P2.10 COUPLING A DISTRIBUTED HYDROLOGICAL MODEL TO REGIONAL CLIMATE MODEL OUTPUT: AN EVALUATION OF EXPERIMENTS FOR THE RHINE BASIN IN EUROPE

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1. INTRODUCTION

The consequences of extreme runoff and extreme water levels are within the most important natural hazards induced by weather. The question about the impact of global climate change on the runoff regime, especially on the frequency of floods, is of utmost importance. The spatial resolution of global circulation models is not sufficient for investigating the changes within European river basins. The spatial scale of regional climate models allows for a more detailed representation of the climate and reduces the scale gap to the hydrologic runoff models. To reproduce hydrologic processes in mountainous catchments, a downscaling of climate variables is still necessary for the representation of fine scale structures over the mountainous topography. The coupling of models of different scale is a possible method of assessing the influence of global climate change on the regional hydrology.

Different coupled atmospheric and hydrologic simulations of different spatial and temporal scale were performed so far. Yu et al. (1999) have driven a runoff model with the output of an atmospheric model for several storms of several days in a catchment in the Eastern United States. Benoit et al. (2000) applied coupled atmospheric and hydrologic modelling for investigating flood forecasting for a single storm. Leung et al. (1996) performed an atmospheric simulation with a subgrid precipitation parametrization driving a hydrologic runoff model for a complete seasonal cycle.

Climate impact studies require multi-year simulations or simulations of multiple seasons. In this study, a one-way coupling of a distributed hydrologic model with a regional climate model is evaluated for the Rhine basin in Central Europe. The simulations cover several years with a special emphasis on the winter seasons. An evaluation of the model chain is presented and the influence of the spatial resolution of the RCM is discussed.

2. THE MODEL CHAIN AND EXPERIMENT SETUP

The model suite consists of the regional climate model CHRM and the distributed runoff model WaSiM. The regional climate model CHRM is based on the mesoscale weather prediction model HRM of the German Weather Service (DWD) and has been adapted for climate simulations (Vidale et al. 2003). The CHRM is being used in a nested mode with horizontal grid spacings of 56 km and 14 km (hereafter called CHRM56 and CHRM14). The model domains are depicted in Figure 1. The distributed runoff model WaSiM is operated at a horizontal grid spacing of 1 km for the whole Rhine

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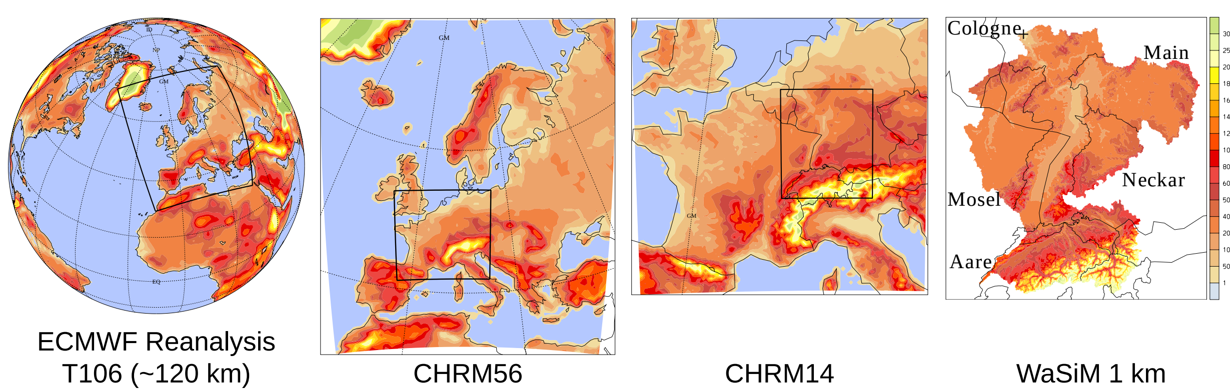

Figure 1: Topography of the ECMWF Reanalysis, the CHRM in 56 and in 14 km horizontal resolution and the distributed runoff model WaSiM to illustrate the model domains and resolutions of the different models.

