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

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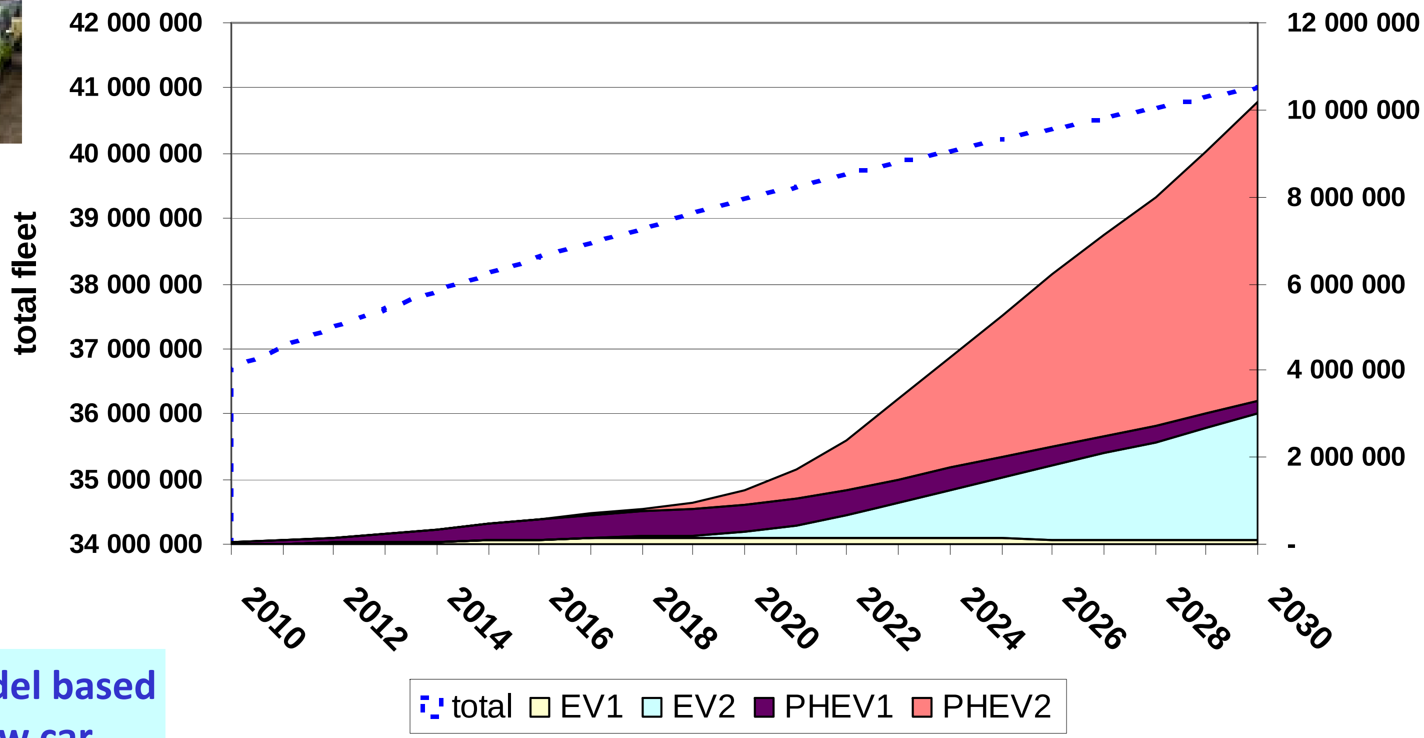
Outline

- The influence of the introduction of **Z**ero **E**mission (**ZE**) vehicles on a urban highway is evaluated by using a Lagrangian Particle Model
- To compare model results with an experimental campaign (Rodes C.E. and Holland D. M. (1981) simulations have been performed
- The introduction of ZE vehicles is studied in term of NO, NO_2 and O_3 concentration variation.

Introduction

- The **P**lug in **E**lectric **V**ehicles (**PEV**) currently available already reach 150 km of cruising range (urban employment)
- The **P**lug in **H**ybrid **E**lectric **V**ehicles (**PHEV**) use both electric and internal combustion engines (currently 60 km with electric engine, 500 km with int. combustion engine) more suitable for ex. urban employment

Introduction (2)



Optimization model based on present new car registration and scrapping trend
+
average hypotheses on EVs/PHEVs roll out

(DeNigris et al.2010)

2030:

- 25% of total (41 Ml) circulating fleet
- 50% of market share
- PHEVs more than EVs (2x)

Pollutants emissions (Italian scenario)

	FC	CO	NO_X	NMVOC	PMexh
Scenarios	[Tg]	[Gg]	[Gg]	[Gg]	[Gg]
2005	24	1077	258	140	12
2030 BaU	28	370	42	36	0.8
2030 EV	22	303	36	29	0.7
% reduction scenario EV vs. BaU	-20.6	-18.1	-14.3	-18.8	-13.8

