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LAGRANGIAN MODELLING EVALUATION OF THE NO_X POLLUTION REDUCTION DUE TO ELECTRIC VEHICLES INTRODUCTION

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Abstract: The problem of the pollution due to the traffic is faced using a numerical model. Simulations of the emission from vehicles in a large freeway were carried out. The results are compared with a literature field experiment. Then the reduction obtained introducing the electric vehicle is evaluated.

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

INTRODUCTION

Simulations of pollution dispersion and chemical transformations of the traffic emission were performed. A Lagrangian particle model was modified in order to account for chemical reaction between nitrogen oxides and atmospheric background ozone (Alessandrini A. and E. Ferrero, 2009 and 2010). The model includes the segregation effect, due to the turbulent mixing, through a parameterization. Furthermore, background ozone is reproduced using the ozone "deficit" as a new substance carried by each particle. An elongated area source representing a large road was considered in a domain of 1x2 km^2. Simulations were performed in order to account for the different possible meteorological and pollution conditions (wind direction, background ozone concentration), in an unstable boundary layer. Firstly we tested the model performances against a field experiment taken in the literature (Rodes C.E. and Holland D. M., 1981). Then, we considered the typical emission of a present-day urban freeway and compared two different scenarios, the present one and those obtained with the introduction of the electric vehicle so as to be able to evaluate the impact of this new technology on the air quality.

MODEL DESCRIPTION

The model used in this work is the Lagrangian stochastic model described in Alessandrini A. and E. Ferrero (2009 and 2010). 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):

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

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 A. and E. 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. 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. Starting from our previous work (Alessandrini A. and E. Ferrero, 2010) we have modified the parameterization to account for a linear source.

