

Photochemical models application in the Po valley (Italy): critical review and intercomparison

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1 Introduction

The development of the national environmental information system on the atmospheric environment, analogously to the European Topic Center Air and Climate Change (ETC-ACC) of the EIONET network, is the main goal of the National Topic Center on Atmosphere, Climate and Air Emission (CTN-ACE) funded by the Italian National Environmental Protection Agency. The activities of CTN-ACE involve regional environmental protection agencies as well as national research institutions. Since the assessment of the air quality in urban areas relies both on monitoring data and modeling estimates, as stated by the EU framework directive 96/62, one task of CTN-ACE is to harmonize, as far as it is possible, modeling approaches in order to establish proper source-receptor relationships, to critically review the models commonly used and to offer reliable information to the decision makers concerning the estimation of the effects of different emission control strategies on the air quality. To meet this goal, different modeling applications have been reviewed considering adopted spatial and temporal scales, source and emission characteristics, orography complexity and characteristic meteorological conditions. Then the category of dispersion models most suitable for each scenario was identified, and a survey of the requirements, limits, expected results and examples of applications was carried out. As an example, hereafter are reported two application of different modeling to two ozone episodes occurred during summer 1996 in Northern Italy.

2 A review of photochemical models applications in Italy

The review has been realized delivering a questionnaire to a large number of researchers and institutions in Italy. Twenty-four groups answered to the questionnaire, describing their experience. The screening of results evidenced that the larger number of investigations have been performed in Northern Italy simulating ozone episodes occurred in Lombardia and Emilia Romagna. Other studies have been conducted in Liguria, Lazio, Piemonte, Toscana, Puglia and Campania region, nevertheless most of them are still preliminary. Some Regions are also applying photochemical models in the frame of Regional Air Quality Assessment and Planning, but conclusive studies are still unavailable for policy making. CALGRID is the more widely photochemical code used in Italy, UAM and STEM models have been also applied together with non reactive dispersion models.

The critical aspects of these studies are generally related to the lack of model validation and verification, suitable emission data and good quality meteorological information. To provide proper data to be used to verify and to validate models results, experimental campaigns have been conducted in Lombardia (subprojects LOOP and SATURN in the frame of EUROTRAC-2 project) and in Emilia Romagna (MOTAP Ozone Monitoring in the Po Valley, performed by regional environmental protection agencies) regions in Po Valley (Northern Italy). This basin is a flat region surrounded by Alpine chain in the north and north – west, by Apennines in the south and by Adriatic Sea on the

eastern boundary. The complex morphological structure of the region is characterized by many small valleys leading into the flat land and by a land-sea contrast on the eastern boundary of the plain. The whole area is densely populated and heavily industrialized and during sunny summer days, when the “chemical air mass” becomes stagnant under conditions of low wind speed, ozone pollution episodes often occurs and ozone reference levels are exceeded. To simulate such situations, two modeling systems have been exercised in Lombardia and Emilia Romagna, to verify models and their capability to reproduce ozone levels in such areas. The Lombardia domain is located near the northern border of the basin and includes the central alps, while the Emilia Romagna one is located in the south eastern part of the basin and includes part of the Apennine chain (Figure 1).

