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ORIGINAL PAPER

Statistical downscaling of daily precipitation over Sweden using GCM output

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Abstract A classification of Swedish weather patterns (SWP) was developed by applying a multi-objective fuzzy-rule-based classification method (MOFRBC) to large-scale-circulation predictors in the context of statistical downscaling of daily precipitation at the station level. The predictor data was mean sea level pressure (MSLP) and geopotential heights at 850 (H850) and 700 hPa (H700) from the NCEP/NCAR reanalysis and from the HadAM3 GCM. The MOFRBC was used to evaluate effects of two future climate scenarios (A2 and B2) on precipitation patterns on two regions in south-central and northern Sweden. The precipitation series were generated with a stochastic, autoregressive model conditioned on SWP. H850 was found to be the optimum predictor for SWP, and SWP could be used instead of local classifications with little information lost. The results in the climate projection indicated an increase in maximum 5-day precipitation and precipitation amount on a wet day for the scenarios A2 and B2 for the period 2070–2100 compared to 1961–1990. The relative increase was largest in the northern region and could be attributed to an increase in the specific humidity rather than to changes in the circulation patterns.

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1 Introduction

The increase of greenhouse gases in the atmosphere because of anthropogenic activities is projected to have a large impact on the global climate. A great challenge for the scientific community is to develop methods and models to evaluate the impacts of global climate change at the local scale. General circulation models (GCMs) are useful tools to describe the large-scale dynamics and they are widely used to assess climate change under the assumption of future emission scenarios. However, the models fail to correctly model important parameters for hydrological impact studies such as precipitation and soil moisture (Loaiciga et al. 1996; Wilby and Wigley 1997; Xu 1999a). The main reason for this is that many sub grid-scale processes such as cloud formation, convective rainfall, infiltration, evaporation, and runoff are parameterised because of computational limitations and the coarse resolution in GCMs (Zorita and von Storch 1999).

GCMs usually model the seasonal variations of precipitation reasonably well (Johns et al. 2003), but they often do not capture properties that are important for impact studies such as extreme events (Xu 1999b). In the last 10 years, hydrologic schemes in GCMs have been developed with the aim of higher complexity and integration. Even so, it is still difficult to directly use deterministic estimation of precipitation from GCMs for hydrological-modelling purposes (Bárdossy et al. 2001; Fowler et al. 2007). Therefore, methods are needed to downscale output from GCMs to local climate variables. Downscaling can be *dynamical* through the use of a regional climate model with boundary conditions from a GCM (e.g. Christensen et al. 2007) or through *statistical* (empirical) methods conditioned on large-scale predictors (Wilby and Wigley 1997; Fowler et al. 2007). Many studies have compared different downscaling methods over the last decade, and the general conclusions are that the choice of method is dependent on the focus of the study, and that more research is needed on impact studies (Fowler et al. 2007).

On the regional scale, atmospheric circulation is one of the most important indicators of weather (e.g. Linderson et al. 2004). It is also well established that the circulation plays an important role in determining the surface climate (Busuioc et al. 2001; Chen 2000). Previous studies on the impact of the circulation on the Swedish regional climate have mainly focused on a monthly scale (Busuioc et al. 2001; Hellström and Chen 2003) and so far less attention has been paid to extremes. The aim of this study was to establish an objective circulation pattern classification that can be applied to any region in Sweden for precipitation-downscaling purposes. The classification was optimised to capture both the extreme events such as 5-day maximum precipitation (max5) and precipitation amount on a wet day (wetday). A case study of statistical downscaling of precipitation using output from the Hadley Centre GCM HadAM3P model over the time period 2070–2100 was carried out to test the behaviour of the model in the IPCC emission scenarios A2 and B2.

2 Study region and data

2.1 Predictands

Daily precipitation data from 40 stations covering Sweden were used as predictands for the Swedish weather pattern classification (SWP, Fig. 1). The data were provided from the Swedish Meteorological and Hydrological Institute through the Swedish Regional Climate Modelling Programme (SWECLIM; Rummukainen et al. 2004). The data had no missing records for the 1961–1990 analysed time period. Two regions were selected as study areas for the local classification and subsequent downscaling of precipitation. One region, located in south-central Sweden (NOPEX) consists of seven precipitation stations, the other, located in the northernmost Sweden (Torne River) consists of eight stations (Table 1). The NOPEX region was selected since it has been the subject of earlier downscaling studies (Wetterhall et al. 2005, 2007), and the Torne River catchment has been studied within the PILPS2 project (Nijssen et al. 2003). The NOPEX and Torne River regions are located in the Swedish precipitation regions 3 and 7 respectively, as identified by Hellström and Malmgren (2004).

