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Refinement of dynamically downscaled precipitation and temperature scenarios

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Abstract A method for adjusting dynamically downscaled precipitation and temperature scenarios representing specific sites is presented. The method reproduces mean monthly values and standard deviations based on daily observations. The trend obtained in the regional climate model both for temperature and precipitation is maintained, and the frequency of modelled and observed rainy days shows better agreement. Thus, the method is appropriate for tailoring dynamically downscaled temperature and precipitation values for climate change impact studies. One precipitation and temperature scenario dynamically downscaled with HIRHAM from the Atmospheric-Ocean General Circulation Model at the Max-Planck Institute in Hamburg, ECHAM4/OPYC4 GSDIO with emission scenario IS92a, is chosen to illustrate the adjustment method.

1 Background

Impact studies on climate change demand realistic assessments of future climate change at specific regions/locations. Global climate scenarios are produced from Atmospheric-Ocean General Circulation Models (AOGCMs) (Räisänen 2001), with different emission scenarios (Cubasch et al. 2001). The models reproduce reasonably well the present climate for annual or seasonal averages representing a broad area (Mitchell et al. 2001). The spatial resolution in most present AOGCMs typically is some hundred kilometers, and this resolution is too coarse for most impact assessment studies, especially in regions with complex topography. The need for downscaling of AOGCMs is crucial for the scenarios to be applicable at regional/local scale.

Climate scenarios developed by AOGCMs are downscaled dynamically by regional climate models (RCMs), empirically (statistically) or by these two techniques in combination (e.g. Giorgi et al. 2001), to obtain higher spatial resolution. The terrain in the RCMs is smoothened, thus the elevation of specific sites is wrongly represented, and the frequency of days with precipitation is overestimated (Charles et al. 1999). Observed

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climate of specific sites is therefore not well reproduced. Empirical downscaling is useful to reproduce the at site climate satisfactorily and to obtain tailored local scenarios (Benestad 2002; Hanssen-Bauer et al. 2000, 2001). Inter comparison of results from dynamical and empirical downscaling techniques have been published demonstrating benefits and drawbacks (e.g. Hanssen-Bauer et al. 2003; Kidson and Thompson 1998; Murphy 1999). The demand from the impact research community for consistency between parameters (e.g. precipitation and temperature) and day-to-day evolution in time to be satisfactorily reproduced, leaves us to output from RCMs until fine scale models or empirical methods are able to cope with these problems. The focus in the present paper is on bridging the gap between RCM output and real local climate.

RCMs are usually run transient in time, and often include a control period representing the present climate and a scenario period representing the future climate. The control period is thought of as one possible realisation of today's weather conditions. The day-to-day evolution is therefore not directly comparable with observations. However, mean monthly values, standard deviation and frequency distribution of daily values as well as daily frequency of days with precipitation, should be realistically estimated in the control run. These criterions, however, are still not fulfilled in dynamical downscaling of AOGCMs leading to a gap between the RCM output and the needs from the impact researchers.

As stated by Wood et al. (2004); a minimum standard of any useful downscaling method for hydrological applications needs the historic (observed) conditions to be reproducible. This is important for other research areas as well. Floods and droughts are of particular interest for many impact assessments, the scenarios however, are not tailored for such conditions (Bronstert 2004). There is large uncertainty connected to AOGCM estimates of rainfall variance. If the modelling of daily rainfall regime is improved, the use of appropriate weather generators with AOGCM outputs should improve impact assessments by creating more reliable and realistic rainfall scenarios (Prudhomme et al. 2002).

So far little has been reported in literature on investigation of adjustment methods of daily output from RCMs. Some methods have traditionally been used; the delta change method, or perturbation method, has been used in different ways to omit the problem with local representativitiy by concentrating on the changes rather than the absolute values (Rummukainen et al. 2003; Reynard et al. 2001; Sælthun et al. 1998). The delta change method modifies the time series obtained by the RCM by altering the variability and important values as extremes, drought etc. And the method is not applicable for scenarios transient in time. A spline method to obtain daily values from empirically downscaled monthly temperatures has been used by Skaugen and Tveito (2004). This method smoothens out the mean monthly temperature values to daily values, neglecting the day-to-day variability. Empirical downscaling has been applied on a daily time resolution (Reichert et al. 1999; Benestad and Hanssen-Bauer 2003). It was found by Reichert et al. (1999) that the composition of predictors and their relative impact varies significantly for individual stations due to their local setting, thus making the method rather complicated and time consuming. Wood et al. (2004) used different approaches to downscale model output to mean monthly values. An additional step was performed to disaggregate monthly values to daily time series (Wood et al. 2002). It was found that only the downscaling method with bias-correction lead to satisfactory results for hydrologic simulation purposes. The SAR method (O'Brien et al. 2001) was used by Dettinger et al. (2004) to transform the probability distribution of RCM simulated temperature and precipitation for the control period to match the historical records. The same transformation was used for the scenario period. To the knowledge of the author, the SAR method is the only method so far that transforms RCM output with daily time resolution directly from regional to local scale without using techniques as weather generators, disaggregation of monthly values etc. Another method is reported here; a simple statistical downscaling method to make RCM output realistic at local scale.

The model experiment, study area and data are presented in Section 2. The empirical method for adjusting interpolated daily time series of precipitation and temperature scenarios to at site locations is described in Section 3. An evaluation of the method is performed in Section 4, and a discussion of the methods applicability for impact research is given in Section 5. A summary and conclusions are drawn in Section 6.

2 RCM experiment and weather stations

The AOGCM used is the ECHAM4/OPYC3 model from Max Planck Institute in Hamburg with the GSDIO integration (Roeckner et al. 1996, 1999). The integration is based upon emission scenario IS92a (Cubasch et al. 2001). The spatial resolution of the AOGCM is T42 (approximately 250 km×250 km) and is a transient simulation over the years 1980–2049. The GSDIO simulation did well in a comparative study where several integrations were compared to observed temperature anomalies during 1946–1996 (Allen et al. 2000).

The scenario is dynamically downscaled with the regional climate model HIRHAM (hereafter called RCM) documented by Christensen et al. (1998). The physical parameterizations are adapted from ECHAM4 (Roeckner et al. 1996). The model is run on a rotated spherical grid (approximately 55 km resolution) and with 19 levels in the vertical (Bjørge et al. 2000). Simulated precipitation and temperatures obtained with RCM are compared with empirical downscaling in Hanssen-Bauer et al. (2003). The experiment is compared to other regional simulations covering a common Nordic mainland area from 1990 to 2050 (Christensen et al. 2001). They found that the spread in temperature among the ensemble members (~1°C) is smaller than the climate change. The present experiment show the lowest temperature increase among the ensemble members due to considerable cooling effects of non-greenhouse gas radiative forcing in the GSDIO integration. Choice of emission scenario is therefore a considerable source of uncertainty. The present experiments simulated change in precipitation is placed well within the results from the ensemble members except during spring where the change is smaller.

