X-020 - μ-MO ASSESSING THE AIR QUALITY IMPACT OF NO_X FROM ROAD TRAFFIC IN MODENA (ITALY)

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ABSTRACT

Based on the air pollutant regional emission inventory data (INEMAR – Arpae Emilia-Romagna 2013) road traffic in Modena, a city in the central Po valley (Northern Italy) located 40 km West from Bologna, contributes up to the 56% of the total emission in terms of NOx, followed by industrial combustion (15%) and domestic heating (8%). Goal of the μ-MO project is to assess the road traffic impact on air quality in the urban area of Modena.
Dispersion of vehicular NO_x was simulated by Parallel Micro Swift Spray (PMSS, Arianet srl, Italy and Aria Technologies, France) over a domain of 6 km x 6 km, including most of the urban areas of Modena, with a horizontal resolution of 4 m. The atmospheric emission sources were estimated by merging local fleet composition data, traffic flux at rush hours simulated by PTV VISUM mobility software and direct measurements collected by radar traffic counters, provided by the Municipality of Modena.
The modelling system, implemented on a 16 cores cluster (64 GB of total memory), includes PSWIFT, a parallelized mass-consistent diagnostic wind field model, and PSPRAY, a three-dimensional parallel lagrangian particle dispersion model, both able to take into account obstacles (buildings). A run of the system on two weeks has been performed and is presented.
Among the final goals of the μ-MO project there is the tentative source-apportionment of urban atmospheric NO_x between traffic emissions, domestic heating and regional background, to support epidemiological studies and finally future urban development strategies.

KEY WORDS: PMSS, vehicular emissions, NO_x, micro-scale dispersion modelling.

PROJECT PURPOSE

Atmospheric pollution is one of the main risk factors for a number of pollution-related diseases and health conditions: they may occur through the appearance of harmful and carcinogenic effects on the respiratory system as well as the onset of other cardiovascular, nervous and ocular pathologies. These critical issues particularly affect urban areas with higher territorial anthropization: a complex mixture of pollutants are produced by inefficient combustion of fuels in internal combustion engines, power generation and other human activities like domestic heating and cooking.

Micro-scale dispersion models, thanks to their ability to provide information, can be a valid support to environmental policies, pollution forecasting, population exposure, urban planning and urban environment management.

To meet this need, a variety of micro [4] and local [1,6] scale air dispersion models have been developed in the last few years, as they can provide an high-resolution information on air pollution level within the urban city area by taking into account space-time emission distribution and local meteorology[2,3].

The µ-MO project described in this report has as one of its goals the estimation of the contribution of vehicular traffic to the NO_x atmospheric concentrations in the urban area of Modena. More in detail, there is the tentative source-apportionment among the main pollutants sources, such as road traffic, domestic heating and regional background to support environmental policies, epidemiological studies and urban planning and management.

The approach used in the project combines an experimental and a modelling activity. The first is based on spatially distributed measurements using low-cost monitoring sensors. The second, presented in this paper, is based on the NO_x dispersion by using the PMSS modelling system [5] implemented on a 16 cores workstation (64 GB of total memory). This software is composed by two main tools: Parallel-Micro-SWIFT, a parallelized 3D wind field model for complex terrain and Parallel-Micro-SPRAY, parallelized Lagrangian particle dispersion model. The choice of this modelling chain was based on their ability to ensure a high resolution over large domains, with reasonable computation time. Secondly, they are both able to take into account the effect of the presence of buildings on both flow and particle dispersion.

EMPLOYED METHODOLOGY

Micro-scale simulation was performed on a 6 km x 6 km square domain covering the city of Modena (Figure 1) with 4 meters horizontal resolution.

Given the low altitude difference between different areas of the city, a flat domain was considered and a 3D buildings reconstruction was made by using the SHAFT pre-processor: 25 600 polygons were transformed into approximately 146 000 triangular prisms directly usable by Parallel-Micro-SWIFT.

