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The Oder flood in July 1997: Transport routes of precipitable water diagnosed with an operational forecast model

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Abstract. A regional simulation of the severe precipitation episode which gave rise to the floods in the eastern part of Central Europe during July 1997 was performed using the meso-β-scale weather prediction model DM of Deutscher Wetterdienst. It is shown that the model reproduces the mesoscale precipitation distribution reasonably well as verified against available rain gauge observations. It is therefore used to investigate the transport routes of the bulk of moisture which led to the wide spread heavy precipitation. Inspection of the atmospheric water budget highlights the importance of the cyclonic advection of moist mediterranean air for the formation of strong precipitation in Central Europe. Autochthonous influences are comparably small.

Introduction

In July 1997 two episodes of wide spread heavy precipitation in the eastern part of Central Europe caused the largest flood desaster in this region for decades. In the Czech Republic and in Poland more than 100 flood casualties occured, hundreds of cities and villages were inundated and vast areas of land were flooded for weeks. The total costs of the damages excess DM 10 billion [*WMO*, 1998].

Predicting severe precipitation continues to be one of the great challenges in meteorology. The theoretical possibility to determine future atmospheric states from known initial conditions was first outlined at the begin of this century [*Bjerknes*, 1904]. Five decades later the then recent electronic computers were more and more applied to forecast dynamical fields (e.g. flow in the mid-troposphere). In the 1980ies direct precipitation forecasts on the mesoscale started to be tested [see e.g. *Nickerson et al.*, 1986 and references therein]. Precipitation is mostly determined by processes acting on the mesoscale. Therefore its forecast necessitates the incorporation of mesoscale processes in numerical weather prediction models. Furthermore, the verification of the precipitation distribution constitutes a substantial task because of the high spatial and temporal rainfall variability which often exceeds 100 % for topographical height differences of 100 m or temporal differences of one minute.

In this study the ability of the Deutschland-Modell (DM) of Deutscher Wetterdienst (DWD, i.e. German Weather Service) to simulate heavy precipitation at high resolution and its potential use as a diagnostic tool is demonstrated.

The investigations are confined to the intense first precipitation episode which initiated the Oder flood and lasted from 4 July till 8 July 1997.

After a short introduction of the numerical mesoscale tool an overview of the synoptic scale weather situation is presented. Subsequently simulated precipitation fields are compared with rain gauge observations. Timeseries of the terms of the atmospheric water budget highlight the evolution of moisture fluxes and give insight in the genesis of the long lasting rainfall event.

Model description and initial conditions

The numerical simulation is performed with the hydrostatic meso-β-scale Deutschland-Modell (DM) [*Schrodin*, 1997]. Introduced in 1993, this regional model is the main short range weather forecasting tool of DWD. The model domain encompasses central Europe (Fig. 1) with a horizontal mesh size of $\Delta x \approx 14\,\mathrm{km}$.

Physical processes associated with cumulus convection occur on scales that cannot be completely resolved by the model. Thus, precipitation processes are divided in resolvable-scale processes and subgrid-scale processes. Grid-scale precipitation includes parameterized cloud microphysics of the Kessler type and allows for interactions between water vapour, cloud water, rain and ice. Subgrid-scale deep convection processes are parameterized by the Tiedtke mass flux scheme, where moisture convergence in the sub-cloud layer is the essential mechanism to generate convection [*Tiedtke*, 1989]. No ice phase is included in this convection scheme.

Six-hourly analyses taylored for DM were used as initial and boundary conditions. Four model runs were performed, initialized at 00 UT every day with a simulation time of +30 h. Only data of the periods +6 h till +30 h of these simulations are considered.

Synoptic overview

Similiar to other flooding events in midlatitudes a quasi-stationary mature depression set the scene for wide spread strong precipitation in Central Europe during 4 till 8 July 1997.

Under the leading edge of an elongated upper level trough extending to the western Mediterranean on 5 July, 00 UT, a surface low formed over northern Italy at the border of warm air masses over the eastern Mediterranean and significantly cooler ones to the west. During 6 July this surface low moved northeastward and joined the depression over the eastern part of Central Europe. Meanwhile a cut-off low developed from the elongated trough at upper levels with

