Hydrological simulations in the Rhine basin

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Abstract Simulations with regional climate models (RCMs), carried out for the Rhine basin, have been analyzed in the context of implications of the possible future discharge of the Rhine river. In a first analysis, the runoff generated by the RCMs is compared to observations, in order to detect the way the RCMs treat anomalies in precipitation in their land surface component. A second analysis is devoted to the frequency distribution of area averaged precipitation, and the impact of selection of various driving global climate models.

Keywords Regional climate modelling; hydrological budget; Rhine basin

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Introduction

Climate change projections with general circulation models (GCMs) are widely used to assess the possible impacts of potential future climate change. However, when zooming in at relatively small areas (such as a single river basin) GCM-projections not rarely suffer from large biases and interpretation is difficult owing to the coarse spatial and temporal resolution of the models. An increasingly popular downscaling method is the use of regional climate models (RCMs), nested in the GCM-archives. In a European project called PRUDENCE (http://prudence.dmi.dk; Christensen *et al*, 2002) a number of RCMs has been used to downscale a number of GCM-projections specifically for Europe. In this paper we will present a number of results from these simulations focusing on the hydrological features of the Rhine basin.

Gross budget calculations and land–atmosphere interaction

Seven RCM models were all used to downscale two time slices of a single long term GCM-simulation from the UK Hadley Centre climate model HadAM3H: a reference period (1960–1990) corresponding to so-called present climate conditions, and a 30-yr period at the end of the 21st century, during which a greenhouse gas emission scenario was followed which lead to a roughly double CO_2-concentration by 2100 (the A2-scenario). In addition, two of these RCMs also downscaled similar GCM-simulations created by the ECHAM4/OPYC GCM. The used grids and domains varied across the RCMs, but they all covered the major part of Europe at a spatial resolution of typically 50 × 50 km.

For the present day climate, the RCMs varied quite a bit with respect to mean annual cycles of precipitation, evaporation, soil buffering and discharge, even while being forced by an identical GCM-run. However, the difference in, for instance, precipitation between various RCMs appeared smaller than differences between various GCMs for the Rhine area, indicating that the large-scale control on the hydrological circulation in this area is relatively important. Figure 1 shows mean annual cycles of precipitation over the Rhine basin simulated by these RCMs. Control and A2 scenario simulations are compared to detailed multiyear observations from the International Rhine Hydrological Commission (CHR).

However, during summertime the range in RCM-simulations driven by the same GCM is larger than the difference induced by changing the driving GCM (see Figure 1).

