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COUPLED CLIMATE-RUNOFF SIMULATIONS: A PROCESS STUDY OF CURRENT AND A WARMER CLIMATE IN THE RHINE BASIN

Jan Kleinn*, Christoph Frei, Joachim Gurtz, Pier Luigi Vidale, Christoph Schär
Institute for Atmospheric and Climate Science, ETH Zurich, Switzerland

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.

In winter-time, two possible climate effects could influence the runoff statistics of large Central European rivers: the shift from snowfall to rain as a consequence of higher temperatures and the increase of heavy precipitation events due to an intensification of the hydrological cycle (e.g. Frei et al 2000, IPCC 2001, Trenberth 1999). The combined effect on the runoff statistics is examined in this study for the river Rhine. To this end, sensitivity experiments with a model chain including a regional climate model and a distributed runoff model are presented. The experiments are based on an idealized surrogate climate change scenario (Schär et al 1996).It should be stressed that this study does not provide a full climate change scenario but merely an analysis of relevant nonlinearities and sensitivities. In addition to these sensitivities, climate change would also imply changes in synoptic climatology that are not considered in this study.

* *Corresponding author address:* Jan Kleinn, Institute for Atmospheric and Climate Science ETH, Winterthurerstrasse 190, CH-8057 Zurich, Switzerland; e-mail: kleinn@geo.umnw.ethz.ch

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). 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 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. 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. It 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 & Bretherton (2000) using a high resolution precipitation climatology (Figure 2) and the downscaling of temperature fields is done using the vertical temperature gradient provided by the climate model and the fine-scale topography.

ECMWF Reanalysis T106 (~120 km) | CHRM 56 km | CHRM 14 km | WaSiM 1 km

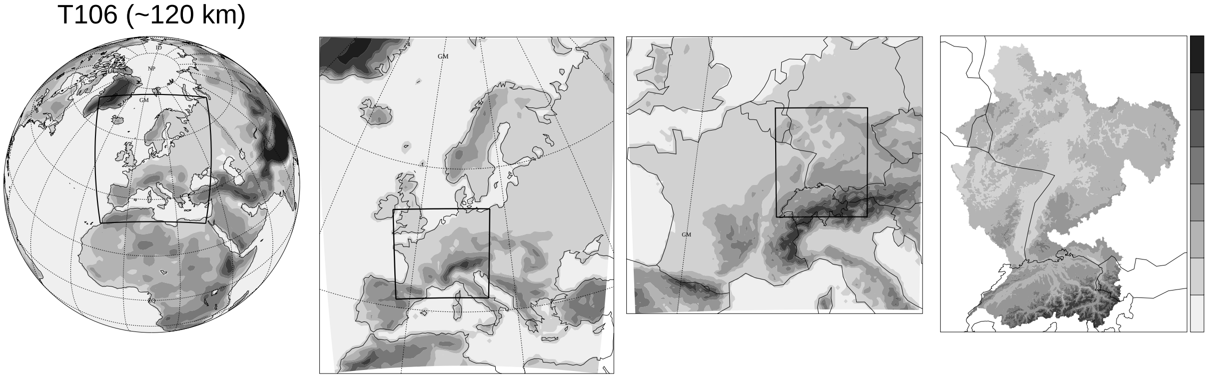

Figure 1: Topography of the ECMWF Reanalysis, the CHRM in 56 and in 14 km horizontal resolution and the distributed runoff model WaSiM to illustrate the model domains and resolutions of the different models.

