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Assessing climate change impacts on hydrology from an ensemble of regional climate models, model scales and linking methods – a case study on the Lule River basin

L. Phil Graham · Johan Andréasson · Bengt Carlsson

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Abstract This paper investigates how using different regional climate model (RCM) simulations affects climate change impacts on hydrology in northern Europe using an offline hydrological model. Climate change scenarios from an ensemble of seven RCMs, two global climate models (GCMs), two global emissions scenarios and two RCMs of varying resolution were used. A total of 15 climate change simulations were included in studies on the Lule River basin in Northern Sweden. Two different approaches to transfer climate change from the RCMs to hydrological models were tested. A rudimentary estimate of change in hydropower potential on the Lule River due to climate change was also made. The results indicate an overall increase in river flow, earlier spring peak flows and an increase in hydropower potential. The two approaches for transferring the signal of climate change to the hydrological impacts model gave similar mean results, but considerably different seasonal dynamics, a result that is highly relevant for other types of climate change impacts studies.

1 Introduction

Changes to climate and climate variability will impact on hydrological systems and affect the flow in rivers. This paper discusses both expected hydrological outcomes from climate change and differences in methods for estimating them, based on an ensemble of regional climate model (RCM) simulations created within the PRUDENCE Project (Christensen et al. 2007). The hydrological modelling based on these RCM simulations is referred to as "hydrological change" here. The focus is on the Lule River Basin in the far north of Sweden.

Although both RCMs and GCMs (global climate models) include representation of hydrology, they generally do not resolve the hydrological cycle at a level of detail that is suitable for hydrological applications (Bergström et al. 2001). For instance, they typically lack sufficient representation of snow storage in mountain terrain, and lake and river flow

L. P. Graham (✉) · J. Andréasson · B. Carlsson
Swedish Meteorological and Hydrological Institute, SE-60176 Norrköping, Sweden
e-mail: phil.graham@smhi.se

routing routines. They are also subject to systematic biases, particularly for precipitation (Varis et al. 2004), the primary variable that dominates in most hydrological regimes. For these reasons hydrological models are used to interpret scenario results from climate models. However, different transfer methods to interface climate models with hydrological models also have an impact on hydrological change.

This paper looks first at how using different RCM simulations affects hydrological change for the Lule River Basin, as modeled by offline hydrological models. Aside from multiple RCMs, differences in the climate simulations include two GCMs, two emissions scenarios, and different horizontal resolutions in the RCMs. Secondly, the paper investigates how using different climate transfer methods affects the outcome of hydrological change results. This incorporates the use of more direct transfer methods and focuses on simulations from a specific GCM/RCM combination. Finally, rudimentary estimates of change in hydropower potential due to hydrological change are presented for the Lule River.

The Lule River is situated in northern Sweden, flowing southeast from the Scandinavian Mountains to Bothnian Bay in the Baltic Sea (Fig. 1). The basin area is some 25,000 km^2 and the main river channel is about 350 km long. With an annual mean temperature of about −2.5°C (1961–1990), cold region hydrology dictates the flow regime. Mean annual precipitation is over 1,000 mm in the upper northwest of the basin, most of which falls as snow. For the lower regions in the southeast, this reduces to 500–600 mm. Mean annual river discharge for the period 1930–1990 is 486 m^{3}s^{-1}, with peak flows typically occurring in late May or June.

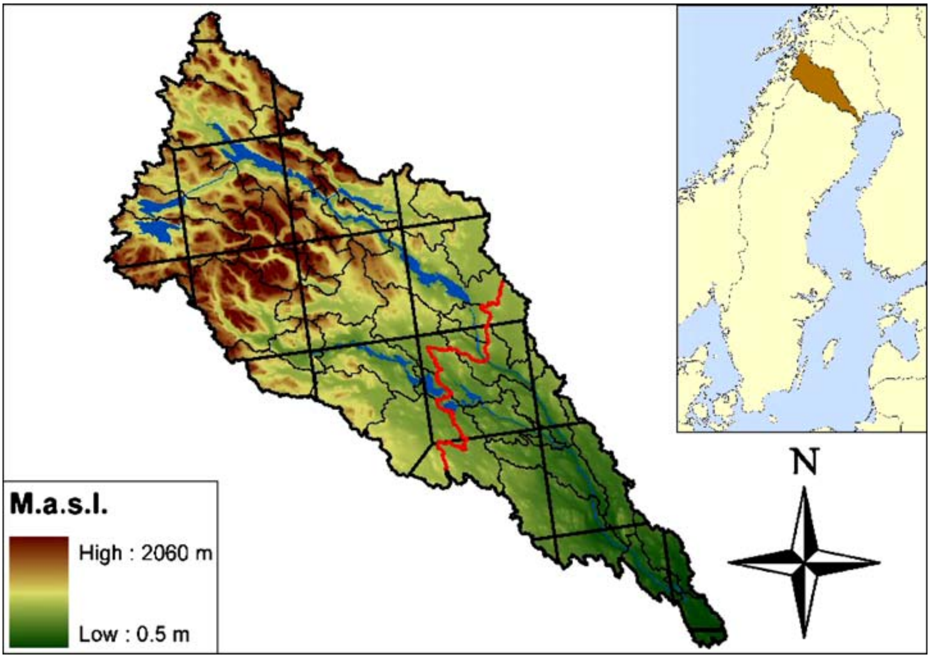


Fig. 1 The Lule River Basin including subbasin divisions (*thin black lines*). The grid delineation is one example of an RCM resolution at about 50 km (RCAO). The *red line* shows the division into northwest and southeast used for subarea calculation of the delta factors. The *background colors* indicate elevation

2 Methods and models

2.1 Regional climate models and scenarios

As described by Christensen et al. (2007), RCMs are used as a means to downscale from the global scale of GCM simulations to regional scales. Of the eleven RCMs included in PRUDENCE, nine used a model domain that extended far enough north to cover the Lule River Basin. Seven of these were included in this study—RCAO, HIRHAM, CHRM, RACMO, CLM, REMO and HadRM3H. The two future climate scenarios are based on the IPCC (Intergovernmental Panel on Climate Change) A2 and B2 SRES anthropogenic emissions scenarios (Nakićenović et al. 2000).

