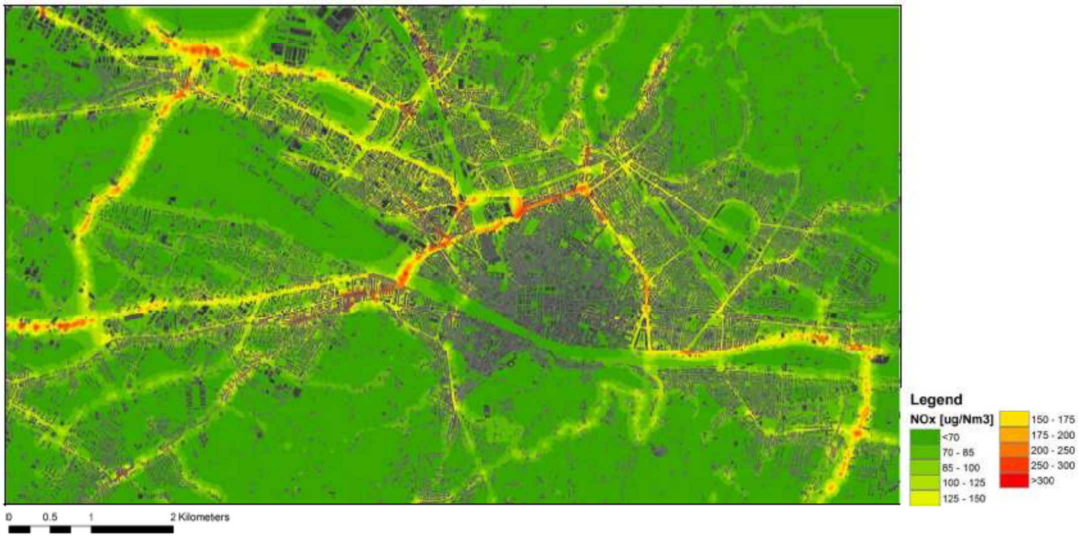


Figure 1. NOx annual mean concentration map estimated with SIRANE (Base scenario)

## MODEL EVALUATION

### Methodology

The model evaluation was performed in order to evaluate simulation results and compare the influence of the different data input used within this work. The results of the simulations were compared to measured data during year 2002 by the monitoring networks of the municipal district of Florence. 8 monitoring stations are present in the study area: 2 background (FI Boboli and FI Bassi) and 6 roadside. The evaluation work included: sensitivity study and validation exercise (see figure 2).