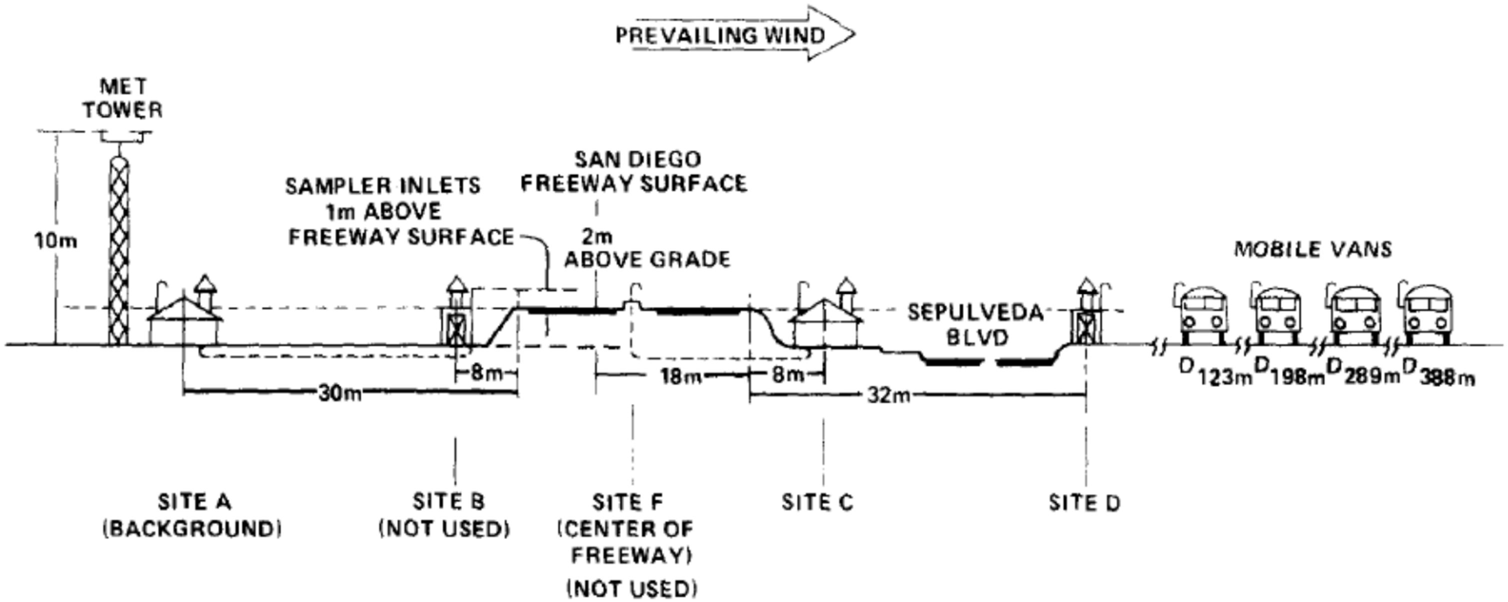
EURO6 most advanced car category for ICE technology

2030:

- Pollutant emission balance: 15% ÷ 20% reduction
    - 20% fuel consumption reduction

Experimental data (Rodes and Holland 1980)

- A short range monitoring study was conducted from 15 July until 31of August 1978 at a location adjacent to the San Diego freeway in Los Angeles
- Flat location, predominant cross-freeway winds, average traffic flow of 200.000 cars/day

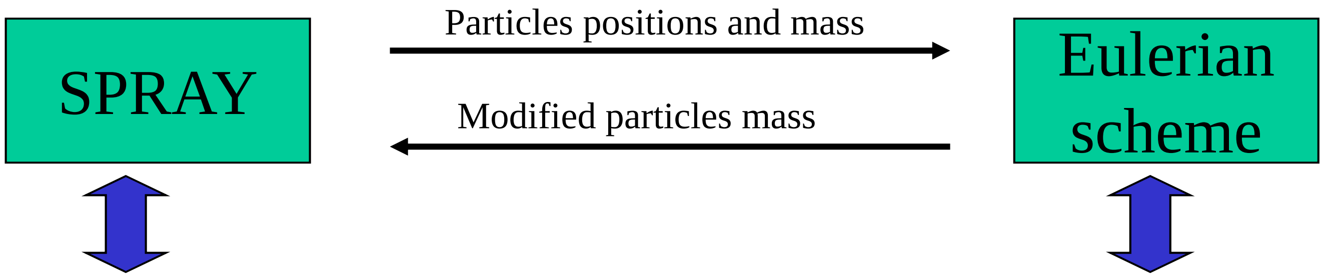


Experimental data (Rodes and Holland 1980)

- Only measurements correspondent to upwind wind speed within the range of 1.3-2.6 m/s and wind directions within ±45° arc sector of the freeway perpendicular
- No specific turbulence information are given together with concentration measurements
- The pollutant hourly conc. measurements were stratified by upwind O_3 levels
- In order to obtain three strata of equal size they were divided in three categories “low” (0-0.057 ppm), “medium” (0.058-0.084 ppm), “high”(0.085-0.202 ppm)
- At each site for each categories all hourly concentrations were averaged for every pollutant (at least 27 hourly values used at each site)

Model (Spray-Chem)

- The Eulerian model is included inside the lagrangian model, SPRAY, following the simple scheme:



•Particles emission
•Lagrangian particle displacements
•Final concentration computation

•Temporary concentration computation on a 3D grid
•Chemical reactions performed on the same grid
•New particles mass of different species computation

Alessandrini S. and Ferrero E. (2009). A hybrid Lagrangian-Eulerian particle model for reacting pollutant dispersion in non-homogeneous non-isotropic turbulence. PHYSICA A, ISSN: 0378-4371, 388, 8, 1375-1387

Model (Spray-Chem)

The set of chemical reactions considered is:

$$NO + O_3 \xrightarrow{k} NO_2 + O_2$$

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

The chemical kinetic follows:

$$\frac{\partial c_{NO}}{\partial t} = \frac{\partial c_{O_3}}{\partial t} = -\frac{\partial c_{NO_2}}{\partial t} = -k \cdot c_{NO} \cdot c_{O_3} + j \cdot c_{NO_2}$$

