

MODELING AND MEASUREMENTS OF THE ABL IN SOFIA, BULGARIA

P58

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1. INTRODUCTION

The horizontal and vertical structure of the atmospheric boundary layer (ABL) can be studied based on output data of mesoscale meteorological models. In this study the ABL over Sofia valley is modelled using high resolution runs of RAMS6.0 mesoscale model for short periods covering the Sofia 2003 boundary-layer experiment. This experiment was carried out in early autumn of 2003, comprising turbulence measurements at 20 and 40 meters above ground and high resolution (both in space and time) radiosoundings to measure vertical profiles of temperature, humidity and wind fields (Batchvarova et al, 2007). RAMS6.0 runs with horizontal resolution of 1 km are evaluated here on Sofia 2003 experiment data.

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) was tested here.

2. RAMS6.0 CONFIGURATION

Case 1: RAMS6.0 was run on three nested domains with grid size 25, 5 and 1 km; with 62, 132 and 202 grid points correspondingly; with 42 vertical levels starting at 50 m (increase factor of 1.15 for the vertical resolution); with time step 30 seconds and ratio 1,5,3; and with center of the domain in the plains about 250 km east of Sofia, the model was stable running the simulation for 6 days.

Case 2: RAMS6.0 was run on three nested domains with grid size 25, 5 and 1 km, 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 center of the domain was Sofia. At this configuration the model was getting unstable after simulation of one or two days.

3. 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 radiosoundings performed with VAISALA equipment for standard aerological observations, but keeping much lower ascend velocity (about 3 ms^{-1}) for detailed information on the atmospheric boundary layer profiles of meteorological parameters.

4. 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:

$$\sigma_{u,T} = \sqrt{12} \sqrt{\frac{z}{Tu}} u$$

and

$$\sigma_{w'\theta',T} = 8 \sqrt{\frac{z}{Tu}} \overline{w'\theta'}$$

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

In Figure 1, when the measured values fall within the margins [$\text{model} - \sigma_{w'\theta',T}$, $\text{model} + \sigma_{w'\theta',T}$], we can say that the model cannot be improved concerning this parameter. RAMS6.0 is predicting very successfully the surface sensible heat flux over the area.

In Figure 2, the wind speed measurements do not fall in the range [$\text{model} - \sigma_{u,T}$, $\text{model} + \sigma_{u,T}$]. In this case, further investigation is needed to select the best configuration with the most appropriate

parameterizations of the boundary layer processes for specific area.

5. RESULTS

The values of the simulated sensible heat flux fall within the interval formed by the natural variability of measurements applied to model result, except for a short period during night of 28-29 September 2003, Figure 1. With grid resolution of 5 km and 42 vertical levels starting at 50 m, RAMS6.0 simulation cannot be improved regarding surface sensible flux.

The surface (10 m) wind is highly over predicted by RAMS6.0 for resolution of 5 km in both Case 1 and Case 2, Figures 2 and 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, Figure 2). 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.

