18th International Conference on
Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes
9-12 October 2017, Bologna, Italy

μ-MO
ASSESSING THE CONTRIBUTION OF NO_X TRAFFIC EMISSION TO ATMOSPHERIC POLLUTION IN MODENA BY MICROSCALE DISPERSION MODELLING

Giorgio Veratti[1], Sara Fabbi[1], Gianni Tinarelli[2], Alessandro Bigi[1], Sergio Teggi[1], Giuseppe Brusasca[2], Grazia Ghermandi[1]

[1]Department of Engineering "Enzo Ferrari", University of Modena and Reggio Emilia, Modena, Italy
[2]ARIANET, Milano, Italy

Abstract: Based on the air pollutant emission inventory data (INEMAR – Arpa Emilia-Romagna 2010) road traffic in Modena, a city in the central Po valley (Northern Italy), contributes up to the 60% of the total emission in terms of NO_x, followed by Domestic Heating (15%) and Industrial Combustion (14%). Goal of the μ-MO project is to assess the road traffic impact on air quality in the urban area of Modena by a combined experimental and modelling approach.
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 an entire day has been performed and is presented.
In the next step of the work, NO_x atmospheric concentration measurements will be provided by the two urban air quality monitoring sites and by a set of 10 monitoring boxes distributed over the domain and featured by small sensors for NO, NO_2 and particulates.
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, electrochemical sensor, parallel computing, microscale dispersion modelling,* NO_x.

INTRODUCTION

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 is produced by inefficient combustion of fuels in internal combustion engines, power generation and other human activities like domestic heating and cooking.
One of the dominant sources of pollution affecting air quality in urban areas is road traffic (European Environment Agency, 2016): it is therefore essential to be able to estimate its contribution in order to improve existing urban development planning, support urban mobility scheduling and local government's choices on sustainable mobility, and to provide sound information on atmospheric pollution to the population. To meet this need, a variety of micro (Moussafir et al, 2004, Öttl, 2015) and local (Tinarelli et al, 1992, Bellasio and Bianconi, 2012, Cimorelli et al, 2004) 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 urban city area by taking into account space-time emission distribution and local meteorological characteristics (Ghermandi et al, 2014, Ghermandi et al, 2015).

The µ-MO project aims to provide an estimation of NO_x concentration fields due to the vehicular emission in the urban area of Modena, a city in the central Po valley (Northern Italy) located 40 km West from Bologna.

The challenge of this project is to provide a more realistic solution than standard Gaussian models with a high accuracy (4m horizontal resolution) on the whole simulation domain by using the PMSS modelling system (Oldrini et al, 2011). This software is composed by two main tools: Parallel-Micro-SWIFT, a parallelized 3D wind field model for complex terrain and Parallel-Micro-SPRAY, a 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.

This paper presents the latest results of this on-going project about the estimate of the road traffic impact on local air quality by PMSS simulation. Project outlooks include the comparison of simulation results with NO_x atmospheric concentration measurements provided by the two urban air quality monitoring sites and by a set of low cost air quality monitoring boxes distributed over the domain that will serve as a basis for detailed validation of the NO_x concentration field provided by PMSS.

MATERIALS AND METHODS

A 3D wind and turbulence field reconstruction and numerical particle air pollution dispersion was performed on a 6km x 6km square domain covering the city of Modena (Figure 1). In the centre of the map in Figure 1 it is possible to distinguish the historical part of the town, characterized by an high density of buildings per unit area forming a relevant canopy density. Around this centre a complex street network is present, connecting the different Modena districts, along with large residential zones. Conversely sparser roads are arranged in the northern and southern parts of the domain, where industrial neighbourhoods (North) and rural zones (North and South) are sited.