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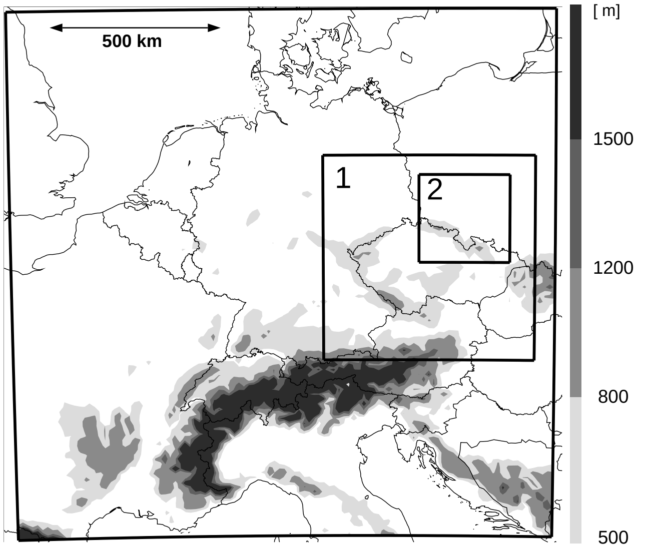

Figure 1. Computational domain of DM and model orography. Subdomains 1 and 2 are referred to in Fig. 3 and 4, respectively.

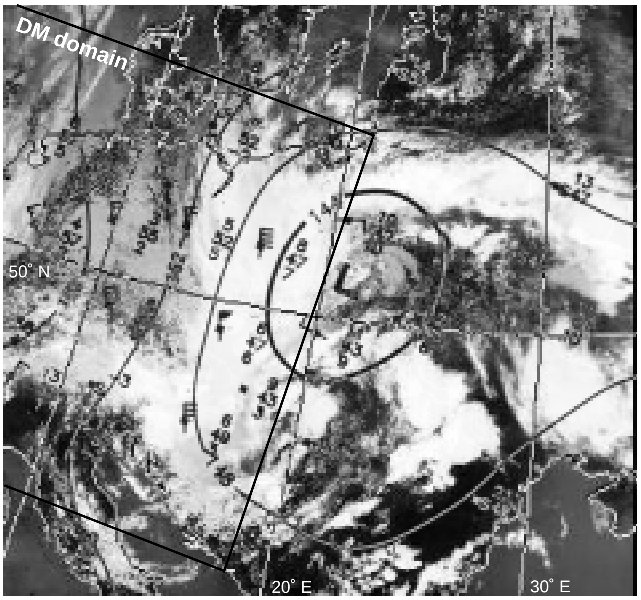

Figure 2. Cloud structures as seen by the NOAA satellite (infrared channel) of 6 July 97, 12:46 UT, superimposed with the 850 hPa observations and geopotential analysis at 12 UT (Europ. Meteorol. Bull., DWD, Offenbach) and the DM domain boundaries.

its center over Slovakia. Around this deepening depression warm and humid airmasses were continuously transported to the eastern part of Central Europe. Synoptic scale lifting processes in the region of the quasi-stationary low induced long lasting, wide spread precipitation. While in the beginning of the precipitation episode convective rainfall ahead of the upper level trough dominated, the large scale lifting of humid air in the region of the upper level low became predominant from 6 July onwards.

The vortex structure of the cyclonic movement around the low center is visualized in the infrared satellite image (Fig. 2). Within the northward advection of moist subtropical air across the Balkans towards eastern Central Europe deep convection was embedded in the region of the Carpathian Mountains. On the other hand the flow was southward on the western part of the deep low pressure system. A large compact cloud system in this region is apparent as a coherent white band west of 20 °E in Figure 2.

Results and Discussion

Before examining the paths of the moisture streams which led to the Oder flood 1997, it is important to ensure that the DM reliably reproduces the precipitation distribution as verified against available rain gauge observations.

We first note the different nature of the data types. Each model value at a resolution of 14 km represents an average over an area of about 200 km^2, whereas the actual precipitation can vary significantly over such an area, especially above complex terrain. Rain gauge observations are point measurements. Their representativity is influenced by factors like, e.g., the location of the gauge with respect to the orography or the variable collection efficiency due to wind drift. The observed precipitation totals of the four-day period are depicted by circles in Figure 3 (left).

The simulated precipitation is shown for an area of 360,000 km^2 (Domain 1 in Figure 1) centered over the Czech Republic. A comparison of observed and simulated rainfall amounts reveals a satisfactory agreement in the spatial precipitation distribution (Fig. 3). Maximum rainfall was observed along the Sudetic Mountains at the Czech-Polish border where totals of up to 466 mm were recorded within the four days. In some areas more than 400 % of the climatological monthly mean precipitation fell in July 97. The model underestimates the peak rainfall slightly, giving 380 mm in the mountainous region at the Czech-Polish border. The west-east gradient of rainfall from Germany across the Czech Republic to Slovakia becomes evident in both the observations and the simulation. Another intense precipitation area in the northern Alpine Region also compares well with station recordings. Somewhat overpredicted are the rainfall amounts north of the Sudetic mountain chain in south-western Poland.

