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EVALUATION OF RAMS6.0 BOUNDARY-LAYER SIMULATION OVER SOFIA (BULGARIA) ON VERTICAL PROFILES OF THE ABL

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Abstract: The horizontal and vertical structure of the atmospheric boundary layer over Sofia have been computed using appropriate high resolution runs of RAMS6.0 mesoscale model for a week period corresponding to a boundary layer experiment conducted in autumn 2003. The RAMS6.0 predictions for sensible heat flux during the intensive campaign (28 September – 3 October 2003) are very close to measurements, while the 10 m wind speed is highly overestimated. The results show further that the diurnal variation of wind speed in the model at 5 km horizontal resolution is quite idealized and very likely the simulation cannot reflect the complex mountain-valley circulation pattern typical for the city. The modelled and measured vertical profiles of wind and temperature are quite different. Thus, even well validated over complex terrain models (RAMS6.0 over Northern Italy, etc) when applied for “new” complex terrain conditions, do not ensure a success. Measurements for validation (and data assimilation) are needed for all applications of mesoscale models.

Key words: *Mesoscale meteorological models, Atmospheric Boundary Layer, Radiosonde measurements of vertical profiles, Eddy correlation measurements of surface turbulent fluxes, Evaluation of model results.*

INTRODUCTION

The complex horizontal and vertical structure of the atmospheric boundary layer (ABL) can be studied based on output data of mesoscale meteorological models, after the latter have been validated. Presently a worldwide effort is going on for better validation procedures and philosophy. A method for validation of models based on estimates of the variability of measured atmospheric parameters (Batchvarova and Gryning, 2009) is applied here for surface values.

Concerning the vertical profiles even of mean meteorological parameters, there are no new options suggested yet and the main tool is graphical presentation and visual comparison. Point to point comparisons are possible for some levels, but this cannot present the complex vertical structure often observed. The method suggested in (Batchvarova and Gryning, 2009) is also not applicably straightforward as there are no assessments of the variability of measurements at different heights. The topic of evaluation of models and comparisons of model results and observations needs further development.

In this study the ABL over Sofia valley is modelled using 5 km resolution runs of RAMS6.0 mesoscale model for short periods during the Sofia 2003 boundary-layer experiment. This experiment was carried out in early autumn of 2003. In addition to standard synoptic, solar radiation, climatological and aerological observations performed at the NIMH, during the experiment turbulence measurements were performed at 20 and 40 meters above ground on a meteorological tower. High resolution (both in space because of low ascent velocity and time – every second hour during the day) radio soundings to measure vertical profiles of temperature, humidity and wind fields were also performed (Batchvarova *et al.*, 2007).

RAMS6.0 CONFIGURATION

Two configurations of RAMS6.0 were used for simulations:

Case 1: RAMS6.0 was run on three nested domains with grid size 25, 5 and 1 km and with 62, 132 and 202 grid points correspondingly. 42 vertical levels were implemented starting at 50 m and with increase factor of 1.15 for the vertical resolution. The simulation was realised with time step of 30 seconds on the first domain and ratio 1, 5, 3. The centre of the domain was chosen in the plains about 250 km east of Sofia. With this configuration the model was stable and a simulation for 6 days in a row was performed.

Case 2: RAMS6.0 was run on three nested domains with grid size 25, 5 and 1 km and with 42, 132 and 252 grid points correspondingly. For this setup 56 vertical levels were chosen, starting at 10 m and with increase factor of 1.15 for the vertical resolution. Time step was 10 seconds for the outer domain and ratio 1, 5, 4 for the inner domains. The centre of the domain was Sofia. At this configuration the model was getting unstable after simulation of one or two days.

THE EXPERIMENTAL DATA

The Sofia Experiment of 2003 (Batchvarova *et al.*, 2007) was a boundary layer experiment comprising turbulence measurements at 20 and 40 m above ground on a meteorological tower (METEK sonic anemometers) and consecutive (every 2 hours) high resolution radio soundings performed with VAISALA equipment for standard aerological observations, but keeping much lower ascend velocity (about 3 $m\ s^{-1}$) for detailed information on the atmospheric boundary layer profiles of meteorological parameters. The radiosonde measurements were performed between 27 September and 3 October 2003. During most of those days clear convective boundary layers have formed and the measurements allowed following the convective boundary layer growth.

