A NEW OPERATIONAL AIR QUALITY PREDICTION SYSTEM OVER ITALY

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1 INTRODUCTION

In this paper we introduce a new operational air quality (AQ) prediction system, with the finest grid over Italy, the first on a National base (http://www.lamiaaria.it/).

The atmospheric flow is predicted by the Fifth-Generation NCAR/Penn State Mesoscale Model (MM5) while the transport, deposition and chemical reactions are computed by U.S. EPA's Community Multiscale Air Quality (CMAQ, Byun et al. 1998) Modeling System. The AQ prediction system, called Air Quality Manager (AQM), includes three nested domains (with 54, 18, and 6 km horizontal grid increments); the coarser grid includes Northern Africa to take into account Saharan dust intrusions.

2 DESCRIPTION OF THE AQM SYSTEM

The AQM system provides twice-daily 120-h AQ predictions over Italy published on LaMiaAria website, see Fig. 1. The coarser forecast domain includes Europe and northern Africa with 54-km horizontal grid spacing, while the finest grid, with 6-km grid increments, covers Italy. The system is based on a Lambert conformal map projection.

Next, the meteorological, emissions, and chemical models are described, including the typical operational timelines of the AQM system.

Fig. 1. www.lamiaaria.it homepage.

2.1 *Meteorological component*

The meteorological input for the system is based on the MM5 meteorological fields. In general, air quality modeling requires a high degree of consistency between the meteorological and photochemical models, in order to ensure mass conservation in the simulation domain and the individual grid cells. For this reason, CMAQ runs on the same horizontal grid spacing and the same map projection as MM5.

The MM5 forecast is given as input to CMAQ-meteorological preprocessor MCIP. Forecast data from the 29 MM5 vertical layers are interpolated to 22 sigma-pressure layers for MCIP. The majority of the 22 layers are in the lower troposphere, i.e., within the PBL where most of the photochemical activity takes place. There are approximately 13 layers below 2 km, and the lowest layer thickness is 22 m.

2.2 *Emissions component*

The required CMAQ emissions data for various pollutants sources at the appropriate spatial and temporal resolutions are performed according to the Joint EMEP/CORINAIR Atmospheric Emission Inventory Guidebook 2007 (the official European methodology, Technical report N° 16/2007).

For each of the three nested domains (grid resolution 54 km, 18 km, 6 km) emissions inventory databases are created with increasingly details concerning spatial and temporal distribution for every kind of source.

The base-year inventories are developed in the Sparse Matrix Operator Kernel Emission (SMOKE) format, for the following pollutants according to the “criteria inventory” setting: carbon monoxide (CO), nitrogen oxides (NO_X), non-methane volatile organic compounds (NMVOC), sulfur dioxide (SO_2), ammonia (NH_3), particulate matter less than or equal to 10 microns (PM10), and particulate matter less than or equal to 2.5 microns (PM2.5).

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The temporal disaggregation (monthly, weekly and hourly) of annual emissions are estimated from average profiles of socioeconomic categories suggested by CORINAIR methodology.

For the 54 and 18 km grid, the contributions of the anthropogenic sources (road transport, non road transport, industry, agricultural sources, etc.) are implemented using the last available version of:

- European Monitoring and Evaluation Programme (EMEP) emission database;
- Emission Database for Global Atmospheric Research (EDGAR), excluded particulate matter, for north African areas;
- European Pollutant Emission Register (EPER) for industrial point sources.

The spatial disaggregation is evaluated according to the methodology of the surrogate variables, using geographic data in a GIS platform (primary traffic, CORINE land cover by European Environment Agency) related to the emissions sources.

The lack of information on biogenic emissions in the EMEP database is resolved by the implementation of a Mediterranean ecosystems biogenic emission methodology, using the results of previous studies (*Project MeditAIRaneo for the part concerning the natural emissions*, 2002-2005) jointly performed by Environmental System Analysis, Tuscia University (Viterbo, Italy) and CNR-IMC (Monterotondo, Italy).