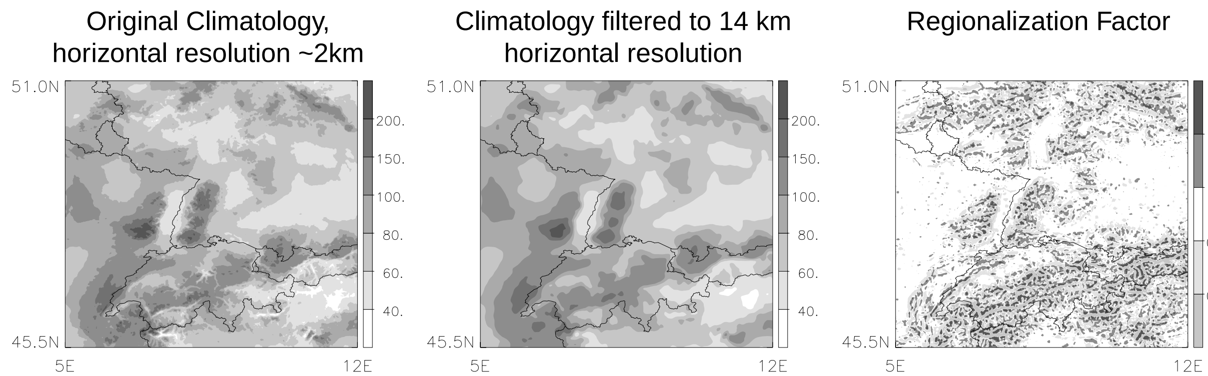

Figure 2: Downscaling of precipitation fields using a high resolution precipitation climatology.

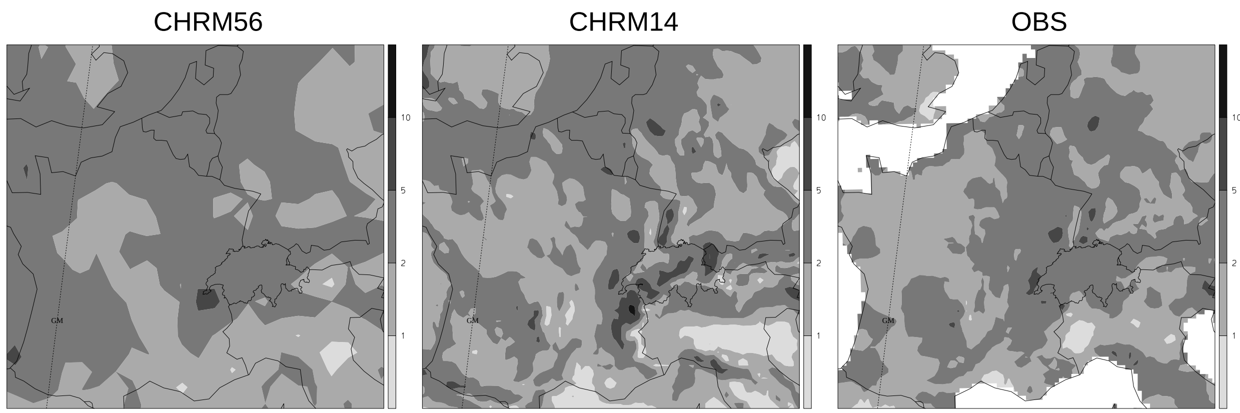

Figure 3: Mean daily precipitation in mm averaged over the winters 1989/90 to 1993/ 94, each winter consisting of November till January.

The boundary conditions for the regional climate model are taken from the original ECMWF reanalysis and from a modified version representing the surrogate scenario, both at a horizontal resolution of approx. 120 km (T106). The scenario of a warmer climate (hererafter called WARM) consists of driving fields with a uniformly increased temperature of 2 Kelvin and therefore an increased atmospheric humidity of approx. 15%. Such a temperature shift can be formulated consistently with the governing equations (Schär et al 1996), and the methodology has earlier been applied by Frei et al (1998). The simulations cover the five winter seasons 1989/90 till 1993/ 94, each from November until January.

3. VALIDATION OF THE MODEL CHAIN

A detailed validation of the model precipitation is done using the precipitation climatology of Frei and Schär (1998), that uses approx. 6000 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. The CHRM14 shows the ability to generate fine-scale precipitation features not represented by the 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

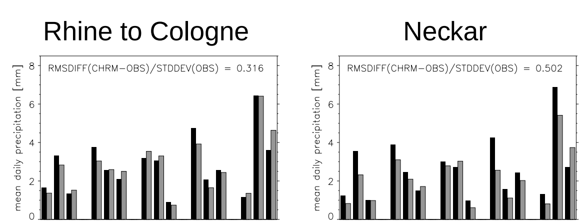

Figure 4: Monthly (Nov, Dec, Jan) mean daily precipitation for the Rhine basin down to Cologne and the Neckar as an example of a subcatchment, observed (black) and CHRM14 (gray).