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

$$k = 5.86 \cdot 10^{-2} e^{-(1450/T)} (ppb^{-1} s^{-1}) \qquad j = 8.9 \cdot 10^{-6} \cdot R \qquad (s^{-1})$$

the O_2 concentrations are neglected because this substance is always present in excess and his variation in time and space does not influence the kinetic *J* of the reaction

Parameterization of segregation coefficient

- The effect of segregation is considered with a parameterization

$$k \cdot < c_{NO} c_{O3} >= k < c_{NO} > \cdot < c_{O3} > \left(1 + \frac{< c_{NO}' c_{O3}' >}{\langle c_{NO} \rangle \langle c_{O3} \rangle} \right)$$

$$k < c_{NO} > \cdot < c_{O3} > (1 + \alpha)$$

$$\alpha = -0.71 \cdot e^{-\frac{0.106}{N_D} \frac{x}{x_s}}$$

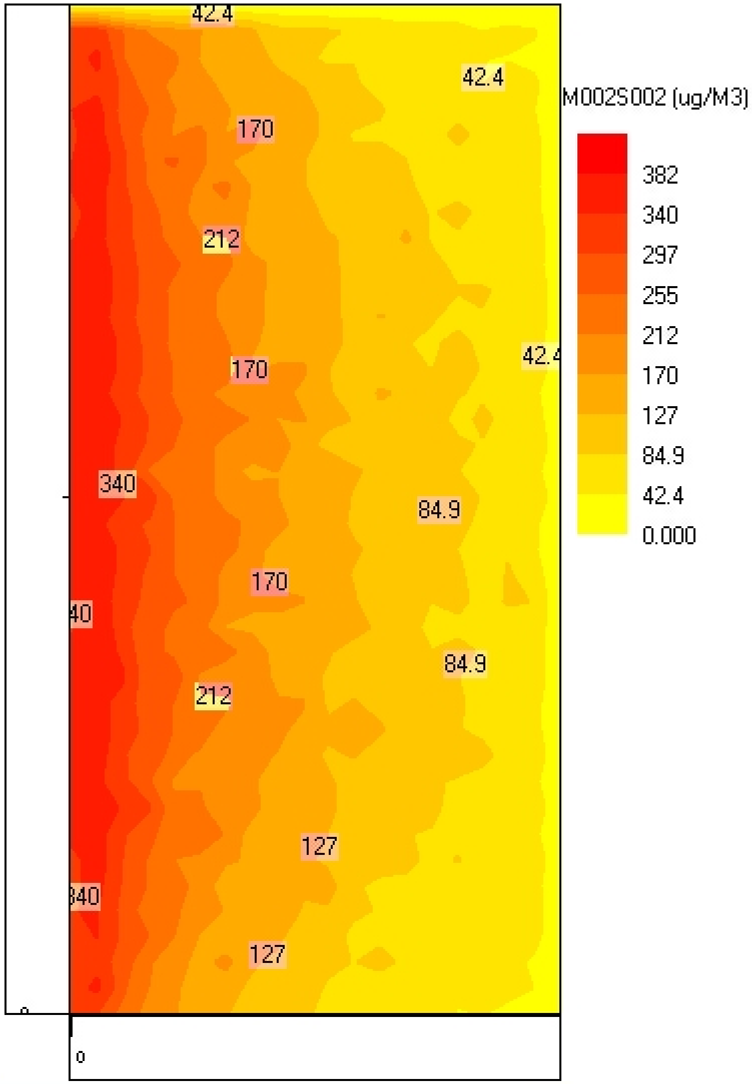
$$x_s = \frac{(Q_{NO} / L)^2}{4\pi\sigma_w^2 \cdot T_{Lw} u \cdot C_{O3}^2}$$

Computed with Gaussian model for linear source

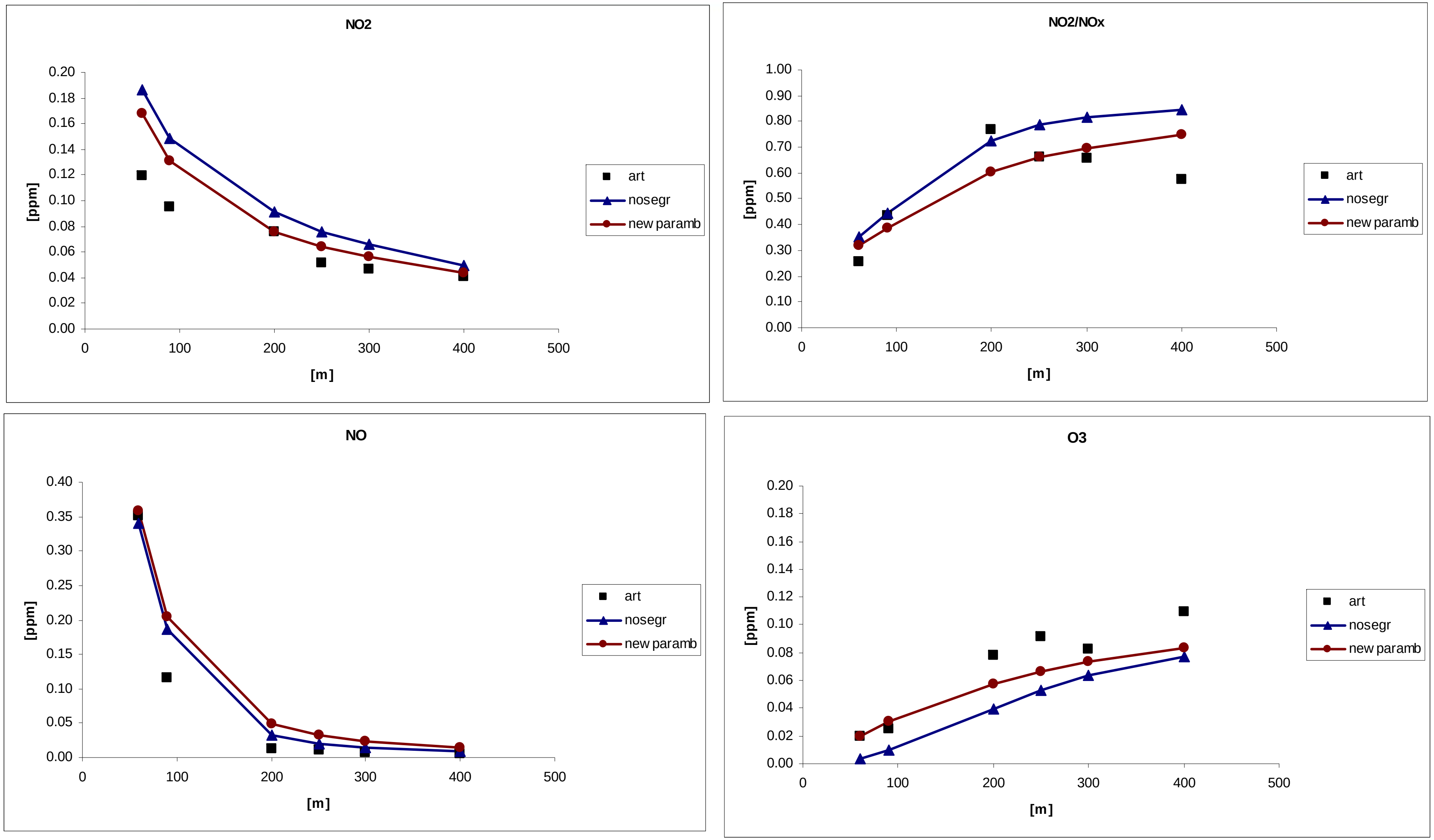
$$N_D = k(C_{O3} + C_{NO})_s \cdot T_{Lw}$$