EVALUATION METHOD

Sreenivasan *et al*, (1978) suggest an applied method for estimation of the standard deviation of the wind speed and the sensible heat flux for a given averaging time, T:

$$\sigma_{u,T} = \sqrt{12} \sqrt{\frac{z}{T\,u}}\; u \qquad (1)$$

and

$$\sigma_{\overline{w'\theta'},T} = 8 \sqrt{\frac{z}{T\,u}}\; \overline{w'\theta'} \,. \qquad (2)$$

The standard deviation $\sigma_{u,T}$ increases with height, z, and wind speed, u, and decreases with averaging time. The standard deviation $\sigma_{\overline{w'\theta'},T}$ increases with height and sensible heat flux, $\overline{w'\theta'}$, and decreases with averaging time and wind speed, (Batchvarova and Gryning, 2009).

When the standard deviations $\sigma_{u,T}$ and $\sigma_{\overline{w'\theta'},T}$ are calculated using the actual averaging time for measurements and an interval is applied correspondingly around the model results, a range of possible values is defined. When measured values fall within the interval, we may conclude that the model prediction is successful.

RESULTS

The values of the measured sensible heat flux (in this case at 20 m and 40 m height above ground) fall within the interval formed by the natural variability of measurements applied to model result (RAMS interpolation for surface heat flux), except for a short period during the night of 28-29 September 2003, Figure 1. We can then conclude that concerning surface sensible heat flux, the case 1 RAMS6.0 simulation cannot be improved. Relatively coarse resolution of 5 km in horizontal directions and 42 vertical levels starting at 50 m provides reliable values for the heat exchange between the atmosphere and the surface.

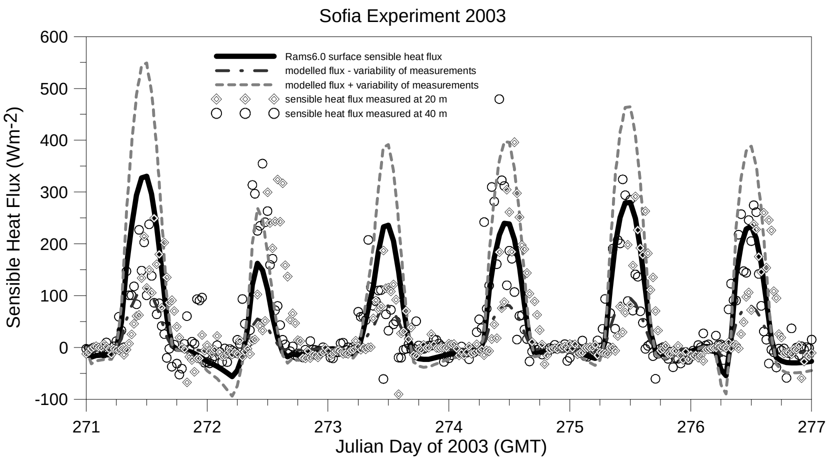

Figure 1. Surface sensible heat flux for the period 28 September – 3 October 2003 of Sofia Experiment. RAMS6.0 case 1 results for 5 km horizontal resolution (thick black line), variability of measurements according Equation 2 between dash-dotted and dashed lines, eddy correlation measurements at 20 m (diamonds) and 40 m (circles) height.

The same simulation (case 1) highly over predicts surface (interpolated) 10 m wind, Figure 2. The measurements are outside the interval set around the model prediction, although taken at 20 and 40 m height. As seen in Figure 3, the first model level (50 m) wind speed is slightly higher than the estimated by RAMS6.0 values of the 10-m wind (case 1). In general, the model prescribes distinct diurnal cycle with maximum at noon, while the measurements show more complex structure. The model considers almost homogeneous conditions with the horizontal resolution of 5 km, while the measurements reflect complex interaction of mountain valley circulation, flows driven by urban geometry and heat island and the synoptic conditions.