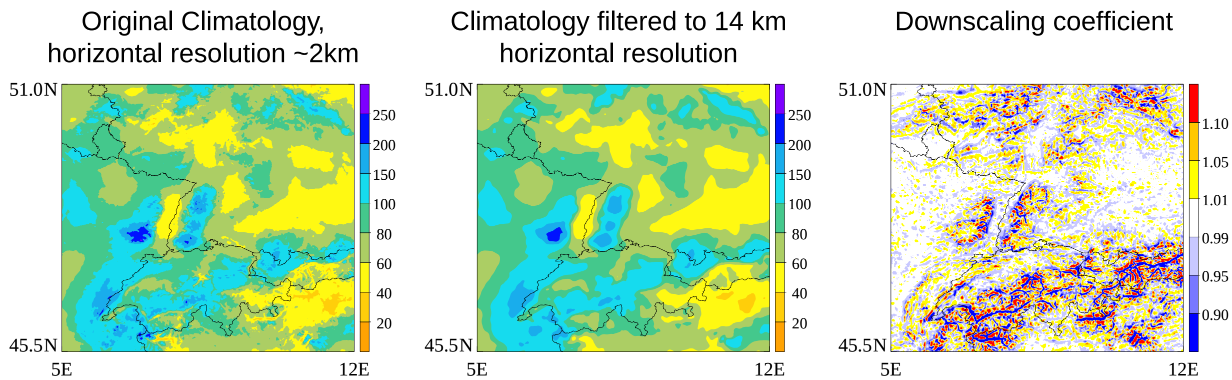

Figure 2: Downscaling of precipitation fields using a high resolution precipitation climatology.

basin down to Cologne, covering approx. 145’000 km^2. WaSiM is a distributed, gridbased runoff model using physically based algorithms like the Richard’s equation for the vertical transport of water within the soil. The entire model suite covers scales of more than two orders of magnitude (Figure 1).

The coupling of the models is purely one-way, i.e. from the large to the small scale. The coupling of the hydrologic model with the climate model is provided by the downscaling of the climate model fields (precipitation, temperature, radiation, humidity, and wind) to the resolution of the distributed runoff model. Downscaling of precipitation fields is done according to Widmann and Bretherton (2000) using a high resolution precipitation climatology with a resolution of approximately 2 km (Schwarb et al. 2001, Figure 2). The downscaling of precipitation is based on the idea that the ratio between the fine scale precipitation fields and the coarse scale precipitation fields is constant throughout each month of the year. The coefficient of the high resolution climatology and the climatology filtered to the resolution of the RCM is used for the downscaling of the precipitation fields. The downscaling of temperature fields is done using the vertical temperature gradient provided by the climate model and the fine-scale topography.

The boundary conditions for the regional climate model are taken from the ECMWF reanalysis with a horizontal resolution of approx. 120 km (T106). The simulations cover 6 years with CHRM56 (09/ 1987 - 01/1994) and the five winter seasons 1989/ 90 till 1993/ 94, each from November until January, with CHRM14.

For the initialization of the soil water content and the snow cover, five repetitive simulations of one year each were performed. These simulations were driven by CHRM56 and began on September 1st 1987. The result of these repetitive simulations was taken as initial condition for the hydrologic simulations driven by CHRM56. The initial conditions for the hydrologic simulations driven by CHRM14 consist of the results of the simulations driven by CHRM56.

3. VALIDATION OF RCM PRECIPITATION

A detailed validation of the model precipitation is done using the precipitation climatology of Frei and Schär (1998), which is based on approx. 6’000 daily precipitation measurements.

The validation of the control simulation shows a good correspondence of the precipitation fields from the regional climate model with measured fields regarding the distribution of precipitation at the scale of the Rhine basin. CHRM14 shows the ability to generate fine-scale precipitation features not represented by CHRM56 (Figure 3). It also shows an overestimation (of approx. 10%) of precipitation in the Alps and a slight upstream shift (~20 km) of the precipitation anomalies along the Black Forest and the Vosges Mountains (Figure 3).

Consideration of monthly mean precipitation (Figure 4) demonstrates the ability of simulating the interannual precipitation variability in response to large-scale forcing. The root mean square (RMS) difference of the CHRM14 monthly means is significantly smaller than the standard deviation of the observations.

The simulated precipitation has systematic errors on the scale of subcatchments, concerning the distribution with height and the frequency distribution.