Simulation (Spray-Chem)

- Linear source (2 km length)
- Cells for concentration computation (50x50x20 m^3)
- For each background O_3 level, 3 wind directions (0°, 30°, 45°)
- U=2 m/s
- Typical values of reaction rates used
- The NO_x emission rate has been set in order to match the first measurement point
- Turbulence profiles from Rams TKE outputs



Simulation results



Scenario Simulation (2030)

Same set of simulation have been repeated in terms of:

- Wind and turbulence
- Domain
- Background O_3 concentrations

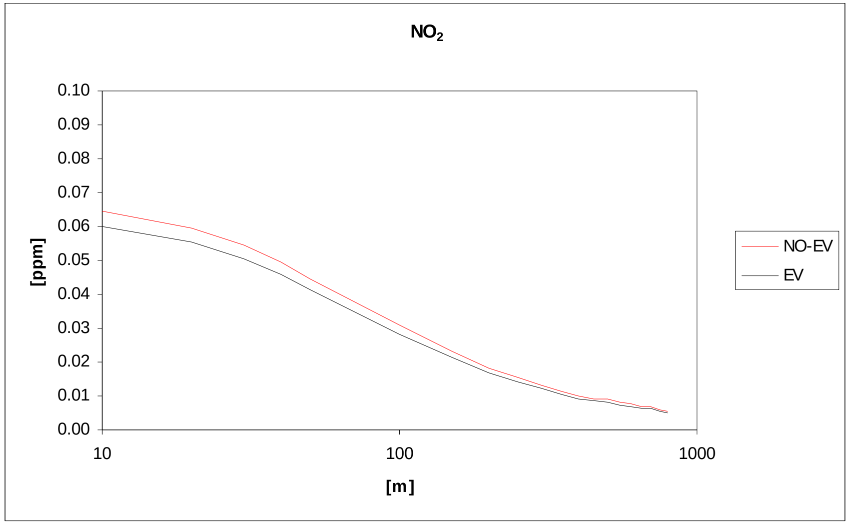
Different Emissions

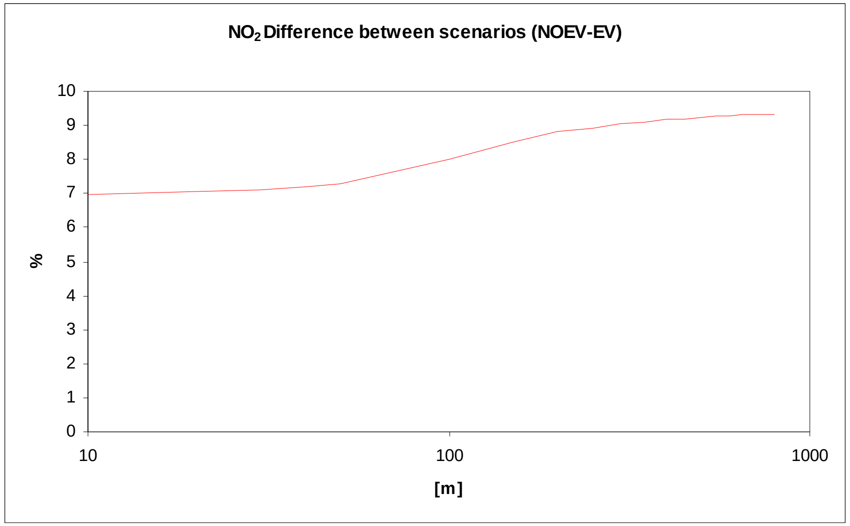
Scenario Simulation (2030)

