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USING THE WRF/CHEM MODEL TO EVALUATE URBAN EMISSION REDUCTION STRATEGIES: MADRID CASE STUDY

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Abstract

In the cities, traffic emissions are the largest contributor to the exceedances of NO2 limit values. It is necessary to develop tools to evaluate if the traffic measures can reduce the air pollution. EMIMO-WRF/Chem air quality modeling system (1 km) has been used to assess the effectiveness of emergency measures based on traffic restrictions to reduce concentrations of air pollutants *during the NO2 pollution episode in the city of Madrid. Two simulations were designed: "REAL" including traffic restrictions and "BAU" representing what would happen if no action were taken. The difference between the two simulations (BAU-REAL) gives us the contribution of traffic restriction measures to reduce concentrations of pollutants in the air. An evaluation of the modelling system's performance has previously been carried out and found to be very satisfactory, demonstrating that the proposed system can be used to simulate pollution episodes in cities. The results indicate that the daily concentration of NO2 decreased by only about 1.3 % and so the measures taken were not sufficiently effective compared to the traffic reduction effort that reached around 10 %. More effective measures must be explore and analyze with the proposed tool.*

Keywords

WRF/Chem, Urban emission, Madrid air quality

1. Introduction

The relationship between increased morbidity and mortality and exposure to different atmospheric pollutants is becoming more and more evident. This relationship has been demonstrated in several published epidemiological studies (Pope and Dockery, 2006; Zhang et al., 2012). Motor vehicles are the main anthropogenic contributors to air pollutant emissions in cities (Duclaux et al., 2002; European Environment Agency, 2003). Annual limit of the NO_2 concentrations is 40 µg/m3 and the hourly limit of 200 µg/m3, can't be exceeded more than 18 times per year. These limits are exceeded in most major European cities, Madrid, London, Paris, etc. Vehicles contribute more than 40% of NOx emissions in the European Union (Heiko 2018). Diesel cars are the main contributor to the NO2 (Carslaw et al 2016). Improving air quality in cities is currently one of the most important concerns. The reduction of nitrogen oxide emissions has historically been one of the main objectives to try to improve air quality in European cities. Nitrogen dioxide is a problem for many cities, such as Madrid, due to its toxicity and the key role it plays in tropospheric ozone formation in summer (Seinfeld et al., 1998). Since road transport is the main contributor to urban air pollution, it is necessary to develop control strategies that minimize environmental impacts but maximize the efficiency of motor transport. Public administrations are testing management strategies aimed primarily at reducing road traffic emissions. These strategies are aimed at either reducing the number of vehicles circulating in cities or mitigating emissions per vehicle. These strategies are medium- or long-term, but are not suitable for emergency situations such as a single pollution episode. Some municipal authorities have developed short-term or emergency actions to try reducing emissions during high pollution episodes because the effects of the permanent actions are very slow and they don´t get to reduce the air pollution in the cities. This is the case of Madrid, where during the NOx episode analysed in this study, only odd-numbered vehicles were allowed into the city, but this type of short-term measures have not been previously evaluated to measure their effectiveness. The first example of such decisions was in Paris on 1 October 1997. At that time, only vehicles with odd numbered registration plates were allowed into the city. Residential parking was free of charge to try to persuade travelers to abandon their cars, and industrial activities decreased. Some 1.000 police officers were deployed to enforce the restrictions. Traffic levels in the center of Paris decreased by 17%, in the ring road by 6%, and around Paris by 14% and concentrations of NO2 were below 300 ug/m3, having exceeded 400 $\mu g/m^3$ the previous days. But, was the reduction due to measures taken or did other factors such as the weather influence? These responses can only be addressed through advanced air quality simulation and modelling systems. Tools are needed to model in detail the spatial and temporal changes of a city's emissions and concentrations when traffic limitation measures are to be applied during a pollution episode to know before applying whether or not it will be an effective measure. The effectiveness of a measure depends on many factors that must be taken into account by the modelling system, such as: the size of the traffic limitation area, the type of vehicles selected for the limitation, the general age and composition of the vehicle fleets, the number and type of vehicles exempted, the level of application and availability, weather conditions, affected days of the week, etc.

One of the ways to assess air quality impacts in complex environments such as cities and the effectiveness of emission reduction strategies is to use an air quality modelling system that includes several models: traffic model, emission model and dispersion-chemical model at different scales. The modelling of vehicle air pollution is essential to find optimal strategies for reducing traffic emissions. Pollutant concentrations depend primarily on traffic and weather conditions. Traffic models can predict the position and speed of vehicles and emission models can estimate the amount of pollution emitted by vehicles. The dispersion of pollutants in the atmosphere can be modelled using atmospheric dispersion models that require meteorological information from meteorological models. The accuracy of the results will depend to a large extent on the reliability of traffic data (traffic volume and speed, its temporal and spatial variations, the composition of road vehicles, etc.) and the emission factors chosen for each type of vehicle. Traffic data are usually obtained by in situ observation, but generally measurements are only made on a limited number of streets or roads. The amount of data observed is often insufficient to adequately quantify traffic on a complete urban network. In order to estimate traffic throughout the city and thus calculate its emissions, an approximation is to make a spatial extrapolation with many assumptions to assign traffic volume to the points where it is not measured, but this requires making many assumptions that in most cases will not be met (Jensen et al. 2001), generating data with great uncertainty. Another methodology that can be used is to distribute traffic emissions over grid cells of the model, resulting in an average emission rate based on roads or streets but without taking into account actual network traffic (Cohen et al. 2005). These indirect methods allow to model the emissions but with a big uncertainty. That is why it is necessary to use a traffic model, as we are going to present in this work, which allows us to know in great detail all traffic data in the entire city.

