CONVECTIVE INITATION IN THE BLACK FOREST REGION IN HIGH-RESOLUTION MM5 SIMULATIONS

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Abstract: Precipitation strongly affects many aspects of our economy and general livelihood. Therefore, efforts to improve quantitative precipitation forecast (QPF) have high priority in meteorological research. This is particularly challenging in the warm season when convective precipitation is more important. To get information about the model performance in predicting convective precipitation, several high-resolution numerical simulations have been conducted with the mesoscale model MM5. A specific goal of our work is to find an optimal model configuration for quasi-operational high-resolution weather forecasts during the field phase of the priority program "Quantitative Precipitation Forecast" (SPP1167). For a number of convection events in summer 2005, we made sensitivity experiments with a nested model configuration and a horizontal grid spacing down to 1 km. Comparison with surface observation data, including high-resolution raingauge measurements, shows substantial differences among the various model configurations tested in this study. The simulated precipitation fields show a systematic dependence on model resolution, which is partly because a convection parameterization is needed at coarser resolution, and on the PBL scheme, whereas the land-surface scheme appears to have a more unsystematic impact. However, the land-surface scheme has a systematic impact on the simulated surface temperatures, with the more sophisticated scheme inducing a marked cold bias in some cases.

Keywords: *orographic precipitation, convection, high-resolution numerical modelling*

1. INTRODUCTION

At present, NWP models still have deficits in predicting the spatial and temporal distribution of heavy precipitation events, especially in the warm season and over mountainous regions. To understand the processes responsible for the development of deep convection, the priority program "Quantitative Precipitation Forecast" (SPP1167) was established by the German Research Foundation (DFG) in 2004. Within this SPP a field campaign (COPS) will take place in summer 2007 in the Black Forest and the surrounding mountain regions, including high density surface measurements and aircraft measurements. The aim of this campaign is to analyze the pre-convective environment and to follow the complete life cycle from the initiation to the decay of the convective system. To get information about the model behaviour in predicting summertime convection, several high-resolution simulations were performed with the mesoscale model MM5. A specific goal of our work is to find an optimal model configuration for high-resolution real time weather forecasts during COPS.

2. DATA AND METHODS

The results described in this abstract are based on simulations of precipitation events in the COPS region during summer 2005 with MM5 version 3.7.3 (Grell et al., 1995). We considered a total of 13 events with convective precipitation over the Black Forest. They have been simulated once with a horizontal resolution of 7 km and once with a nested configuration with horizontal resolutions of 3 km and 1 km, respectively. The 7-km model grid consists of 100$\times$120 grid points, whereas the nested configuration uses 223$\times$195 for the 3-km grid and 223$\times$223 for the 1-km grid. In the vertical, 36 σ-layers are used in both simulations. Terrain data was obtained from USGS, and the initial and boundary conditions are taken from operational ECMWF analysis data every 6 h with a spatial resolution of 0.125°. In the reference setup, the physics parameterizations include the Reisner2 scheme (Reisner et al., 1998) for cloud microphysics, the MRF scheme (Hong and Pan, 1996) for boundary layer physics, the Noah land-surface-model (Chen and Dudhia, 2001), the RRTM scheme (Mlawer et al., 1997) for radiation, and, for the 3-km and 7-km grids, the Kain-Fritsch-2 (Kain and Fritsch, 1993; Kain, 2004) convection parameterization. For the high-resolution grid no convective parameterization was used because the model should be able to simulate convection explicitly. All experiments started at 00 UTC and ended at 06 UTC on the following day. Within our attempt to find an optimal model configuration for the COPS region, sensitivity tests with different options for boundary layer physics and LSM physics were conducted for four selected cases with the nested model configuration. Moreover, the operational 7-km LM forecasts of the German Weather Service (DWD) were considered for comparison with the 7-km MM5 simulations.

To validate the model results against observations, we used hourly 2-m temperature, 2-m dewpoint and 10-m windspeed data from the SYNOP network of the German Weather Service (DWD) and hourly raingauge data from the Environmental Protection Office of Baden-Württemberg and Météo France. The area of investigation was limited to the COPS region as shown in Fig. 1.