In addition to the good spatial agreement of the rainfall distribution the temporal evolution of the precipitation episode is well captured by the model (not shown).

Having identified DM as a reliable tool we proceed to inspect the atmospheric water budget to gain insight in the transport directions of the precipitable water which resulted in heavy precipitation. The atmospheric water budget comprises the following terms:

$$Fq_D + Fq_w + EV + \Delta Q - RR = Res$$

where Fq_i represents the netto flux of moisture ($Fq_i = Fq_{i,in} - Fq_{i,out}$; q_D:water vapor; q_w:liquid water), EV evapotranspiration, ΔQ the storage of water in the control volume, RR precipitation, while Res designates a residual which ideally vanishes. The vertically integrated moisture fluxes are averaged over domain 2 (see Fig. 1) comprising south-western Poland with the Sudetic Mountains and the Oder valley and covering an area of about 260 × 260= 67,600 km^2.

The temporal evolution reveals the moisture advection Fq_D as the main source term balancing the loss of atmospheric moisture by precipitation RR (Fig. 4). A fraction of this moisture humidifies the air of the control volume (ΔQ). This storage term is coupled with the air temperature, a daytime increase of atmospheric moisture is followed by a

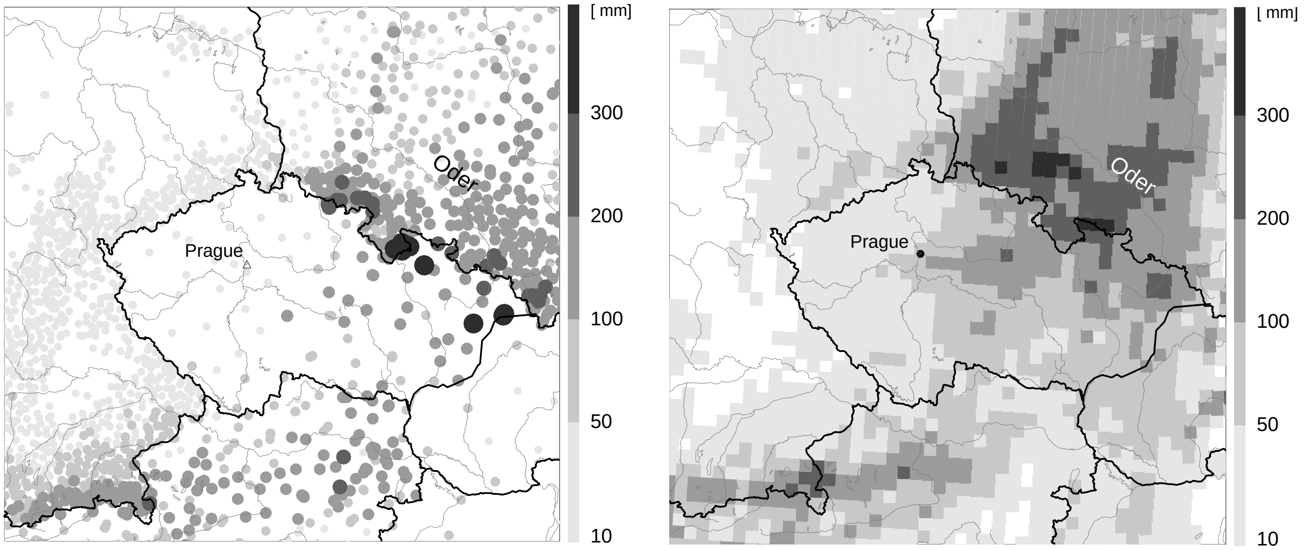

Figure 3. Observed (left) versus simulated (right) precipitation for the 96 h period starting at 4 July, 06 UT.

decrease during the night in undisturbed conditions (e.g. on 4 July). Autochthonous influences, through term EV, contribute comparatively little to overall RR. The dependence of the evapotranspiration on the solar insolation with its maximum around noon becomes clearly evident. The daily sum of the moisture flux due to evapotranspiration amounts to 4 mm/day on 4 July and decreases to 2.5 mm/day on 7 July when a compact cloud system (Fig. 2) inhibited insolation. The advection of cloud water Fq_W can be neglected. The discontinuities in the curves at 06 UT are caused by the not complete consistence between the four 30 h-integrations. The residual lies lower than 5 % of the main contributors

