CONVECTIVE BOUNDARY EVOLUTION IN URBAN AREA SITUATED IN A COMPLEX TERRAIN - EVALUATION OF MESOSCALE MODEL PROFILES AGAINST RADIOSOUNDING DATA

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Abstract:
The separate evaluation of the meteorological model against data is a valuable step in understanding the results of an air quality modelling system. Moreover, in complex terrain and urban conditions the atmospheric boundary layer (ABL) is characterised by complex structure, which affects in addition the dispersion of pollutants.
Here, we evaluated the dynamics given by the Weather Research Forecasting model (WRF) against radiosounding data of 2 hours resolution during 5 days in Sofia, Bulgaria. The radiosoundings were performed with about 5 m vertical resolution (twice higher than standard) during an urban PBL experimental campaign (Sofia Experiment 2003) in early autumn convective conditions.
The numerical simulations were performed with WRF version 3.3.1, initialized with the US National Center for Environmental Prediction Final Analyses (FNL). The model was set on 4 domains, with horizontal grid size of the finest domain 1.33 km covering Sofia and the surrounding mountains, and on 26 vertical levels (13 of which below 2 km).
Statistical comparisons between modelled and measured parameters showed that WRF simulated relative humidity, temperature and wind direction better in the morning than in the afternoon hours, while the wind speed was insignificantly better simulated in the afternoons. The best match between WRF values and radiosounding data was observed at 15 LST (12 GMT), and the worst - at 19 LST.
It was found that the values of the coefficient of determination decrease slowly by 10 % from the ground up to 1500 m. Higher up, reaching 2750 m, the decrease is faster. At height of about 2000 m ag the coefficient of determination for all parameters exhibits changes, which might be associated with the influence of Vitosha mountain, pointing the inability of WRF to reproduce always the complex structure of the profiles created by the combination of complex terrain, urban conditions and synoptic forcing.
We found that WRF with Maylor-Yamada-Janjic PBL scheme simulated relatively well the shape of the vertical profiles of all analysed parameters, except for wind direction which was poorly resolved in the lowest 1000 m above ground.

Key words: Weather Research Forecasting model (WRF), atmospheric boundary layer (ABL), consecutive radiosoundings, vertical profiles of meteorological parameters, mountain valley, air pollution

INTRODUCTION

The goal of the presented study is to contribute to the understanding of the complex layer vertical structure of the urban atmospheric boundary layer. The investigated site is representative of urban areas in large cities in the Eastern Europe with blocks of apartments of different size and configuration, and vast open areas between them. The accuracy of description of meteorological parameters profiles within the atmospheric boundary layer is of critical importance for air pollution modeling applications. This study examines the sensitivity of the performance of Weather Research and Forecast (WRF) model using Mellor-Yamada-Janjic ABL scheme. The model results are compared with data from high resolution radiosoundings which were performed with Vaisala equipment at NIMH.

METHODOLOGY

Description of experimental campaign (Sofia Experiment, 2003)

The “Sofia experiment 2003” field campaign was carried out in Sofia in September and October, 2003 (Batchvarova et al, 2006). Days with typical convective condition were chosen to document the convective boundary layer development. Seven soundings per day were performed providing data with 2 hour time resolution and increased vertical resolution as the ascend velocity was kept about 3-4 ms^{-1} (two times slower than standard radiosoundings). The data set comprise vertical profiles of air temperature, humidity, wind speed and direction from high resolution radiosoundings for 5 days in the period 27 September – 03 October 2003 and is used here for WRF model performance evaluation.

