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MICROSCALE SIMULATION OF ROAD TRAFFIC EMISSIONS FROM VEHICULAR FLOW AUTOMATIC SURVEYS AND COMPARISON WITH MEASURED CONCENTRATION DATA

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Abstract: In order to assess the impact of road traffic on local air quality, a microscale simulation of pollutant concentration fields due to vehicular traffic emissions have been performed. The investigated area is in downtown Reggio Emilia, a city in central Po valley, Italy, and focused on a crossing within the inner ring road, where an air quality monitoring station is present and where traffic is expected to be the main local source of atmospheric pollutants. A microscale simulation approach is suitable to face dispersion within an urban area, where buildings may lead to local peaks in pollutant concentration. The simulation has been performed by the micro-scale model suite Micro-Swift-Spray (Aria Technologies) a Lagrangian particle dispersion model directly derived from the SPRAY code, able to account for obstacles. Simulated pollutants are NO_x and CO, as main tracers of combustion emissions. Direct measurement of traffic flow have been collected by radar traffic counter for 12 days and used for the hourly modulation of vehicular emissions. Emission factors were calculated according to the EMEP/EEA guidelines for air pollutant emission inventory. Specific emission factors were used depending on vehicle type, fuel type, speed and EURO category. Simulated concentration fields were investigated over the period with availability of traffic counts (13-24 January 2014). Results were compared to local air quality measurements next to the investigated road and within the simulated domain. The simulated NO_x hourly concentrations highlighted the role of local traffic emissions in occasional exceedances of air quality limit. Simulated CO hourly concentrations result always well below limits. Simulated and observed concentrations show a large agreement for NO_X and a fair agreement for CO.

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

INTRODUCTION

Road traffic is notoriously a significant source of air pollution. The pollutants emitted by vehicles are among the main causes of the degradation of air quality in urban areas, even away from busy streets and mainly in regions where meteorological condition are unfavourable to pollutant dispersion in the atmosphere. The atmospheric monitoring of NO_x and CO, main tracers of combustion emissions, provided by the Environmental Agencies with fixed–site monitoring stations, clearly shows the impact of the daily traffic trend both at kerbside sites on main urban streets and also in urban background sites, with concentration peak during rush hours. The urban background concentrations can be in fact attributed to all sources in the whole agglomeration, among which motor vehicle exhaust emissions give a relevant contribution. At the kerbside sites (traffic stations) the local influence of traffic on the adjacent street is superimposed on the urban background (P. Lenschow et al. 2001), producing higher NO_x and CO concentration values.

Within the same rationale, the regional background concentration can be attributed to all sources outside the agglomeration, i.e. natural sources and long range transport at local and global scale, with negligible influence of the sources within the agglomeration. Nevertheless, in the Central Po Valley (Northern Italy), whose meteorology is mostly characterised by recurrent wind calm episodes and high-pressure conditions, long-lasting high concentrations might occur at remote rural sites, not due to a direct influence by the large metropolitan and industrial areas of the Valley.

The comparison of the atmospheric concentration measurements at regional and urban background sites and at traffic stations, support source apportionment for main pollutants in urban areas. The investigation of the various contributions to urban air pollution due to different emission sources is one of main applications of air quality models, supporting environmental impact assessment studies, and policy strategies for urban air pollution control. The evaluation of the direct impact of road traffic on air quality may be effectively performed by microscale simulation of pollutant concentration fields due to motor vehicle exhaust emissions.

In a previous work (Ghermandi et al., 2014) the NO_x and CO emissions from an urban crossroad in Modena (Central Po Valley, Italy) was simulated by means of the lagrangian particle dispersion model Micro-Swift-Spray, (Aria Technologies, 2010), a newer release of the Spray code (Arianet, 2010) which has been developed specifically for micro-scale applications in urban environments (Tinarelli et al., 2004). In that study hourly modulation patterns of traffic fluxes taken from literature were used. In the present case we performed a microscale simulation of the concentration fields due to traffic emissions in the vicinity of a crossing within the inner ring road in Reggio Emilia, a 170 000 inhabitants city in the central Po Valley, about 30 km West of Modena. Direct measurements of traffic flow have been collected by the local Environmental Agency (ARPAE) with a radar traffic counter from 13 to 24 January 2014; these data provided the hourly modulation of vehicular emissions for the duration of the measurement campaign (12 days). Hourly concentration of atmospheric NO, NO_2 and CO at this same street were provided by an ARPAE air quality monitoring station placed at kerbside (Figure 1 (a)).

The simulation results were compared to local air quality measurements of the traffic station next to the investigated road and with the measurements collected at urban background site of Reggio Emilia and at a rural background site of the region. The simulated NO_x hourly concentrations show a very large agreement with observed concentrations, allowing to estimate the role of traffic emissions to the observed atmospheric concentrations at the traffic site. The study outlines the importance of direct hourly measurement of traffic flows and of accurate determination of the emission factors in order to optimize the simulation results.

