A Comprehensive Modelling System for Photochemical Pollution Control in Metropolitan Areas

A contribution to subproject SATURN

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Summary

Different integrated modelling systems have been designed and applied to Lombardia region, a densely inhabited and industrialised area, located in the Po Valley (Northern Italy), where frequent ozone episodes occur mainly during summer months. The systems are devoted to support air quality plans and management. Mainly two classes of models were taken into account.

The first one integrates 3D eulerian photochemical simulation models (STEM-FCM, CALGRID-FCM or UAM-V), meteorological (CALMET, RAMS) and emission pre-processors (POEM, POEM-PM, TESEA). The systems have been applied over Lombardia region domain to simulate two ozone episodes (5-7 June 1996 and 1-5 June 1998) and a seasonal period (May-September 1996). The model POEM-PM has been designed to provide particulate matter emission fields; it estimates the chemical composition and the size distribution of primary particles. The model also allows the VOC splitting and lumping in SAPRC90, SAPRC97 and CB-IV classes.

The second class integrates stochastic models and soft computing techniques to set up real time predictors. The alarm system has been tested for the metropolitan areas of Brescia and Milan.

Two experimental campaign, especially devoted to particulate matter analysis, were performed in Milan urban area (Piazza Carbonari) during winter and summer 2001.

Aim of the research

Final goals of the project are:

- to set up a *decision support system* allowing the urban and regional environmental managers to examine alternative emission scenarios, in order to delineate proper photochemical pollutant abatement strategies;
- to perform experimental activity focused on investigation about *urban gas and aerosol* chemical composition and related aerodynamic distribution;
- to set up urban pollutants *forecast and alarm systems.*

Starting from the implementation and validation on Milan and Brescia metropolitan areas, the main objective of the research is to assign the general methodological and input/output requirements of the system, in view of its possible application to other urban areas in collaboration with local and national environmental agencies.

Activities during the year

The activities performed by the research operational units are the following:

Mesoscale photochemical modelling

- STEM-FCM modelling system has been applied over Lombardia region domain (episode from 5 to 7 June 1996) in order to evaluate the influence of different meteorological drivers on concentrations. More precisely the sensitivity analysis has been carried out comparing CALMET diagnostic model with RAMS prognostic model.

- CALGRID model has been modified to allow the user for changes in chemical schemes; this goal has been obtained implementing Flexible Chemical Mechanism (FCM) interface. So the implemented chemical mechanisms are:
  - SAPRC-90, including 54 chemical species with 129 reactions and the QSSA solver for the integration of kinetic equations.
  - SAPRC-97 considering 82 chemical species and 184 reactions.
  - COCOH-97 similar to SAPRC-97, but considering also condensable organic compounds yields and 2 dummy species (NH_3 and HCl).
  - Carbon Bond IV with 37 chemical species and 78 reactions.

Original CALGRID integration solver (QSSA) has been substituted by the IEH solver, as FCM makes it possible to distinguish among fast and slow reacting species. The episode chosen to be simulated as base-case for Lombardia is the intense IOP detected from 1 to 5 June 1998 during the PIPAPO measurements campaign, performed also in the frame of EUROTRAC-2 Project. During the selected period, values exceeding the health protection threshold have been recorded in many stations of the regional network.

Urban air quality impact simulations have been performed with the four chemical mechanisms implemented for the base case meteorological and emission fields in order to point out the differences between the schemes themselves. All mechanisms give good agreement between the ozone simulated concentrations and the experimental data, both in urban and rural sites (see two examples in Figure 1).

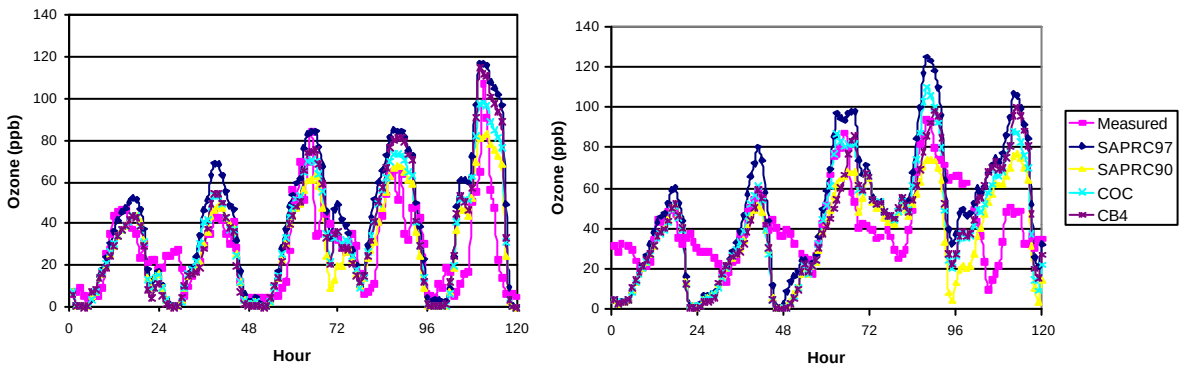

Figure 1. O_3 concentration for Milano (urban site) and Erba (rural site).

