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ASSESSMENT OF URBAN PARAMETERIZATIONS IN THE WRF MODEL FOR AIR QUALITY MODELLING PURPOSES IN MADRID (SPAIN)

D. de la Paz[1], R. Borge[1], J.M. de Andrés[1], J. Pérez[1] J. Lumbreras[1], M.E. Rodríguez[1]

[1]Laboratory of Environmental Modelling. Technical University of Madrid (UPM). Madrid, SPAIN

dpaz@etsii.upm.es

INTRODUCTION

Eulerian 3D mesoscale models can consistently describe a wide range of spatial scales, from continental to urban scale. However, urban areas present features that are usually missed by land-surface and PBL modules commonly implemented in such models. As environmental issues in urban areas grow, canopy layer modelling becomes increasingly important (Ching, 2013). Models such as the Weather Research and Forecasting model (WRF) (Skamarock and Klemp, 2008) incorporate urban parameterizations to take into account changes in albedo, roughness length and thermal properties imposed by buildings. However, their application is not straightforward and should be specifically tested in the domain of interest before they can be integrated in air quality modelling activities. In this study, four urban parameterizations were tested for the Madrid urban area (Spain). Summer and winter, 1 km² resolution runs were performed for the following parameterizations:

- Urban parameterization within the Noah Land Surface Model (**Bulk scheme**) (Liu et al., 2006)
- **Building Energy Parameterization (BEP)** (Martilli et al., 2002) considering two different setups for street parameters
- **Building Energy Model (BEP+BEM)** (Salamanca & Martilli, 2010)

METHODOLOGY

Model outputs were compared with observations from five meteorological stations throughout the Madrid city, representative of different urban morphologies in two 1-month periods (winter and summer). Multi-layer, more complex parameterizations brought about a reduction of wind speed overestimation of the reference option (bulk) (Table.1) and slight improvements on surface temperature predictions.

Figure 1. Air Quality System.

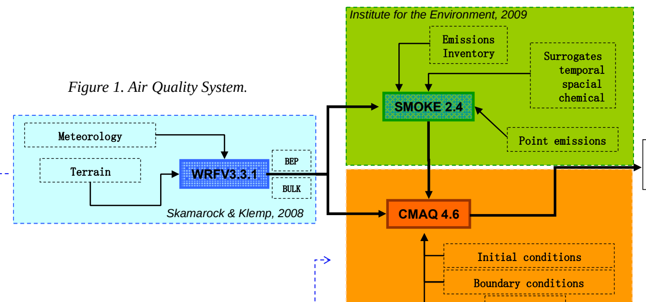


Table 1. Basic statistics results for wind (summer-winter average)

Canopy model	Direction MB (º)	Direction Error (º)	Speed MB (m/s)	Speed RMSE (m/s)	Speed IOA
BULK	13.4	49.4	0.4	0.6	0.502
BEP	10.7	43.3	0.2	0.6	0.665
BEP+BEM	5.9	46.1	0.2	0.5	0.695

BEP was identified as the optimal setting as a compromise of model performance, input data requirements and CPU time. Finally, the selected parameterization was used to produce annual meteorological inputs to feed the CMAQ to understand the impact of incorporating WRF+BEP instead of standard WRF (bulk scheme)

WRF MODEL CONFIGURATION

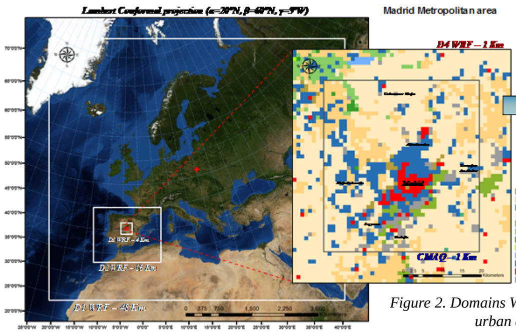
WRF simulations were driven by the NCEP (1º x 1º - 6h) spatial – temporal resolution.