3. RESULTS

Comparison of the reference simulations with the available surface observations reveals a number of interesting results (Fig. 2a). While the 2-m temperature of the 7-km MM5 simulations agrees very well with the observations, the 1-km runs show a warm bias in the early morning and during the night and a slight cold bias in the afternoon. The LM of the DWD shows the same behaviour as the 1-km MM5 during the early morning and in the evening but tends to overestimate the maximum temperatures. On the other hand, the simulated wind speeds are closer to observations in the 1-km MM5 simulations than in both 7-km simulations. While the latter overestimate the surface wind speed throughout the day, the 1-km simulations have only a small positive bias at night. At both MM5 resolutions, the simulated 2-m dewpoint shows a step-like increase at sunrise and a further gradual increase during the day until 17 UTC, greatly exceeding the observed values. Afterwards, the dewpoint decreases rapidly. This indicates that the simulated daytime evaporation is too large, which would be consistent with the fact that the MM5 has a notable cold bias on some days (see Fig. 2b). However, the moist bias of the LM forecasts is even larger although this model exhibits a warm bias during the day.

For the hourly accumulated surface precipitation, we find a substantial overestimation for the 7-km MM5 whereas a slight underestimation occurs at 1 km. Moreover, there are large differences in the temporal evolution, with convection evolving 3–4 hours too early at 7 km resolution and 1–2 hours too late at 1 km resolution. This suggests that the Kain-Fritsch convection scheme initiates convection systematically too early, whereas the explicitly simulated convective initiation is more realistic. Interestingly, the temporal evolution of the 7-km LM rainfall is again completely different, showing a double peak structure with a local minimum at about the time of the observed rainfall maximum (see also Damrath, 2004). Apart from that, the spatial distribution of the convective rainfall is more realistic at 1 km resolution (not shown), mainly because explicitly simulated convection cells move with the ambient wind whereas parameterized convection produces the rainfall at the place where the convection is initiated. The bias in the spatial pattern of parameterized convection is sometimes referred to as “luff-lee effect” because there tends to be too much rain over the windward slope and over the crest of the mountain, whereas a pronounced dry bias occurs in the lee.

The results of our sensitivity tests, averaged over the four selected cases, are displayed in Fig. 2b. The selected subset of cases differs from the full period in that the reference runs exhibit a marked cold bias during the day, which seems to be partly due to an early appearance of clouds on three out of the four days and partly due to an overestimation of surface evaporation on hot summer days. The experiments with the ETA-PBL scheme (Janjić, 1994) show an even larger underestimation of the 2-m temperature, which is probably related to a further increased temporal bias in the formation of clouds, causing a decrease in the net radiation flux. On the other hand, the overestimation of the dewpoint further increases compared to the MRF PBL (Hong and Pan, 1996). The wind speed shows only small differences compared to the reference run, but the simulated rainfall greatly decreases, turning a marked positive bias (for the subset of four cases) into a pronounced negative bias. Simulations with the 5-layer soil model (Dudhia, 1996) instead of the Noah-LSM show much better results for the 2-m temperature, but it is remains to be tested whether the temperature would be overestimated on other days for which the Noah-LSM predicted realistic temperatures. The impact on the daytime 2-m dewpoint is small, but nocturnal dewpoints become less realistic than with the Noah scheme because they do not decrease enough after sunset. Moreover, the nocturnal wind speeds tend to be overestimated with the 5-layer soil model. However, there is nearly no effect on the spatially averaged hourly surface precipitation. The simulations with Blackadar-PBL (Zhang and Anthes, 1982) also use the 5-layer soil model because this PBL scheme cannot be combined with the Noah-LSM. Except for a higher peak precipitation rate, the results differ only slightly from those with the MRF PBL and 5-layer soil model. Simulations with the truly horizontal diffusion scheme (Zängl, 2002) for temperature and moisture exhibit slightly better results for temperature, but the impact on the rainfall amounts is fairly small. However, inspection of the fields suggests a somewhat improved agreement of the rainfall patterns (not shown). Further sensitivity tests revealed that using the 1-km model domain without the surrounding 3-km domain greatly degrades the model performance because the distance from the lateral model boundary then becomes too small for a proper development of convection. Moreover, increasing the vertical resolution from 36 to 60 layers has no systematically positive impact and thus is regarded as a waste of computing time.