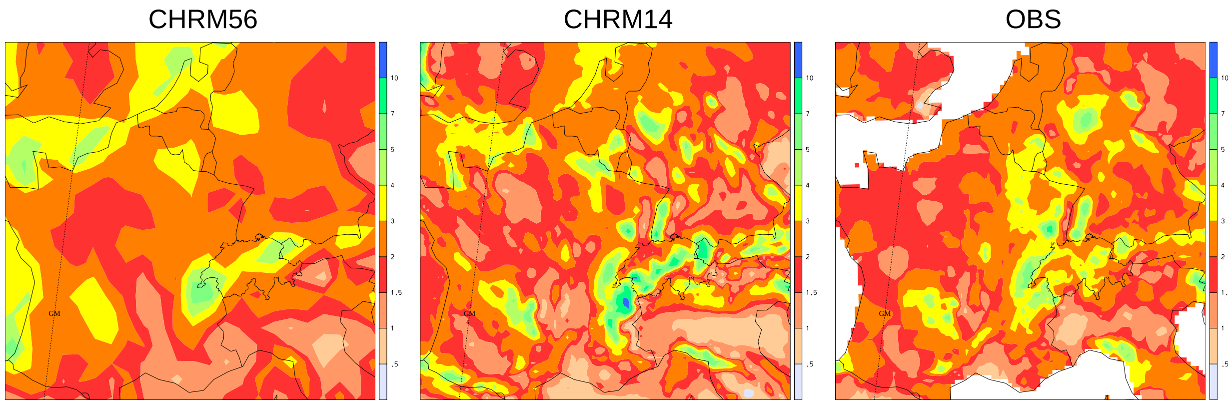

Figure 3: Mean daily precipitation in mm averaged over the winters 1989/90 to 1993/ 94, each winter consisting of November till January.

The number of small precipitation events is slightly underestimated in most catchments (Figure 5) whereas the number of strong precipitation events is usually overestimated. The different characteristics of the catchments concerning the precipitation frequency are well represented.

The previously mentioned overestimation of precipitation in the Alps can be seen in Figure 6. Whereas precipitation is overestimated between altitudes of 1’000 to 2’000 m a.s.l., precipitation is underestimated between 200 and 1’000 m a.s.l.

4. VALIDATION OF SIMULATED RUNOFF

The runoff regime of the Rhine river is characterized by a shift in discharge throughout the basin (Disse and Engel 2001, Frei et al. 2000). The Alpine catchments are dominated by snowfall and hence have their peak discharge in early summer. Further downstream the runoff regime is dominated by winterly rainfall and hence the peak discharge is in winter. This shift in the runoff regime can also be observed in the simulation period of 09/1987 - 01/1994 (Figure 7). The model chain of CHRM56 and WaSiM reproduces this shift in the runoff regime from the Alpine catchments to the gauges further downstream (Figure 7).

The comparison of simulated and observed daily runoff values reveals a good timing of runoff events in the simulations driven by CHRM56 (Figure 8) as well as in the simulations driven by CHRM14 (Figure 9). The amplitude of runoff events is not always captured in the simulations. The deviations between simulated and observed runoff are larger in the Alpine basins compared to the foreland basins and compared to the whole Rhine basin.

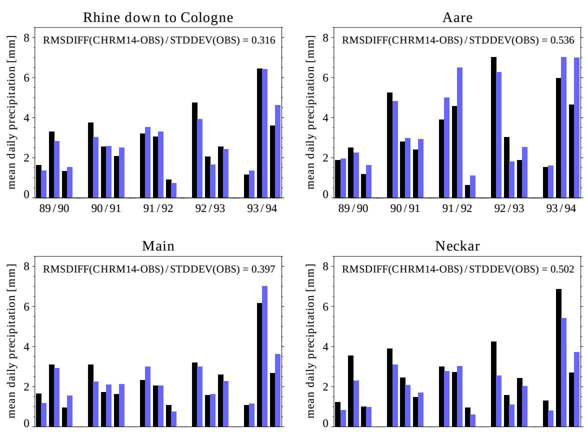

Figure 4: Monthly (Nov, Dec, Jan) mean daily precipitation for the Rhine basin down to Cologne and in different subcatchments, observed (black) and CHRM14 (blue).

