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The use of a modelling system as a tool for air quality management: Annual high-resolution simulations and evaluation

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ABSTRACT

The high levels of air pollutants over the North-Western Mediterranean (NWM) exceed the thresholds set in current air quality regulations. They demand a detailed diagnosis of those areas where the exceedances of thresholds related to human health are found. In this sense, there is a need for modelling studies for the specific area of the NWM that take into account the annual cycle to address the diagnosis of air pollution. A new approach to the modelling of air quality in the NWM has been adopted by combining the WRF-EMICAT-CMAQ-DREAM modelling system to diagnose the current status of the levels of photochemical air pollution (focusing on ozone, O_3; nitrogen dioxide, NO_2; carbon monoxide, CO; and particulate matter, PM10) in the area during an annual cycle (year 2004). The complexity of the area of study requires the application of high spatial and temporal resolution (2 km and 1 h). The annual simulations need to cover the complex different meteorological situations and types of episodes of air pollution in the area of study. The outputs of the modelling system are evaluated against observations from 52 meteorological and 59 air quality stations belonging to the Environmental Department of the Catalonia Government (Spain), which involve a dense and accurate spatial distribution of stations in the territory (32,215 km^2). The results indicate a good behaviour of the model in both coastal and inland areas of the NWM, with a slight trend to the overestimation of tropospheric O_3 concentrations and the underestimation of other photochemical pollutants (NO_2, CO and PM10). The modelling diagnosis indicates that the main air quality-related problems in the NWM are the exceedances of the 1-hr O_3 information threshold set in the Directive 2002/3/EC (180 $\mu g\ m^{-3}$) as a consequence of the transport of O_3 precursors downwind the Barcelona Greater Area (BGA); and the exceedances of the annual value for the protection of human health for NO_2 and PM10 (40 $\mu g\ m^{-3}$, Directive 1999/30/EC), both in the BGA, as a consequence of the high traffic-related emissions.
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1. Introduction

The impact of air pollution, especially by ozone and particulate matter, is a key subject in climate and the environment (Akimoto, 2003; Baldasano et al., 2003). According to a study of the European Environmental Agency (EEA, 2005), air pollution is the environmental factor with the greatest impact on health in Europe and is responsible for the largest burden of

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environment-related diseases. Particulate matter and especially small particles with a diameter less than 2.5 μm (PM2.5) are associated with increased mortality, especially from cardiovascular and cardiopulmonary diseases. The societal cost of asthma has been estimated at 3 billion euros per year.

In Europe, the mother Directive 1996/62/EC on air quality establishes the basic principia of a European common strategy to set the air quality objectives to avoid; prevent or reduce the harmful effects on the health and the environment. One of the topics in which the European Commission has shown a greater concern through initiatives as GMES (Global Monitoring for Environment and Security) is the necessity of developing actions that allow increasing the knowledge on transport and dynamics of pollutants to assure the accomplishment of legislation and to inform the population about the levels of pollutants, especially before 2010, date when directives 1999/30/EC and 2002/3/EC come into effect. The regulation is especially demanding when the threshold levels are exceeded. In this case, it demands a detailed diagnosis of those areas where the exceedances are found. Namely, the directive establishes the possibility of using modelling techniques to assess air quality.

A number of studies (e.g. Ziomas et al., 1998; Sanz and Millán, 1998; Sanz et al., 2000; Dueñas et al., 2002; Ribas and Peñuelas, 2004; Palacios et al., 2002, 2004) shows that the north-western Mediterranean Basin (NWM) frequently exceeds the thresholds of air quality established in the legislation. Additionally, not only the anthropogenic pollution contributes decisively to the failure in the meeting of European directives. Thus, the atmospheric mineral dust coming from deserts all around the planet represents an essential contribution to the content of tropospheric aerosols. The Sahara reveals as one of the most important dust sources, being northern Africa responsible for half of the global emissions of mineral dust. In the Iberian Peninsula, the mineral fraction of suspended particles comes from the local re-suspension and external contributions such as the Saharan/Sahelian dust (Pérez et al., 2006a,b), contributing to the exceedances of the PM10 limit values of Directive 1999/30/EC (Artíñano et al., 2001; Rodríguez et al., 2001; Rodríguez et al., 2002; Querol et al., 2004).

