VALIDATION OF WRF MODEL DURING BOTH PRIMARY AND SECONDARY POLLUTANTS EPISODES OVER AN ATLANTIC COASTAL REGION

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ABSTRACT

The episodic validation of meteorological models to be applied in air quality modelling is usually focused in specific conditions which are more favourable to high glc of either primary or secondary pollutants. These conditions can be similar over urban areas with sparse emissions sources. However, huge point sources with high stacks only produce glc episodes of primary pollutants in specific strong wind conditions; on the other hand, the production of secondary pollutants, as O_3, usually requires low winds and pollutants trapping. From 2002 to 2007 years both kind of pollutants (primary SO_2 and secondary O_3) were detected in the Northwest Iberian coast around large point sources, at different periods. In case of SO_2, glc values were far below legal thresholds; however, its values allow the use of this primary pollutant as a tracer of a large power plant emission. About O_3, during the warm season (March-September) the population information threshold (Directive 2008/50/EEC) was close to be exceeded. In order to get an accurate simulation of the atmospheric conditions along both kind of air quality episodes, the meteorological WRF model was applied at a 3 km resolution to drive regional scale air-quality model. Four configurations of WRF model with four different planetary boundary layer (PBL) schemes (Pleim-Chang, Mellor-Yamada-Janjic, Nakanishii-Nino and Hong-Noh-Dudhia) were compared. As test cases, three different SO_2 and three O_3 episodes were selected. During those episodes, surface temperature and wind (speed and direction) simulation results were compared to the hourly measurements from six surface stations, located in both urban and rural areas. Results show that different results were achieved with better performance for specific PBL schemes, depending on the primary or secondary pollutant episode considered. Therefore, PBL scheme selection should be a significant feature to obtain the best results of WRF model, both in primary and secondary pollutants episodes. In terms of the application of WRF model in air quality policy assessment, depending on the sensitivity of the air quality model to the meteorological input, it should be necessary to select different PBL schemes depending on the type of pollutant to be considered, either primary or secondary.

1. INTRODUCTION

The accuracy of numerical meteorological models to provide the required data input to air quality models is usually none-sensitive to either primary or secondary pollutants are considered. However, simulation of the dispersion of primary pollutants from huge stacks is solved with Lagrangian approaches; in the opposite, the simulation of secondary pollutants generation usually requires the application of Eulerian models (Zannetti, 1990). In addition, the meteorological conditions which are more favourable to high ground level concentrations (glc) of primary pollutants from large sources usually correspond to strong winds, while the production of secondary pollutants, as O_3, requires soft winds and pollutants trapping (Jacobson, 2002). In addition, other parameters (as temperature) have a significant influence in this chemical production. Therefore, a numerical meteorological model which provides good results as input to a Lagrangian model is not necessarily the best solution for estimating secondary pollutants glc. The evaluation of meteorological simulations is very important to obtain a complete understanding of the air quality model performance, either with traditional model evaluation statistics (Zhang et al., 2006) or with spectral decomposition or inter-correlation of variables (Hogrefe et al., 2001, Guilliam et al., 2006).

In this work, different WRF numerical meteorological model configurations were applied to simulate diverse high glc episodes of both kind of pollutants (primary SO_2 and secondary O_3) at the same environment. These episodes were detected in the Northwest Iberian coast (Galician coast) around large point sources, at different periods on 2002-2003 (O_3) and 2005-2006 (SO_2). In the case of SO_2 glc, its values were far below legal thresholds; however, its values allow the use of this primary pollutant as a tracer of a large power plant emission. About O_3 glc, during the warm season (March-September) the population information threshold (Directive 2008/50/EC) was sometimes exceeded. Surface temperature and wind speed estimated by WRF model were compared to measurements at different sites in the region, using several PBL parameterizations, in order to evaluate the accuracy of different WRF configurations along both primary and secondary pollutants episodes. This comparison can provide a guide to the operational application of WRF model when both kind of pollutants are of interest in a region.

2. METHODOLOGY

2.1 Selection of air pollution episodes: Synoptic and meteorological conditions.

Six 3-day air pollution episodes in the NW coast of Iberian Peninsula (IP) were selected, three of them with high O_3 ground level concentration (glc) and other three with high SO_2 glc (table 1). Air pollution data from five air quality sites placed in the region were applied to identify the periods, and meteorological data from ten meteorological stations were considered to describe the local weather pattern and to validate the model results.