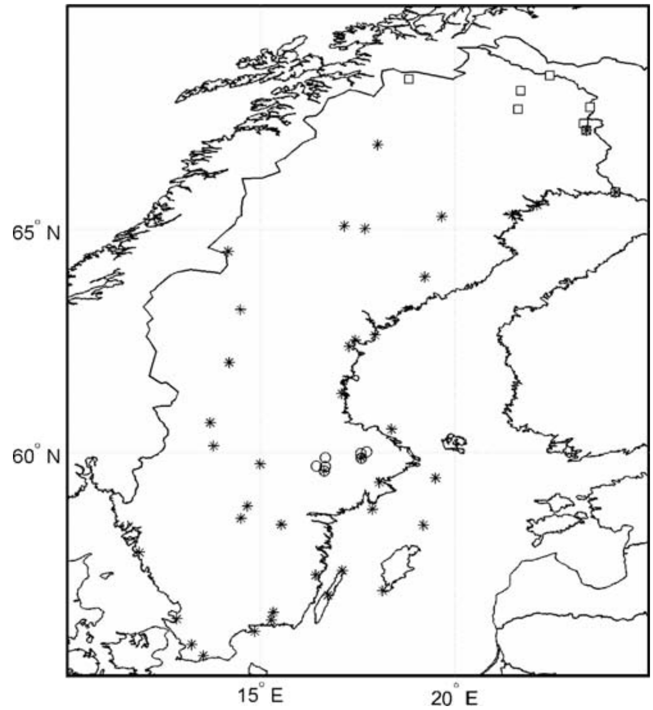

Fig. 1 Location of the precipitation stations used in the study. The *circles* denote stations in the NOPEX area, *boxes* are in the Torne River catchment and the *stars* are the stations used for classification of the Swedish circulation patterns

Table 1 The mean annual precipitation (1961–1990) and the coordinates of the precipitation stations used in the study

No.	Station	Latitude N	Longitude E	Annual precip. (mm)
NOPEX				
1	Västerås-Hässlö	59°35′	16°37′	561
2	Sundby	59°41′	16°39′	659
3	Skultuna	59°42′	16°26′	656
4	Sala	59°54′	16°39′	637
5	Uppsala airport	59°53′	17°35′	599
6	Drälinge	59°59′	17°34′	615
7	Vattholma	59°1′	17°43′	657
Torne River				
1	Karesuando	68°26′	22°27′	442
2	Övre Sopporo	68°5′	21°42′	432
3	Abisko	68°21′	18°49′	304
4	Parkajoki	67°44′	23°29′	499
5	Kaunisvaara	67°22′	23°19′	512
6	Pajala	67°13′	23°23′	520
7	Vittangi	68°41′	21°37′	456
8	Haparanda	65°50′	24°8′	558

2.2 Predictors

The first step in statistical downscaling is the selection of appropriate predictors. The main demands on large-scale variables are that they should be (1) reliably simulated by GCM, (2) readily available from archives of GCMs output, (3) strongly correlated with the surface variables of interest and (4) carry climate-change information (Wilby et al. 1999). The predictor variables for the classification in this study were large-scale grid-point data of mean-sea-level pressure (MSLP) and geopotential heights (GPHs) at 850 and 700 hPa (H850, H700). Meridional and zonal winds at 850, 700 and 500 hPa (U/V850, U/V700, U/V500) and specific humidity (S850, S700, S500) at the same levels were used to describe moisture flux for the precipitation model. All data has the resolution of 2.5°×2.5° lat-long. Data from the NCEP/NCAR reanalysis project were used for the optimisation of the classification patterns (CP) and calibration of the precipitation model over the period 1961–1990. The data were downloaded from the NCEP/NCAR reanalysis project web site (Kalnay et al. 1996; http://dss.ucar.edu/pub/reanalysis/). The predictor variables for the climate-change study were output from the Hadley Centre's HadAM3P model (Pope et al. 2000; Johns et al. 2003). The model has a horizontal resolution of 1.25°×1.875° lat-long, but the data was regridded to 2.5°×2.5° lat-long using bivariate interpolation to make it comparable to the NCEP/NCAR reanalysis data. The interpolation was done within the STARDEX project (STARDEX 2005). Emission scenario A2 predicts a doubled atmospheric CO_2-concentration at the end of this century compared with today, whereas the B2 scenario predicts a more moderate increase. The time period evaluated for the A2 and B2 emission scenarios was 2071–2100. The geographical extent (45–80°N, 30°W–40°E) was chosen to include all areas with noticeable influence on the circulation patterns that govern weather in Scandinavia (Hanssen-Bauer and Førland 2000). The areal extent was also earlier evaluated by Wetterhall et al. (2007).