The majority of RCM simulations were performed with a horizontal resolution around 50 km, using the global HadAM3H scenario A2 for boundary driving conditions. Two simulations were performed with 25 km resolution (henceforth referred to as RCAO25 and HIRHAM25). Four simulations used the global ECHAM4/OPYC3 for boundary conditions. For all cases, 30-year control climate simulations of present climate representing the period 1961–1990 were compared to future climate simulations representing the period 2071–2100. More detail on the RCMs and their results are found in Christensen and Christensen (2007), Déqué et al. (2007), and Jacob et al. (2007).

2.2 HBV hydrological model

The HBV hydrological model (Lindström et al. 1997) was used to interpret hydrological change from the climate scenarios. This is a conceptual semi-distributed rainfall runoff model originally developed for operational runoff forecasting. It has also been used extensively to perform impact studies for both climate change assessments (Vehviläinen and Huttunen 1997; Bergström et al. 2001; Andréasson et al. 2004), water quality (Arheimer and Brandt 1998), and a combination of the two (Arheimer et al. 2005). The model is usually operated on a daily timestep and includes routines for snow accumulation and melt, soil moisture accounting, groundwater response and river routing. Input data include precipitation, 2 m temperature and potential evapotranspiration. HBV is typically calibrated against river flow observations to obtain optimal performance in terms of both seasonal dynamics and runoff volume.

2.3 Interfacing the transfer between RCMS and HBV

Outputs from regional climate models are subject to systematic biases. Although this can be particularly pronounced for precipitation, it also occurs for 2 m temperature. Thus, direct use of output from RCM control simulations into hydrological model simulations typically leads to considerable deviation in river discharge from observations (Graham et al. 2007). An interface to transfer results from RCMs to hydrological impact models is therefore required.

2.3.1 Delta approach

The most common transfer method used to date has been the delta approach (e.g., Arnell 1998; Gellens and Roulin 1998; Lettenmaier et al. 1999; Middelkoop et al. 2001; Bergström et al. 2003; Graham 2004), often referred to as “delta change.” In this approach, differences in relevant climate variables—typically precipitation, temperature and evapotranspiration—are extracted from the control and scenario simulations of the climate model and processed before being transferred onto an observed database. The delta-perturbed database is thereafter used to make offline simulations with a hydrological model to provide a response to the future climate.

For application in the Lule River basin, the delta factors were summarized and applied over two subareas (Fig. 1). Temperature factors used linear transfer functions in which the change in temperature is a function of the observed daily mean. These functions were calculated seasonally from a frequency analysis of change between RCM control and scenario results (Andréasson et al. 2004) and applied to observed daily mean temperatures. This takes into consideration the fact that RCM-generated changes in temperature in the scenarios differ for high and low temperatures, and for Northern Europe in particular are stronger for low temperatures.

For precipitation, monthly-derived change factors were summarized for the two subareas and applied to each daily observation within these areas. As the same factors were used for all years and for all precipitation events, this method does not alter the number of rainy days from observations. Relative change in evapotranspiration was transferred to the hydrological model such that changes calculated by the HBV Model matched the percent change from the respective RCM (see Andréasson et al. 2004). The observational database used for the delta approach covered the period 1982–1998. This is the same period to which the HBV Model was calibrated.

2.3.2 Scaling approach

Using the delta approach does not typically include changes in variability between RCM control and scenario simulations. One way to make more use of information from climate models while producing reasonable hydrological simulations for the present climate is to use a scaling approach. Scaling implies an adjustment of specific variables to reduce systematic biases. The *scaling factors* derived for the control simulation of a particular climate model are applied to adjust scenario simulations from the same RCM. With the aim of altering RCM results as little as possible, only simple techniques for scaling precipitation and temperature were tested here. An example using more complex techniques is reported by Lenderink et al. (2007).

Precipitation and temperature series were constructed for each subbasin of the Lule River using simple area weighting from a combination of the climate model grids and the subbasin polygons. Mean annual RCM precipitation and temperature were scaled to mean annual observations with constant scaling factors. Precipitation observations in this case have been corrected for gauge undercatch and cover the entire period of 1961–1990 (Johansson 2000). Monthly scaling factors to match monthly means were also tested.

2.4 Assessing effects on hydropower

About half of the electricity produced in Sweden comes from hydropower; of this some 20% is produced from the Lule River Basin in 15 hydropower stations. To determine how projected climate change could affect this production, a simple method to calculate *hydropower potential* from a correlation of annual hydropower production to total annual river flow was used. Although there is some interannual storage in the reservoirs, mean annual river flow is strongly tied to the annual water volume available for hydropower. As documented by Carlsson et al. (2001), a linear regression to data for the period 1982–1997 achieved an R^2 fit of 0.7. It is important to point out that this method only provides estimates of "potential." Generation and timing of hydropower is based on numerous complex parameters and a complete study of future hydropower requires much more detail, not the least of which would be scenarios of how the future regional power mix for Northern Europe will develop.

