Evaluation of convection-resolving model simulations with the COSMO-Model in mountainous terrain

Jörg Trentmann[1], Ulrich Corsmeier[2], Jan Handwerker[2], Martin Kohler[2], Heini Wernli[1]

[1] Institute for Atmospheric Physics, Johannes Gutenberg University Mainz, Mainz
[2] Institute for Meteorology and Climate Research, Research Center and University Karlsruhe, Karlsruhe
E-mail: *jtrent@uni-mainz.de*

Abstract: Convective precipitation is the main form of summertime precipitation in mid-latitude mountainous regions. To improve the forecasting of convection, numerical weather prediction (NWP) models have been developed that explicitly resolve the spatial scales and the processes associated with deep convection. Here, we use the COSMO-Model, an operational NWP model, for the simulation of a convective situation in Central Europe on 12 July 2006. The model results are evaluated with observations obtained within the PRINCE field experiment in the Black Forest in South-West Germany. In general, the performance of the model is satisfactorily. Convection is initiated by the model, and the overall impact of the convection (vertical transport of heat and moisture) is reproduced. Discrepancies in the location of the precipitation, however, suggest shortcomings of the model incorrectly initiating local convection from small scale valley circulations.

Keywords: *convection-resolving modeling, deep convection, mountainous area*

1. INTRODUCTION

In mid-latitude mountainous regions, convective precipitation is the dominant form of summer precpitation. Forecasting convective precipitation remains a challenge for current state-of-the-art numerical weather prediction (NWP) models. Especially in mountainous regions small scale local flow systems can determine the timing and location of convection. Only very recently, the spatial resolution of NWP models has been increased to an extent that they start to explicitly resolve the processes associated with deep convection. The objective of the present work is to evaluate the performance of a convection-resolving NWP model under convective conditions in mountainous terrain in Central Europe.

2. CASE STUDY: 12 July 2006

We use observations obtained within the PRINCE - Prediction, identification, and tracking of convective cells - field experiment (Corsmeier and Zeigler, 2006) to evaluate the model results. PRINCE was designed to observe deep convection in the northern part of the Black Forest. Available observations include precipitation radar measurements from Karlsruhe, radiosoundings from Brandmatt (on the western slope of the Black Forest), and mobile radiosoundings close to active convection within the study area. Continous measurements using cloud radar, aerosol and temperature lidar were conducted from Hornisgrinde (i.e. the highest elevation in the northern Black Forest, 1177 m asl).

Here, we focus on the situation on 12 July 2006. This day was characterized by weak synoptic forcing over Central Europe and the initiation of local convection along mountainous regions at about 11 UTC. Figure 1 shows the atmospheric soundings at 09 UTC and 15 UTC from Brandmatt. CAPE and CIN of the morning sounding are about 1700 $\mathrm{J\,kg^{-1}}$ and 85 $\mathrm{J\,kg^{-1}}$, respectively, pointing to high convective potential. Horiontal winds were very weak suggesting the formation of local ordinary convective cells. Another striking feature of this profile is the dry layer between 550 hPa and 600 hPa with dew point temperature down to $-40°$C. This dry airmass is characterized by a more stable temperature stratification. The origin of this airmass is currently under investigation. Around local noon, several single convective cells formed in the study area close to the Murg Valley lasting about 3 hours. The total precipitation derived from the radar observations from Karlsruhe between 09 and 19 UTC is shown in Figure 1. Most precipitation in the area of interest can be found north of Freudenstadt in the Murg Valley with maximum values of more than 60 $\mathrm{mm\,(10\,hrs)^{-1}}$.

The atmospheric sounding at 15 UTC after the convection has ceased shows a significantly modified atmospheric stratification (Figure 1). While the changes in the temperature and humidity below 700 hPa are minor (with the exception of the lowest 50 hPa), a significant warming has occurred between about 620 hPa

