ICCS 2015
International Conference on City Sciences
New architectures, infrastructures and services for future cities
Shanghai, 4-5 June 2015
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Development of urban air quality plans and measures in Madrid (Spain) under a multi-scale air quality modeling approach

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INTRODUCTION

Poor urban air quality is one of the main environmental concerns worldwide. According to WHO (WHO, 2014) outdoor air pollution caused 3.7 million premature deaths in 2012, most of them in urban areas where both, emission sources and population concentrate. Even in Europe, despite of significant efforts, exceedances of air quality standards are common in large urban areas, particularly for NO_2 (EEA, 2014). Therefore, tackling urban air quality constitutes a pressing priority from the social and political point of view. However, air pollution dynamics in urban environments is extremely complex and the design and assessment of effective emission abatement plans and measures posses a major scientific challenge. Emissions of different pollutants from a variety of sources interact through intertwined atmospheric transport processes and chemical transformations involving several spatial and temporal scales. In this context, air quality modelling constitutes an essential research tool for understanding and simulating the potential effect of emission abatement measures as well as to identify the best course of action to improve air quality in cities. This contribution reflects on the inherent complexities of urban air pollution and the development of air quality plans for the Madrid city as a representative case study.

METHODOLOGY

Last-generation, 3D Eulerian models including full photochemical schemes can consistently describe transport and transformation processes of air pollutants from continental to urban scale. This is possible due to scalable physics and thermodynamics (governing equations, variable states and coordinate system), nesting capability and a modular coding structure and wide range of representation for scale-dependent processes. For this particular study the WRF (Skamarock and Klemp, 2008) – CMAQ (Byun and Schere, 2006) modeling system was used. The modeling system was run in four nested domains with increasing spatial resolution, from 48x48 km^2 down to 1x1 km^2 in the Madrid metropolitan area (Figure 1).

Domain	Spatial resolution (km)	Dimensions (km)		Vertical levels
		x	y	
D1	48	6144	5376	30
D2	16	1200	960	
D3	4	192	192	
D4	1	40	44	