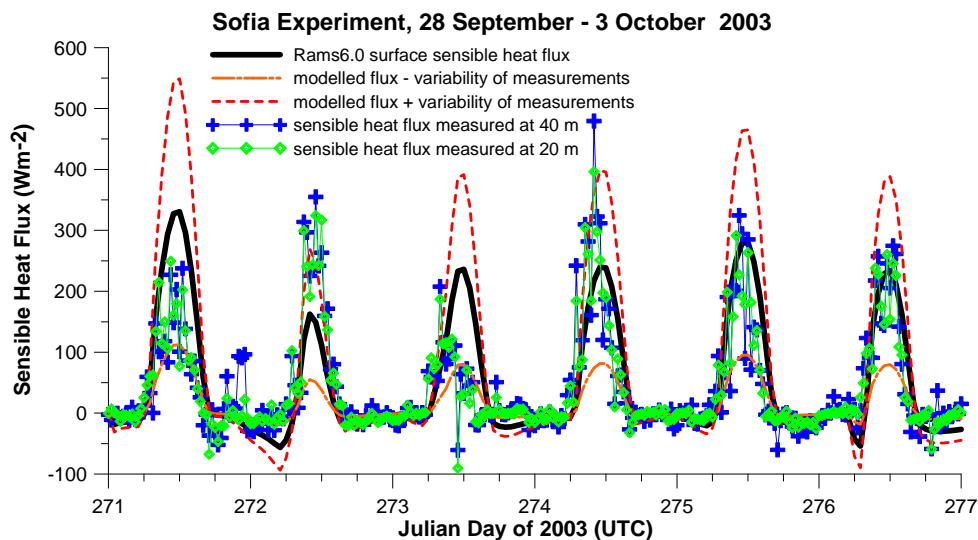


Figure 1. Sensible heat flux for the period 28 September – 3 October 2003 in Sofia. Symbols denote measurements with ultrasonic anemometers at 40 m (blue cross) and 20 m (green diamond) above ground. The solid black line shows the model estimate (case 1, grid 2 – 5 km resolution) for the surface sensible heat flux, while the orange (dash dotted) and the red (dashed) lines set the natural variability of measurements.

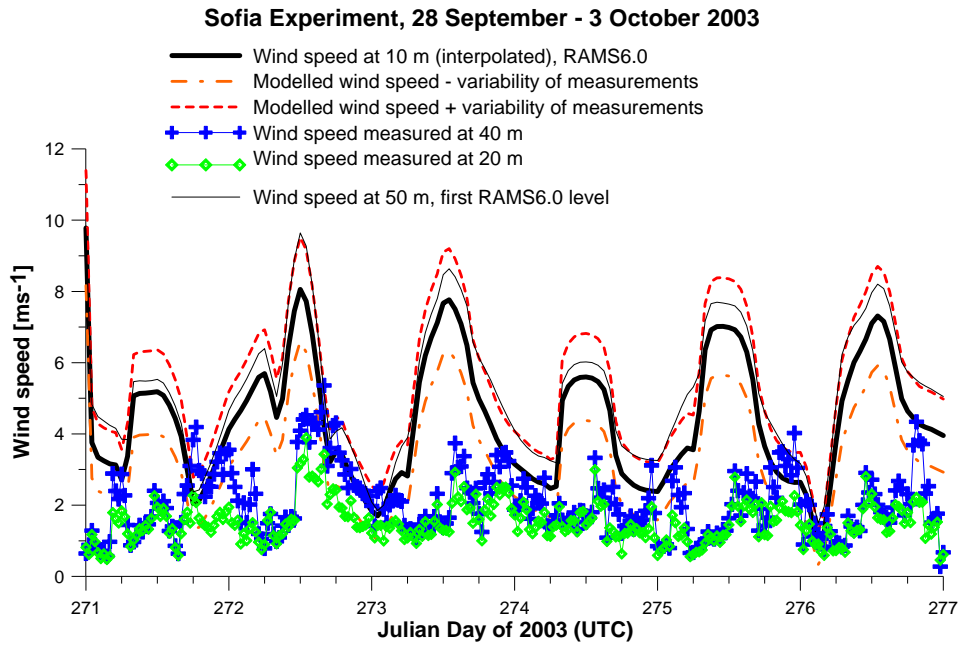


Figure 2. Wind speed for the period 28 September – 3 October 2003 in Sofia. Symbols denote measurements at 40 m (blue cross) and 20 m (green diamond) above ground. The solid black line shows the model estimate for 10-m wind (case 1, grid 2 – 5 km resolution), while the orange (dash dotted) and the red (dashed) lines set the natural variability of measurements around it. The thin black line shows the wind speed at the first model level of 50 m (case 1, grid 2 – 5 km resolution).