Madrid metropolitan area with horizontal resolution 1 x 1 km and 30 layers (Lowest level = 7 meters)

Four nested domains were used for the WRF simulations

Domains for the WRF simulations

Geographic scope	X-Y dimensions (km)	Horizontal
Europe	6720 x 5952	Δx =48 km
Iberian Peninsula	1536 x 1248	Δx =16 km
Greater Madrid area	256 x 256	Δx =4 km
Madrid Metropolitan area	56 x 60	Δx =1 km



Three urban classes were defined to use urban scheme (from land use database CORINE)

Figure 2. Domains WRF model and three urban classes

Table 2. Model configuration for the WRF simulations

	BULK	BEP. Urban scheme. (Martilli, 2002)
Shortwave radiation	Dudhia scheme	Dudhia scheme
Longwave radiation	Eta Geophysical Fluid Dynamics Laboratory (GFDL)	Eta Geophysical Fluid Dynamics Laboratory (GFDL)
Land-surface model	Noah LSM	Noah LSM
PBL scheme	Yonsei University (YSU)	Bougeault and Lacarrère
Horizontal resolution	Δx =1 km (56×60)	Δx =1 km (56×60)
Vertical resolution	30 sigma levels (Lowest level ≈ 7 m)	30 sigma levels (Lowest level ≈ 7 m)

METEOROLOGY

- Two annual runs were made with the BEP urban parameterization and the BULK scheme, used as a reference. Some of the most influential variables from the air quality point of view were compared with observations from 6 urban meteorological stations: temperature (K), wind direction (º) and wind speed (m/s).

- **T2**. BEP yields higher ground-level temperature, mainly in High residential density areas (also in low residential density areas not considered as urban surface in the standard land cover used in BULK). The average temperature differences ranges from 0.5 to 1.2 K, mostly due to higher temperature predictions in winter.

- **Wind Speed.** The urban parametrization has a strong effect in wind speed predicted by WRF. Wind intensity is reduced by 0.8 m/s as an average in the city center and up to 3 m/s in the city outskirts.

- Beside this comparison, predicted PBLH were scrutinized (YSU - BULK and BouLac– BEP).

- **PBL Height,** BEP increases PBLH predictions in general (40 - 60 m as an average), mainly in winter.

URBAN [BEP]– BASE [BULK]

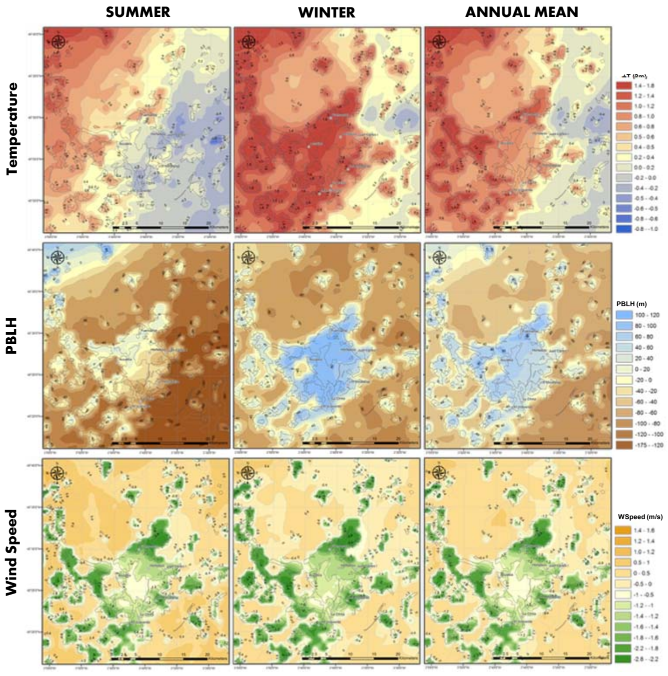
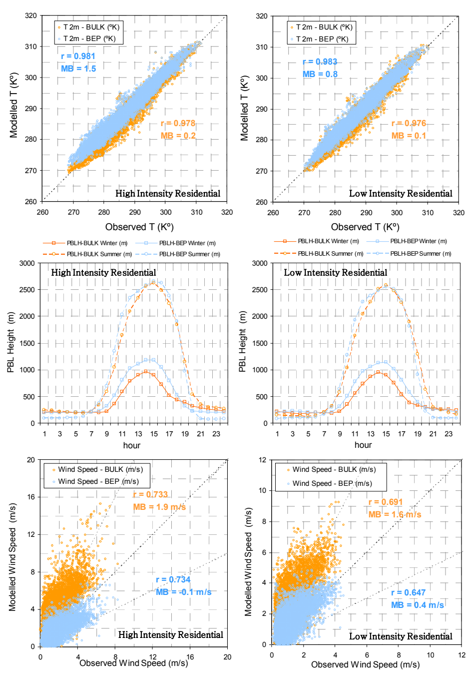


