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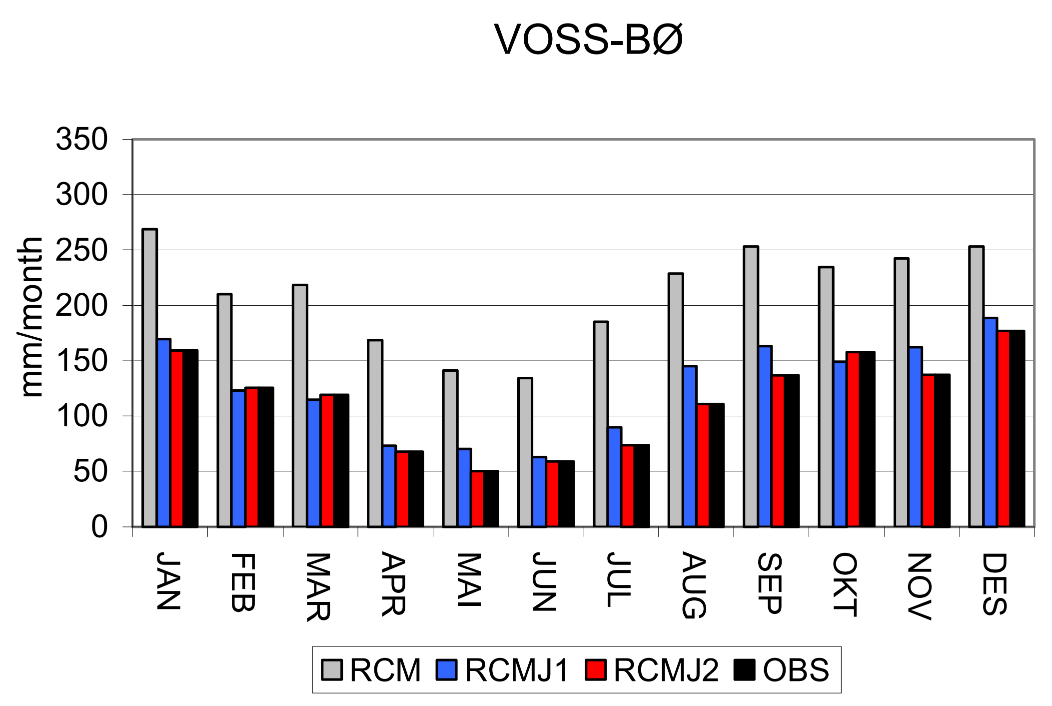
Climate

# Refinement of dynamically downscaled precipitation and temperature scenarios

## Torill Engen - Skaugen



**Mean monthly precipitation at Voss-Bø in Western Norway (OBS). Mean monthly precipitation interpolated from HIRHAM (RCM) and adjusted with two different adjustment methods (RCMJ1 and RCMJ2).**

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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.

**Keywords**
Adjustment

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# 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, however, only on large spatial scales and for annual or seasonal averages. 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, which 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 the 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)

Climate scenarios are downscaled, dynamically, empirically or by these two techniques in combination (e.g. Giorgi et al., 2001), to obtain higher spatial resolution for regions or at site locations. AOGCMs are usually run with a control run representing the present climate. A control run is thus supposed to be one possible realisation of to-days weather conditions. The day-to-day variability is not directly comparable with observations. However, for precipitation and temperature, mean monthly values, standard deviation and daily frequency of days with precipitation, should be realistically estimated in the control run. These criterions are not fulfilled in “the real world”.

The time resolution of output from dynamically downscaled scenarios is on a 6 hourly basis. The spatial resolution (typically 50 x 50 km$^2$), however, is too coarse to be representative locally. The terrain in the regional climate models is smoothened, the locations elevation is wrongly represented, and the frequency of days with precipitation is overestimated (Charles et al., 1999). Observed climate of specific sites is therefore not well reproduced.

