A Tool to Evaluate the Air Quality Impact for Industrial Plants: an Application over the Madrid Area

R. San José, J. L. Pérez, F. Camacho, R. Barquín, J. Blanco[1] and R.M. González[2]

[1]*Environmental Software and Modelling Group, Computer Science School, Technical University of Madrid, Campus de Montegancedo, Boadilla del Monte 28660 Madrid (Spain). roberto@fi.upm.es, http://artico.lma.fi.upm.es*

[2]*Department of Geophysics and Meteorology, Faculty of Physics, Universidad Complutense de Madrid, Ciudad Universitaria 28040 Madrid (Spain)*

Abstract

The air quality impact of the industrial emissions is one of the most important areas of research in the last years not only because of the progressive public interest on environmental issues but also from the industrial approach. The interest of knowing the exact and detailed portion of different air concentrations in the area where an industrial plant is located in real-time and in forecasting mode opens a considerable number of possibilities which are useful for the public, environmental authorities and industrial managers.

In this contribution we will show the performance of a mathematical / software tool which is used to forecast the air quality impact of an industrial source (virtual source in this example) over the Madrid domain. We have developed an expert system which is used as a visual and managing interface for presenting the information to the industrial manager almost on real-time and based on the results of the simulation of the mathematical model. Two different environmental modelling systems have been used: the OPANA model as representative of the second generation of air quality models and the MM5 (PSU/NCAR) mesoscale meteorological model and the CMAQ (EPA, Community Multiscale Air Quality Modelling System) as representative of the third generation and state-of-the-art of the environmental air quality models.

We have used an industrial plant located at the north part of the Madrid city. This industrial plant emits SO2, NOx and VOC's. We have investigated the effect on NO2, NO, SO2, CO and O3 air concentrations over the whole area for the test period of February 4-8, 2002 as a preliminary analysis. Results show important differences on air concentrations, particularly for those cells located in the predominant wind direction during the simulation period and also for ozone and reactive primary pollutants. The process and analysis suggests that the visualization and analysis capabilities of the post-process study are essential for an improving of the industrial management decision processes. The complexity of the post-process expert system is important since the number of variables and the size of the output files are on the order of several Gbytes.

Introduction

The present and future industrial plants are becoming cleaner than the old industrial plants in developing countries. The need to evaluate both over the actual industrial plants and also over the future construction of industrial plants the air quality impact over the surrounding area is an important issue in particular for the future EU Directives which will impose more severe limits not to be exceeded over short and long period of times. The industrial manager needs to know on real-time and particularly under forecasting scenarios what will be the impact of his/her industrial plant over the surrounding areas and also he/she would like to know, at any time, the percentage of the air pollution concentrations – forecasted or actually measured by the municipal and regional monitoring station networks – which can be assigned to the emissions of his/her industrial plant.

In order to fulfil above requirements we are building a tool – into TEAP-EUREKA project – which provides the required information and it is served to the industrial manager in understandable and reliable form. The use of complex three dimensional Eulerian air quality modelling systems (AQMS) is a mandate in this type of applications due to the detailed information demand which is implied on this task. In this contribution, we will show results for a test experiment over Madrid domain by using an industrial plant located at the north part of Madrid model domain. We have used two different air quality modelling systems: OPANA and MM5-CMAQ.

OPANA model stands for Operational Atmospheric Numerical pollution model for urban and regional areas and was developed at the middle of the 90's by the Environmental Software and modeling Group at the Computer Science School of the Technical University of Madrid (UPM) based on the MEMO model developed in the University of Karlsruhe (Germany) in 1989 and updated on 1995, for non-hydrostatic three dimensional mesoscale meteorological modeling and SMVGEAR model for chemistry transformations based on the CBM-IV mechanism and the GEAR implicit numerical technique developed at University of Los Angeles (USA) in 1994. The OPANA model has been used (different versions) for simulating the atmospheric flow – and the pollutant concentrations – over cities and regions in different EU funded projects such as EMMA (1996-1998), EQUAL (1998 – 2001), APNEE (2000-2001). In these cases and others the model has become an operational tool for several cities such as Leicester (United Kingdom), Bilbao (Spain), Madrid (Spain), Asturias region (North of Spain) and Quito (Ecuador, BID, 2000). In all these cases the model continue to operate under daily basis and simulates the atmospheric flow in a three dimensional framework. The OPANA model, however, is a limited area model – which means that the model domain is limited by the earth curvature – and the cloud chemistry and particulate matter is not included (aerosol and aqueous chemistry).