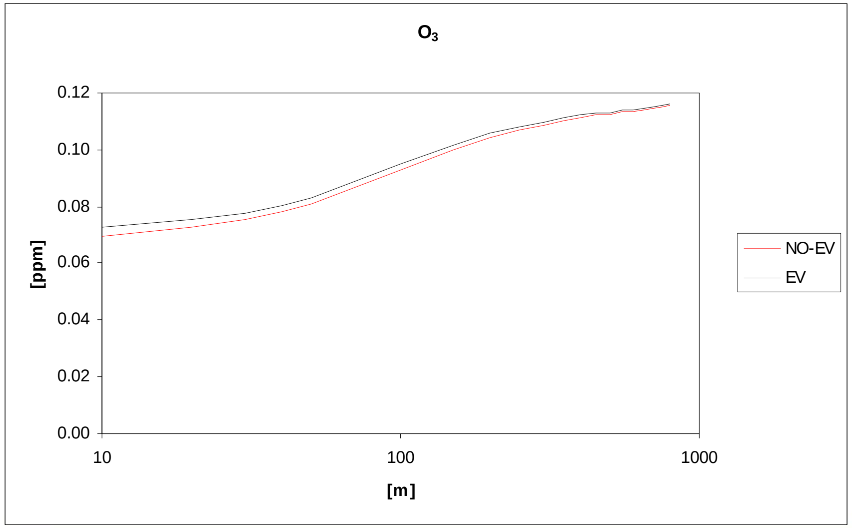
- Emissions for a 1380/hour heavy transport and a 9570/hour light transport vehicles fluxes with 90 km h^{-1} speed **(**as measured on a Urban Highway in Milan**)**
- Two emission scenarios were considered
- (NO-EV) the present traffic situation
- (EV) 25% of electric vehicles in the car fleet

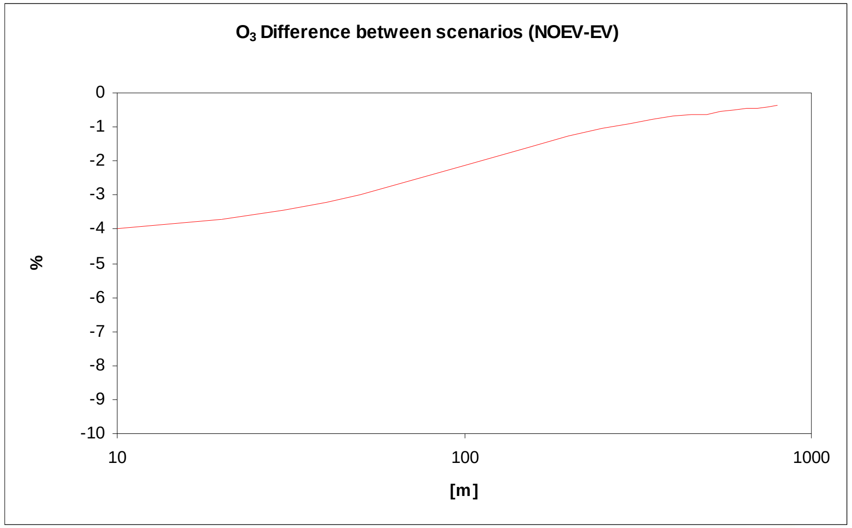
SCENARIO	**NO_X**	**NO**	**NO_2**
	(g km^{-1} h^{-1})	(g km^{-1} h^{-1})	(g km^{-1} h^{-1})
Present (NO-EV)	11737	10095	1615
Future (EV)	10615	9168	1427
reduction %	-9.6	-9.2	-11.7