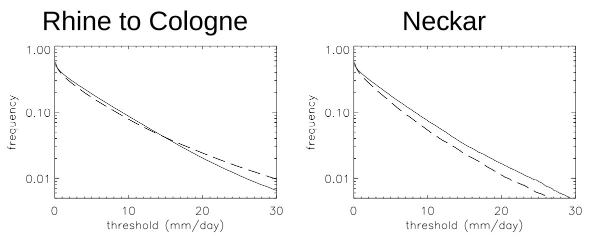

Figure 5: Precipitation frequency of daily precipitation.

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. 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 between the different catchments 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 1000 to 2000 m a.s.l., precipitation is underestimated between 200 and 1000 m a.s.l.

Despite the errors in the simulated precipitation, the simulated runoff, shows good correspondence with the observed runoff (Figure 7). Looking at the runoff from a climatological point of view, i.e. looking at the frequency distribution of runoff (Figure 8), a net improvement in the simulation of

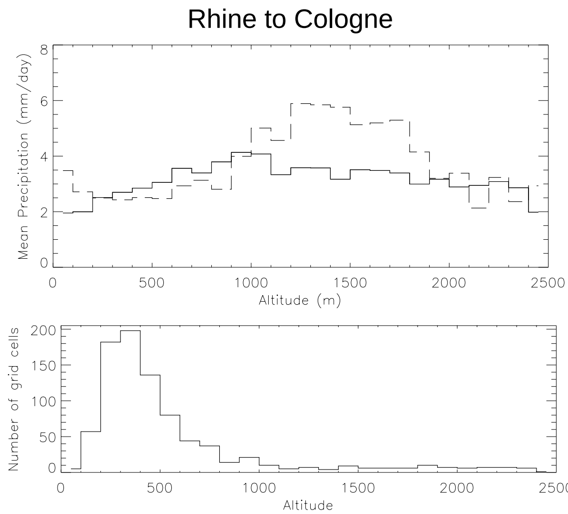

Figure 6: Altitude distribution of precipitation. Mean daily precipitation per altitude bin of 100 meters.

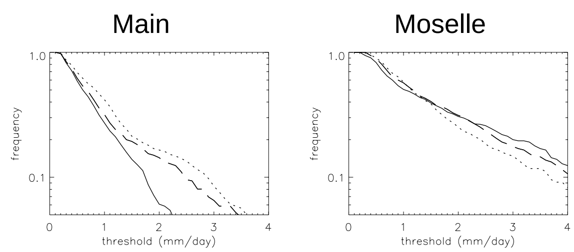

Figure 8: Runoff frequency of the Main and the Moselle basin, observed (solid), hydrologic simulation driven by the CHRM14 (dashed) and by the CHRM56 (dotted).

high runoff events can be seen due to the increased resolution of the CHRM14 compared to the CHRM56.