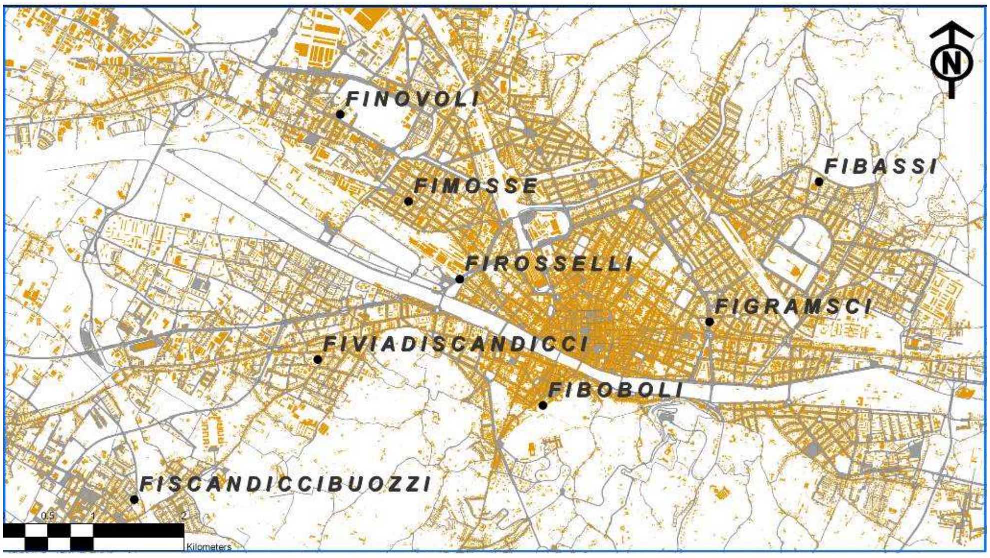


Figure 2. Monitoring stations in the study area

Both exploratory data analysis by data plots and statistical evaluation were carried out. The statistical indices used for the sensitivity study and the validation exercise are derived from the BOOT software (Hanna, 1989) and the Model Validation Kit (MVK, Olesen, 1995, 2005). Furthermore, two other indices originally proposed by Poli and Cirillo (1993) were used. The resulting statistical set is similar to that applied by Canepa and Builtjes (2001): mean (MEAN), bias (BIAS), fractional bias (FB), geometric mean bias (MG), standard deviation (SIGMA), fractional standard deviation (FS), linear correlation coefficient (COR), fraction within a factor of 2 (FA2), normalised mean square error (NMSE), geometric variance (VG), weighted normalised mean square error of the normalised ratios (WNNR), and normalised mean square error of the distribution of normalised ratios (NNR). Chang and Hanna (2004) introduced acceptability criteria for some of the statistical indices provided by the BOOT software, basing on an extensive literature review. They proposed the following criteria for a "good" model: FA2>0.5; -0.3<FB<0.3; NMSE<4.

**Sensitivity analysis**

Hourly and annual mean concentrations of $NO_x$ have been calculated at each monitoring site for three scenarios plus the base scenario. These are: scenario S1 (parameter changed: traffic emissions input data calculated using fleet of cars of the year 2008 instead of the year 2002), scenario S2 (parameter changed: street geometry not considered; all the streets were considered open terrain streets) and scenario S3 (parameter changed: urban background estimated using ADMS-Urban results from MODIVASET-2 project -Giambini *et al.* 2008- instead of using concentrations of the monitoring station of FI-BOBOLI). Calculated concentrations and the statistical indices described previously have been compared one to another and to the monitored values. Only statistics based on annual mean concentrations are reported in Table 1 for brevity.

Table 1. Statistical indices based on annual mean concentrations of $NO_x$. Model performances are defined acceptable if $FA2>0.5$, $-0.3<FB<0.3$ and $NMSE<4$ ("acceptability" criteria of Chang and Hanna, 2004).

| Scenario | MEAN [$\mu g\ m^{-3}$] | FB | SIGMA | FS | COR | FA2 | NMSE | WNNR | NNR |
|---|---|---|---|---|---|---|---|---|---|
| Measures | 161.0 | 0 | 77.0 | 0 | 1 | 1 | 0 | 0 | 0 |
| Base | 143.7 | 0.11 | 89.5 | -0.15 | 0.87 | 1.00 | 0.10 | 0.11 | 0.09 |
| S1 | 122.2 | 0.27 | 67.4 | 0.13 | 0.89 | 1.00 | 0.14 | 0.13 | 0.14 |
| S2 | 110.6 | 0.37 | 39.4 | 0.63 | 0.90 | 1.00 | 0.23 | 0.23 | 0.13 |
| S3 | 135.6 | 0.17 | 79.5 | -0.05 | 0.88 | 1.00 | 0.11 | 0.12 | 0.11 |

Examination of the statistics shows that results proved to be particularly sensitive both to fleet of cars, street geometry and urban background.

Replacing emission prediction using fleets of cars of the year 2008 instead of the year 2002 (scenario D1) results in a consistent change of the concentration levels. There is a substantial decrease in calculated concentrations of $NO_x$, due to the lower emissions of the newer fleet of cars. On the base of this result the choice of the fleet of cars related to the year of interest appear to be crucial in order to obtain reliable predictions.

The use of simplified geometry of the streets (scenario D2, all the streets were considered open terrain) instead of distinguishing between street canyons and open terrain streets on the base of street height and width, leads to the largest decrease in calculated concentrations of $NO_x$. The reason for this result is connected with the underestimation tendency of the Gaussian plume model for street canyon configurations; this is due to the neglecting of the pollutant recirculation that causes high concentration levels inside the canyons. On the base of this result the evaluation of the street geometry (canyon or open terrain) appear to be fundamental in order to obtain reliable results.