The aim of the project was to improve the emission inventory of biogenic VOC in the Mediterranean regions, with respect to the CORINAIR approach. The methodology has been adopted to retrieve FPAR (Fraction of absorbed Photosynthetically Active Radiation) estimate by processing satellite data provided by the MODerate resolution Imaging Spectroradiometer MODIS) and Novel Maps for Forest Tree Species in Europe provided by IES (Institute for Environment and Sustainability, ex JRC Ispra).

Methods based on light and temperature dependency were implemented for the calculation of annual basal emission rates for species emitting monoterpenes (Gunther et al., 1993; Tingey et al., 1980); in addition combined algorithms were proposed for those species (such as Picea abies and Fagus silvatica) that exhibit a double mechanism of emission, according to Staudt et al. (2000).

The inventory of emissions for the Italian national territory (6 km grid) is carried out using the National Emission Inventory provided by the Institute for Environmental Protection and Research (ISPRA), available according to the CORINAIR classification and with a spatial disaggregation on a provincial basis.

The base-year emissions data are elaborated to perform a municipal spatial disaggregation by every Italian municipality then on the grid and a temporal disaggregation (monthly, weekly and hourly) of annual emissions.

The municipal spatial disaggregation is carried out from the emissive data on a provincial base according to the methodology of the proxy (or surrogate) variables. This processing is done using a large amount of statistics (socio-economical, demographic and agricultural) and geographical data: each kind of source, according to the CORINAIR classification, was associated to an appropriate proxy variable. Geographic data from a GIS platform concerning administrative boundaries is also used, including infrastructure information, land use (urban areas, agricultural areas and industrial areas); for natural areas was used CORINE land cover at a high level of detail.

According to CORINAIR, emissions from vehicular traffic are provided by type of road network (highways, rural and urban roads) and by type of vehicle (passenger cars, light-duty vehicles < 3.5 t., etc.). Through the use of the population and industrial census together with detailed map data, emissions by rural roads are divided in more detail as following: main state roads (70 % of rural driving) and secondary state roads (30 % of rural driving).

2.3 Chemical component

Models of atmospheric processes use simplified photochemical reaction mechanisms, and one mechanism that is most commonly used is the Carbon Bond IV (CB-IV) mechanism, where individual compounds with similar reactivity characteristics or carbon bond structures are grouped into a single mechanism species.

Thus the emission inventory information was processed as CB-IV reactivity classes. The first step was to identify the appropriate speciation profile (relative amounts of each compound in the total emissions) to be assigned to source categories and pollutant (VOC or PM2.5). These speciation profiles were obtained from EPA's SPECIATE3.2 model, and updated to SPECIATE4.0. A preliminary step was to connect USA Source Classification Code (SCC) categories to CORINAIR categories, in order to have an appropriate SSC profile assignment file. Then was necessary to both update the profiles from SPECIATE3.2 to 4.0 and modify few profiles to aggregate explicit fuel information. We used emitdb.xls tool (Carter, 2000) for VOC speciation which automates the assignment of individual compounds to CB-IV model species (i.e. lumping). It was also used to create a set of split-factors (mols of model species per mass total VOC) from each speciation profile.

To update the profiles we combined the information in SPECIATE 4.0 about a VOC or TOG compound and the relative chemical composition of profiles obtaining a VOC-TOG Conversion Ratios File. We then assign the variables necessary to generate speciated VOC emissions in either molar or mass form using the speciation profiles found in the CBIV Profiles File by means of SPECIATE 4.0 and emitdb.xls tool.

Concerning PM2.5, the only two steps are the assignment of a profile based on SCC, and the multiplication of the profile's mass fractions times the PM2.5 mass to create the individual species masses. The final step in speciation of PM2.5 emissions is to assign the variables necessary to generate speciated emissions in mass form only using the speciation profiles found in the Profile File. Unlike the speciation of VOC, particulate matter is not converted to molar values, as the chemistry applied in the air quality models does not currently require it as direct input.

3 THE DUST MODEL

In southern Europe a significant contribution to particulate matter mass is made by desert dust transported from North Africa. Owing to the different health effects, it is important to distinguish between high concentration levels due to these natural episodes and those produced by pollution events (European Air Quality Directives specify that limit values are not to be applied to events defined as natural).

