Multi-model simulations of a convective situation in mountainous terrain

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Abstract: Convective precipitation is the dominant form of summertime precipitation in mid-latitude mountainous regions. Forecasting convective precipitation remains a challenge for current numerical weather prediction (NWP) models. The goal of the present study is to investigate the variability of simulated convective precipitation by three convection-resolving models using different setups and initial and boundary conditions. The COSMO-Model, the MM5 and WRF have been used to simulate the atmospheric situation on 12 July 2006, when local convection occurred in Central Europe under weak synoptic forcing. Here, we focus on the convective precipitation observed from radar in the northern Black Forest in South-West Germany. Precipitation fields from the nine model simulations differ considerably. Five simulations capture the spatially variable distribution of the event with peak amplitudes above 20 mm/10 hrs. However, they differ in the location and timing of the intense convective cells. Four simulations do not capture the convective nature of this event. Further studies will explore the reasons for the differences in the model simulations, especially the processes leading to the initiation of convection.

Keywords: *multi-model, 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 the processes associated with deep convection can be explicitly resolved in these models. The objective of the present work is to evaluate the performance of state-of-the-art convection-resolving models under convective conditions in mountainous terrain in Central Europe.

2. PARTICIPATING MODELS

We compare model results from three different non-hydrostatic numerical models: the operational weather forecast model COSMO-Model (formerly known as the Local Model, LM), the MM5, and the WRF-Model. All model simulations were conducted without the use of a parameterization of deep convection, i.e., the formation of deep convection in the model simulations is explicitely calculated. Details about the different models and their local setups are given below.

Model results from the COSMO-Model (Steppeler et al., 2003; Schättler et al., 2005) are contributed by three groups using different technical setups. The model simulations at the Institute for Atmospheric Physics at the University Mainz (IPA) were conducted with COSMO-Model V3.21 using a model domain of $371\times351\times50$ grid points with a horizontal grid point distance of 0.025° (about 2.8 km), with hourly operational DWD-COSMO-LME analysis data (on a 0.0625° grid) as initial and boundary conditions. The solution of the dynamical equations is based on the Runge-Kutta Scheme using a timestep of 30 sec. Shallow convection was parameterized using a modified Tiedke-Scheme, no parameterization of deep convection was employed. More information on the model setup is given in Trentmann et al. (2007).

The model simulations at the Institute for Meteorology and Climate Research in Karlsruhe (IMK) were conducted using the COSMO-model Version 3.19 with a model domain of 121×101 horizontal grid points

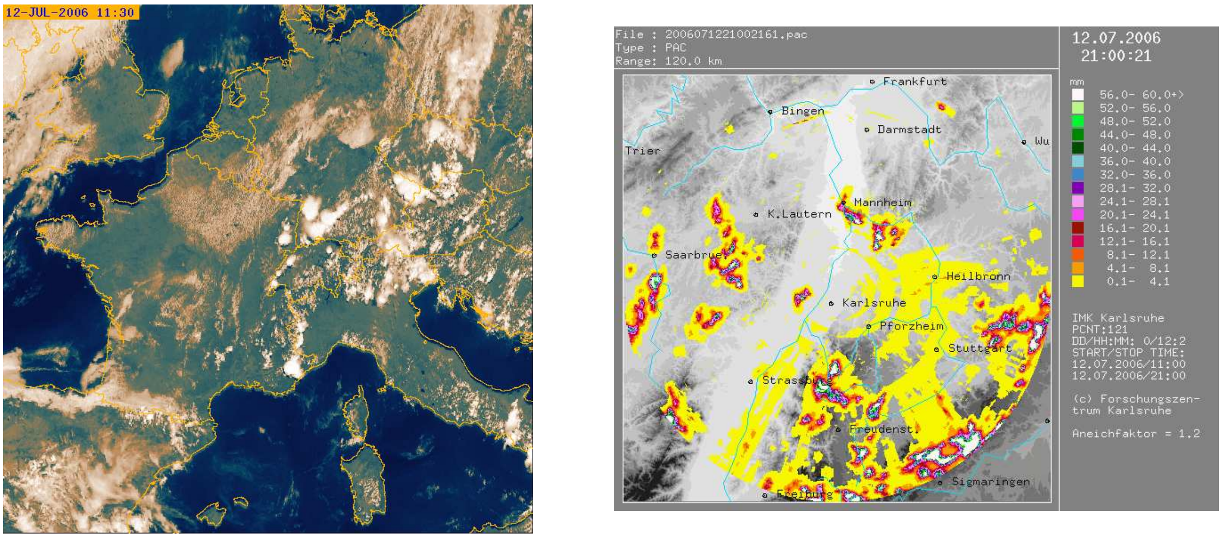

Figure 1: Left: MSG, visible image, 1130 UTC, 12 July 2006, provided by Harald Sodemann, ETH, Zürich; right: Surface precipitation between 09 UTC and 19 UTC on 12 July 2006 derived from radar measurements from Karlsruhe.

and 40 vertical layers. The three time-level Leapfrog scheme was used with a timestep of 12 sec. Only shallow convection was parameterized. The simulations was initialized at 00 UTC with GME analysis data. For the boundary condition, GME forecast data was used.