3 Results

3.1 Ensemble of delta approach simulations

Results from the RCM ensemble of delta approach hydrological simulations for the total Lule River are shown in Figs. 2 and 3. Figure 2 presents both the climate model meteorological changes interpreted with the delta approach and the resulting impacts on river discharge.

Although all of the models exhibit similar seasonal dynamics for 2 m temperature, they differ from each other some 1–2°C throughout the year (Fig. 2a). Most of the simulations correspond to an annual increase of 4–5°C. The HadAM3H-A2 driving GCM exhibits the warmest trend for summer and autumn temperatures, but does not stand out during the rest of the year. The largest change in temperature for all model simulations occurs in the winter months. Although this change occurs at mean temperatures well below zero, one should keep in mind that these are average values in both time and space over the entire basin and do not exclude the occurrence of increased snowmelt for different parts of the basin during some years. All simulations project an increase of precipitation throughout the year for the Lule River Basin (Fig. 2b). The largest increases are during autumn and winter for most of the simulations. The largest differences in the climate models also occur during winter. The range between models during summer months is low.

River discharge results from all of the delta simulations are shown together in Fig. 2c. The remaining plots in Fig. 2 show river discharge results according to similar driving conditions and model resolutions. Maximum, mean and minimum annual river discharge resulting from each of the climate models is shown in Fig. 3.

All of the simulations show a similar tendency of reduced peak flows occurring about one month earlier than the present climate. Both autumn and winter flows are considerably higher than the present climate. The range of impacts attributed to A2 scenario simulations show a larger deviation from the present climate than those attributed to B2, which agrees with the less severe climate change from B2. Although they still occur earlier, the peak B2 flows are much closer to present day peaks. The effect of using different GCMs to drive the RCMs indicates generally higher river flow year round for the ECHAM4/OPYC3 boundary conditions versus HadAM3H boundary conditions. Regarding resolution at 25 km, although one of the simulations indicates somewhat higher peak flows from both the ensemble collection of RCMs and its own 50 km simulation, the benefits of using finer resolution simulations with the delta approach are inconclusive (Fig. 2f).

3.2 Scaling approach simulations

Three climate model pairs of control and A2 scenario simulations were chosen for use in tests of the scaling approach. These were from the global climate model HadAM3H and two RCM simulations, RCAO and RCAO25, driven by the same model. This also provided a consistent chain of results to assess the value of increased climate model resolution.