The hourly meteorological data used as input for PSWIFT were derived from COSMO mesoscale model simulation by ARPAE Emilia-Romagna, which provides a vertical profile of temperature, humidity, wind intensity and wind direction inside the investigated domain. In addition mixing height values and main turbulence parameters (i.e. friction velocity, Monin-Obukhov length and convective velocity scale) are also given. Thus, a 3D wind, temperature and turbulence flow was obtained for 20 vertical levels from 2 m up to 500 m above the ground with a logarithmic trend.

The vertical grid structure used by Parallel-Micro-SPRAY consists of 20 levels with a logarithmic progression up to 500 m above the ground level with 3 m height for the first layer close to the soil to represent ground level concentrations.

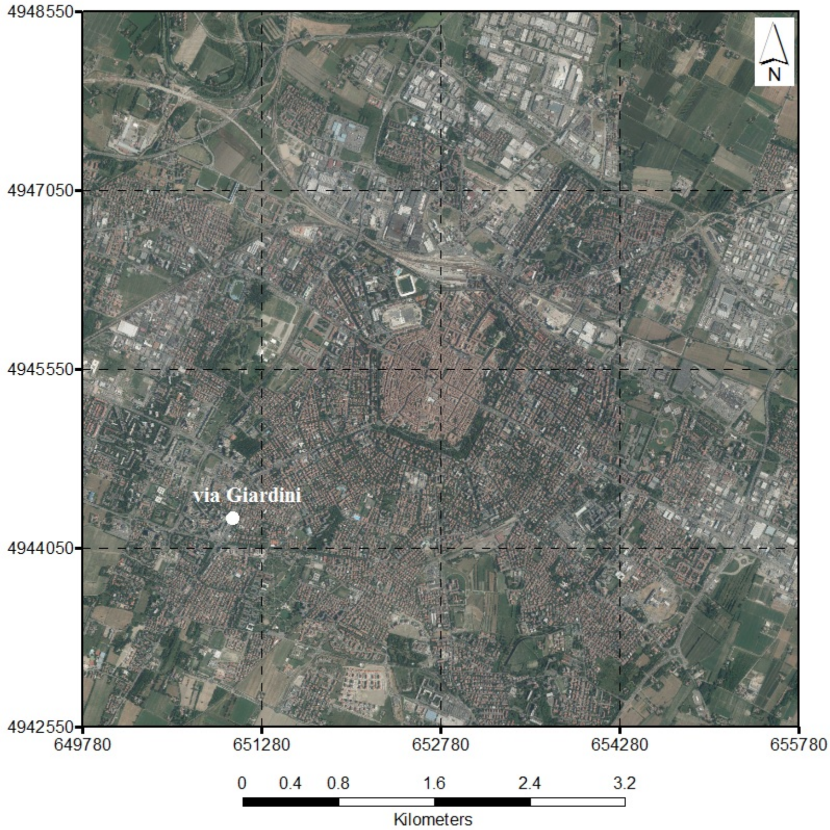

Figure 1: Investigated domain centered on the historical part of the Modena city.

The methodology chosen for evaluate traffic emissions pairs a traffic model (PTV VISUM) with an emission model (TREFIC) implementing the COPERT IV official methodology. In collaboration with the municipality of Modena, the PTV VISUM model was used to estimate heavy (duty vehicles) and light (motorcycles and cars) traffic flows at rush hour (from 7:30 a.m. to 8:30 a.m.) in a typical working day on a road network composed by 1100 sections with a total length of 210 km.

Simulated traffic data were used as input for the TREFIC emission model, able to calculate for each road segment the NO_x atmospheric emissions in terms of pollutant mass per trip unit. Vehicles fluxes, estimated by PTV VISUM, were further subdivided by TREFIC on the base of the local fleet composition (provided by Automobile Club Italia, ACI) depending on the type of fuel (diesel, gasoline, LPG, CNG), engine capacity, load displacement and the EURO emission standard.

Finally, in order to reproduce hourly NO_x emission, a direct traffic flow measurement campaign was carried out continuously over two weeks between October 28 and November 8, 2016, with 4 doppler radar counters (one for each road lane) in a four-lane road chosen as representative for the whole network. Two different traffic modulations were considered, depending on the vehicle type: one modulation for vehicles shorter than 6 m, classified as light (motorcycles or cars), and one for vehicles longer than 6 m, classified as heavy (duty vehicles).