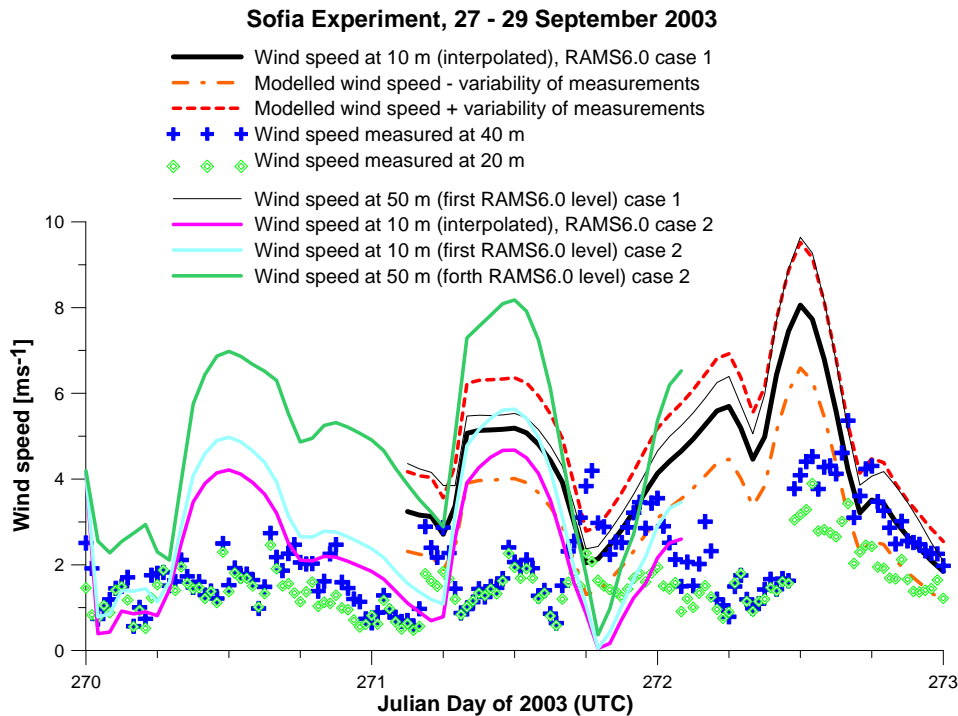


Figure 3. Wind speed for the period 27 - 28 September 2003 in Sofia. Symbols for measurements, solid and thin black lines, orange (dash dotted) and red (dashed) lines are as in Figure 2. Here, simulations of case 2 (grid 2 - 5 km resolution) are presented with magenta line for the interpolation from the first model level to 10-m wind; sky blue line for the calculated values at first model level (10 m) and green line for the fourth level (49.9 m).

For case 2, RAMS6.0 was set up to give more details in vertical direction by 56 vertical levels and start at 10 m. For this setup the simulations were getting unstable after 1 or 2 days. In Figure 3, the first level RAMS6.0 (10 m) wind speed is compared with the estimated 10 m wind speed and the 4th level (49.9 m) wind speed for 27 and 28 of September 2003. On 28 September, it is seen that the wind speed from both model runs (50 m first level and interpolation of RAMS6.0 for the 10 m wind from case 1 and 10 m level and the interpolated 10 m wind for case 2) falls within the borders of natural variability of measurements (red dashed line and orange dash-dotted line) set relative to the interpolation of 10 m wind in case 1 (thick black line). Thus, model predictions agree within the range of natural variability. The wind speed at 50 m for case 2 is much higher (green line) than the suggested variability, while the measurements on that day, even though taken at 20 and 40 m above ground are showing much lower wind speed.

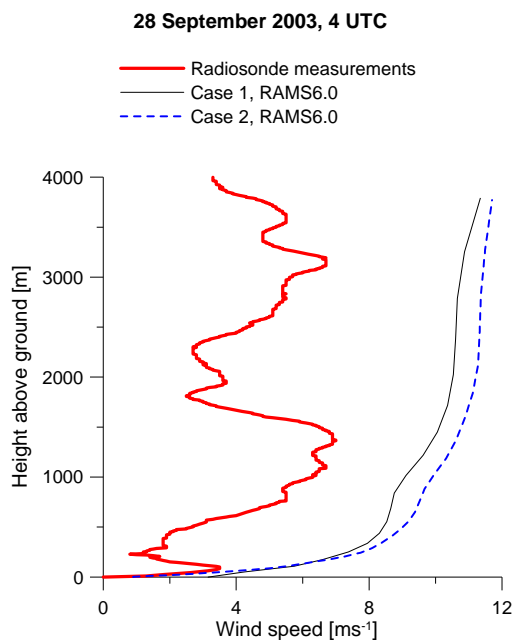


Figure 4. Wind profile at 4 UTC (local sunrise). Solid red line denotes radiosounding measurements, black line denotes RAMS6.0 simulation of Case 1 and blue dashed line Case 2, both for grid 2 of 5 km horizontal resolution.

