An Operational Real-Time Forecasting Decision Support System (TEAP) for Industrial Plants by Using MM5-CMAQ: Spain Case

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EXTENDED ABSTRACT

Industrial plant and particularly new electric power plant are important emission sources generally surrounding large, medium and small cities. Energy forecasts indicate that the growing demand for electricity will require the construction of more electric power plant that use different fuels. In Spain, the growing electricity demand has been met with natural gas fueled combined cycle electric power plant. While the air quality impact associated with the newer technologies is relatively lower when compared to older technologies, modern EU Air Quality legislation requires the control of air quality impact in real-time and forecasting mode. An operational real-time forecasting decision support system systemhas been developed and implemented in Spain on a 4-unit (400 MW per unit) combined cycle electric power plant, which is located in the surrounding area of Madrid Community (Spain). The system is based on the MM5-CMAQ-EMIMO modelssystem. The MM5 model is widely used all over the world and was developed by PSU/NCAR (USA). The CMAQ model is the so-called Community Multiscale Air Quality Modelling System developed by USEPA. EMIMO is an anthropogenic and biogenic air emissions model , which produces hourly emissions per pollutant per square kilometer. The system is implemented in an 8-node PIV-3, 4 GHz Dell computer cluster to minimize computation time. The system covers three model domains: 405 x 405 km with 9 km spatial resolution; 81 x 99 km with 3 km spatial resolution; and 24 x 24 km with 1 km spatial resolution. The three domains have 23 vertical layers up to 100 mb. The system runs on a daily basis and forecastes up to 72 hours. The system runs all the scenarios needed to obtain the air quality impact of each of the 4-units for every grid cell, hour and air pollutant simulated. The estimated electric power plant emissions are produced on a weekly basis and provided on-line to the modelling system. Changes to expected emissions for the electric power plant are introduced automatically in the modelling system on a daily basis. The system is accessed over the Internet by the environmental authorities and company managers on a daily basis. The system produces alerts every day according to the results of the model. Any decision related to possible shut-down for a limited period of time of the different power plant units , where the EU Directive limits may have been exceeded, is taken by environmental authorities in real-time. The system prototype was part of the EUREKA project TEAP (A tool to evaluate the air quality impact on industrial plant) (2001-2003). The same approach can be used for any other industrial plant and also for any emission source apportionment such as traffic over specific sections of the model domain or even specific pollutants over certain areas in the model domain.

1. INTRODUCTION

Accurately estimating the air quality impact of industrial plant is becoming increasingly important due to the more strict EU Air Quality legislation . The 2002/3/EC Directive of the European Parliament and of the Council of 12 February 2002 related to ozone in ambient air provides information related to short-term action plans at the appropriate administrative levels. In accordance with this legislation, industrial plant are required to have appropriate control systems in place so that air quality impact can be predicted in real-time and forecasting modes. . The EU directives are mainly concerned with the impact associated with O3, SO2, NOx, CO and PM10 levels. . The ability to reduce emissions in real-time according to a forecast for a specific area and period of time is very challenging. In the past, the ability to forecast air quality in a timely manner was largely limited by computer power and the cost of vector parallel computers. Nowadays, a cluster system using a number of PC processors (3,4 GHz or 3,6 GHz) largely solves this problem but it requires that the architecture of the air quality modelling system is carefully designed first.

The concept of real-time in our case is the ability to make appropriate decisions in advance to avoid exceedances of the EU Directive limits. The EU Directive gives the responsibility for the design of short-term action plans, including trigger levels for specific actions, to each of the Member States. Depending on the individual case, the plans may provide for graduated, cost-effective control measuresand, where necessary, reduce or suspend certain activities, including motor vehicle traffic, which contribute to emissions that result in the alert threshold being exceeded. These may also include effective measures in relation to the use of industrial plant or products. In this application we focus on the possible reduction of industrial activities – in our case, a combined cycle electric power plant -.

The complete system designed for this application is called TEAP (a Tool to Evaluate the Air quality impact of industrial Plant) (San José et al., 1994, 1996). This system isdesigned to be used by environmental staff at the plant . The system the provides the air quality impact associated with industrial emissions in the form of contour and ltime series plots for specific geographical locations in the model domain. The model domain is designed in a way so that the industrial source of interest is located approximately in the centre of the model domain. The model domain can be as large as required but a specific nesting architecture should be selected for each case together with balanced computer architecture.