Model configuration

Numerical simulations were performed with Weather Research Forecasting WRF model (with ARW core), version 3.3.1. The model was initialized with the US National Center for Environmental Prediction Final Analyses (FNL) with space resolution of 1x1 degree and 6 hours time resolution. WRF model was run with two-way nesting on 4 domains with horizontal grid resolution 36, 12, 4, 1.33 km and horizontal grid dimensions: 58x58, 43x43, 37x34, and 43x43, respectively (Fig.1). These 4 domains were located in such way that the finest domain covered Sofia and the Vitosha mountain and the location of radiosounding site (23.38°E, 42.65°N) was in the centre of the domain 4 (x=23, y=22). Simulations were performed with Lambert conformal conic projection with true latitude at 30°N and longitude 60°E, and the central point with coordinates 42°N and 24°E. Physical options which were used are summarized in Table 1. Land use categories from USGS 24-category data were used. All simulations were performed with 26 levels (13 of them are below 2000m) going up to 50hPa. The WRF model was run for 7 days, covering the period from September 30 to October 03. The first 12 hours of simulations were treated as spin-up and the remaining period was used for evaluation.

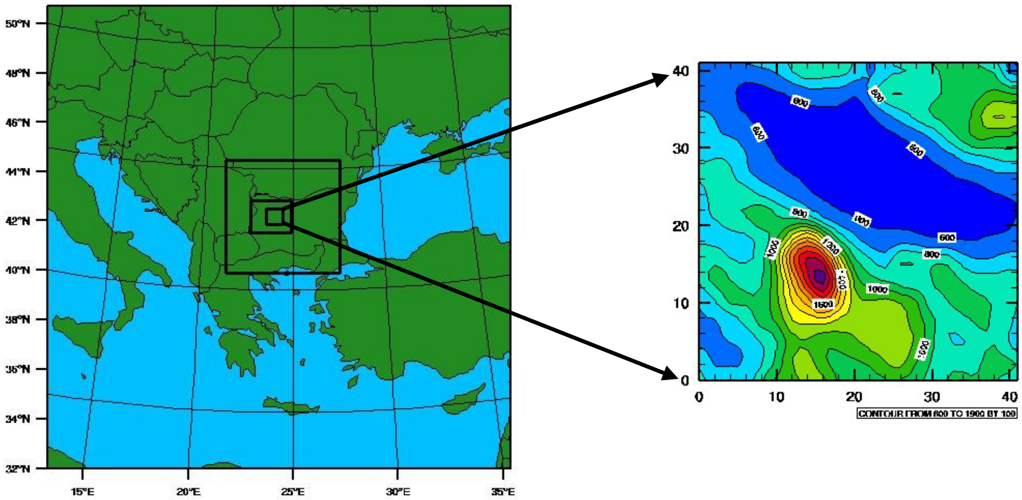

Figure 1. Computational domains and terrain feature of domain 1

Table 1. WRF physics used

Mycrophysics	8 (3.4 domain)= Thompson graupel scheme; 4(1.2 domain)=WSM 5-class scheme
Longwave radiation	1 = RRTM
Shortwave radiation	2 = Goddard
Surface layer	2 = Monin-Obukhov (Janjic-Eta) scheme
Land surface	Noah LSM
ABL	2 = Maylor-Yamada-Janjic TKE scheme (MYJ)
Cumulus parametrisation	5 = New Grell scheme (only for domains 1 and 2)

ANALYSIS AND RESULTS

Comparison between measured and modelled profiles

The synoptic conditions were characterized by weak anti cyclonic pressure field near the ground and warm and sunny weather during 27-29 September and 2 – 3 October. On September 30, a cold front has passed over Bulgaria and rain of 2.6 mm was reported for Sofia on October 1.

In order to examine ability of WRF to reproduce structure of ABL vertical profile, plots of measured and modelled relative humidity, potential temperature, wind speed are prepared for entire period of Sofia Experiment 2003 for every hour of radiosounding data (Fig. 2). Most often WRF overestimates relative humidity in the first few hundred meters. WRF shows tendency to underestimate the height of which maximum of relative humidity is observed and the value of which maximum is either close to the observed one or more often overestimated (up to 25 %). This effect might be caused by the local closure

in the chosen ABL, as discussed by Hu, 2010. MYJ lacks to entrain adequately drier air from the surface higher up in the PBL. Modelled potential temperature profiles are the closest profiles to the observed ones. Wind speed is underestimated by the model close to the ground. Wind direction is unsatisfactory resolved by the model (not shown here).
The best match between WRF values and radiosounding data is observed at 15LST (12GMT), and the worst – at 19 LST (Fig. 2). In particular, potential temperature profiles at 15 LST are very well simulated up to 1450 during weak pressure situations, while bigger difference are observed on October 3.