Traffic NO_x dispersion simulations were performed over a period of about 12 days, between October 28 and November 8, 2016, when measured traffic flow data were available.

In order to simulate dispersion of domestic emissions quantitative measurement of civil and industrial methane gas consumption, subdivided by neighbourhood, were undertaken during the whole 2016. This information coupled with the buildings volumetry and typology and with INEMAR emission inventory data, represent the main input for estimating domestic heating emissions. The simulation of the dispersion of this source is at a preliminary stage and the results here presented include only traffic emissions.

OBTAINED RESULTS

Consistently with meteorological and emission data, hourly NO_x dispersion simulation was performed between October 28 and November 8, 2016 with the PMSS model. The obtained output contains 3D hourly average concentration fields of NO_x due to vehicular emission from the considered road traffic network.

Goal of the µ-MO project is to assess the vehicular emission impact in the atmospheric layer where the human population exposition is maximum, for this reason PMSS concentration was analysed on the first grid vertical step, 3 m high from ground level.

The estimated concentrations clearly reflect the traffic pattern by radar count data for a typical working day, in the early hours of the day, from 1:00 a.m. to 4:00 a.m., average hourly NO_x concentrations are very low with a spatial mean value, over the whole domain, lower than 15 µg m^{-3} (values lower than 5 µg m^{-3} are not considered). From 5:00 a.m. to 8:00 a.m. average hour pollutant concentrations undergo exponential growth up, until at 8:00 a.m. the plume concentration at ground over the domain is about 180 µg m^{-3}. In central hours of the day and in the early afternoon, street network vehicular traffic reduces its flow and NO_x concentrations slightly decrease to 100 µg m^{-3}. Then, between 6:00 p.m. and 8:00 p.m., a second daily concentration peak is reached and the spatial average concentration during these two hours is about 190 µg m^{-3}. Finally, at night time in the last hours of the day, road traffic and consequently computed NO_x concentration drop down. At 11:00 p.m. the spatial average concentration is less than 70 µg m^{-3}.

In Figure 2 the average hourly NO_x concentrations (scaling from white to red) for a typical working day at rush hour are shown.