The TEAP system (a EUREKA-EU project) has the capability to incorporate different modelling systems. In a preliminary stage we have tested the system with the so-called OPANA model (ETC/ACC03). The OPANA model (San José et al, 1996) – which stands for Operational Atmospheric Numerical pollution model for urban and regional areas and was developed during the middle of the 90's by the Environmental Software and modelling Group at the Computer Science School of the Technical University of Madrid (UPM) – is based on the MEMO model (ETC/ACC03) developed in the University of Karlsruhe (Germany) in 1989 and updated in 1995, for non-hydrostatic three dimensional mesoscale meteorological modelling and the 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 system 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 continues to operate on a 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's curvature – and the cloud chemistry and particulate matter is not included (aerosol and aqueous chemistry).

Examples of "state-of-the-art" meteorological models are: MM5 (PSU/NCAR, USA), RSM (NOAA, USA), ECMWF (Redding, U.K.), HIRLAM (Finnish Meteorological Institute, Finland), etc. Examples of "state-of-the-art" of transport/chemistry models – also called "third generation air quality modelling systems" – are: EURAD (University of Cologne, Germany), *Stockwell et al.*, (1977), EUROS (RIVM, The Netherlands), *Lagner et al.* (1998), EMEP Eulerian (DNMI, Oslo, Norway), MATCH (SMHI, Norrkoping, Sweden), *Dervent R. and Jenkin M.* (1991), REM3 (Free University of Berlin, Germany), (2000), CHIMERE (ISPL, Paris, France), *Schmidt et al.* (2001), NILU-CTM (NILU, Kjeller, Norway), *Gardner et al.* (1997), LOTOS (TNO, Apeldoorm, The Netherlands), *Roemer et al.* (1996), DEM (NERI, Roskilde, Denmark), *Gery et al.* (1989), STOCHEM (UK Met. Office, Bracknell, U.K.), *Collins et al.* (1997). In USA, CAMx Environ Inc., STEM-III (University of Iowa) and CMAQ (EPA, US) are the most up-to-date air quality dispersion/ chemical models. In this application we have used the CMAQ model (EPA, U.S.) which is one of the most complete models and includes aerosol, cloud and aerosol chemistry.

2. THE MM5-CMAQ MODELLING SYSTEM

The CMAQ model (Community Multi-scale Air Quality Modeling System, EPA, US) is implemented in a consistent and balanced way with the MM5 model. The CMAQ model is fixed "into" the MM5 model with the same grid resolution (6 MM5 grid cells are used at the boundaries for CMAQ boundary conditions). An example domain architecture is shown in Figure 1 for an application in a combined cycle power plant in the south area of Madrid Community. MM5 is linked to CMAQ by using the MCIP module whichprovides the physical variables for running the dispersion/chemical module (CMAQ), such as boundary layer height, turbulent fluxes (momentum, latent and sensible heat), boundary layer turbulent stratification (Monin-Obukhov length), friction velocity, scale temperature, etc. We have run the modelling system (MM5-CMAQ) with USGS 1 km landuse data and GTOPO 30'' for the Digital Elevation Model (DEM) which can be substituted by more accurate high spatial resolution landuse information if required.

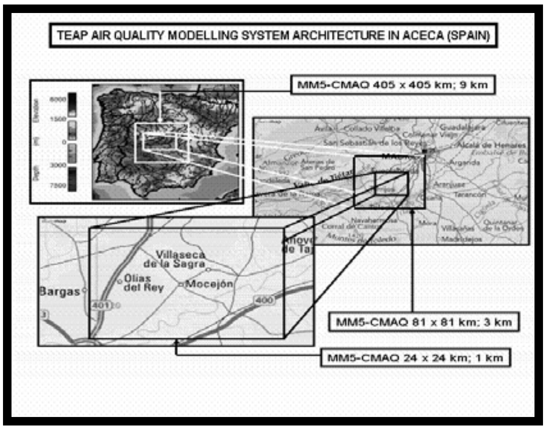

Figure 1. Model domain architecture.