Analyzing the wind profile from both RAMS6.0 set up cases and radiosonde measurements even bigger discrepancy is revealed. Case 2 wind profile is characterized by stronger winds than the case 1 wind profile. Both are giving values much higher than the observed. Better agreement is seen for the period about sunrise (4 UTC or 7 local summer time), but only in the first 50 – 100 m, Figure 4. The increase of vertical resolution, did not improve the prediction of the wind profile on a 5 km horizontal grid resolution, Figures 4, 5 and 6.

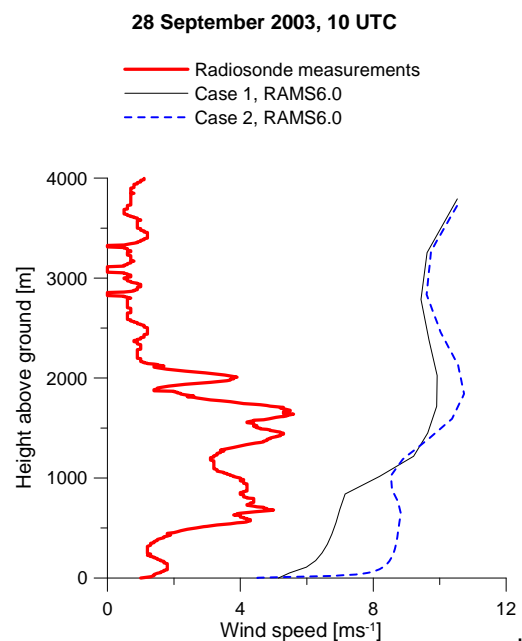


Figure 5. Wind profile at 10 UTC (local noon). Solid red line denotes radiosounding measurements, black line denotes RAMS6.0 simulation of Case 1 and blue dashed line Case 2, both for grid 2 of 5 km resolution.

If such prediction of wind speed is driving atmospheric pollution model, the concentrations would be highly underestimated.

A reliable prediction of the vertical profiles of wind and temperature is another issue that is not usually considered for model evaluations, but important for air pollution, wind energy and other applications of mesoscale models.

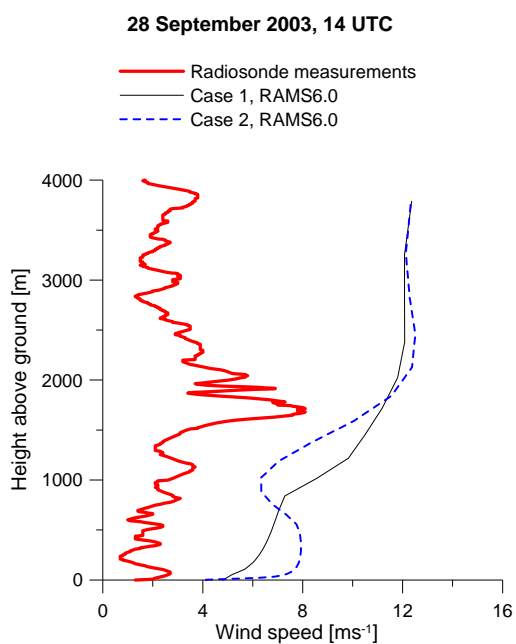


Figure 6. Wind profile at 14 UTC. Solid red line denotes radiosonde measurements, black line denotes RAMS6.0 simulation of Case 1 and blue dashed line Case 2, both for grid 2 of 5 km resolution.