Scenario Simulation (2030), high O3

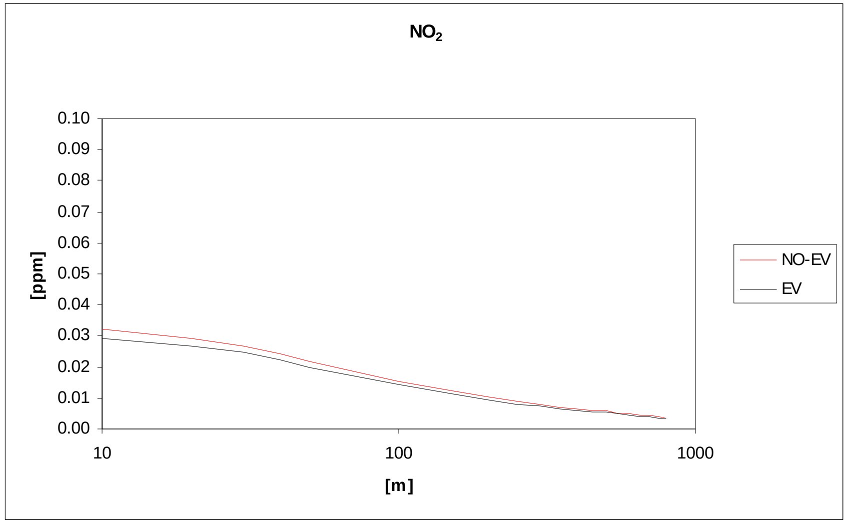


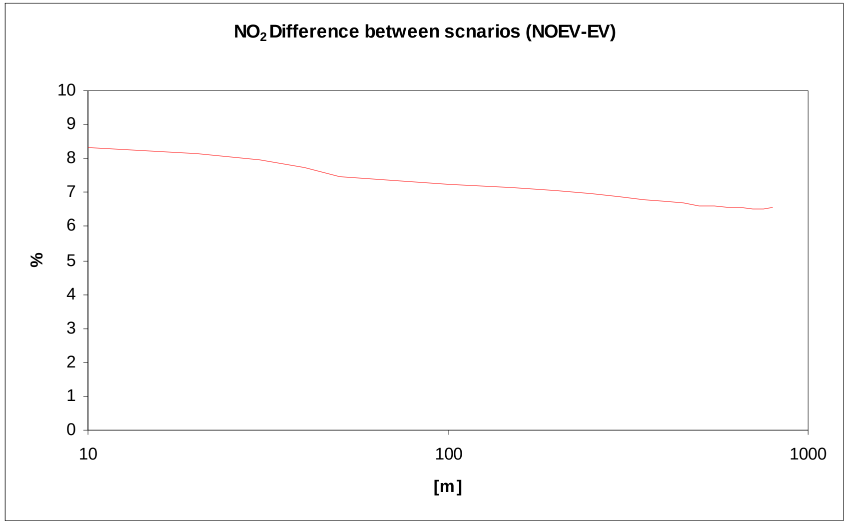


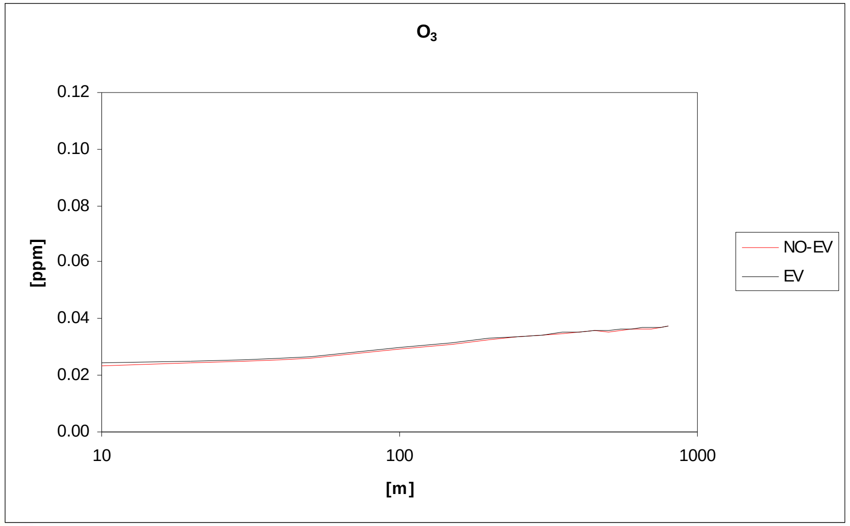


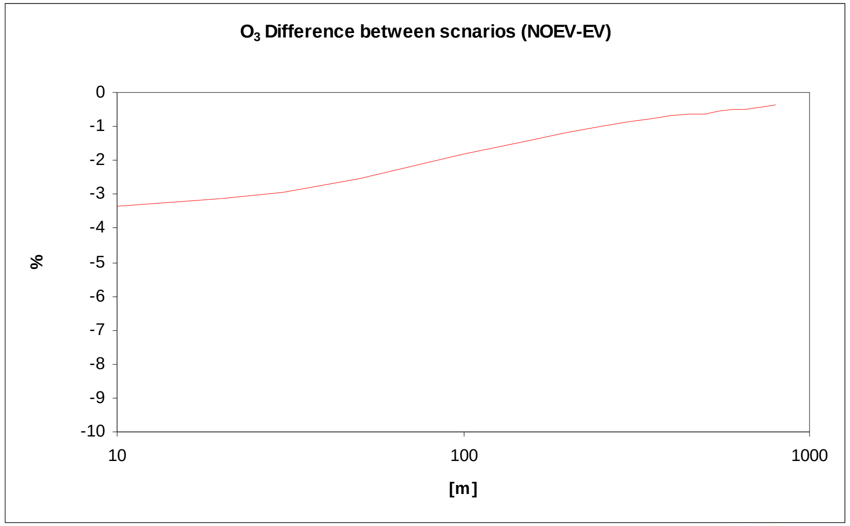