Episode	Air pollutant	Peak hourly glc (g/m^3)
16-18 July 2002	O_3	201.0
19-21 March 2003	O_3	148.0
14-16 September 2003	O_3	193.0
13-15 July 2005	SO_2	304.0
01-03 June 2006	SO_2	324.0
09-11 July 2006	SO_2	174.0

Table 1. High-ozone and sulfur dioxide episodes selected in the NW coast of IP, indicating the maximum O_3 or SO_2 hourly peak.

Two simultaneous criteria were considered in order to identify the aforementioned episodes in this local area,

a) Hourly maximum O_3 concentration exceeding 140 g/m^3 (which is 20% below the first hourly European standard threshold) and hourly maximum SO_2 concentration exceeding 170 g/m^3 (which is about half of the European hourly limit value for the protection of human health). Being O_3 a secondary pollutant, its exceedances have to be achieved in at least two of the five stations considered.

b) Synoptic representativeness of the episodes, being typical conditions for O_3 and SO_2 episodes in the Northwestern IP.

The synoptic weather pattern during the six episodes is clearly anticyclonic and stable, but there are some slight differences between both types of episodes. The rising of surface O_3 levels is associated with a well-defined high pressure center placed to the north of the IP, over Central Europe or the British Isles (Saavedra, 2010) causing E-SE wind circulation along the northwestern IP (fig. 1a). The synoptic conditions during SO_2 episodes is more variable, but characterized by the Azores anticyclone extending its influence to the IP and causing a E-NE synoptic flux along the same northwestern region (fig. 1b). Meteorological conditions correlated with high SO_2 in the study area were characterized by high temperatures and light or gentle winds, blowing mainly from East or Northeast whereas during O_3 episodes temperatures are slightly hotter, wind are usually from East or Southeast with lower speeds, and sea breezes from Northwest or West are very common.

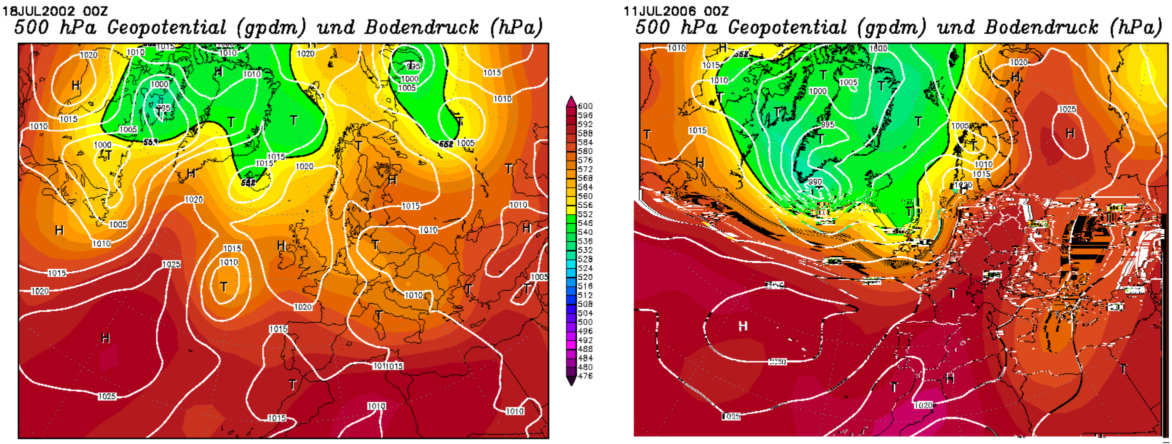

Figure 1. Surface pressure (hPa) and 500 hPa geopotential (geopotential dm) maps corresponding to (a) O_3 episode (18th July 02) and (b) SO_2 episode (11th July 06) in the NW IP. Maps source: Wetterzentrale (2010).

2.2 Description of WRF model and parameterizations

The present study applies the WRF version 3.2 (Skamarock et al., 2008), configured with 29 or 30 vertical layers (depending on the PBL parameterization tested), and three nested domains with horizontal resolutions of 27, 9 and 3 km (Borrego et al., 2012). The other selected model settings include the Kain-Fritsch cumulus scheme (outer and medium domain), WSM 3-class microphysics scheme, a RRTM longwave and Dudhia shortwave radiation scheme, and a 5-layer soil model (except with ACM2 Pleim-Xiu PBL scheme, with Pleim-Xiu soil model). A one-way nesting option was applied. The NCEP (National Center for Environmental Prediction) GFS analysis data available at a horizontal resolution of 1^o x 1^o and a 3-hour time resolution were used to input the initial and lateral boundary conditions. Elevation and land cover data were provided by the digital terrain model from the United States Geological Survey (USGS, 2008). Four numerical experiments for each episode were done, changing the PBL scheme: Yonsei University scheme (YSU), Mellor-Yamada-Janjic (MYJ), Mellor-Yamada Nakanishi and Niino Level 2.5 PBL (MYNN) and Asymmetric Convective Model (ACM2).