Empirical downscaling is useful to reproducing the at site climate satisfactory 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 Tompson, 1998; Murphy, 1999). However, e.g. hydrological modelling needs consistency between climate parameters (e.g. precipitation and temperature) and consistent day-to-day evaluation in time which is obtained with regional climate models. Thus, methods for refinement of output from regional models are needed.

The adjustment, or tailoring, of dynamically downscaled climate scenarios addressed above is currently being studied. The problem is actualised in Norway due to the large climate gradients with topography. 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).

A spline method to obtain daily values from empirically downscaled monthly temperature data have been used by Skaugen and Tveito (2004). This method, however, smoothens out the mean monthly temperature values to daily values, thus neglecting the day-to-day variability. Empirical downscaling has been applied on a daily time resolution as well (Reichert et al., 1999, Benestad and Hanssen-Bauer, 2003). It was found, however, 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 six different approaches to downscale model output to mean monthly values; linear interpolation, spatial disaggregation, and bias-correction and spatial disaggregation. An additional step was performed to disaggregate the monthly values to daily time series (Wood et al., 2002) which is the requirement for many impact models. The three methods were used both on output from one AOGCM directly and after dynamical downscaling of the model.

The study area and data are presented (section 2), an empirical method for adjusting interpolated daily time series of precipitation and temperature scenarios to at site locations is outlined (section 3). An evaluation of the method (section 4) and a discussion of the methods applicability for impact research (section 5) are performed.

# 2 Study area and data

One scenario downscaled with the HIRHAM[1] model (Bjørge et al., 2000) at 5 locations in Norway (Figure 1) is selected. The regional climate model is run with three different domains, the intermediate domain is used in this study. The difference in altitude in the regional climate model versus real station altitude is presented in table 1. The AOGCM used is the Max Planck model ECHAM4/OPYC3 GSDIO (Roeckner et al., 1999) with the IS92a scenario (Cubash et al., 2001). This is a transient simulation for the years 1980 – 2049.

***Figure 1 Location of the selected weather stations used in the present study.***

***Table 1 Station altitude ($H_1$), model altitude ($H_2$) and the difference ($H_2$-$H_1$) at 5 selected weather stations in Norway [m a.s.l.].***

| 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 Empirical adjustment of dynamically downscaled data

## 3.1 PRECIPITATION

HIRHAM is run with “perfect boundaries”, applying observationally based re-analysed data (www.ecmwf.int/research/era/ERA-15/) from ECMWF[2] during the period 1979-1993 to define the boundary conditions. Temperature and precipitation data were interpolated from the HIRHAM grid points with bilinear interpolation to station sites. If HIRHAM is able to reproduce observational data satisfactory, the modelled precipitation values in the ERA-15 period (1979-1993) 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 HIRHAM is too coarse to give detailed estimates of point values. Thus the first refinement step (Eq. 1) was to adjust the interpolated precipitation data from HIRHAM. Adjustment factors for each calendar month were calculated from the ratio between mean monthly ERA-15 values and mean monthly values based on observations for the same period (1979-1993). Thus there are twelve (*i*) adjustment factors, $a_i$, for each station:

***Eq. 1***

$$a_i = \frac{RR_{i,OBS}}{RR_{i,ERA}}$$

$RR_{i,OBS}$ and $RR_{i,ERA}$ is mean monthly observed and modelled within the ERA15 dataset precipitation respectively for month (i).

These monthly adjustment factors are used to adjust the day-to-day precipitation from the model run (Adjustment 1):

***Eq. 2***

$$RR_{RCMJ1ijk} = a_i \, RR_{RCM\,ijk}$$

where $RR_{RCM1ijk}$ is the adjusted precipitation for day *j* of month *i* in year *k*, $RR_{RCM\,ijk}$ is the dynamically downscaled precipitation interpolated to station site.

The method summarised above has shown to be too simple and the need for better adjustments of the method to be applicable for impact studies is necessary. Consequently an empirical approach has been carried out for the modelled precipitation data to better represent the at site values.

Daily precipitation values, adjusted as outlined above, 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 that we want to model (Eq. 3).