- POEM, a model for the evaluation of gas phase emissions in the Lombardia region (Northern Italy), has been integrated with a module to provide particulate matter emission fields from road traffic. The new model, POEM-PM, estimates the particulate emission fields by means of a *bottom-up* approach following this procedure:
  i. the vehicle fleet (number of vehicle and age distribution) is split in the CORINAIR road traffic categories;
  ii. the yearly national emissions are computed for the estimated vehicle fleet by means of the COPERT III;
  iii. emission factors, in terms of size resolved and chemically speciated particulate matter, are estimated (per vehicle class, per production year, per road class and per fuel type) on the basis of experimental data provided by EURON-Agip Petroli research laboratory;
  iv. the emission scenarios, spatially and temporally resolved, are provided by the emission model POEM-PM;
  v. POEM-PM estimates the chemical composition and the size distribution of primary particles. The model, implementing the FCM module, can alternatively provide the VOC splitting and lumping in SAPRC90, SAPRC97 and CB-IV classes.

Present and alternative emission fields for particulate matter have been estimated and designed for the Lombardia region by means of this integrated model.

- A proposal of air quality alarm system has been designed by means of different forecast modelling methodologies (*non-stationary/non-linear grey box, neural network* and *neuro-fuzzy* predictors). The metropolitan areas of Brescia and Milan have been considered as case study. The cities are characterised both by high industrial, urban and traffic emissions and continental climate. The examined data records consist of O_3, CO, NO and NO_2 hourly concentrations measured by the urban air quality monitoring stations. Local monitored temperature and forecast data are available from the Meteorological Office. The models were identified on 1994-1999 summer season data (from May to September) and validated on the same season of 2000. The performance of different predictors to foresee if the O_3 concentration will overcome an assigned threshold has been evaluated in terms of skill parameters, defined by the European Environment Agency.

Experimental campaigns

Two experimental campaigns (winter and summer 2001) were performed at Milan – Piazza Carbonari especially devoted to particulate matter analysis (PM10, PM2.5, HNO_3, HNO_2, particulate nitrate and sulphate).

Principal results

UAM-V sensitivity analysis was performed on the Milan case (2-5- June 1998). Transport from boundaries was changed setting up new boundary conditions for UAM-V simulation on Milan area, extracting pollutants flux from the CALGRID regional simulation (*nested procedure*); finally results were compared. Boundary conditions for UAM-V simulation, in the inner domain, have been firstly set to constant values, both in time and space, for almost all compounds. Only ozone concentrations have been assumed to increase from 30 to 40 ppb in the last two days of the simulated period. A second UAM-V run has been performed using CALGRID regional simulation results, providing temporally and spatially variable boundary conditions for the smaller domain, enclosed in the regional one and centred on the city of Milan. As for organic compounds, they were lumped according to

SAPRC scheme (in fact, no univocal correspondence to CB-IV is commonly established); therefore assumptions where made on VOC composition in order to assign their respective attribution to similar species in the two schemes. UAM-V simulation with nested boundary conditions, rather than with constant transport, show ozone levels closer to measured data, confirming that variable boundary conditions are required to properly simulate ozone episodes. In general UAM-V results have been affected by an incorrect parameterisation of vertical diffusion (K_v) which has not been derived by a dedicated meteo pre-processor module. This is particularly true at night time when K_v values have a stronger effect on ozone predictions.

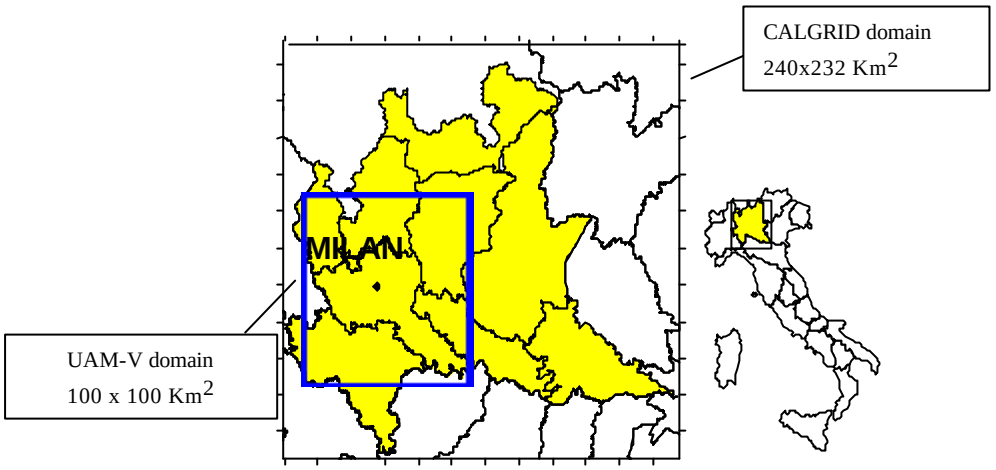

Figure 2. Simulation domains

Main conclusions

Starting from the high interest related to Northern Italy photochemical pollution, due to geographical, meteorological and emission complexity of the area, a strong need for co-ordination among the research and local agencies teams was once more evidenced. A cross comparison and validation of all the studies performed on Lombardia region in the frame of EUROTRAC-2 could effectively properly finalise the final report of the project.

Aims for the coming year

- Processing of future sustainable emission abatement scenarios.
- Comparing the different chemical mechanisms to test sensitivity to the emission fields; evaluating chemical indicators and performing a photochemical analysis of the domain.
- Implementing the aerosol processor MAPS in the photochemical model to evaluate the aerosol role in ozone photochemistry.
- Performing long term simulation of photochemical pollution over Lombardia region, with the following particular aims:
  - evaluation of long term exposure indexes and comparison with observations;
  - CALGRID, STEM II models inter-comparison;
  - sensitivity analysis.

Acknowledgements

This research was supported by MURST, Provincia di Brescia, ANPA (Italian National Environmental Agency), CESI and Agip Petroli-ENI.