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MESOSCALE SIMULATION OF METEOROLOGICAL PROFILES DURING THE SOFIA EXPERIMENT 2003

Hristina Kirova and Ekaterina Batchvarova

National Institute of Meteorology and Hydrology – Bulgarian Academy of Sciences

Abstract: The 1,5-million-inhabitant city of Sofia is situated in a mountain valley, which creates significant air pollution problems in cases with shallow or stable boundary layer. Unfortunately, only one vertical sounding is operationally performed at noon, so the Sofia experiment 2003 is a unique data base for convective boundary-layer evolution. Here we present an evaluation of one configuration of the Weather Research and Forecasting (WRF) model against consecutive and high vertical resolution radiosounding data from Sofia Experiment 2003. 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 nested domains, with horizontal grid step of the finest domain 1.33 km covering Sofia and entirely the Vitosha mountain, and on 26 vertical levels (13 of which below 2 km). Mellor-Yamada-Janjic boundary-layer scheme was used.
Innovative statistical analysis was performed for all model levels and times of radiosoundings, as well as for some integral characteristics within the boundary layer. In order to examine the ability of presented configuration to simulate observed tropospheric profiles, a statistical comparison is performed between data from 35 radiosoundings and corresponding in time model results (the lowest 19 levels) up to 8000 m.
The vertical profiles of relative humidity, temperature, potential temperature and wind speed were reproduced well, while wind direction was poorly resolved in the lowest 1000 m. Statistical comparisons between modelled and measured parameters showed that WRF simulated most of the analysed parameters better in the transition periods than during convective conditions. The profiles of the coefficient of correlation for all parameters are analysed to illustrate the statistics of WRF performance in height. In general, this configuration of WRF was able to reproduce the complex structure of the profiles created by the combination of complex terrain, urban conditions and synoptic forcing.

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

INTRODUCTION

This study is focused on investigation of the convective atmospheric boundary layer (ABL) evolution in urban area, located in a complex terrain (Sofia valley, Bulgaria) by comparing vertical profiles calculated by numerical weather prediction model and measured from radiosoungs. The radiosounding site is in the Eastern part of Sofia city. The neighborhood (blocks of apartments with different height and configuration, and vast open grassy areas between them) is representative for urban areas in large cities in Eastern Europe. The geographical characteristics of the area combined with large emissions lead to problems with air quality in Sofia – smog near the ground, strong inversion situations in winter and high PM10 concentrations in summer despite the deep ABL. Reliable description of profiles of meteorological parameters is essential to air pollution modelling in complex and urban areas. Therefore, this study examines the performance of the Weather Research and Forecasting (WRF) model with Mellor-Yamada-Janjic boundary layer scheme comparing with data from high resolution in time and height radiosoundings.

"SOFIA EXPERIMENT, 2003"

The "Sofia experiment 2003" field campaign was carried out in the early autumn of 2003, September 27 – October 3 in Sofia (Batchvarova et al, 2006). During the experimental campaign thirty five soundings were performed to document the convective boundary layer development. The sondes were launched from National Institute of Meteorology and Hydrology (starting at 7 a.m. ending at 19 a.m.). The soundings were performed with 2 hour temporal resolution and increased vertical resolution as the ascend velocity was kept about 3-4 ms^{-1} (two times slower than standard radio sounding). The collected data set of intensive observations comprises vertical profiles of air temperature and humidity, as well as wind speed and direction.

MODEL CONFIGURATION

Numerical simulations were performed with the Weather Research and Forecasting (WRF) model (with ARW core), version 3.3.1 (Skamarock et al., 2008). The model was initialised with the US National Center for Environmental Prediction Final Analyses (FNL) with 1x1 degree spatial and 6 hours temporal resolution. WRF model was run with two-way nesting on 4 domains with horizontal grid step 36, 12, 4, 1.33 km and horizontal grid dimensions: 58x58 (D1), 43x43 (D2), 37x34 (D3), and 43x43 (D4) points, respectively (Fig.1) and 26 vertical levels up to 50 hPa. The parameterisations used were Thomson graupel (D3, D4) and WSM 5-class (D1, D2) scheme for cloud physics; RRTM for longwave and Goddard for shortwave radiation; Mellor-Yamada-Janjic TKE scheme for ABL with Noah LSM and Janjic-Eta surface layer. The new Grell cumulus parameterisation was used only for D1 and D2.

