# 1.29 MODEL SIMULATION OF VENEZIA-MESTRE RING ROAD AIR POLLUTION: EXPERIMENTAL CHECK AND MODEL INTERCOMPARISON

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## INTRODUCTION

Mestre is the mainland part of the City of Venice, one of the most densely populated urban centres in the Veneto Region. Its ring road is a 6-lane motorway, 8 kilometre long, passing through the urban centre (see. Figure 2). It is a toll-free elevated road, located in the intersection between the most important motorways in North-East Italy: the A4 motorway, connecting NW to NE Italy, and the A27 motorway that is part of the link between Southern and Northern Italy. The ring road is used not only for long-range travels, but also to drive through the urban area of Mestre, avoiding the urban network of roads. During winter time, average daily traffic (ADT) counts up to 40,000 vehicles. 60% is represented by Light Duty Vehicles (LDV), while the remaining 40% by Heavy Duty Vehicles (HDV). The highest ADT counts up to 65,000 vehicles, where 90% is represented by LDV while 10% by HDV. This ADT has been recorded in the summer season, when commuter and commercial travels add to vacation travels, whose destination are the beaches in the Veneto region coastline. This is the reason why drivers frequently experience long queues (some kilometre long) at the motorway toll booths. The discussion over the "Mestre bottleneck" removal started several years ago. Recently (in summer 2003), the Venice-Padua Motorway Company, that supervises the Mestre ring road, decided to use the hard shoulders as running-lanes, resulting in the present 6-running-lane configuration.

## MODEL SIMULATION

Primary contribution of CO, benzene and $PM_{10}$ to urban air pollution from Mestre ring road has been assessed. For this purpose, ADMS-Urban (Atmospheric Dispersion Modelling System) model has been used, a model suitable to simulate atmospheric dispersion of pollutants released by industrial and domestic sources and by traffic in urban areas (ADMS-*Urban, Urban Air Quality Management System, Version 2.0 and 2.0.4.0.).*

The emission source was divided in 57 lines (straight, entrance, exit and link roads). Traffic emissions have been estimated by European COPERT3 methodology, adding the emission factors proposed by IIASA and TNO for $PM_{10}$ non-exhaust emissions (tire, brake wear and road abrasion, as well as re-suspension are included). Pollutant concentrations have been evaluated, at every hour of the day, considering the ADT variations between working days, Saturdays and Sundays, both for winter and summer. The output grid amounts to almost 10,000 receptors, placed up to 800 m far from the ring road, 2 m (man target height) and 7 m (average motorway height) high from the ground.

In the following we represent the interpolation of maximum hour concentration values of CO produced by daily emissions on 2 m high receptors. Summer and winter periods are distinguished. All the information refer to 2002, when the ring road was still in 4-lane configuration.