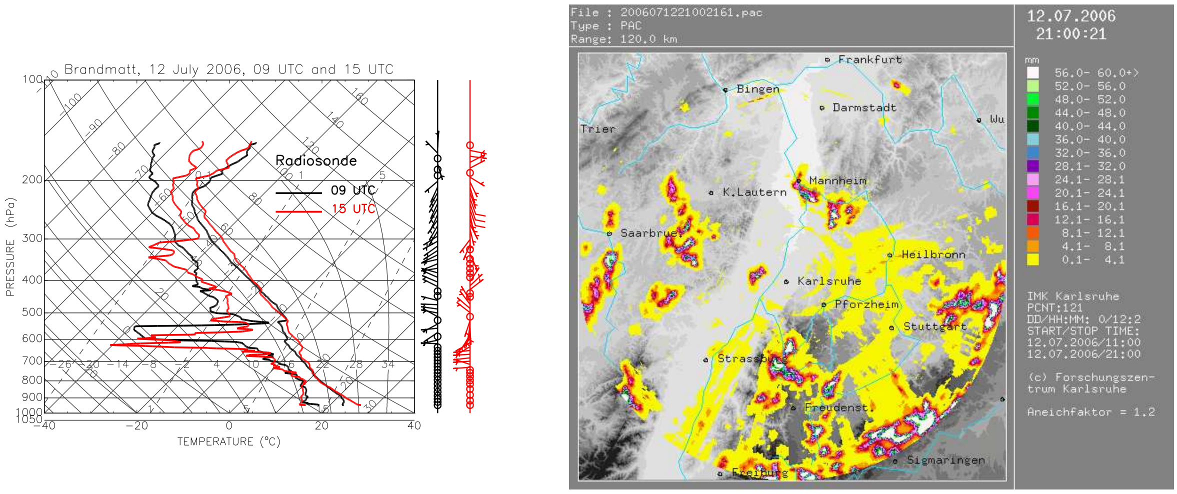

Figure 1: Left: Observed soundings from Brandmatt at 09 UTC (black line) and 15 UTC (red line) on 12 July 2006, right: Precipitation between 09 UTC and 19 UTC on 12 July 2006 derived from radar measurements from Karlsruhe.

and 520 hPa. Additionally, there is a significant warming of the upper troposphere above 400 hPa and a lifting of the cold point by about 17 hPa from 215 hPa to 198 hPa. CAPE and CIN of the afternoon profile are about 690 $\mathrm{J\,kg^{-1}}$ and 25 $\mathrm{J\,kg^{-1}}$, respectively. Since horizontal winds were low throughout the troposphere, horizontal temperature and humidity advection was insignificant and we attribute the changes in the vertical temperature and humidity profiles to vertical transport of heat and moisture by the local convection.

3. MODEL DESCRIPTION

The model developed by the Consortium for Small-Scale Modelling (Steppeler et al. (2003), Schättler et al. (2005), formerly known as the Local Model, LM) is used in the present work. The non-hydrostatic COSMO-model is used for operational NWP at several European weather services, including the German Weather Service, DWD. It has recently been extended for convection-resolving simulations and will be used for operational high-resolution short range forecasting at DWD starting in spring 2007 (Baldauf et al., 2006).

Here, we are using a similar model setup as is used at DWD for NWP. The horizontal grid spacing is 0.025° (≈2.8 km) using 371×351 horizontal grid points, the lowest vertical layer of the 50 terrain-following layers is located 10 m above the local topography. No parameterization of deep convection is employed. The solution of the dynamical equations is based on the Runge-Kutta Scheme using a timestep of 30 sec. Transport of the humidity variables is based on the forth-order Bott-Scheme. Microphysical processes were calculated using the recently developed Graupel-Scheme, shallow convection was parameterized using a modified Tiedke-Scheme. Vertical turbulent diffusion is calculated using a prognostic scheme based on the turbulent kinetic energy (TKE), horizonal turbulent diffusion is not considered. For the initial and the boundary conditions hourly data from the operational COSMO-LME analysis from DWD at a horizontal resolution of 0.0625° are used. The simulations presented here started at 07 UTC on 12 July 2006.

4. EVALUATION OF MODEL RESULTS

In the following, a first evaluation of the model simulations with the available observations is presented. Here, we focus on the radiosoundings from Brandmatt and the radar observations from Karlsruhe. A more comprehensive model evaluation will be presented at the conference. Model results for this case from several model simulations including the MM5 and the WRF model can be found in Trentmann et al. (2007).