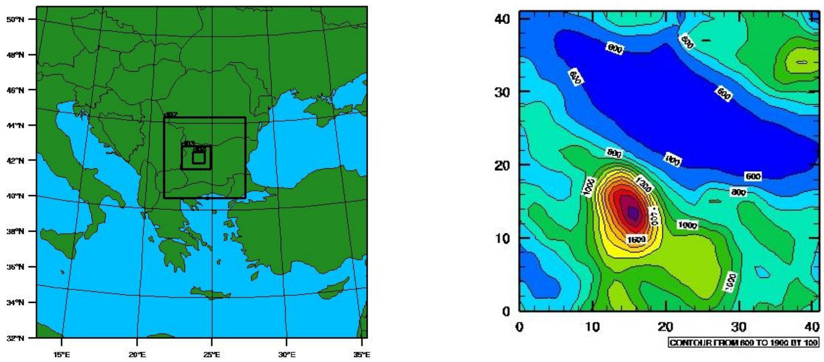

Figure 1. Domain configuration (left) and terrain features of domain 4 (right)

MODEL RESULTS AND EVALUATION

The performance of the presented configuration is evaluated: mean, bias (model - measurement), root mean square error - RMSE, standard deviation – SD, correlation coefficient – r (Table 1). The studied parameters are temperature (Temp), potential temperature (Theta), relative humidity (RH), mixing ratio (MR) and wind speed (Wsp). Calculations are performed for the period 28.09 – 03.10 using data from 35 soundings and all levels up to 8000 m (665 pairs).

Table 1. Summary statistics (using integrated data up to 8000 m for all radiosoundings)

	Mean_WRF	**Bias**	**RMSE**	**SD**	**r**
Temp	277.9229	-1.7243	2.7704	2.1701	0.9971
Theta	302.6186	0.7356	1.3995	1.2204	0.9928
RH	58.6498	4.7696	14.7138	13.8942	0.8194
MR	5.3234	0.1749	0.9744	0.9584	0.9485
Wsp	5.3501	-0.0546	2.1795	2.1802	0.9037

There is positive very strong (0.8<r<1) correlation between model and measurements for all studied parameters. Slight underestimation of temperature and wind speed and overestimation of potential temperature, mixing ratio and relative humidity can be noted. The most dispersed parameters are MR, Wsp and RH, all illustrated by the scatter plots in Fig. 2.

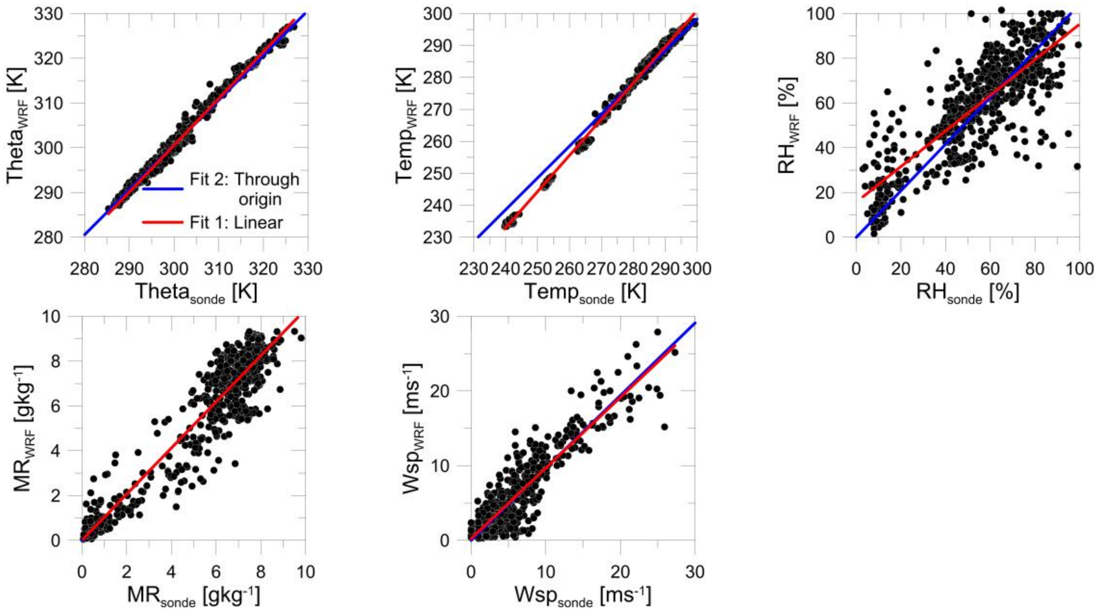

Figure 2. Scatter plots of Theta, Temp, RH, MR, Wsp for all radiosoundings and all levels up to 8000 m