MM5-CMAQ is a representative of the last generation of AQMS (third generation) developed by EPA (USA) in 2000. The model uses a full modular stratucture with the last advances on computer programming (FORTRAN-95). In essence many of the features of MM5-CMAQ are similar to OPANA but the programming and modularity is more advanced. MM5-CMAQ is not a limited area model and it can run over large domains (even at global level although a CMAQ global version is not existing yet). The model domains are obviously closely related to model forecast horizon so that the nesting capability (in a similar way that it was done in OPANA) plays an essential role to have reliable simulations over city and regional domains. Another representatives of third generation of AQMS are CAMx (Environ Co., USA) and EURAD (European Ford Research Group and university of Cologne (Germany).

In both cases and in all Eulerian models, the input datasets are key elements to work down to have reliable and accurate simulations. These datasets are: DEM (Digital elevation model), Land use data (usually satellite data, AVHRR/NOAA, Landsat, Spot, etc.), Initial and boundary meteorological conditions, initial and boundary air concentration profiles and finally, emission data sets. The emission datasets are usually the bottle neck on this type of applications since the uncertainty involved is important. In spite of this limitation, the TEAP tool extract the most important benefits from the relative difference between a simulation with full emission inventory and a second simulation with an emission inventory *without* the industrial plant to be studied.

Experiment

We have implemented the MM5-CMAQ modelling system in a nesting architecture. The MM5 Mesoscale Meteorological Model (PSU/NCAR) and the Community Multiscale Air Quality Model (CMAQ) [1] from EPA (USA) (third generation of air quality modelling systems) are used as mainframe platform. The MM5 is built over a mother domain with 36 x 36 grid cells (81 km spatial resolution) and 23 vertical levels. This makes a domain of 2916 x 2916 km. The nesting MM5 level 1 model domain is built over a 69 x 66 grid cells (27 km spatial resolution) and 23 vertical levels, which makes a model domain of 1863 s 1782 km centred over the Iberian Peninsula. CMAQ model domains are 30 x 30 grid cells for mother domain and 63 x 60 over the nesting level 1 model domain. CMAQ mother domain lower left corner is located at (-1215000 m, -1215000 m) at the reference locations (-3.5W, 40N) and the first and second standard parallels (30N, 60N). The CMAQ nesting level 1 lower left corner is located at (-891000, -810000) with the same reference locations. The 9 km MM5 spatial resolution model domain has 54 x 54 grid cells, the 3 km MM5 spatial resolution model domain has 33 x 39 grid cells and finally the 1 km MM5 spatial resolution model domain has 30 x 30 grid cells. The corresponding CMAQ model domains are: 48 x 48 km, reference (-216000, -216000) in Lambert Conformal projection with 9 km spatial resolution; 27 x 33 grid cells, reference (-54000, -9000) with 3 km spatial resolution and finally, 24 x 24 grid cells, reference (-27000, 33000) with 1 km spatial resolution. In this contribution we will show results for the 3 km spatial resolution or nesting level 3 only.