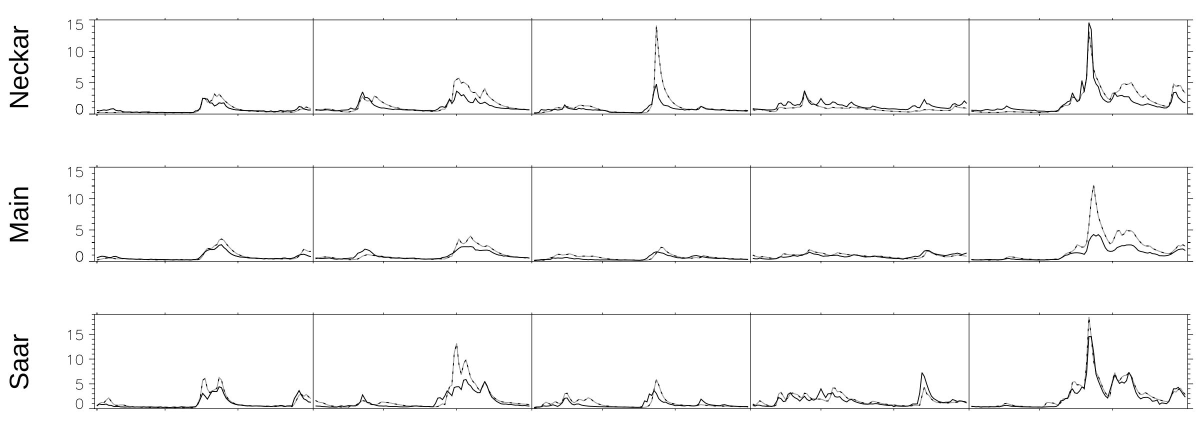

Figure 7: Daily runoff of 5 winters, 1989/90 until 1993/94, from Nov. till Jan. each, observed (black, solid) and simulated (gray-black, dashed)

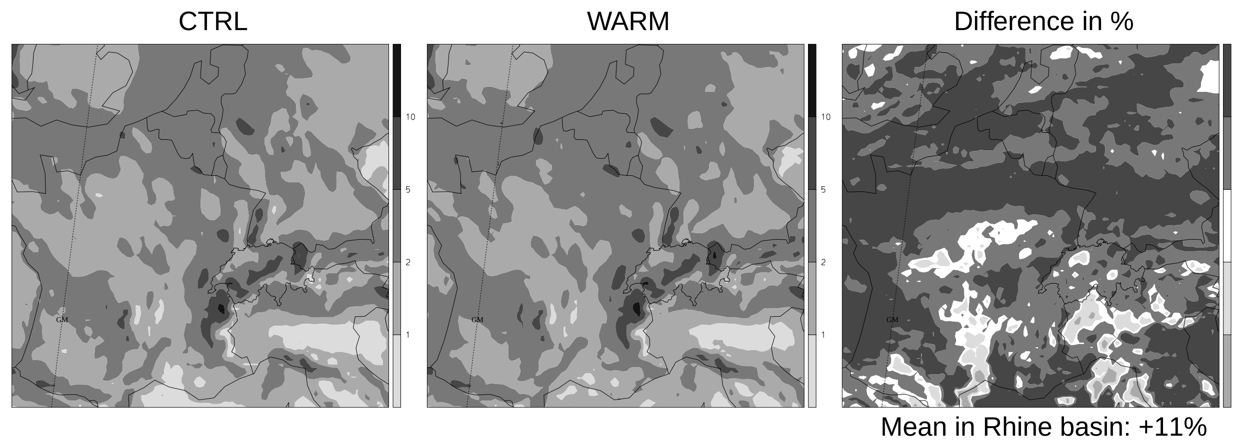

Figure 9: Mean daily precipitation mm, control run and warmer climate.

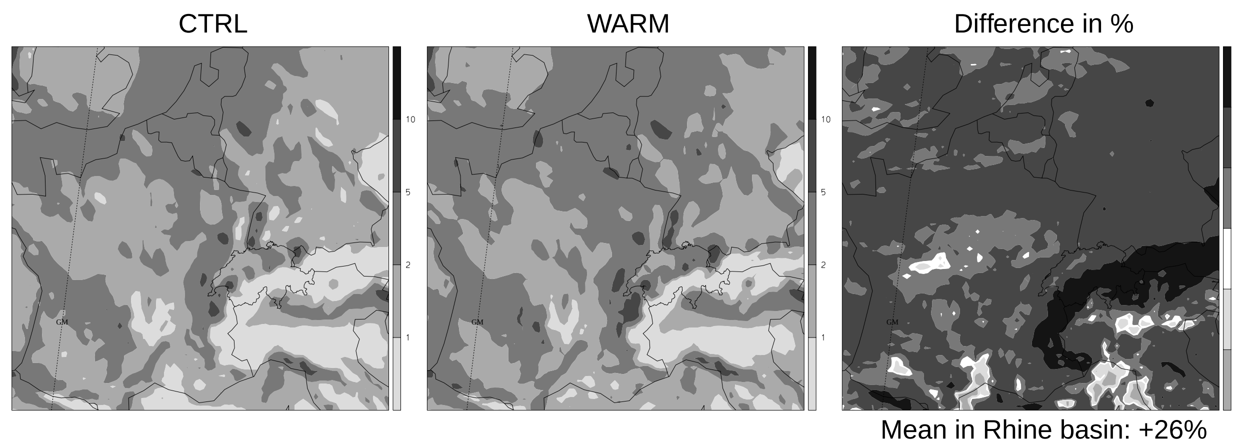

Figure 10: Mean daily liquid precipitation mm, control run and warmer climate.