Scenario Simulation (2030), low O3



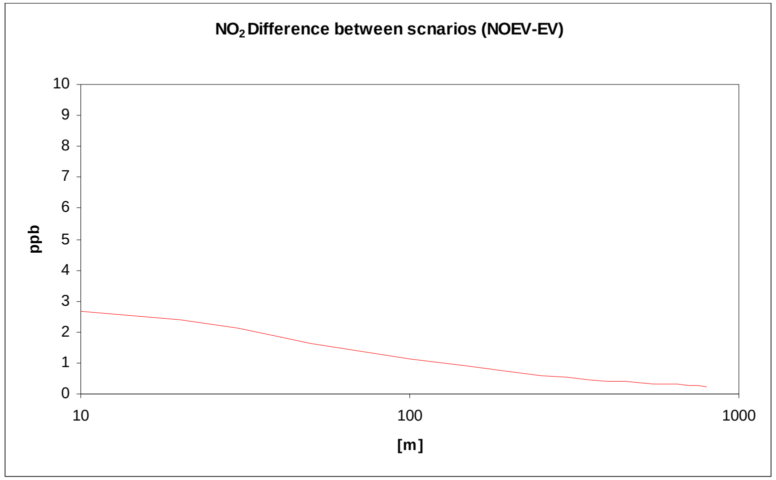


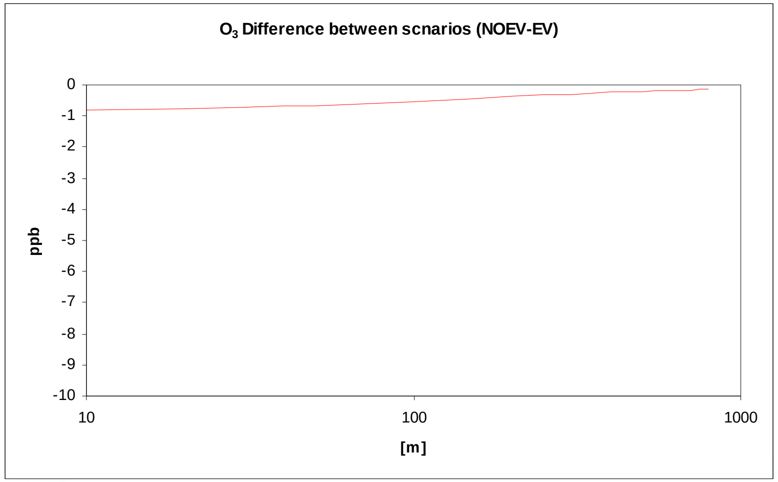




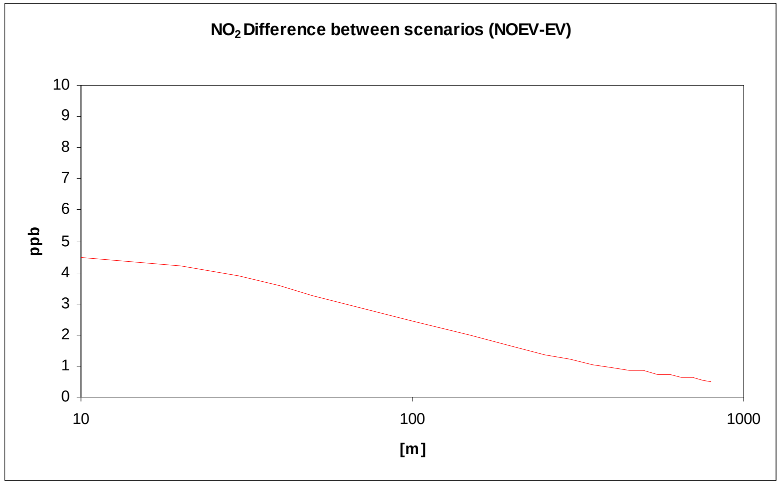
Scenario Simulation (2030)