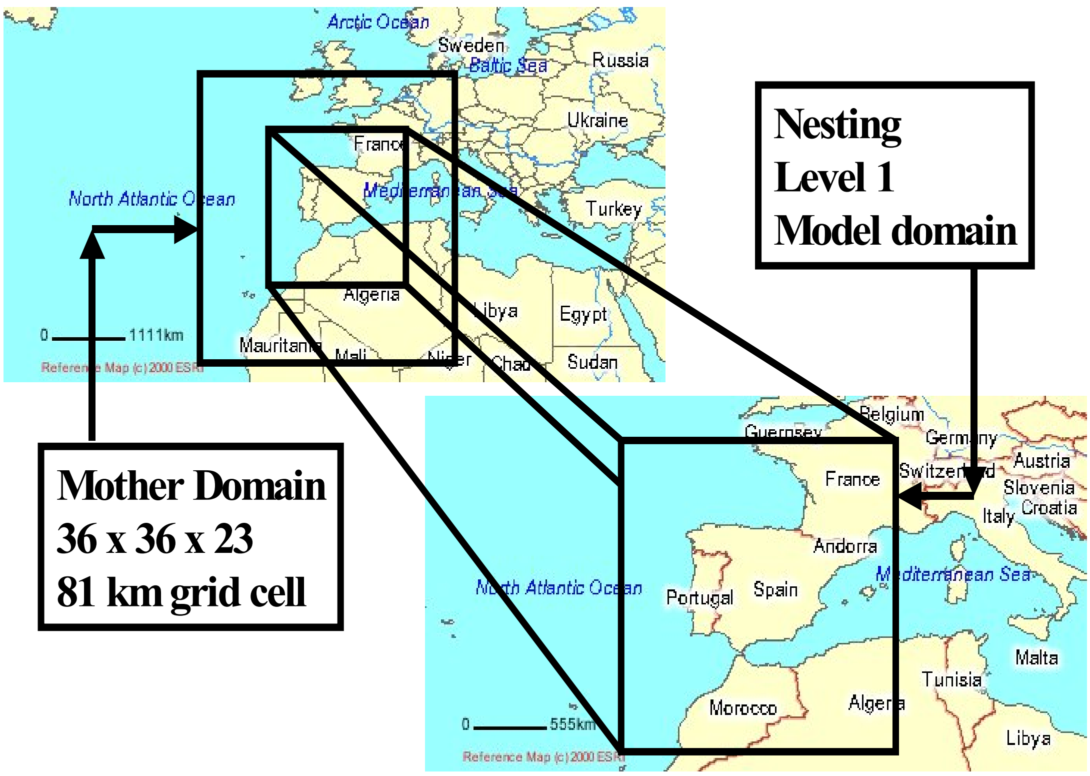

Figure 1. Mother and nesting level 1 on this experiment for MM5-CMAQ modelling system.

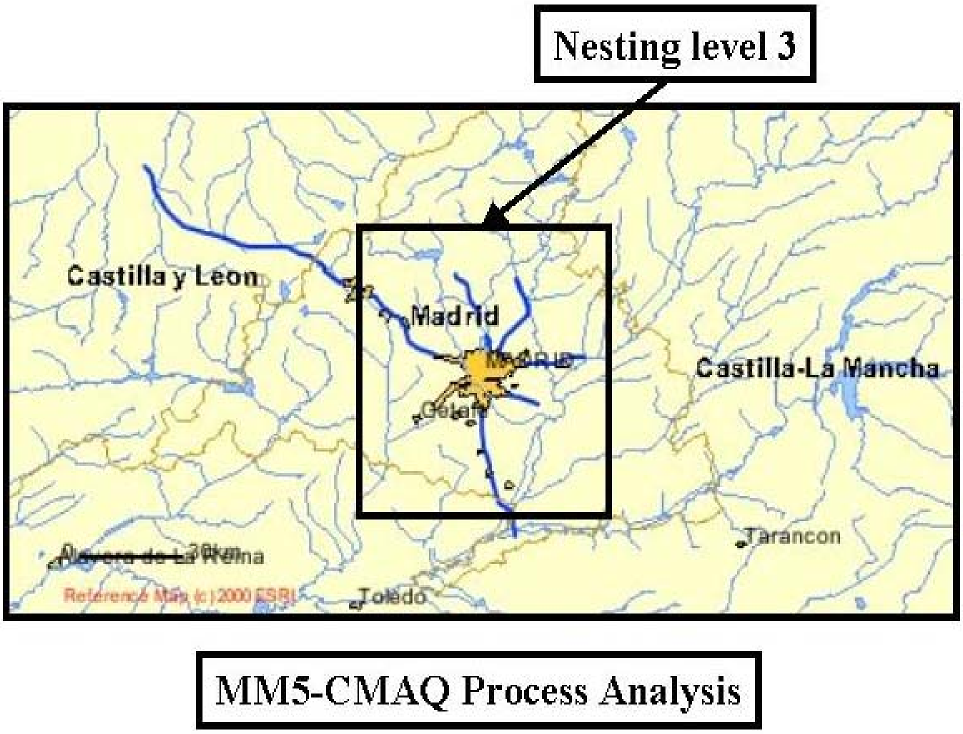

Figure 2. Nesting level 3 for MM5-CMAQ modelling system and mother domain for OPANA.

The nesting level 3 is used by OPANA as mother domain to run OPANA model with 5 km spatial resolution. The industrial plant is located at (.6727.0, 62909.65) in Lambert Conformal Coordinates. This industrial plant emits 340 Tn/year of SO2, 155 Tn/year NOx and 2.9 Tn/year VOC's. We have selected – as a preliminary test – the period of February 4-8, 2002. The emission database is obtained from the EMIMA model [2] and EMIMO model – a new emission model for large domains based on global emission inventories such as GEIA, EMEP, EDGAR and the Digital Chart of the World - . MM5-CMAQ is initiated by using global data sets from MRF (NOAA/NCEP, USA) and mother, nesting levels 1 and 2 provide the boundary conditions for running MM5-CMAQ for nesting level 3 over the Madrid Community Area with 27 x 33 grid cells (3 km) which makes 81 x 99 km. The OPANA model runs over a domain of 80 x 100 km with UTM coordinates and using only EMIMA data sets. EMIMA datasets are also used for MM5-CMAQ over nesting level 3. EMIMO data set is used for mother and nesting levels 1 and 2 for MM5-CMAQ. We have performed two simulations for each model (OPANA and MM5-CMAQ), one simulation with the industrial plant emissions and the second one *without* the industrial plant emissions.

