ANALYSIS OF THE INTEGRATED ENVIRONMENTAL AND METEOROLOGICAL FORECASTING AND ALERT SYSTEM (SIAM) FOR AIR QUALITY APPLICATIONS OVER DIFFERENT REGIONS ON THE IBERIAN PENINSULA

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Abstract: SIAM is an integrated prediction-alert system which provides environmental information. The aim of this system is to provide prediction and hindcast products operationally in order to alert the exceedance of critical air quality thresholds. SIAM tool has been developed in order to help performing a better management of the impacts and the conflictive situations that this environmental phenomena may cause, and to be a warning communication system to authorities and population of health and environmental risks. SIAM is applied in different regions obtaining different meteorological variables and pollutant concentrations.

Key words: *Air Quality Modelling, CMAQ, Alert System, Forecast.*

INTRODUCTION

SIAM is a functional system that integrates emissions and high resolution weather forecast in a photochemical model, obtaining a management tool that allows:

- to evaluate the potential environmental impact of industrial activity, allowing to take optimum steps in advance (increase or decrease production);
- and to perform scenarios for decision-making and development of protocols.

The application has been designed and applied in different areas, and it has been tested in urban and industrial environments.

INTEGRATED MODELLING SYSTEM

The basis of this system is the coupling of meteorological models with applied models providing information organized in different units based on the field application. The Weather Research and Forecasting (WRF, Skamarock and Klemp, 2008) modelling system is the base of the system. Initial and boundary conditions are obtained from GFS (Global Forecast System) run by NOAA. The WRF model is coupled with an air emission model developed by Meteosim, called AEMM (Air Emission Model of Meteosim), and with an EPA photochemical model, CMAQ (Community Multiscale Air Quality, Byun and Ching, 1999), in the air quality application. CMAQ is a numerical, deterministic, Eulerian, photochemical model, applied at regional and local scale. This model enables to solve the equation for the conservation of different atmospheric pollutants through a generalized coordinates system. SIAM system works operationally in high-computation cluster with 27 nodes and more than 150 cores. These models are configured with the parameterizations according to Table 1.

Table 1. Modelling numerical options

Configuration	Physical and chemical options
Arquitechture	2-way nesting (WRF) and 1-way (CMAQ)
Time-step and levels	90 s and 32 levels
Cumulus	Grell 3D (Grell and Debenyi, 2002)
PBL Scheme	Yonsei University (Hong et al., 2006)
Microphysics	Lin (Chen and Sun, 2002)
Radiation Scheme	GFDL – lw (Schwarzkopf and Fels, 1991) & MM5 scheme – sw (Dudhia, 1989)
Land Surface Scheme	Noah LSM (Chen and Dudhia, 2001)
Surface Layer Scheme	Eta similarity (Janjic, 2002)

Anthropogenic Emissions	Air Emission Model of Meteosim (AEMM).
Dust emissions	Dust emissions in AEMM (Marticorena and Bergametti,1995; Vautard et al. 2005).
Biogenic Emissions	Guenther parameterizations (Guenther et al., 1994)
Sea-salt emissions	Sea-salt emissions in CMAQ
Gas-phase mechanism	CB05 (Yarwood et al., 2005)
Aerosol module	AERO5 (Carlton et al., 2010)
Photolysis scheme	Photolysis rates from JPROC and PHOT modules (Byun and Ching, 1999)

In figure 1 we can see the examples corresponding to the north-west of Spain with a scheme of 25-5-1 km of horizontal resolution; and corresponding to the area of Catalonia in north-east of Spain, 27-9-3-1 km

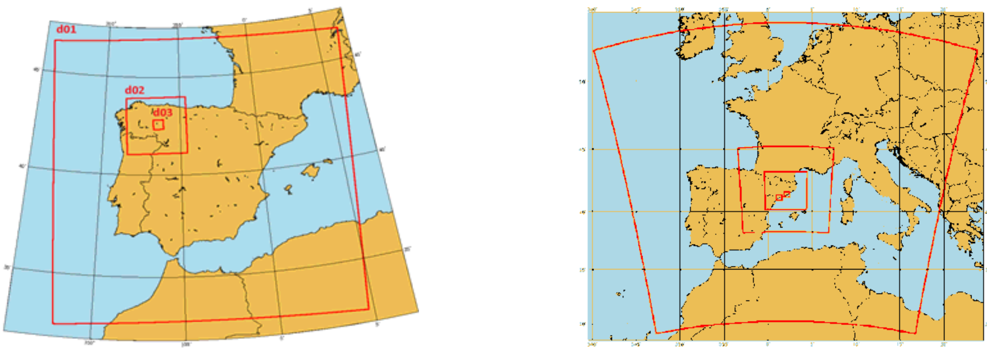

Figure 1. Architecture domains.

