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The effect of downscaling techniques on assessing water resources impacts from climate change scenarios

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Abstract Assessing the impact of climate change on water resources is often based on simulations from global climate models (GCMs) that have been downscaled. Downscaling of GCMs, to improve representation over a limited region, can be done either by use of a regional climate model (RCM) or by statistical downscaling of the GCMs. Although both of these techniques are common, they are seldom compared. This paper investigates the effect of using different downscaling techniques for the assessment of climate change impacts on water resources. The results show that both dynamical and statistical downscaling are useful methods to downscale GCM output. However, when there are orographic influences that affect the local climate, such as mountains, the method of statistical downscaling should be used more carefully.

Key words climate change; downscaling techniques; HBV model; hydrological impacts; RCA model; Sweden

INTRODUCTION

The prospect of climate change is an issue of high importance regarding future water resources. About 50% of Sweden's electric power production is generated by hydropower, which raises questions about how a future climate will affect both the frequency of extreme runoff events and the seasonal river runoff. During the last decade the occurrence of floods appear to be more frequent than experienced before, which furthermore adds to the question—is this a result of climate change that we can see already today?

Global climate models (GCMs) are used as a tool to create scenarios on the kind of changes in the future climate that might be expected. However, the typical horizontal resolution of GCMs is 200–300 km, which tends to greatly smooth the geographical features of the Earth's surface. There is therefore a need for more detailed information when studying climate change effects on a regional scale, as is the case when one wants to estimate the effects on single drainage basins. Downscaling of GCMs, to improve representation over a limited region, can be done either by use of a regional climate model (RCM) or by statistical downscaling of the GCMs. Although both of these techniques are common, they are seldom compared. This paper investigates the effect of using different downscaling techniques for the assessment of climate change impacts on water resources.

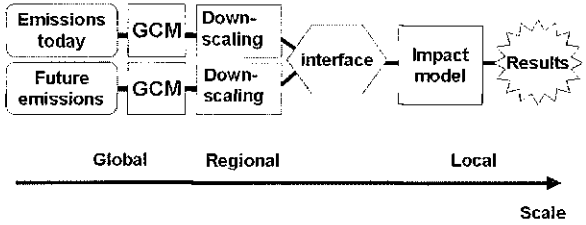

Fig. 1 The analysis chain for assessment of hydrological impacts from climate change.

DOWNSCALING METHODS

The typical steps for analysing impacts of climate change on hydrological systems are shown in Fig. 1. Uncertainties arise in every step. Downscaling from the global scale of GCMs to the local scale of hydrological models occurs prior to the transfer of the climate change signal into hydrological models. Three approaches for assessing the effects of different downscaling techniques were evaluated as follows:

(a) no downscaling (direct from GCM);
(b) dynamical downscaling;
(c) statistical downscaling.

The GCMs used were HadCM2 (Johns *et al.*, 1997) and ECHAM4 (Roeckner *et al.*, 1996). The Rossby Centre Regional Climate Model (RCA; Rummukainen *et al.*, 2001) was used for the dynamical downscaling. The statistical downscaling used long time series of sea level pressure, temperature and precipitation to establish relationships with the GCM control run (present climate). These were applied to the GCM scenario simulations to obtain a more regionally oriented future climate result (Chen *et al.*, 2001).

Both the direct GCM and statistical downscaling applications are based upon the exact same emissions scenario simulations, as described by Räisänen (2000), which corresponds to an annual global warming of 1.7°C for HadCM2 and 1.4°C for ECHAM4. The dynamical downscaling simulations used scenarios with a higher emissions rate, which corresponds to an annual global warming of 2.6°C. Although it is recognized that these are not exactly comparable, qualitative comparisons can be made until more consistent results are available.

HYDROLOGICAL IMPACTS MODEL

The HBV hydrological model (Bergström, 1995; Lindström *et al.*, 1997) was used for the hydrological impacts analyses. The model is a conceptual semi-distributed runoff model originally developed at the SMHI for operational runoff forecasting. It has previously been used in climate change studies in the Nordic countries (Bersgström *et al.*, 2001; Gardelin *et al.*, 2002; Vehviläinen & Huttunen, 1997; Saelthun *et al.*, 1999), as well as in other countries (Booij, 2002; Butina & Balint, 1997; Menzel & Bürger, 2002; Menzel *et al.*, 2002; Yu *et al.*, 2002). The model is run on a daily time step and includes routines for snow accumulation and melt, soil moisture accounting, groundwater response, and river routing. Climate input data to the model are precipitation and temperature. Evapotranspiration for these simulations was calculated using a simple temperature-index method. Specific considerations for lake evaporation are included.

For the hydrological impacts simulations, changes in precipitation and temperature from the respective climate model scenarios were transferred to off-line simulations with the HBV model. Monthly average values of change for both precipitation and temperature were processed in a model interface and added to an observed database before use in the HBV model. The same relative changes were thus used for all years of the impacts simulations, summarizing both extreme and average conditions.