Results

Figure 3 shows the 120 hour average for the differences between simulation with industrial plant (ON) and the simulation without the industrial plant (OFF) (ON-OFF) with the OPANA model. Figure 4 shows the 120 hour average for the differences between simulation with industrial plant (ON) and the simulation without the industrial plant (OFF) (ON-OFF) with the MM5-CMAQ model. The results show important differences in relative values – more than five times higher when using MM5-CMAQ than those obtained with OPANA – and also in the geographical distribution. OPANA simulation generates ozone concentration changes that are distributed in all directions in a way quite homogeneous. On the contrary, MM5-CMAQ generates ozone concentration changes higher and distributed mainly along the North-

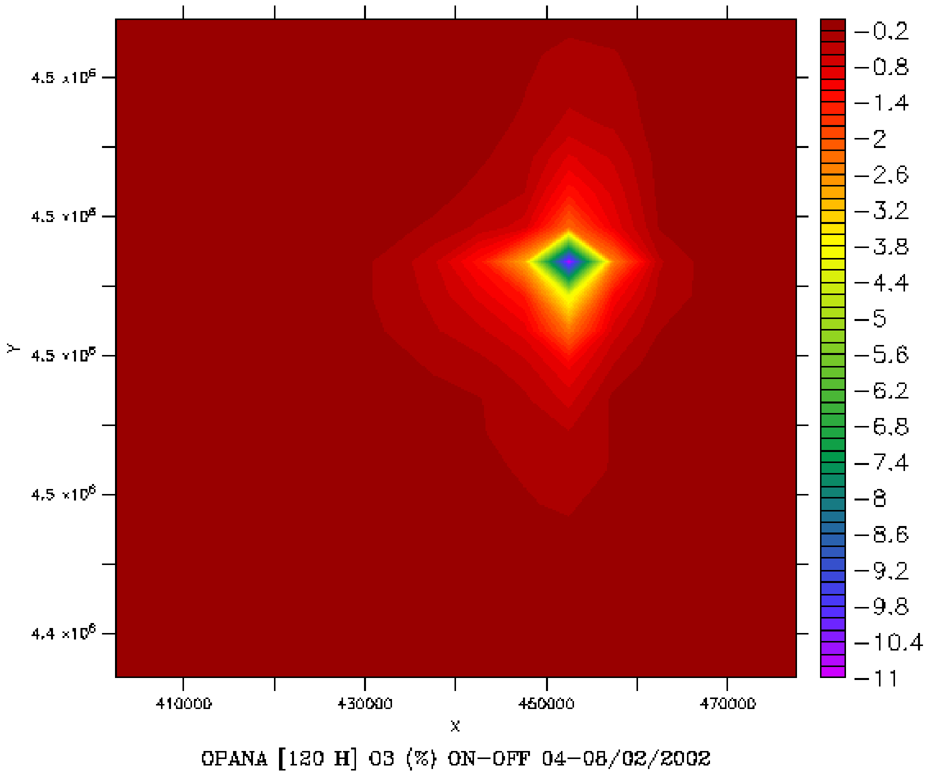

Figure 3. 120 hour average for the differences between simulation with industrial plant (ON) and the simulation without the industrial plant (OFF) (ON-OFF) with the OPANA model

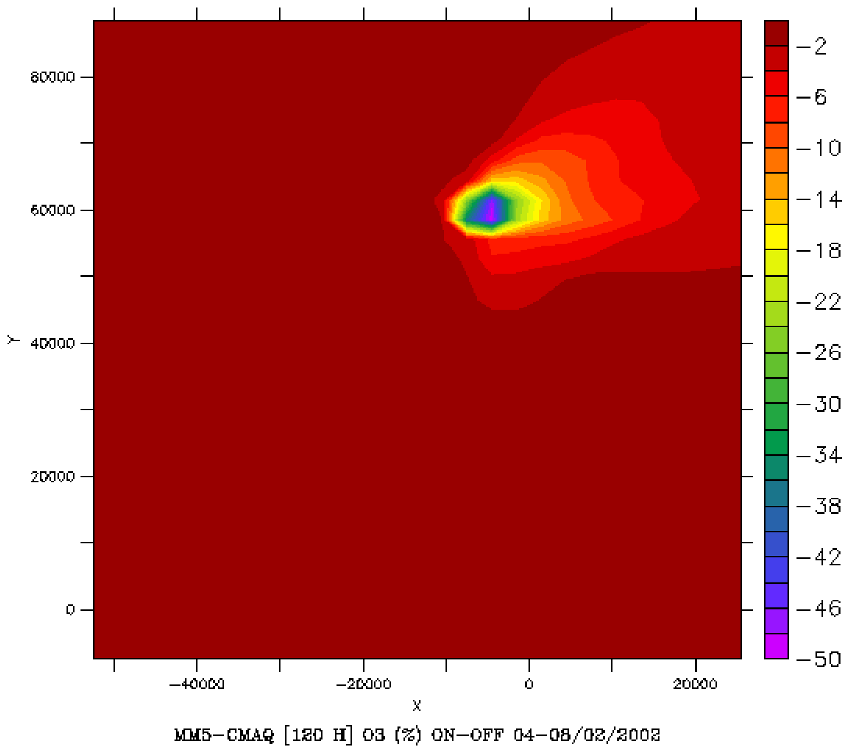

Figure 4. Figure 3 shows the 120 hour average for the differences between simulation with industrial plant (ON) and the simulation without the industrial plant (OFF) (ON-OFF) with the OPANA model.