The area covered by the integration domain are visualised (Fig. 1) together with five locations chosen to represent the southern, northern, coastal and inland parts of Norway. The difference in altitude represented in the RCM versus real station altitude is largest in western parts where the topography is steep compared to eastern parts of the country. Height difference at the selected stations is presented in Table 1.

3 Empirical adjustment of dynamically downscaled data

Precipitation and temperature scenarios for the years 1980–2050 with daily temporal resolution is interpolated with bilinear interpolation from the four nearest RCM grid points (Section 2) to station sites. There is a marked disagreement between observed mean monthly values and standard deviation in observed and simulated climate within the control period 1980–1999. This emphasizes the need for RCM output to be adjusted to be applicable in impact analyses of climate change at local scale. Two adjustment strategies are applied on precipitation and temperature output from RCM. First, for precipitation; the model error can be accounted for by adjusting RCM-precipitation data with an expression

Fig. 1 The integration area of RCM and location of the selected weather stations

of the RCM-error obtained from RCM (Section 2) run of observationally based re-analysed data (http://www.ecmwf.int/research/era/ERA-15/) from ECMWF (European Centre for Medium-Range Weather Forecast) over the years 1979–1993 (hereafter called ERA-15) (Section 3.1.1). For temperature; a straight forward height correction of modelled temperatures is used to account for the model error (Section 3.2.1). Second, an empirical approach has been applied for the modelled data to better represent the at site values, described for precipitation in Section 3.1.2 and for temperature in Section 3.2.2.

Table 1 Station altitude (H_1), model altitude (H_2) and the difference (H_2−H_1) at five selected weather stations in Norway [m a.s.l.]

Weather stations	H_1	H_2	H_2−H_1
700 Drevsjø	672	740	68
18700 Oslo–Blindern	94	237	143
43500 Ualand–Bjuland	196	271	75
51590 Voss–Bø	125	766	641
90450 Tromsø	100	227	127

3.1 Precipitation

3.1.1 Adjustment of precipitation with ERA-15

RCM is run with the same domain and resolution as the present experiment (Section 2) with "perfect boundaries," applying ERA-15 to define the boundary conditions. Precipitation from ERA is interpolated with bilinear interpolation to the selected stations location by the four nearest neighbours. If RCM is able to reproduce observational data satisfactorily, the modelled precipitation values in the ERA-15 period should be comparable with observations for the same period. Comparison of results from this simulation and observations from Norwegian meteorological stations during the same period showed that temperature and precipitation fields produced by RCM is too coarse to give detailed estimates of point values (Skaugen et al. 2002). Adjustment factors for each calendar month were calculated from the ratio between mean monthly ERA-15 values $P_{j,\mathrm{ERA}}$ and mean monthly values based on observations $P_{j,\mathrm{OBS}}$ for the years 1979–1993 (Eq. 1). Thus there are 12 adjustment factors, a_j, for each station:

$$a_j = \frac{P_{j,\mathrm{OBS}}}{P_{j,\mathrm{ERA}}} \tag{1}$$

These monthly adjustment factors are used to adjust the day-to-day precipitation from the model run:

$$P_{\mathrm{RCMJ1}sc,ijk} = a_j P_{\mathrm{RCMsc},ijk} \tag{2}$$

where $P_{\mathrm{RCMJ1}sc,ijk}$ is the adjusted precipitation for day i of month j in year k, in a scenario period sc. $P_{\mathrm{RCM}sc,ijk}$ is the dynamically downscaled precipitation interpolated to station site for day i of month j in year k in a scenario period sc.

3.1.2 Empirical adjustment of precipitation

Daily precipitation values, adjusted with Eq. 2, are both normalised and standardised for a scenario period (e.g. the time window 2030–2049) to obtain a residual containing the variability of the daily precipitation data series (Eq. 3).

$$\frac{P_{\mathrm{RCMJ}sc,ijk} - m_{P,\mathrm{RCMJ1}sc,j}}{\sigma_{P,\mathrm{RCMJ1}sc,j}} = \varepsilon_{P,sc,ijk} \tag{3}$$

where $P_{\mathrm{RCMJ1}sc,ijk}$ is daily precipitation adjusted with Eq. 2 at day number i in month j in the scenario period sc. $m_{P,\mathrm{RCMJ1}sc,j}$ is the mean monthly precipitation value in month j in the scenario period sc, $\sigma_{P,\mathrm{RCMJ1}sc,j}$ is the standard deviation based on daily values for month j in the scenario period sc, and $\varepsilon_{P,sc,ijk}$ is the residual at day i of month j in year k in the scenario period sc.

The method assumes that the monthly RCM error of variability in the scenario period is the same as for the control period, γ_{Pj} (Eqs. 4a and 4b).

$$\gamma_{Pj} = \frac{\sigma_{P,\mathrm{obs},j}}{\sigma_{P,\mathrm{RCMJ1-ctrl},j}} \tag{4a}$$

$$\widehat{\sigma}_{P,sc,j} = \gamma_{Pj}\sigma_{P,sc,j} \tag{4b}$$

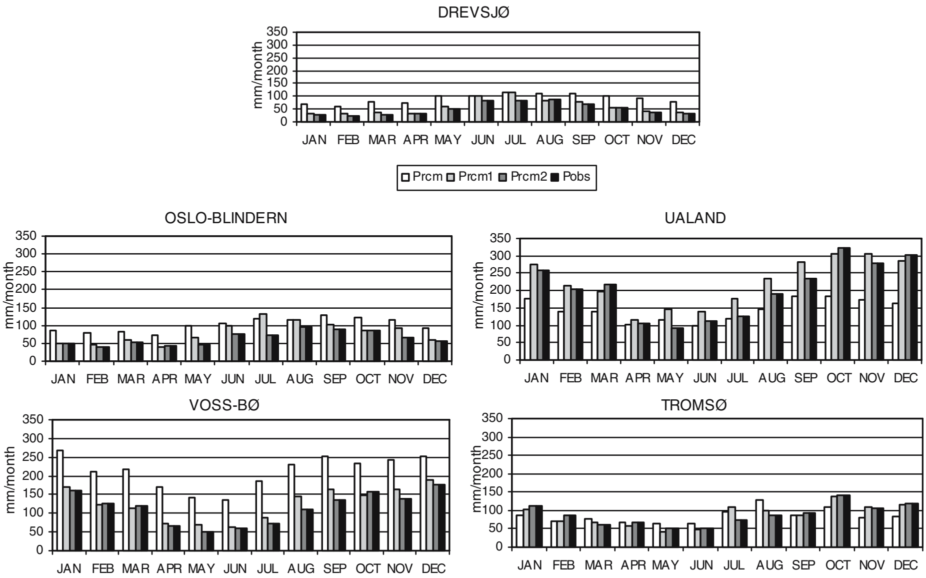

Fig. 2 Mean monthly precipitation sum at the selected stations interpolated from RCM (Prcm), adjusted with Eq. 2 (Prcm1), adjusted with Eqs. 3–6a and 6b (Prcm2) and observed (Pobs) for the control period (1980–1999)

