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VEHICULAR EXHAUST IMPACT SIMULATED AT MICROSCALE FROM TRAFFIC FLOW AUTOMATIC SURVEYS AND EMISSION FACTOR EVALUATION

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Abstract: Vehicular emissions are a large NO_x and CO source in Italian urban areas. In order to assess the impact of heavy traffic roads on local air quality a micro-scale simulation of pollutant concentration fields was produced. The investigated areas are in downtown of Reggio Emilia and Modena, two cities in central Po valley, Italy, and focused on high traffic intersections. An urban traffic station of the regional air quality monitoring network is present in both investigated areas, where traffic is expected to be the main local source of atmospheric pollutants. The simulation has been performed by the micro-scale model suite Micro-Swift-Spray (Aria Technologies, France and ARIANET, Italy) a Lagrangian particle dispersion model directly derived from the SPRAY code, able to account for buildings and obstacles. Simulated pollutants are NO_x and CO, as main tracers of combustion emissions. Direct measurements of traffic flow have been continuously collected for 12 day survey periods (in Reggio Emilia from January 13 to 24, 2014 by a two channel doppler radar traffic counter and in Modena from October 28 to November 8, 2016 by four one channel doppler radar traffic counters) and used for the hourly modulation of vehicular emissions. Specific emission factors were obtained by the combination of radar counts with vehicular fleet composition for each municipality: these depend on vehicle type, fuel type, speed and EURO category and were calculated according to the EMEP/EEA guidelines for air pollutant emission inventory. Simulated concentration fields were evaluated over the period with direct traffic counts for the two studied areas: for both areas the results were compared to local air quality measurements collected at the traffic urban monitoring stations and also at the respective urban background stations. The simulated NO_x hourly concentrations show a very large agreement with the observations, even if they result underestimated compared to the observed atmospheric concentrations at the traffic site. Simulated and observed concentrations show a fair agreement for CO. The results outline the representativeness of air quality stations in characterizing the sites for pollution level and for dominant pollutant sources.

Key words: *MICROSPRAY, vehicular emissions, radar traffic counter, emission factors,* NO_x*, CO.*

INTRODUCTION

Vehicular traffic is known to be a major source of atmospheric pollution. Air quality in urban areas is significant affected by vehicular emission contamination, even in areas not contiguous to intense traffic roads, and especially where prevailing meteorological conditions are not favorable to pollutant dispersion in atmosphere. The air quality monitoring carried out by the local environmental agency with fixed measuring site networks detect both in urban traffic and background stations (DL 155 of 13/08/2010, implementation of Directive 2008/50/EC), significant NO_x and CO concentrations, pollutant tracers for vehicular traffic emissions. In urban traffic stations the level of pollution is mainly influenced by vehicle emissions from adjacent roads, which overlap the urban background (Lenschow et al., 2001), producing higher NO_x and CO concentration. In the Po Valley (Northern Italy), the meteorology is characterized by low winds and high pressure conditions, and even in remote rural sites high concentrations of pollutants (Bigi and Ghermandi, 2011, Bigi et al., 2012, Bigi and Ghermandi, 2015, Bigi and Ghermandi, 2016) can persistently be detected, due to the permanence and homogenization of air masses at a regional scale. Simulation models are largely applied to study pollutant dispersion in atmosphere and to assess the direct impact of airborne emissions, as provided by Italian law, both at local (Ghermandi et al, 2014) and at microscale (Ghermandi et al, 2015). In urban environment, microscale models effectively simulate the pollutant dispersion amongst obstacles and urban building.

This study simulates NO_x and CO concentration fields due to vehicle emissions in two sites: in the

vicinity of a crossing within the inner ring road in Reggio Emilia (170,000 inhabitants), and in the proximity of the intersection with the urban ring road in Modena (185,000 inhabitants), two cities of the central Po Valley (Northern Italy), 70 km and 40 km West of Bologna respectively.
The simulation was carried out with the Lagrangian particle dispersion model, Micro Swift Spray (Tinarelli et al., 2004) enhancement of SPRAY code (Tinarelli et al., 1998) for microscale applications. These models are able to simulate the dispersion of passive pollutants in non-homogenous conditions, under calm and low wind events (Ghermandi et al., 2012).
The use of standard hourly traffic modulation curves, available in literature, to evaluate the hourly modulation of traffic pollutant emissions, allows realistic emissions estimates, but may be a limit to optimize the correlation between time series of simulated and measured concentrations.
In the present study traffic flows were directly collected with radar traffic counter (in collaboration with the local environmental agency Arpae), continuously for several days: from the collected traffic flows, the hourly modulation of traffic was obtained and hence the modulation of NO_x and CO emission rates for the studied roads during the survey periods.
Preliminary results about Reggio Emilia case study had been presented in Harmo 17 Conference (Ghermandi et al., 2016).