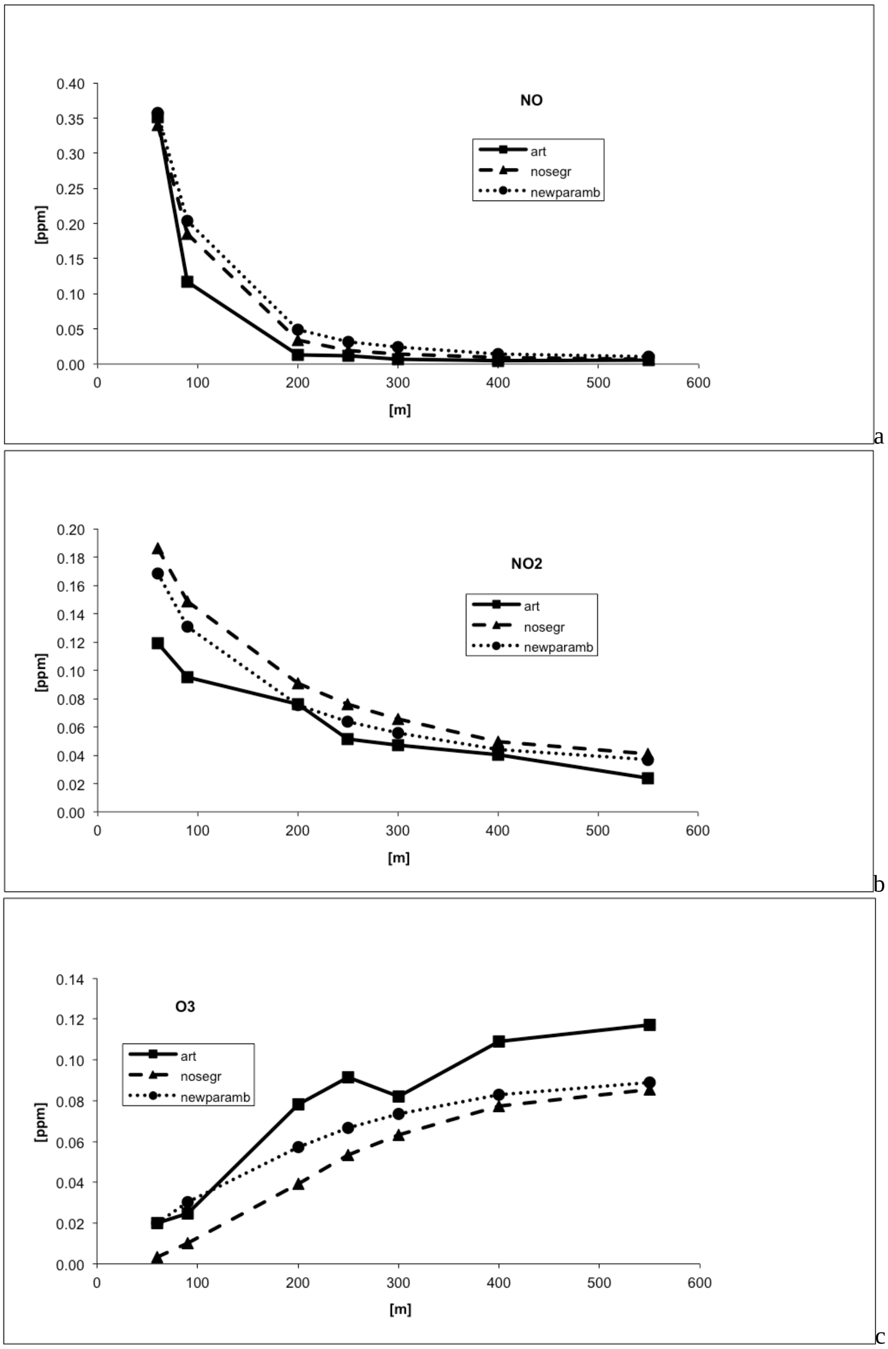

Figure 7: Intercomparison between model simulations, with ("newparamb") and without ("nosegr") segregation, and measurements ("art") for NO (a), NO_2 (b) and O_3 (c).

MODEL ASSESSMENT

In order to assess the ability of the model in simulating the emission from a large road and, in particular, the new segregation parameterisation, the experiment carried out by Rodes C.E. and Holland D. M. (1981), was considered. In that paper, measurements of NO, NO_X and O_3 performed during August 1978 at a large freeway in Los Angeles are presented. Wind speed between 1.3 and 2.6 ms^{-1} and wind direction within a ± 45° arc sector of the freeway perpendicular were taken into account. The results are presented as an average on at least 27 hourly values. Three backgrounds O_3 concentration were considered (as the mean value of different experiments) corresponding to 0.04 ppm ("low"), 0.07 ppm ("medium") and 0.12 ("high") respectively. For the sake of brevity, only the comparison of the case "high" is presented in Figure 1.

In order to reproduce the average concentrations we performed several simulations in which the wind speed was taken equal to 2 ms^{-1} and the wind direction equal to 0°, 30°, 45° respect to the freeway perpendicular.

The simulation results show that the new parameterisation of the segregation ("newparamb") improves the model performances concerning NO_2 and O_3, while, in the case of NO, the simulation performed without considering the segregation effect ("nosegr") agrees slightly better with the experiment data ("art"). From Figure 1, it can be also deduced that the segregation coefficient acts in the first 300 m only, while for larger distances the simulations performed with and without segregation give comparable concentrations.

SCENARIO INTERCOMPARISON

We performed numerical simulations of pollutant dispersion from an elongated area source representing a typical suburban road. Two emission scenarios were considered. In the first one the emission were considered due to the present traffic situation, while the second one accounts for a hypothetical future scenario determined by the reduction in the NO_X emissions obtained by introducing the 25% of electric vehicles in the car fleet. The emissions were changed with respect to the previous case to be consistent with a typical nowadays situation of a large road. Emissions for the two scenarios are presented in Table 1.The emissions have been calculated using the COPERT4 (Ntziachristos L. et al., 2007) software for free highway conditions with vehicle speed equal to 90 km/h for passenger cars and 70 km/h for heavy-duty vehicles. Fleet composition has been assumed equal to the Italian 2005 national fleet but with only the more recent category (from ECE-04 to EURO-VI). In this way passenger cars are powered by gasoline for the 65% and 35% powered by diesel fuel.

Table1:Emissions for a 1380/hour heavy transport and a 9570/hour light transport vehicles fluxes with 90 km h^{-1} speed.

SCENARIO	**NO_X**	**NO**	**NO_2**
	(g km^{-1} h^{-1})	(g km^{-1} h^{-1})	(g km^{-1} h^{-1})
Present	11737	10095	1615
Future	10615	9168	1427
reduction %	-9.6	-9.2	-11.7

Figure 2 (on the next page) shows the comparison in the case of high background ozone concentration (240.77 µg/m^3). Four simulations are considered. Two for each scenario, the one considering the present emissions (NOVEL) and the one obtained with the introduction of the electrical vehicle (VEL). Furthermore, either the simulation considering the effect of the segregation and the one that neglects its contribution are presented ("nosegre" and "newparamb" respectively). Noticeable differences are found only in the first 100 m from the source. It can be observed the effect of the segregation. Both the simulations, accounting for its parameterisation, show lower NO and O_3 concentrations and higher NO_2 concentrations. Moreover, differences due to the introduction of the electrical vehicle are found. Using this new technology reduces the NO and NO_2 concentrations while O_3 remain almost the same. The effects on the air quality of the introduction on electric vehicle may be more significant on the NO_2 air quality level taking into account the increasing proportion of diesel fuelled cars in the Italian fleet as a consequence of the increased market share in the recent years. Diesel cars emit higher levels of NO_X compared to gasoline cars. Moreover, new real-world diesel cars produce a higher proportion of their NO_X as NO_2 (Alvarez R. et al., 2008).