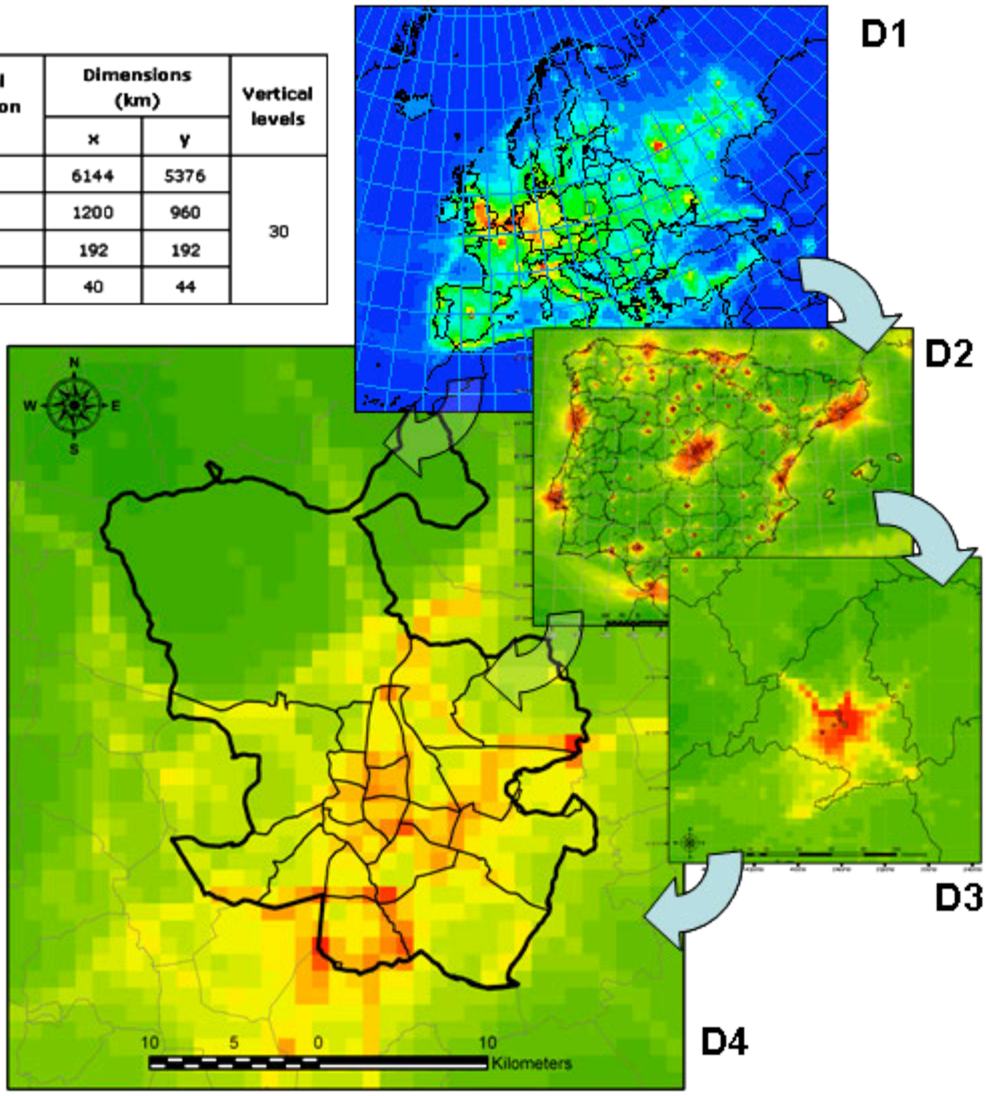

Figure 1. CMAQ modeling domains

A multi-scale modeling approach implies the need of reliable and flexible inventories that describe relevant emissions consistently across the scales while meeting the requirements of the chemical-transport model. Emissions from continental, national, regional and local inventories were processed and harmonized to achieve a consistent representation through the application of common methodological concepts for emissions computation combined with representative and consistent statistics at each geographical domain (Borge et al., 2014). The compilation of the emission inventory for the innermost domain (D4) combined bottom-up and top-down computation methods paying special attention to keep the consistency across domains / inventories. It involved very detailed, source-specific methods such as the integration of the regional traffic demand model used by the Madrid City Council in the inventory for the computation of high temporal and spatial resolution emissions from road traffic. These methods where flexible and detailed enough to reflect the outcome of relevant emission reduction measures.

Once the model was properly setup, tested and assessed, a source apportionment study was made to understand external constrains (i.e. influence of non-controllable emissions sources), define the basic emission abatement strategy / course of action and to help identify the maximum feasible AQ improvement related to the main emitting sectors. The contribution of particular emission sources and regions where estimated through single-perturbation or brute force method (BFM) (Borge et al., 2014). The results demonstrate that road traffic should be the main target of local measures to improve NO_2 levels in Madrid. Consistently with these findings, a series of traffic-related measures such as the definition of a Low Emission Zone (LEZ), reduction of road capacity and pedestrianized areas in the city center, and renovation of city bus fleet to incorporate clean technologies (electric and hybrid natural gas-fuelled busses) were included in the Madrid Air Quality Plan (Madrid City Council, 2012).

The air quality modelling system was also applied to simulate the additional effect of temporal traffic restrictions under high pollution episodes in order to reduce peak concentration values under unfavourable meteorological episodes. In addition, strategies to couple even finer-resolution models are being investigated to expand the capabilities of the modelling system so additional microscale measures can also be taken into account to deal with remaining hot-spots throughout the city.

RESULTS

The application of multi-scale modeling techniques including the development of consistent emission inventories to model NO_2 ambient air concentration levels in Madrid demonstrates the capabilities of these numerical tools to support the development and assessment of air quality plans in urban areas. The results show that by acting on the road traffic sector, emissions can be significantly reduced. Measures aimed at reducing passenger cars mobility in the city centre with an impact on traffic flows in the whole metropolitan area have been found the most effective way to improve air quality in Madrid. According to the simulation, actions taken only during adverse meteorological conditions have a limited effect. Although the modeling study performed has been useful for the purposes stated, additional research is needed for further refinement and enhancement of the modeling techniques in order to provide a more consistent and holistic view of urban air quality issues and therefore a more solid basis to leverage the abatement burden through the sources taking into account all the relevant scales within the city. This is the main goal of the TECNAIRE-CM research project that intends to provide new methods for monitoring and modeling air pollution that can consistently describe urban pollution dynamics from the regional to the street scale.

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