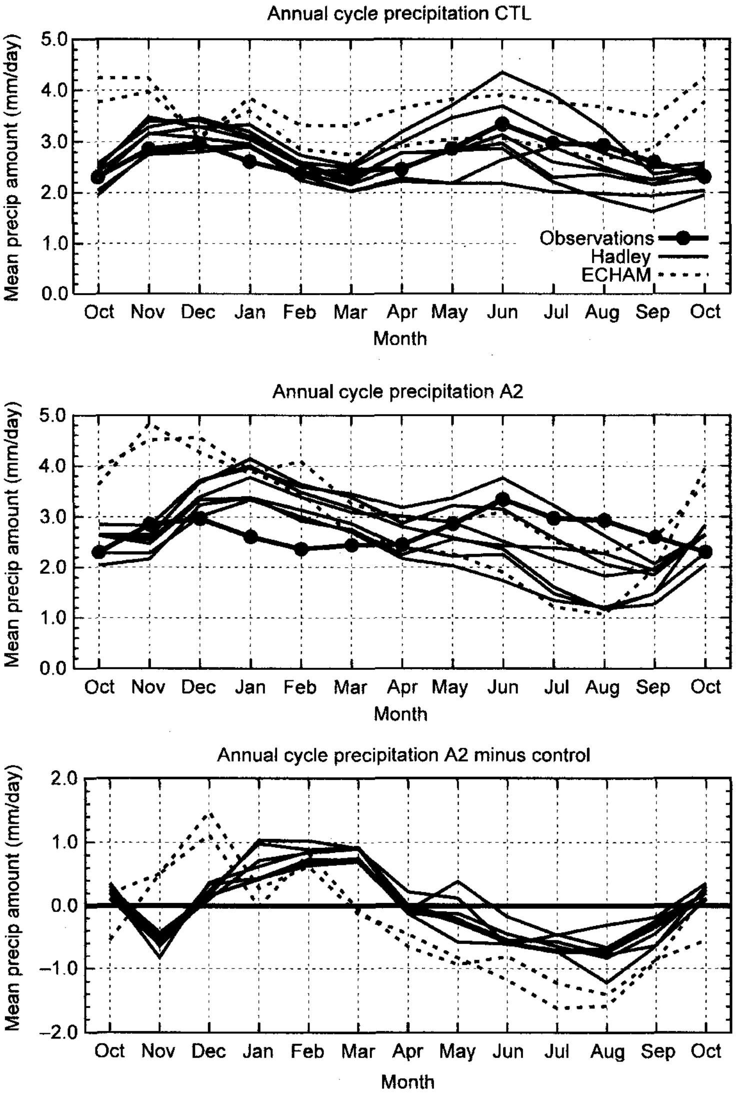

Figure 1 Mean annual cycle of daily precipitation averaged over the Rhine basin as simulated by 7 RCMs using the Hadley GCM simulations (solid lines) and 2 RCMs using the ECHAM4/OPYC simulations (dashed lines) for a control climate (upper panel), and the 2070–2100 time slice consistent with an A2 greenhouse gas emission scenario (middle panel). The bottom panel shows the RCM response to a change from the control to the A2 scenario. Solid lines with symbols in the upper two panel denote 1960–1995 observations derived from the CHR database

Van den Hurk *et al.* (2005) demonstrate that there is a fairly clear impact of the soil moisture memory on the likelihood of generating dry summertime conditions: small soil storage capacities lead to an increased sensitivity to summer drought. This is analysed by comparing the partitioning of precipitation minus evaporation ($P - E$) over soil storage and runoff to large-scale observations retrieved from reanalysis data and river discharge data. The observations favour a fairly strong buffering of $P - E$-anomalies in the soil, leading to a relatively small sensitivity to summer drought (Figure 2).

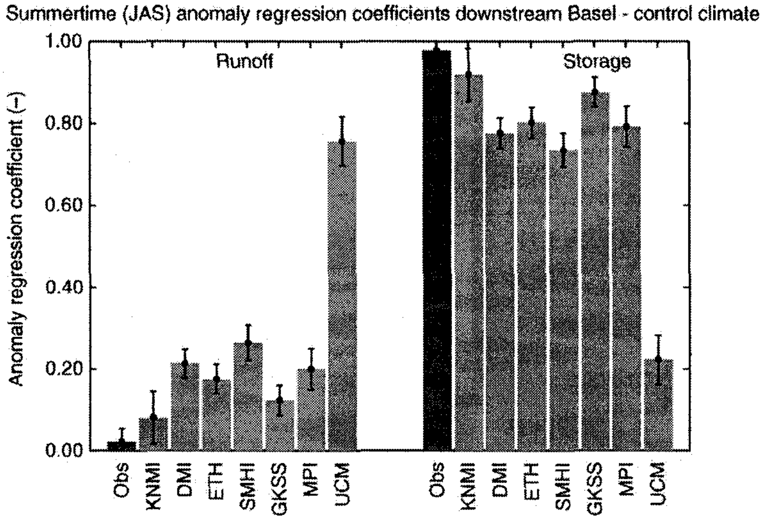

Figure 2 Partitioning of anomalous P – E over either runoff (left set of bars) or storage in the soil (right set of bars) during summer months in the Rhine basin. The dark shaded bars are obtained from reanalysis and Rhine discharge data, the remaining columns each represent a single RCM driven by the Hadley Centre GCM control simulation

What does this mean for climate change calculations carried out with RCMs? The simulations carried out for the end of the 21st century time slice showed that although the driving GCM was similar for each of the participating RCMs, the response in terms of runoff and evaporation was again quite different. The results of the analysis indicated that models with a relatively large capacity to buffer $P-E$-anomalies in the soil also resulted in a relatively small response of the hydrological cycle to a change in greenhouse gas concentrations.