This research focus on to investigate impacts on urban pollution of real traffic restrictions applied in the city of Madrid during a critical NOx episode. Changes in air quality are assessed using the EMIMO-WRF/Chem modeling system. We also show how the proposed air quality modelling system can be used to reproduce pollution episodes in cities. Other measures can also be evaluated as change the car transport to bicycling and walking (Rabl and de Nazelle, 2012).

2. Methodology

This section describes the modeled NOx episode in Madrid, the proposed air quality modelling tool and the experiment to evaluate the effectiveness of traffic restrictions applied in the city of Madrid during the episode.

2.1 Episode

Madrid is a city of about 3.5 million inhabitants with a population density of 5208 inhabitants/km2. The city is surrounded by 4 ring roads, the inner ring M30 is the boundary of the Central District. The road network in the city centre is very dense, with a high volume of traffic. In 2016, the city of Madrid approved a new protocol for high levels of nitrogen dioxide pollution. Four scenarios are considered depending on the pollution concentration of the different measuring stations in the city. The scenarios add new traffic restriction measures as the level of NO2 alert increases. Traffic restriction measures range from a reduction of the speed limit (70 km/h) on the M30 road and its access (scenario 1) to a complete traffic restriction in the city centre (scenario 4). Intermediate scenarios also consider a downtown parking restriction (scenario 2) and a partial traffic restriction depending on the license plate (scenario 3). In the episode analysed in this work, it was activated up to scenario 3 as detailed below. In December 2016, the levels of N02 in Madrid were so high that authorities restricted access to the city centre for half of the cars based on whether the license plate was even or odd. The episode occurred from 26 to 30 December 2016, during which NO2 hourly concentrations reached 200 µg/m3 in several monitoring stations. The worst monitoring stations, where the maximum levels of NO2 were reached were: E. Aguirre station located east of the city, C. Caminos station is located north of the city center and F. Ladreda station that is outside the city center and is located south of the city, so the whole city recorded high concentrations of NO2 those days. All three stations are classified as traffic stations and are therefore highly affected by traffic emissions. Figure 1 shows the temporal evolution of NO2 concentrations in the three monitoring stations mentioned above and the location of all stations of the Madrid air quality network. E. Aguirre station measured 286 ug/m3 on 27/12/2016 20:00 hours.

During the NO2 episode, several traffic restrictions were adopted by the Madrid municipality according the Madrid Air Quality Plan 2011-2015. Figure 2 summarizes the actions for each day. On Wednesday, December 28, the city of Madrid temporarily banned parking in the city center by non-resident car drivers and restricted speed limits on the main highway (M30) to 70 km/h instead of 90 km/h. Non-residents were prohibited from parking from 9:00 a. m. local time until 9:00 p. m. within the regulated parking lots. The restriction of access to the city centre for private vehicles was applied on Thursday 29th December, only the odd number plates could access the inner area delimited by the road M30 (city centre). It was activated between 6:30 a. m. and 9:00 p. m. There are several exceptions to the ban, such as motorcycles, hybrid cars, vehicles of three or more people or vehicles for people with disabilities. Buses, taxis and emergency vehicles are also excluded. The measurement was triggered when the previous day's nitrogen dioxide levels in the atmosphere exceeded 180 µg/m3 and predictions did not ensure the weather conditions needed to improve air quality the next day.

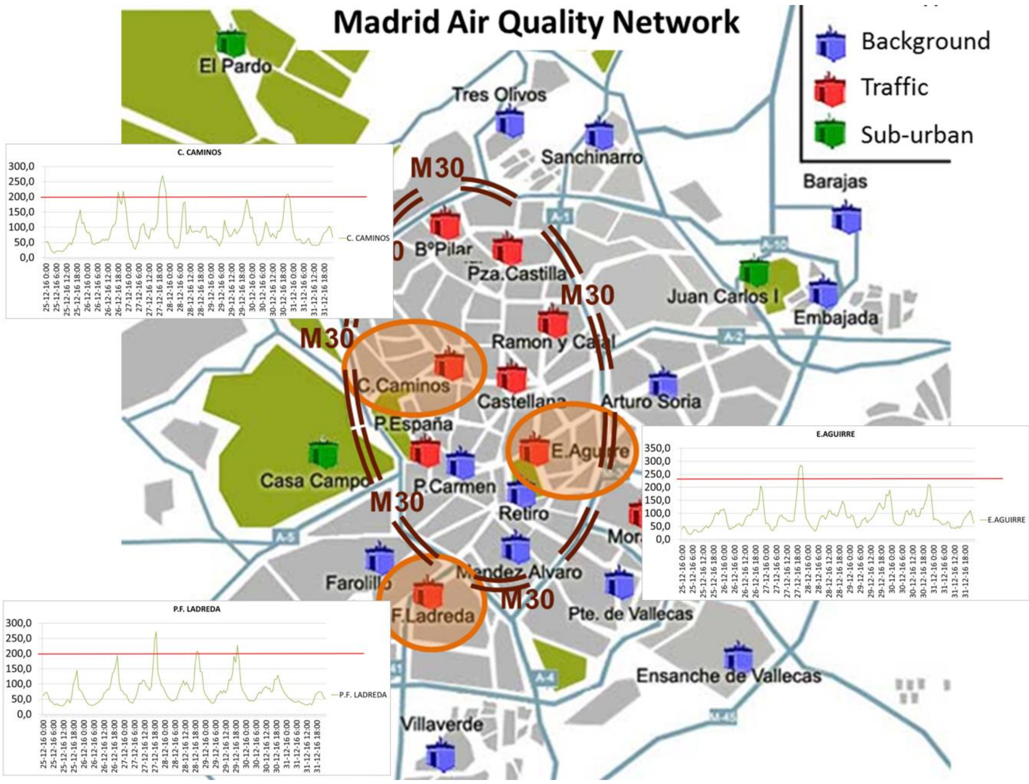

Figure 1: *Map of the Madrid air quality monitoring network and hourly values of NO2 concentrations at the three worst measurement stations on Madrid, during December, 25-31, 2016*