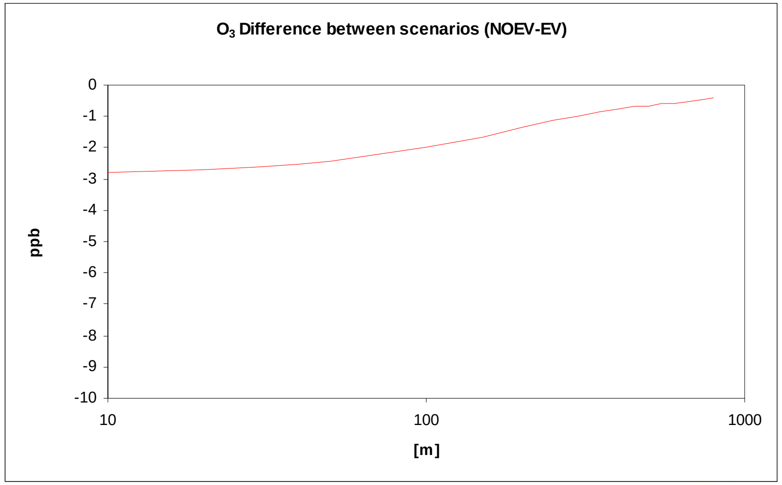
Low background O_3





High background O_3



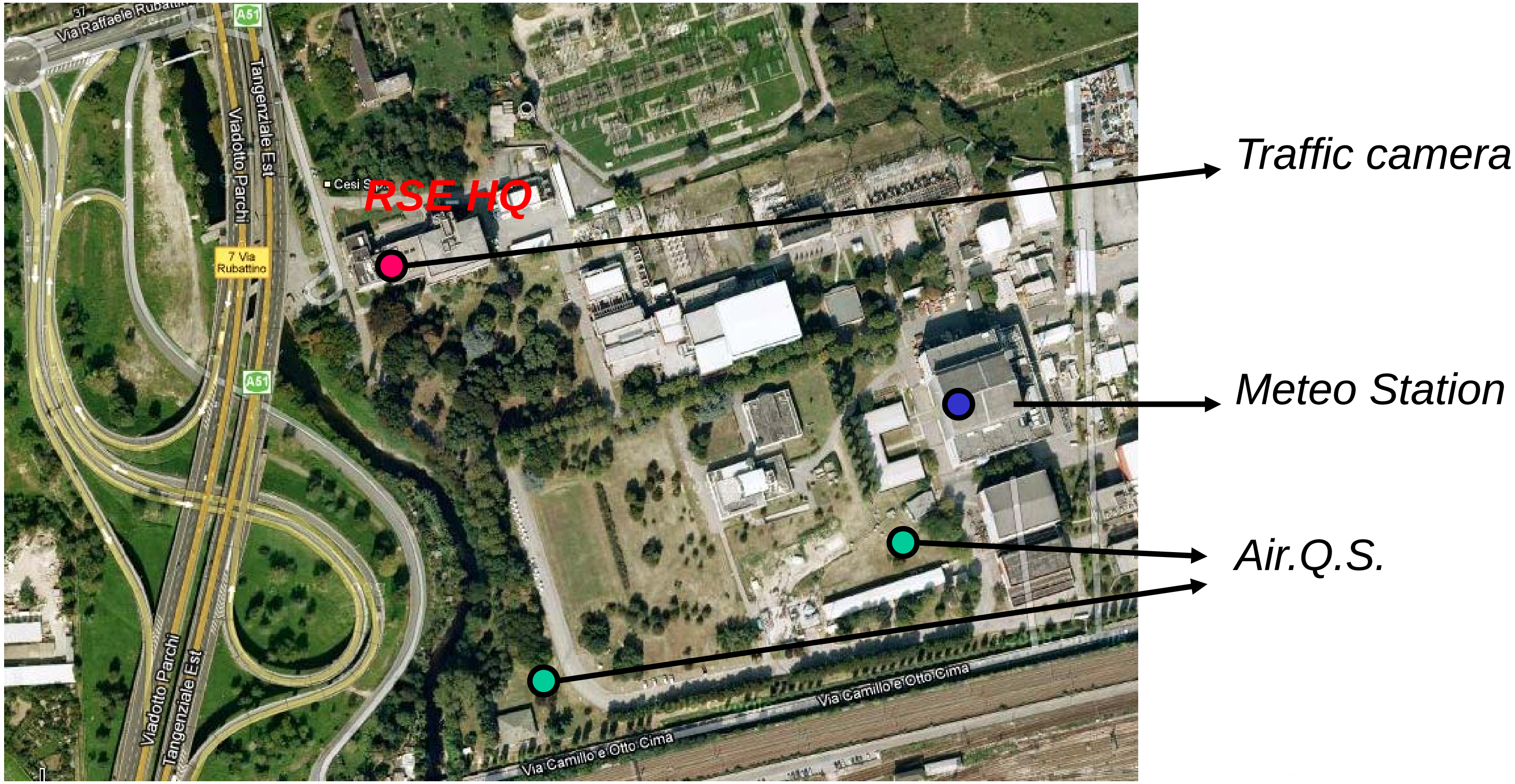


Conclusions

- The segregation seems to improve the accuracy in the considered test case
- The reduction due to the introduction of 25% EV in the car fleet can be significant only in the first 100 m from the highway
- In the first 100m a reduction of at most 7-8% of NO_2, of the scenario EV vs No-EV, corresponds to an increase of 3-4 % in O_3
- The effects of EV may be more significant on the NO_2 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.

Future work

- An experimental campaign has been performed during January 2011 at the RSE h.q. with traffic monitoring, meteorological and concentration measurements



Future scenario to optimistic?

By Report Nr. I-25/10 Haus-Em 07/10/676 from 29.11.2010
Prof. Dr. Stefan Hausberger

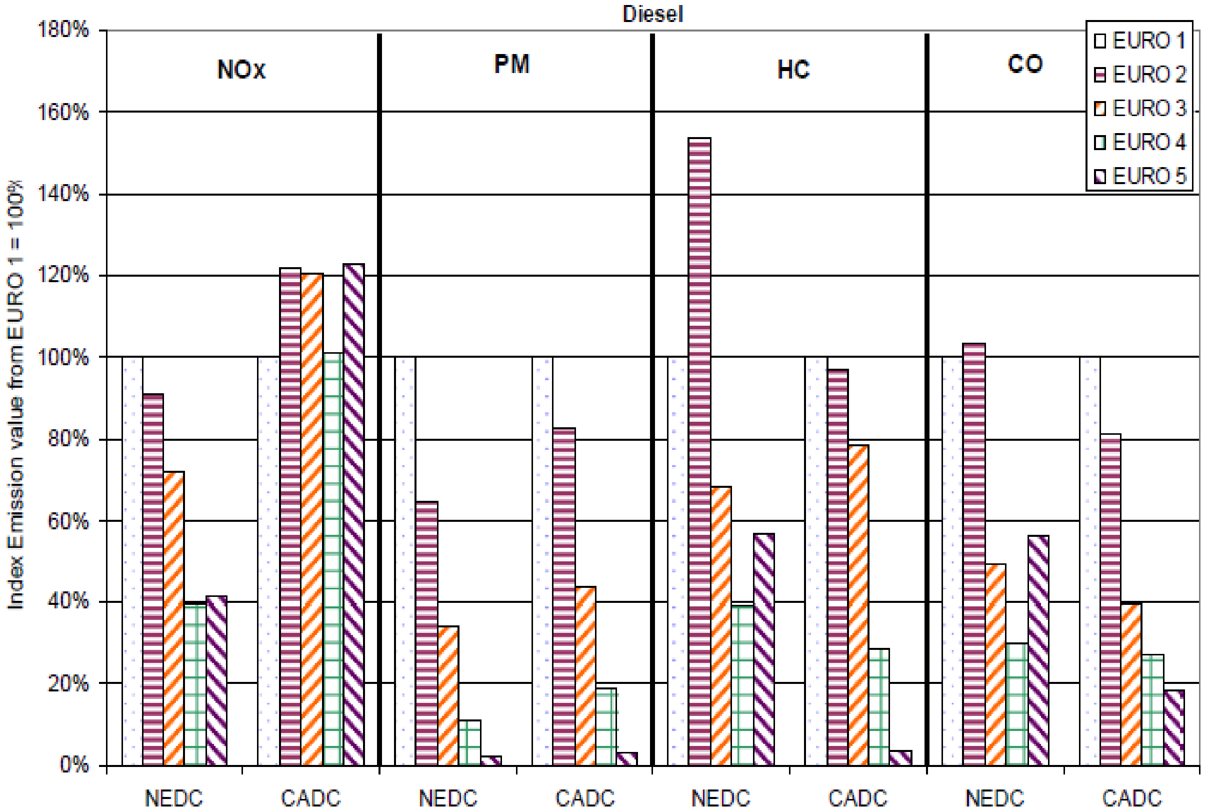


Figure 4: Change of the emission levels from **diesel cars** in the NEDC (20°C cold start) and in the CADC 1/3 Mix (hot start) per type approval class compared to the EURO 1 type approval class

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