3 Methodology

3.1 MOFRBC

The precipitation model used in this study is an automated multi-objective fuzzy-rule based classification (MOFRBC) method conditioning a stochastic precipitation model. The method is described briefly below. For a full description, see Bárdossy and Plate (1992), Bárdossy et al. (2002), Stehlik and Bárdossy (2002) and Yang (2008). The method has been applied to a number of areas in Europe, i.e. Germany (Bárdossy et al. 2001), Sweden (Wetterhall et al. 2007) and mainland Europe (Stehlik and Bárdossy 2002). It has also been proven useful in Chinese catchments, where it was run with no a priori classification (Wetterhall et al. 2006). The method has two steps. Firstly, large-scale circulation features from gridded predictor data are classified to a series of circulation patterns (CPs). The CPs are optimised using stochastic simulated annealing to maximise an objective function calculated from modelled and observed precipitation. The aim of the optimisation is to derive weather patterns that are well correlated with local precipitation patterns. Secondly, precipitation probability of occurrence as well as amount is modelled conditionally on the CPs. The model takes into account spatial correlations between stations as well as autocorrelation within each series. The most recent development is the inclusion of atmospheric moisture flux to improve the precipitation model (Yang 2008). MOFRBC was chosen as downscaling technique in this study since it has proven well in earlier studies (Wetterhall et al. 2006, 2007). It captures the spatial correlation between stations and with the inclusion of moisture flux it can differentiate between wet and dry years. The model also successfully models sequences of wet and dry spells as well as the number of rain events.

3.2 Calibration and evaluation of classifications

The optimum weather patterns were derived through a sensitivity analysis in which settings of the large-scale predictor, predictand and pattern features were allowed to vary systematically. The predictor set was varied in terms of large-scale parameters (MSLP, GPH) and the number of grid points used. The predictand was varied by using normalised, ranked precipitation (NRP) alongside the original precipitation series. NRP dampens the variability in the predictand, thereby forcing MOFRBC to derive CPs that can capture even small perturbations in precipitation patterns. The settings for the CPs were varied by using (1) patterns described by the European Grosswetterlagen (GWL; Baur et al. 1944) or (2) no a priori information on weather patterns as starting classification. Also, the number of patterns was varied between 8 and 12.

Classification patterns were first optimised using all of the stations in the study (Fig. 1) to derive a Swedish classification of weather patterns (SWP). SWP was then used as a starting point to create local CPs for the two regions NOPEX and Torne. Finally, SWP was evaluated for each study region in comparison with locally derived classifications CPs. The CPs were optimised and evaluated according to the ability of the classification to separate dry and wet weather patterns, focusing on precipitation occurrence (I_1), and precipitation amount (I_2)

$$I_1 = \frac{1}{T}\sum_{t=1}^{T}\left(p(\mathrm{CP}(t)) - \overline{p}\right)^2 \tag{1}$$

$$I_2 = \frac{1}{T}\sum_{t=1}^{T}\left|\ln\left(\frac{z(\mathrm{CP}(t))}{\bar{z}}\right)\right| \quad (2)$$

where T is the number of classified days, $p(\mathrm{CP}(t))$ is the probability of precipitation on day t with classification CP, $\overline{p}$ is the probability of precipitation for all days, $z(\mathrm{CP}(t))$ is the mean precipitation amount on day t with classification CP and $\bar{z}$ is the mean precipitation. High values of I_1 and I_2 denote a good classification in terms of patterns that can differentiate between wet and dry conditions. The physical realism of the classification was visually analysed by plotting composite maps of the anomalies for each classification along with frequency of the patterns and a wetness index (WI).

$$WI(i) = \frac{\frac{1}{P}\sum_{t=1}^{T}p(t_i)}{\sum\frac{t_i}{T}} - 1 \quad (3)$$

where p is the total amount of precipitation on day t classified in pattern i, P is total amount of precipitation for all the T classified days. In order to achieve negative values for dry patterns, 1 was subtracted from the primary term. Days that were not classified in any of the 12 patterns were allocated to a residual group (UC).

A contingency table (CT) was made for each pair of classifications in order to investigate independency between classifications (Stehlik and Bárdossy 2003). The conditional independence was tested with the Pearson χ^2 -test

$$\chi^2 = \sum_{i=1}^{r}\sum_{j=1}^{s}\frac{\left(n_{ij}-e_{ij}\right)^2}{e_{ij}} = \sum_{i=1}^{r}\sum_{j=1}^{s}\frac{\left(n_{ij}-\frac{n_{i\cdot}n_{\cdot j}}{n}\right)^2}{\frac{n_{i\cdot}n_{\cdot j}}{n}} \quad (4)$$

where r is the number of rows, and s the number of columns in the CT, n_{ij} is the number of observed cases in cell ij in the i^{th} row and j^{th} column, e_{ij} is the expected cases in cell ij, n_j is the number of cases in row i, $n_{i\cdot}$ is the number of cases in column j and n is the number of classified days. The hypothesis "H_0: the classifications are conditionally independent" is rejected on the selected significance level α if χ^2 is greater than the tabulated χ^2-distribution with $(i-1)(j-1)$ degrees of freedom. The alternative hypothesis H_1 is that the classifications are dependent, and the strength of the dependency between each pair of CPs can be expressed with the contingency coefficient C_{cont} and the Cramer coefficient V (Bonham-Carter 1994)