It is not possible to take into account Saharan dust contribution to PM concentrations by means of a static emission inventory. Many factors governing dust emission are time-varying, as for instance soil moisture and turbulence. Others are static or present slow time variation like soil structure and vegetation cover type.

In Fig. 2. is shown a Saharan dust outbreak event dated 17 May 2009, as predicted by the system and as seen by MODIS on board of Terra Satellite.

The algorithm used to assess surface dust flux is based on the Dust Entrainment and Deposition model (DEAD, Zender, 2002), suitably modified. The dust algorithm uses MM5 forecasted wind fields, friction velocity, soil moisture, and estimated precipitation as input.

The release of aerosol is considered when the friction velocity exceeds a threshold wind friction speed which is a function of the particle diameter, soil moisture content and soil roughness length.

The quantity of dust released in the atmosphere depends on the soil texture, in particular on the fraction of clay, throughout the sandblasting mass efficiency.

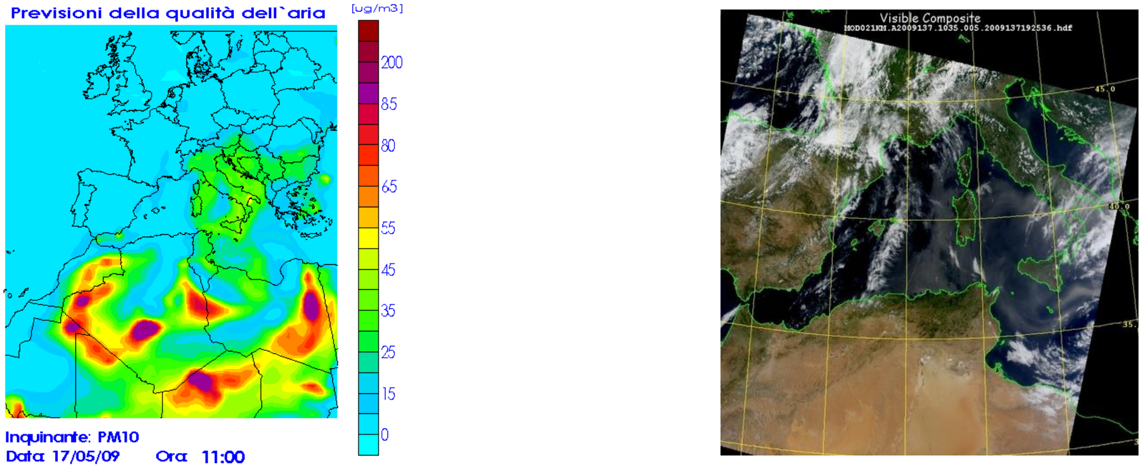

Fig. 2. Dust intrusion event predicted by the system (left) and seen by MODIS (right).

4 CMAQ CONFIGURATION

The computational domain is decomposed horizontally in space, where each partitioned domain is assigned to a processor. Since CMAQ is a limited area model, concentrations of chemical species must be specified at the lateral boundaries conditions (BC) to account for mass advected into the computational domain. The BC in the AQM system are set using a background continental profile. However standard profiles boundary conditions lack temporal and spatial variations, thus we are planning to implement a global model to take into account BC effects.

The initial conditions for CMAQ are set from the previous forecast cycle.

5 OPERATIONAL TIMELINES

Fig. 3 shows the operational timeline.