2.2 Experiment

The experiment was designed to achieve two objectives: the first is to show how the air quality modelling simulation system works in a NO2 episode and the second is to evaluate the effectiveness of traffic restriction actions taken to reduce NO2 concentrations during the episode. In order to achieve both objectives, we have designed two simulations, the first of which has taken into account the real traffic situation of those days that included traffic restrictions on Wednesday and Thursday, this simulation has been called "REAL" and includes traffic restrictions on Wednesday 28 (parking) and Thursday 29 (access). This simulation is based on traffic conditions measured by vehicle detectors installed in the city. In the second simulation, we have deactivated traffic restrictions on Wednesday and Thursday, considering that those two days; traffic followed a similar pattern to Wednesday and Thursday of the previous week in which there were no restrictions. In this simulation, traffic conditions are based on the traffic measurements of Wednesday (21), Thursday (22) and Friday (23) of the week prior to the episode. Therefore, in this simulation the same configuration and the same input data has been maintained except that traffic emissions are different considering a "typical" traffic day on Wednesday, Thursday and Friday, so this simulation has been called "BAU" (Business As Usual). Therefore, the only difference between the "REAL" and "BAU" simulation is that traffic restrictions do not apply in the BAU. The BAU simulation represents what would have happened if no action had been taken on Wednesday and Thursday to reduce pollution.

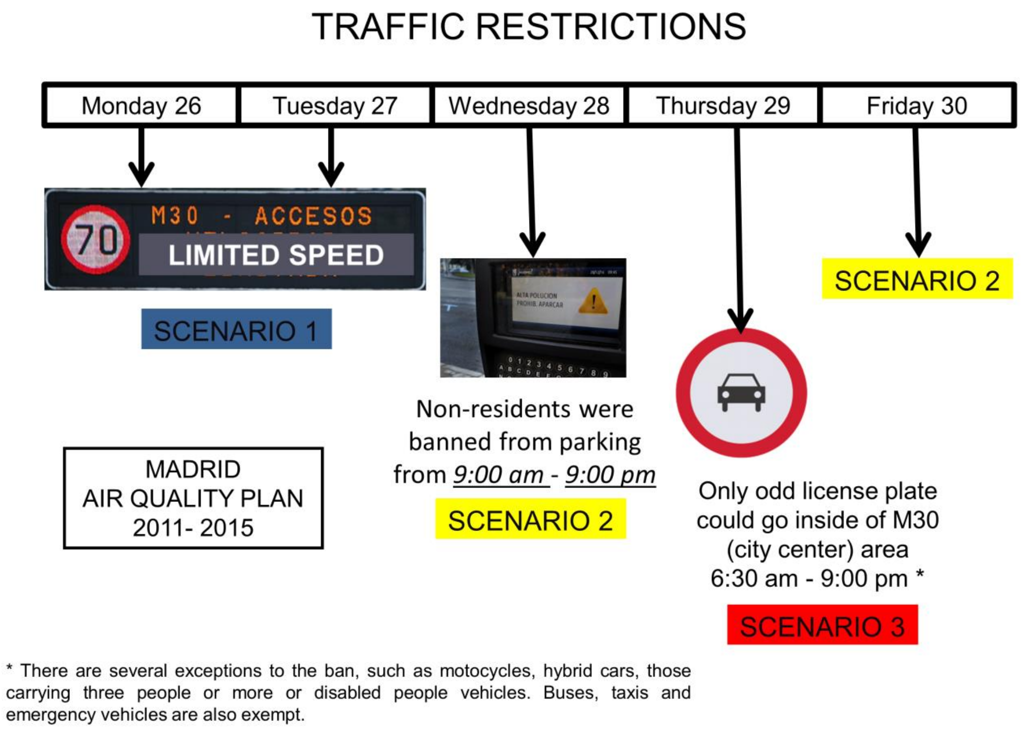

Figure 2: *Scenarios and traffic restrictions applied during the Madrid NOx episode. December 26-30, 2016*

The difference between the two simulations (BAU-REAL) gives us the contribution of traffic restriction measures in reducing concentrations of pollutants in the city of Madrid. The experiment is designed to answer the question: What was the impact of traffic restrictions on air pollution concentrations? This contribution may be either positive (traffic restrictions have reduced concentrations) or negative (restrictions have not improved air quality, but have aggravated pollution by increasing concentrations in relation to BAU simulation). We simulate the concentrations of atmospheric pollutants for the episode from December 25 to 30, 2016. The simulation starts 2 days before the episode for spin-up effects. The experiment is high demand computing exercise. The advances in high performance air quality model codes have allowed running high-resolution simulations and a large number of simulations. In this case we have used the Magerit supercomputer (CESVIMA-UPM).

2.3 Air quality modeling system

The health In order to predict and analyse air pollution problems in cities, it is not enough to know the flow of vehicular traffic and emissions produced by vehicles; in addition, an air pollution dispersion model is needed to predict temporal and spatial variation in air quality. The main input data required for the air quality model are the spatially distributed (1 km) and temporarily resolved (1 hour) emissions provided by the emission model (which in turn requires traffic data) and the meteorological inputs. In this research we have used de EMIMO-WRF/Chem meteorological-air quality modelling system. The EMIMO-WRF/Chem modeling system is a three dimensional, Eulerian simulation system representing the most advanced models in air quality simulations. The Weather Research Forecasting and Chem 3.8.1 (WRF-Chem) (Grell and Dévényi, 2002) has coupled meteorological, microphysical, chemical, and radiative processes. WRF-Chem is a model with an increasing number of users and which has been used to simulate air quality in many cities. On the cases that it has applied to simulate high concentrations of pollutants, the results obtained are very satisfactory (Forkel et al., 2012, Žabkar et al. 2013).