The system uses the EMIMO model to produce hourly 1 km x 1 km gridded emissions of total VOC's (including biogenic), SO2, NOx and CO. EMIMO is an emission model developed at our laboratory in 2001. This model uses global emission data from the EMEP/CORINAIR European emission inventory (50 km spatial resolution) and EDGAR global emission inventory (RIVM, The Netherlands). In addition the EMIMO (EMIssion Model) model uses data from DCW (Digital Chart of the World) and USGS land-use data from AVHRR/NOAA 1 km satellite information. The EMIMO model includes a biogenic module (BIOEMI) developed also in our laboratory based on the algorithms for natural NOx, monoterpene and isoprene emissions as a function of LAI (leaf Area Index) and PAR (photosynthetic active radiation). The emission inventory is a model, which provides in time and space the amount of a pollutant emitted to the atmosphere. In our case we have quantified the emissions due to traffic, domestic , industrial, tertiary sector and biogenic sources in the three model domains with 9 km, 3 km and 1 km spatial resolution mentioned above. The two general approaches for creating an emission inventory are as follows: a) Top-down and b) Bottom-up. In reality a balanced combination of both approaches offers the best results. Because of the high non-linearity of the atmospheric system, due to the characteristics of the turbulent atmospheric flow, one way of estimating the impact of a portion of the total emissions (due to traffic or one specific industrial plant, for example), is to run the system several times, each time with a different emission scenario. The general scheme of application of a set of combined cycle power plant can be seen in Figure 2.

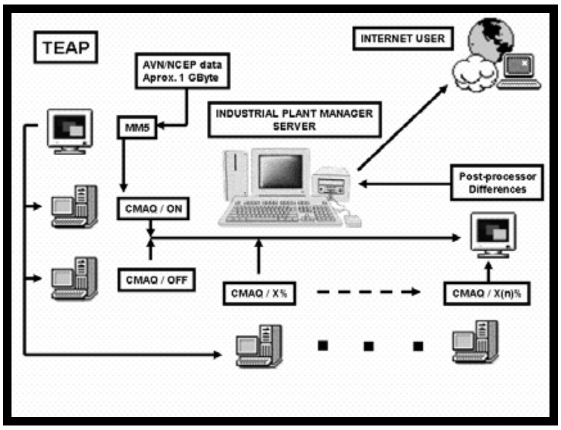

Figure 2. General scheme for full application with N different combined cycle power plant.

We have applied the MM5-CMAQ modelling system on a power plant with 4 400 MW combined cycle units, which are expected to operate simultaneously. The system is designed to operate in ON-OFF mode which means that it will simulate the scenarios representing the full operation of all groups and the emission reduction scenario without the four groups operating. The system was calibrated for a 60-day periods by using 5-day periods per month during 2004. Figure 3 shows the comparison between NO air concentration in Leganes monitoring station (located in the surrounding area of Madrid city) and the simulated NO concentrations. Figure 4 shows the comparison between O3 observations and modelling results for the monitoring station Rivas located also in the surrounding area of Madrid city. The system compares with actual measures in a very acceptable way however the inclusion of O3 events produced outside of the model domain (405 x 405 km) are not possible to be captured by the system. The O3 events with origin outside of this model domain are somehow common in the sense that during last decade a substantial decrease in pollution levels has been obtained from primary pollutants but long range transport is increasing the importance day by day partially due to the decrease of impact on local events. The EU Directive 2002/3/EC requires that the differences between O3 model data and observations should be between the 50 % range for the corresponding percentiles. In our calibration process for the 1 km domain 3 monitoring stations were included, for the 3 km domain 10 monitoring stations were included and finally for the 9 km domain a total of 21 monitoring stations were included. All comparisons between modeling and monitored data fulfilled the above EU Directive or in other words the 21 monitoring and modeled O3 data where into the 50 % range prescribed by the Directive.

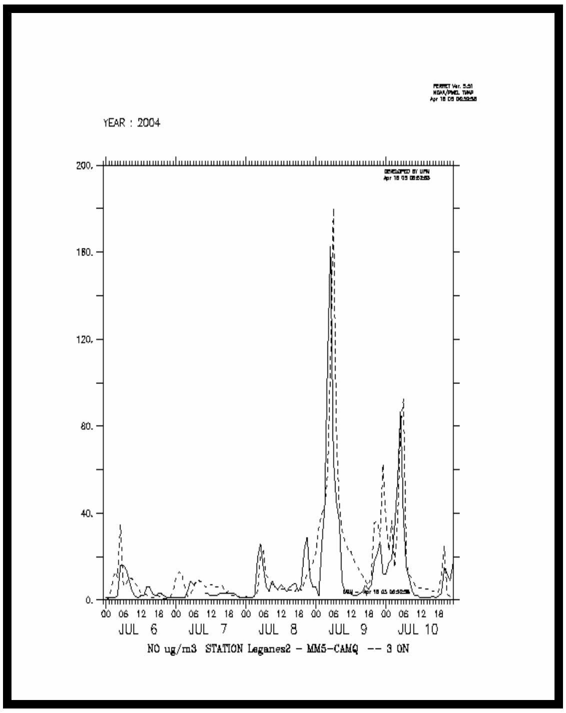

Figure 3. Comparison between NO observations and simulated data by using TEAP system for analyzing the impact of emissions from a combined cycle plant.