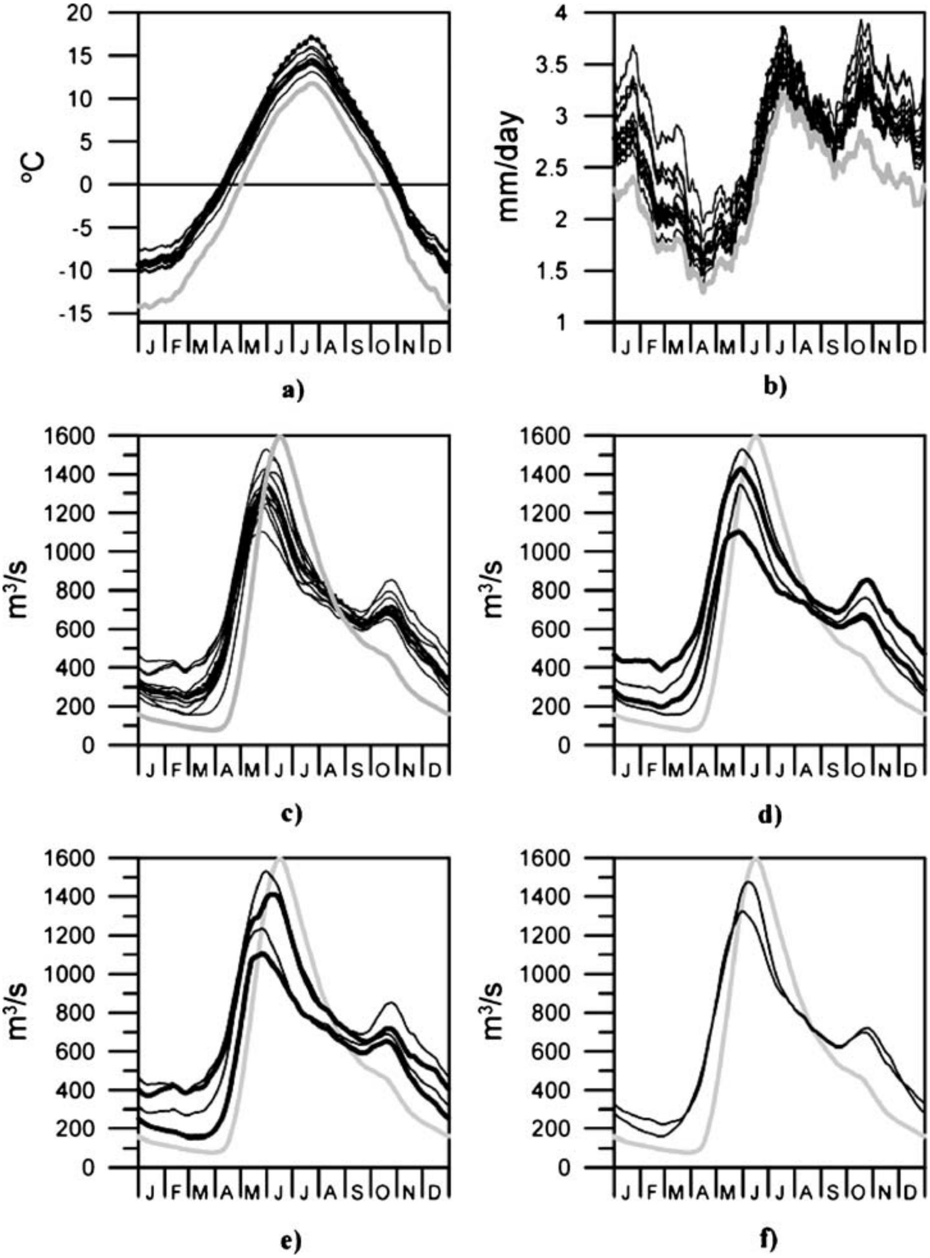


Fig. 2 Basinwide **a** 2 m temperature, **b** precipitation, and **c–f** river discharge for HBV hydrological simulations using the delta approach with an ensemble of 15 climate model simulations for the Lule River Basin; specific RCMs are not identified. Meteorological inputs **a** and **b** represent future conditions and are observations from 1982–1998 plus climate scenario changes. The *grey lines* are the actual observations used for the reference simulation; the *dotted line* in **a** shows GCM results from HadAM3H. Mean river discharge for all simulations is shown in **c**. The remaining plots show the ensemble range for, **d** all A2 (*thick lines*) and all B2 (*thin lines*) simulations, **e** all HadAM3H (*thick lines*) and all ECHAM4/OPYC3 (*thin lines*) simulations, and **f** the two 25 km simulations

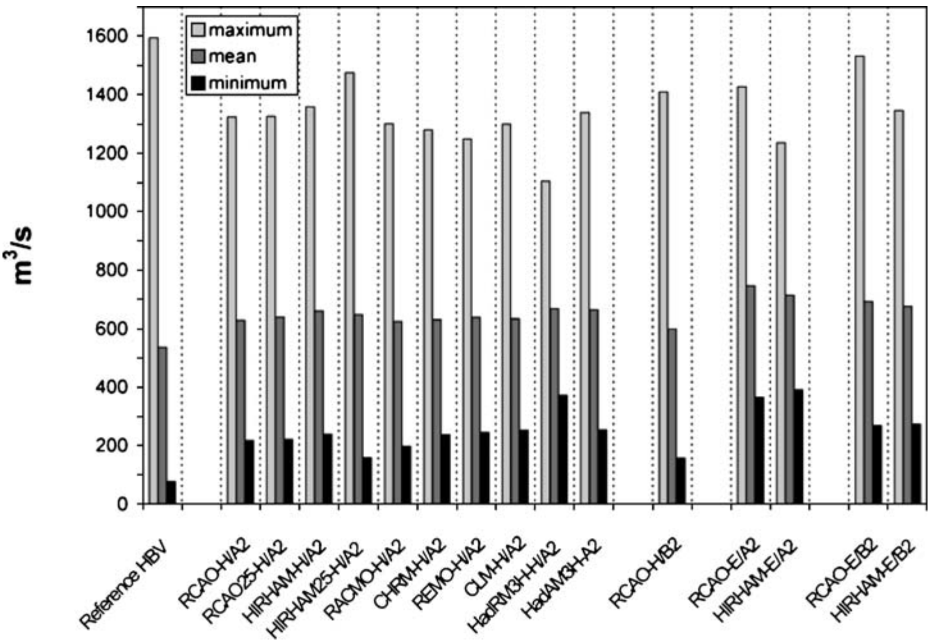
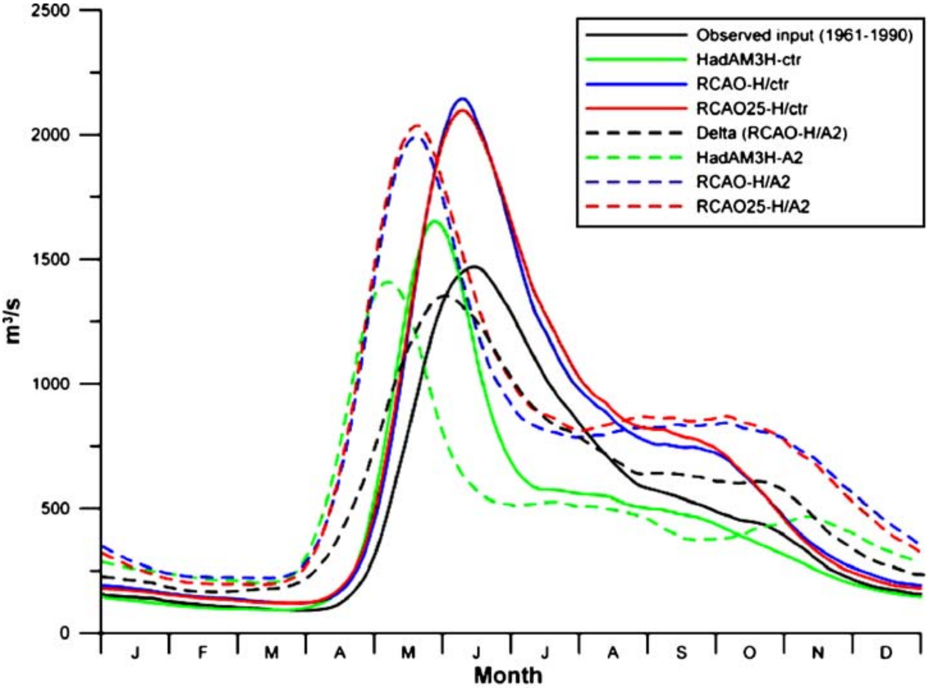


Fig. 3 Mean maximum, mean annual and mean minimum river discharge for Lule River from HBV hydrological simulations using the delta approach. The simulations are grouped according to boundary GCM and scenario. For comparison, the HBV reference simulation for 1982–1998 is shown