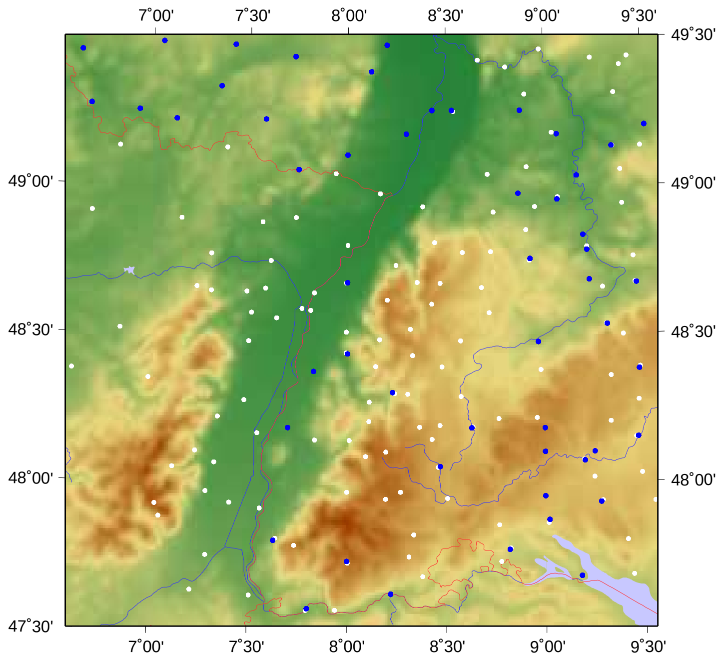

Figure 1: Investigated area with DWD-SYNOP-network (blue) and hourly precipitation network (white)

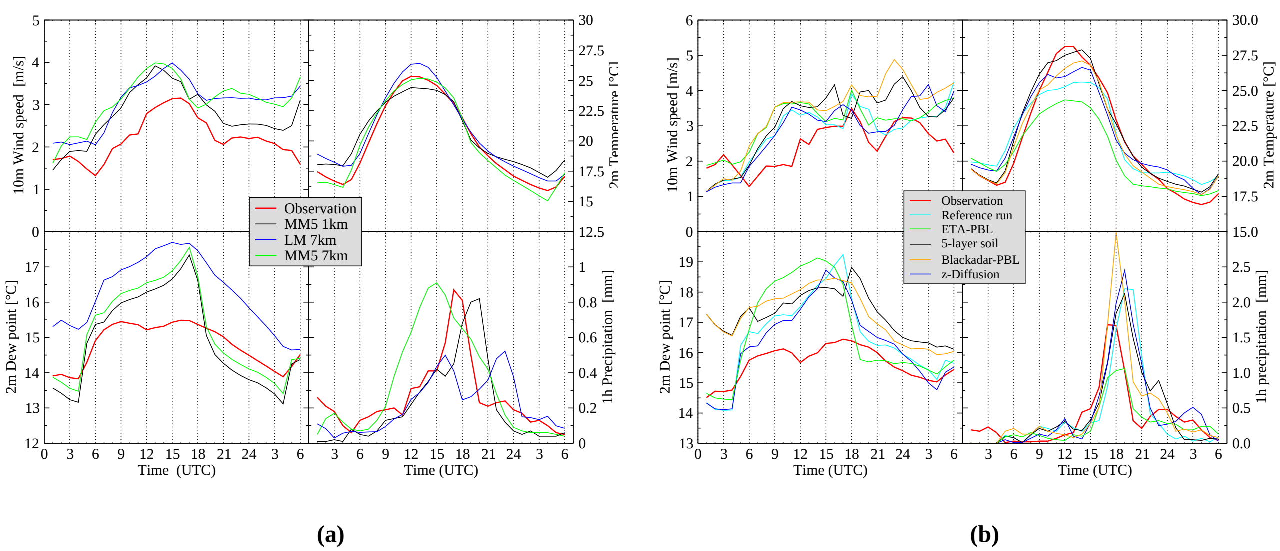

Figure 2: left: Average diurnal cycles (13 cases) of wind speed, temperature, dewpoint and precipitation for the MM5 reference simulations and LM; right: Average diurnal cycles (4 cases) for MM5 sensitivity experiments.

4. CONCLUSIONS

Several simulations of precipitation events in the COPS region during summer 2005 have been conducted. We used MM5 version 3.7.3 (Grell et al., 1995) at two different resolutions (1 km and 7 km) with the same physics options except that no convective parameterization was used in the nested 1-km model grid. In an attempt to find an optimal model configuration for operational forecasts for the COPS campaign, we also conducted sensitivity tests for boundary layer and LSM physics.

Our results show that the simulated precipitation fields are much more realistic at a model resolution of 1 km than at 7 km, both with respect to the temporal evolution and to the average amount. Moreover, the spatial distribution becomes more realistic at high resolution because the drift of individual convection cells can only be reproduced when convection is resolved explicitly in the model. For the temperature and wind fields, the benefit of enhancing the model resolution is not as clear; the surface temperatures even show better agreement with observations at 7 km resolution than at 1 km. The sensitivity experiments conducted so far suggest that the ETA PBL would not be a good choice for operational use. Moreover, the z-diffusion scheme appears to have a moderately positive impact on the results. The soil model strongly affects the daytime surface temperatures, but further tests are needed to make a final decision because the cases selected for the sensitivity tests were not representative in terms of temperature bias.

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