East direction. Important differences are found when both models are run for the industrial plant cell the impact on ozone concentrations is much larger on the MM5-CMAQ simulation than when OPANA model is run. Main differences are found due to the boundary conditions.

MM5-CMAQ is run with two nesting levels up and one mother domain with 2430 x 2430 km. OPANA takes the MRF vertical meteorological soundings only as initial meteorological conditions to run the model. Naturally, the MM5-CMAQ should produce more realistic results. In Figures 4 and 5 we see both simulations with industrial emissions ON and OFF. In Figures 7 and 8 we observe the NO concentrations for the ON and OFF scenarios by using OPANA and MM5-CMAQ modelling systems. Differences are important between both models which essential can be due to boundary conditions and a different wind patterns generated by both models. The MM5-CMAQ modelling system has been run over a more realistic domain for the simulation period, MM5-CMAQ can be considered more realistic by using these principles. MM5-CMAQ has been run with 3 km spatial resolution and OPANA has been run with 5 km spatial resolution – mainly because this 5 km version is currently being used as operational tool for Madrid Municipality -.

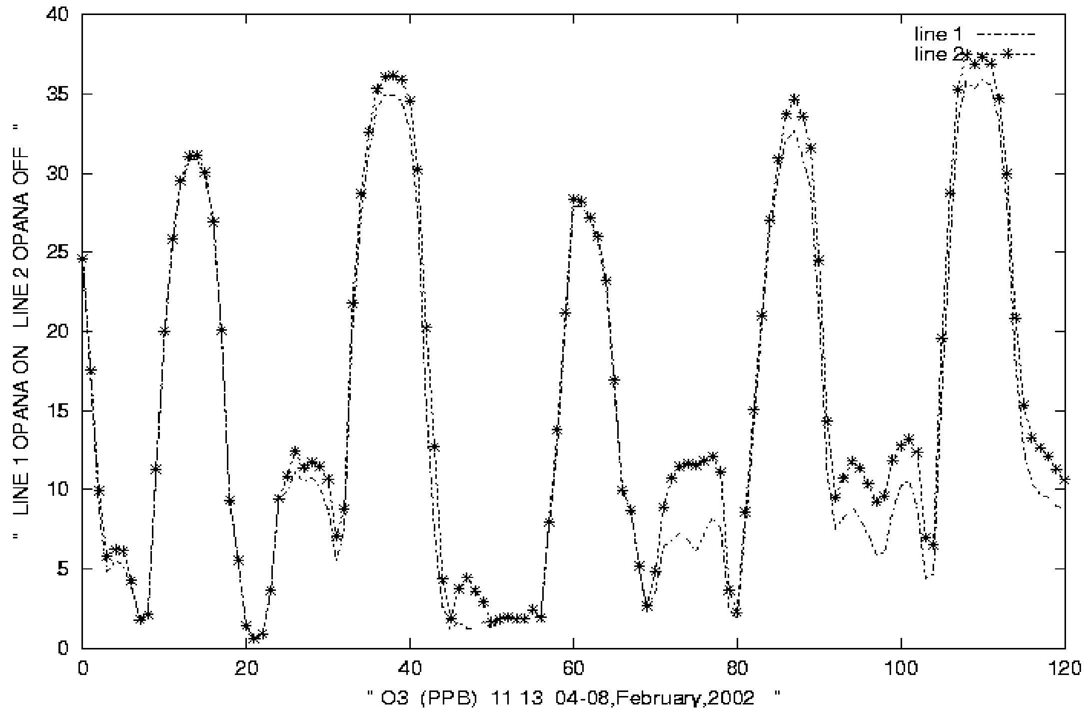

Figure 5. OPANA ozone concentrations at industrial plant cell with and without industrial emissions.