$$C_{\mathrm{cont}} = \sqrt{\frac{\chi^2}{\chi^2+n}} \quad (5)$$

$$V = \sqrt{\frac{\chi^2}{n(n-1)}} \quad (6)$$

If the coefficients are close to 0 there is no dependency, whereas a value close to 1 indicates a strong dependency. The reason for using C_{cont} and V in this study was to assure that the SWP had a strong relationship with the optimum classification for each region. Although the starting point for the local classifications was the SWP, the optimisation procedure created patterns that differed very much from the original classification. All classifications were calibrated and evaluated using the same time period 1961–1990. This was regarded acceptable since SWP was optimised on 40 stations and then evaluated on a small sub-sample of these stations.

3.3 Climate-scenario evaluation

Evaluation of the precipitation downscaling was focused on extreme events rather than monthly or annual amounts. The FP5 research programme STARDEX (2001) project recognised the need and difficulty to capture extreme events in climate impact studies and proposed the use of key indices of statistical properties of precipitation. The same approach has been followed by recent European (Moberg et al. 2006) and Swedish (Achberger and Chen 2006) projects. Accordingly, this study used precipitation amount on a wet day (wetday) maximum 5-day precipitation (max5) and maximum length of dry spell (maxdry) as evaluation criteria. The modelled precipitation series from scenario runs A2 and B2 over the period 2071–2100 were evaluated relative to the modelled precipitation from the control run 1961–1990. The precipitation modelled with MOFRBC will be referred to as M_x where the suffix denotes the predictor data (Table 2). MH_x will refer to M_x with moisture flux. For the HadAM3P precipitation output GCM_x will be used with the simulated scenario suffixed.

4 Results and discussion

4.1 Optimum classification for Sweden

The classifications identified H850 as the optimal predictor for the SWP (Fig. 2). The CPs were optimised with ranked precipitation as target predictand instead of time series of precipitation. The CPs with GWL as starting point were

Table 2 Abbreviations used for the modelled precipitation

Abbreviation	Predictor data
M_{NCAR}/MH_{NCAR}	NCEP/NCAR reanalysis data 1961–1990
M_{CTL}/MH_{CTL}	HADAM3P control run 1961–1990
M_{A2}/MH_{A2}	HADAM3P scenario A2 2071–2100
M_{B2}/MH_{B2}	HADAM3P scenario B2 2071–2100