MATERIAL AND METHODS

Direct traffic flow measurements were carried out continuously in the cities of Reggio Emilia and Modena with doppler radar, traffic counters (Easy Data SDR) installed and used in collaboration with Arpae (Fig. 1). In Reggio Emilia, from January 13 to 24, 2014, a two channel radar was positioned along an intense three-lane traffic road, in the vicinity of a crossing within the inner ring road. Each radar channel detects the vehicle flow on one road lane, i.e. only two lanes were directly monitored: the veichle flow in the non-monitored lane was assumed equal to the one monitored by the radar on the adjacent lane, having the same flow direction. In Modena, a very busy four-lane road, in the proximity of the intersection with the urban ring road, was monitored from October 28 to November 8, 2016. Four radars were used, one for each road lane. The radars have been positioned, both in Reggio Emilia and in Modena case, close to a fixed-site Arpae monitoring station (traffic urban site), as shown in Figure 1.

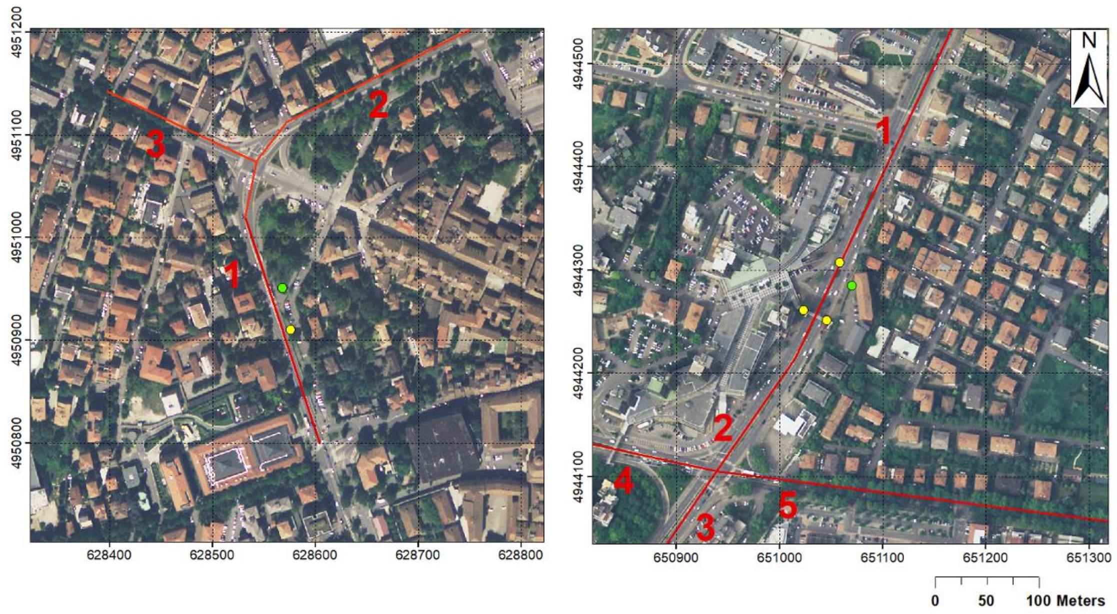

Figure 1. Maps of the investigation domain for Reggio Emilia (left) and Modena (right) case studies. Traffic counter sites (yellow points) and Arpae fixed stations (green point) are reported. The road sections (red lines) 1,2, 3 in Reggio Emila and 1,2,3,4,5 in Modena were considered in the simulations as linear emission sources.

The radar traffic counters recorded time, length and speed for each passing vehicle. The recorded vehicles were divided in five groups according to the length L: motorcycles (1 m ≤ L ≤ 2.5 m), cars (2.5 m < L ≤ 6 m), light commercial vehicles (6 m < L ≤ 8 m), heavy vehicles (8 m < L ≤ 12 m) and buses (12 m < L ≤ 15 m). The vehicles were further subdivided, by reference to the composition of the local fleet (up-to-date data provided by Automobile Club Italia, ACI), depending on the type of fuel (diesel, gasoline, LPG, methane) and the EURO emission standard, and finally in 14 speed classes. The speed value distribution into each class was estimated, with the median value taken as representative of the corresponding class, and used to obtain emission factors (EF) for NO_x and CO as a function of vehicle speed, following the European guidelines EMEP/EEA (EMEP/EEA, 2013) (Table 1). The NO_x EF from European guidelines are given as NO_2 equivalent (NO_{2eq}): consequently, both simulated and measured NO_x concentrations in the present study are given as NO_{2eq}.