Simulations were carried out for three Swedish drainage basins, Suorva, Torpshammar and Torsebro, ranging in size from 3665 to 4646 km^2. There are large differences in the hydrological regimes of these basins, especially between the southernmost basin, Torsebro, and the other two basins. Sweden is an elongated country with hard winters in the north and mild winters in the south. The large spring flood resulting from the melting of the accumulated snow pack dominates the hydrographs for Suorva and Torpshammar, while Torsebro does not consistently have a snow pack that results in a dominant spring flood. Suorva reflects the most mountainous terrain of the three drainage basins.

RESULTS AND DISCUSSION

Figure 2 and Table 1 show seasonal and annual results, respectively, from the hydrological model simulations of climate change impacts from the three different downscaling applications. For the Torsebro and Torpshammar basins, the impacts from the dynamical downscaling scenarios are greater, both in runoff volume and seasonal distribution. This follows expectations as both global and regional warming from these scenarios is greater than from the direct GCM and statistical downscaling cases. The statistical downscaling scenarios show greater impact than direct use of the scenarios from GCMs for both Torpshammar and Suorva basins. For Torsebro, there is no discernible difference in the seasonal averages between direct GCM *vs* statistical downscaling, although the annual runoff volumes show a larger range of impacts from statistical downscaling.

The differences between dynamical downscaling and statistical downscaling for Suorva are opposite to those exhibited in the other two basins. That is, the seasonal distribution for the dynamical case lies much closer to present conditions than for the statistical case. This occurs even though both the global and regional warming from the dynamically downscaled scenarios is considerably larger than in the statistically downscaled and GCM direct scenarios. However, the impact on annual runoff volumes is larger. As the Suorva Basin is located in a mountainous part of Sweden, one explanation for this could be that the orographic influence of the mountains are better described in the dynamical downscaling than in either the GCMs or in the statistical downscaling of the GCMs. In regard to this, an important consideration for statistical downscaling is the fact that high mountain areas are often not adequately represented by the observations used to derive statistical relationships. Observation stations tend to be located at lower elevations nearer to valley bottoms.

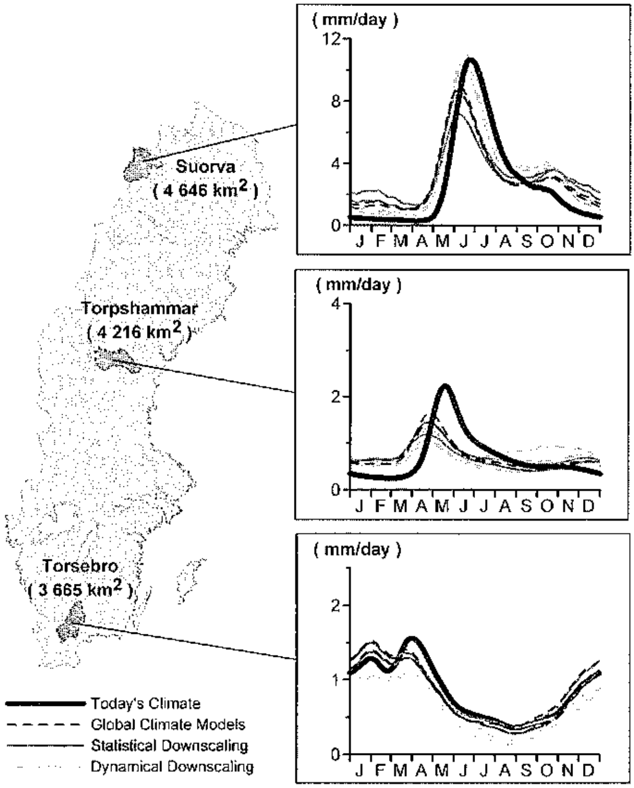

Fig. 2 Results of the assessment of hydrological impacts from climate change with no downscaling, dynamical downscaling, and statistical downscaling. The output is in daily averages over the 30-year simulation period.

Table 1 Change in annual runoff volume (%) according to different downscaling techniques.

	Suorva	Torpshammar	Torsebro
Global climate models	+4 to +7	–7 to –2	–8 to +3
Statistical downscaling	+8 to +13	–11 to +2	–9 to +2
Dynamical downscaling	+18 to +29	–19 to +10	–26 to –15

CONCLUSIONS

Preliminary results indicate that the orographic influence described in dynamical downscaling has an effect on the outcome of the water resources studies. Statistical downscaling methods are efficient and particularly useful when dynamical downscaling is not available. They also provide additional ensemble simulations that aid in the assessment of uncertainty. However, as illustrated by the above results, there is a need for more careful evaluation of when it is appropriate to use statistical downscaling. One cannot expect statistical downscaling to capture all of the orographic influences where prominent geographic features, such as mountains, affect the local climate. The small ensemble of simulations presented in this study provides a measure of the uncertainty in assessing future water resources in a changing climate. Further studies with more consistent applications of compatible emissions scenarios should be carried out.

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