The model WRF-Chem can be configured with several physical and chemical parameterizations. Choosing the best configuration for the type of simulation to be run is very important to obtain good results. In this work, we have configured WRF/Chem to simulate using the same parameters as in the ES1 simulations made for the International Air Quality Assessment Model Assessment Initiative (AQMEII Phase II) (San José et al., 2015). This configuration is already tested and evaluated with very good results. The mother domain of the WRF/Chem model requires initial and boundary weather data to run the simulations. In this experiment we have generated this data from global meteorological data produce by the GFS model (Global Forecast System) of the National Meteorological Service of the United States (NWS) and whose data are freely accessible. In this case we have used the 0.5º resolution datasets.

The EMIMO emission model has been developed at UPM (San José et al., 2008) to estimate emissions of gaseous and particulate pollutants. Regional and non-transport urban anthropogenic urban emissions have been taken from the TNO-MACC-II emission dataset (Kuenen et al., 2014), which was processed during phase II of the European initiative AQMEII (Pouliot et al., 2014). The horizontal and vertical distribution of emissions in the model's grids, their temporal variability (monthly, daily and hourly) and the NMVOC speciation is carried out following Tuccella et al. (2012). Global annual emissions were processed using the EMIMO model and distributed temporarily using profiles from Spain. Emissions are then allocated according to grid cells according to local population and road density in the cells. Biogenic emissions are online estimated based on the Guenther algorithm (Guenther et al., 1993, 1994) which is included in WRF/Chem. For this study, a very important module within EMIMO is the one that estimates road traffic emissions. This module mainly uses a bottom-up approach using the Tier 3 method described in the EMEP/EEA 2016 Inventory of Emissions of Air Pollutants Guide - Update Dec. 2016 (Passenger cars, light commercial trucks, heavy vehicles including buses and motorcycles) that include specific emission factors and cover different engine conditions, which is implemented in Copert 4 (Ntziachristos et al., 2016). Vehicles are classified by category according to fuel type, vehicle weight, age of the vehicle and engine capacity. For each category there are specific emission factors, which in turn depend on the speed of the vehicle. The EMIMO traffic emissions module includes hot exhaust gases, cold exhaust gases and evaporative emissions.

The Madrid vehicle fleet is specifically defined for this study using the data provided by the Madrid vehicle register of December 2016. In addition to the vehicle and fuel type, classification also takes into account the vehicle's engine type, vehicle technology (age of vehicles). More than 600 vehicle categories have been considered in the emissions model. In December 2016, 78% of vehicles were passenger cars, 10% motorcycles and 12% commercial vehicles. The most commonly used fuel is 58% diesel, compared to 42% gasoline. Vehicles over 15 years old account for 27% of vehicles. In December 2016, Madrid had 4397972 registered vehicles. Traffic activity is one of the main input data for estimating traffic emissions. We can use measurements at a certain point, but it is not possible to obtain sufficient measurements for all study area. Therefore, traffic flow for each segment must be supplied by a traffic model. In order to calculate traffic emissions we need to know the number of vehicles, vehicle mileage and speeds. All these entries are obtained through traffic simulations with the SUMO model.

The microscopic SUMO traffic simulation (Krajzewicz et al., 2012) can be used to determine the large-scale effects of traffic management measures. SUMO (Simulation of Urban MObility) is a microscopic, space-continuous and time-discrete (1s.) traffic flow simulation platform. It is mainly developed by employees of the Institute of Transportation Systems at the German Aerospace Center and its source code is open source. In SUMO each vehicle is given explicitly, defined at least by a unique identifier, the departure time, and the vehicle's route through the network. The SUMO tool is composed by three main sub models: a) Car-following model which calculated the speed of a vehicle based on the vehicle ahead. SUMO uses an extension of the stochastic car-following model developed by Stefan Krauß; b) intersection sub model which decides the behavior of vehicles at intersections taking into account right-of-way rules, gap acceptance and avoiding junction blockage and sub-model c) Lane-changing which selected the lane on roads with multiples lines and ajusts the speed by the lane changes.

The first input to SUMO is the road network, which describes the roads and intersections used by vehicles during their journey. The road network can be obtained from OpenStreetMap database. Our road network consists of more than 100,000 streets and road segments. After you have generated a network, the next step is to move the vehicles in the network. SUMO allows you to use traffic detector data to generate traffic demand. The information collected from traffic sensors can be used to construct vehicle routing and volumes. First, random traffic is generated for the road network and then detectors have been used as calibrators, which are used to adjust traffic demand to the measured data. Traffic conditions are extracted from the more than 3,000 detectors located on Madrid's streets and highways and 2/3 of them have been used to calibrate traffic simulations, as explained below. Hundreds of traffic simulations have been carried out for each day, with different route configurations and the best simulation (more close to the measured data) of each day has been chosen. More than 3,000 traffic counters were available for calibration of the SUMO model, of which 2/3 were used for calibration and 1/3 for evaluation. A summary of the EMIMO with its traffic emissions sub-module can be found in Figure 3.