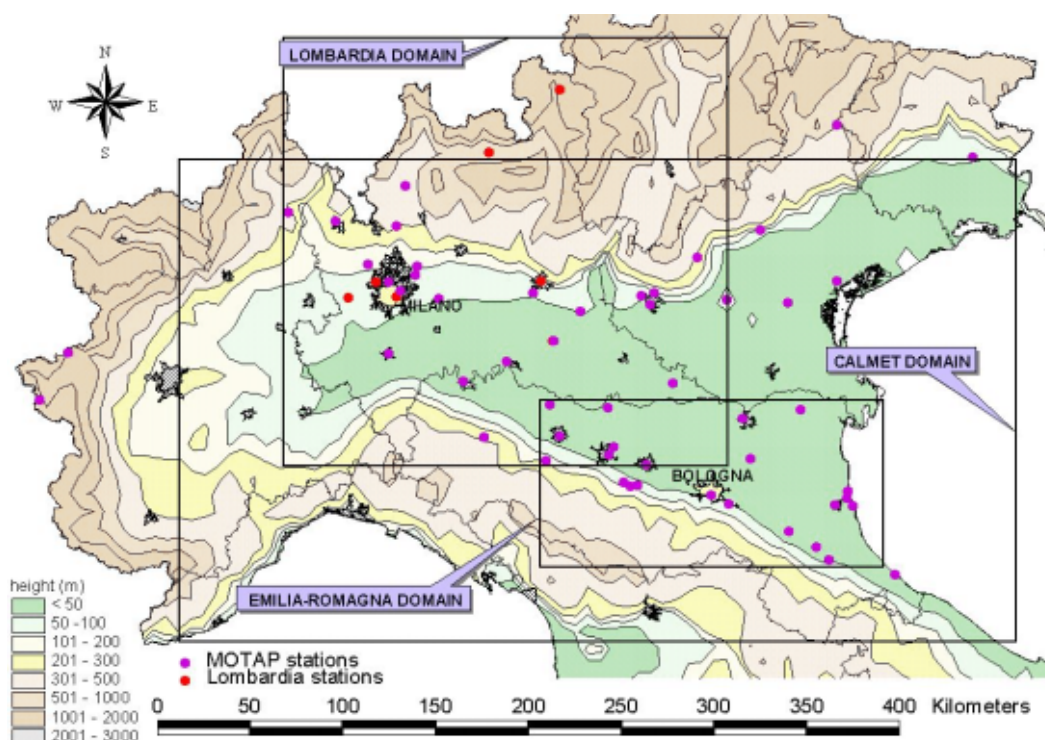


Figure 1 Orography of Po Valley (m above m.s.l.) and Lombardia and Emilia Romagna studied areas. Location of monitoring stations are indicated. The large frame indicates the domain where the CALMET meteorological pre processor runs on a daily base (available from ARPA Emilia Romagna meteorological service www.smr.arpa.emr.it).

3 Lombardia modeling system

The modeling system used to simulate the ozone episode include the emission pre-processor POEM (Pollutant Emission Model; Volta and Finzi, 1999), two meteorological diagnostic model: MINERVE (Geai, 1987) and CALMET (Scire et al., 1999) and two photochemical Eulerian dispersion models: CALGRID (Yamartino *et al.*, 1992) and a new version of STEM-II (Carmichael *et al.*, 1991) model that includes an interface with the FCM chemical interpreter (Kumar *et al.*, 1995). The last model is interfaced with different gas-phase chemical mechanism, such as CBM-IV, RADM-II and SAPRC-90/97/99, an aqueous phase chemistry mechanism and an aerosol module. Thanks to these capabilities, the last version of STEM model represent an useful tool to investigate chemical-physical processes relevant in Po valley such as cloud and fog chemistry (Mircea *et al.*, 2001) and photooxidant and secondary aerosol formation processes.

4 Emilia Romagna modeling system

The Emilia Romagna Environmental Agency (ARPA), in close co-operation with local authorities, is performing the design of an Integrated Operational Decision Support System to predict and simulate air pollution. The modeling system uses CALGRID models and the CALMET meteorological preprocessor coupled with the meso-scale Limited Area Model model LAMBO (Paccagnella *et al.*, 1994). CALMET runs on a daily base in the Po valley basin using ground and upper air meteorological stations data to provide high resolution fields over the area (Deserti *et al.*, 2000).