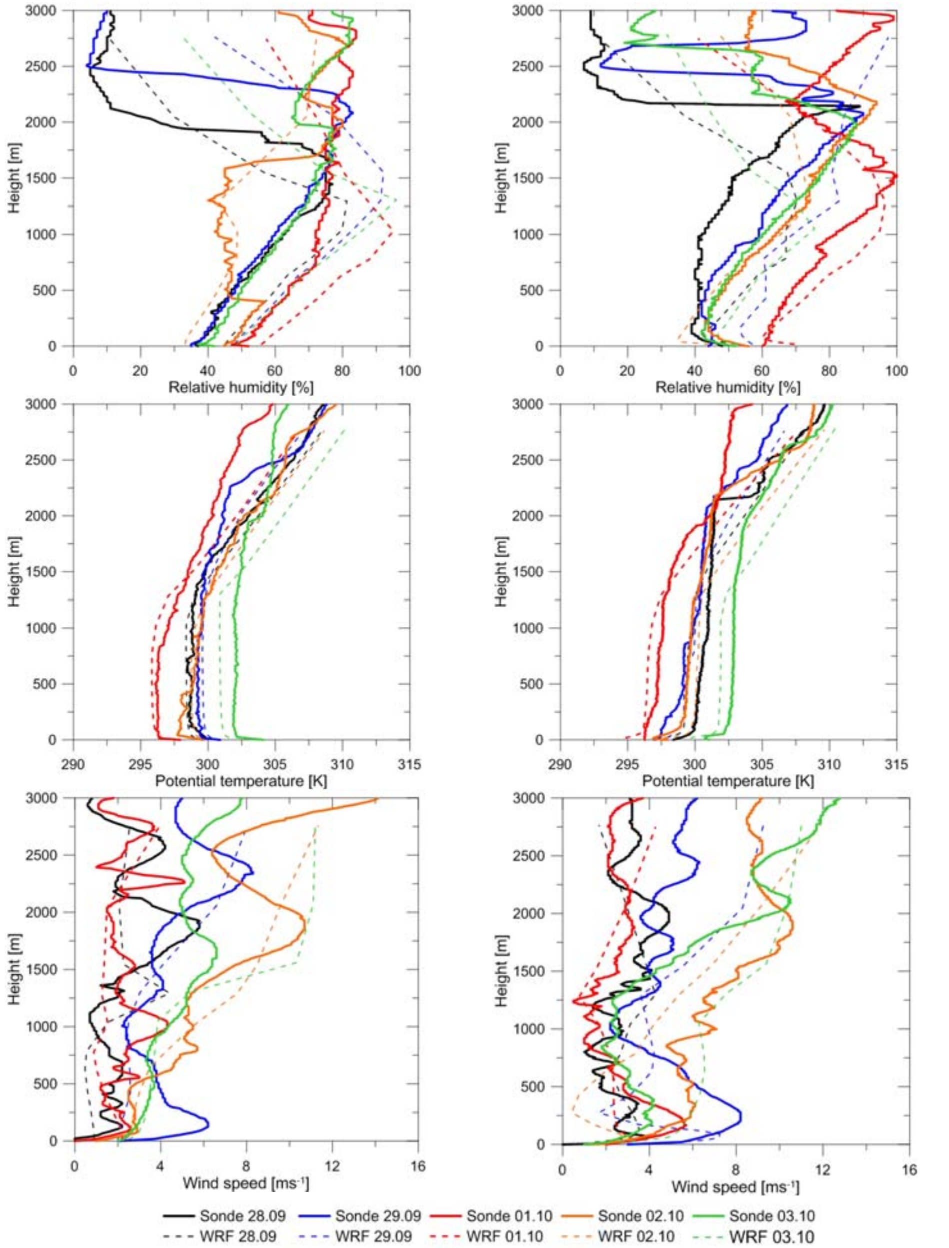

Figure 2. Comparison between measured and modelled parameters at 15 (left) and 19 LST (right).