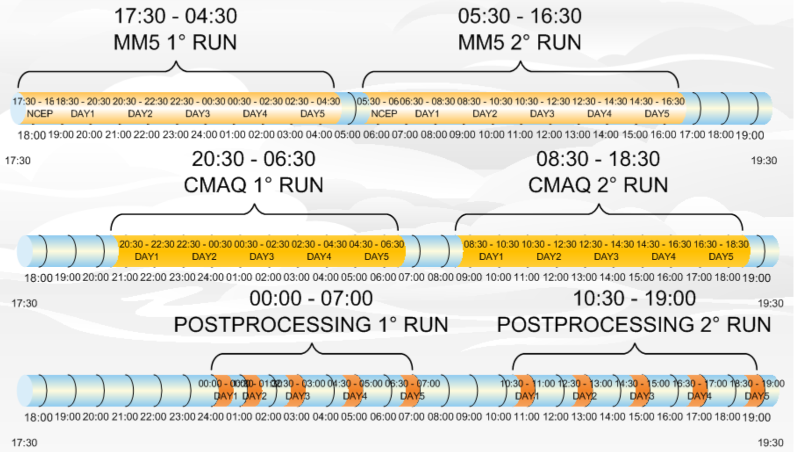

Fig. 3. Operational 120-h forecast periods for the AQM system. MM5 and CMAQ forecast (1° run) and updated forecast (2° run) are shown together with Post-processing timelines.

6 RESULTS

Due to the large economic, public health, and environmental impacts often associated with the use of air quality models, it is important to perform a proper evaluation of the results.

The AQM evaluation is done on a daily basis comparing the forecast results with observed data provided by the national monitoring network.

The same data are also used to compute monthly, seasonal and annual statistics.

Few hourly comparisons are shown in Fig. 4.

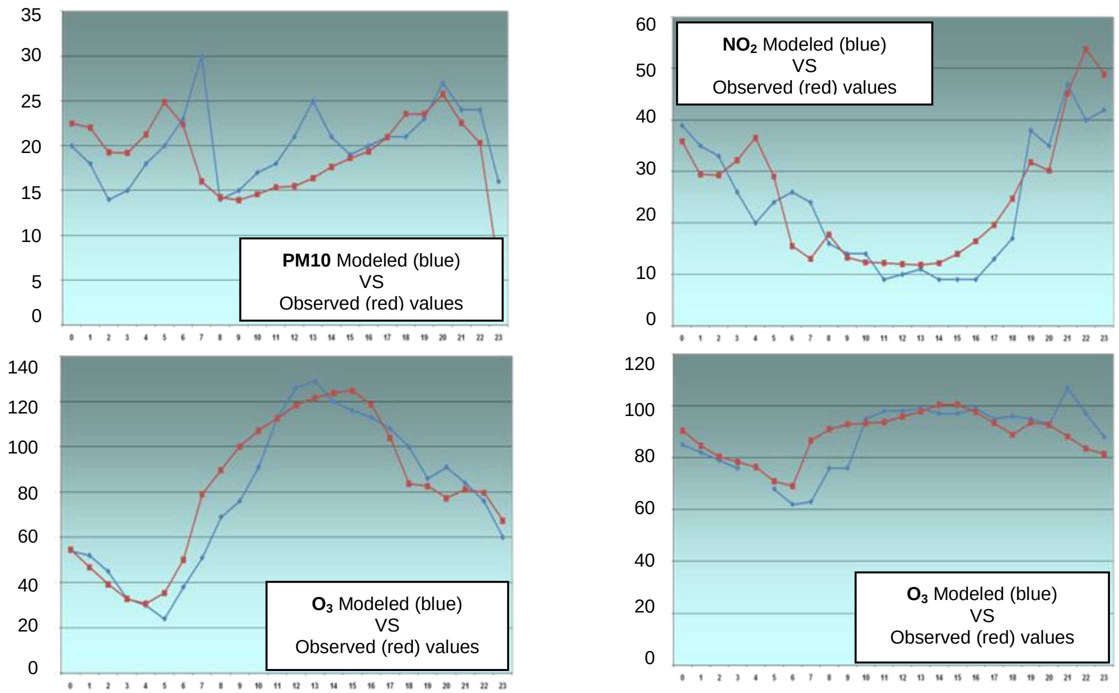

Fig. 4. Hourly comparisons between modeled and observed values. The selected stations are Mantova Lunetta for O_3 (North Italy), Ponzone (North Italy) for PM10 and Crema (North Italy) for NO_2. Concentrations are expressed in $\mu g/m^3$

6.1 Overall Performance and Summary Statistics

To assess the uncertainty associated with the model the official index following the directive 2008/50/EC of the European parliament on ambient air quality and cleaner air for Europe is used.