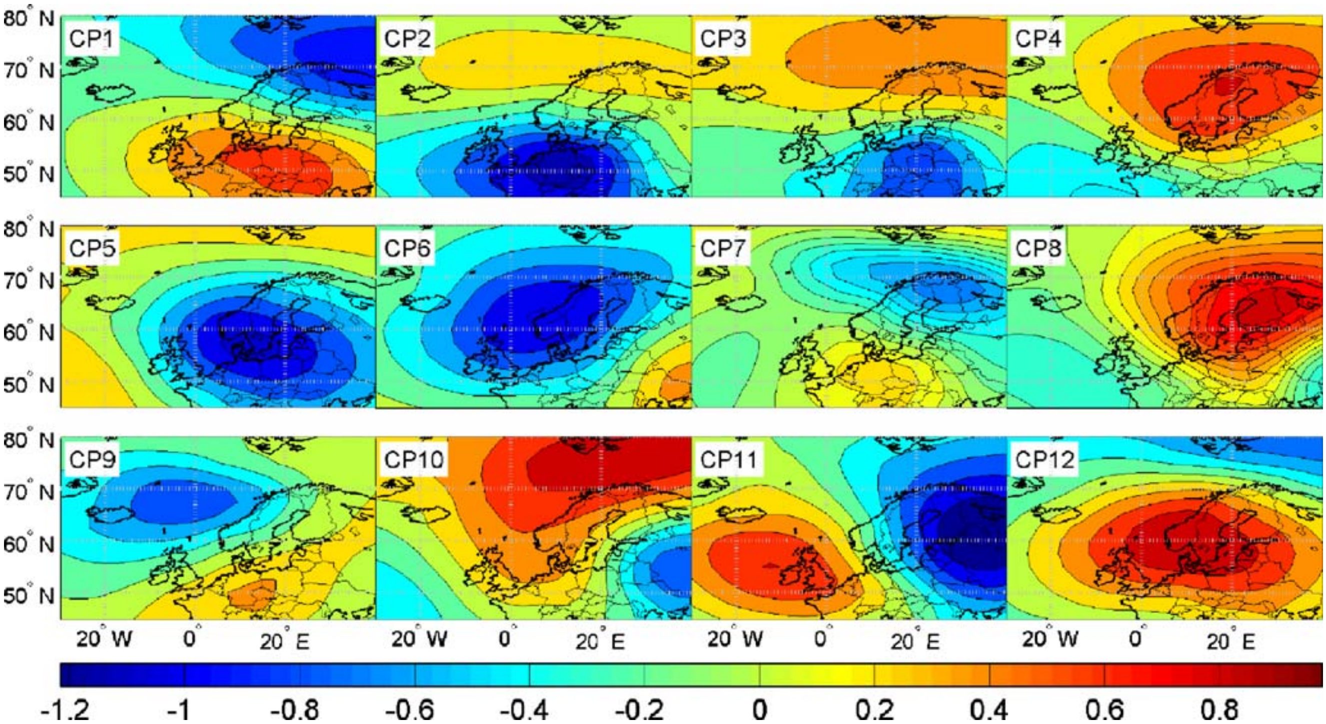

Fig. 2 Mean normalised H850 anomalies (hPa) with the SWP classification for the period 1961–1990

better than those obtained with no a priori information on weather patterns. Different numbers of CPs were tested, but 12 patterns gave the best result in terms of I_1 and I_2. The frequency of the CPs varied with season, but the WI for each CP did not change significantly (Fig. 3). The sign of the WI was the same for both regions with the exception of CP1. Also CP5 differed clearly between the stations. The proportion of unclassified days for winter and autumn was high, around 15%. The Pearson χ^2-test with the hypothesis that two classifications were independent was rejected for

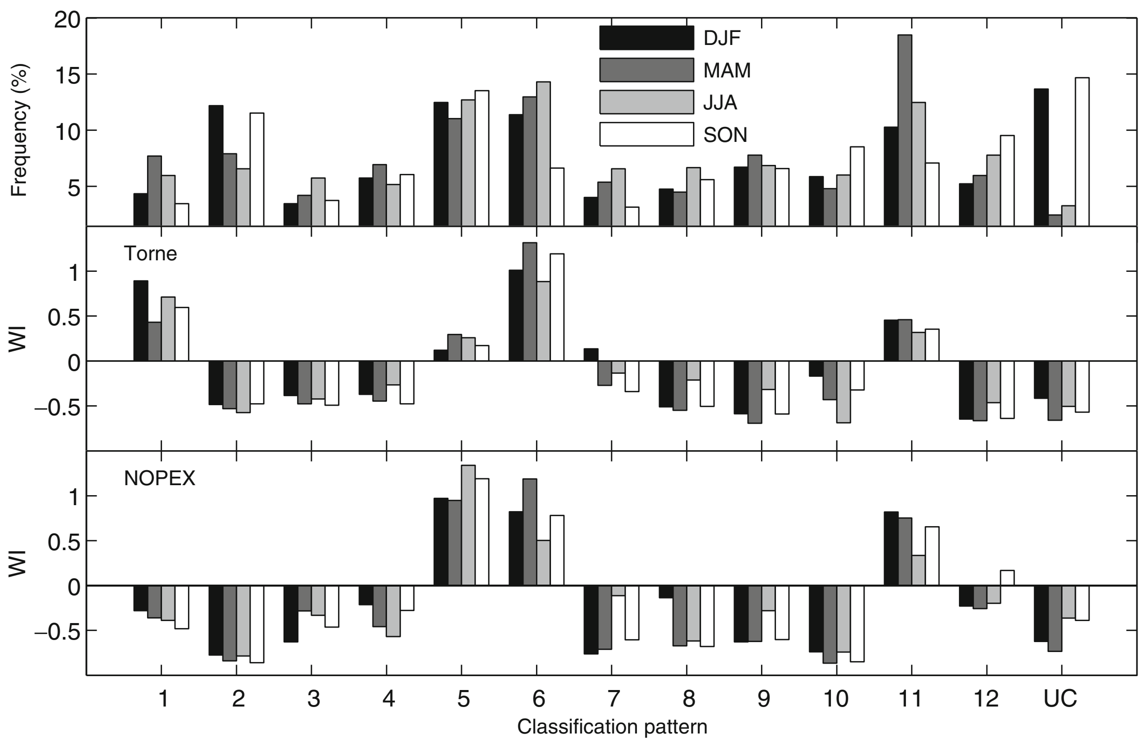

Fig. 3 Frequency and *WI* for SWP in the Torne River and NOPEX regions evaluated for different seasons

Table 3 Evaluation parameters for the Swedish classification for each region

	C_{cont}	V	I_1^{SWP}	I_2^{SWP}	I_1^{local}	I_2^{local}
Torne River						
MSLP	0.76	0.34	0.16	0.66	0.20	0.86
H850	0.75	0.33	0.16	0.66	0.18	0.78
H700	0.72	0.30	0.15	0.67	0.18	0.80
NOPEX						
MSLP	0.79	0.37	0.20	0.81	0.22	0.99
H850	0.77	0.35	0.20	0.87	0.22	0.96
H700	0.69	0.28	0.20	0.85	0.21	0.92