Diurnal variability of measured and modelled parameters

Statistical comparisons between modelled and measured parameters show that the performance of the model is slightly better in the morning hours (which covered data/model output at 07, 09, 11 and 19 LST) than in the afternoon hours (11, 13, 15, 17 LST). The coefficient of determination is almost 1 for temperature and lower for relative humidity, showing difference less than 1 % between mornings and afternoons for both parameters. Lower values are obtained for wind speed where values are with 6 % higher in the afternoons. Very low coefficient of determination and larger difference between mornings and afternoons are calculated for wind direction.

Table 2. Values of coefficient of determination in morning and afternoon hours for relative humidity (RH), potential temperature (Theta), temperature (Temp), wind speed (Wsp) and wind direction (Wdir).

	Coefficient of determination R-squared	
	Morning hours	**Afternoon hours**
RH	0.676919	0.674078
Theta	0.988321	0.987029
Temp	0.993557	0.992711
Wsp	0.782512	0.828081
Wdir	0.240608	0.16046

Space and time variability of measured and modelled parameters

In order to study the ability of WRF to predict time variations of different meteorological parameters, modelled data are compared with measurements at every hour of observation for the entire period of the Sofia Experiment (Table 3). For the specific five-day period, scatter plots showed the best fit between different parameters from WRF and radiosounding data at different hours, but it might be concluded that regarding the complex of parameters the model is closest to the observations at 15 LST.

Table 3. Values of coefficient of determinations for RH, Theta, Temp, Wsp and Wdir for specific hour of observation (07, 09, 11, 13, 15, 17, and 19 LST) averaged for the lowest 19 of WRF levels.

	Coefficient of determination R-squared				
LST	**RH**	**Theta**	**Temp**	**Wsp**	**Wdir**
7	0.669613	0.991046	0.99368	0.785667	0.1181
9	0.732143	0.991874	0.995019	0.84443	0.128801
11	0.542442	0.9834	0.992372	0.929449	0.047241
13	0.609062	0.984368	0.995586	0.872867	0.024821
15	0.77672	0.985747	0.995496	0.838167	0.337975
17	0.603693	0.980774	0.997025	0.671144	0.319298
19	0.570335	0.977433	0.977433	0.747809	0.607347

Regarding the ability of the model to simulate temperature profiles at different levels (Fig. 3), it is found that the values of the coefficient of determination decrease by 10 % from the ground up to 1500 m.

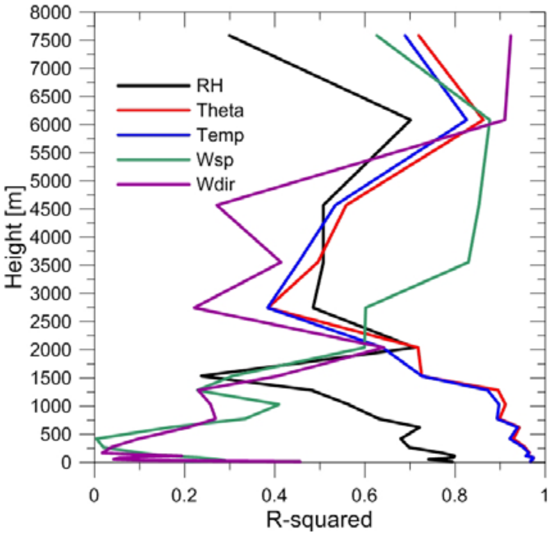

Figure 3. Variations with height of the coefficient of determinations for RH, Theta, Temp, Wsp and Wdir at specific WRF modelling level averaged for all hours of observations.