The European directive states that the uncertainty for modeling is defined as the maximum deviation of the measured and calculated concentration levels for 90 % of individual monitoring points, over the period considered, by the limit value (or target value in the case of ozone), without taking into account the timing of the events:

$$EVA = 100\frac{MAX\,(C_{pred} - C_{obs})}{LM} \qquad (1)$$

Where c_{pred} is the forecasted concentration, c_{obs} is the observed concentration and *LM* is the limit value while *EVA* states for European Validation Algorithm.

The European directive states that this uncertainty must be less than 50 % for SO_2, NO_2 and O_3 while a limit for PM10 is not defined yet. Monthly values for EVA are shown in Fig. 6.

The results are encouraging since the regulatory target is matched with few exceptions.

A total number of 83 stations for O_3, 114 for NO_2 and 53 for PM10, spread out all over Italy are used in the following statistics.

A useful index witch give immediate information is the *fractional bias* (FB).

The fractional bias is defined as follows:

$$FB = 2\frac{(\overline{c_{pred}} - \overline{c_{obs}})}{(\overline{c_{pred}} + \overline{c_{obs}})} \qquad (2)$$

Where $\overline{c_{pred}}$ and $\overline{c_{obs}}$ are the mean predicted and observed concentration respectively. The *FB* is limited (between -2 and 2) and symmetric.

Negative values mean the system is underestimating the real concentrations while positive values mean it is overestimating.

In Fig. 5 is shown the *FB* for summer2009. As it can be seen, it is very low for ozone and it is generally ≤ 0.5.

In Fig. 7. scatter plots for the same period are shown. As it can be seen in Fig. 7., O_3 max modeled values are 96.4% inside the range ±30% and 86.7% inside ±20%. A very good result considering also that it is related to the summer period when most of the ozone pollution events take place.

PM10 results are not as good as ozone since the system present a significant underprediction.

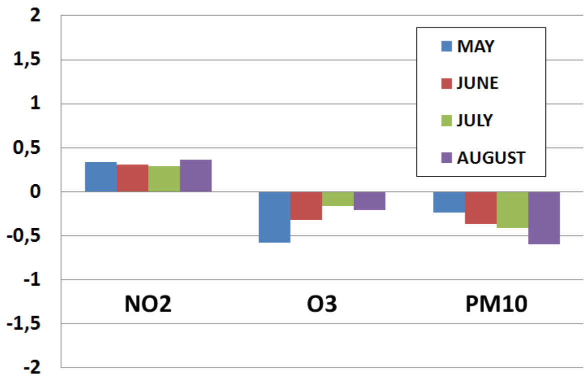

Fig. 5. Fractional Bias (FB) for NO_2, O_3 and PM10.

This is largely due to the impossibility of comparing point receptors (monitoring stations) to model grid cells of 6x6 km^2. This factor affects specially those pollutants, like PM10, characterized by high spatial and temporal variability where even 1x1km^2 is not enough to reveal hot spots**.**

