DOES ELECTRIC VEHICLE INTRODUCTION IN THE CAR FLEET IMPROVE THE AIR QUALITY?

Stefano Alessandrini[1], Alessia Balanzino[2], Maurizio Riva[1] , Enrico Ferrero[2],

[1]RSE; Milano, Italy
[2]Dipartimento di Scienze e Innovazione Tecnologica-, Università del Piemonte Orientale, Alessandria, Italy

Abstract: The problem of the pollution due to the traffic is faced using a numerical model. An experimental campaign was conducted close to the East Highway in Milan (Italy). Meteorological parameter and chemical concentrations were measured and the traffic emissions evaluated. Numerical simulations of the dispersion from the highway were carried out. Then a possible future emission scenario due to a partial introduction of the electric vehicle was hypothesized and new simulations were performed. The results of the two simulations are compared in order to evaluate the pollution reduction obtained introducing the electric vehicle.

Key words: *Lagrangian dispersion model, traffic pollution, electric vehicle.*

INTRODUCTION

Among the main pollutant sources in urban areas the traffic can be considered as one of the more dangerous. As a matter of fact, emissions from vehicles contribute to the photochemical pollution involving ozone and nitrogen oxides. Nowadays, new technologies allow reducing the NOx emission thanks to the electric engines. For this reason, it is very important to evaluate the degree of pollution reduction related to hypothetical scenarios, which account for the introduction of the electric vehicle in the car fleet. To this aim, a model able to simulate both dispersion and chemical reaction should be used and a proper data set collected. We performed a field campaign near a highway in the suburban area of Milan (Italy). In order to evaluate the number of vehicles a camera continuously recorded the traffic for a month. Meteorological and chemical measurements were carried out at a station located about 400 m far from the highway. Furthermore, data from meteorological stations of the ARPA network were available. Then, we applied the stochastic Lagrangian dispersion model SPRAY-RSE (Alessandrini and Ferrero, 2011) for two periods in winter and spring respectively. The model is able to simulate the pollutant dispersion and the chemical reaction involving nitrogen oxides, ozone and the photo-dissociation. The simulation results are compared with the measurements carried out at a station located downwind to the highway. With the aim of evaluating the air quality improvement a new hypothetical fleet scenario, based on the electric vehicle introduction, was considered and the simulation repeated. The results are analyzed to evaluate the real extent of the air quality improvement.

MODEL DESCRIPTION

The model used in this work is the Lagrangian stochastic model described in Alessandrini and Ferrero (2009, 2010 and 2011). The chemistry and dispersion are treated separately and sequentially; each particle (n) released by the source may bring mass of different substances. At each time step the particle position $X^{(n)}(t)$ is updated using the stochastic model equation, then the concentrations of each substance is calculated in a fixed Eulerian grid and the chemistry is updated.

Formation of NO_2 occurs when NO is emitted in an atmosphere containing O_3. During the daytime, photo-dissociation of NO_2 by absorption of ultra-violet radiation leads to the production of NO and O_3. The chemical reactions considered in our model are:

$$NO + O_3 \xrightarrow{k} NO_2 + O_2 \qquad\qquad NO_2 + O_2 + h\nu \xrightarrow{J} NO + O_3 ,$$

where k depends on temperature and is around 0.4 $ppm^{-1}sec^{-1}$ while J depends on solar radiation and ranges between 0, during the night, and 0.4 min^{-1} in the full sunlight. The discretized form of the chemical equation is (for NO and similarly for the other compounds):

$$\left\langle c_{NO}(\mathbf{x}_j, t_1)\right\rangle = \left\langle c^*_{NO}(\mathbf{x}_j, t_1)\right\rangle - k\Delta t\left\langle c^*_{NO}(\mathbf{x}_j, t_1)\right\rangle\left\langle c^*_{O_3}(\mathbf{x}_j, t_1)\right\rangle + j\Delta t\left\langle c^*_{NO_2}\left(x_j, t_1\right)\right\rangle ,$$

where * indicates the concentration in the cells after the turbulent dispersion but before the chemical reaction. For O_3 concentration, the *deficit of concentration* is introduced as described in Alessandrini and Ferrero (2009).

In order to simulate the chemical reaction, in a turbulent flow, on a time scale less than the typical equilibrium scale, the cross covariance term between the concentration fluctuations of the two compounds participating to the reaction should be accounted for (Garmory et al. 2006). The contribution of this term is often referred as "segregation" and

$$\alpha = \frac{< c_A' c_B' >}{< c_A > \cdot < c_B >}$$

is the segregation coefficient, which has to be parameterized.