C_{cont} is the contingency coefficient; *V* the Cramer coefficient; I_1 and I_2 objective functions to evaluate occurrence and amount of precipitation; *SWP* the Swedish classification; *local* the best local classification

all classifications carried out in this study. The optimum predictor for the study areas NOPEX and Torne River were MSLP, and the C_{cont} and V ranked highest for the Swedish MSLP-classification (Table 3). However, I_2 was higher for H850 and H700, especially H850 for NOPEX. Notably is that the local classification outperforms SWP when applied to the catchment where it was classified, especially regarding precipitation amount. The SWP classification was thus based on H850. CP6 was a wet pattern for both stations (Figs. 2 and 3). The physical interpretation of this pattern is a cyclonic activity west of Sweden bringing in moist air from the Baltic Sea. For Torne River the second wettest was CP1, representing a dipole structure resulting in westerly flow of air from the North Atlantic. CP11 was similar to CP1, which was the third wettest for Torne River. CP5 was also a wet pattern for both stations, but of a different magnitude. This circulation represents a more easterly direction than CP6. For NOPEX this would imply moist air from the Baltic Sea.

Development of a circulation pattern that can be used for statistical downscaling of precipitation on any location in Sweden has many advantages. The inter-comparison of studies conducted at different locations is possible with a common classification. Using one classification also saves computation time. The negative effect is that the classification sub-optimal and could be seclude important local climate signals. However, when developing a European classification with H700 as the optimum predictor, Stehlik and Bárdossy (2003) showed that little information related to precipitation was lost when using regionally optimised classifications. The results from this study confirm their results. In local classifications MSLP is often found to be the best predictor, as it was in this study (Table 3). H850 was the optimum for the scale of Sweden, and Stehlik and Bárdossy (2003) identified H700 as optimum on the european continental scale. Physically this makes sense since MSLP may pick up local variations in, for example, orography that are important for the precipitation pattern at a certain station. Larger synoptic circulation patterns are more important at the regional scale, being better captured in the troposphere than near the surface. The optimum number of circulation patterns for precipitation downscaling purposes is usually around 12, independent on region (Wetterhall et al. 2006, 2007; Stehlik and Bárdossy 2003). The reason for this could be that 12 patterns are enough to include circulations that are important for differences in precipitation patterns.

4.2 Precipitation modelling

The MOFRBC overestimated precipitation amount on wetday and max5 for most stations and seasons, as illustrated by Uppsala (NOPEX) and Haparanda (Torne River) for the period 1961–1990 (Table 4). Including humidity in the precipitation model affected the results differently depending on season. The winter precipitation

Table 4 Precipitation indices for Uppsala and Haparanda stations for the NCAR and control-run simulations with MOFRBC and HADAM3P

	Uppsala airport		Maxdry (days)	Haparanda		Maxdry (days)
	Wetday (mm)	Max5 (mm)		Wetday (mm)	Max5 (mm)	
Winter						
Observed	3.5	53	18	2.6	49	17
M_{NCAR}	3.8	64	18	2.8	54	16
MH_{NCAR}	3.7	77	15	3.2	66	14
M_{CTL}	3.8	61	18	2.8	52	16
MH_{CTL}	4.2	75	15	3.4	69	13
GCM_{CTL}	1.9	24	4	2.5	64	11
Spring						
Observed	3.3	50	36	3.0	45	33
M_{NCAR}	3.8	64	24	3.1	55	25
MH_{NCAR}	3.6	72	25	3.1	69	21
M_{CTL}	3.8	65	25	3.1	55	25
MH_{CTL}	4.0	87	24	3.5	91	22
GCM_{CTL}	1.6	47	6	2.3	59	12
Summer						
Observed	5.7	85	25	4.5	73	33
M_{NCAR}	6.1	99	24	4.7	81	23
MH_{NCAR}	6.0	103	21	4.6	85	22
M_{CTL}	6.0	100	22	4.6	81	23
MH_{CTL}	6.3	109	21	4.4	88	20
GCM_{CTL}	2.1	78	6	3.3	80	13
Fall						
Observed	4.5	48	18	4.3	62	22
M_{NCAR}	5.1	43	19	4.4	83	18
MH_{NCAR}	4.2	38	21	3.8	110	21
M_{CTL}	5.0	43	20	4.4	83	17
MH_{CTL}	4.6	45	20	3.5	77	24
GCM_{CTL}	2.3	71	5	3.2	72	11