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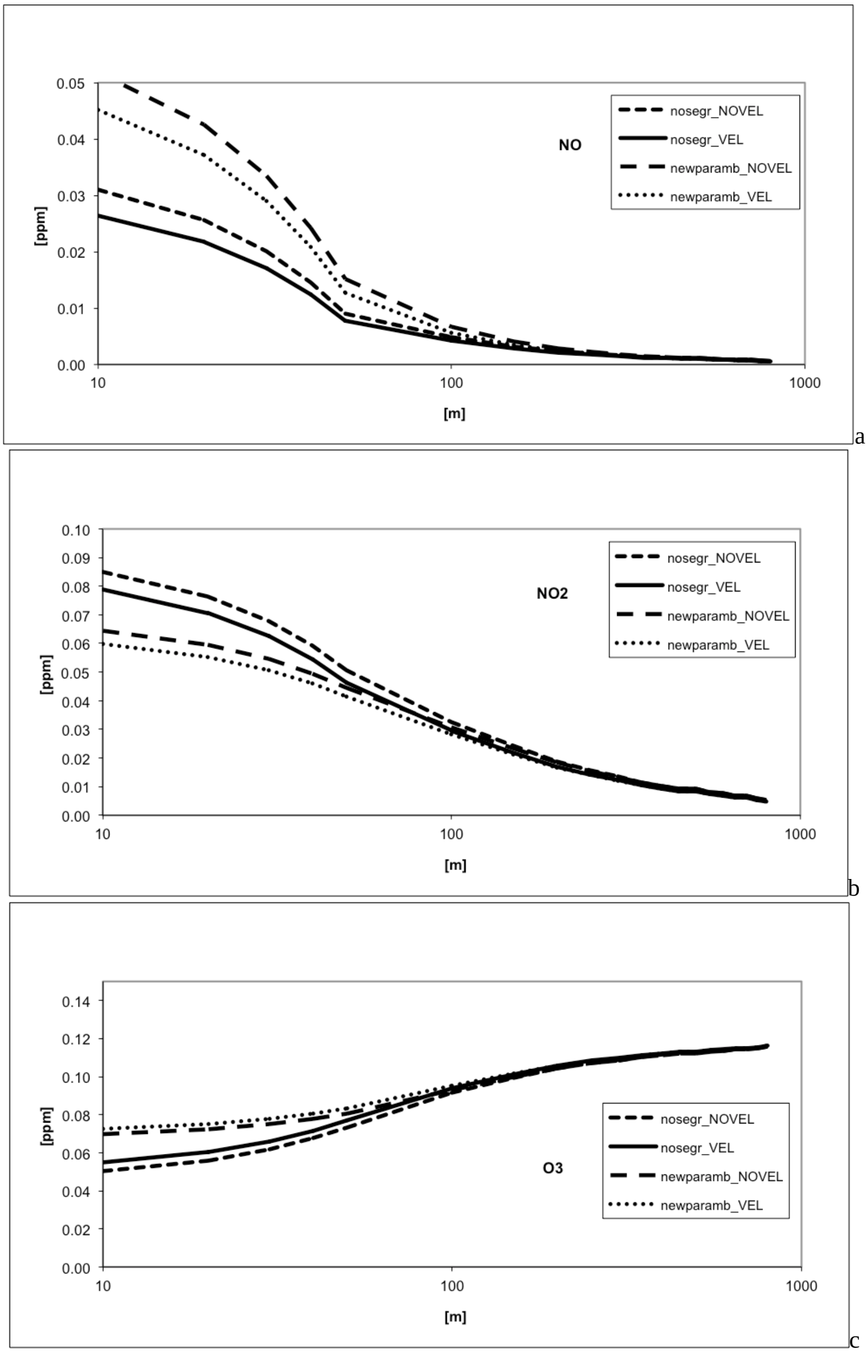

Figure 8: Scenarios comparison for high background ozone concentration,with (“newparamb”) and without (“nosegr”) segregation, considering the present emissions (NOVEL) and the one obtained with the introduction of the electrical vehicle (VEL), for NO (a), NO_2 (b) and O_3 (c)