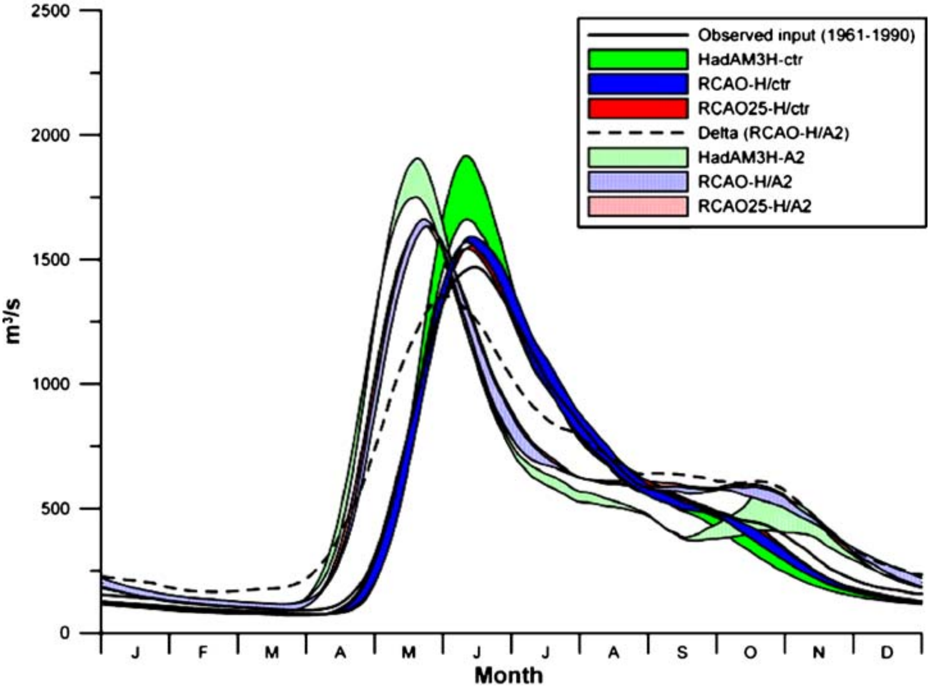
As shown in Fig. 4a, none of these climate models, regardless of resolution, were able to produce hydrological model simulations that were comparable to using observed climate as input. The direct input simulation from the GCM gave a volume error of −9% as compared to the reference simulation. Winter river discharge was well simulated while both summer and autumn discharges were underestimated. The spring peak flow was on average about 13% too large, and some 2–3 weeks too early. RCAO resulted in a volume error of about +34%. This error was rather evenly distributed throughout the year providing a relatively good simulation of seasonal dynamics. The timing of the spring peak flow was on average within less than a week off from the reference simulation. Results from the RCAO25 simulation were similar.

With scaling applied on an annual basis, the volume error for the GCM control simulations was reduced to less than 3% (Fig. 4b), but the spring peak flow was overestimated by as much as 30%, on average; winter and autumn river discharge was underestimated. Scaling on a monthly basis considerably improved the results, but the spring peak flow was still overestimated by 13%, on average. The timing of the spring peak was close to the reference simulation for both annual and monthly scaling. The scaling simulations using RCAO and RCAO25 gave nearly identical results for both annual and monthly scaling. The spring peak flow was near to exact in its timing compared to the reference simulation, but it was overestimated by 8 and 7% for the RCAO simulations and 6 and 5% for the RCAO25 simulations for annual and monthly scaling, respectively. This volume error was compensated for by a slight underestimation during the rest of the year.

The magnitudes of the scaling factors for the three simulations are given in Table 1. Figure 5 shows how annual corrections for precipitation and temperature vary spatially within the basin. Regarding precipitation, although the GCM showed a good match


2500
2000
1500
1000
500
0
m³/s
Observed input (1961-1990)
HadAM3H-ctr
RCAO-H/ctr
RCAO25-H/ctr
Delta (RCAO-H/A2)
HadAM3H-A2
RCAO-H/A2
RCAO25-H/A2
J F M A M J J A S O N D
Month

a)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Observed input (1961-1990)
HadAM3H-ctr
RCAO-H/ctr
RCAO25-H/ctr
Delta (RCAO-H/A2)
HadAM3H-A2
RCAO-H/A2
RCAO25-H/A2
J F M A M J J A S O N D
Month

b)

Table 1 Area mean precipitation and temperature scaling factors needed to achieve the same mean as for observations

Model	Scaling factors for Precipitation (P, ratio) and Temperature (T, °C)													
	Spring		Summer		Autumn		Winter		Annual		Sd temporal		Sd spatial	
	P	T	P	T	P	T	P	T	P	T	P	T	P	T
HadAM3H	0.80	1.7	0.98	1.5	1.13	2.0	1.08	4.5	1.00	2.2	0.14	1.40	0.28	1.36
RCAO	0.71	0.9	0.84	−0.2	0.78	0.6	0.73	3.9	0.78	1.2	0.06	1.80	0.09	0.68
RCAO25	0.68	0.9	0.79	0.1	0.77	0.4	0.73	3.6	0.75	1.1	0.05	1.58	0.07	0.49

Sd temporal is the standard deviation of the seasonal scaling factors and Sd spatial is the standard deviation of the annual scaling factors for all subbasins

compared to observations on an annual basis, spring precipitation was too high while autumn and winter were too low. The precipitation scaling factors for RCAO and RCAO25 were similar to each other; both simulations consistently overestimated precipitation. Regarding overall temporal and spatial variation of the precipitation scaling factors—judged by standard deviations for the seasonal and annual values, respectively—both decreased with increased resolution. For RCAO and RCAO25, the temporal and spatial standard deviations were similar. The GCM standard deviation for spatial corrections was twice as high as temporal corrections and both were considerably higher than those for either the RCAO or RCAO25. This is also apparent in the distribution of the spatial corrections shown, where high corrections are needed for the GCM in the northwestern part of the basin and lower corrections are needed to the southeast.