The values are averaged over the period 1961–1990

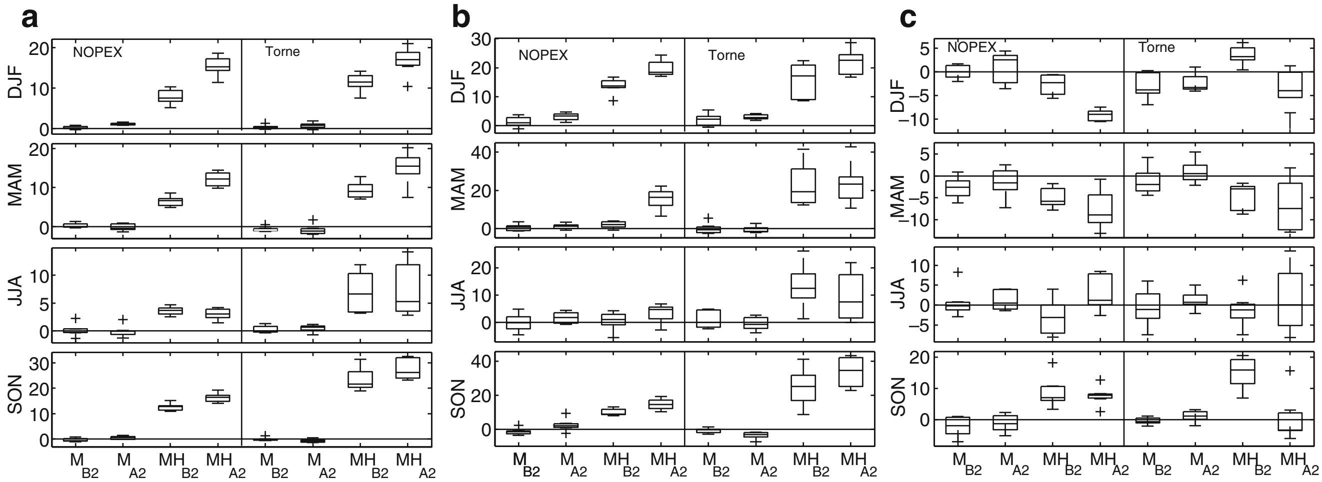

Fig. 4 **a** Difference in percent for amount of precipitation on a wet day (wetday) compared to the control run. The boxplot includes all stations at each region. **b** Difference in percent for maximum 5-day precipitation (max5) compared to the control run. The boxplot includes all stations at each region. **c** Seasonal differences in percent for maximum length of dry spell (maxdry) compared to the control-run. The boxplot includes all stations at each region