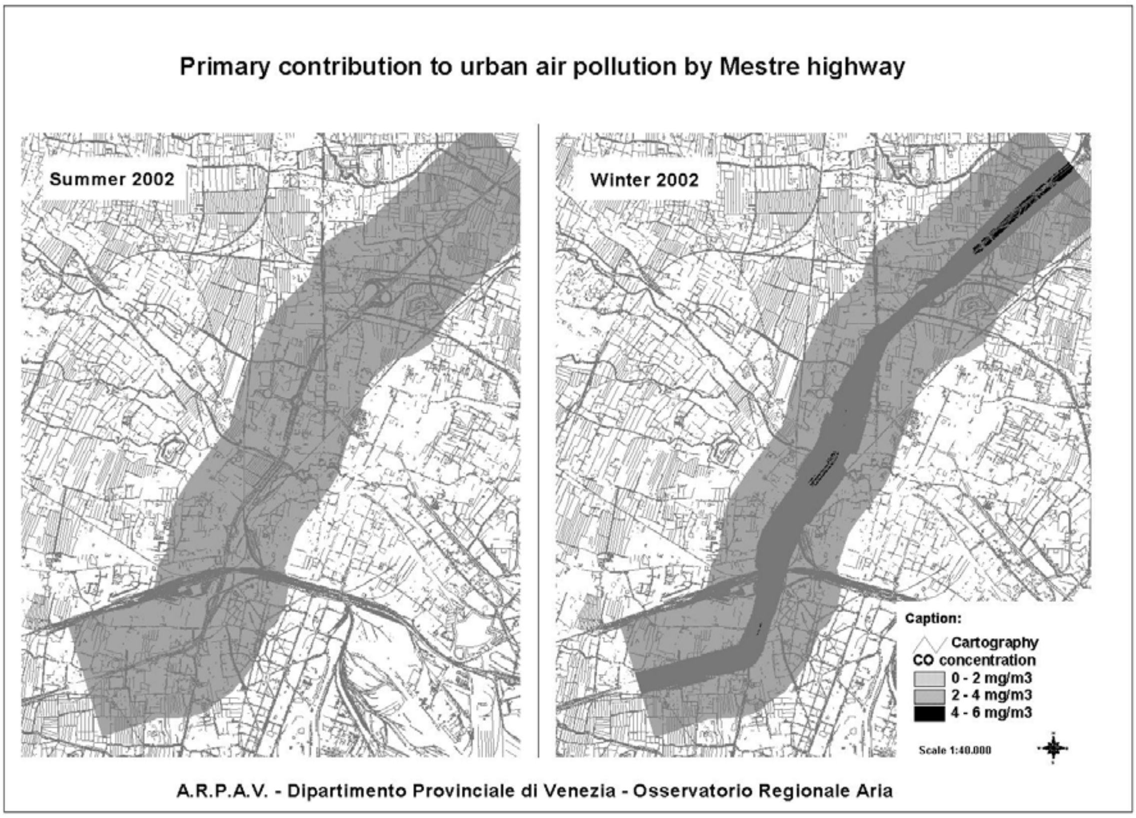


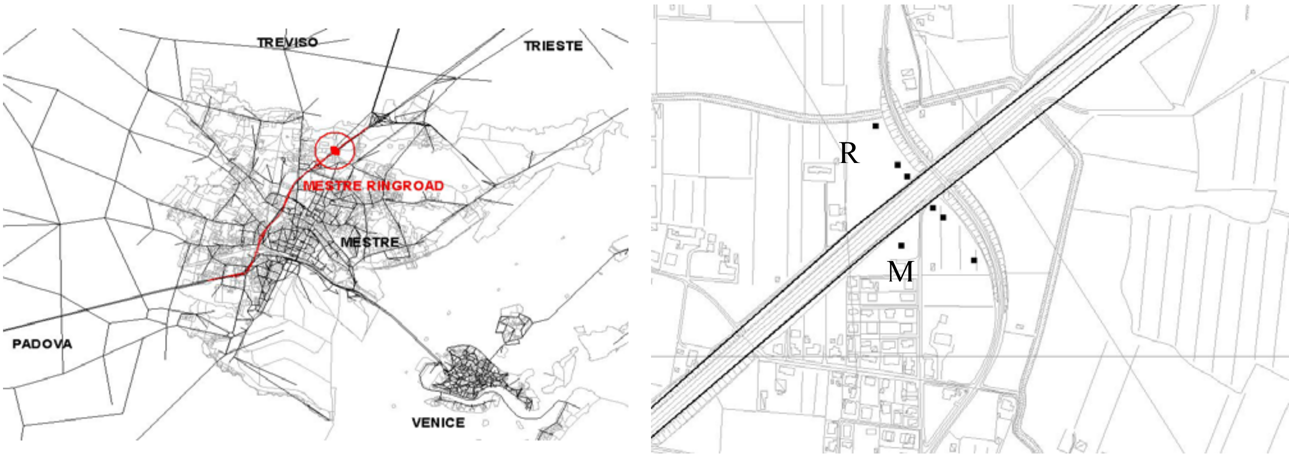

*Figure 1. Maximum hour concentration values of CO produced by daily emissions on 2m high receptors*

**Field measurements to evaluate models performance**

In order to validate modelling results with experimental data, an air quality monitoring campaign has been performed, placing a mobile laboratory by the ring road from 06/11/2003 to 07/01/2004. The measurement site is beside a green area 30 m from the ring road (see Figure 2). The station is equipped with continuous analysers for sampling and measuring CO, $SO_2$, $NO_x$, $O_3$, $CH_4$, NMHC and BTEX. At the same time $PM_{10}$ has been sampled. $PM_{10}$ ha been successively analysed with gravimetric method, while PAH (benzo(a)pyrene) have been analysed with HPLC. Passive samplers (Radiello®) have also been used to determine benzene-toluene-xylene (BTX) with gas chromatography. Some meteorological parameters have been achieved: temperature, relative humidity, atmospheric pressure, wind speed/direction, direction standard deviation and solar radiation. During the monitoring period $PM_{10}$ concentration exceeded the daily human health protection limit for 26 days. No other exceedances of short term legal limits have been observed for the other pollutants. In the same period 6 passive samplers (Radiello®) have been placed along a line orthogonal to the road at a distance of 10, 30, 100 m on both sides of the ring road. With this device a week sample of benzene has been collected.