4. SCENARIO OF A WARMER CLIMATE

Simulations of a warmer climate show an increase in precipitation by more than 10% in most parts of Europe (Figure 9). The increase in liquid precipitation is even stronger (Figure 10), with increases as high as 50% in large parts of the Alps, as a shift from snowfall to rain occurs in warmer winter months. This precipitation cannot be stored and therefore runs off immediately. The increase in precipitation mostly comes from an increase in the heavy precipitation events. While the number of days with precipitation hardly changes, the frequency of days with more than 20 mm precipitation increases by approx. 25% (Figure 11).

As a result of stronger precipitation, the mean winterly runoff also increases by 10% to 25%, depending on the catchment (Table 1). An increase of strong events can also be seen in the runoff, where the number strong runoff events increases (Figure 12).

5. CONCLUSION

To asses the influence of a warmer climate to the regional hydrology, coupled climate-runoff simulations were performed. The model chain is capable of reproducing the interannual variability of

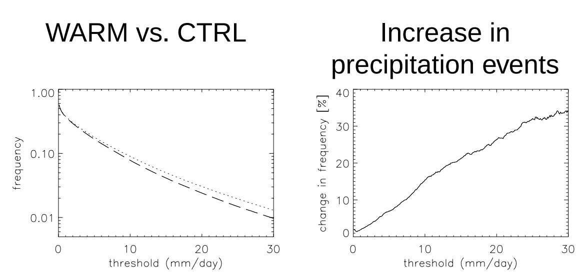

Figure 11: Change in precipitation intensity in a warmer climate in the Rhine basin, WARM (dotted) vs. CTRL (dashed), difference in %.

Basin	CTRL	WARM	Diff in %
Neckar	1.14	1.44	26.3
Main	0.96	1.07	11.9
Saar	1.56	1.93	23.7
Moselle	1.67	1.94	16.4

Table 1: Mean runoff in the control and warm simulation (mm/day) and difference in %.

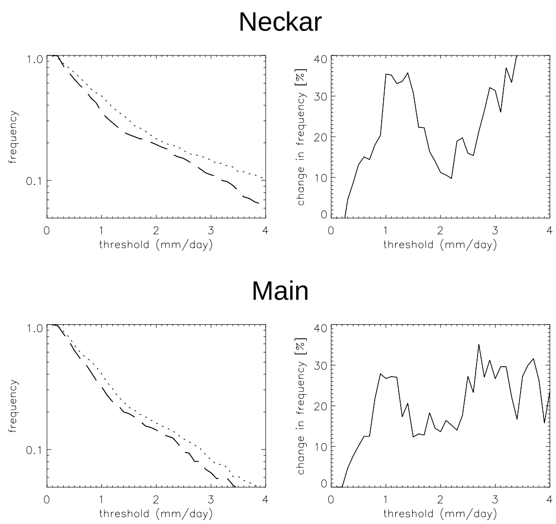

Figure 12: Change in runoff intensity in a warmer climate in the Neckar and Main basins, WARM (dotted) vs. CTRL (dashed), difference in %.

precipitation as well as its finescale distribution and the runoff. Deviations to the observations are to be found in the altitudinal distribution of precipitation and in the precipitation distribution along mountains.

The sensitivity experiments of a warmer climate with the CHRM show an increase in precipitation and an increase in the number of strong precipitation events. Due to warmer conditions, a shift from snowfall to rain occurs. These signals in precipitation significantly influence the runoff statistics resulting in a longer duration and/or a larger number of high winter runoff events.

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