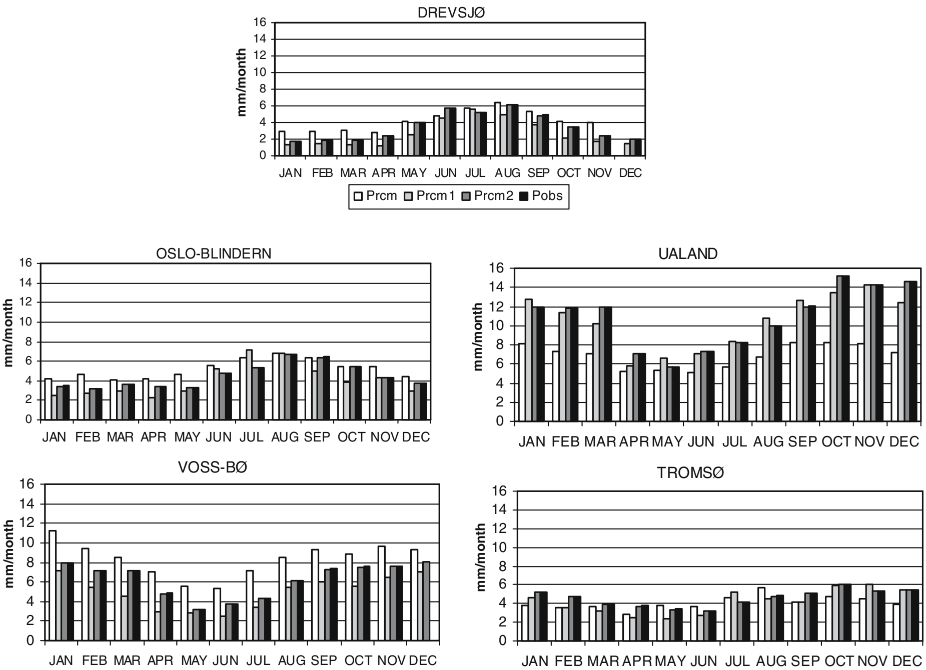

Fig. 3 Mean monthly standard deviation based on daily precipitation values at the selected stations interpolated from RCM (Prcm), adjusted with Eq. 2 (Prcm1), adjusted with Eqs. 3–6a and 6b (Prcm2) and observed (Pobs) for the control period (1980–1999)

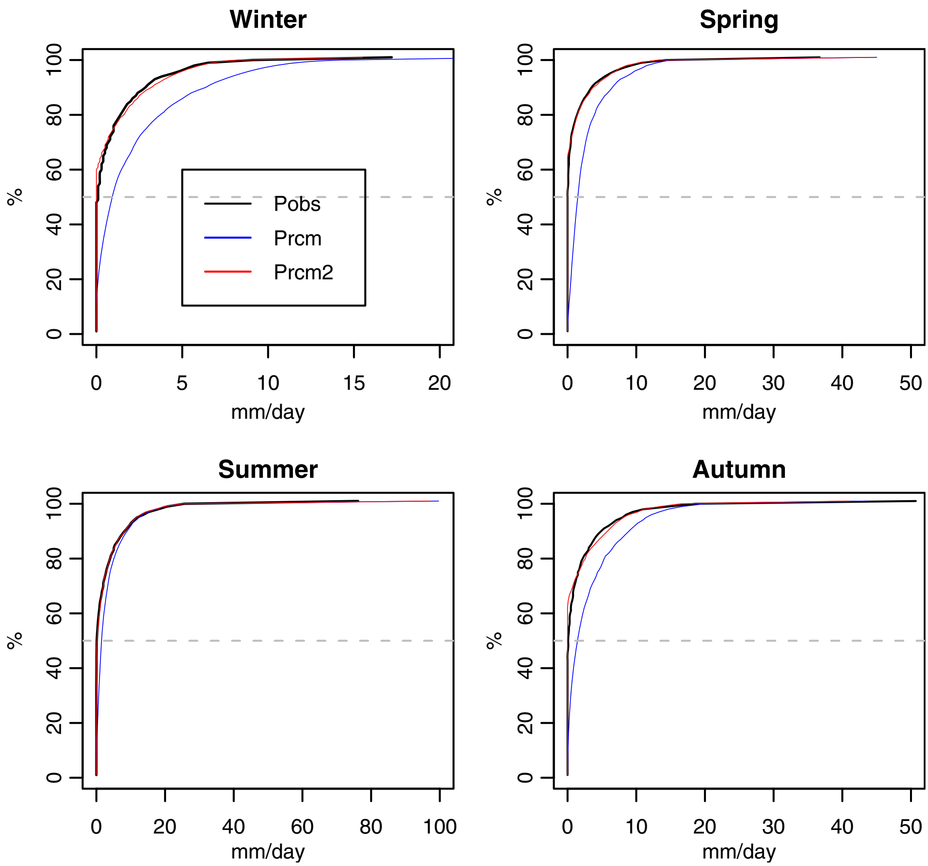

Fig. 4 Cumulative distribution functions of observed (Pobs), simulated with RCM (Prcm) and adjusted simulated with RCM (Prcm2) daily precipitation at station 700 Drevsjø for the control period (1980–1999)

$\sigma_{P,\mathrm{obs},j}$ is monthly (j) standard deviation (σ) based on observed daily values (obs) within the control period. $\sigma_{P,\mathrm{RCMJ1-ctrl},j}$ is monthly (j) standard deviation (σ) based on modelled daily values RCMJ1−ctrl within the control period

β_{Pj} is the ratio between the scenario mean monthly (j) sums ($m_{P,\mathrm{RCMJ1}sc,j}$) and control mean monthly (j) sums ($m_{P,\mathrm{RCMJ1ctrl},j}$) based on daily values,:

$$\beta_{Pj} = \frac{m_{P,\mathrm{RCMJ1}sc,j}}{m_{P,\mathrm{RCMJ1ctrl},j}} \tag{5}$$

Adjusted daily precipitation is obtained by multiplying daily residuals (Eq. 3) with the adjusted standard deviation for the scenario period (Eq. 4b). Mean monthly values of daily precipitation based on observations within the control period multiplied with $\beta_{P,j}$ is added. The mean differences between mean monthly values in a scenario period and a control period are maintained:

$$P_{\mathrm{RCMJ2}sc,ijk} = \varepsilon_{P,sc,ijk}\widehat{\sigma}_{P,sc,j} + m_{P,\mathrm{obs},j}\beta_{Pj} \tag{6a}$$

$$P_{\mathrm{RCMJ2}sc,ijk} = \left(P_{sc,ijk} - m_{P,sc,j}\right)\gamma_{Pj} + m_{P,\mathrm{obs},j}\beta_{Pj} \tag{6b}$$

where $P_{\mathrm{RCMJ2}sc,ijk}$ is the adjusted precipitation for day i in month j for the scenario period.