5 Models results

To compare the response of Lombardia and Emilia Romagna modeling systems to different emission scenarios, a simulation of two ozone episodes, occurred during 1996 summer period, has been performed. The Lombardia modeling system described above has been applied to the June 1996 5th - 7th, summer smog episode reported as one of the most widespread in Western Europe (de Leeuw *et al.*, 1998). The Emilia Romagna modeling system was applied to simulate the July 1996, 10th - 13th ozone episode, occurred during the intensive observation period of the MOTAP project (Deserti *et al.*, 1998). The results of the two simulations are shortly presented and discussed.

5.1 June episode simulation (Lombardia)

CALGRID and STEM-FCM models were used to simulate the transport and the chemical behavior of pollutants in the studied area (Fig. 1). Both models use same accurate advection-diffusion scheme, in terrain-following coordinates with variable vertical spacing, an analogue resistance-based dry deposition algorithm, taking into account pollutant properties and local meteorology and terrain features. The detailed gas phase SAPRC-90 chemical mechanism (Carter, 1990) was used to derive the lumped versions implemented in the models.

The domain considered for the modeling application (240x232 km², fig. 1) is quite heterogeneous, including several cities (Milano, Brescia and others), rural areas in the Po Valley (southern part of the domain), the Central Alps (reaching 4000 m) and portions of Southern Switzerland (northern part of the domain). The area was subdivided into a 60x58 cells horizontal grid system, with a resolution of 4 km and 11 vertical layers of variable thickness (faces were set to 20, 45, 80, 130, 230, 400, 650, 1000, 1700, 2800 and 3900 m above ground-level). The emission processor POEM was used to generate hourly emission fields for the selected episode. POEM relies on a bottom-up approach for road transport, agriculture and biogenic sectors and on a top-down spatial disaggregation of CORINAIR data for all the other activity sectors. POEM perform also the temporal disaggregation of estimated emissions and the speciation of VOC emissions in the lumped classes of SAPRC-90. Meteorological fields were provided by merging analyzed wind and temperature fields, from the ECMWF model, with experimental data by using MINERVE and CALMET models as documented in Pirovano *et al.* (1999). Boundary layer concentrations were assigned on the basis of the 6-hourly fields computed by EMEP ozone model (Simpson, 1992), assuming a well-mixed PBL surmounted by an exponential decrease for all species, except for ozone where a constant free atmosphere background level of 60 ppb was assumed above the 3000 m level. Initial concentration fields were also prepared on the basis of EMEP fields integrated with experimental data provided by the regional air quality network.

In figure 2 is presented the comparison between observed and predicted ozone concentrations at some stations confirming the capability of the system to reproduce observed daily patterns.

5.2 July episode simulation (Emilia Romagna)

The Emilia Romagna modeling system described above was applied to simulate the dynamics of an observed ozone episode for which a complete data set is available. The episode simulated occurred in

July, 10th – 13th 1996, during the intensive observation period of the MOTAP project. The domain considered for the modeling application is of 185x90 km² large, with an horizontal resolution of 5 km spacing and eleven vertical levels up to 5000 m. The northern part of the model domain for the simulation is located in the flat Po-Valley and is bounded by the Apennine mountain chain in the South and West, and by the Adriatic Sea in the East.

The emission inventory is based on the CORINAIR data-base and has been adapted spatially and temporarily for the species required by the CALGRID photochemical mechanism SAPRC-90. Anthropogenic emission sources are concentrated mainly in a heavily industrialized area near the coast, in urban areas along the mountain chain and along highways, crossing the domain from the north-west corner to the south-east and from north to south. Natural emissions are distributed in the mountain region and in the extended agricultural areas in the flat. CALMET meteorological pre-processor was used to interpolate surface and upper-air station data and to calculate boundary layer turbulence and stability parameters in order to get a complete three dimensional meteorological field. To increase the quality of the derived meteorological fields, data include ordinarily SYNOP and radio-sounding data and all data from local network monitoring stations belonging to the Regional Meteorological Service. A semi-empirical model, based on air quality data from MOTAP experimental campaigns, was used to simulate initial and boundary conditions. Finally, CALGRID was used to predict the hourly, three-dimensional concentration fields for ozone, nitrogen oxides and various volatile organic compounds for the July 1996 episode. Verification with data (see Figure 3) show the capability of the system to satisfactorily reproduce the ozone distribution in the domain and peak values observed near the main urban agglomerates. Also the daily cycle and the peak-concentrations are well reproduced by the simulation. Moreover wind field analysis has shown a slow south - easterly flow during the episode explaining the high sensitivity of computed values on initial and boundary conditions.