CASE STUDY

In order to evaluate the effect of the introduction of the electrical vehicle in the car fleet we considered the East highway of Milan (Italy). An experimental campaign was conducted in which the traffic, the meteorological parameters and the chemical compounds concentration were measured. The number of cars in each day hour was evaluated thanks to the camera images. Data from meteorological and air quality stations of the ARPA network were also available.

In particular hourly average concentrations of NO, NO_2 and O_3 as well as meteorological measurements of speed, wind direction and solar radiation for the period 15 December 2010-25 January 2011 were collected. The air quality measurements were performed within the area where is located the headquarters of RSE at about 400m from the east highway of Milan, which represents the main road under study. Moreover, the Lambro and Limito quality stations concentration measurements, carried out by ARPA (Regional Environment Agency) Lombardia, were taken into consideration. They are respectively located at about 600m and 5000m from the highway. The traffic flows for the period, required for estimating the emission, were determined with the help of movies recorded by a webcam located on the RSE roof. Figure 1 shows the map with the position of the principal instruments (traffic camera, meteo and air quality stations) used during the experimental campaign with respect to the east highway.

Figure 1: Map of the experimental campaign site

The resulting emission trend for two weeks and the three pollutants is presented in Figure 2. It can be observed the lower emission during the weekend and the highest value on Friday. These emissions are representative of the present scenario (NEV), a car fleet without electric vehicle. Then we considered a second scenario (EV) in which an introduction of 25% of electric vehicle in the light vehicle fleet is hypothesized. This brought an emission reduction

to about 8%, 10% and 8% for NO, NO_2 e NO_x respectively.

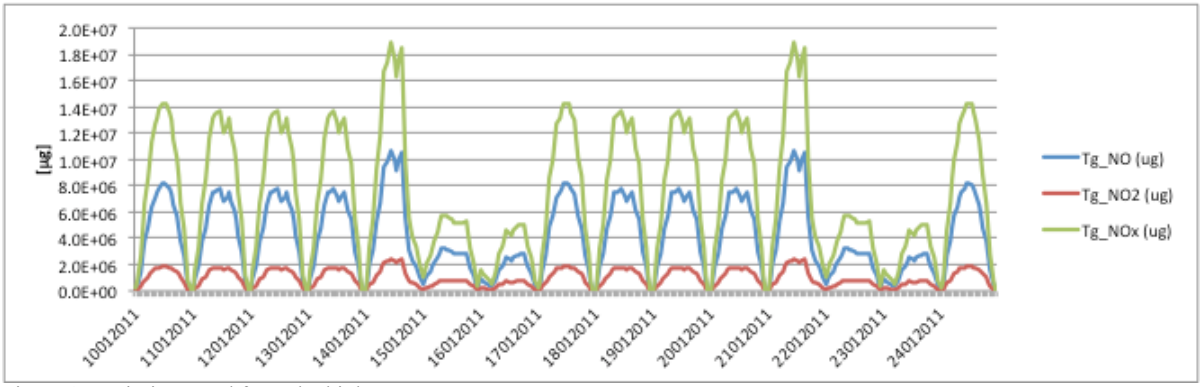


Figure 2: Emission trend from the highway

SIMULATION RESULTS

The meteorological input to the dispersion model was provided by a mesoscale model using as initial and boundary conditions the large-scale analysis from the European Centrum for Medium range Weather Forecast (ECMWF). Furthermore the local measurements were assimilated into the model.