If $m_{P,sc,j} > m_{P,obs,j}$, scenario values of daily precipitation $P_{RCMJ2sc,ijk}$ will be negative. Negative values are set equal to 0.0 mm, thus, the mean monthly precipitation sum and standard deviation based on daily precipitation will be too large compared to the statistical moments based on observations. The Eqs. 3–6a and 6b are therefore performed all over again on the new dataset ($P_{RCMJ2sc,ijk}$). The iteration is repeated until the mean value and the standard deviation is satisfactorily reproduced.

By considering every e.g. 5 years as a separate scenario any trend in the data is maintained and analyses with transient model runs may be applicable. This might lead to time series with pronounced stepwise mean values. To account for this, a 5 year moving window approach may be applied where year 1–5 is considered as scenario period, then year 2–6, 3–7 etc.

3.2 Temperature

3.2.1 Lapse rate correction of daily temperature

At low-lying sites, and particularly valley stations, the temperature interpolated from the regional climate model are estimated too low because of the positive altitude difference (Table 1). To correct the daily temperatures for altitude biases a temperature lapse rate

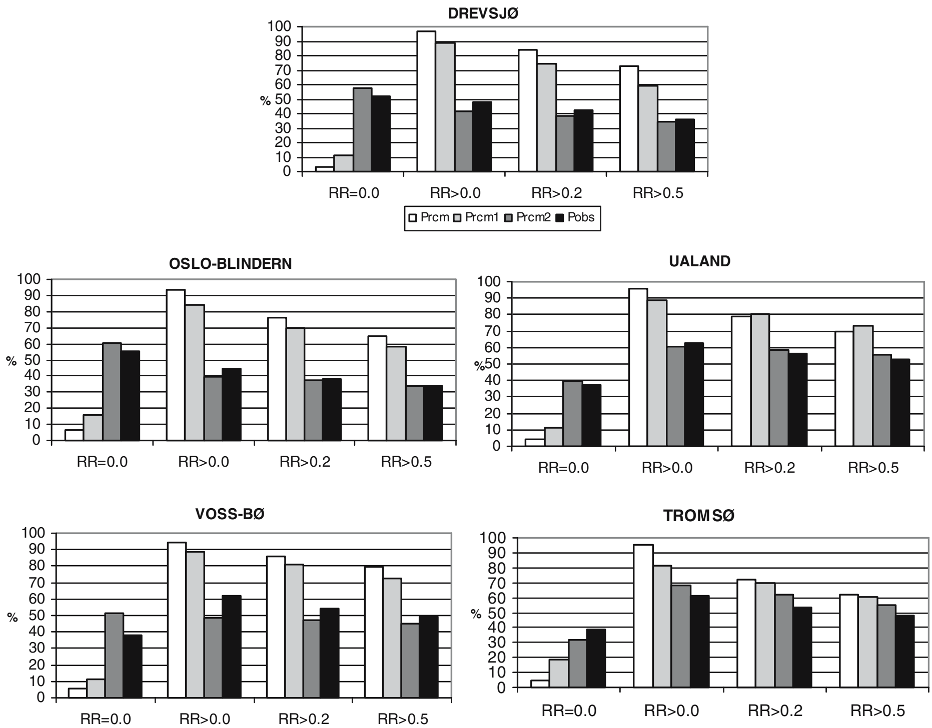

Fig. 5 Number of days with precipitation >0.0 mm, >0.2 mm, >0.5 mm and number of days without precipitation (= 0.0 mm) at the selected stations interpolated from RCM (Prcm), adjusted with Eq. 2 (Prcm1), adjusted with Eqs. 3–6a and 6b (Prcm2) and observed (Pobs) for the control period (1980–1999)

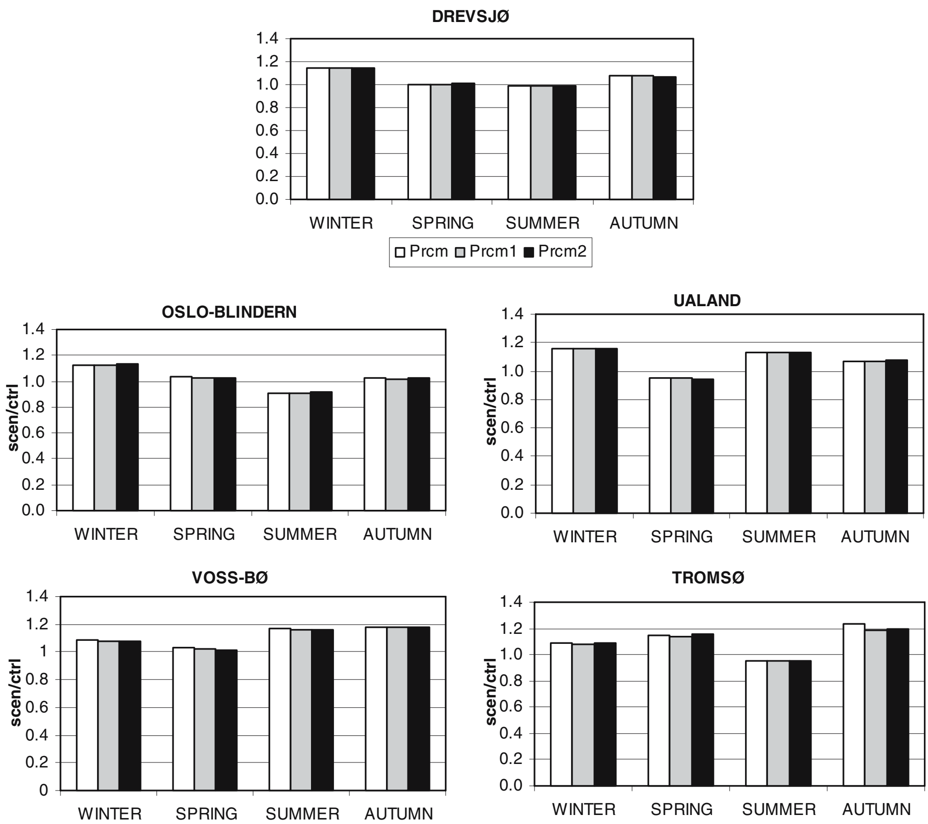

Fig. 6 Relative change in mean monthly precipitation at the selected stations interpolated from RCM (Prcm), adjusted with Eq. 2 (Prcm1), adjusted with Eqs. 3–6a and 6b (Prcm2) and observed (Pobs) for the control period (1980–1999)