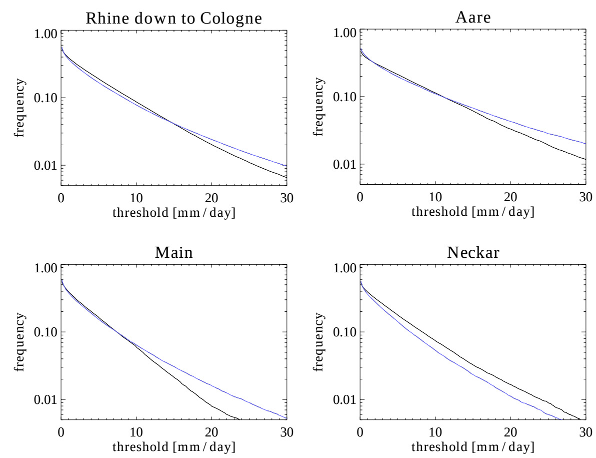

Figure 5: Precipitation frequency of daily precipitation in the Rhine basin and different subbasins, observed (black) and CHRM14 (blue).

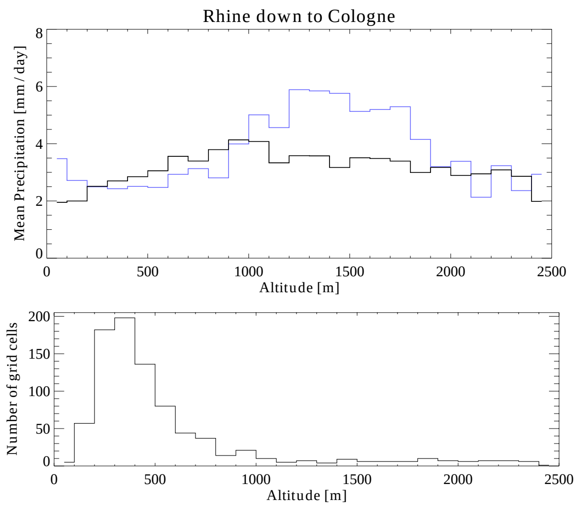

Figure 6: Altitude distribution of precipitation. Mean daily precipitation per altitude bin of 100 meters, observed (black) and CHRM14 (blue).

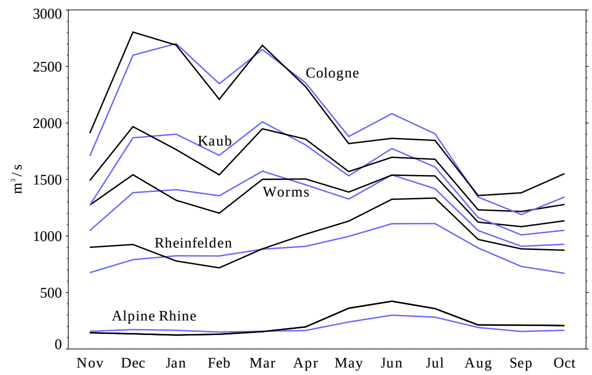

Figure 7: Mean monthly discharge from observations (black) and simulations driven by CHRM56 (blue).

Differences in winter runoff from the hydrologic simulations driven by CHRM14 compared to the hydrologic simulations driven by CHRM56 are surprisingly small. A possible reason for these small differences is that CHRM14 generates finer scale precipitation fields but the errors at catchment scale are larger. These errors at catchment scale can probably not be corrected with the applied downscaling technique. Further investigation is needed to understand the influence of downscaling technique, RCM resolution, and RCM errors on the hydrologic simulations.

For climate impact studies, it is necessary to look at the frequency distribution of runoff rather than at single runoff events. The frequency