3. RESULTS AND DISCUSSION

For the present study, meteorological measurements (2-m temperature and 10-m wind speed) were available at ten meteorological sites over the study area, and compared to the simulations results. Statistical parameters considered were mean bias (MB), mean absolute gross error (MAGE) and root mean square error (RMSE). Results of 2-m temperature and 10-m wind speed for every PBL parameterization were shown in tables 2-5.

	16-18 July 02			19-21 March 03			14-16 September 03		
PBL parameterization	MB	MAGE	RMSE	MB	MAGE	RMSE	MB	MAGE	RMSE
ACM2	-0.819	***1.274***	***1.623***	0.584	***1.569***	***2.073***	***-1.100***	***2.138***	***2.615***
MYJ	-1.496	1.955	2.331	-2.032	2.907	3.470	-2.016	3.157	3.728
MYNN	-1.940	2.213	2.577	-1.915	2.723	3.352	-2.732	3.349	3.962
YSU	***-0.110***	1.275	1.676	***-0.545***	2.005	2.556	-1.152	2.492	3.095

Table 2. Statistical summary for 2-m temperature with four PBL schemes (ACM2, MYJ, MYNN and YSU) during O_3 episodes: mean bias MB, mean absolute gross error MAGE and root mean square error RMSE.

	16-18 July 02			19-21 March 03			14-16 September 03		
PBL parameterization	MB	MAGE	RMSE	MB	MAGE	RMSE	MB	MAGE	RMSE
ACM2	-0.726	1.731	2.301	1.391	2.266	2.861	0.600	1.627	2.122
MYJ	***-0.359***	***1.495***	***1.952***	1.660	2.222	2.848	1.060	1.708	2.277
MYNN	-0.973	1.717	2.278	***0.621***	***1.766***	***2.181***	***0.521***	***1.485***	***1.900***
YSU	-0.811	1.605	2.182	1.186	1.980	2.508	0.540	1.537	2.016

Table 3. Statistical summary for 10-m wind speed with four PBL schemes (ACM2, MYJ, MYNN and YSU) during O_3 episodes: mean bias MB, mean absolute gross error MAGE and root mean square error RMSE.

	13-15 July 05			01-03 June 06			09-11 July 06		
PBL parameterization	MB	MAGE	RMSE	MB	MAGE	RMSE	MB	MAGE	RMSE
ACM2	***0.046***	***2.559***	3.466	***0.262***	1.548	1.963	-1.058	2.187	2.741
MYJ	0.739	2.926	3.537	-0.540	1.551	1.944	-0.980	2.159	2.718
MYNN	0.104	2.561	***3.355***	-1.025	***1.516***	2.133	-1.201	2.132	2.660
YSU	1.091	2.649	3.626	0.534	1.681	***1.891***	***-0.341***	***1.831***	***2.417***

Table 4. Statistical summary for 2-m temperature with four PBL schemes (ACM2, MYJ, MYNN and YSU) during SO_2 episodes: mean bias MB, mean absolute gross error MAGE and root mean square error RMSE.

	13-15 July 05			01-03 June 06			09-11 July 06		
PBL parameterization	MB	MAGE	RMSE	MB	MAGE	RMSE	MB	MAGE	RMSE
ACM2	0.351	1.286	1.623	0.399	2.105	2.695	-0.185	1.633	2.138
MYJ	0.579	1.339	1.686	0.900	2.144	2.860	0.212	1.579	2.028
MYNN	***0.263***	***1.232***	***1.569***	***-0.109***	2.015	***2.441***	-0.168	***1.512***	***1.967***
YSU	0.524	1.283	1.597	0.313	***1.949***	2.534	***-0.074***	1.514	1.984

Table 5. Statistical summary for 10-m wind speed with four PBL schemes (ACM2, MYJ, MYNN and YSU) during SO_2 episodes mean bias MB, mean absolute gross error MAGE and root mean square error RMSE.

The statistics (RMSE and MAGE) show how the model presents a better behavior of temperature using ACM2 during high-O_3 episodes, followed by YSU. MYJ and MYNN PBL schemes provide