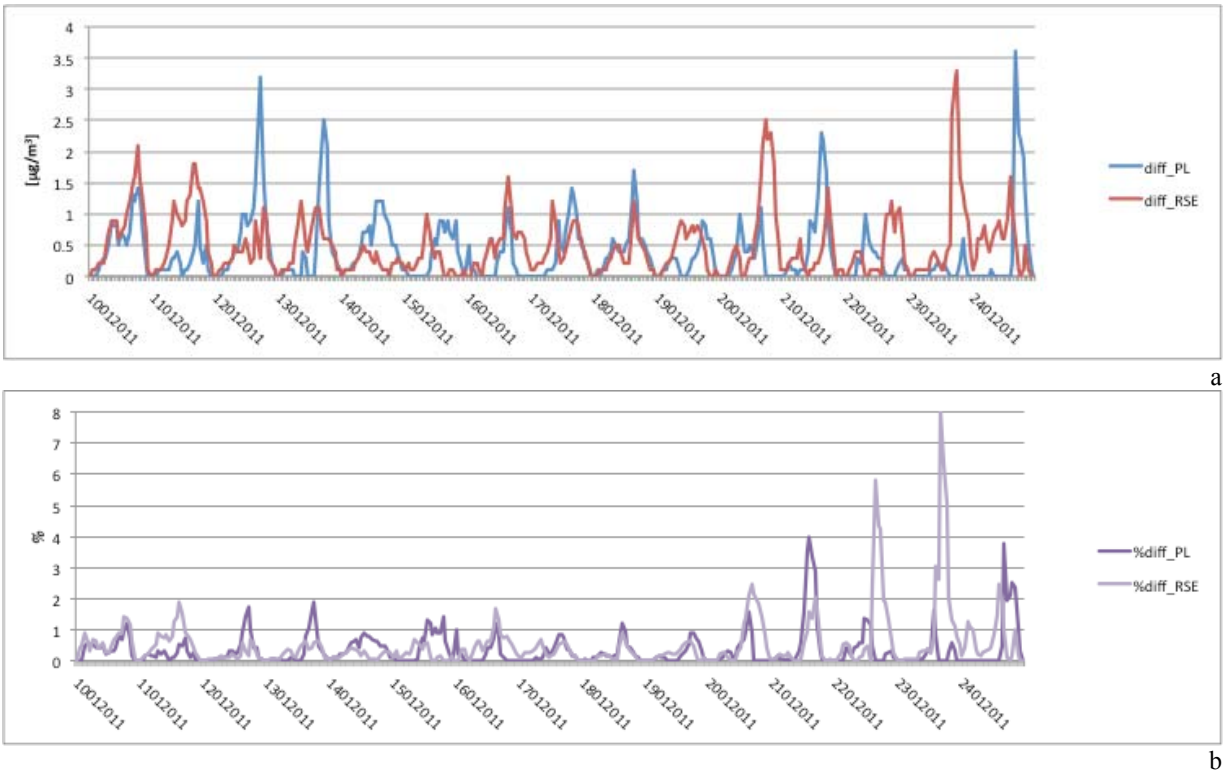
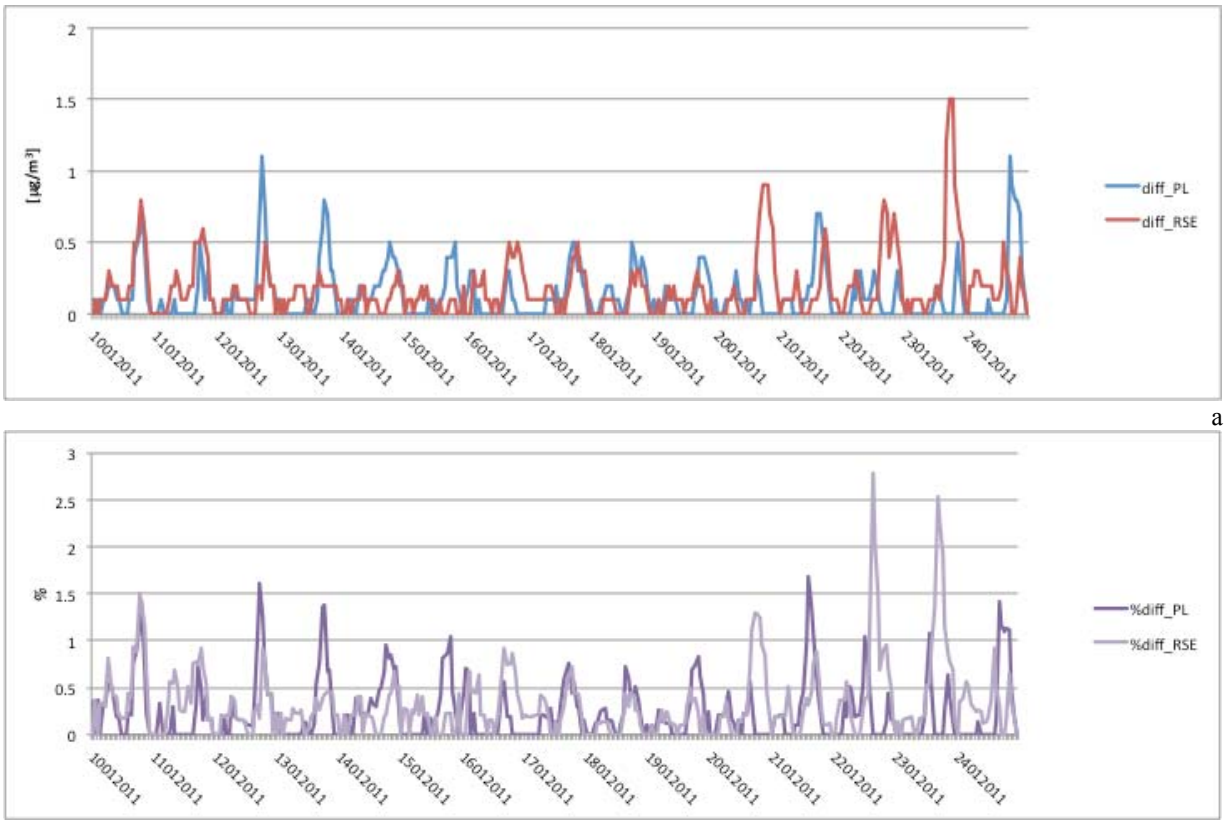