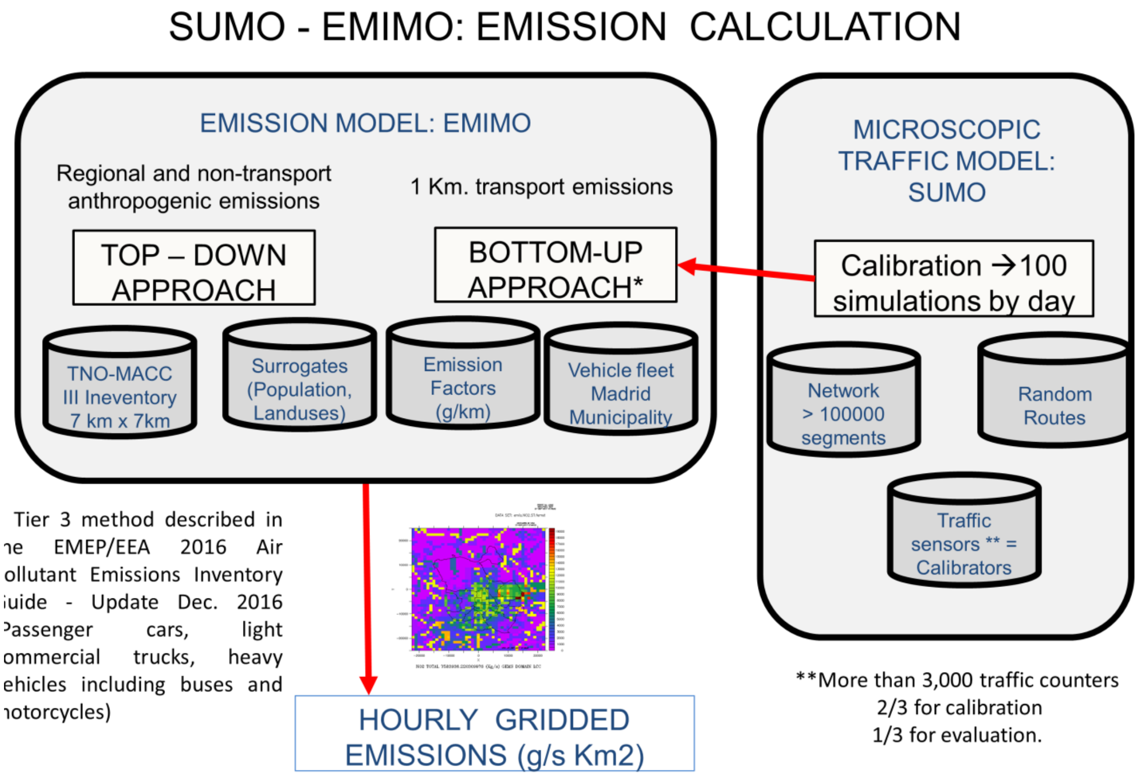

Figure 3: *Schematic representation of EMIMO emission model including SUMO – Traffic emissions submodule.*

2.4 Simulation domains

Three domains have been defined. They are connected by a one way nesting approach. This means that output from the coarse grids are used as input to the next domain. Nested domains need boundary conditions from its mother domains. The setup of the WRF/Chem computational domains is the following: Horizontal resolutions of 25, 5 and 1 km and 45 by 50 grid cells respectively. The final domain (D3) is centered in Madrid, 3.704ºW, 40.478ºN. The first domain (D1) covers the Iberian Peninsula (1000×1125 km2) and the Madrid domain (D3) is bigger than Madrid area (40×45 km2) to assess not only the effects in urban areas, but also to simulate the surrounding areas of the city. For the vertical resolution, the atmosphere is resolved with 33 layers reaching 50 hPa on high, with the highest resolution of 25m near the ground. About 15 levels are located within the lowest 2 km to assure fine vertical resolution which is needed to simulate the daytime planetary boundary layer.

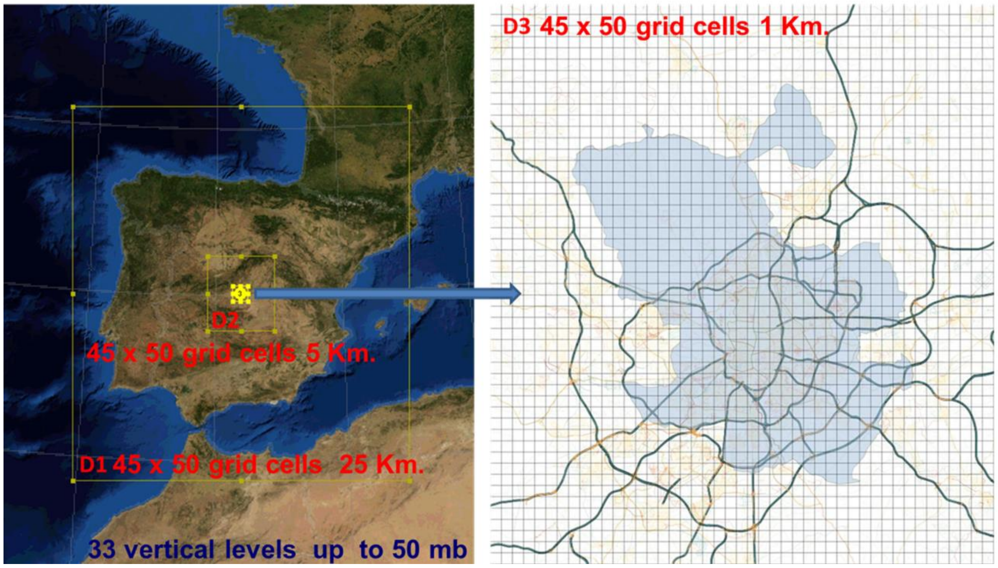

Figure 4: *Computational domains*

3. Evaluation

Before showing the impact of traffic restrictions on air quality in the city of Madrid, it is necessary to analyse the performance of the simulation tool in order to have confidence about the impact results. First we show the evaluation of traffic simulation, then the evaluation of air quality simulation.