EXPERIMENTAL AND METHODS

Direct measurements of traffic flows were collected in downtown Reggio Emilia, Northern Italy, by a 2 channel radar traffic counter for 12 days, from 13 to 24 January 2014. The radar was placed in the vicinity of a crossing within the inner ring road, as shown in Figure 1 (a).

The radar traffic counter recorded the time, the length and the speed of each passing vehicle, for all lanes of the adjacent road. The vehicles were divided in three groups depending on the length L: motorcycles ($1 \text{ m} \leq L \leq 2.5 \text{ m}$), passenger cars ($2.6 \text{ m} \leq L \leq 6 \text{ m}$) and light vehicles ($6 \text{ m} \leq L \leq 8 \text{ m}$). Heavy duty vehicles (HDV) were omitted, having a negligible count during the measurement campaign. Recorded vehicle speed was divided in classes according to type: 12 for motorcycles, 14 for passenger cars and 10 for light duty vehicles (LDV). The speed value distribution into each class was estimated, with the median value taken as representative of the corresponding class. Class medians were 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). The EF for each pollutant vary also depending on the EURO emission standard of the vehicle and on the type of fuel.

Therefore, EF values were mathematically weighted to obtain a single EF for each group of vehicles and for each pollutant (Table 1); the accuracy of the calculation of the weighted EF values depends on the availability of supporting data. The calculation was most accurate for passenger cars (corresponding to about 80% of all recorded vehicles), given the availability of detailed vehicle fleet composition data for the year 2013 in Reggio Emilia provided by Italian Automobile Club (ACI, 2013), including also fuel type and emission standards. For motorcycles and LDV, the average value of EF for the different EURO categories and for the fuel type (mainly diesel for LDV (ACI, 2013)) were evaluated. For mopeds (motorcycles with engine capacity < 50 cm^3) the guidelines directly provides the EFs.

Table 1. Emission Factors (g/km) weighted values

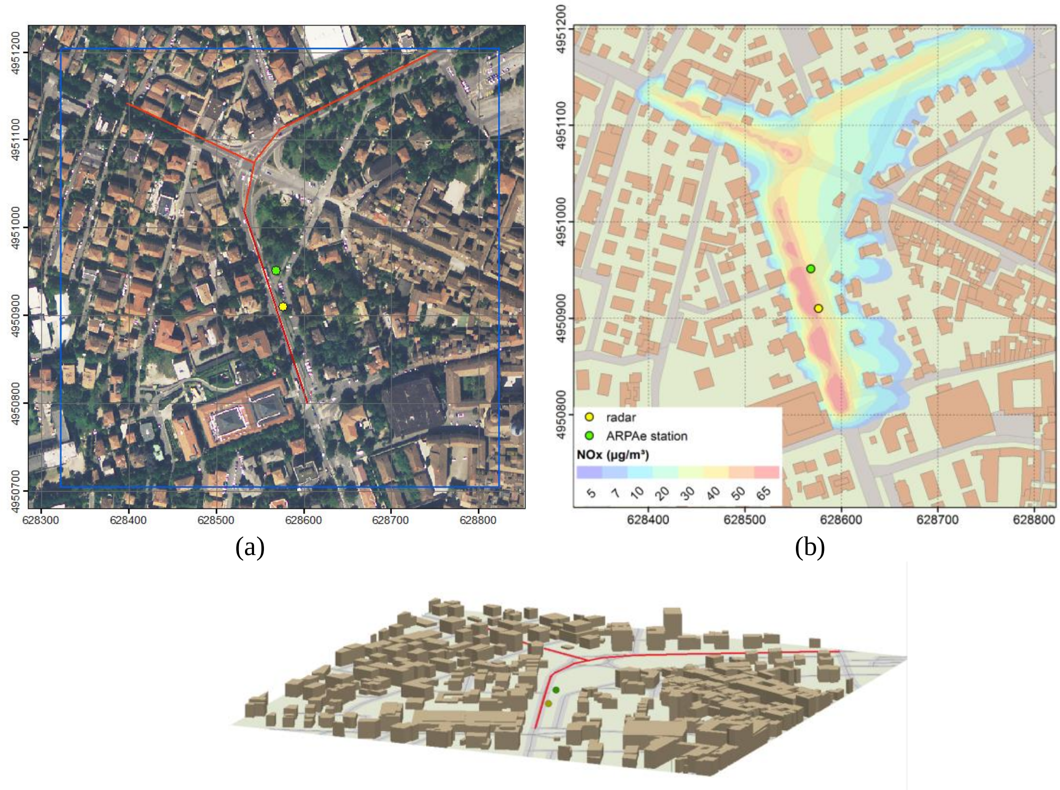
	Passenger cars	Motorcycles	Light vehicles
NO_x	0.277	0.108	0.692
CO	0.191	5.971	0.387

Coupling the hourly radar records with the EF value for each counted vehicle, the hourly mass flows of CO and NO_x emitted for the whole road length were estimated: the modulated traffic emissions according to the hourly variation of traffic fluxes has been thus obtained for each day of the measurement campaign.

