MODELLING EVALUATION OF EU ROAD TRAFFIC EMISSION STRATEGIES

Giovanna Finzi, **Veronica Gabusi**, **Marialuisa Volta** [1]

D.E.A., Università degli Studi di Brescia, Via Branze 38, I-25123 Brescia, Italy

Abstract: The comprehensive Gas Aerosol Modelling Evaluation System (GAMES) was used to investigate the impact of EU Directives on road traffic emissions scheduled for 2010 on photochemical pollution. The area under study is located in Northern Italy, where orographic features and the emissive mix represent a critical issue in ozone production and accumulation processes. The long-term period April-September 1996 was selected as the reference case, and an impact assessment simulation for the year 2010 was performed, including the future emission fields based on the current legislation. In order to evaluate the effectiveness of the EU road traffic abatement policy in Northern Italy, graphical indicators were computed and analysed.

Keywords: Air pollution, nonlinear systems, mathematical models, decision support systems, traffic control

1. INTRODUCTION

Tropospheric ozone is considered one of the most significant pollutant with respect to its potential impact on human health and natural ecosystems, in terms of critical episodes and long-term exposures. To identify and to implement ozone reduction strategies is a complex and difficult task; indeed, the formation and build up of ozone concentrations are consequent to a large number of photochemical non-linear reactions taking place in the atmosphere and involving temperature, humidity, solar radiation as well on the primary emissions of nitrogen oxides (NOx) and volatile organic compounds (VOC). Thus, the effectiveness of ozone abatement measures is consequent to a great number of variables involved in its production and accumulation. In this framework air quality modelling systems can and must play an essential role in air quality management, as suggested in Directive 1996/62/CE (Palacios *et al.*, 2002); in fact, they allow to study photochemical pollution and to analyse and assess appropriate emission reduction strategies.

Throughout Europe, a wide range of modelling studies were performed to examine the benefits of NOx versus VOC control policies by means of sensitivity modelling simulations, mainly aimed at investigating the ozone response to precursors control, focusing on local critical ozone episodes (Blanchard and Stoeckenius, 2001), (Palacios *et al.*, 2002) or on European scale (Simpson, 1995), (Zlatev *et al.*, 1996). Road transport is widely recognized to be a significant and an increasing source of photochemical pollution precursors, being one of the main sources of NOx emissions. In this framework, EU Directives in force up to 2010 ask for substantial NOx and VOC emission decreases. This study focuses on the photochemical

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pollution in the Po Valley region (Northern Italy). The ozone precursors emission reduction may improve or further deteriorate air quality, due to the emission mix and to the photochemical regime characterizing the area. In such domain the critical anthropogenic emissions, the frequent stagnating meteorological conditions and the Mediterranean solar radiation regularly cause high ozone level episodes, especially during summer months.

The seasonal impact of the EU Directive on road traffic emissions scheduled for 2010 was investigated as follows: (1) the summer season 1996, from April to September, was selected as the reference case; (2) the future emission scenario was assumed to be equal to the base-case one except for road traffic sources; (3) these emissions were evaluated assuming the fleet emission trend in accordance to the EU Directives implementation. This paper is organized as follows: the main features of the modelling system and the selected domain are presented in the first section; in the second one the emission field estimation procedure is illustrated. Finally, the impact simulations resulting from the EU Directive scheduled road traffic emissions scheduled for 2010 are presented and compared with the base scenario.

2. THE LONG-TERM MODELLING APPLICATION

2.1 The modelling system description

Air quality simulations were carried out by means of GAMES (Gas Aerosol Modelling Evaluation System) (Volta and Finzi, in press), that allows to perform long-term homogenous gas-phase and multi-phase simulations.

The gas-phase seasonal application includes the 3D meteorological processor CALMET (Scire *et al.*, 1990), the emission model POEM-PM (Carnevale *et al.*, in press) and the photochemical transport model CALGRID (Yamartino *et al.*, 1992) (Figure 1).

The diagnostic *meteorological pre-processor* CALMET provides (1) 3D wind and temperature fields, (2) turbulence parameters, merging background fields provided by regional model with measurements.