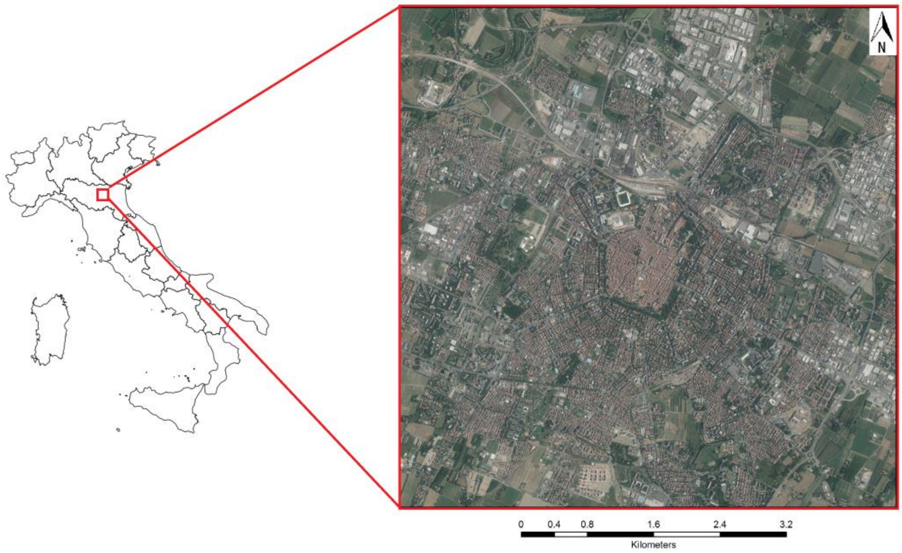

Figure 1. Map of the investigation domain and its position inside the Po valley (Northern Italy).

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 contained in the ESRI shapefile (provided by Geoportale Regione Emilia-Romagna) were transformed into approximately 146,000 triangular prisms directly usable by Parallel-Micro-SWIFT.

In order to guarantee both flow and pollutant dispersion fields at a high resolution in each part of the domain, a horizontal grid step of 4 meters (square cells) was chosen. The vertical grid structure used by Parallel-Micro-SPRAY consists of 5 levels with a logarithmic progression up to 500m above the ground

level with 3m height for the first layer close to the soil to represent ground level concentrations. This arrangement leads to a configuration of 1504 x 1504 x 5 nodes and a total amount of $1.1{\cdot}10^7$ cells.
The hourly meteorological data set used as input for PSWIFT were derived from CALMET and COSMO mesoscale model simulation by ARPAE Emilia-Romagna (the local Environmental Protection Agency), 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 3D fields of wind, temperature and turbulence were obtained at a 4m horizontal resolution for 20 vertical levels from 2m up to 500m above the ground with a logarithmic trend.
Since the number of computational cells is very large, only one single computer core cannot deal with the whole domain, for this reason a 16 core cluster architecture with 64 GB of total memory was employed. As a result, based on available computing resources, the whole investigated domain was subdivided into 16 communicating tiles of 375x375 horizontal cells each, so that a core was assigned to each tile.
Once the weather condition and urban canopy were simulated, suitable fine-scale tools are needed to estimate pollutants emission from mobile sources running on the main streets of Modena city centre. The methodology chosen for this estimation coupled a traffic model, which allows to map processes occurring in transport system such as traffic flows, with an emission model equipped with road vehicles emission factor (EF) evaluated taking into account specific features (i.e. vehicle type, fuel consumption, average traveling speed and road type) as detailed below.
In collaboration with the Modena Municipality, the PTV VISUM mobility model was used for this study, one of the most used and advised traffic simulation model for integrated planning system (Sawicki et al, 2016).
In order to obtain detailed traffic data, PTV VISUM used two different types of traffic count: radar traffic counts collected during rush hour (from 7:30 a.m. to 8:30 a.m.) at selected main streets on a campaign basis and counts by inductive loop. In addition, direct flow measurement campaigns were 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 in the proximity of the intersection with the urban ring road (Figure 2). The road network considered includes about 1100 sections with a total length of 210 km (Figure 2).
Simulation results provided by PTV VISUM is the flux of light and heavy vehicles at a rush hour (from 7:30 a.m. to 8:30 a.m.) and the related average travelling speed. Then, on the basis of local light and heavy vehicles fleet composition, this flux was subdivided respectively between motorcycles and passengers cars and between light and heavy duty vehicles.