The model simulations at the DLR were conducted using the COSMO-Model, V3.21, with a horizontal grid point distance of 0.025°. For initial and boundary condition the results from the COSMO-LEPS Ensemble prediction system were used. The model simulations were started at 06 UTC. In total 10 simulations were conducted using different initial and boundary data. For the present work, three representative members were selected. A detailed analysis of all members is presented in Keil et al. (2007).

Model simulations using the PSU/NCAR mesoscale model (Grell et al., 1995) (known as MM5) were conducted at the Institute of Physics and Meteorology (IPM) at the University of Hohenheim. These model simulations were conducted using two 2-way nested grid with grid spacings of 8.4 km and 2.8 km, respectively. The innermost domain consists of 343 $\times$ 343 grid points and 36 vertical layers. Initial and boundary conditions were taken from operational ECMWF analysis (retrieved at 0.25° $\times$ 0.25° horizontal resolution). The chosen physical parameterizations include the Reisner 2 cloud microphysical scheme, the MRF boundary layer scheme, and the 5-layer soil model. No parameterization for deep or shallow convection is employed. Further information on the model and results from model simulations for other cases can be found in Schwitalla et al. (2007).

The Weather Research and Forecasting Model (WRF), Version 2.2, with the ARW (Advanced Research WRF) dynamical core (Skamarock et al., 2005) is used at the Max Planck Institute for Chemistry (Mainz). A total of seven runs have been performed, two of which are included in this presentation. In both runs two sub-domains with 10 km and 2 km horizontal resolution and domain sizes of 112$\times$97 and 171$\times$171 grid points, respectively, were recursively nested into a coarse domain with 30 km resolution. One of the simulation was initialized with NCEP Final Analysis (FNL) Data and employed 54 vertical layers. The second simulation was driven by with ECMWF analysis (retrieved at 1.25° $\times$ 1.25°) using 34 vertical layers. The Lin microphysics parametrization and the Yonsei State University (YSU) planetary boundary layer parametrization were used in the two runs. The simulations were chosen to reflect the range of the results obtained from the seven WRF sensitivity simulations.

3. CASE STUDY: 12 JULY 2006

As a first case study, we investigate the performance of the different model simulations for 12 July 2006. This day was characterized by weak large scale forcing over Europe and the formation of single cell convection in the early afternoon over mountainous regions across Central Europe (Figure 1). Here, we focus on the