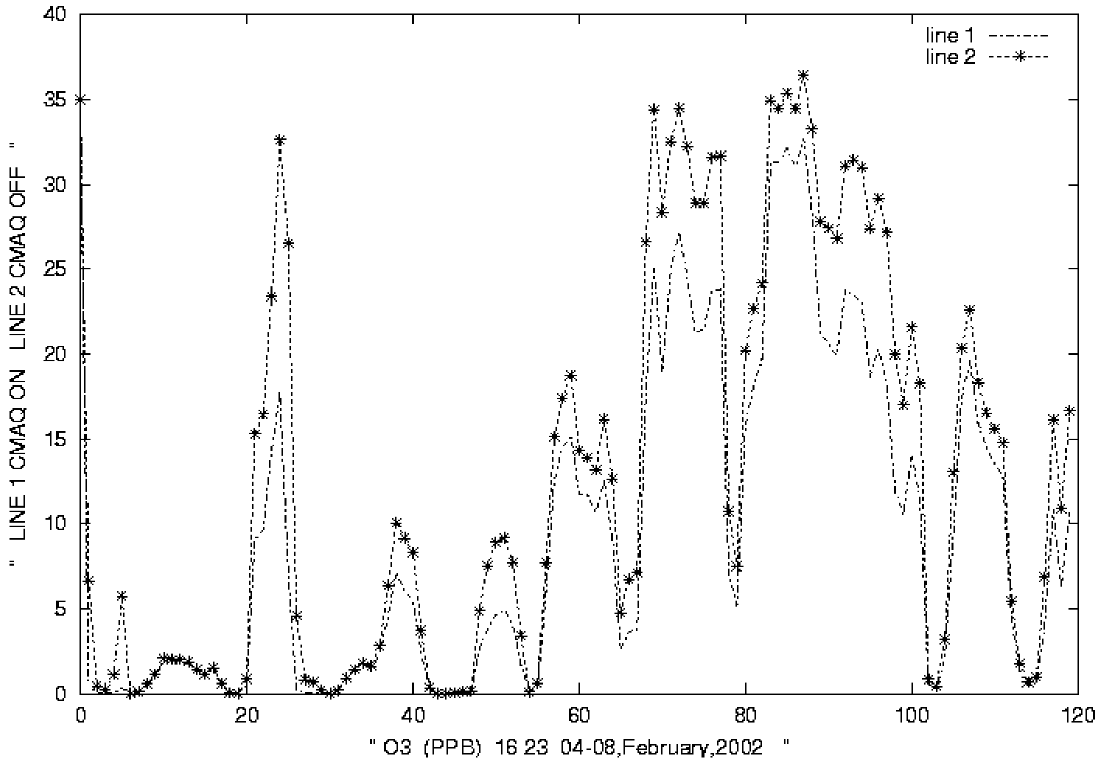

Figure 6. MM5-CMAQ ozone concentrations at industrial plant cell with and without industrial emissions.

In both cases, differences are important but more important on ozone concentrations for MM5-CMAQ than for NO concentrations where OPANA produces larger differences. In Figure 9 we observe a comparison between observed ozone concentration (with industrial plant ON), MM5-CMAQ (ON) ozone concentrations and OPANA (ON) ozone concentrations. Thee results show a better performance of MM5-CMAQ modelling system than OPANA. An important consequence is that the atmospheric numerical model to be used should be calibrated against different monitoring stations and use this calibration for interpreting the differences for the industrial impact. The surface patterns illustrated here show that differences between 10 to 50 % - depending of the air pollution model - can be found in the surrounding area of the industrial plant. These differences are important since they generate increases in ozone concentrations up to 40 % in the surroundings of the industrial plant in MM5-CMAQ model. In Figure 9 we observe a comparison between observed ozone concentration (with industrial plant ON), MM5-CMAQ (ON) ozone concentrations and OPANA (ON) ozone concentrations. The results show a better performance of MM5-CMAQ modelling system than OPANA. An important consequence is that the atmospheric numerical model to be used should be calibrated against different monitoring stations and use this calibration for interpreting the differences for the industrial impact.