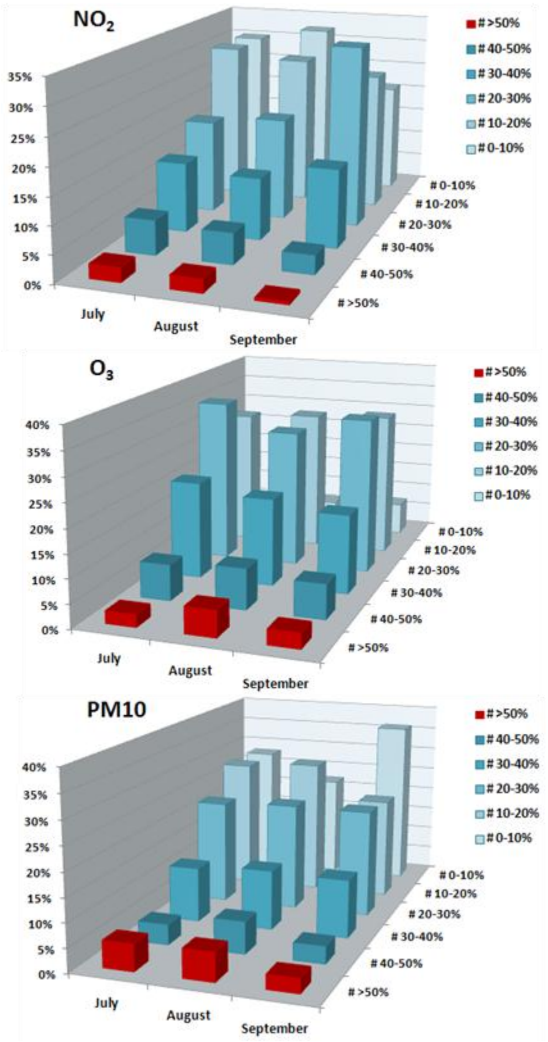

Fig. 6. EVA with values exceeding the regulatory target depicted in red.

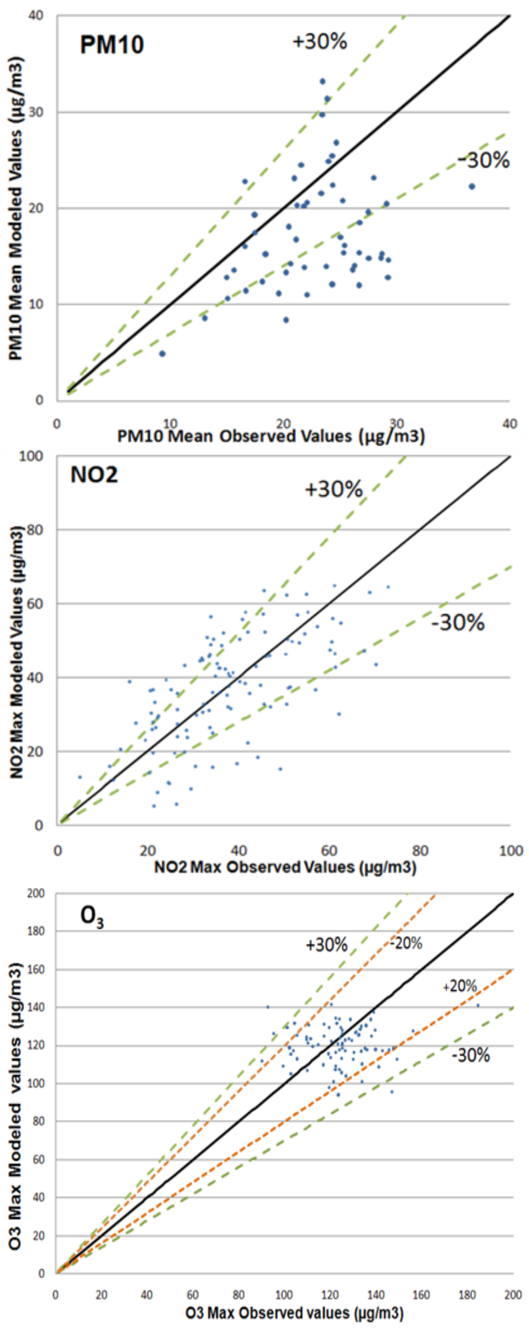

Fig. 7. Scatter plots for PM10, NO2 and O3.

7 SUMMARY AND FUTURE PLANS

During the last two decades, by the time of The Urban Airshed Model (UAM, Morris and Meyers, 1990), huge progresses in air quality modeling have been made. These advances have been made mainly thanks to improvement in meteorology forecasting and computer capabilities.

The AQM system has been continuously brought up to date, resulting in a state-of-the-art capability.

The chemistry model will be soon upgraded to CB-V chemical mechanism. The meteorology component is leaving MM5 in favor of WRF.

In order to assure consistent BC to CMAQ a dispersion-chemistry global model is under implementation. Improvements in emission estimations are under study, especially those related to road-transport and natural sources.

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