Figure 3. Differences T2, PBLH and Wind Speed

Comparison with surface observations



Statistics

Table 3. Statistics for temperature

Aggregated statistics for Temperature	nº stations	nº Observations	Canopy model	MB (º)	Error (º)	IOA
	6 stations	48936	BEP	1.7	0.6	0.980
			BULK	**0.7**	**0.4**	**0.990**

- **T2.** Both, the reference configuration and the urban parameterization overestimate ground-level temperature. Although the temporal variation patterns are perfectly described in both cases, the urban parametrization predictions are worse in all cases with an overal bias of 1.7 K (Vs. 0.7 for the reference model)
- **PBL Height.** BEP produced higher values of PBLH (mainly in winter) in urban areas, both high and low intensity although usually the mixing height predicted by BouLac is lower during night-time. The result for non-urban land uses is basically the opposite.

Table 4. Statistics for wind

Aggregated statistics for Wind Direction	nº stations	nº Observations	Canopy model	MB (º)	Error (º)
	6 stations	46513	BEP	-19.8	**60.1**
			BULK	**-5.9**	65.2

Aggregated statistics for Wind Speed	nº stations	nº Observations	Canopy model	MB (m/s)	RMSE (m/s)	IOA
	5 stations	39075	BEP	**0.0**	**0.6**	**0.732**
			BULK	1.6	2.0	0.611

- **Wind** BEP brings about a clear improvement of wind fields. Average bias for wind speed is practically null, in constrast with the 1.6 m/s overestimation of the BULK scheme.

AIR QUALITY

- WRF outputs were used to feed the chemical-transport model CMAQ. To assess the implications of the WRF configuration in air quality, the corresponding outputs were compared with ground-level observations of NO_2, O_3 and $PM_{2.5}$ from 26 monitoring stations throughout the modelling domain.
- Figure 4 shows the differences of the results coming from BULK and BEP runs for policy-relevant air quality metrics:

- **NO_2** BEP brings about an increase of 10-18 µg/m³ in the annual mean within the city. Nonetheless, the predictions of BEP for non-urban areas in the SW area are lower.

- **O_3** Ground-level ozone concentrations predicted in the BEP run are lower all over the domain, reaching a maximum annual difference of 14 µg/m³ in the city centre.

- **$PM_{2.5}$** CMAQ predictions for $PM_{2.5}$ are also increased when the urban parameterization is applied. This is specially evident in winter. Differences up to 2 µg/m³ in the annual mean are observed in the high-density innermost part of the city .

URBAN [BEP]– BASE [BULK]

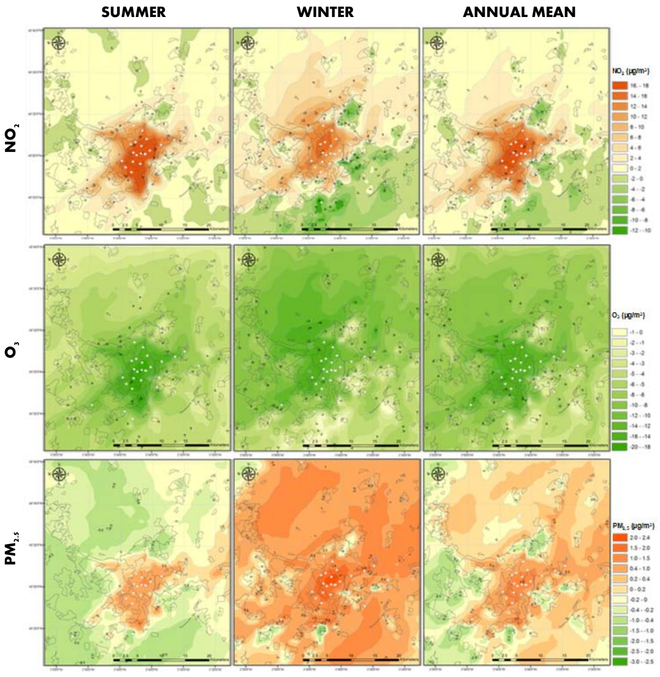
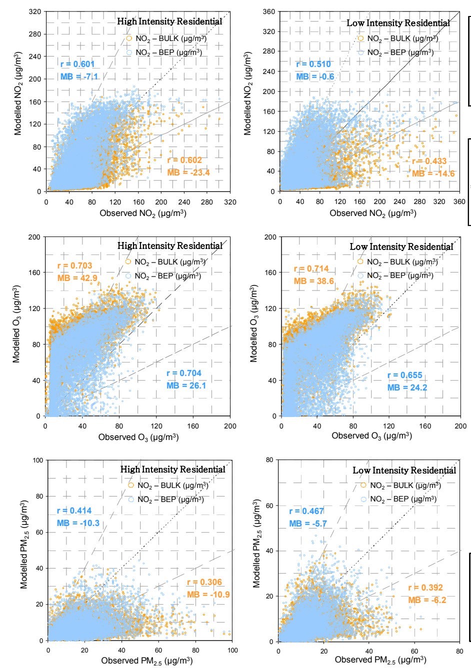