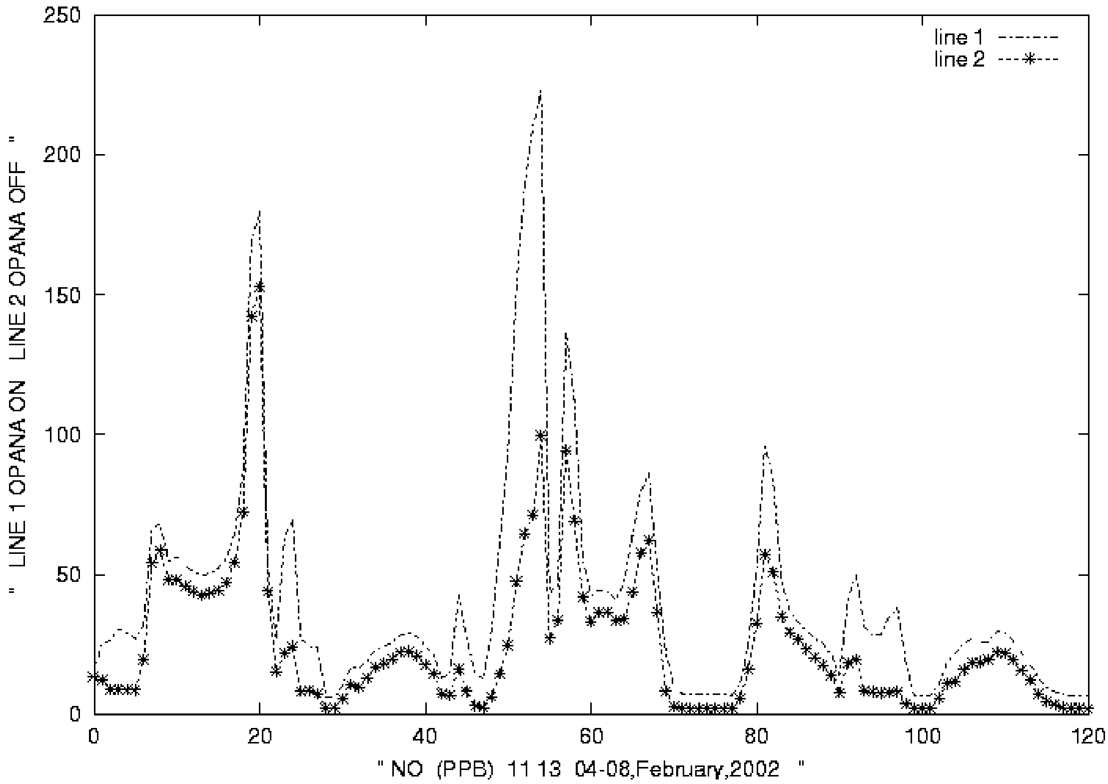

Figure 7. OPANA NO concentrations at industrial plant cell with and without industrial emissions.

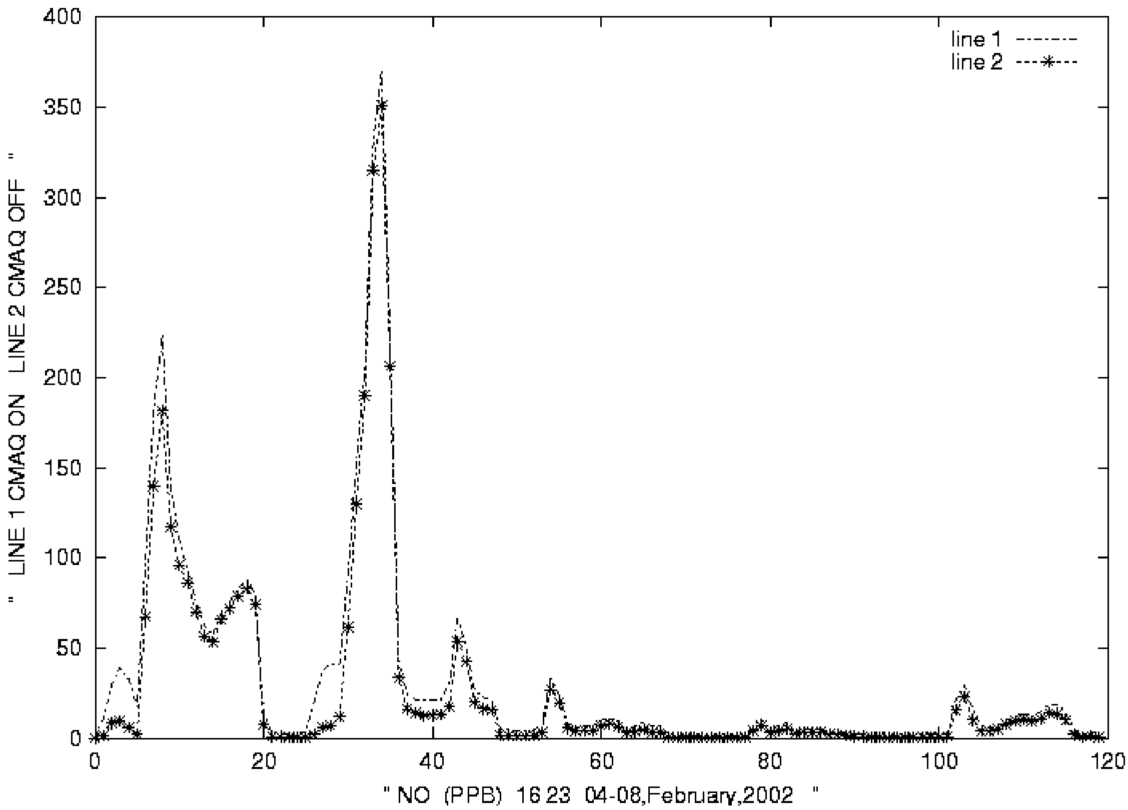

Figure 8. MM5-CMAQ NO concentrations at industrial plant cell with and without industrial emissions.