Figure 3 shows the change with height of the mean difference between modeled and measured parameters and its standard deviation based on 35 soundings. The largest underestimation of temperature is observed between 4500 - 8000 m. The potential temperature is slightly over predicted near the ground and above 1500 m. Overestimation of RH is obtained below 1700 m and above 4000 m with maximum of 20 % around 1000 m and 7600 m. In the first 1200 m MR is over predicted by 0.75 $g.kg^{-1}$. Higher up, within the adjacent 3300 m thick layer MR is under predicted of the same magnitude, in layer 4500 to 8000 m the simulated values of MR almost coincide with the measured ones. Wsp is underestimated up to 1.2 $m\ s^{-1}$ in the first 1000 m and higher up is overestimated up to 1.7 $m\ s^{-1}$.

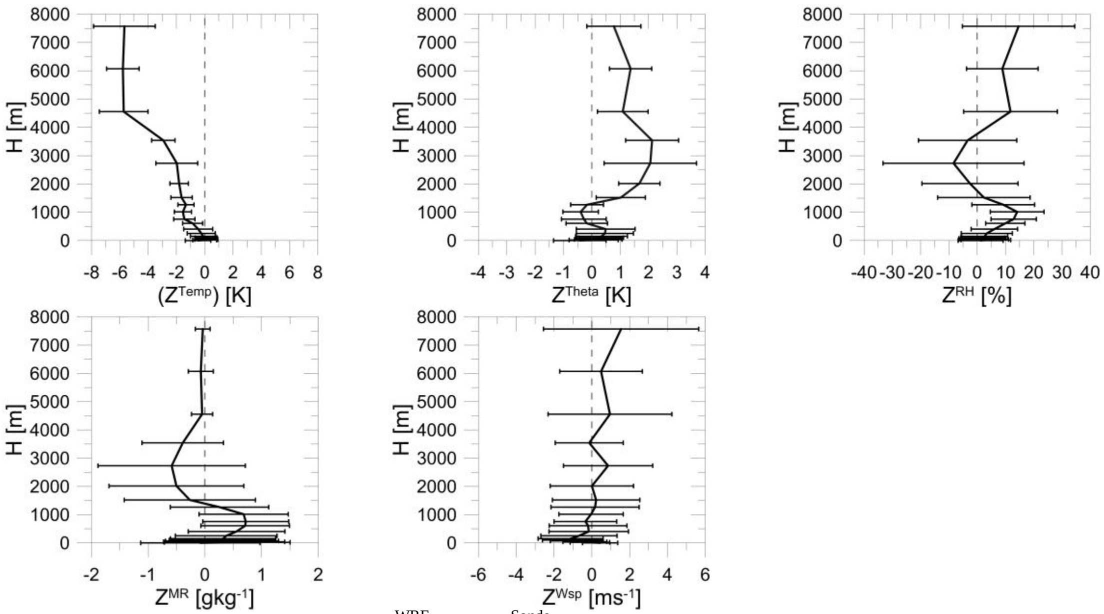

Figure 3. Averaged value of Z (Z = $Value^{WRF}$ - $Value^{Sonde}$) from all 35 soundings and its SD for each model level up to 8000 m

In order to examine the way WRF (in the presented above configuration) reproduces the structure of the ABL over Sofia, analysis was performed of all modelled to measured parameters for entire period of "Sofia Experiment 2003" at every hour of radiosounding data and for all model levels. Illustration of profiles evaluation is given in Figure 4 for 15 LST and 19 LST on 29 September and 3 October 2003. Most often WRF overestimates the relative humidity within the boundary layer with 20 – 25 %.