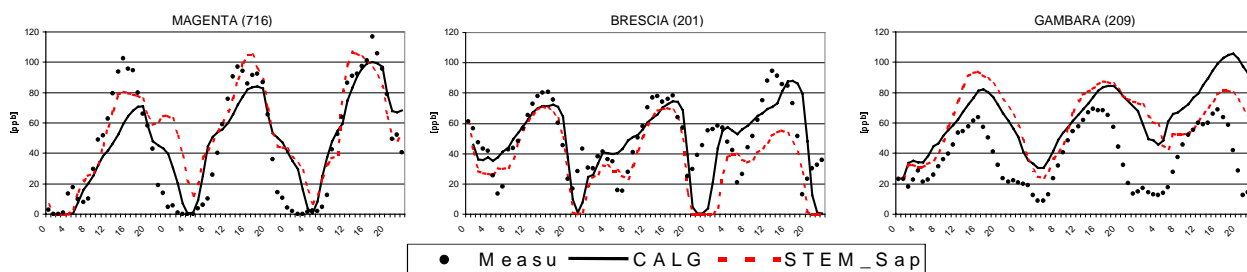


Figure 2 Comparison between measured O₃ concentrations and values computed by CALGRID (black) and STEM-FCM/ SAPRC-90 (dashed red) models; time series start on 5.6.1996, at 1 UTC.

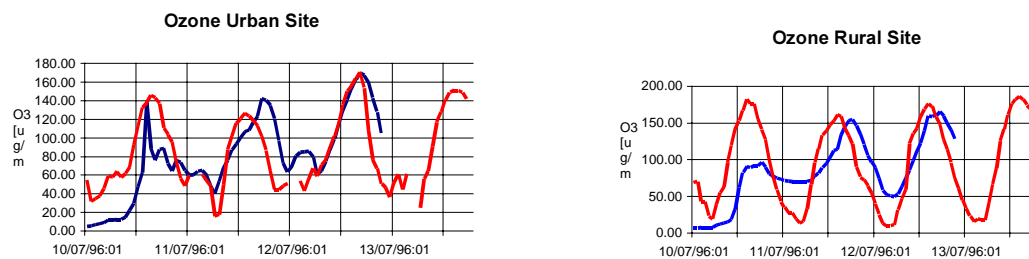


Figure 3 Comparison between measured O₃ concentrations (red) and values computed by CALGRID (blue) model at urban and rural sites of the Emilia – Romagna region.

6 Conclusions

Results obtained evidenced that the July ozone episode (simulated in the Emilia Romagna domain) was strongly influenced, under a slow south - easterly atmospheric circulation, by ozone and ozone precursors transport through the model domain boundaries. On the other hand the June episode (simulated in the Lombardia domain) under typical air mass stagnation conditions, is dominated by precursors emissions into the domain. Comparison between the total emissions amount used to simulate the two episodes reveal that in Lombardia, emissions are from 2 to 4 times larger than in Emilia Romagna for most of the chemical species considered. Moreover Emilia Romagna emissions are mainly located in urban and industrial areas. This reveal a probable underestimation of rural and biogenic emissions in Emilia Romagna.

The comparison of the two modeling exercises underlies the sensitivity of the model simulation to emission inventory and meteorological input characteristics. These results need of further investigations in order to properly set up emission control strategies in the two areas in order to reduce ozone levels.

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