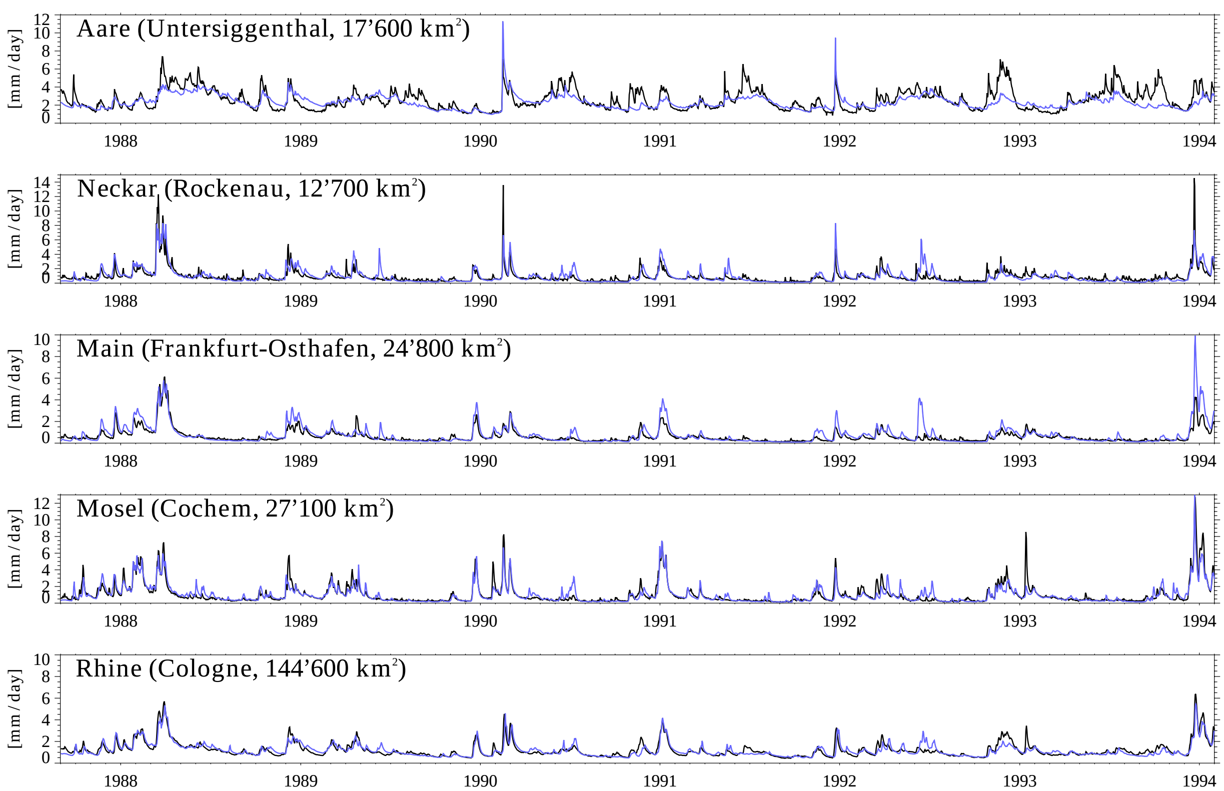

Figure 8: Daily runoff of 6 years, 09/1987 until 01/1994, observed (black) and simulated (blue). Hydrologic simulations are driven by CHRM56.