3.1 Traffic simulation evaluation

The modelling results of traffic flow in Madrid network are compared with the traffic data obtained at 1/3 of the counting stations to evaluate the simulation results with the observed traffic volumes. Traffic simulation underestimated traffic flow (vehicles/hour) by 7.8%. The adjustment obtained in the model calibration process shows a good convergence between the actual traffic flow data and the results obtained with the corresponding R^2 of 0.97, so it can be observed that the simulated data can describe the real traffic situation Figure 5 shows the correlation between the average of the validation traffic counters hourly traffic flow (intensity mean hourly - IMH) on simulated days and the simulation results.

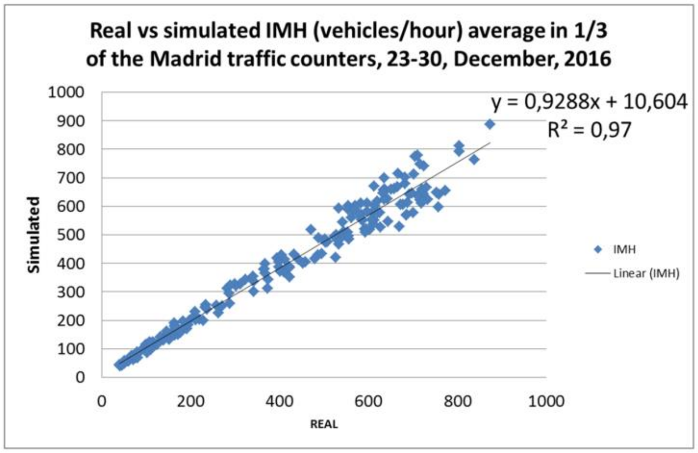

Figure 5: *Linear regression of the hourly mean intensity of average of 1/3 measurements versus simulation results.*

3.2 Air quality simulation evaluation

Next step was to evaluate NO2 predictions of the WRF/Chem model. To assess the performance of the simulation system to forecast nitrogen dioxide, data from air quality stations per hour were averaged in the study domain. Measurements of pollutants were recorded by 24 surface air quality monitoring stations in the Madrid area. The statistical parameters calculated are the NMB (Normalize Mean Bias), RMSE (Root Mean Square Error) and correlation coefficient R^2. For nitrogen dioxide, the concentration of this pollutant is accurately predicted in the stations (NMB, -25.42%; RMSE 27.95 ug/m3; R2, 0.8). Figure 6 shows time series and linear regression of the modelled and measured data. The value of the correlation coefficient is very significant. A slight underestimation of modelled NO2 concentrations is observed. When assessing primary pollutants, such as NO2, it should be considered that in the model instantaneous emissions are distributed over the full grid cell, resulting underestimated concentrations near the source. It appears that a finer grid is important for treating air pollution episodes in urban areas and further research will be undertaken in this sense, using Computational Fluid Dynamics (CFD) models in the next experiments.

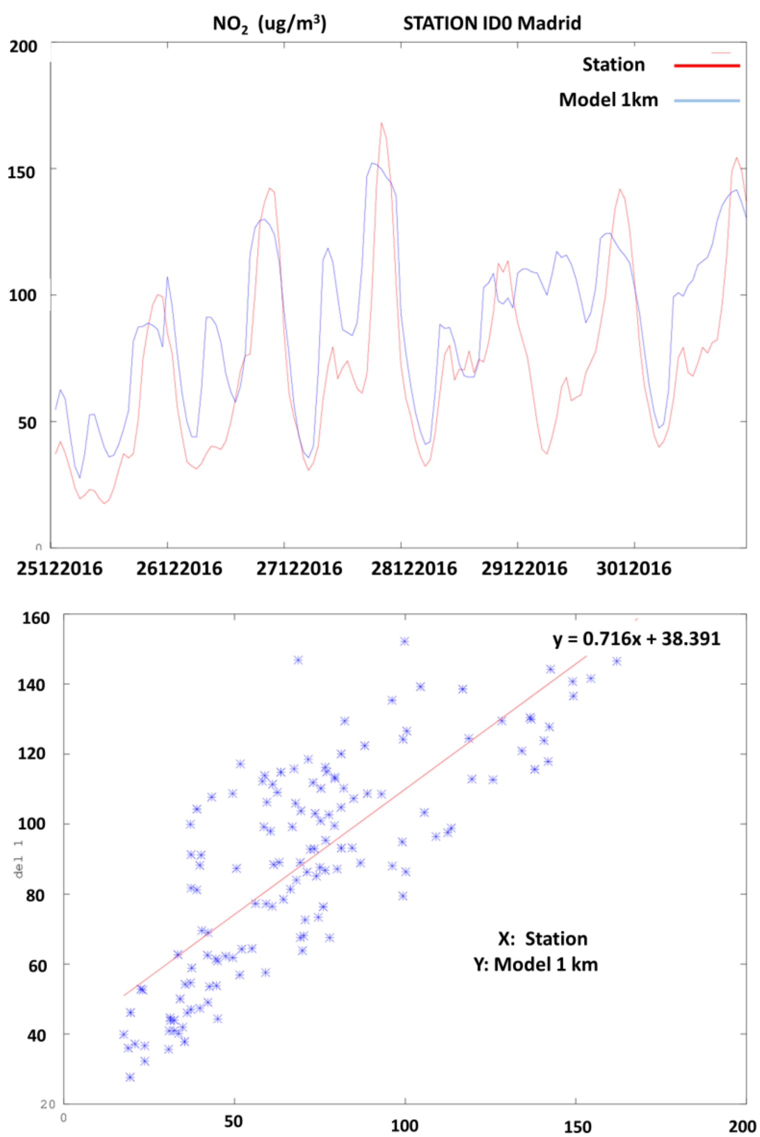

Figure 6: *Time series and linear regression of the modelled and measured hourly NO2 concentrations*

4. Results

In this section the most outstanding results about the impacts and effectiveness of the measures taken are showed. First we summary the traffic and emission results from the traffic and emission model and them we focus on the air quality.