Modelling of extreme events

While the soil hydrological properties may impact on the likelihood of generating dry low-flow summertime conditions, the occurrence of high discharge leading to flood risk is more related to the realism of the precipitation simulations. Using a detailed 35-yr precipitation data base the PRUDENCE model results were evaluated with respect to the temporal and spatial variability of the precipitation. It appeared that, although the mean annual cycle of many models show a significant discrepancy from the observations, the statistical distribution of daily precipitation averaged over the whole Rhine basin appeared fairly consistent for most models: extreme events are systematically underestimated, likely because of the still relatively coarse model grid point resolution.

The likelihood of generating extreme precipitation events in response to a doubling of the CO_2-concentration showed a fairly wide range of RCM-results (Figure 3). In general, the RCMs driven by the same GCM display a fairly consistent response. Rare events become more intense when daily data are analysed (left panel of Figure 3). However, the persistent circulation patterns in the ECHAM4 GCM result in a similar response to an A2 greenhouse gas scenario when 10-day precipitation sums are considered. In contrast, the RCMs driven by the Hadley model do show a much smaller response for extreme events, probably because the circulation patterns are less persistent and incidental high precipitation events are compensated by low intensity events on the subsequent days. A firm statement on the quality of these predictions is still difficult to give.

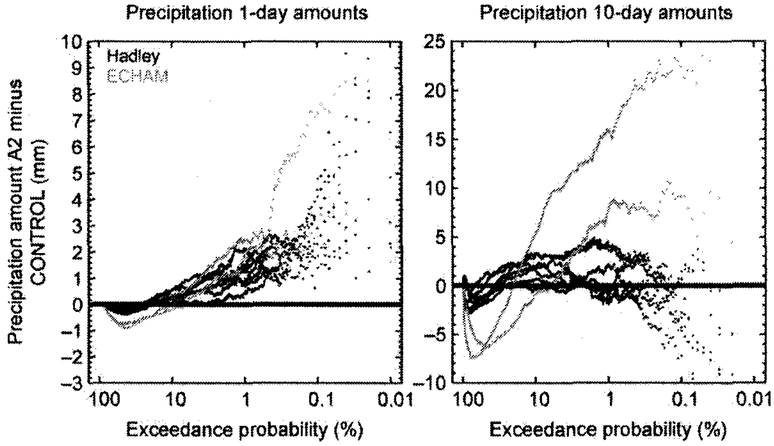

Figure 3 Change of the intensity of daily precipitation corresponding to a given exceedance probability when changing from present day climate to the A2-scenario 2070–2100. Left panel shows daily precipitation sums, right panel 10-daily sums. Light symbols are from RCMs driven by ECHAM/OPYC, dark symbols HadAM3H-runs. The plot shows that events occurring relatively often (left-hand side) decrease in intensity, while rare extremes increase

Conclusions

Downscaling with RCMs is often used to make a local interpretation of climate change projections calculated with GCMs. Although this downscaling step is necessary, it does include a new source of uncertainty in future climate effects, since different RCMs result in different projections. However, this extra uncertainty may be interpreted as an inevitable chaotic manifestation of climate, which may cause large climate effects when small-scale processes vary. The challenges for the near future are: (a) to keep reducing the model uncertainty by sophisticated evaluations with available observations, (b) to adequately sample natural climate variability in order to ensure that projections of future climate will indeed contain the true evolution, and (c) to further develop the tools to translate this uncertainty into useful information supporting policy decisions.

References

Christensen, J.H., Carter, T. and Giorgi, F. (2002). PRUDENCE employs new methods to assess European climate and change. *EOS*, **82**, 147.

Van den Hurk, B., Hirschi, M., Schär, C., Lenderink, G., van Meijgaard, E., van Ulden, A., Rockel, B., Hagemann, S., Graham, P. and Kjellström, E. (2005). Soil control on runoff response to climate change in regional climate model simulations. *J. Climate* (in press).