Under this perspective, air quality modelling is a useful tool for managing and assessing photochemical pollution that has been extensively used worldwide (e.g. Streit and Guzmán, 1996; Reis et al., 2000; Vinuesa et al., 2003). Historically, the models used for air quality assessment involved simplified Gaussian approaches or simply box models. The use of Eulerian models, which include a more realistic description of the atmosphere (especially in urban areas), has become more frequent during the last years (Seinfeld, 1988; Russell and Dennis, 2000). This work presents an assessment of the situation related with air quality for the year 2004 through high-resolution air quality modelling, focusing in the NWM. For that purpose, we have developed, implemented and validated an integrated air quality modelling system with a high resolution (2 km for the NWM), formed by a set of models that take into account both anthropogenic and natural pollution. The modelling system used for air quality simulations is WRF (meteorology)/EMICAT (emissions)/CMAQ (chemistry transport). The DREAM natural dust model (Nickovic et al., 2001) is finally used to estimate the mineral dust contribution. Despite the most important problems come from urban areas, the mesoscale models used through nested simulations have shown its efficacy when assessing air quality problems in cities, especially in areas with a complex topography as coastal regions (Fenger, 1999); in certain seasons, the urban areas can significantly affect and be affected by sources located hundreds of kilometres far from the point of study (Kallos, 1998). The models used represent the state-of-the-art in air quality modelling; they are highly supported and their behaviour is well-know for the NWM (e.g. Jiménez and Baldasano, 2004; Jiménez et al.; 2005a,b, 2006a,b).

2. Methods

The main objective is to assess the air quality in the NWM on an annual basis corresponding to the year 2004, focusing on the determination and diagnosis of the problems and exceedances related with tropospheric ozone (O_3), nitrogen dioxide (NO_2), carbon monoxide (CO) and particulate matter (PM10); as well as the evaluation of the results against air quality observations for the entire year 2004. Finally, an analysis of the obtained results with the simulations on an annual basis is compared with the thresholds established in the European regulations, assessing then the current status of air quality problems in the NWM.

The domains of study defined for the simulations are: Europe (D1, horizontal resolution of 54 km); the Iberian Peninsula (D2, 18 km); the north-eastern Iberian Peninsula (D3, 6 km) and NWM (D4, 2 km), despite the study focuses on D4. The domain covers 272 km × 272 km^2. This high resolution for this domain is needed because of the complexity of the area of study in order to describe the transport and transformation of pollutants, as well as the dynamics on an hourly basis (Jiménez et al., 2005a, 2006b). The relationship among the different domains simulated can be found in the Fig. 1. The Weather Research and Forecasting (WRF) Model (Michalakes et al., 2005; Skamarock et al., 2005) provides the meteorology dynamical parameters as inputs to CMAQ. The WRF model represents a next-generation mesoscale numerical weather prediction system designed for operational forecasting needs. WRF dynamical and physical options used for the simulations are: ARW dynamical core; Yonsei University PBL scheme; Kain-Fritsch cumulus scheme; single-moment 3-class microphysics' scheme; RRTM for long-wave radiation scheme and Dudhia scheme for short-wave scheme; and the Noah Land Surface Model. Initialization and boundary conditions for the mesoscale model are introduced with forecast data of the Global Forecast System of the National Center for Environmental Prediction (NCEP). Data are available at a 0.5-degree resolution (50-km approx. at the working latitude) at the standard pressure levels every 6 h. 366 simulations of 36 h have been performed (from 12 UTC of the previous day to the 00 UTC of the following day, with the aim of performing a cold initialization with 12 h of spin-up).

The high resolution (1 h and 1 km^2) EMICAT emission model (Parra et al., 2006) has been applied to the domain. This model includes the emissions from vegetation, road-traffic, industries and emissions by fossil fuel consumption, domestic/

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