The traffic counter, positioned as shown in Figure 1(a) for the entire campaign, directly monitored the lanes on the street side next to the radar; the traffic flows for the other two main roads of the crossing (red lines in Figure 1 (a)) derive from modeled data provided by the Municipality of Reggio Emilia.

MODEL SETUP AND METEOROLOGICAL DATA SET

The Micro Swift Spray (MSS) simulation domain is 500 m x 500 m large (Figure 1 (a)) with grid step of 2 m (square cells). The vertical grid consists of 5 layers, 2 m deep each, with the domain top of 10 m high above ground level, and the first layer for concentration computing is 2 m high above ground. Building volumes and road geometry were outlined from a high resolution 3D vectorial cartography (UVL_GPG) of the studied domain (E. R., 2013) (Figure 1 (c)). Following the model by Hertel and Berkowicz (1989), for the studied case the traffic induced turbulence height ranges between 6 - 8 meters above ground level and the traffic induced turbulence width ranges between 14 -21 m around the road axis; these values has been used for MSS simulation. The simulation period spans from 13 to 24 January 2014.
The simulation was ran 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 model simulations by ARPAE (Deserti *et al.*, 2001).



(a) (b)

(c)

Figure 1. Map of the investigation domain (UTM32-WGS84), with corner S-W (628 322, 4 950 704)m (blue square); traffic counter site (yellow point) (628 574, 4 950 910)m; ARPAE station (green point) (628 568, 4 950 950)m; road sections (red lines) considered in the simulation as linear emission sources (a).
Average hourly NO_x concentration (µg/m³) in the first atmospheric layer, 2 m above ground level, for 17 January 2014 (b). Block-shaped structures in Micro Swift Spray simulation (c).

During the simulation period unusual weather conditions for the winter period in the Central Po Valley occurred, with heavy storm rainfall on 18 and 19 January, better suitable for spring time. This atypical weather condition also affected air quality. Mean wind speed during the simulation period is lower than 1 $m \cdot s^{-1}$, the daily average air temperature ranges from 3 to 10 °C, with higher daytime excursion (up to 9 °C) over the last four days of the period.

RESULTS AND DISCUSSION

MSS simulation provided hourly NO_x and CO concentration fields in the first atmospheric layer, from which average daily concentration maps (i.e. average values over 24 hours) are obtained: in Figure 1 (b) the concentration map for NO_x generated by traffic emissions for 17 January 2014, as an example, is presented.

Moreover, the time series of hourly simulated concentrations, from 13 to 24 January 2014, may be compared with measured concentration values collected at ARPAE air quality monitoring stations. The simulated concentration were evaluated at 4 m above ground level, i.e. the same height of the inlet of air quality monitoring instruments by ARPAE. The time series of hourly NO_x concentrations measured at the ARPAE traffic station at kerbside on the monitored street from 13 to 24 January 2014, are presented in Figure 2, along with the hourly NO_x concentration valued simulated by MMS. The measured concentration results from local traffic emissions and from the sources in the whole agglomeration, that correspond to the urban background. The MMS simulated concentrations represent only the contribution by traffic emission to atmospheric NO_x .