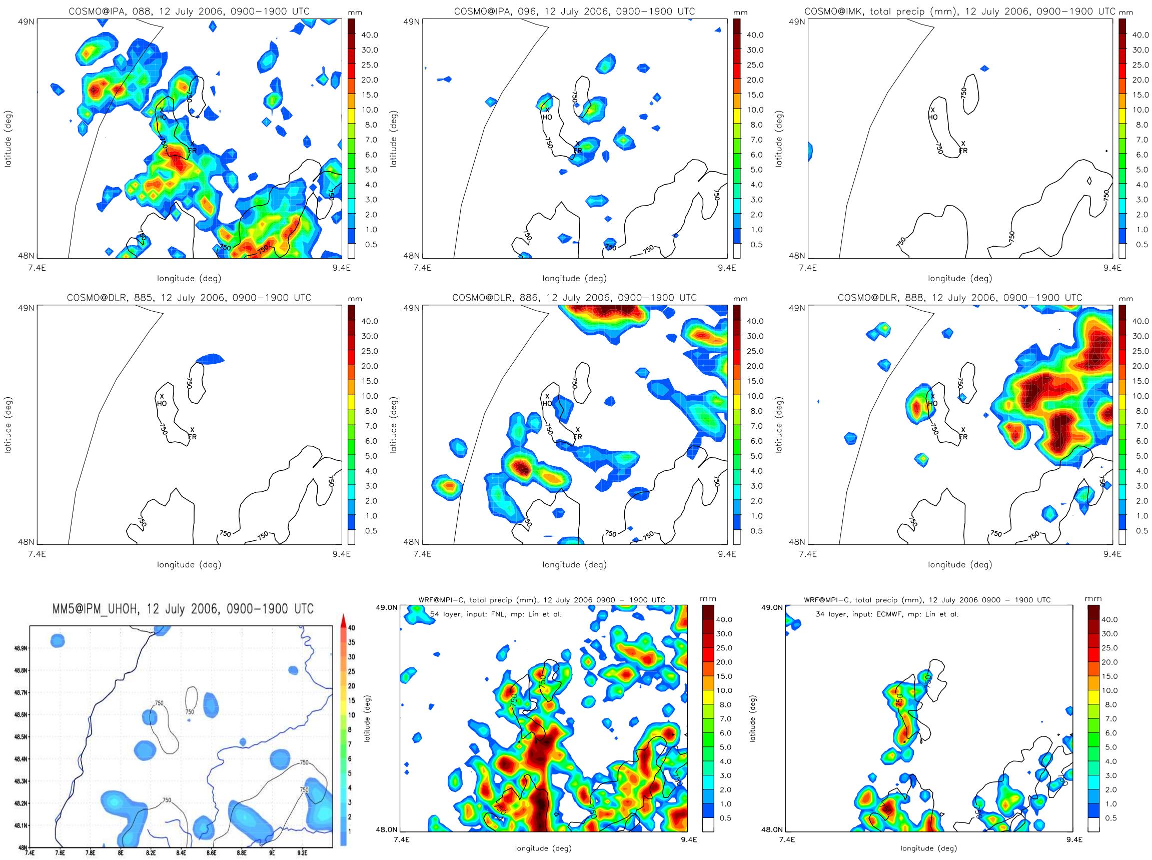

Figure 2: Simulated precipitation betwenn 09 UTC and 19 UTC for nine model simulations in the Black Forest, black contour line reprents the 750 m-isoline of the topography. First row, left to right: COSMO-model, IPA, start of the simulation at 07 UTC; COSMO-model, IPA, start of the simulation at 04 UTC; COSMO-model, IMK; second row: three members of the ensemble simulations with the COSMO-model, DLR; third row, left to right: MM5, IPM; WRF, MPI, 54 vertical layers, FNL initial and boundary conditions; WRF, MPI, 34 vertical layers, ECMWF initial and boundary conditions

situation in South-West Germany. At around local noon, ordinary convective cells formed in the northern part of the Black Forest that lasted for about three hours. The precipitation field derived from radar measurements from Karlsruhe between 09 UTC and 19 UTC shows an area of convective precipitation in the Murg Valley north of Freudenstadt with maximum precipitation of more than 60 mm $(10\ \text{hrs})^{-1}$ (Figure 1).

This day was one of the intensive observation periods of the PRINCE (Prediction, identification, and tracking of convective cells) experiment. During PRINCE, additional measurements were conducted in the northern Black Forest. For further information on PRINCE and a more detailed model evaluation with the observational data, see Trentmann et al. (2007). Here, we focus on the variability of model simulations for this situation.

4. MODEL RESULTS

Figure 2 shows the simulated surface precipitation between 09 and 19 UTC on 12 July 2006 across the Black Forest for nine different model simulations. There is a large variability of the simulated precipitation pattern between the different models. However, there is also significant spread between the results obtained from one model, but using different setups and initial and boundary conditions. In principle, all models are able to simulate convective precipitation in the Black Forest region, as was observed. However, the location and the timing (not shown here) of the convection differ substantially between the simulations; and some simulations miss the convective character of the event.

The first row of Figure 2 shows the variability of the simulations between different setups of the COSMO-model. The huge impact of the starting time of the model simulation is especially striking (compare the first two figures). The difference between the two COSMO-model setups (IPA and IMK) can be attributed to the different model starting times as well as the use of different initial and boundary conditions. The second row of Figure 2 depicts three representative members out of the total of ten members of the LMK Ensemble. Each of the simulation was started at 06 UTC from different members of the COSMO-LEPS Ensemble based on the ECMWF EPS System. For a detailed evaluation of these ensemble simulations see Keil et al. (2007). The third row of Figure 2 shows the model results obtained with the MM5 and the WRF model. In the WRF simulations the simulated precipitation correlates well with the topography as was observed.

5. CONCLUSIONS AND OUTLOOK

We presented a first comparison of the performance of three convection-resolving models (COSMO-model, MM5, WRF) under a convective condition with weak synoptic scale forcing. On 12 July 2006 local convective cells formed in mountainous region across Central Europe, including the Black Forest.

The models were driven by different meteorological data and were run with different setups by several research groups. The simulated convective precipitation for 12 July 2006 was found to be very sensitive to the model configuration and the initial and bondary conditions. Five simulations capture the convective character of the event with peak surface precipitation above 20 mm (10 hrs)$^{-1}$. However, they differ in the location and timing of the intense convective cells. Four simulations do not capture the convective nature of this event.

From the results presented here, it seems clear that explicit, deterministic simulation and therefore forecasting of local convection in mountainous terrain using a NWP convection-resolving model is very difficult for current models, and requires a careful choice of an appropriate model setup. As expected, the initial and boundary conditions used for the high-resolution model simulations play a key role for the simulated precipitation. Additional studies not shown here explored the impact of the use of different numerical schemes and physical parameterizations. In general, these modifications had a smaller impact on the simulated precipitation than the use of different initial and boundary conditions. Results from these studies will be presented at the conference.

The processes leading to convection in the model simulations will be investigated further. The spread of the model simulations will be used to determine critical model parameters that lead to the initiation of convection or prevent the initiation of convection. These parameters could include the surface or 2 m-temperature and humidity, the equivalent potential temperature, the convective inhibition (CIN), or low-level convergence. These investigations will help to understand the initiation of deep convection in convection-resolving model simulations. In combination with appropriate field observations from PRINCE and the upcoming COPS (Convective and Orographically-induced Precipitation Study) experiment in summer 2007 these studies will help to evaluate the model simulations towards their ability to describe convective initiation in mountainous terrain.

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