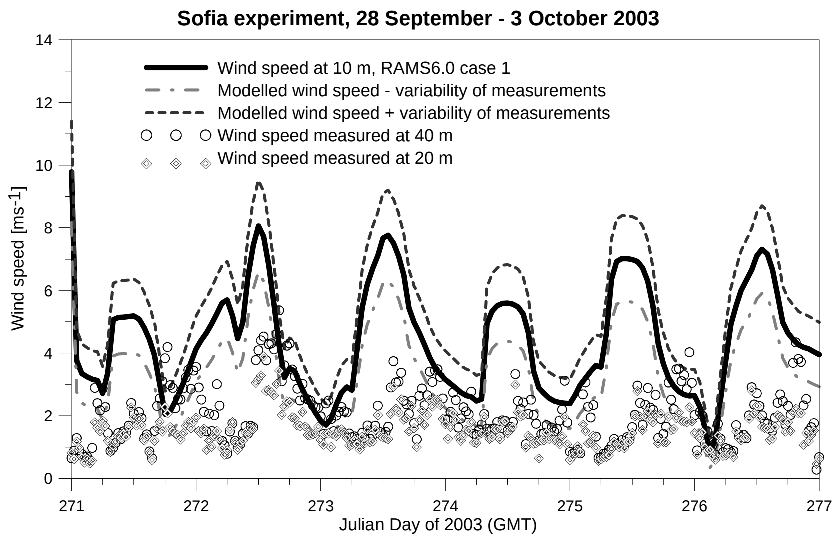

Figure 2. Wind speed for the period 28 September – 3 October 2003 of Sofia Experiment. Wind speed interpolation to 10 m from RAMS6.0 case 1 (thick black line). Variability of measurements (according Equation 1) between grey dash-dotted and dashed lines. Wind speed from eddy correlation measurements at heights of 20 m (diamonds) and 40 m (circles).

Comparing only model predictions in Figure 3, shows that the first model level (50 m) wind speed is slightly higher than the estimated by RAMS6.0 values of the 10-m wind (case 1). Setting the first model level very low (10 m) forces bigger differences between 10 m and 50 m wind speed (case 2).

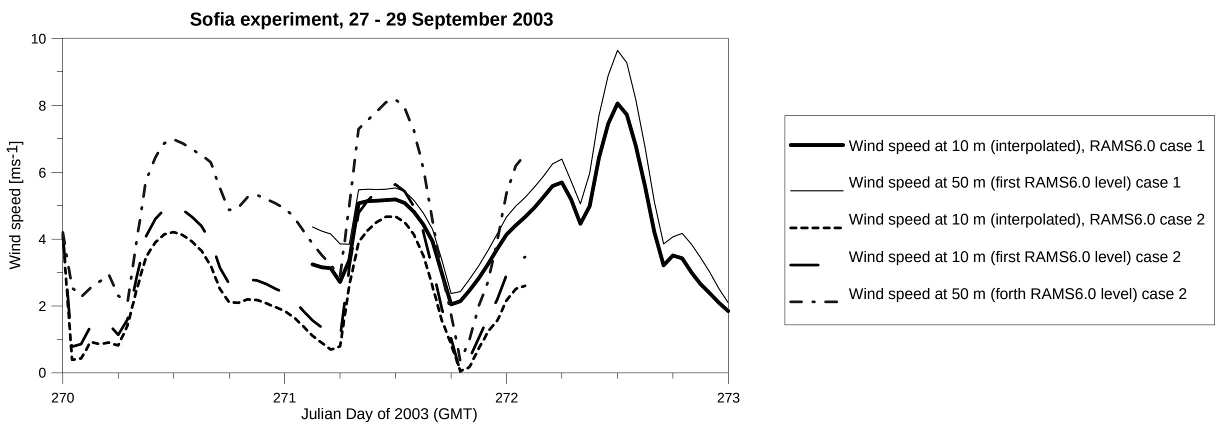

Figure 3. Wind speed for the period 27 – 29 September 2003 of Sofia Experiment. Wind speed interpolation at 10 m from RAMS6.0 case 1 (thick black line) and case 2 (short dashed line) for 5 km horizontal resolution. First model level wind speed in case 2 (10 m, long dashed line). Wind speed at 50 m from direct model outputs for case 1 (thin black line) and case 2 (dash dotted line).