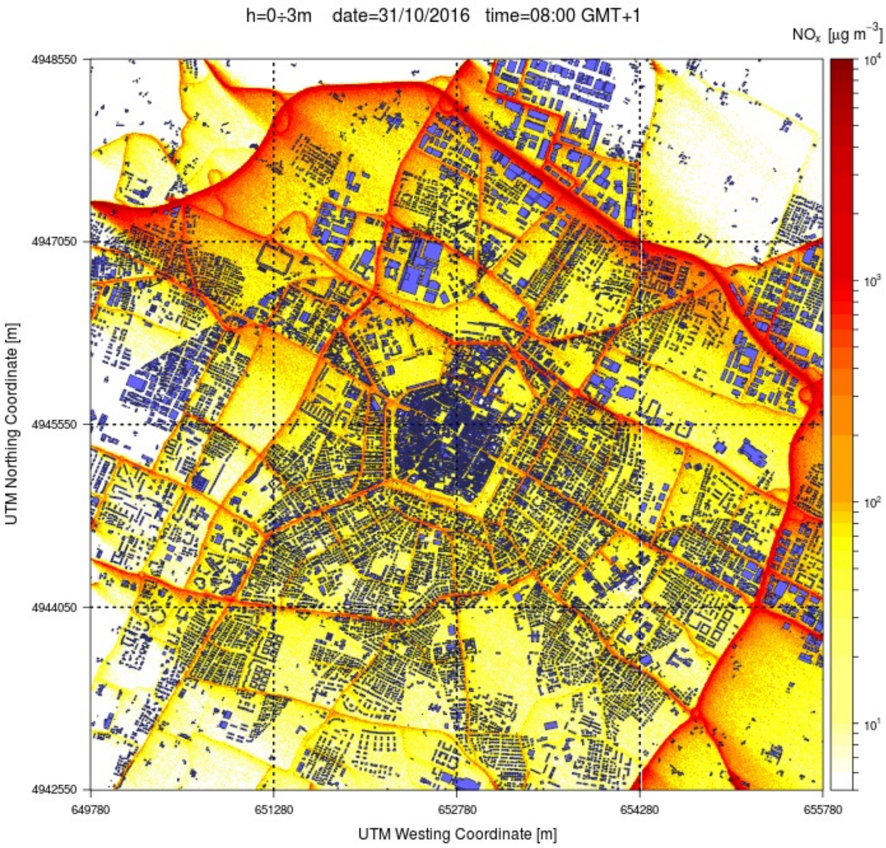

Figure 2: NO_x hourly concentrations map on October 31[th] 2016, from 7:00 a.m. to 8:00 a.m.

In order to estimate the different impact of heavy and light vehicles on Modena air quality, other two simulations were performed in the same period between October 28 and November 8, 2016. In the first one only light vehicles (motorcycles and cars) emissions were considered, conversely in the second simulation only the heavy duty vehicles emissions were taken into account.

Figure 3 shows the different NO_x concentration fields reproduced by keeping separate light from heavy vehicles emission.

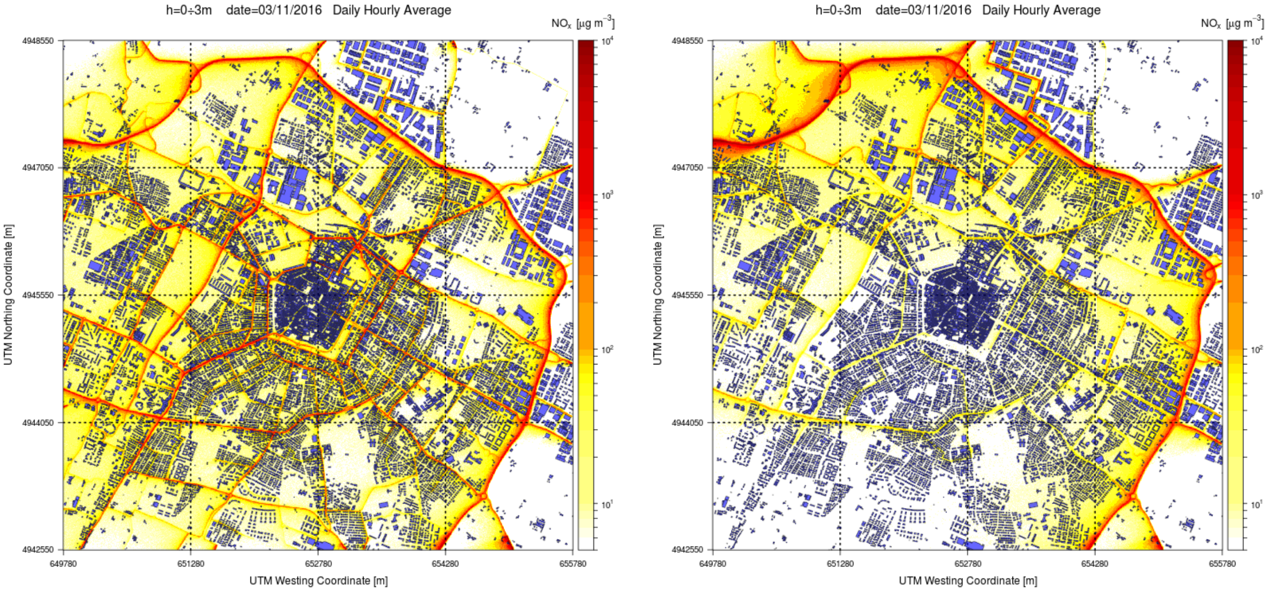

Figure 3: NO_x daily hourly average concentrations maps on November 3th 2016. On the left only light vehicles emission are considered and on the right only heavy vehicles emission are taken into account.