Table 1. Emission Factors, EF (g/km)

	cars		**motorcycles**		**light commercial vehicles**		**heavy vehicles**		**buses**	
	RE	**MO**	**RE**	**MO**	**RE**	**MO**	**RE**	**MO**	**RE**	**MO**
NO_x	0.40	0.36	0.09	0.09	1.00	0.84	11.48	8.63	8.19	7.77
CO	0.75	0.67	8.61	8.74	0.79	0.54	2.58	1.94	2.33	1.83

Coupling the proper EF with each recorded vehicle, the estimate of NO_x and CO mass flows due to traffic emissions (per unit length of road) on the monitored street sections (section 1 for Reggio Emilia case, sections 1 and 2 for Modena, Fig. 1) were obtained; the modulated traffic emission rates according to the hourly variation of traffic fluxes thus resulted for each day of the monitoring periods (from January 13 to 24, 2014 in Reggio Emilia and from October 28 to November 8, 2016 in Modena). The traffic fluxes for the street sections not directly monitored by the radars, but included in the simulations, derive from modeled data for rush hours provided by the Municipality of Reggio Emilia and Modena, to which the hourly emission modulation obtained in this study was applied.

The atmospheric emissions from the road sections, considered as linear sources, were simulated using the Micro Swift Spray (MSS) model over 500 m x 500 m domains (Fig.1) with grid step of 2 m (square cells). The vertical grid consists of 5 layers, 2 m deep each, with the domain top 10 m above ground level, and the first layer for concentration computing 2 m high above ground. Building volumes and road geometry were outlined from a high resolution 3D vector cartography of the studied domains. The simulation was run at hourly time step, consistently with the meteorological data. The hourly meteorological data, mixing height values and turbulence parameters (i.e. friction velocity, convective velocity scale and Monin-Obukhov length) used, were derived from CALMET and COSMO mesoscale model simulations by Arpae.

The simulation provides 3D hourly average concentration fields of NO_x and CO due to vehicular emissions, from which concentration maps may be obtained, and time series of concentration values for points of interest. In the present study, series of simulated concentration hourly values at the position of the urban Arpae traffic sites close to the radars and at the height of the inlet of air quality monitoring Arpae instruments (4 m above ground level), were extracted over the period with direct traffic counts for the two studied areas of Reggio Emilia and Modena respectively (referred below as MSS simulated concentrations).

RESULTS AND DISCUSSION

MSS simulated and traffic site observed concentrations show a fair agreement: Reggio Emilia case, Pearson coeff. $r = 0.49$ for NO_x and $r = 0.43$ for CO; Modena case, $r = 0.27$ for NO_x and $r = 0.12$ CO. The correlation for CO is impaired by the low sensitivity of the CO monitoring instruments, given the high regulatory limits for CO concentration in atmosphere.

However, the MSS simulated concentrations represent only the contribution of vehicular emissions, while the atmospheric NO_x and CO measured at the urban traffic sites result also by the contribution of the whole agglomeration sources, that correspond to the urban background. Urban background NO_x are measured by Arpae in urban background stations while CO monitoring is performed only at traffic sites. Urban background NO_x show a very similar pattern with traffic site concentrations: it depends on the local meteorological regime, influenced by the Po valley morphological conformation and by recurrent wind calm episodes, that determinates accumulation and persistence of the pollutant load. In fact, the

urban background account for 60 % in Reggio Emilia and 74% in Modena of atmospheric NO_x measured at the urban traffic sites over the observation periods.
The time series of concentrations measured at the urban traffic sites of Reggio Emilia ad Modena, over the periods with direct traffic counts, were compared with the MSS simulated concentrations added to the concentrations measured at the urban background stations of Reggio Emilia and Modena for the same periods.
The comparisons between NO_x time series (traffic site measured and sum of MSS simulated plus background site measured concentrations) are reported in Figure 2, where all the NO_x data are given as $NO_{2\ eq}$. The two series show very high correlations: Pearson coefficient r = 0.84 for the Reggio Emilia case and r = 0.89 for the Modena case.