In Figure 2 the simulated vertical profiles from Brandmatt at 09 UTC, i.e., before the convective activity,

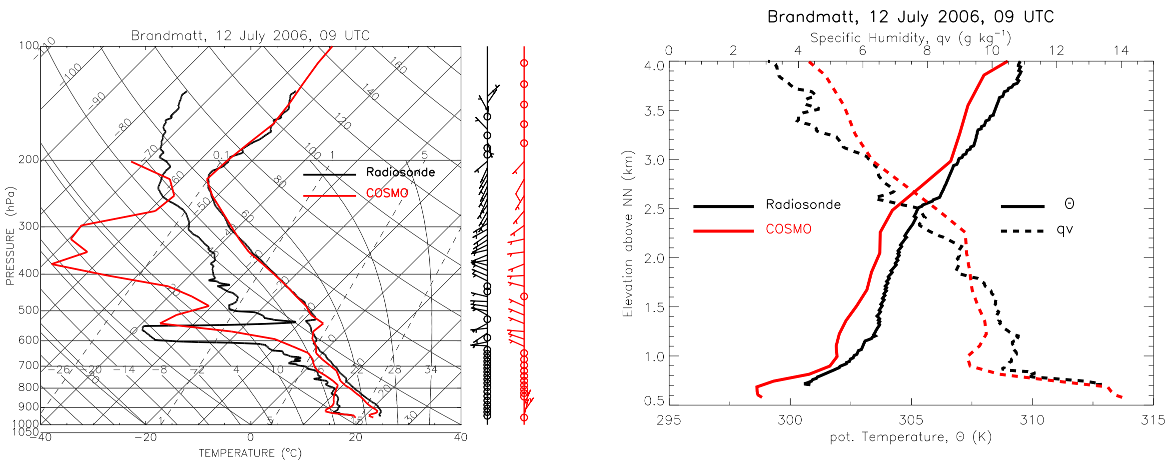

Figure 2: Observed (black) and simulated (red) atmospheric profiles on 12 July 2006, 09 UTC, from Brandmatt before the convective activity. Left: Temperature, dew point, wind, right: potential temperature (solid) and specific humidity (dashed) in the lowerest 4 km.

are compared with the observations. In general, the atmospheric stratification is well captured by the model, resulting in comparable value for CAPE (1950 $\mathrm{J\,kg^{-1}}$ compared to 1700 $\mathrm{J\,kg^{-1}}$ based on the sounding) and CIN (61 $\mathrm{J\,kg^{-1}}$ compared to 85 $\mathrm{J\,kg^{-1}}$). The layer of dry air can be found also in the model simulation at about 550 hPa. Above 500 hPa the humidity is significantly underestimated in the model simulation. This can be attributed to the initial conditions.

The right panel in Figure 2 compares the simulated and the observed profiles in the lowest atmospheric layers. The observations show a well-developed mixed layer between about 1.2 km and 2.5 km with a potential temperature between 303.5 K and 305 K and a specific humidity between 8 $\mathrm{g\,kg^{-1}}$ and 10.5 $\mathrm{g\,kg^{-1}}$. Above 2.5 km, the potential temperature increases and the specific humidity decreases substantially. Below 1.2 km, the potential temperature decreases to 301 K at the surface and the specific humidity increases to 13 $\mathrm{g\,kg^{-1}}$. The model results feature similar characteristics. The lowest model layers are substantially colder and wetter than the well-mixed layer between 0.7 km and 2.4 km. Compared to the observations, however, potential temperature in the well-mixed layer is about 2 K too cold, while the specific humidity compares rather well.

Figure 3 shows the simulated precipitation between 09 UTC and 19 UTC. Significant precipitation is predicted in the area of interest with a maximum of 32 mm within 10 hours. The simulated precipitation occurs mainly in three regions: a) the Rhine valley, b) the Black Forest, in particular the Kinzig Valley, and c) the Swabian Alb in the south-easterly part of the figure. This distribution can be compared to the radar observations presented in Figure 1. Note that the spatial domain of the measurements extends further north than shown in Figure 3 from the model simulation. Within the overlapping region, the location of the precipitation is reasonably well reproduced by the model. Especially the precipitation along the Swabian Alb is well located, although the accurancy of the radar observations is reduced at the edge of the scan region. The main precipitation area in the northern part of the Black Forest is predicted slightly too far south. In the observations, most precipitation occurs north of Freundenstadt, mainly in the Murg Valley. The simulation depicts most precipitation south of Freudenstadt in the Kinzig Valley. This points to model deficiencies associated with the initiation of convection from small scale valley circulations. Further details of the processes leading to convection in the model simulations will be presented at the conference.