On average, during working days, heavy and light vehicles emissions are almost the same. Daily NO_x average motorcycles and cars emissions are 1.169 tons, and 1.094 tons for heavy vehicles. On the other hand, during non-working days, light emissions are the 60% of the total emissions, with a daily average of 0.783 tons. Heavy emissions, instead, represent the 40% of the total emissions with a daily average of 0.561 tons.

The PMSS simulated concentrations were finally compared with NO_x observed concentrations at the "via Giardini" air quality monitoring station, sited within the simulation domain and under urban traffic conditions . The comparison (Figure 4) between NO_x time series measured by "via Giardini" monitoring station (Figure 1) and locally simulated data is satisfactory, highlighting the ability of the PMSS system to reconstruct the distribution of the pollutant within the simulation domain.

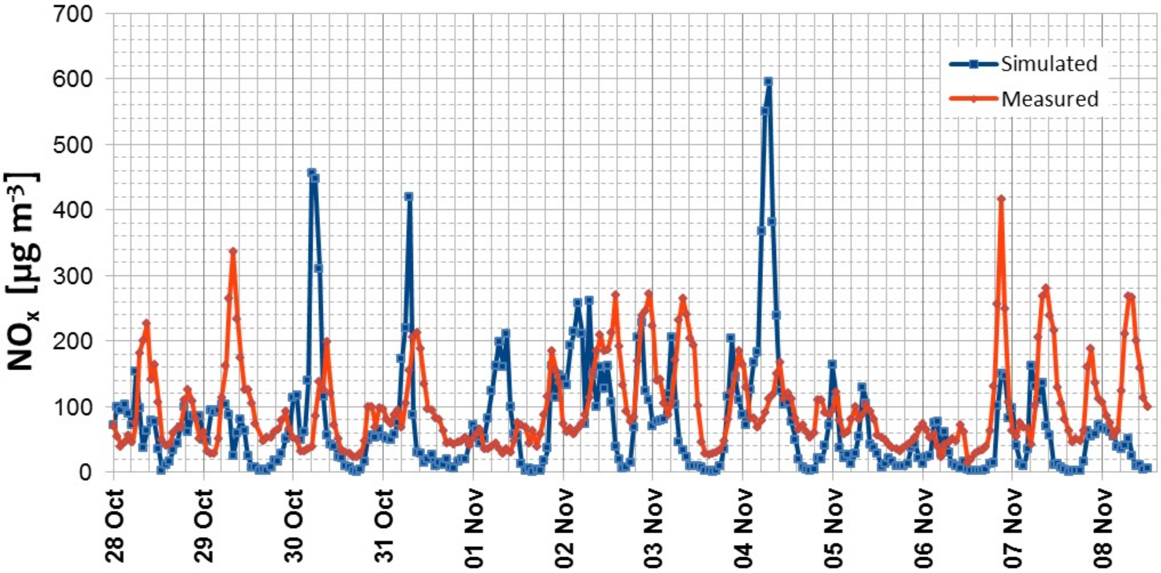

Figure 4: NO_x time series comparison between mesured concentration at "via Giardini" monitoring station and extracted modeled concentration at the correspondin grid point, from October 28th to November 8th.

In particular, the comparison shows that the model is able to reproduce the hourly concentration pattern with a good agreement, despite an overestimation at rush hour on October 30 and 31 and on November 4, besides on the contrary during night hours, concentrations tend to be underestimated. This can be explained with the lack of urban background NO_x concentration, not considered in the simulations.

CONCLUSIONS

The µ–MO project is now in its first stage of development and in this paper is highlighted the great capability of the PMSS model to simulate 3D air pollutant dispersion with a very high-resolution on a sizeable domain. Thanks to the introduction of additional sources and background concentrations this modelling system can be exploited as a tool in decision support system and to estimate the source-apportionment of urban NO_x between road traffic emission, domestic heating and regional background with high level of accuracy in Modena.

In order to improve the present results, it is planned the deployment of a set of low-cost air quality monitoring boxes featured by NO, NO_2 and particulates that will be distributed over the simulation domain, with the aim of to providing measured concentration data useful for model calibration and validation.

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