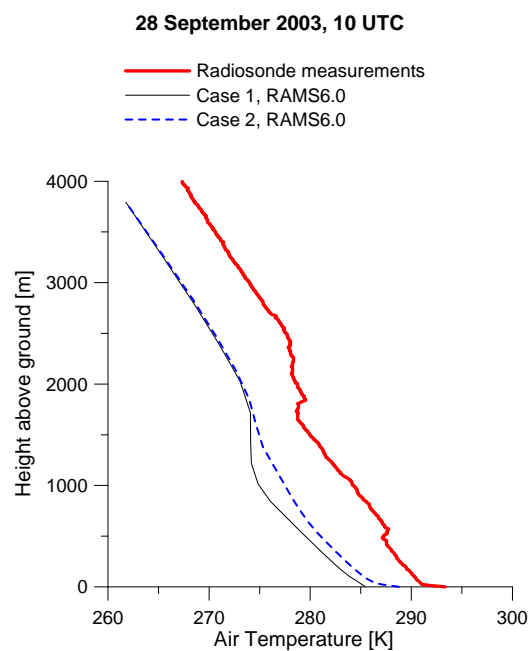


Figure 8. Temperature profile at 10 UTC. Solid red line denotes radiosonde measurements, black line denotes RAMS6.0 simulation of Case 1 and blue dashed line Case 2, both for grid 2 of 5 km resolution.

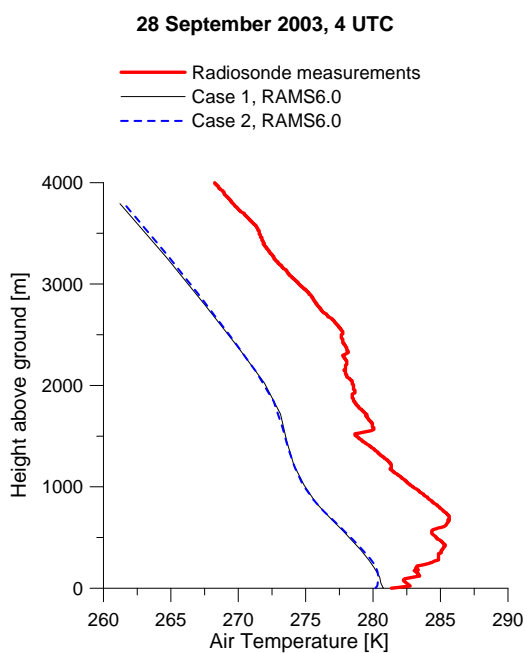


Figure 7. Temperature profile at 4 UTC. Solid red line denotes radiosonde measurements, black line denotes RAMS6.0 simulation of Case 1 and blue dashed line Case 2, both for grid 2 of 5 km resolution.

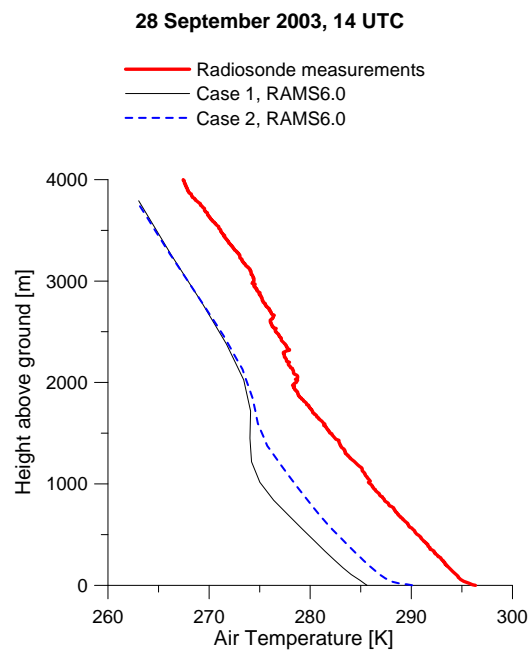


Figure 9. Temperature profile at 14 UTC. Solid red line denotes radiosonde measurements, black line denotes RAMS6.0 simulation of Case 1 and blue dashed line Case 2, both for grid 2 of 5 km resolution.

Comparing the simulated and measured temperature profiles shows poor agreement as well. The predicted temperatures are 5-10 degrees lower than measured (Figures 8 and 9) and the shape of the temperature profile is not reproduced by the model. Only at 4 UTC the predicted surface temperature is close to the measured one, but the difference increases with height (Figure 7).

6. 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. From another side, 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 modeling.

The wind and temperature profiles are not satisfactory modeled which results in difficulties of estimation the atmospheric boundary layer height, another crucial parameter in air pollution studies.

There are no methods to evaluate the model performance for vertical wind profiles, as there are not enough measurements to assess how the variability of those parameters changes with height.

The results show also that even well validated over complex terrain models when applied for "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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