Emissions

Emissions in SIAM are calculated by the Air Emissions Model developed Meteosim (AEMM, figure 2). It is a numerical, deterministic, Eulerian and local-scale model. AEMM allows obtaining the intensity of emissions in different areas, either anthropogenic (traffic, industry, residential, etc.) or natural (emissions caused by vegetation or erosion dust). This model combines two emission calculation methods: top-down and bottom-up. The first is based on the space-time disaggregation of lower-resolution inventories (e.g.: EMEP or EDGAR) in accordance with land use and statistical functions associated with different socio-economical variables. Through the second method the model calculates the cell-to-cell emissions from the relevant domains based on emission factors (EMEP/EEA or EPA) or local emission inventories (e.g.: PRTR or autonomic inventories). AEMM is designed to work with various chemical mechanisms (CB4, CB5, SAPRC, AERO4, AERO5) and it is adaptable to other chemical mechanisms. AEMM is coupled to the meteorological model WRF and to the CMAQ photochemical model, and may be coupled to other models.

SIAM as tool for improvement and forecast air quality

To evaluate the system Meteosim considers the concept of “model uncertainty” referred in the European Directive EC/2008/50. This concept allows us to use SIAM as tool for improvement and forecast air quality if uncertainty conditions are fulfilled.

The uncertainty for modelling 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”. To calculate SIAM uncertainty we use the definition of the Maximum Relative Directive Error (MRDE) proposed on the Guidance on the use of models (Denby et al., 2010). Using MRDE we conclude and verify that SIAM accomplishes the model uncertainty limits according with the Directive for the pollutants O_3, NO_2, PM_{10}, SO_2 and CO in all the regions where SIAM application has been developed.

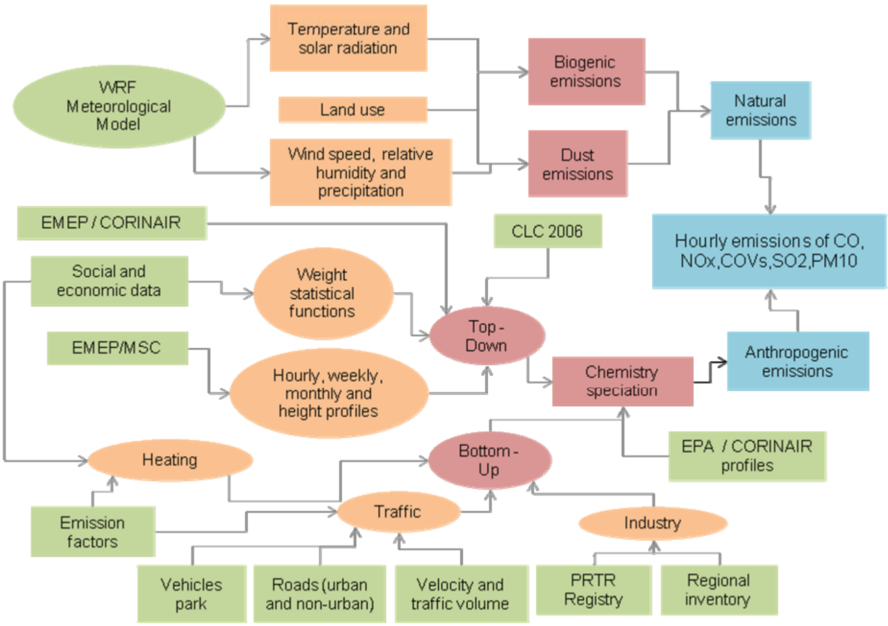

Figure 2. Air Emission Model Scheme.

Moreover, SIAM could be a very useful tool to introduce improvement plans of air quality in urban areas. In this way, a special module of SIAM has been developed to evaluate measures as: rejuvenation of vehicles park; traffic restrictions (affecting to the density flow of vehicles); replacement of diesel use by natural gas in urban buses; velocity limiting access to urban areas; or control scenarios of emissions in industries.

SIAM PLATFORM

A user web-interface with exclusive and restricted access has been developed to allows the user to consult all applications integrated in different modules. SIAM user is able to visualize modelling outputs.
SIAM contains several: geographical visualization of forecast (hourly and statistical values) of each model that integrates the system; tabular information in the same location where exists air quality stations and daily profiles for different variables; and an alert system for administrative regions representing the alarm level associated with each risk. Besides, the system generates automatic reports including mapping, graphical and tabular information.

Furthermore, the user is able to interact with the modelling system, e.g., adding new industrial emissions, a new topography, a new modelling domain or modifying the alert thresholds. SIAM configuration (selected by the user through web-interface) is sent as an input to the modelling system. After the modelling system is executed, a web server display prepares maps, time series and checks the defined alert thresholds to be available to consult through the SIAM web-interface.