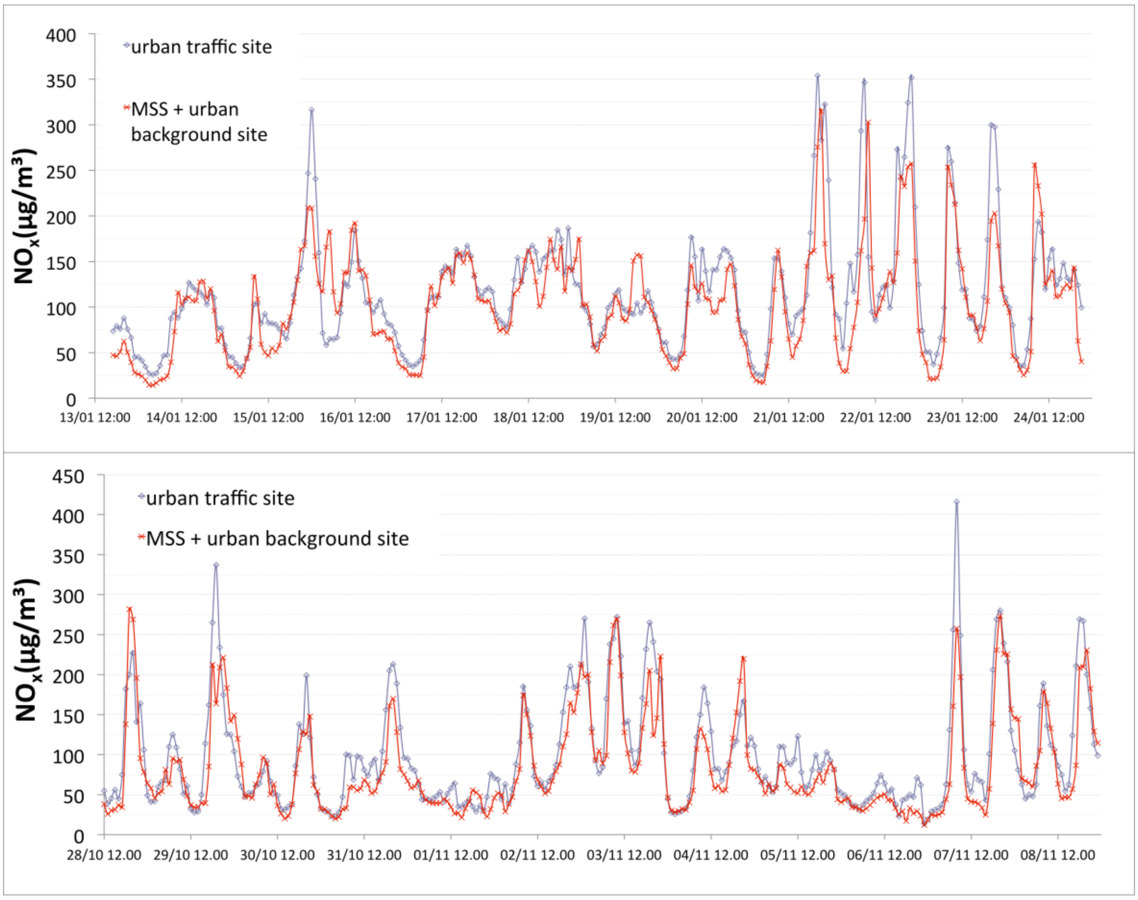

Figure 2. Hourly NO_x concentrations measured at Arpae urban traffic stations (blue curve) and MSS simulated plus urban background site concentrations (red curve) from 13 to 24 January 2014 in Reggio Emilia (upper) and from 28 Oct. to 11 Nov., 2016 in Modena (lower).

The traffic contribution may be estimated also from measurement data, as the difference between NO_x concentrations measured at traffic site and at urban background site: respect to this evaluation, the traffic contribution obtained by MSS simulation resulted underestimated of about 30% in Reggio Emilia and almost 50% in Modena. The underestimation is mainly due to have considered, in both the case studies, only sections of the busiest streets as traffic pollutant sources and not the whole road network within the simulation domain. In addition, the radar is not able to count vehicles that stop on the street lanes (vehicles in queue near the crossroads and, occurring mainly in Modena, urban and extra urban bus stops); furthermore, in Modena, a large parking area is adjacent to the monitoring site.
A preliminary evaluation had been performed for Reggio Emilia data (Ghermandi et al., 2016) omitting heavy duty vehicles and buses, and omitting vehicles fueled by LGP and methane, having a very low count (< 5%) over the periods with direct traffic record. Respect to that preliminary evaluation, the correlation between traffic site measured concentrations and sum of MSS simulated plus background site

measured concentrations is basically unchanged, while the underestimation of the traffic contribution obtained from MSS simulation decreases from about 50% (Ghermandi et al., 2016) to 30%. This is a clear indication of the role of heavy vehicles and buses in increasing the contamination of urban air.

CONCLUSIONS

This work highlights the high reliability of the Micro Swift Spray model to simulate concentration fields and concentration trend in urban environment, and suggests its application for impact assessment studies. The obtained results show also the effectiveness of the use of direct measurements of traffic flows, detailed classification of vehicular fleet of and accurate evaluation of pollutant Emission Factors as input to MSS traffic emission simulation.

The results also confirm the great significance of Arpae fixed monitoring sites in representing conditions and levels of pollution due to the predominant influence of certain sources.

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