which closely matches the average observed lapse rate in the troposphere (−0.65°C/100 m) (Houghton 1985) is used:

$$T_{\mathrm{RCMJ1}sc,ijk} = T_{\mathrm{RCM}sc,ijk} - 0.65 \times \frac{\Delta \mathrm{h}}{100} \tag{7}$$

where $T_{\mathrm{RCM}sc,ijk}$ is interpolated temperature values from the regional climate model, $T_{\mathrm{RCMJ1},ijk}$ is height corrected temperature values and Δh is the height difference.

The real lapse rate may deviate substantially from the average conditions during special weather situations, though. In a Nordic study covering Fennoscandia, the temperature lapse rate also showed to vary with season (Tveito et al. 2000).

3.2.2 Empirical adjustment of temperature

Equations similar to Eqs. 3–6a and 6b are for temperature expressed as shown in Eqs. 8–11a and 11b, respectively. Daily height corrected temperatures modelled with RCM $T_{\mathrm{RCMJ1}sc,ijk}$ (Eq. 7) is first normalised and standardised (Eq. 8).

$$\frac{T_{\mathrm{RCMJ1}sc,ijk} - m_{T,\mathrm{RCMJ1}sc,j}}{\sigma_{T,\mathrm{RCMJ1}sc,j}} = \varepsilon_{T,sc,ijk} \tag{8}$$

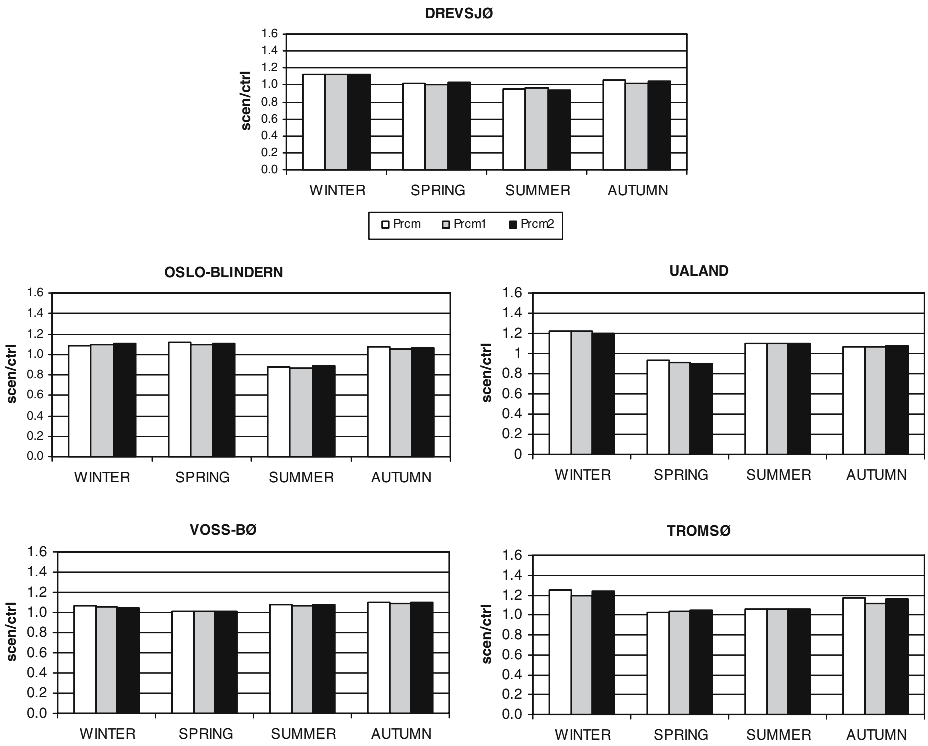

Fig. 7 Relative change in standard deviation based on daily precipitation at the selected stations interpolated from RCM (Prcm), adjusted with Eq. 2 (Prcm1), adjusted with Eqs. 3–6a and 6b (Prcm2) and observed (Pobs) for the control period (1980–1999)

$m_{,T,RCMJ1sc,j}$ is the mean monthly temperature in month j in the scenario period sc, $\sigma_{T,RCMJ1sc,j}$ is the standard deviation based on daily values from month j in the scenario period sc, and $\varepsilon_{T,sc,ji}$ is the residual at day i of month j in year k in the scenario period sc.

The method assumes, as for precipitation, that the monthly RCM error of variability in the scenario period is the same as for the control period, γ_{Tj} (Eqs. 9a and 9b).

$$\gamma_{Tj} = \frac{\sigma_{T,\mathrm{obs},j}}{\sigma_{T,\mathrm{RCMJ1ctrl},j}} \tag{9a}$$

$$\widehat{\sigma}_{T,sc,j} = \gamma_{Tj}\sigma_{T,sc,j} \tag{9b}$$

The method force the modelled data to satisfactorily reproduce mean monthly values in the control period obtained by RCM by using the absolute change between the scenario mean monthly values ($m_{T,\mathrm{RCMJ1}sc,j}$) and control mean monthly values ($m_{T,\mathrm{RCMJ1ctrl},j}$), β_{Tj}:

$$\beta_{Tj} = m_{T,\mathrm{RCMJ1}sc,j} - m_{T,\mathrm{RCMJ1ctrl},j} \tag{10}$$

Adjusted daily temperatures are obtained by multiplying daily residuals (Eq. 8) with adjusted standard deviation for the scenario period (Eq. 9b) and add the observed mean value and β_{Tj}:

$$T_{\mathrm{RCMJ2}sc,ijk} = \varepsilon_{T,sc,ijk}\widehat{\sigma}_{T,sc,j} + \left(m_{T,\mathrm{obs},j} + \beta_{Tj}\right) \tag{11a}$$

