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Estimated changes in flood quantiles of the river Meuse from resampling of regional climate model output

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Summary Precipitation and temperature data from three regional climate model (RCM) experiments were used to assess the effect of climatic change on the flood quantiles of the French–Belgian river Meuse. In two of these experiments the RCM was driven by the global atmospheric model HadAM3H of the Hadley Centre (HC), and in the other experiment the RCM was driven by the global coupled atmosphere–ocean model ECHAM4/OPYC3 of the Max-Planck Institute for Meteorology (MPI). RCM simulations for the control climate (1961–1990) and the SRES-scenario A2 (2071–2100) were available. The HBV rainfall–runoff model was used to simulate river discharges. Long synthetic sequences of precipitation and temperature were resampled from the RCM output using a nearest-neighbour technique to obtain the flood quantiles for long return periods. The maxima of 10-day precipitation and discharge for the winter half-year (flooding season) were analysed. It was found that the changes in the extreme quantiles of 10-day precipitation and discharge were highly sensitive to the driving GCM. In the runs driven by HC, there was little change in the most extreme quantiles, whereas the MPI-driven run projected a remarkable increase. It is shown that this difference between the HC- and MPI-driven runs is strongly related to the change in the coefficient of variation of the 10-day precipitation amounts, which decreases in the former and hardly changes in the latter. The relevance of bias correction of RCM output with regard to the estimated changes of flood quantiles is demonstrated.

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Introduction

From the perspective of policy making the interest in the impacts of local climatic change on river flows is increasing. It is generally believed that climate change will lead to increased flooding in many areas (Kay et al., 2006). For the Netherlands potential changes in the statistics of extreme flows are highly relevant, since the major part of the country is situated in the delta of the rivers Rhine and Meuse.

Most of the research on the impact of climate change on river discharges in the Netherlands relates to the river Rhine. To assess the impact of climate change on the monthly mean and peak discharges of the river Rhine, Kwadijk and Rotmans (1995) applied gridded patterns of changes in temperature and precipitation, obtained from seven equilibrium experiments with general circulation models (GCMs), to the observed monthly precipitation and temperature and used the perturbed data to drive a distributed hydrological model (RHINEFLOW) for the river basin. The same approach was followed in a study coordinated by the International Commission for the Hydrology of the Rhine Basin (CHR) using the output from one transient and two equilibrium GCM experiments (Grabs, 1997; Middelkoop et al., 2001). As in Kwadijk and Rotmans (1995), the effect of climate change was calculated by applying the changes found in the GCM experiments to the baseline climate and RHINEFLOW was used at a monthly resolution for the rainfall—runoff modelling of the Rhine basin. The assessment of the changes in river discharges was limited to the mean annual cycle at different gauging stations. In a later study (Middelkoop, 2000) the RHINEFLOW model was operated at a temporal resolution of 10 days, using data from the UKHI GCM of the Hadley Centre of the UK Met Office. Shabalova et al. (2003) were the first to use data from a regional climate model (RCM) to assess the impact of climate change on the discharges of the river Rhine in the Netherlands. They used HadRM2 of the Hadley Centre nested within the global coupled climate model HadCM2. The changes in 10-day precipitation and temperature were applied to the observed baseline series. Using RHINEFLOW, it was found that the changes in extreme 10-day flows were very sensitive to the type of transformation (linear or nonlinear) applied to the precipitation amounts. This sensitivity was also observed in a study of Prudhomme et al. (2002) for the Severn catchment (UK). Lenderink et al. (2007) investigated the direct use of bias-corrected 10-day HadRM3H regional climate model data (also from the Hadley Centre) as input to RHINEFLOW. They compared the changes in discharge with those obtained by perturbing the RCM control run. One of their findings was that direct use of RCM data should be preferred if other discharge characteristics than the mean (such as extremes) are of interest.

Several other studies have been performed for individual subbasins of the river Rhine upstream of the Netherlands. A number of relatively small subbasins were considered in the CHR study described by Grabs (1997) and Middelkoop (2000). Detailed hydrological models were used to estimate climate change impacts. As in the RHINEFLOW application to the entire river basin, scenarios for future climate were obtained by perturbing the baseline climate with the changes from three GCM experiments. Bárdossy and Zehe (2002) studied the impact of climate change on floods and the runoff regime of the major German subbasins of the river Rhine, using a stochastic downscaling technique for generating daily precipitation and temperature, conditional on the circulation patterns of a control and a scenario run of the ECHAM4 GCM, and the semi-distributed HBV model (Lindström et al., 1997) for hydrological simulations. Kleinn et al. (2005) nested the distributed hydrological model WaSiM-ETH for the Rhine upstream of Cologne into a cascade of two versions of the Swiss/German regional climate model CHRM (with respective spatial resolutions of 14 km and 56 km). The 56-km model was driven by observed lateral boundary conditions from a 5-year ECMWF reanalysis. Future climate conditions were not considered in that study.

For the Meuse basin an extensive study has been carried out by Booij (2002, 2005). He used a first order Markov chain to generate a time series of daily basin-average precipitation and developed a discrete random cascade model for spatial disaggregation of precipitation. The parameters of the Markov chain for the current and the future climate were obtained from transient runs of three GCMs (CGCM1, HadCM3 and CSIRO9) and two RCMs (HadRM2 and HIRHAM4). The parameters for the cascade model were estimated from the two RCMs. HBV was used for the hydrological simulations. A subdivision of the Meuse basin into 15 subbasins was compared with a subdivision into 118 subbasins and no subdivision. de Wit et al. (2007) analysed the impact of climate change on the occurrence of low flows in the river Meuse, using RCM simulations from the EU-funded PRUDENCE (Prediction of Regional scenarios and Uncertainties for Defining EuropeaN Climate change risks and Effects) project, see e.g. Christensen and Christensen (2007). Their study indicates that climate change will lead to a decrease in the average discharge of the Meuse during the low flow season. Considerable problems were, however, encountered with the simulation of critical low flow conditions of the Meuse. Bultot et al. (1988) and Gellens and Roulin (1998) investigated the impact of climate change for some Belgian subbasins of the river Meuse by perturbing the baseline climate.

Leander and Buishand (2007), from here LB07, presented a detailed study of bias correction of RCM output for the Meuse basin. They also applied nearest-neighbour resampling to obtain long sequences of daily precipitation and temperature required to simulate long-duration series of river flows. The study was restricted to two experiments with the KNMI regional climate model RACMO under current climate conditions. The simulated series were successfully used to estimate flood quantiles for return periods far beyond the extent of the original RCM runs. Therefore, this approach offers a possibility to estimate extreme flood quantiles for a future climate using data from scenario runs.

In this study the methodology presented and tested in LB07 is employed to assess the effects of RCM climate change projections on rare flood quantiles. In that sense, it is a continuation of the work presented in LB07. It could also be regarded as an extension of the work done by Lenderink et al. (2007), because it demonstrates a new way to take advantage of RCM output for the investigation of rare flood quantiles, by using a resampling method and a more sophisticated bias correction. Furthermore, the hydrological model is operated at a