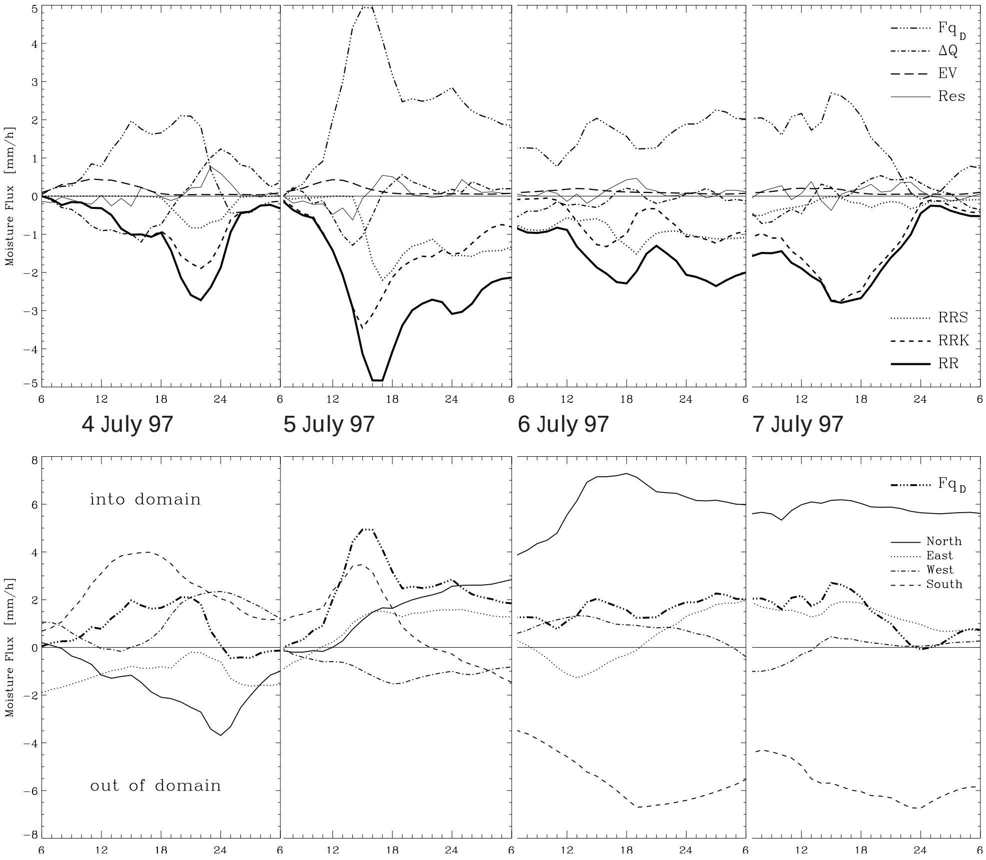

Figure 4. Time series of the moisture fluxes contributing to the atmospheric water budget averaged over domain 2 (top) and of the directional components of the advective moisture flux Fq_D (bottom).

to the budget for most of the period; it mainly reflects the discrete nature of the budget calculation from hourly model output fields.

A decomposition of the advection term Fq_D into its zonal and meridional components elucidates a cyclonic rotation (bottom part of Fig. 4). On 4 July advection from the south-westerly direction dominates. The flow from south-east on 5 July is followed by a north-easterly direction at 18 UT. During the following two days a northerly flow prevails, while a north-westerly flow is succeeded by a north-easterly one on 7 July. The intimate connection of heavy precipitation with moisture convergence can clearly be seen in the afternoon of 5 July, when the inflow into domain 2 exceeds the westward outflow about six times. This convergence results in concurrent strong rainfall in this region.

A partition of the rainfall in convective precipitation (RRK) and grid-scale precipitation (RRS) reveals its more convective character at the beginning of the precipitation episode. During the afternoon on 5 July the grid-scale precipitation increases and amounts to 46 % of the total rainfall on 6 July. This agrees well with the synoptic evolution described above.

Conclusions

The heavy precipitation episode from 4 July till 8 July 1997, which initiated the devastating Oder flood of summer 1997, was well simulated by the Deutschland-Modell.

On the basis of the good temporal and spatial agreement of observed and simulated precipitation patterns an analysis of the atmospheric water budget was performed. Inspection of the moisture budget highlights the importance of the moisture advection which dominates the budget in subdomain 2 up to 90 %. The contribution of local evapotranspiration is small and constitutes not more than 8 % of the precipitation flux.

The cyclonic rotation of the moisture advection was deduced by investigating the zonal and meridional components separately. A southerly flow is succeeded by a northerly flow the following two days. During the latter half of the precipitation episode the warm and moist air flows across Eastern Europe before turning near the Baltic Sea and entering the precipitation region from the north.

We conclude that the operational hydrostatic DM has a good potential to serve as a numerical investigation tool for mesoscale weather evolutions, especially if combined with synoptic-scale precipitation trajectory methods as recently applied for Alpine precipitation events [*Massacand et al.*, 1998].

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