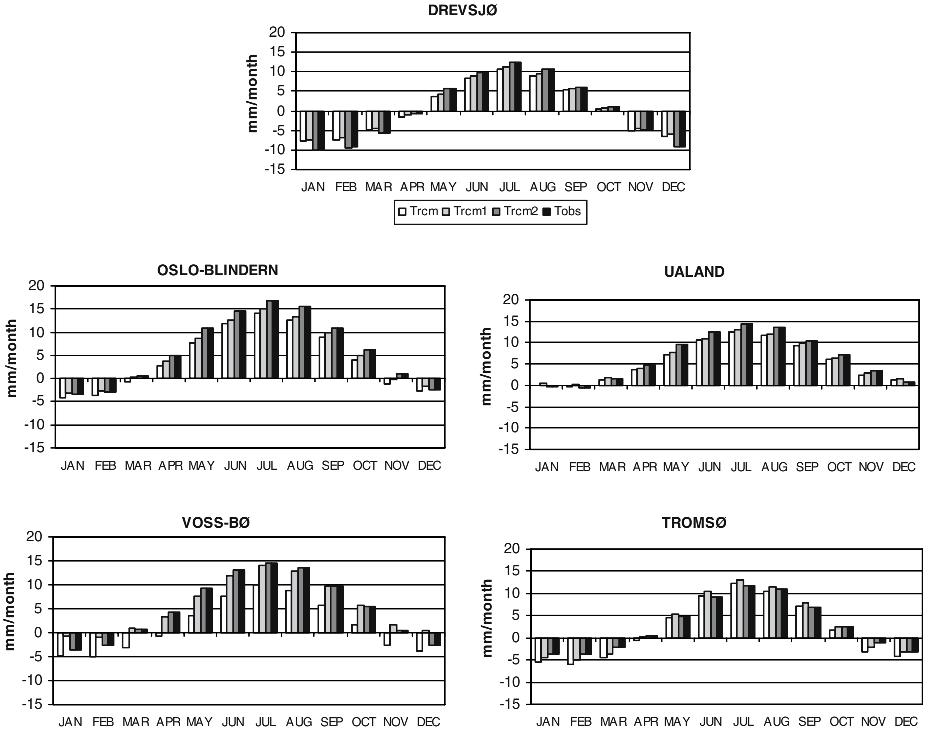

Fig. 8 Mean monthly temperature value at five selected stations interpolated from RCM (Trcm), adjusted with Eq. 7 (Trcm1), adjusted with Eqs. 8–11a and 11b (Trcm2) and observed (Tobs) for the control period (1980–1999)

$$T_{\mathrm{RCMJ2}sc,ijk} = \left(T_{sc,ijk} - m_{T,sc,j}\right)\gamma_{Tj} + \left(m_{T,\mathrm{obs},j} + \beta_{Tj}\right) \tag{11b}$$

Mean value and variability for the control period is then reliably estimated and the mean differences in mean value and standard deviation as obtained by RCM is maintained.

4 Results

Daily precipitation and temperature is simulated by RCM transient in time for the period 1980–2049. The period 1980–1999 is used as control period (Section 2). A new scenario period is defined every 5-year from 1980 to utilize the transient simulation and to maintain a potential trend in the time series originally estimated by RCM. The methods presented above (Section 3.1) are applied.

4.1 Precipitation

Four precipitation datasets are considered; interpolated directly from RCM to selected weather stations (Prcm), adjusted with ERA-15 as described in Section 3.1.1 (Prcm1), adjusted with the empirical method described in Section 3.1.2 (Prcm2) and observed precipitation (Pobs). Mean monthly precipitation sum from the three simulated datasets together with the observed (Prcm, Prcm1, Prcm2, Pobs) is estimated for five selected locations within the control period. The mismatch in mean monthly values in Prcm is large compared to Pobs (Fig. 2). Prcm1 show better agreement, but is still not satisfactorily reproduced. The empirical adjustment step (Prcm2), leads to perfect agreement on mean monthly precipitation sum at all the selected stations. The estimated standard deviation based on daily values for the respective data series together with observations shows similar pattern (Fig. 3); the variability is not well reproduced in Prcm but is satisfactory adjusted with the empirical adjustment method (Prcm2). Comparison of the cumulative distribution curve of daily simulated precipitation (Prcm) and daily observed precipitation (Pobs) show that RCM simulates too much precipitation, especially in autumn, winter and spring. The agreement between cumulative frequency distribution curve of daily observed precipitation (Pobs) and adjusted precipitation (Prcm2) show good agreement (Fig. 4). For simplicity only station 700 Drevsjø is presented in Fig. 4.

A well known problem with RCM is that the frequency of days with precipitation is too large compared to the observed situation (Frei et al. 2003). This is the case in the present run as well; the number of days with precipitation simulated with RCM is too large (Fig. 5) both for number of days with precipitation >0 mm, >0.2 mm and >0.5 mm. After the adjustment (Prcm2), the agreement between modelled and observed number of days with precipitation is improved.

It is shown that the empirical adjustment method (Section 2) reproduces both mean monthly observed precipitation sum, standard deviation based on observed daily values and

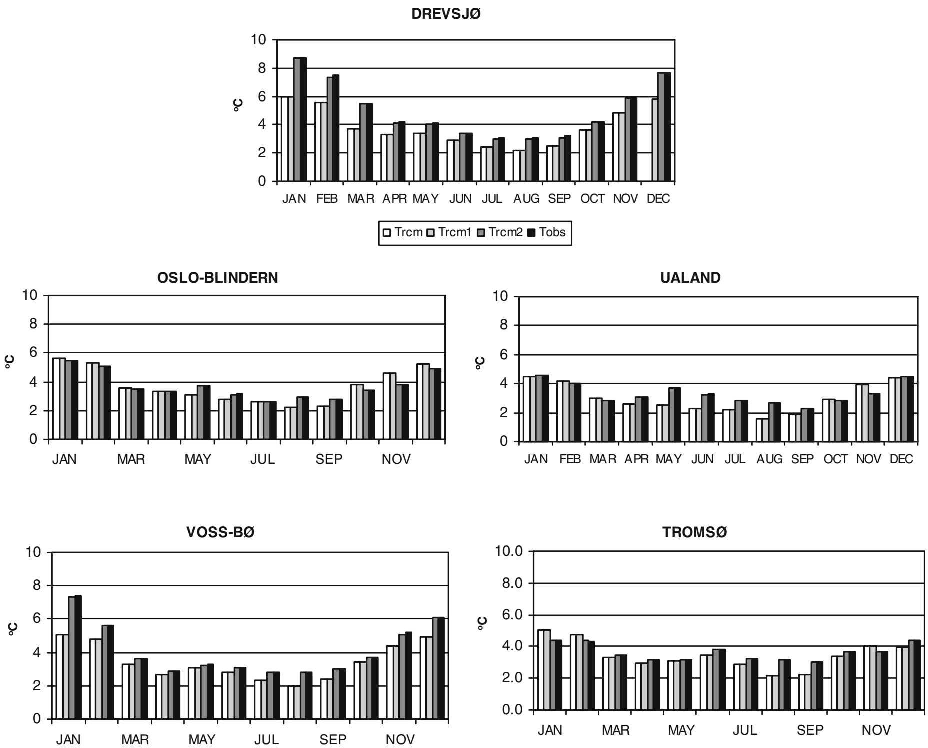

Fig. 9 Standard deviation based on daily temperature values at five selected stations interpolated from RCM (Trcm), adjusted with Eq. 7 (Trcm1), adjusted with Eqs. 8–11a and 11b (Trcm2) and observed (Tobs) for the control period (1980–1999)

observed number of days with precipitation at the selected stations properly, at least on an average basis. Figures 6 and 7 shows that the adjusted precipitation (both Prcm1 and Prcm2) preserve the relative mean monthly change in precipitation and relative change in standard deviation based on daily values as well. Annual precipitation in the selected scenario is projected to increase (especially in the west and north) or remain the same at the selected stations.