The urban background turns out be another important factor that should be accurately taken into account. In this case, the use of urban background estimations from MODIVASET-2 model simulations (scenario D3) doesn't provide significant improvements in the model performances. The use of model estimations of the urban background in applications like this, where the background monitoring sites are well located inside the study area, doesn't appear to be convenient if we consider the complexity of the model, the computational and the processing time.

On the base of the critical analysis of the sensitivity results, the set of parameters used in the modelling of the Base scenario (fleet of cars of the year 2002, inclusion of street geometry, urban background from FI-Boboli monitoring station) turn out to be the best calibration for SIRANE in the present application; for this reason SIRANE results used in the following validation exercise were carried out adopting the parameters of the Base scenario.

**Validation versus monitoring data**

Statistics described previously have been calculated based on annual mean concentrations and on the time series of hourly mean concentrations of $NO_x$, $NO_2$, CO and $PM_{10}$ for each monitoring site. Only results about concentrations of $NO_x$ are reported in Table 2 for brevity.

Table 2. Statistical indices based on annual mean concentrations and on the historical series of hourly mean concentrations of $NO_x$. Model performances are defined acceptable if $FA2>0.5$, $-0.3<FB<0.3$ and $NMSE<4$ (criteria of Chang and Hanna, 2004).

| NOx | | MEAN [$\mu g\ m^{-3}$] | FB | SIGMA | FS | COR | FA2 | NMSE | WNNR | NNR |
|---|---|---|---|---|---|---|---|---|---|---|
| Annual mean concentrations | Measures | 161.0 | 0 | 77.0 | 0 | 1 | 1 | 0 | 0 | 0 |
| | Simulations | 143.7 | 0.11 | 89.5 | -0.15 | 0.87 | 1.00 | 0.10 | 0.11 | 0.09 |
| Time series of hourly mean concentrations | Measures | 158.4 | 0 | 156.9 | 0 | 1 | 1 | 0 | 0 | 0 |
| | Simulations | 142.1 | 0.11 | 158.4 | -0.01 | 0.73 | 0.66 | 0.61 | 0.34 | 0.58 |

Good performances are obtained for nitrogen and carbon oxides both in terms of annual mean concentration and of time series of hourly mean concentrations, while performance values for $PM_{10}$ seem to be poorer, but however provided satisfactory values. As a matter of fact, acceptability criteria proposed by Chang and Hanna (2004) are verified for all the pollutants, although Chang and Hanna's results are referred to research level measurements.

The exploratory data analysis by simply plotting the data confirms the result obtained in terms of statistical analysis. Good performances are obtained for all the pollutants both in terms of annual mean concentrations and time series. An example of time series results for a roadside site in a winter and a summer week is shown in figure 3, as well as a comparison with the measures and the background concentrations. The comparison between predicted and observed values is quite good, the general trend of the time series is correctly reproduced, specially in the winter period. Most of the measured concentration peaks are correctly reproduced by the model. During summer the model has the general tendency to overestimate the concentration value; this is probably due to the over-prediction of the traffic volume data derived from the mobility model VISUM 10. The time series plots show that the urban background turns out be an important factor that must be accurately considered in order to avoid systematic underestimation.