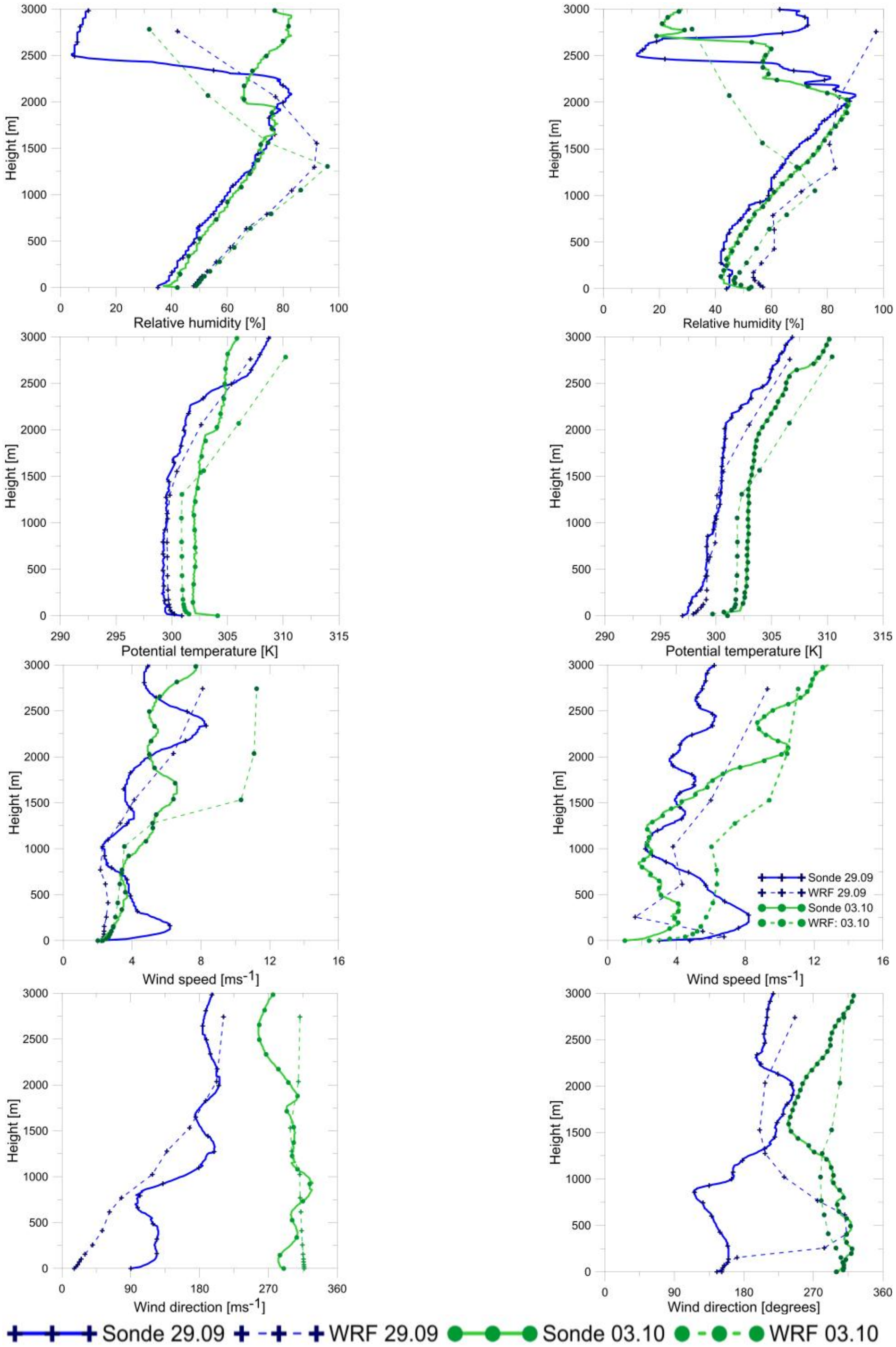

Figure 4. Comparison between measured and modelled parameters at 15 (left) and 19 LST (right) on 29 September and 3 October 2003

Hu et al, 2010 discussed that the local closure MYJ scheme lacks to entrain adequately drier and warmer air from the surface higher up in the ABL which we also observe in relative humidity, but not in temperature. In fact temperature (not presented here) and potential temperature profiles are the closest profiles to the observed ones. Vertical profiles of potential temperature at 15 LST are nearly constant with height as it is expected during daytime in well-mixed ABL (Srinivas et al, 2007). Wind speed is underestimated by the model close to the ground. Wind direction is unsatisfactory resolved, with the exception of October 3, the day when the variability of wind direction from radiosounding data in height was the smallest

For further analysis, the data are divided into two groups: transition hours (TH) covering model output vs measurements at 07, 09, 19 LST and afternoon hours (AH) covering model output vs measurements at 11, 13, 15, 17 LST. Summary statistics is shown in Table 2.