4.2 Temperature

As for precipitation, four temperature datasets are considered; interpolated directly from RCM to selected weather stations (Trcm), height corrected as described in Section 3.2.1 (Trcm1), adjusted with the empirical method described in Section 3.2.2 (Trcm2) and observed temperatures (Tobs). Mean monthly temperature from the three simulated datasets together with the observed (Trcm, Trcm1, Trcm2, Tobs) is estimated for five selected weather stations (Section 2) within the control period. Figure 8 demonstrate the marked mismatch in mean monthly values in Trcm and Trcm1 compared to Tobs (Fig. 8). The empirical adjustment step (Trcm2), leads to perfect agreement on mean monthly temperature at all sites. The estimated standard deviation based on daily values for the

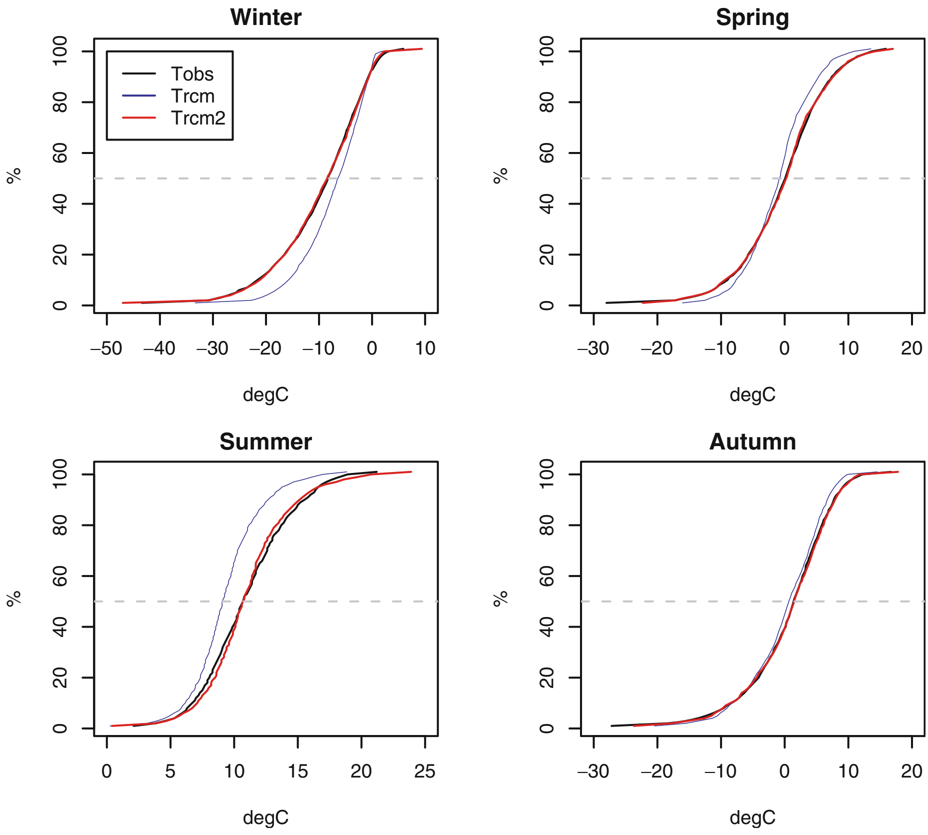

Fig. 10 Cumulative distribution functions of observed (Pobs), simulated with RCM (Prcm) and simulated with RCM and adjusted (Prcm2) daily precipitation at station 700 Drevsjø for the control period (1980–1999)

respective data series together with observations shows similar pattern (Fig. 9); the variability is not well reproduced in Trcm but is satisfactory adjusted with the empirical adjustment method (Trcm2). The cumulative frequency distribution curve of simulated daily temperatures (Prcm) show rather large mismatch with the cumulative frequency distribution curve of observed daily temperatures (Fig. 10). For simplicity only station 700 Drevsjø is presented in the figure. The agreement with the cumulative frequency distribution curve of observed temperatures is very good after adjustment of the simulated temperatures with the empirical method (Prcm2).

It is shown that the empirical adjustment method reproduces both mean monthly observed temperature and standard deviation based on observed daily values at the selected stations properly, at least on an average basis. Figures 11 and 12 shows that the adjusted temperature (both Trcm1 and Trcm2) preserve the relative mean monthly change and relative change in standard deviation based on daily values as well.

5 Applicability for impact research

Norway is characterised by large climate gradients, from west to east and from north to south. Eastern inland parts have low laying regions with cold winters and warm summer seasons in general. Annual precipitation is lowest in these parts of the country. Western parts is characterised by large topographic complexity. The climate is influenced by the