For temperature, all three model cases show a warm deviation from the observed temperature. The highest correction factors were needed for the GCM simulation. The lowest correction factors were needed for RCAO25, although the difference compared to RCAO was small. Even though the GCM had the largest deviation in all seasons, the overall temporal pattern judged by the standard deviation for the seasonal correction factors was best among the three. Regarding the spatial pattern of the scaling—judged by the standard deviation of the annual factors—it improved with resolution.

Table 2 shows results in terms of 20-year flood flows and also provides an indication of how seasonal dynamics are represented by the scaled simulations at different resolution. The spring flood is most pronounced in the present climate and also dominates as the annual flood. The high deviation for the spring flood shown for the simulation scaled from the GCM indicates that it does a poor job representing these peaks. With low values of deviation, both of the scaled RCAO simulations achieve good representation of the spring flood. However, they do not do as good a job representing the lower magnitude autumn floods.

◀ **Fig. 4** **a** Mean river discharge from HBV hydrological simulations using observed input (*black solid*) and the delta change approach (*black dotted*) compared with direct use of climate model input from HadAM3H (*green solid*), RCAO (*blue solid*) and RCAO25 (*red solid*). The corresponding scenario simulations are *dashed lines*. **b** Mean river discharge from HBV hydrological simulations using observed input (*black solid*) and the delta change approach (*black dotted*) compared with simulations using scaled climate model output. The *filled intervals between lines* show differences resulting from scaling on annual and monthly basis

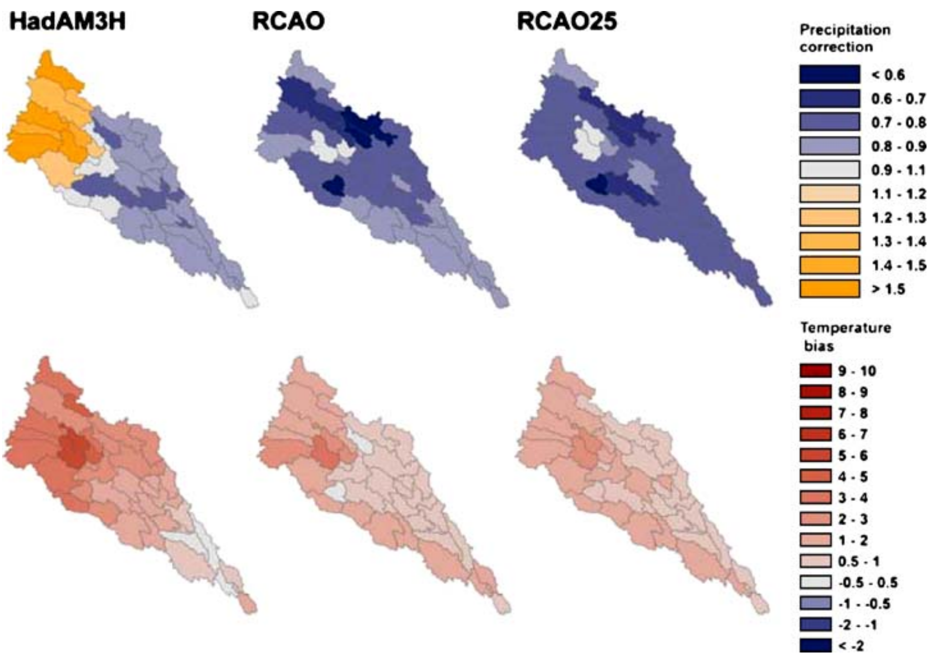


Fig. 5 Deviation from observed precipitation (corrected for gauge undercatch) and temperature for HadAM3H, RCAO and RCAO25 in the Lule River Basin

3.3 Delta simulations versus scaling simulations

Some comparison of results between the delta approach and the scaling approach follows here, based on the series of RCAO-H simulations. This comparison gives an indication how such scaling of the other RCM simulations would differ from their respective delta

Table 2 Deviation and change in the 20-year flood calculated seasonally and annually from frequency analyses using the Gumbel distribution

	Percent deviation–Present			Percent change–Future						
	Scaled HadAM3H ctr	*scaled* RCAO ctr	*Scaled* RCAO25 ctr	Delta RCAO H/A2	*Scaled* HadAM3H A2		*Scaled* RCAO H/A2		*scaled* RCAO25 H/A2	
Relative to	Ref	ref	ref	ref	Ref	ctr	ref	ctr	ref	Ctr
Spring (%)	42	3	0	−10	40	−1	17	14	12	12
Autumn (%)	5	−10	−12	19	26	20	−19	−10	−9	4
Annual (%)	42	3	0	−12	39	−2	17	14	12	12

This is expressed in percent relative to either the reference simulation (ref) or to the respective scaled control simulation (ctr). The columns on the left show percent deviation for the present climate control simulations; the columns on the right show the percent change for the future climate simulations. All scaling was performed on an annual basis. Spring is defined as January–July and autumn as August–December approach simulations. Concerning seasonal dynamics, both methods agreed on an earlier spring flood and higher winter and autumn runoff (Fig. 4b). Use of the delta approach, however, resulted in lower spring peak flows, whereas the scaling approach shows some increase. For summer flows, the scaling approach shows more decrease than the delta approach. Regarding mean annual runoff volumes, the two methods gave comparable results with increased volumes (Fig. 6a).