**Model inter-comparison**

Comparison between model results and air quality data has been carried out to assess the suitability of ADMS Urban for this study. The selected period for the comparison is 28/11/03 – 03/12/03, corresponding to a week passive sampling of benzene in the 6 sites across the ring road. Furthermore, in this period a negligible number (1%) of calm wind conditions (wind speed < 0.5 m/s) happened. The modelled scenario accounts for the new 6-lane configuration of the ring road.




a b

*Figure 2. a)Mestre ring road; b) the monitoring sites (mobile laboratory - M and passive samplers - R).*

To evaluate the performance of the models currently in use at the Veneto Region Environmental Protection Agency, the simulation has also been performed with:

- CALINE4 (zeta version dated October 1991) which is the successive version of the US-EPA reference model to evaluate extra-urban roads impact (CALINE3);
- AERMOD (original version 99351) which, like ADMS Urban, is based on the similarity theory approach for boundary layer parameterisation;
- CALPUFF (version 5.7 dated 030402) which is the only non stationary model used for urban air quality modelling.

A first application of the new AERMOD beta version (dated 04079), comprehending gas and particulate deposition algorithms, has also been carried out. Before processing the meteorological input, wind speed for calm wind conditions has been set to 0.5 m/s.

Simulations have been carried out using the hourly meteorological data collected by the mobile laboratory. Clouds cover data were provided by synoptic station 16105 located at Venice Marco Polo Airport (10 km from the area investigated).

ADMS Urban modelling system has a built-in pre-processor for the calculation of micrometeorological parameters needed for the dispersion model. AERMET processor (version 04079) has been used to obtain the meteorological input files for AERMOD and CALPUFF. Moreover, for CALINE4, Pasquill stability classes have been obtained from solar radiation and clouds cover data.

Simulation options are summarized in the table 2.

*Table 2. Model options*

| **Source characteristics** | **ADMS** | **CALINE** | **AERMOD** | **CALPUFF** |
|---|---|---|---|---|
| Type | Linear | Linear | Adjacent volumes | Adjacent volumes |
| Numbers | 20 link | 20 link | 983 | 983 |
| Traffic-induced dispersion treatment | included in model algorithms | included in model algorithms | resulting from: σ_yinit = 17/2.15 σ_zinit = 2.5/2.15 or 4.3 | resulting from: σ_yinit = 17/2.15 σ_zinit = 2.5/2.15 or 4.3 |
| Dispersion coefficients | Internally calculated from micrometeorological data (L, u*, Hmix,z0…) | Based on Pasquill stability classes | Internally calculated from micrometeorological data (L, u*, Hmix,z0…) | Internally calculated from micrometeorological data (L, u*, Hmix,z0…) |

Every simulation has been performed by using hourly variable emission factors, in accordance with traffic flows, for a total of 6 daily runs for each model. Seven receptors have been identified in the mobile laboratory and passive samplers locations.
For optimisation purpose (CPU time) during CALPUFF simulation, carried out only for CO, we chose the following configuration:

- maximum number of puffs released from one source during one time step = 10;
- maximum number of sampling steps for one time step = 6.

Model compilation has been set for a maximum number of 50.000 puffs. First day simulation has been performed without initial conditions, whereas for the other days the restart files produced by previous run have been used. There is a relevant different source treatment among these air quality models. ADMS and CALINE4 support linear sources for road modelling and consider traffic-induced turbulence (cfr. Technical manual), while AERMOD and CALPUFF don't. For the latter models, the ISC3-approach for line sources has been used. Initial vertical dimension for adjacent volume sources was fixed at 2.5 m.
In table 3, model results are presented. Background concentrations haven't been taken into account. Benzene observed values refer to passive sampler measurement placed 30 m southwards the ring road.
Comparison with monitoring data outlines a general underestimation of CO and $PM_{10}$ levels, whereas for benzene, predictions of the models show a tendency to overestimation. This is particularly evident for ADMS and AERMOD v. 04079. $PM_{10}$ results can be explained by the absence of the secondary contribution.
AERMOD beta version results have shown an hourly trend close to other models, especially with ADMS, although some anomalous behaviours are remarked: in particular we obtain different to zero concentrations at receptor, also when this is upwind respect the ring road.

Performance models for CO are evaluated on the basis of hourly concentration recorded by mobile laboratory. The results are summarized in table 4.