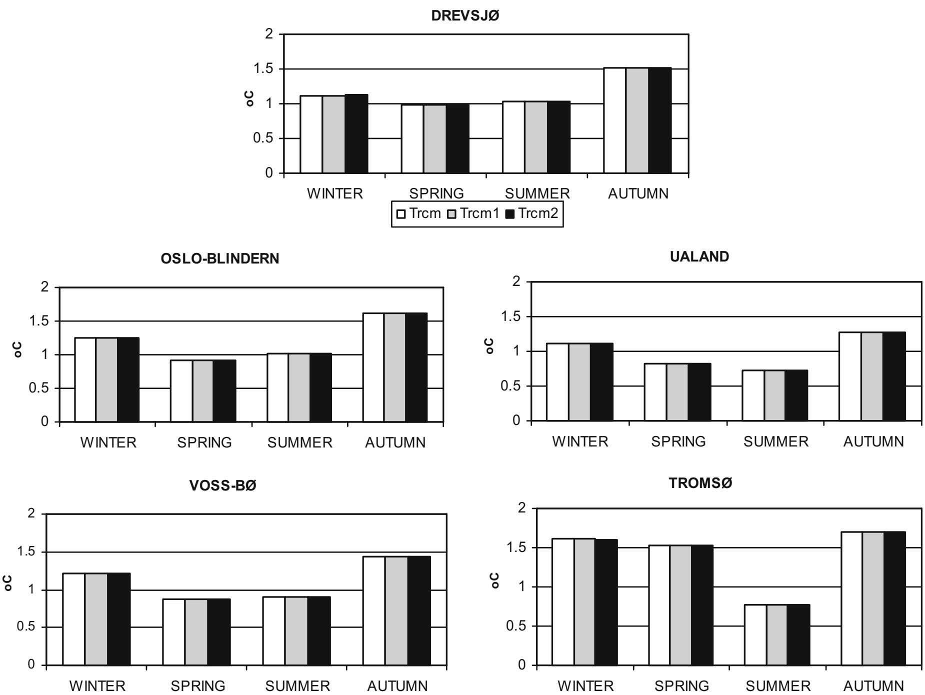

Fig. 11 Absolute change in mean monthly temperature value at five selected stations interpolated from RCM (Trcm), adjusted with Eq. 7 (Trcm1), adjusted with Eqs. 8–11a and 11b (Trcm2) and observed (Tobs) for the control period (1980–1999)

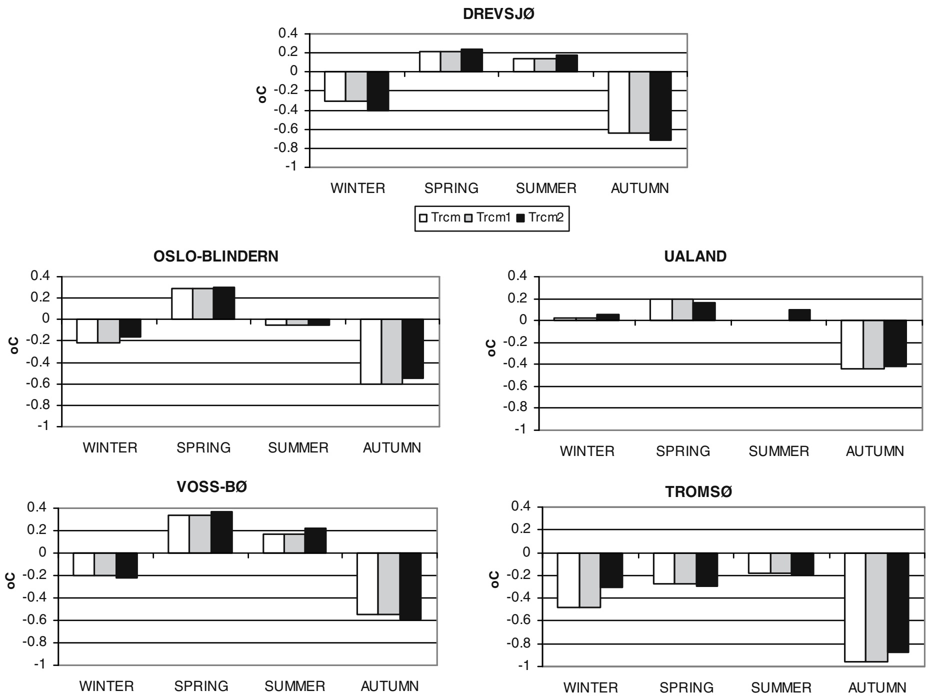

Fig. 12 Absolute change in mean monthly standard deviation based on daily temperature values at five selected stations interpolated from RCM (Trcm), adjusted with Eq. 7 (Trcm1), adjusted with Eqs. 8–11a and 11b (Trcm2) and observed (Tobs) for the control period (1980–1999)

long coast with less diurnal variability in precipitation and mild winters. Western parts are exposed for rather heavy winter storms and annual precipitation is largest in these regions. The Norwegian main land covers a very long region from north to south (~latitude 58°–72°) which is reflected in the climate gradients.

Norwegian weather stations reflect the Norwegian climate. Most of Norway is reasonably well represented by weather stations, however the highest altitudes are underrepresented (Tveito et al. 2005). Weather stations are often located in narrow valley bottoms. The spatial resolution of the regional climate model is too coarse to fully reflect the valleys. Huge height differences as experienced here (Table 1) may therefore occur and, among other reasons, lead to large gaps between simulated and observed climate. Other causes like e.g. not fully represented physical processes in RCM, may also lead to rather large differences in simulated and observed climate at local scale. Adjustment of regional climate model output is therefore necessary for Norwegian regions.

6 Summary and conclusions

Impact research is frequently based on observations of climate (analyses in e.g. hydrology, glaciology, agriculture, biology, human health). The applicability of output from regional climate models are increasing rapidly, demanding climate simulations of historic and future climate at local scale to be reliably reproduced. The spatial resolution of simulated climate elements is too coarse leading to a mismatch between observed and simulated climate especially in regions with complex topography. The need for adjustment of regional climate model output is therefore argued. An empirical refinement method to bridge the gap from regional to local scale in climate modelling is presented.

The tailoring of interpolated dynamical downscaled temperature and precipitation with the empirical adjustment method outlined above has improved the statistical moments (mean value and standard deviation) from a regional climate model. It is shown that RCM simulates too many rainy days, but the number of days with precipitation, however, is reduced to a realistic level after the adjustment. The mean monthly change predicted by RCM is maintained both for precipitation and temperature. Thus, the adjusted time series is applicable at least on an average level. However, the crucial issue is whether it is possible to use the data as transient daily time series as input to effect models (e.g. hydrological rainfall-runoff models). The climate signal is preserved after the adjustment and the adjusted precipitation and temperature data from the control period reproduce the same frequency distribution curve of daily values as for the observed climate. Thus, it is possible to use the adjusted scenario data as transient time series input to effect models. The method has successfully been applied in Kaste et al. (2006) where water quality in a watershed in Southern Norway is analysed in a future climate. Adjusted precipitation and temperature scenarios are by Kaste et al. (2006) used as input in a hydrological model to obtain runoff scenarios to be used in a water quality model (Integrated Catchments Model for Nitrogen, INCA). The adjustment method is therefore recommended for tailoring of simulated daily temperature and precipitation to specific locations.

The empirical adjustment method is simple and the need for computer resources is limited. It involves the use of time series of observed climate from weather stations, though, limiting the method to be used only on existing weather station locations.

Uncertainty in climate modelling is an unsolved problem and is discussed in a wide manner in literature (Moore et al. 2001). The uncertainty connected to future climate projections obtained with AOGCMs and regional climate models is not altered with the adjustment procedure.

A question still not answered when using the adjustment method is how the consistency between climate elements obtained by the regional climate model is altered. This is of greater interest for several impact research areas.

The adjustment method presented does not alter the climate signal obtained with RCM. Further development of the method should focus on the possibility of incorporating our well documented knowledge of local climate to improve the reliability of simulated climate signals.

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