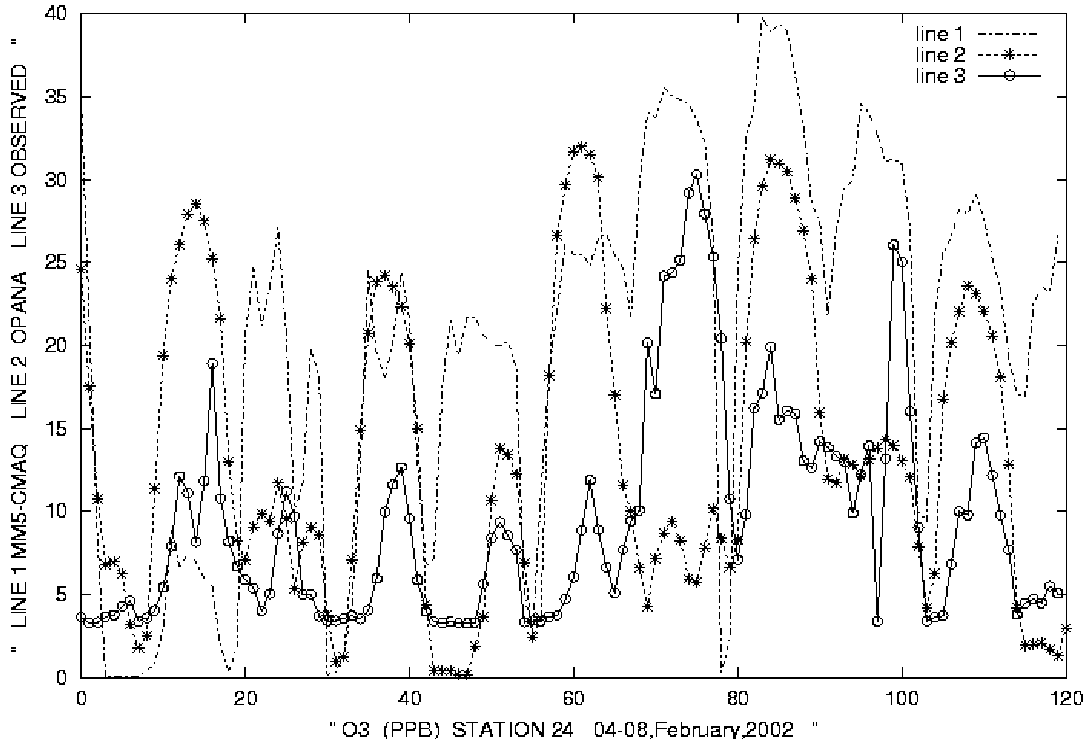

Figure 9. OPANA, MM5-CMAQ and observed ozone concentrations at Casa de Campo monitoring station.

The surface patterns illustrated here show that differences between 10 to 50 % - depending of the air pollution model - can be found in the surrounding area of the industrial plant. These differences are important since they generate increases in ozone concentrations up to 40 % in the surroundings of the industrial plant in MM5-CMAQ model. Further analysis and more simulation periods are required to establish more solid consequences than those obtained in this preliminary analysis. The TEAP-EUREKA project is intended to develop an expert system tool to analyse a large amount of simulation periods to establish the calibration between monitoring data and simulated data. The results will be used to interpret the relative differences between ON and OFF scenarios with the corresponding error margins. The results in real-time will be used by the industrial plant managers to optimise the cost-performance-pollution impact relation in order to quantify the impact on the area of the different emissions.

Acknowledgements

We would like to thank EUREKA network for approving the TEAP proposal and the Spanish Science and Technology Ministry for funding the Spanish section of the proposal. Also, we would like to thank the Spanish Centre for the Development of Industrial Technology for the full support received for this proposal.

References

Byun, D.W., J. Young, G. Gipson, J. Godowitch, F. Binkowski, S. Roselle, B. Benjey, J. Pleim, J.K.S. Ching, J. Novak, C. Coats, T. Odman, A. Hanna, K. Alapaty, R. Mathur, J. McHenry, U. Shankar, S. Fine, A. Xiu and C. Jang; Description of the Model-3 Community Multiscale Air Quality (CMAQ) model, in: *Proc. of the American Meteorological Society 78th Annual Meeting,* Phoenix, AZ, Jan 11-16 (1998) 264-268.

San José R., J. Cortés, J.F. Prieto and R.M. González; Accurate ozone prognostic patterns for Madrid area by using a high spatial and temporal Eulerian photochemical model, *Environ. Monitoring and Assessment,* **52** (1998) 203-212.