Analyzing the wind profile from both RAMS6.0 cases and radiosonde measurements reveals even bigger discrepancy. Case 2 wind profile is characterized by stronger winds than the case 1 wind profile and introducing more complex structure. Both simulations give values much higher than the observed. Better agreement is seen for the transition periods (6 GMT or 9 local summer time – Figure 4, right panel), but only in the first 50 – 100 m. The increase of vertical resolution (case 2 compared to case 1) did not improve the prediction of the wind speed, but improved the simulation of the shape of the profile during convective conditions, Figures 5 and 6 (right panels).

Comparing the simulated and measured temperature profiles shows poor agreement as well, Figures 4, 5 and 6 (left panels). The predicted temperatures are more than 5 degrees lower than measured and the shape of the temperature profile is not reproduced by the model. Only at 6 GMT the predicted surface temperature is close to the measured one, but the difference increases with height (Figure 4).

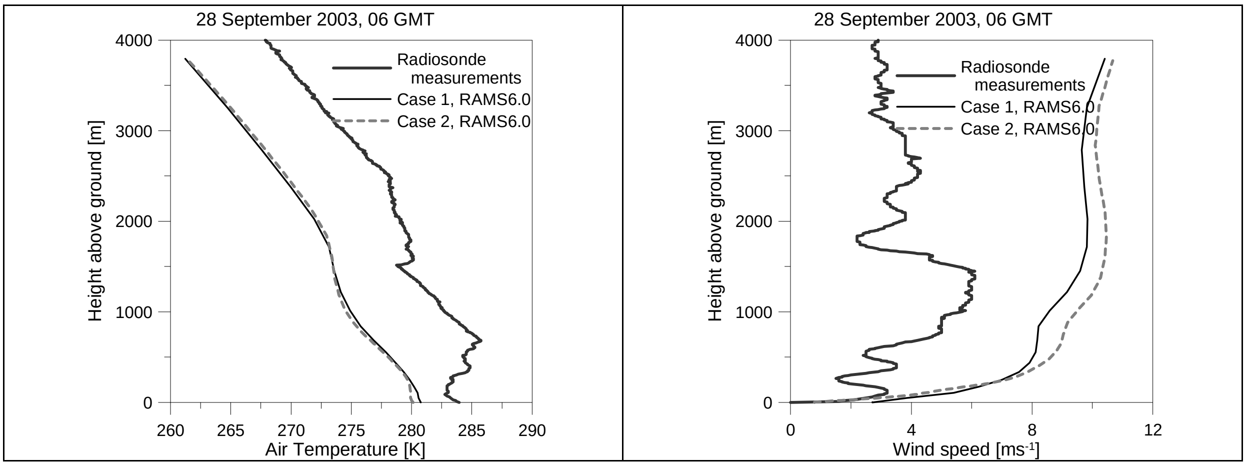

Figure 4. Wind speed profile at 6 GMT (9 local summer time) on 28 September 2003. High resolution (about 3-4 ms^{-1} ascend velocity) radiosonde measurements are represented with thick line, RAMS case 1 with thin black line and RAMS case 2 with grey dashed line.