The *emission processor* POEM-PM was designed to produce present and alternative emission fields. It processes the CORINAIR database considering diffuse and main point sources from different activity sectors.

The *photochemical model* CALGRID is an Eulerian three-dimensional model. It implements an accurate advection-diffusion scheme in terrain following coordinates with vertical variable spacing; a resistance-based dry deposition algorithm takes into account pollutant properties, local meteorology and terrain features. The chemical module implements SAPRC-90 mechanism (Carter, 1990), including 54 chemical species with 129 reactions and the QSSA (Quasy Steady State Approximations) solver (Hessvedt *et al.*, 1978) for the integration of kinetic equations.

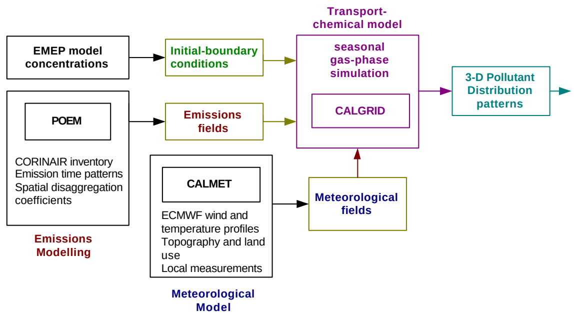


Fig. 1. Modelling system overview.

2.2 The modelling domain

Photochemical pollution in Northern Italy was investigated in recent years, either with experimental campaigns (Vecchi and Valli, 1999), (Neftel *et al.*, 2002) or by means of modelling studies, e.g. (Silibello *et al.*, 1998), (Gabusi and Volta, in press). In effect, although Italian cities are located in geographic positions characterized by very different climate and circulation features, the present understanding of photochemical pollution is strongly biased toward the Northern part of the country, and mainly focused on the Po Valley. The Po Valley is a mostly flat area extending 500 km from east to west, bounded north by the Alps and south by the Apennines. While, the southern part is an agricultural area, extending along the Po River, the central part is mainly urbanized. The Milan metropolitan area, in the western part of the basin, is, in fact, the most industrialized and inhabited area of Northern Italy, with a close road network. As for the meteorological characterization, the region exhibits frequent stagnant meteorological conditions associated with relatively high insolation: calms or weak winds occur almost 40% of the summer days. In the absence of prevailing synoptic weather systems, the atmospheric circulation is strongly influenced by the topography of the region that produces mountain-valley breezes, especially during summertime.

The selected area, 240×232 km^2 wide, includes the whole Lombardia Region and it was subdivided according to a grid system having 60 per 58 horizontal cells, with 4 km step size and 11 vertical layers of variable thickness (20, 45, 80, 130, 230, 400, 650, 1000, 1700, 2800 and 3900 m a.s.l.). Figure 2 shows the domain, together with its main orographic features and urban areas.

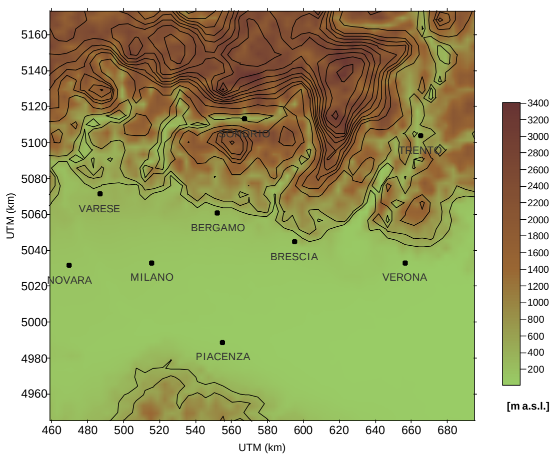


Fig. 2. The selected modelling domain.