Table 2. Summary statistics for Temp, Theta, RH, MR and Wsp in TH and AH

	TH (07, 09, 19 LST)					***AH (11, 13, 15, 17 LST)***				
	Temp	**Theta**	**RH**	**MR**	**Wsp**	***Temp***	***Theta***	***RH***	***MR***	***Wsp***
Mean WRF	277,40	301,27	62,33	5,33	5,36	*279,04*	*303,12*	*55,99*	*5,48*	*5,09*
Bias	-1,56	0,75	3,32	0,04	-0,12	*-1,67*	*0,66*	*5,18*	*0,25*	*0,12*
RMSE	2,72	1,41	15,22	0,92	2,46	*2,78*	*1,52*	*14,88*	*1,09*	*1,94*
SD	2,43	1,20	14,87	0,92	2,46	*2,23*	*1,37*	*13,97*	*1,07*	*1,94*
r	0,997	0,994	0,823	0,950	0,879	*0,997*	*0,989*	*0,775*	*0,938*	*0,919*

The calculated values of coefficient of correlation for all parameters show strong or very strong relationship between observed and modeled values. WRF performance is slightly better in the transition hours than in afternoon hours, except for wind speed. WRF tends to overestimate Theta, RH, MR and Wsp in AH and underpredicted Temp (in AH and TH) and Wsp in TH.

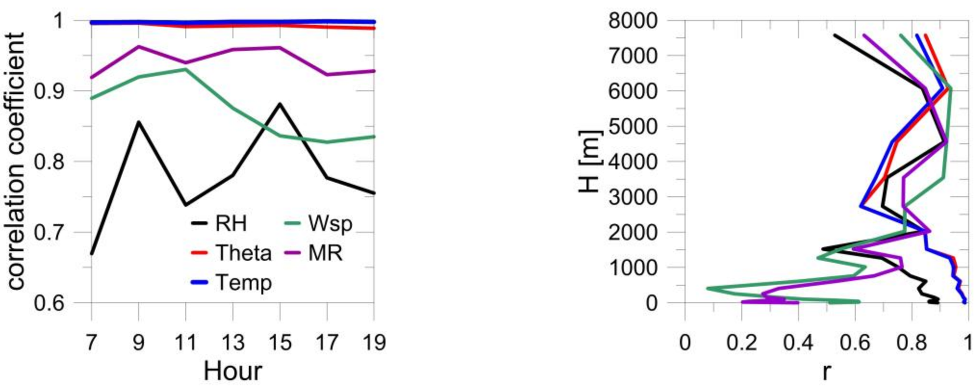

Figure 5. Variation of correlation coefficient with time (left) and height (right).

Figure 5 (left) shows the diurnal change of the correlation coefficient. It is noted that almost constant high values of r are calculated for temperature parameters, while r for wind speed and moisture parameters shows distinct diurnal pattern and lower values. Reconstruction ability of this configuration to reproduce vertical structure of the ABL (Fig. 5, right) is examined by comparing the model output at each level with measurements from all 35 radiosoundings up to 8000 m. There is very strong positive correlation (r>0.8) for Temp and Theta up to 1200 m, as well as for two of the higher levels around 6000 m and 7600 m. There is strong correlation (r>0.6) between output from WRF and measurements for Theta and Temp for all levels up to 8000 m, the lowest value for r being calculated at height around 2700 m. Strong up to very strong correlation is observed for RH values except at height around 1500 m (r=0.48). MR is simulated with r<0.5 up to 250 m, for the higher levels r>0.5. The lowest values of r (r<0.5) for wind speed are between 100 m and 600 m and at height 1270 m, for the rest levels r>0.5.

CONCLUDING REMARKS

The planetary boundary layer in an urban area situated in a mountainous valley was simulated with WRF (ARW) v3.3.1 and modeled profiles were evaluated against radiosounding data, collected during the "Sofia Experiment 2003".

The set up of WRF (with MYJ) simulated in a satisfactory way the vertical profiles of temperature, potential temperature and relative humidity, while the wind speed was reasonably resolved above 1500 m. The wind direction was poorly simulated in the lowest 1000 m.

The overall performance of the model, based on data set formed by all WRF levels (up to 8000 m) and all time periods of radiosoundigs showed strong positive correlation (0.80-0.99) for Temp, Theta, RH, MR and Wsp.

The profile of the correlation coefficient (comparison between model and observations for all 35 soundings at each model) revealed low correlation for Wsp and MR in the first few hundred meters and higher correlation (> 0.80) above 2000 m, while for temperature stronger correlation was obtained below this height.

The temporal variations of the studied parameters, except the RH, were reconstructed with strong correlation.

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