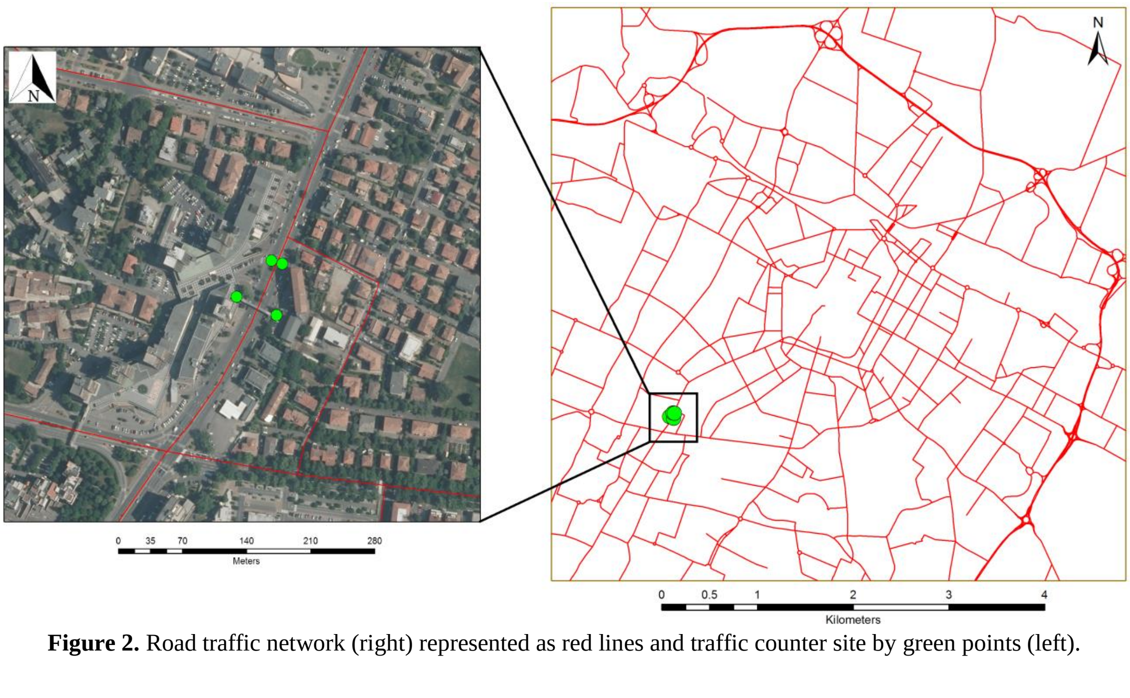

Figure 2. Road traffic network (right) represented as red lines and traffic counter site by green points (left).

Traffic data, either simulated and measured, were used as input for TREFIC, an emission model implementing the COPERT IV official methodology, able to calculate for each road segment NO_x atmospheric emissions in terms of pollutant mass per trip unit. Vehicles fluxes, estimated by VISUM, were further subdivided by TREFIC on the basis of the local fleet composition (provided by Automobile Club Italia, ACI) depending on the type of fuel (diesel, gasoline, LPG, methane), engine capacity, load displacement and the EURO emission standard. Finally, to appropriately describe NO_x emissions under typical working day flow conditions, hourly modulation rate for all road network was made by considering the real traffic flow recorded in intense traffic road by the radar counters from October 28 to November 8, 2016, in the mentioned measurement campaign.
The reference day chosen for the simulation was November 4, 2016.

RESULTS AND DISCUSSION

Consistently with meteorological and emission data, hourly NO_x dispersion simulation was performed on November 4, 2016 with 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, 3m high from ground level.
The estimated concentrations clearly reflect the emission trend reproduced by TREFIC: 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 whole 6km x 6 km 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. hourly average pollutant concentrations undergo exponential growth up, until at 8:00 a.m. the spatial average concentration at ground over the domain is about 210 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 130 µg m^{-3}. Then, between 6:00 p.m. and 8:00 p.m., a second daily concentration pick is reached and the spatial average concentration during these two hours is about 270 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}.
Throughout the simulation period the effects of local meteorology are not negligible. As shown in Figure 3, in the first hour of the day the pollutant plume appears stretched approximately from North-East to South-West and subsequently, in the afternoon and in the evening, it gradually moves and looks stretched from East to West.