3. EMISSION FIELD ESTIMATION

Emission fields used in these modelling applications were provided by POEM-PM model, recommended by the Italian National Environmental Agency (APAT) (Deserti *et al.*, 2001). POEM-PM implements an integrated top-down and bottom-up approach allowing the assessment of real and alternative emission scenarios, as well as the harmonization of non-homogenous emission data. It implements a NMVOC lumping algorithm for both lumped structure and molecule approach and provides emission fields suitable for mesoscale and local scale multiphase modelling application. The road transport, agriculture and biogenic emissions were estimated by means of a bottom-up approach while emissions of the other sectors were disaggregated, modulated and splitted on the basis of last available Italian CORINAIR database (1994). In particular, the road transport emissions are obtained by the following procedure:

- The national vehicle fleet (number of vehicles and age distribution) is split in the CORINAIR road traffic categories. The driving condition parameters (annual mileage per vehicle class, annual mileage per road class, average vehicle speed) are estimated on the basis of the recorded data.
- The yearly national emissions were computed for the estimated vehicle fleet by means of the software COPERT III (Kouridis *et al.*, 2000); this model approach is based on four main information classes: the fuel consumption (per fuel type and per vehicle category), the vehicle park (number of vehicles per vehicle category, age distribution of the vehicle park per vehicle category), the driving conditions (annual mileage per vehicle class, annual mileage per road class, average speed of vehicles) and the emission factors (per vehicle class, per production year, per road class). The model includes the emission factors for future EU regulations scheduled up to 2010.
- The emission scenarios are spatially and temporally resolved by the POEM-PM. The spatial distribution is supported by the output of a traffic model, starting from the regional road transport network and the traffic load data.

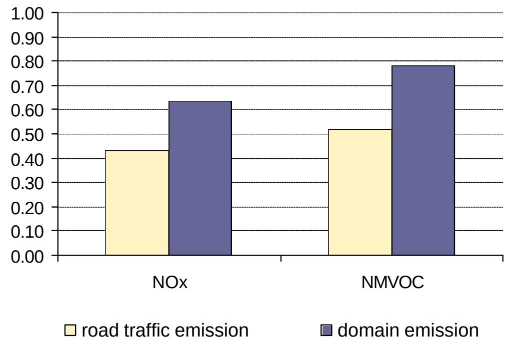


Fig. 3. Emission ratio between the 2010 and the base case scenario.

Table 1 shows the diffuse annual emission in the simulation domain. Analysing such data, it can be noticed that the transport is the main source of NOx emissions, representing 74% of total diffuse emissions, as well as for CO (63%) and NMVOC (41%).

Table 1. Total diffuse emissions over the domain [%].

Activity	NO_X	CO	SO2	NMVOC
Industry	13.03	9.97	55,91	7.45
Solvents	-	-	-	39.06
Transport	74.24	63.17	38.54	40.67
Waste	2.84	36.61	5.55	5.95
Agriculture	0.02	0.24	-	0.05
Biogenic	9.86	-	-	6.83

The 2010 emission scenario was assumed to be the base-case except for road traffic sources, assigned in accordance to the EU Directives implementation. Following the above-mentioned procedure, the first step implies the forecasting of the vehicle fleet up to 2010. The procedure consists of the national fleet growth evaluation and the estimation of the vehicle age trends, as described in (Volta and Finzi, 1999). Such estimates indicate that present EU Directives on road traffic emissions will yield reductions of about 60% on NOx and 50% on NMVOC (Figure 3). As a consequence of the emission sectors distribution overall the domain, it comes out an estimated total reduction amount of about 40% for NOx and 20% for NMVOC.

4. AIR QUALITY ASSESSMENT SIMULATIONS

4.1 The base-case simulation

GAMES system was run for the 1996 base case. The model skill in simulating the long-term dynamics of pollutants in the atmosphere was assessed by means of performance indicators and graphical tools. The estimates were computed for a restricted number of monitoring stations, selected as representative of different orographic and emissive features (Gabusi *et al.*, 2003), (Pirovano *et al.*, 2004). The evaluation was performed taking into account (1) US EPA recommandations (US Environmental Protection Agency, 1991), (2) the recent European Directive (European Communities, 2002) and (3) other classical statistical indices and parameters, as the correlation coefficient and the root mean square error.

For the 1996 seasonal simulation, the performance assessment pointed out that the modelling system is able to reproduce the overall temporal and spatial behaviours of measured ozone and NO_2 concentrations meeting US-EPA and EU requirements (Gabusi *et al.*, 2003), (Pirovano *et al.*, 2004), (Gabusi and Volta, in press).