The largest difference between the methods was found for extreme runoff, as shown in Table 2 and Fig. 6b. The delta approach resulted in a decrease of the 20-year flood of about 10%, both on an annual basis and for spring. The autumn flood increased by almost 20%. For the scaling approach based on the same RCM resolution (RCAO-H/A2), the result was almost the opposite. Both the annual and spring 20-year floods increased by some 14–17%, while the autumn flood decreased by 19% compared to the reference simulation and 10% compared to its own control simulation.

Differences in extremes are also apparent (Fig. 6b). For the mean of the maximums for the future, the scaled RCAO-A2 shows values some 20% higher than those achieved with the delta approach. By examining the spread of the individual years, one can also see that the interannual variability of the delta results is lower than for both the scaled and reference simulation results. It is also apparent that direct use of GCM results, even with scaling, provides a poor representation of extremes.

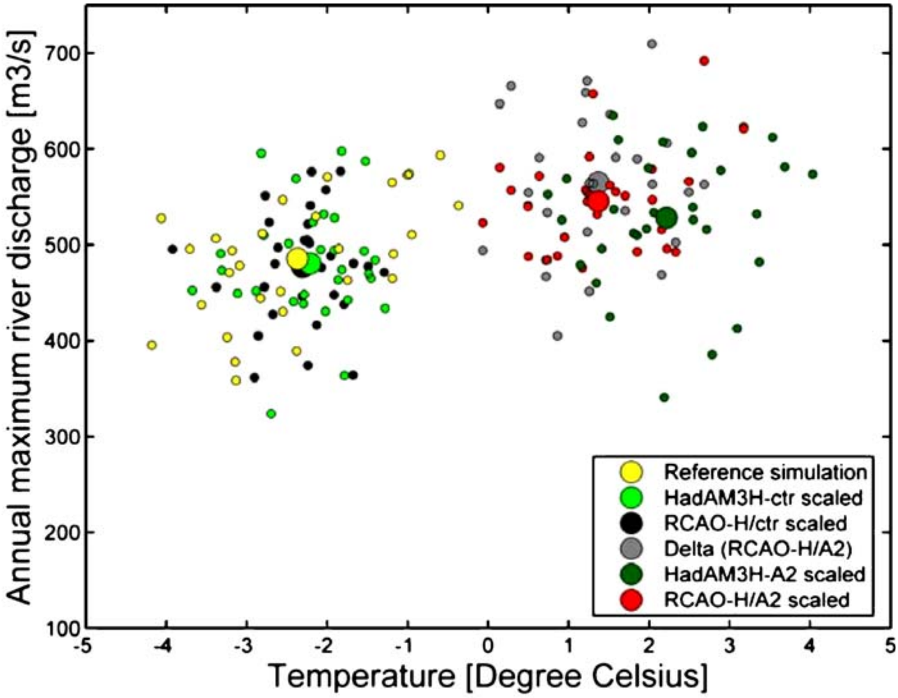
3.4 Effects on hydropower

Given the fact that all simulations showed some increase in annual river discharge, it is not surprising that all simulations also show an increase in hydropower potential using the simple linear regression approach. The range (including A2 and B2) is from +18% to +59% and the ensemble mean of all delta approach RCM simulations is +34%. Results from simulations using the scaling approach are close to those given from the corresponding delta approach simulations, about +26%.

Potential effects on interannual variability and extremes of river discharge were examined for the scaled simulations. They showed that annual means, maximums and minimums all tended to increase. The interannual fluctuation around the long-term mean was some ±20% for mean annual flow, which is similar to what observations from the present climate show. These results indicate that an increase in the frequency of shortages in river flow would not be expected. On the contrary, according to these simulations, the reservoir system along the river would likely be required to spill more water than it presently does. This indicates that downstream communities would have to adapt to more frequent periods of spill (high water in the river) under the projected future.

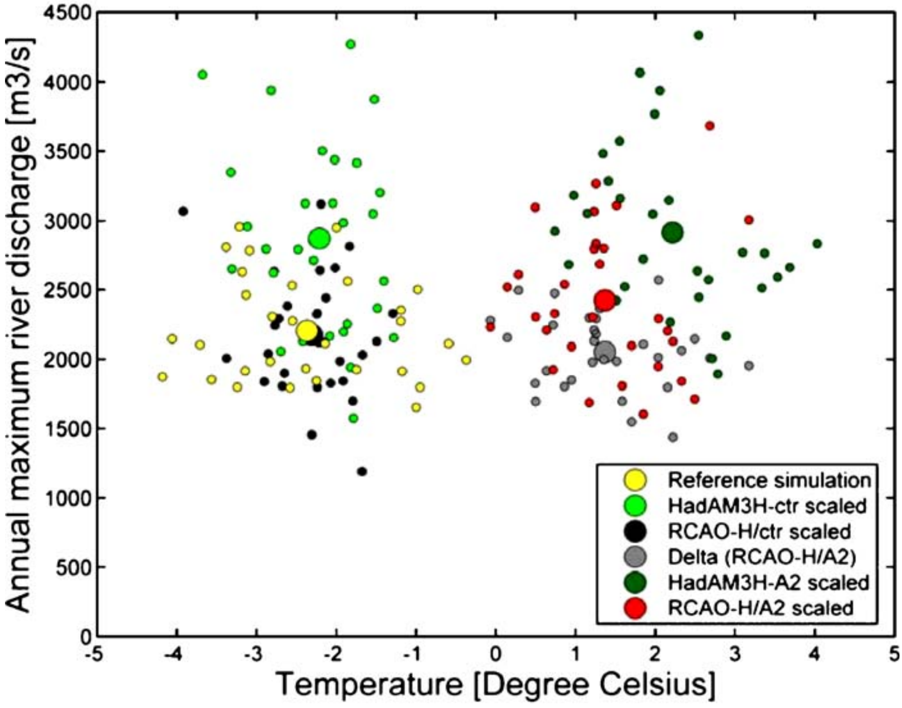
4 Discussion

Results from the delta approach provide an overall comparison of how the assessment of hydrological change is affected by RCM configurations and scenarios. It is a robust method making it possible to use output from climate models even if they do not produce a present climate with similar statistics to observations. The scaling approach provides results on extremes that are more consistent with the RCMs, however it is best used with models that provide good representation of regional seasonality. Both of these methods make considerable modification to climate model results and implicitly assume that the