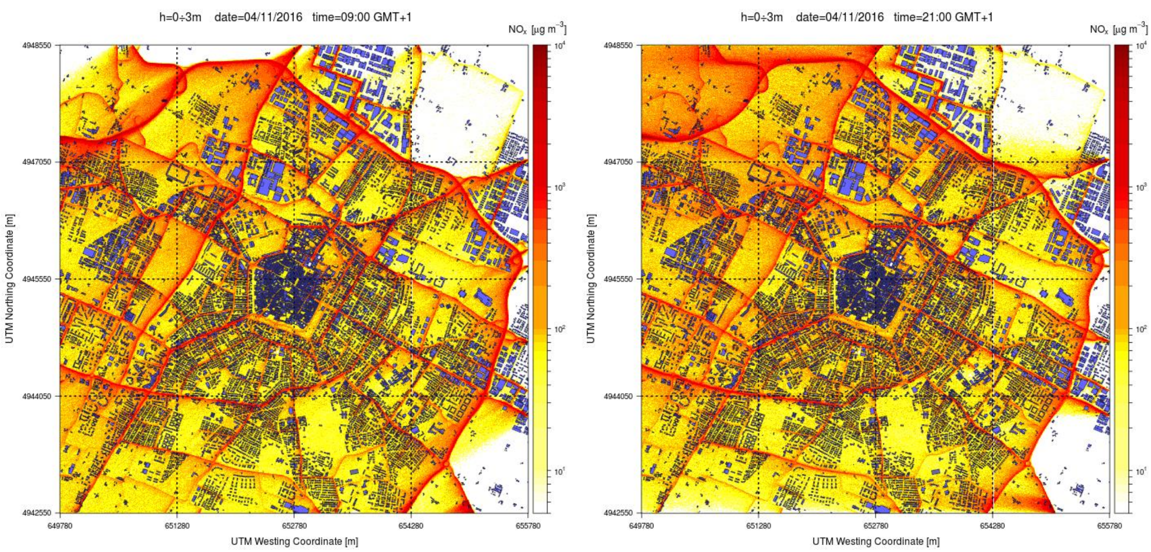

Figure 3.. NO_x hourly concentrations maps on November 4th 2016, from 8:00 a.m. to 9:00 a.m. on the left and from 8:00 p.m. to 9:00 p.m. on the right.

In Figure 3 the buildings reconstruction made by SHAFT pre-processor (in blue) and the average hourly NO_x concentration (scaling from white to red) are shown. In both the images the huge spatial data variability is evident: concentration values range from few μg per cubic meter (in areas far from road sections and in up-wind condition), to the order of thousand μg per cubic meter in the middle of streets characterized by highest traffic circulation.
The computing time required for a one day run is currently about 26 hours. To reduce it, is now under evaluation the possibility of increasing the computing resources, which might be useful for possible further applications of the modelling chain.

CONCLUSIONS

The μ–MO project is now in its first stage of development and this paper shows some preliminary results. In particular it is highlighted the great capability of the PMSS model to simulate 3D air pollutant dispersion with a very high-resolution on a sizeable domain. This can be exploited 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 the number of segments in the road network will be increased, to better describe emission sources from urban city traffic. Furthermore, 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. In addition, air quality short-range predictive modelling chain (24-48 hours) can be developed as a final step of the project, given that an increase in the computing resources will be accomplished.

REFERENCES

ACI: http://www.aci.it/

Bellasio R., R. Bianconi, 2012: The LAPMOD modelling system for simulating atmospheric pollution in complex orography. *Ingegneria Ambientale*, vol. XLI, n. 6, 492-500.

Cimorelli, A. J., S. G. Perry, A. Venkatram, J. C. Weil, R. J. Paine, R. B. Wilson, R. F. Lee, W. D. Peters, and R. W. Brode, 2004: AERMOD: A dispersion model for industrial source applications Part I: General model formulation and boundary layer characterization. *J.Appl.Meteor*.

European Environment Agency, 2016. Air quality in Europe – 2016 report.

Ghermandi, G., S. Fabbi, M.M. Zaccanti et al., 2014: Trigeneration power plant and conventional boilers: pollutant flow rate and atmospheric impact of stack emissions. *Int. Journal Environ. Science and Technology*, **12** (2): 693-704.

Ghermandi, G., S. Fabbi, M. Zaccanti M. M., A. Bigi A., S.Teggi, 2015: Micro–scale simulation of atmospheric emissions from power–plant stacks in the Po Valley. *Atmospheric Pollution Research*, **6**, 382-388.

Moussafir J., Oldrini O., Tinarelli G, Sontowski J, Dougherty C., 2004: A new operational approach to deal with dispersion around obstacles: the MSS (Micro-Swift-Spray) software suite. 9th International Conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes Garmisch 1-4 June 2004.

Oldrini O., C. Olry, J. Moussafir, P. Armand and C. Duchenne, 2011: Development of PMSS, the Parallel Version of Micro SWIFT SPRAY. Proc. 14th Int. Conf. on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes, 443-447.

Öttl, D., 2015: Evaluation of the revised Lagrangian particle model GRAL against wind-tunnel and field experiments in the presence of obstacles. *Boundary-Layer Meteorol*, 155, 271-287.

Sawicki P., Kiciński M., Fierek S., 2016: Selection of the most adequate trip-modelling tool for integrated transport planning system, *Archives of Transport* 37(1) 55–66.

Tinarelli G., Giostra U., Ferrero E., Tampieri F., Anfossi D., Brusasca G., Trombetti F., 1992: SPRAY, a 3-D particle model for complex terrain dispersion", Proc. of 10th Symposium on Turbulence and Diffusion, American Meteorological Society, Portland, Oregon (USA), 29-Sept. 2-Oct, P2.9, 147-150.