The impacts – due to the high chemical non-linearity involved – are analyzed using the absolute concentration pollution values and and then compared with the EU Directive limits. The post-processing is done automatically and presented in the specifically designed Web site.

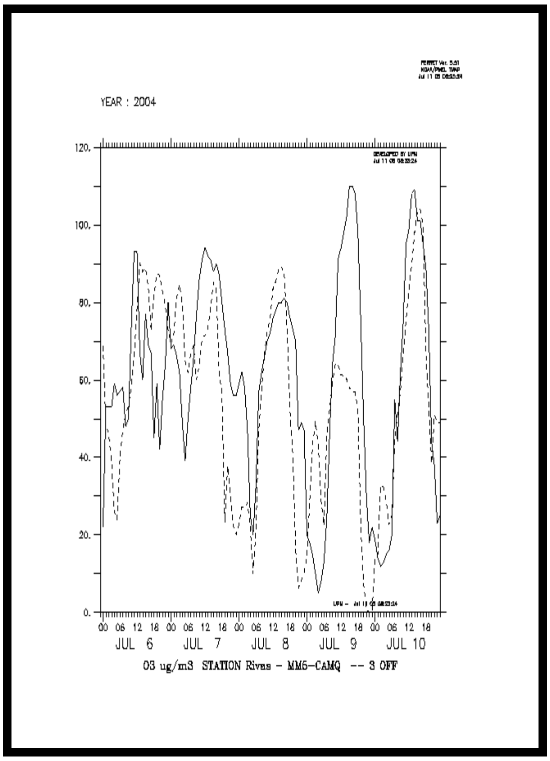

Figure 4. Comparison between O3 observations and modelling data for Rivas monitoring station (Madrid) for the period 6-10, July 2004.

3. RESULTS

The system has been operating since July 1, 2005 with full success. The developed system provides 72-hour forecasts for the impact of the 4 independent 400 MW combined cycle power units. The access to the web site is restricted to environmental authorities and company authorized personnel. The system is operating from the Computer Center at Computer Science School at Technical University of Madrid (UPM) managed by the Environmental Software and Modelling Group (ESMG). The system has been mounted over an 8-node 3,4 GHz cluster platform. Figure 5 shows an example of the TEAP prototype mounted over a Petrochemical plant also in the South of Madrid Area (150 km away).

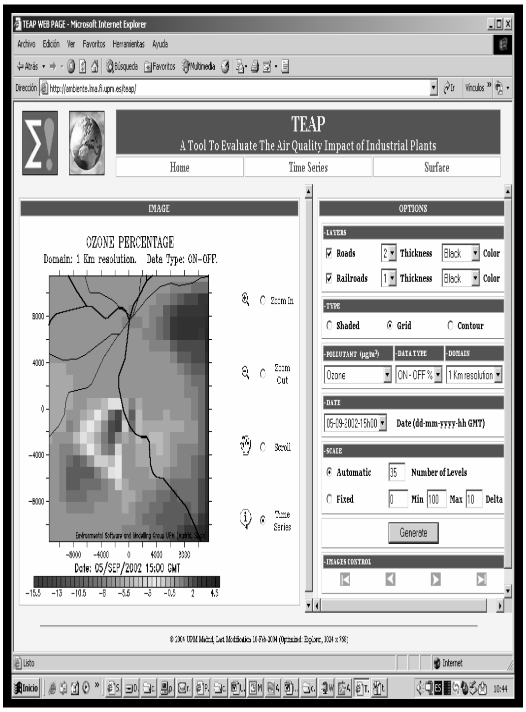

Figure 5. TEAP web site to analyze the impact of a petrochemical plant located 150 km at the south of Madrid area.