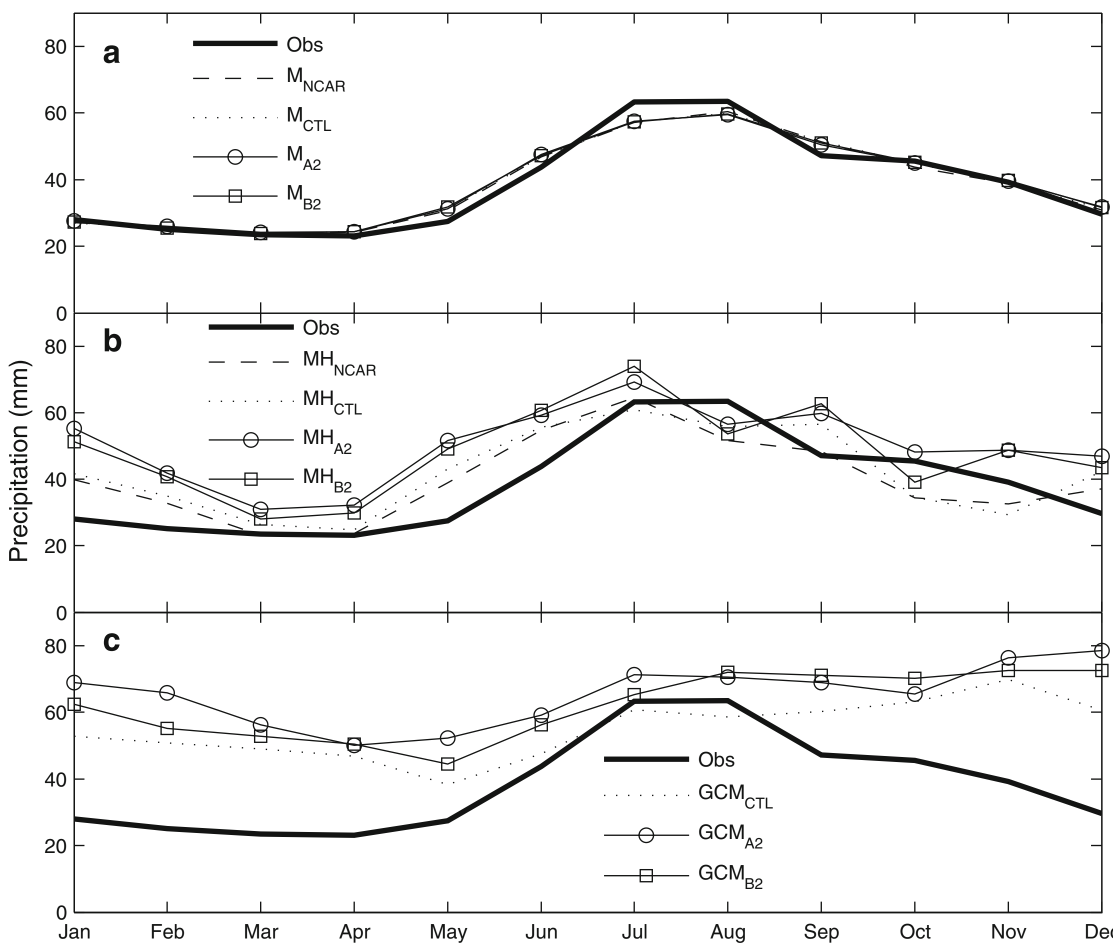

Fig. 5 Monthly precipitation for the NOPEX region simulations with MOFRBC for **a** the model without moisture flux, **b** with moisture flux included and **c** direct output for the 9 grid points closest to the NOPEX area. The monthly values are averaged over all stations (**a**–**b**) and all grid points (**c**)

was overestimated with the introduction of moisture flux and the fall precipitation underestimated. The simulations from the control run generated similar results as with the NCAR data as predictor. Compared to direct use of precipitation from HadAM3P, MOFRBC improved the modelling of precipitation indices, especially for NOPEX. The raw GCM output for Torne River was reasonable, but the seasonal variation was under-estimated (Table 4).

The evaluation of precipitation indices indicated an increase in max5 and wetday for almost all seasons and areas under the A2 and B2 scenarios for the period 2071–2100 compared to the control run when moisture flux was included in the model (Fig. 4a–b). The results are presented as relative increases in percent of the control run. The increases were significant on the 0.01 level with Student's *t*-test. The results for MH_{B2} for max5 (Fig. 4b) during spring and summer in the NOPEX region were not significantly different from the control-run on the 0.01 level. The simulations without moisture flux produce a small increase in wetday and max5 during winter for both regions, but the increases were not significant. Adding moisture flux to the precipitation model increased the magnitude of projected precipitation, both for wetday and max5 (Fig. 4a–b).

Maxdry increased for NOPEX during autumn and decreased in winter and spring with the MH model, but the results were not conclusive for Torne River (Fig. 4c). Intensified precipitation because of higher humidity could explain the results for winter and spring. The results for the NOPEX area in autumn indicate an increased variability in the precipitation pattern, since all indices are significantly larger for MH_{B2} and MH_{A2} compared to MH_{CTL} (Fig. 4a–c).

Meridional moisture fluxes were best correlated with precipitation, and it was only for the most westerly station Abisko that zonal moisture flux was used in the precipitation model. The correlation in the vertical direction varied with season, where fluxes at 850 hPa had the strongest correlation during winter and autumn and the strongest correlation is found at 700 and 500 hPa during spring and summer respectively. These results agree with Hellström (2005) who found that extreme events in Sweden are correlated with southerly winds, bringing moisture from the Baltic Sea. The increase was larger in the northern catchment (Torne River) than in south-central Sweden (NOPEX), which is consistent with Chen et al. (2006). Hellström et al. (2001) found that humidity is more important for statistical downscaling of precipitation in northern than in southern Sweden. Change in atmospheric moisture flux seems to be the most important climate-change signal predictor for this region.

The intra-annual variation of precipitation totals in the NOPEX region M_{NCAR}/MH_{NCAR} and M_{CTL}/MH_{CTL} was well captured compared to the GCM_{CTL} (Fig. 5a–c). M_{A2} and M_{B2} indicated a small increase in precipitation for late spring and early summer and a slight decrease in late summer. The annual cycle of precipitation was shifted towards the beginning of the year when humidity was included in the precipitation model (Fig. 5b). The overestimation of monthly precipitation during winter and spring was evident for all methods and scenario projections. Similar results were derived for the Torne River catchment. The biased intra-annual variation in the MOFRBC for the MH_{CTL} (Fig. 5) could be caused by the positive bias in S850 in winter and negative bias in summer over Scandinavia in the HadAM3P model compared to NCEP/NCAR data (STARDEX 2005). Also the NCEP/NCAR data have a positive bias in specific humidity over the North Atlantic compared to measured values (Smith et al. 2001). The results from the scenario runs were therefore interpreted in comparison with the control-run simulations rather than the observed values to compensate for the biased humidity. This study showed that circulation patterns alone do not contain enough information to model the increase in precipitation projected by the A2 and B2 scenarios modelled by HadAM3P model (Figs. 4 and 5). This is shown in many similar studies (e.g. Wilby and Wigley 2000; Hanssen-Bauer et al. 2005).

5 Conclusions

The optimised classification for Sweden (SWP) using H850 as predictor was found to capture precipitation variability with little information lost compared to local classifications. SWP could therefore be used for precipitation downscaling in the whole of Sweden. The increase in predicted precipitation in the scenario runs could be attributed to the increase in specific humidity, rather than in the changes in the frequency of circulation patterns. The introduction of moisture flux was found to be crucial to model the differences between the scenario projections and between future and present climate simulations.

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