Annual maximum river discharge [m3/s]
Temperature [Degree Celsius]
Reference simulation
HadAM3H-ctr scaled
RCAO-H/ctr scaled
Delta (RCAO-H/A2)
HadAM3H-A2 scaled
RCAO-H/A2 scaled

a)



Annual maximum river discharge [m3/s]
Temperature [Degree Celsius]
Reference simulation
HadAM3H-ctr scaled
RCAO-H/ctr scaled
Delta (RCAO-H/A2)
HadAM3H-A2 scaled
RCAO-H/A2 scaled

b)

systematic biases for the present climate will be the same for the future climate. Advantages and shortcomings of the two approaches are detailed below.

Advantages of the delta approach As it uses observed climate as a baseline, the capability of the RCM to produce simulations that are comparable to observed climate is less crucial. It is stable and always gives results that can be related to present conditions.

Shortcomings of the delta approach The use of observed climate as a baseline implies that the number of rainy days does not change for a future climate. Extreme precipitation is modified by the same factor as all other precipitation events. Summarizing RCM output for large regions (as done in this study) limits the use of improved detail in RCM simulations, e.g., increased resolution.

Advantages of the scaling approach It provides a more direct representation of RCM results and thus climate variability more consistent with the RCM simulations. It has potential to develop together with the RCMs, such that eventually little or no scaling may be necessary. It can make use of increased detail in the RCM simulations, e.g., increased resolution.

Shortcomings of the scaling approach It is quite sensitive to the quality of the RCM used as input. It assumes a static bias correction that may not adequately represent future climate changes, such as changes in circulation.

One of the important factors that improves with increased resolution of the climate models is elevation. The elevations used in the GCM deviate greatly from the elevations used in the respective subbasins of the HBV model. As resolution becomes finer, deviations in elevation diminish. At 25 km resolution, the RCM uses elevations that are considerably better matched to the hydrological model on a subbasin scale. This has implications for representation of both temperature and precipitation, which is apparent in the scaling factors. The finer the climate model resolution, the more systematic and less spatially variable the scaling factors become. Better scaling is achieved when the spatial variability of biases is low.

It is also important to evaluate what is used as an observational baseline. A positive bias in temperature was especially large during winter for the models tested with the scaling approach (Table 1). This can in part be explained by orographical differences between the climate models and the hydrological model, as biases were larger the coarser the model resolution. The larger bias in wintertime could also be related to observational biases. Most of the observation stations used are situated in valleys, which in winter are typically colder than higher elevations for this area (Johansson 2002). Deviation in temperature from the observations was indeed greatest for high elevation.

Evapotranspiration plays an important role in the hydrological cycle and there is often disagreement between models regarding this variable (Graham et al. 2007). The delta approach, as applied here, used the change in evapotranspiration from the RCMs to govern the future climate evapotranspiration. The scaling approach relied on a temperature index method for simulating future evapotranspiration. This type of calculation generally works

◀ **Fig. 6** **a** Mean annual river discharge and **b** maximum annual river discharge plotted against mean annual temperature for the HBV reference simulation (1961–1990), annually scaled RCAO-H/ctr, HadAM3H-ctr, corresponding scaled A2 scenarios, and the corresponding A2 delta scenario. *Small dots* show individual years and *large dots* are the respective mean values for all years well for hydrological applications that can be calibrated (i.e., present climate), but is suspect to overestimation in future climates (Andréasson et al. 2004). However, such an error was assumed negligible in this case as the Lule River is situated in such a cold region that the amount of evapotranspiration for both the present climate and the projected future scenarios is small compared to precipitation. Applications of the scaling approach in warmer regions should investigate appropriate alternatives for representation of evapotranspiration in the future climate.

Regarding analysis of effects on hydropower, the approach used here is admittedly coarse. However, it does provide an indication of both the direction and range of expected change in hydropower. The analysis looked at potential hydropower, which assumes that existing hydropower generating facilities would be upgraded as needed to accommodate the changes. Additional detailed analysis of the actual power generating system and its physical constraints is needed to give more firm estimates.

5 Conclusions

An ensemble of future climate projections indicates an overall increase in runoff from the Lule River Basin, with peak spring flows occurring about one month earlier than for the present climate. This indicates an ensemble mean increase in hydropower potential of some 34% over present day conditions. The choice of GCM in providing boundary conditions for RCMs plays a larger role in assessing hydrological change than the choice of emissions scenario. Delta and scaling transfer approaches give similar results regarding changes in runoff volumes, but they differ regarding seasonal dynamics and extreme river discharge. The delta approach is limited as to how much it can take advantage of increased RCM resolution. According to the models used here, finer RCM resolution resulted in biases that were more systematic and less spatially variable, which leads to better application with the scaling approach. Results from the testing of two transfer approaches are highly relevant for other types of climate change impacts studies.

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