4.1 Traffic and emissions results

Traffic simulations of SUMO REAL and BAU show that on day 28 (parking restrictions) traffic was reduced by 10.24%, on day 29 (access restrictions) traffic was reduced by 16%, and on day 30 (parking restrictions) traffic was reduced by 6.06% If we focus on the city centre (within the M30) on day 28 the reduction only reached 4%, but on day 29 it reached 20%. It seems clear that access restriction measures were more effective in reducing traffic in the city centre, while parking restrictions for non-residents affected more vehicles from outside the centre of Madrid. Because they could not park and used other modes of transport to arrive to the city. The main differences between REAL and BAU simulations can be observed on day 29, especially during the early hours of the day when people go to work. On the 30th, which was Friday parking restrictions did not reduce traffic almost in the afternoon. On the 28th (Wednesday) the reduction is maintained throughout the whole day (morning and afternoon). If we now compare Madrid's emissions for these days, we can see that on day 28 parking restrictions reduce the emission of NOx to -8.27%, on day 29 -10.28% and on day 30 the reduction is only -1.77%.

4.2 Air quality results

In the previous sections, the air quality modelling system was described and evaluated. This section presents some results on impacts and will comment on the efficacy of traffic restrictions to reduce air pollution in Madrid on the days of the episode. Figure 7 shows the spatial distributions of average daily NO2 concentrations for REAL simulation (without traffic restrictions) for days 28 and 29 (the two most important days of the episode) with 1 km of spatial resolution. Representative wind vectors of those days are also shown. In Figure 7, we can see that the concentration are higher in the day 29 that in the day 28. In the day 29, the maximum concentrations cover all the city center area, while the day 28 the most affected areas are those are located on the South and West part of de Madrid, according with the predominant wind direction. Figure 8 shows the spatial distributions of NO2 daily average differences for REAL and BAU traffic conditions.

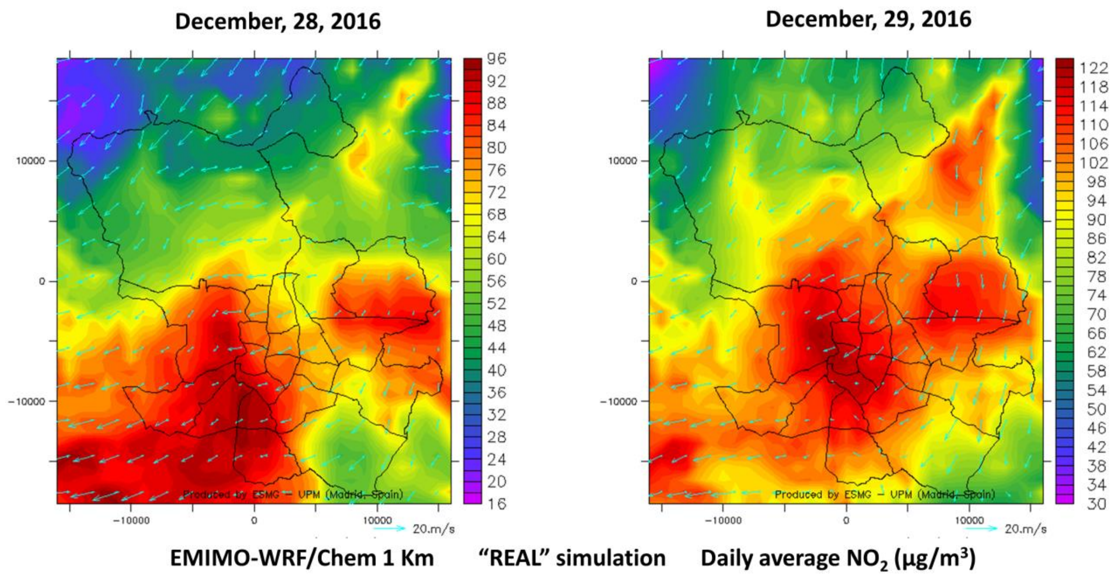

Figure 7: *Madrid, 1 kilometer resolution. NO2 daily average concentrations. December, 28 left and 29 right with winds vectors*