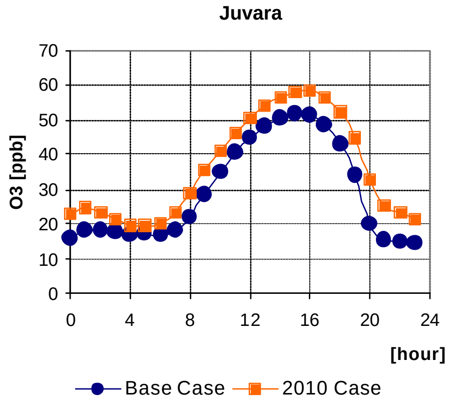
4.2 2010 emission scenario impact assessment

GAMES was run for the 2010 Scenario using the 1996 meteorological fields and boundary conditions, while the emission fields were estimated as described above. The modelling simulations results over long-term periods were summarized by means of proper seasonal indicators, as mean ozone and AOT40 patterns.

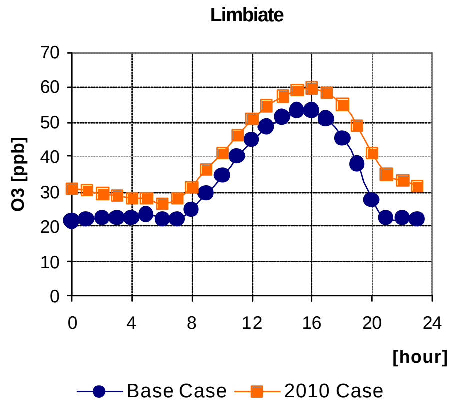
A first evaluation of emission abatement effects was carried out on the simulated mean daily pattern, computed by averaging hourly concentrations over the 6-months period, in correspondence of two monitoring stations (see Figure 4). Both stations are located in the Milan metropolitan area, characterized by high traffic emissions. As for the 2010 scenario, it results that the estimated ozone behaviours in terms of trends are similar for both stations. The EU traffic emission strategies, mainly focused on reduction NOx emissions, lead an increase of ozone concentrations in the main metropolitan area.

To gain further insight into the effective impact of this emission abatement strategy, the spatial distribution of ozone concentrations inside the domain was analysed. Figure 5 shows the estimated differences in seasonal ozone mean concentrations between 2010 and 1996 simulated scenarios (ranging from -15% to 25%). As highlighted from the map, the ozone increases over the Po Valley, where most metropolitan areas and road networks are located. In the Milan surrounding areas, the mean value rises up to 25% with respect to the base-case value. On the other hand, in the northern part of the domain, corresponding to the Alpine relieves, the model estimates a decrease up to 15% in the ozone mean value. Such analysis confirms that the Po Valley is a VOC sensitive area, as already pointed out (Gabusi and Volta, in press); this means that ozone concentrations increase when NOx emissions decrease (Sillman, 1999).

Finally, Figure 6 illustrates the simulated changes in AOT40 levels for estimated emission reductions. The map presents a distribution pattern similar to the preceding mean values map; in this case, the percentage differences between the two are higher and range from -60% to 90%. Again, the AOT40 estimated features evidences the highest increase in the Po Valley area.



(a) Juvara site (Milan city).



(b) Limbiate site (metropolitan area).

Fig. 4. Ozone mean day pattern for two stations.

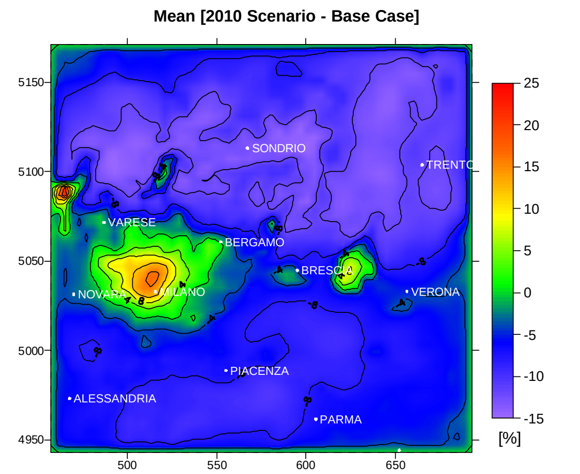


Fig. 5. Calculated differences [%] of ozone mean value between 2010 emission scenario and the reference case.