The system is completed with an alarm system levels associating different meteorological and air quality variables with different risk or alarm levels shown in table 2.

Table 2. Alarm system levels and definitions

Risk	Green Level	Yelow Level	Orange Level	Red Level	Variable or Parameters
Wind	$<20ms^{-1}$	$20\text{-}30ms^{-1}$	$30\text{-}40ms^{-1}$	$>40ms^{-1}$	Hourly gust
Rain	<20mm	20-40mm	40-90mm	>90mm	Hourly Rain Convective and Non Convective

Frost	--	RH=100 % T < 0ºC 0.375<CC<0.500	RH=100 % T < 0ºC 0.250<CC<0.375	RH =100 % T < 0ºC CC < 0.250	Hourly 2-m Temperature Hourly 2-m Relative Humidity Cloud Cover
Visibility	Vis>50Km	10<Vis<50Km	1<Vis<10Km	Vis < 1Km	Hourly Visibility
Heat Wave	< 35ºC	35-38 ºC	38-41ºC	>41ºC	Daily maximum 2-m temperature
Cold Snap	> -4 ºC	(-4) – (-8)	(-8) – (-12) ºC	< -12 ºC	Daily minimum 2-m temperature
NO_2	--	NO_2 max1h > 100 µgm^{-3}	NO_2 max1h > 200 µgm^{-3}	NO_2 max1h > 400 µgm^{-3} during 3-consecutive hours	NO_2 – Maximum daily 1-h mean
CO	--	CO max 8h > 5 mgm^{-3}	CO max 8h > 10 mgm^{-3}	CO max 8h > 15 mgm^{-3}	CO – Maximum daily 8-h mean
SO_2	--	SO_2 diario > 125 µgm^{-3}	SO_2 max 1h > 350 µgm^{-3}	SO_2 max 1h > 500 µgm^{-3} during 3-consecutive hours	SO_2 – Maximum daily 1-h mean and daily value
PM_{10}	--	PM_{10} dia > 25 µgm^{-3}	PM_{10} dia > 50 µgm^{-3}	PM_{10} dia > 75 µgm^{-3}	PM_{10} – Daily value
O_3	--	O_3 max 8h > 120 µgm^{-3}	O_3 max 1h > 180 µgm^{-3}	O_3 max 1h > 240 µgm^{-3} during 3-consecutive hours	O_3 – Maximum daily 1-h and 8-h mean

* RH corresponds to relative humidity; ** T corresponds to temperature at 2 meters; *** CC corresponds to cloud cover.

In figure 3 we present some snapshots of SIAM system corresponding with the geographical visualization, tabular information and alert system for different regions.

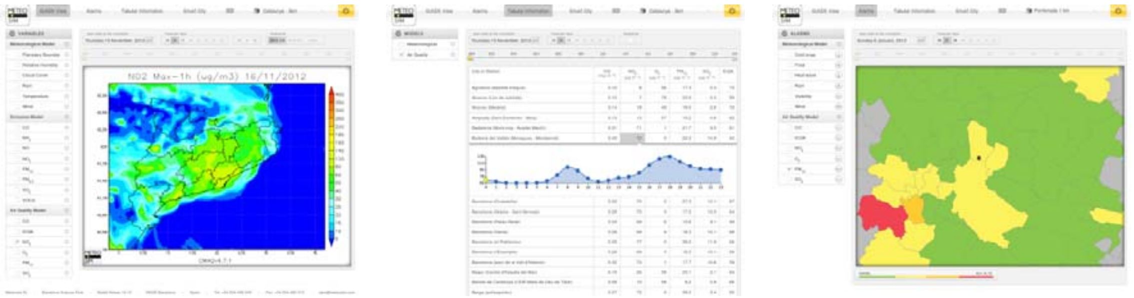

Figure 3. Examples of SIAM view.

SIAM and Smart Cities

Cities occupy less than 0.1% of the land area, but 50% of the total population is living in these cities. According to UN data, this percentage is expected to increase up to 60% by 2030. These population cluster cores generate the largest amount of gases and aerosols emitted into the atmosphere, influencing weather and climate (Crutzen, 2004). And in turn, they represent a source vulnerable to extreme weather events thus affecting the associated air quality in the region. For this reason, and with the aim of increase urban competitiveness and living standards of the population, we have coupled SIAM as a module in smart cities technologies. The system lets to plan and manage production, human resources, activities and emergency proceedings. In this way, SIAM works as a useful tool for air quality responsible of local administrations. The development of SIAM allows providing an information system of alerts in case that extreme events or exceedances happen. In this module SIAM incorporates a geographical visualization of measurements around the cities, and integrates the instrumental information to the modelling, therefore the quality of the forecasts increases and the uncertainty decreases.

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