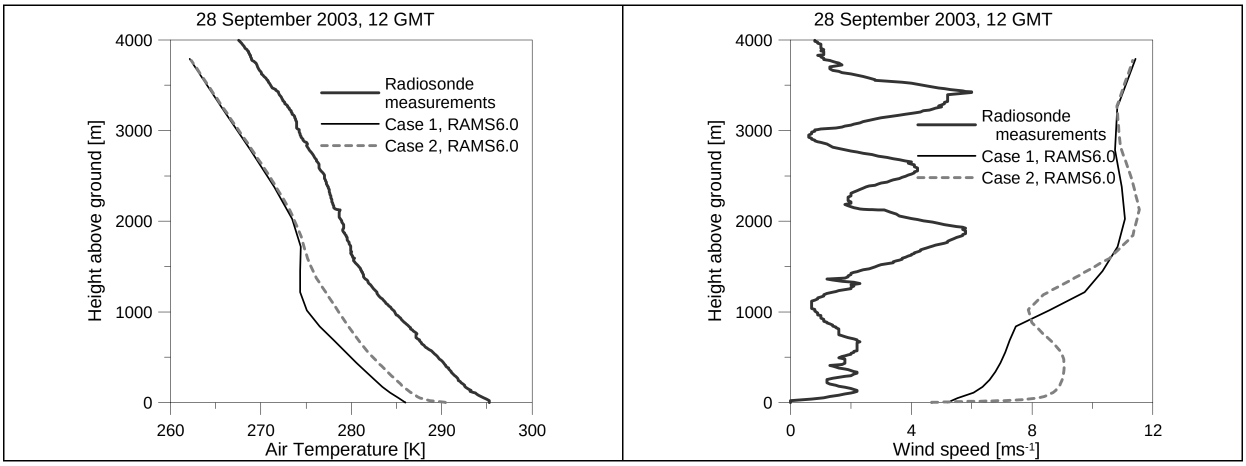

Figure 5. Wind speed profile at 12 GMT (15 local summer time) on 28 September 2003. High resolution (about 3-4 ms^{-1} ascend velocity) radiosonde measurements are represented with thick line, RAMS case 1 with thin black line and RAMS case 2 with grey dashed line.

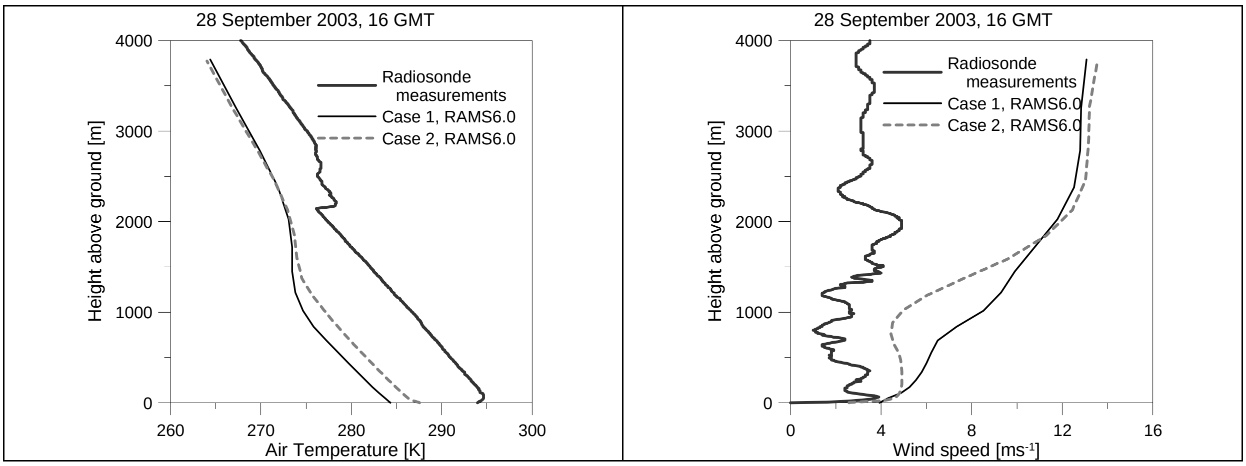

Figure 6. Wind speed profile at 16 GMT (19 local summer time) on 28 September 2003. High resolution (about 3-4 ms^{-1} ascend velocity) radiosonde measurements are represented with thick line, RAMS case 1 with thin black line and RAMS case 2 with grey dashed line.

CONCLUDING REMARKS

The predictions of RAMS6.0 for the surface heat flux are in good agreement with measurements during the Sofia 2003 Experiment, while the wind speed near the surface is largely over predicted and temperature under predicted. Such performance for wind speed is typical in regions with complex terrain. On the other hand, the good prediction of near surface wind and the boundary-layer wind profiles, as well as the temperature profile, are most critical parameters for a number of applications. Of those, most important for Sofia is the air pollution modelling. With the simulations driving atmospheric pollution model reported here the concentrations would be underestimated.

The wind and temperature profiles are not satisfactorily modelled which results in difficulties in estimation of the atmospheric boundary layer height and mixing parameters, other crucial issues in air pollution studies.

The results show also that even well validated over complex terrain models when applied to “new” complex terrain conditions, do not ensure a success. Measurements for model initial conditions, data assimilation and model validation are needed for all applications of mesoscale models. Moreover, regular profile measurements are needed for all meteorological parameters (and possibly air pollution) in order to meet the increased requirements of society for more reliable forecasts of weather and air pollution, more precise climate models and renewable energy potential assessments.

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