Also shown in Figure 3 is the impact of the convective activity on the atmospheric stratification in the model simulation. Comparable to the observations shown in Figure 1, the simulated deep convection leads to a warming in the middle (between 680 hPa and 580 hPa) and the upper (between 380 hPa and 220 hPa)

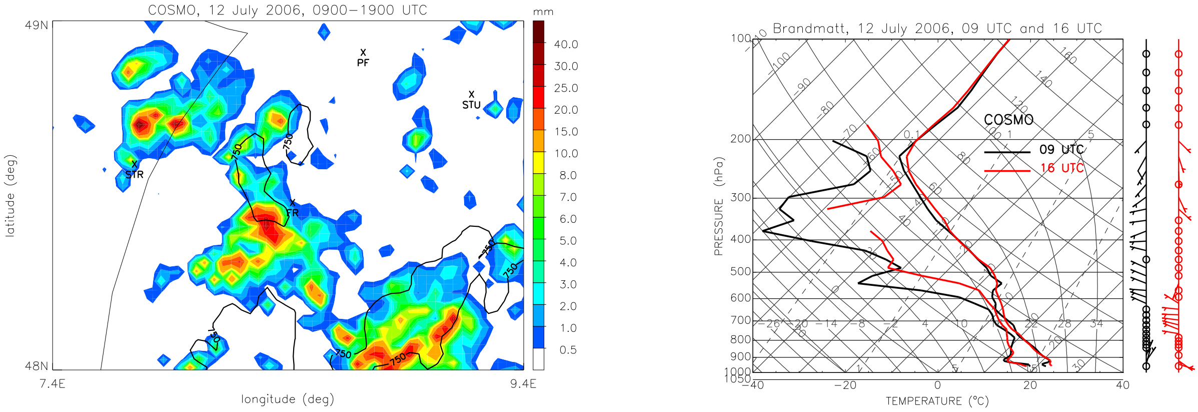

Figure 3: Left: Simulated surface precipitation between 09 and 19 UTC on 12 July 2006. The locations of Pforzheim (PF), Stuttgart (STU), Freudenstadt (FR), and Strassburg (STR) are indicated by crosses. Right: Simulated vertical sounding at 09 UTC (black line) and 16 UTC (red) in Brandmatt.

troposphere, even though the warming is not as pronounced as observed. Also, no significant rise of the cold point is simulated. As in the observations, the troposphere above 300 hPa is significantly moister after the convection. In general, the model is able to correctly simulate the effects of convection on the atmospheric stratification.

5. CONCLUSIONS AND OUTLOOK

We compared convection-resolving model simulations conducted with the COSMO-Model, an operational NWP model, with dedicated field observations during a convective situation in Central Europe. On 12 July 2006 weak synoptic forcing lead to the initiation of local convective cells over orographically-structured terrain in Central Europe including the Black Forest. Field observations obtained within the PRINCE experiment give insights into the pre-convective environment and the initiation of convection. The evaluation of the model simulation shows that the general meteorological situation and the formation of convective precipitation is well captured by the model. The impact of convection (i.e., vertical transport of heat and moisture) is reasonably well reproduced by the model. The shift between the location of the simulated precipitation compared to the observations suggests deficiencies of the model in the processes that lead to the initiation of deep convection in the complex topography.

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REFERENCES

Baldauf, M., K. Stephan, S. Klink, J. Förstner, T. Reinhardt, A. Seifert, C.-J. Lenz, F. Theunert, 2006: The new very short range forecast model LMK for the convection-resolving scale, 2nd International Symposium on Quantitative Precipitation Forecasting and Hydrology, 5–8 June 2006, Boulder, Colorado, USA.

Corsmeier, U. and J. Ziegler, 2006: PRINCE – Prediction, identification and tracking of convective cells, Operation Plan, Institut für Meteorologie and Klimaforschung, Universität Karlsruhe/Forschungszentrum Karlsruhe.

Schättler, U., G. Doms, C. Schraff, 2005: A Description of the Nonhydrostatic Regional Model LM, Part VII: User's Guide, Consortium for Small-Scale Modelling

Steppeler, J., G. Doms, U. Schättler, H. W. Bitzer, A. Gassmann, U. Damrath, G. Gregoric, 2003: Meso-gamma scale forecasts using the nonhydrostatic model LM, *Meteorol. Atmos. Phys.*, **82**, 75–96.

Trentmann, J., C. Barthlott, H.-S. Bauer, C. Keil, M. Salzmann, J. Handwerker, M. Lawrence, D. Leuenberger, H. Wernli, V. Wulfmeyer, 2007: Multi-model simulation of a convective situation in mountainous terrain, Extended abstract, ICAM 2007.