Figure 3: NO concentration differences between NEV and EV scenarios at the Lambro (PL) and RSE stations. (a) absolute difference, (b) relative difference.

In Figure 3 the comparison between the two scenarios for the NO is presented. The trend of the difference between

the hourly concentrations calculated by the model with the NEV and EV scenarios at the two stations (Lambro Park and RSE) is presented. It can be observed that, except for a few episodes the differences do not exceed the value of about 2 μg/m^3 and the relative difference is below the 2%.
The same as in Figure 3 but for the NO_2 is shown in Figure 4. Also in this case the differences are small, generally below 0.5 μg/m^3 and the 1% for the relative one.



a

(b)

Figure 4: NO_2 concentration differences between NEV and EV scenarios at the Lambro (PL) and RSE stations; (a) absolute difference, (b) relative difference.

It is worth to notice that the data analysis showed, as expected, the presence of high background concentrations that makes the additional contribution of the highway evident only in a few situations, when the meteorological conditions are favourable for the dispersion from the highway to prevail respect to other diffuse sources.
Finally, we performed a statistical analysis between the model results corresponding to the two scenarios for the two stations (RSE and Lambro) accounted for. We considered the Normalised Mean square Error (NMSE) and the Fractional Bias (FB). The results are reported in Table 1.

	NO_X	NO_2	NO
NMSE (RSE)	0.017	0.017	0.018
NMSE (PL)	0.022	0.023	0.022
FB (RSE)	-0.022	-0.022	-0.021
FB (PL)	-0.021	-0.022	-0.021

Table 1: Statistical analysis

The results presented in Table 1 confirm the previous observations. The difference between the two scenarios are very small, even including the episodes which show peaks in the difference trend, and comparable for the two stations.

CONCLUSIONS

In this work the results of numerical simulations of the dispersion from a highway are presented. The period considered lasts two weeks and the simulations of the wind fields and turbulence were carried out. The output of the meteorological model was used as input data for the dispersion simulation with a Lagrangian particle model. The results have confirmed that the contribution of the emissions of the highway on measured concentrations is very limited with respect to the background pollution. Furthermore the simulations have quantified the effect that it may have on air quality (especially in terms of NO and NO_2) the substitution of the 25% of the car fleet with zero emissions electric vehicles. Only light transport vehicles were considered for the electric vehicle introduction. The effect of this change is limited to a mean concentration decrease of less than 1% for NO_2, and of about 2% for NO, in correspondence of measurement stations analysed. The results seem to suggest that to achieve further improvements on air quality around a highway such as the one considered, may be not sufficient to limit the emissions of light transport vehicles, but it is necessary to reduce also emissions from commercial transport.

Acknowledgments

This work has been financed by the Research Fund for the Italian Electrical System under the Contract Agreement between RSE (formerly known as ERSE) and the Ministry of Economic Development - General Directorate for Nuclear Energy, Renewable Energy and Energy Efficiency stipulated on July 29, 2009 in compliance with the Decree of March 19, 2009.

REFERENCES

Alessandrini S. and E. Ferrero, 2009, A hybrid Lagrangian-Eulerian model for reacting pollutant dispersion in non-homogeneous non-isotropic turbulence, *Physica A*, **388**, pp. 1375-1387

Alessandrini S. and E. Ferrero, 2010, An application of a Lagrangian particle model with chemical reactions to power plant pollution dispersion in complex terrain, in *Air Pollution Modeling and its Application XX*, (Eds.) D.G. Steyn and S.T. Rao, 361-366

Alessandrini S. and E. Ferrero, 2011, A Lagrangian particle model with chemical reactions: application in real atmosphere, Int. J. Environment and Pollution, 47, 1-4, pp. 97-107

Garmory A., E.S. Richardson, E. Mastorakos (2006) Micromixing effects in a reacting plume by the stochastic fields method, Atmos. Environ. 40 1078–1091.