Figure 4. Differences NO_2, O_3 and $PM_{2.5}$

Comparison with surface observations



Statistics

Table 5. Statistics for NO_2

Aggregated statistics for NO_2	nº stations	nº Observations	Type station	Canopy model	MB (µg/m³)	MFB (%)	MFE (%)	RMSE (µg/m³)	r	IOA
	26 stations	220637	Traffic station	BEP	**-6.8**	**-25.3**	**64.7**	**40.0**	**0.534**	**0.691**
				BULK	-17.5	-45.6	70.5	40.4	0.529	0.663
	7 stations	58594	Urban station	BEP	**-1.0**	**-11.7**	**61.6**	23.9	**0.639**	**0.767**
				BULK	-3.8	-20.9	64.8	**23.8**	0.604	0.744

Table 6. Statistics for O_3

Aggregated statistics for O_3	nº stations	nº Observations	Type station	Canopy model	MB (µg/m³)	MFB (%)	MFE (%)	RMSE (µg/m³)	r	IOA
	26 stations	219078	Traffic station	BEP	**27.3**	**50.2**	**82.0**	**38.8**	0.610	**0.647**
				BULK	39.7	79.2	87.8	46.3	**0.653**	0.583
	5 stations	41051	Urban station	BEP	**27.3**	**55.7**	**64.1**	**37.0**	**0.702**	**0.707**
				BULK	32.7	63.4	67.7	41.4	0.682	0.661

- The application of the BEP urban parameterization brings about a clear improvement of CMAQ predictions for all the main pollutants. It reduces the underestimation of NO_2 and $PM_{2.5}$ and the overestimation of O_3. Despite improving biases and errors, also a better index of agreement is achieved for most of the monitoring stations.
- The average NO_2 bias of the model is reduced to 1 µg/m³ (less than 12%) for the urban stations (that provide the most relevant reference for assessment with this spatial and temporal model resolution)

Table 7. Statistics for $PM_{2.5}$

Aggregated statistics for $PM_{2.5}$	nº stations	nº Observations	Type station	Canopy model	MB (µg/m³)	MFB (%)	MFE (%)	RMSE (µg/m³)	r	IOA
	3 stations	26089	Traffic station	BEP	**-8.7**	**-63.5**	**84.1**	**15.1**	**0.346**	**0.503**
				BULK	-9.7	-69.8	88.0	15.8	0.264	0.459
	2 stations	15058	Urban station	BEP	**-3.2**	-35.3	**45.4**	**5.4**	**0.213**	**0.321**
				BULK	-3.3	**-34.9**	45.5	5.6	0.169	0.295

CONCLUSIONS

- The BEP (Building Effect Parametrization, Martilli et al., 2002) was selected as the option to perform WRF simulations over the Madrid city.
- This urban parameterization overestimates the ground-level temperature. Wind direction bias is also worse than that of the reference configuration (Bulk scheme included in the Noah L-S model) although errors are diminished. BEP application significantly improves wind speed predictions in the city.
- Wind speed can be pointed out as a key variable for AQ modelling in urban areas, since this improvement has a strong positive effect on CMAQ predictions.
- The influence of the representation of mixing height is difficult to identify due to the lack of reliable observational data for this case study

Next steps

- Model outputs will be further scrutinized to gain a better understanding of the effects of the parameterizations used and the influence of particular schemes and input data, mainly the PBL scheme and the land uses considered in each case.
- The incorporation of finer, more up-to-date land uses and urban features may further improve the results and should be tested.

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