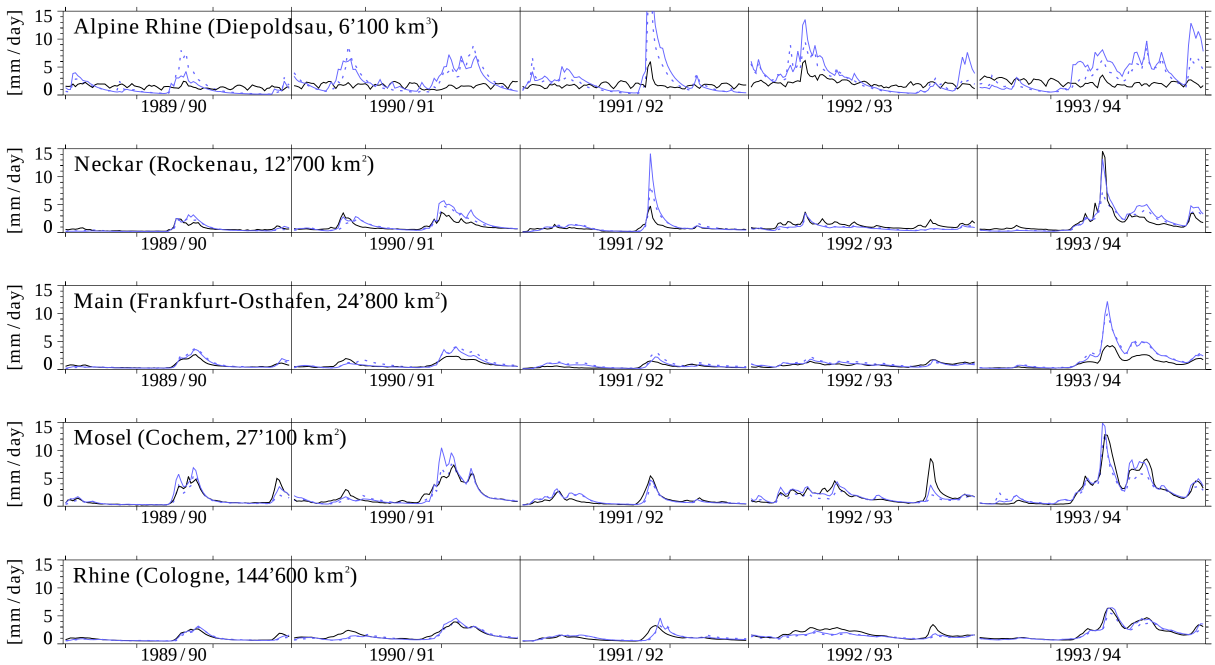

Figure 9: Daily runoff of 5 winters, 1989/90 until 1993/94, from Nov. till Jan. each, observed (black) and simulated driven by CHRM14 (blue, solid) and by CHRM56 (blue, dashed).

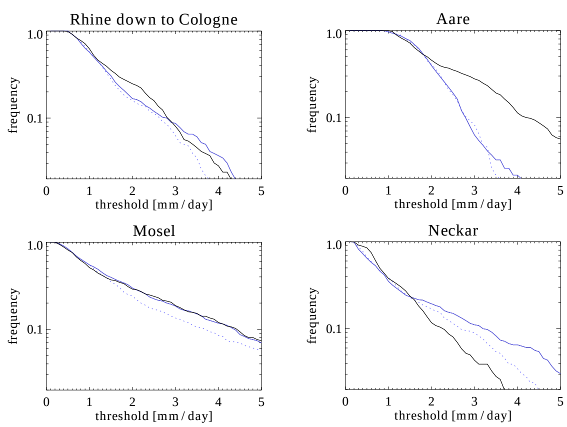

Figure 10: Runoff frequency of the Rhine at Cologne and subbasins of the Rhine basin, observed (black), hydrologic simulation driven by the CHRM14 (blue, solid) and by the CHRM56 (blue, dashed).

distribution of the runoff from observations and simulations (Figure 10) show an improvement in the simulation of high runoff events in a few of the subbasins and for the whole basin. This improvement is probably due to the increased resolution of the CHRM14 compared to the CHRM56. Furthermore, the difficulty remaining in the alpine Aare basin can be seen even stronger in the runoff frequencies than in the time series of daily runoff values (Figure 9).

5. CONCLUSION

A distributed hydrologic model was driven by regional climate model data. Downscaling was applied to precipitation and temperature fields to account for the gap in spatial scales between the models.

The model chain is capable of reproducing the interannual variability of precipitation as well as its finescale distribution. Deviations to the observations are to be found in the altitudinal distribution of precipitation and in the precipitation distribution along mountains.

The runoff simulations correspond well with observations for foreland subbasins and for the whole Rhine basin. The yearly cycle in monthly discharge as well as the statistics of daily runoff values shows good correspondence between simulation and observation. The runoff simulations of the alpine subbasins still show some deficiencies. Several reasons are possible for the lower quality in the simulations of alpine catchments:

- The topographic complexity is highest in the Alpine catchments. Precipitation and snow cover have to be of high spatial detail and accuracy. On the other hand, the CHRM has stronger biases over topography.
- Lake retention and regulation were not taken into account in the hydrologic simulations.
- Soil freezing is not taken into account in the hydrologic simulations.
- Runoff in the Alpine catchments is heavily influenced by anthropogenic activities, which could not be taken into account in the hydrologic simulations.

At this stage, results from the model chain presented in this study have to be interpreted with care for the Alpine basins. The model chain performs well in foreland basins and for larger basins. An application of the model chain for climate impact studies can be found in Kleinn et al. (2003) in this volume.

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