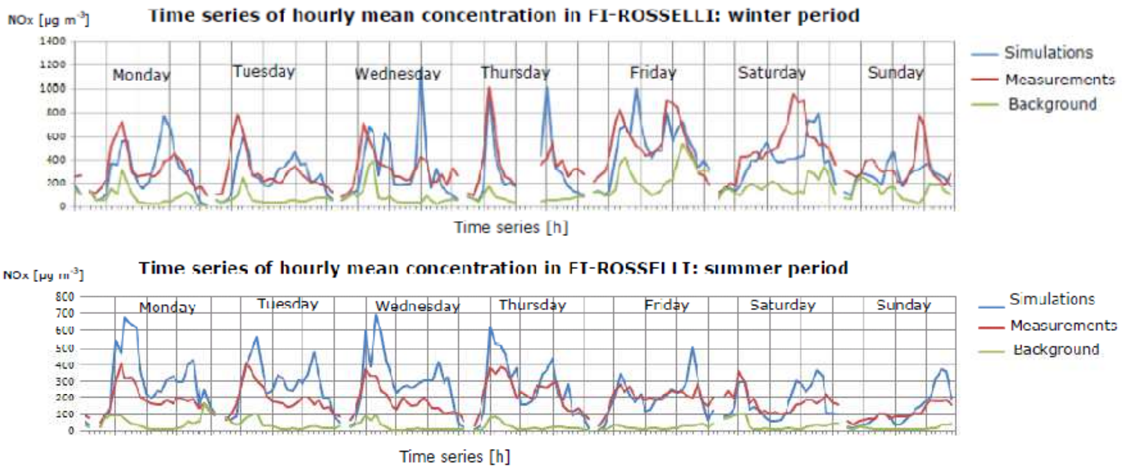


Figure 3. Comparison of simulated and measured time series of hourly mean concentration in correspondence of the traffic monitoring station FI- Rosselli for a winter (top) and a summer (bottom) week

**CONCLUSIONS**

The obtained results permitted to identify the most critical input data requirements:

1) Street geometry: an evaluation of the height and width of the streets is necessary to identify the presence of the street canyons and their characteristics and consequently to estimate the air quality impact also in the hotspot located in the urban area.

2) Fleet of cars and traffic volume data: on the basis of the sensitivity analysis and the validation study, the availability of reliable traffic volume data (both spatial and temporal disaggregation) and the correct choice of the fleet of cars turn out to be one of the most important requirements to obtain satisfactory predictions.

3) Urban background: looking at the validation study results, it comes clear that not to consider the urban background produces a systematic underestimation of the pollution levels. The urban background can be considered simply taking into account the concentration observed in a monitoring station well located inside the area of interest; it could be better than using data deriving from complex models. However, this doesn not affect the analysis of future scenarios (starting from the hypothesis that background concentrations do not change).

All the aspects listed above were accurately considered in the evaluation procedure and permit to obtain a reliable tool that will permit to evaluate the effects of transport planning policies in the study area.

**REFERENCES**

Canepa, E. and P.J.H. Builtjes, 2001: Methodology of model testing and application to dispersion simulation above complex terrain. *International Journal of Environment and Pollution*, **16** (1-6), 101-115 pp.

Chang, J.C. and S.R. Hanna, 2004: Air quality model performance evaluation. *Meteorology and Atmospheric Physics*, **87** (1-3), 167-196 pp.

European Environment Agency, 2007: EMEP/CORINAIR Atmospheric Emission Inventory Guidebook, 2007. EEA, Copenhagen, 2007.

Giambini P., Carpentieri M. and Corti A., 2008: Inter-comparison, sensitivity and uncertainty analysis between different urban dispersion models applied to an air quality action plan in Tuscany, Italy, 12th International Conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes, Cavtat, Croatia, 6-9 Ottobre, 2008.

Hanna, S.R.,1989: Confidence limits for air quality model evaluations as estimated by bootstrap and jackknife resampling methods. *Atmospheric Environment*, **23** (6), 1385-1398 pp.

Olesen, H.R., 1995: Datasets and protocol for model validation. *International Journal of Environment and Pollution*, **5** (4-6), 693-701 pp.

Olesen, H.R., 2005: User's Guide to the Model Validation Kit. Initiative on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes.

Poli, A.A., and M.C. Cirillo, 1993: On the use of the normalized mean-square error in evaluating dispersion model performance. *Atmospheric Environment*, **27** (15), 2427-2434 pp.

Soulhac L., Mejean P., Perkins R.J., 2001: Modelling vehicle-generated atmospheric pollution in a quarter of Lyon using the model SIRANE. In: 7th International Conference of Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes, Belgirate, Italy, 28-31 May, 2001.

U.S.S.M.A.F.F., 2009: Rapporto 2009/07, Estensione del sistema tramviario - Scenario C1B - Analisi trasportistica ai fini dell’impatto ambientale. U.S.S.M.A.F.F., Comune di Firenze.