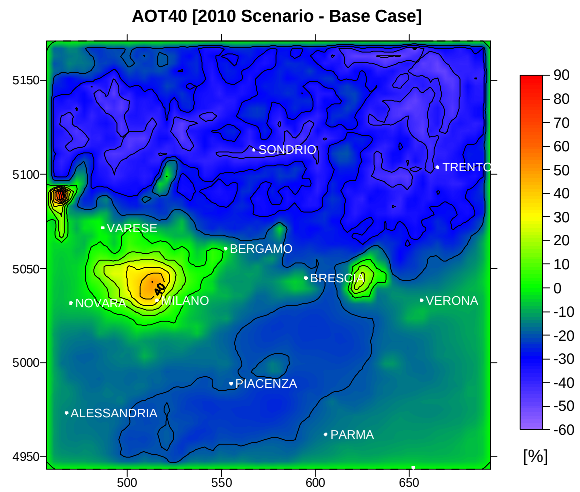


Fig. 6. Estimated changes [%] in AOT40 fields for the summer period April - September 1996.

4.3 Statistical significance evaluation

In order to evaluate the statistical significance of the alternative emission scenario impact with respect to the base case one, a Student's t-Test (95% confidence level) was performed. Boundary conditions were left out from such analysis, as they were assumed the same in the two cases. Furthermore, the domain cells were grouped (16×16 km^2), in order to perform the test for contiguous areas inside the domain.

Figure 7 shows the spatial distribution of the estimated difference between the simulated mean ozone concentrations in the two examined scenarios. It appears that the 2010 scenario is significantly different from the 1996 summer season over a large part of the domain; darker areas (green or red) point out a statistical significant difference (95% confidence level) between the estimated 2010 scenario and the base case, in terms of an ozone concentration increase (red area) or decrease (green area) respectively.

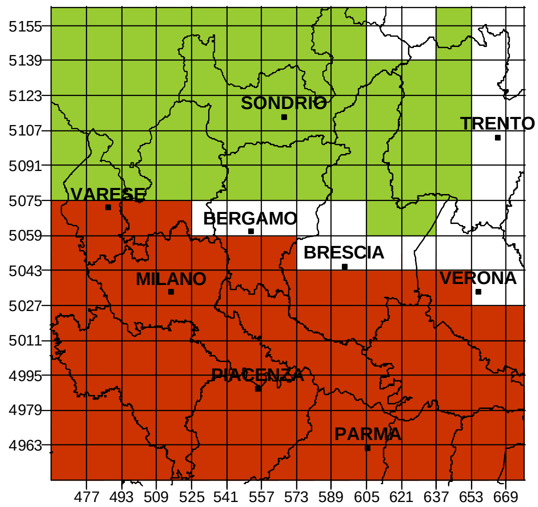


Fig. 7. Spatial distribution of the statistical difference between the 2010 scenario and the base case.

5. CONCLUSIONS

GAMES modelling system was applied to a seasonal simulation (April-September 1996) over Lombardia Region (Northern Italy) in order to perform long-term analysis of photochemical pollution in the selected domain. Since the road traffic was estimated to be the main source of pollutants in the area, the impact of the EU Directive on road traffic emissions scheduled up to 2010 was investigated on the area, providing a decision support for local Air Quality Authorities in selecting effective emission reduction strategies.

The modelling evaluation of the 2010 scenario has pointed out the following evidences.

(1) Estimated total emission reduction results of about 40% for NOx and 20% for NMVOC, with even higher abatement rates in urban areas.
(2) Estimated 2010 scenario results to be significantly different from the 1996 base case, assessing the results consistency.
(3) As a consequence of the prevailing VOC-limited photochemical behaviour of the domain, the EU pollution abatement measures for road traffic emissions alone seem to be inadequate or at least not sufficient for the complex considered domain.

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