*Table 3. Statistics*

| **pollutant** | **model** | **min** | **mean** | **max** | **25°perc.** | **50°perc.** | **75°perc.** | **98°perc.** |
|---|---|---|---|---|---|---|---|---|
| CO | observed | 0.1 | 1.0 | 3.1 | 0.5 | 0.8 | 1.1 | 2.8 |
| | ADMS | 0.0 | 0.4 | 2.1 | 0.0 | 0.2 | 0.7 | 1.8 |
| | CALINE4 | 0.0 | 0.2 | 0.8 | 0.0 | 0.1 | 0.4 | 0.7 |
| | AERMOD v99351 | 0.0 | 0.2 | 1.2 | 0.0 | 0.0 | 0.2 | 0.9 |
| | AERMOD v04079 | 0.01 | 0.4 | 2.1 | 0.1 | 0.3 | 0.6 | 1.9 |
| | CALPUFF | 0.0 | 0.4 | 2.3 | 0.0 | 0.2 | 0.6 | 1.8 |
| C6H6 | observed | | *2.3* | | | | | |
| | ADMS | 0.0 | 5.4 | 28.8 | 0.0 | 2.1 | 8.6 | 23.9 |
| | CALINE4 | 0.0 | 2.5 | 11.2 | 0.0 | 1.1 | 4.8 | 9.7 |
| | AERMOD v99351 | 0.0 | 2.0 | 17.0 | 0.0 | 0.1 | 3.2 | 12.5 |
| | AERMOD v04079 | 0.1 | 5.4 | 29.2 | 1.3 | 3.6 | 7.3 | 24.6 |
| PM10 | observed | 17 | 48 | 77 | - | - | - | - |
| | ADMS | 0 | 10 | 48 | 0 | 4 | 16 | 45 |
| | CALINE4 | 0 | 5 | 23 | 0 | 1 | 8 | 21 |
| | AERMOD v04079 | 1 | 12 | 43 | 4 | 9 | 16 | 38 |

The normalised mean square NMSE error and the root mean square error RMSE have been calculated, both with and without the addition of the local background levels of CO. For

simplicity, the minimum value recorded by automatic analyser has been selected for this background level, which instead depends from the variability of the atmospheric dispersion conditions.
In general the models have a quite close mean error, probably due to insufficient emission and meteorological characterisation. Nevertheless, CALINE4 e AERMOD v. 99351 don't adequately simulate the higher concentration, as shown by NMSE values.

*Table 4. Model's performance for CO*

| model | correlation pred. vs obs. | BIAS | NMSE | RMSE | NMSE with background | RMSE with background |
|---|---|---|---|---|---|---|
| ADMS | 0.54 | -0.53 | 1.53 | 0.79 | 1.04 | 0.72 |
| CALINE4 | 0.50 | -0.78 | 5.64 | 0.97 | 3.03 | 0.89 |
| AERMOD v99351 | 0.57 | -0.79 | 6.01 | 0.93 | 3.13 | 0.78 |
| AERMOD v04079 | 0.48 | -0.53 | 1.51 | 0.79 | 1.04 | 0.73 |
| CALPUFF | 0.54 | -0.58 | 1.83 | 0.81 | 1.22 | 0.75 |

The comparison between predicted and observed benzene mean levels monitored with passive samplers is displayed in the Figure 3. In the ordinate axis the sites normal to the ring road are represented, from the farthest northern position (A3: 100 m far from route) to the farthest southern position (B3). AERMOD 04079, ADMS and CALPUFF show the overestimation of concentrations. The models a typical bell trend for mean concentration along the sampling sites, while passive samples show a flat trend.

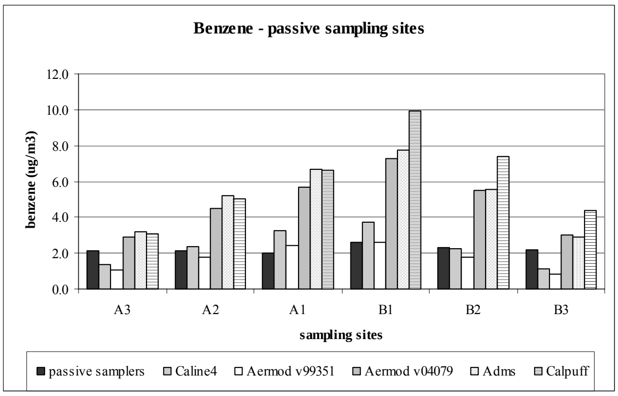



*Figure 3. Benzene prediction vs observation*

## CONCLUSIONS

In this work we assessed the suitability of models currently implemented in ARPAV to the estimation of direct contribution of urban sources to local levels of primary pollutants. Since stationary models are more and more often used in different emission scenarios and in political supporting decisions, it is important to study the outputs of modelling systems with regard to the emission and meteorological inputs available.
Since in many areas of the Veneto region calm wind conditions are frequent, the use of stationary models could be inconsistent. For this reason the comparison among different models presented here includes a non stationary model such us CALPUFF, even if it wasn't expressly meant for road sources. CALPUFF performances in our configuration have not showed significant improvements compared to stationary models.

Moreover, vertical dimension of volume sources to simulate the effect of traffic induced dispersion are critical for CALPUFF and AERMOD. Therefore configurations tested in these study need further investigation.
An inconsistency between model results and observed data for benzene has been outlined. We are then currently studying the improvement of the estimation of emissions of this pollutant.
None of the models tested in this study showed a major suitability, therefore further investigations are needed.

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