Higher up, reaching 2750 m, the decrease is faster. Scatter plots at different levels also show better agreement between model and measurements at lower heights (Fig. 4). At height of about 2000 m ag the coefficient of determination for all parameters exhibits changes, which might be associated with the influence of the Vitosha mountain (the height of which is 2290 m), pointing inability to reproduce always the complex structure of the profiles created by the combination of complex terrain, urban conditions and synoptic forcing

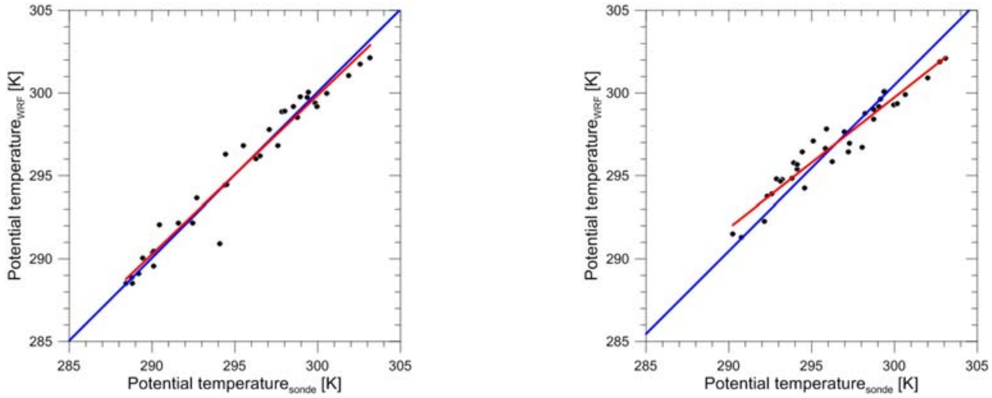

Figure 4. Scatter plots of potential temperature at 100 m (right panel) and 400 m (left panel) averaged for all hours of observations

CONCLUSIONS

Convective boundary layer evolution in an urban area in complex terrain was simulated with WRF-ARW v3.3.1 and modelled profiles were evaluated against radiosounding data. Simulations were performed with 1.5 order local closure scheme on 4 domains with resolution 36, 12, 4, 1.33km, respectively and 26 vertical layers.

Statistical comparisons between modelled and measured parameters showed that simulated relative humidity, temperature, potential temperature and wind direction were slightly better in the morning hours than in the afternoon hours, while the wind speed was insignificantly better resolved in the afternoons.

Concerning the ability of the model to reproduce specific temporal variation of meteorological parameters it was found that the best match between WRF values and radiosounding data was observed at 15 LST, and the worst- at 19 LST

The WRF model simulated in a satisfactory way the vertical profile of temperature, potential temperature and relative humidity (R^{RH}-squared for most of the investigated height was above 0.5), while the wind speed was reasonably resolved above 1500 m ag. The wind direction was poorly simulated in the lowest 1000 m, pointing inability of the model to reproduce always the complex structure of profiles influenced by a complex terrain, urban conditions and synoptic forcing.

Comparison of the model output and radiosounding data revealed that WRF with Mellor-Yamada-Janic PBL scheme simulated relatively well the shape of the vertical profiles of all analysed parameters, except wind direction.

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REFERENCES

Batchvarova, E, Gryning, S.-E., Rotach, M.W and Christen, A., 2006, Comparison of modelled aggregated turbulent fluxes and measured turbulent fluxes at different heights in an urban area, In: Air pollution modeling and its application, XVII, Borrego, C. and Norman A. (Eds.), (Kluwer Academic/Plenum Publishers) (NATO Challenges of Modern Society series), 363-370.

Floors, R., G. L. Vincent, S.-E. Gryning, A. Pena, E. Batchvarova, 2013, The wind profile in the coastal boundary layer: wind lidar measurements and numerical modelling, Boundary-Layer Meteorology, 146, 1-23 (Article in Press).

Hu, Xiao-Ming, 2010**,** Evaluation of Three Planetary Boundary Layer Schemes in the WRF Model, J. Appl. Meteor. Climatol., 49, 1831–1844.

Skamarock. W., J. B. Klemp, J. Dudhia, D. O. Gill, D. M. Barker, M. G. Duda, Xiang-Yu Huang, W. Wang, J. G. Powers, 2008, A Description of Advanced Research WRF Version 3 http://www.mmm.ucar.edu/wrf/users/docs.

WRF, 2011, User's Guide for Advanced Research WRF (ARW) Modelling System Version 3 http://www. mmm.ucar.edu/wrf/users/docs.