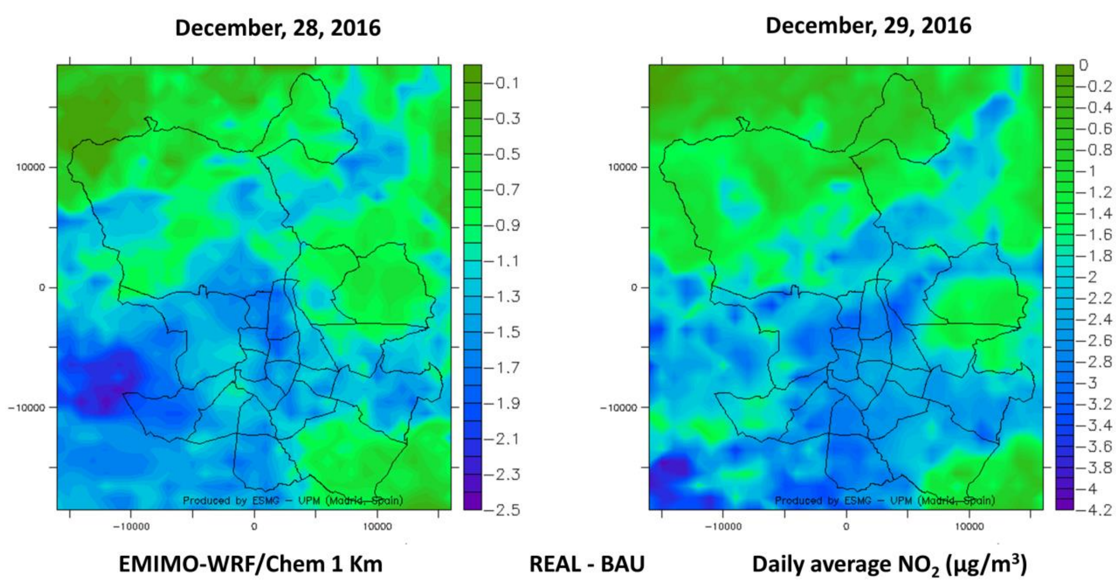

Figure 8: *Madrid, 1 kilometer resolution. Differences between REAL and BAU simulation for NO2 daily average concentrations. December, 28 (parking restrictions) left and 29 (access restrictions) right.*

Figure 8 represents the difference in the spatial distribution and magnitude of concentrations between REAL and BAU for NO2 in our inner domain. It shows small differences between REAL and BAU NO2 concentrations (-2.5 ug/m3 for day 28 and -4.2 ug/m3 for day 29). The differences are more important on day 29 than on day 28, so access restrictions have more impacts on NO2 concentrations than parking limitations. The North of the city is the part where the traffic has less impact (green areas) on the air quality, so the lowest difference occurs in the North and small area in the East of the city for both days.

Figure 9 shows the spatial distributions of NO2 daily maximum differences for REAL and BAU traffic conditions for the day 29. In Figure 9 we can see that the traffic access restriction of the day 29 can reduce the daily maximum concentrations of NO2 up to 14 µg/m^3 in the west-south part of the city. It is not enough to avoid the exceedances of the NO2 directive. If we focus on the location where the highest NO2 concentrations were reached (E. Aguirre station), the traffic restrictions had soft effects, on day 28 -1.62 % , on day 29 -2.04% and on day 30 -0.36%. Both simulations (REAL and BAU) are quite similar, so the traffic restrictions were not effective to avoid the NO2 episode and new decisions must be research.

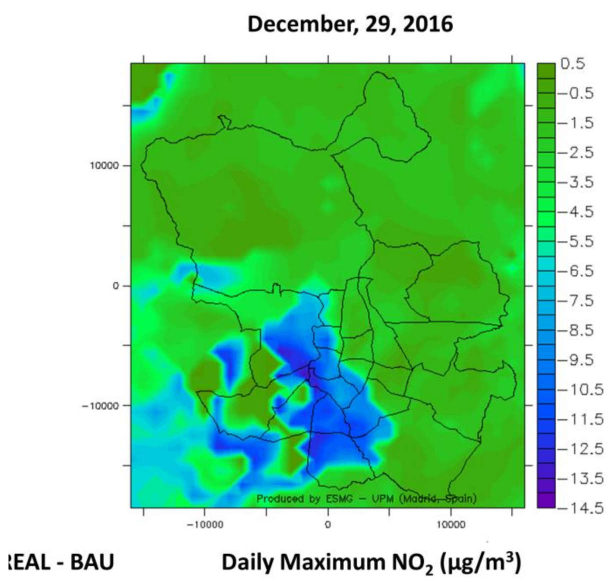

Figure 9: *Differences between REAL and BAU simulation for NO2 daily maximum concentrations. December, 28 (parking restrictions) left and 29 (access restrictions) right.*

4. Conclusions

An air quality modelling system has been implemented, evaluated and applied for a high pollution episode. The model includes an emission model (EMIMO), which includes the SUMO model for traffic and a transport and pollutant chemistry model (WRF/Chem). The modelling system has been used to simulate an episode of high NO2 concentrations in the city of Madrid during December 2016 with high spatial resolution (1 km). Performance evaluation has been satisfactory, with good values in correlation coefficients, although at some local points the system has not been able to reach the maximum peaks of NO2 concentrations measured by monitoring stations. The 1 km resolution has not been enough to capture some very local peaks of concentration. We are working on integrating a CFD (50-meter resolution) model into the system to more accurately reproduce observed air concentrations. However, the statistical values obtained by comparing simulated measurements and concentrations are consistent with the reference values set in European Directive 1999/30/EC and 2008/50/EC for the uncertainty of air quality models. The results of the SUMO model - like those obtained in this experiment - are fully applicable in future CFD simulations (future works) because the SUMO model produces vector data adapted to any spatial grid resolution.

The modeling system has been used to assess the effectiveness of the traffic restriction measures (parking restrictions at points 28 and 30; access limitations at point 29) taken by the Madrid City Council to try to reduce NO2 concentrations. The evaluation was carried out by comparing the REAL simulation (with traffic restrictions) with a BAU simulation (without traffic restrictions). Although traffic decreased by 10% on 28 December, 16% on 29 December and 6% on 30 December, daily NO2 concentrations decreased by only 1.5%, 28.2% on 29 December and 0.5% on 30 December. These results show that the measures taken were not sufficiently effective compared to the effort to reduce traffic. Other studies over different cities have shown that meteorological conditions are the main reasons for air pollutant episodes and that the emission control measures are not effective to mitigate the air pollution (Liu et al., 2017). Other measures should be evaluated with less impact on citizens and with a greater capacity to reduce air pollution (transformation of diesel fuel into electric vehicles, prohibition of driving vehicles over 15 years old, reduction of traffic speed, etc.). Some of these actions have been evaluated with a different modelling tool over other Spain regions (Arasa et al., 2014).

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