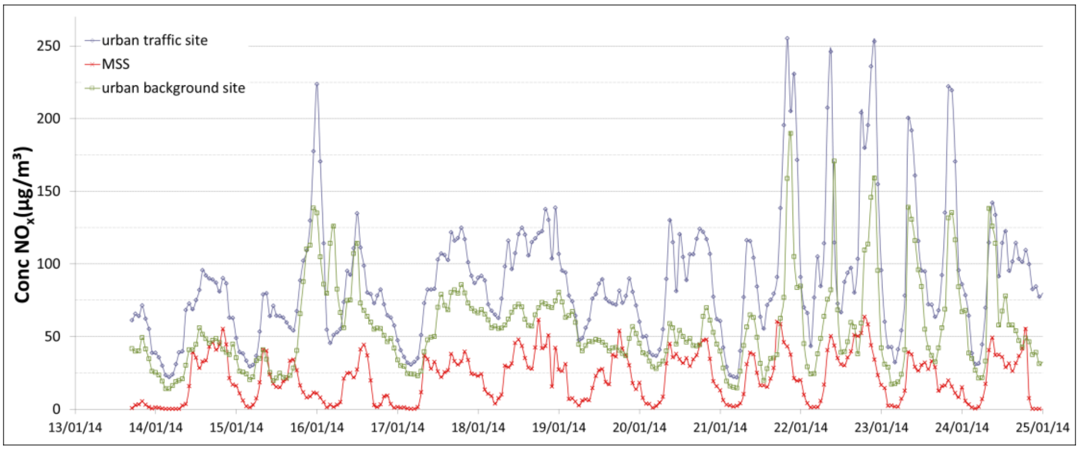


Figure 2. Hourly NO_x concentration measured at ARPAE urban traffic station (blue curve), measured at ARPAE urban background station (green curve) and simulated by MMS (red curve) from 13 to 24 January 2014.

The simulated concentrations remain constantly lower than the measured concentration both at the urban traffic and urban background stations. The pattern of the three series shows a good agreement, the measured concentration peak on 16/01/2014 (maximum at 01:00) a part: that unusually high NO_x night value measured both in traffic and urban background in Reggio Emilia was also measured at the same time in urban background and traffic ARPAE stations in the nearby city of Modena; also the CO concentrations measured both in Reggio Emilia and Modena traffic stations (CO measurements are not collected at urban background sites) had a high peak at that time. This may be due to a meteorological event constricting low and polluted air masses towards the ground, as for the local evolution of a cold air front (Li et al., 2015).

The NO_x traffic and urban background measured concentrations show a very similar pattern; this mostly depends on the Po Valley meteorological regime, mainly influenced by the valley morphological conformation and characterised by recurrent wind calm episodes, occurring also during the measurement campaign. This condition determinates accumulation and persistence of the pollutant load, therefore also at the urban background site the air quality is clearly affected by the diurnal variability of the main pollutant source. The differences of NO_x between the traffic station and the urban background station can be attributed to the local influence of traffic, and this has been here estimated by MSS simulation. In Figure 3 the hourly NO_x concentrations measured at the ARPAE traffic station are compared with the sum of NO_x hourly simulated concentrations and corresponding urban background measured values. The two time series result highly correlated (Pearson coefficient $r = 0.86$).

The traffic emission contribution to air quality at the traffic site, as evaluated by MMS simulation in the present study, corresponds to ~24% of the NO_x atmospheric concentrations, while about 56% is given by regional background contribution. The remaining 20% corresponds to agglomeration sources emissions (including, e.g., domestic heating).

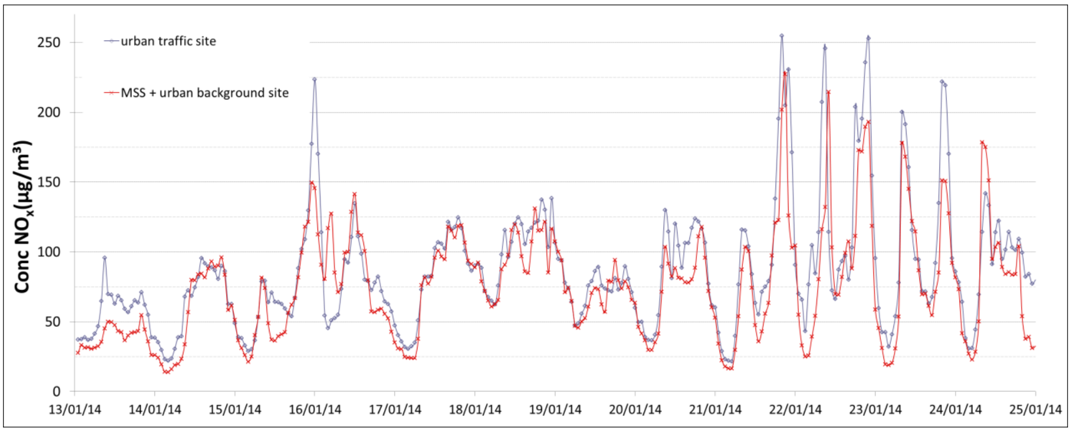


Figure 3 Hourly NO_x concentration measured at ARPAE urban traffic station (blue curve) and MMS simulated plus urban background site concentrations (red curve) from 13 to 24 January 2014. The red curve in this figure corresponds to the sum of red and green curve as reported in Figure 2

For the town of Reggio Emilia the traffic contribution to NO_x emissions had been estimated (E.R., 2013) in about 52 %, consequently traffic emissions have a relevant impact both on urban and on regional background NO_x. CO monitoring is performed only at traffic site, therefore no CO data is available from urban background. The correlation between measured and simulated CO is quite large (r = 0.42). The low sensitivity of the CO monitoring instrument has also to be considered, since it prevents to successfully repeat the data processing as done in this work for NO_x.

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