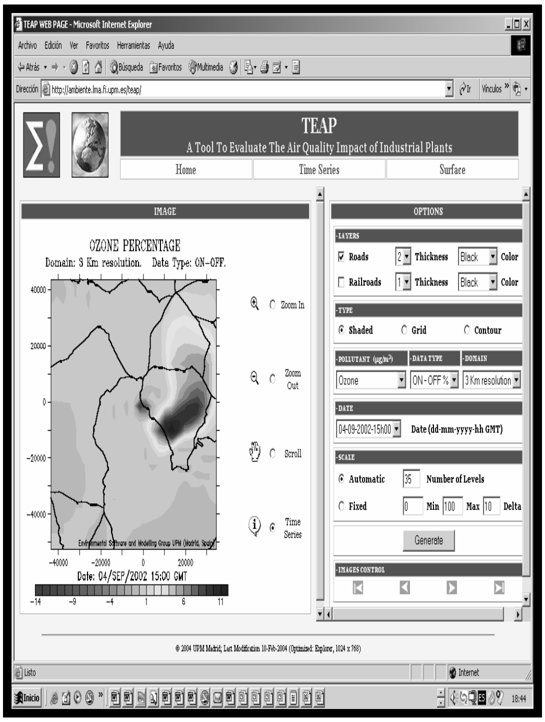

Figure 6. O3 power plant concentrations impact at 15h00 on September, 4, 2002 for the 3 km spatial resolution model domain showing the areas with increase and decrease on O3 concentrations due to the emissions from the power plant.

In figure 6 we show the impact on O3 concentrations at a different location in the south of Madrid Community on September 4, 2002, 15h00 GMT as obtained during the tests. The O3 concentrations are increased up to 11 % over the levels (without the emissions from the power plant) and with decreases up to 14 %. The increased levels are located at distances between 10 – 20 km to the East of the power plant location (centre of the domain) and the decreased levels are located in the immediate surrounding areas of the power plant (center of the domain).

Figure 7 shows the O3 percentage change during 120 hours simulation and when activating the power plant after 72 hours. We observe that in that specific location (4336,1770 m, UTM) we expect increases and decreases on O3 concentration in a range up/down 6%. The TEAP system provides a full time and spatial information related to the absolute and relative impact of different emissions (different combined cycle power units) in real-time and forecasting mode under daily operations with an 8-node cluster platform.

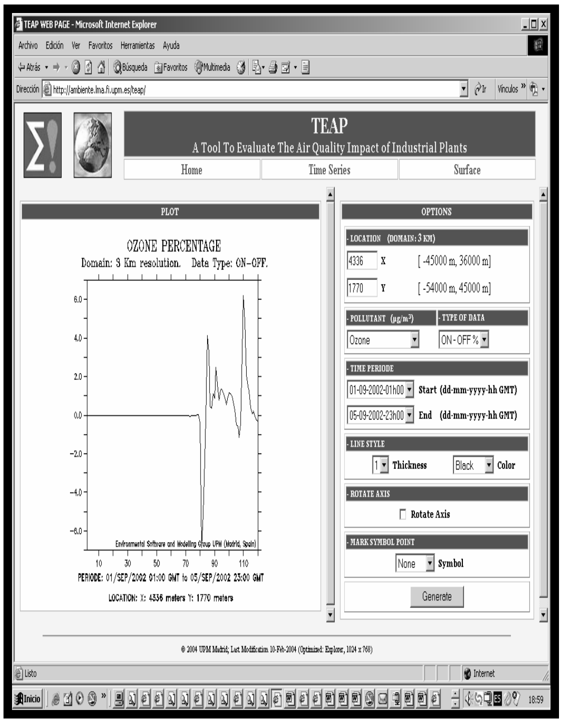

Figure 7. O3 concentration percentage impact due to the emissions of the power plant located in the Southern area of Madrid Community for the test period (1-5, September, 2002) at location (4336,1770, UTM).

The system has been operating three months and it is providing a very detailed information to authorities and company managers in order to take corresponding actions in case of need. However, the final decision derived to take active actions in function of results of the real-time operating system is depending on additional aspects such as social and economical consequences of adopting short-term emission reduction strategies.

The system is the first operating in Spain by using such a sophisticated 3rd Generation Air Quality Modelling System and it is expected to be installed in several other combined cycle power plant and in general in different industrial plant to help the local and regional authorities to identify the relative impact of the different industrial plant located in the surrounding area. The system can be adapted to identify the impact of traffic sources and also different scenarios.

4. ACKNOWLEDGEMENTS

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