***Eq. 3***

$$\frac{RR_{RCMJ1sc,ji} - m_{RCMJ1sc,i}}{std_{RCMJ1sc,i}} = \varepsilon_{sc,ji}$$

where $RR_{RCMJ1\,sc,ji}$ is daily precipitation adjusted with Eq. 2 at day number *j* in month *i* in the scenario period *sc.* $m_{RCMJ1sc,j}$ is the mean monthly precipitation value in month *i* in the scenario period *sc,* $std_{RCMJ1sc,j}$ is the standard deviation based on daily values for month *i* in the scenario period *sc, and* $\varepsilon_{sc,ji}$ is the residual at day *j* in month *i* in the scenario period *sc*.
We can force the control and scenario data to satisfactorily reproduce mean monthly values and standard deviation by using the ratio between the scenario and control mean values ($m$) and standard deviation ($\sigma$), $\gamma$ and $\beta$ respectively:

***Eq. 4a***

$$\gamma_{RR} = \frac{\sigma_{RCMJ1sc,i}}{\sigma_{RCMJ1ctrl,i}}$$

***Eq. 4b***

$$\beta_{RR} = \frac{m_{RCMJ1sc,i}}{m_{RCMJ1ctrl,i}}$$

If we multiply the daily residuals with the observed standard deviation multiplied with $\gamma$ and add the observed mean value multiplied with $\beta$, we force the mean value and variability for the control period to be reliably estimated and the mean differences in mean value and standard deviation is maintained:

***Eq. 5***

$$\overset{\wedge\wedge}{RR}_{RCMJ2sc,ji} = \varepsilon_{sc,ij} \times \left(\sigma_{obs,a} \times \gamma_{RR}\right) + m_{obs,i} \times \beta_{RR}$$

where $\overset{\wedge\wedge}{RR}_{RCMJ2sc,ji}$ is the adjusted precipitation at day *j* in month *i* for the scenario period.
If $m_{sc,i} > m_{obs,i}$, the problem with negative precipitation values appears. All the negative values are set equal to 0.0 mm, thus, the mean monthly precipitation sum and standard deviation based on daily precipitation values will be too large compared to the statistical moments based on observations. Eq. 2 and 3 are therefore performed all over again on the new dataset ($\overset{\wedge\wedge}{RR}_{RCMJ2sc,ji}$). The iteration is repeated until the mean value and the standard deviation is satisfactory reproduced.
The method outlined above will eliminate the trend in the dataset and only considerations of a scenario dataset compared to a control dataset on an average level will be of interest. By estimating the statistical moments of the scenario ($m_{sc}$ and $\sigma_{sc}$ in Eq. 3) for e.g. every 5 years, any trend in the data is maintained and analyses with transient model runs may be applicable.

## 3.2 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 adjust for this altitude difference, a temperature lapse rate which closely matches the average observed lapse rate in the troposphere $\left(-0.65^{\circ}C \big/ _{100m}\right)$ (Houghton, 1985) is used:

***Eq. 6***

$$T_{RCMJ1} = T_{RCM} - 0.65 \times \frac{\Delta h}{100}$$

where $T_{RCM}$ is daily interpolated temperature values from the regional climate model, $T_{RCMJ1}$ is daily adjusted temperature values and $\Delta h$ is the height difference.

However, the real lapse rate may deviate substantially from the average conditions during special weather situations. In a Nordic study covering Fennoscandia the temperature lapse rate also showed to vary with season (Tveito et al., 2000). Using the lapse rates from Tveito et al. (2000) the winter temperature was satisfactory adjusted; however, summer temperature remained too low. However, in order to meet the present demands from impact research scientists, we use the same empirical procedure as outlined for precipitation, except the last iteration step, to adjust daily temperature data. Absolute differences were used instead of relative changes as used for precipitation. The equations 3, 4a, 4b and 5 for precipitation can for temperature be written as outlined in equations 7, 8a, 8b and 9 respectively. The modelled temperature data with HIRHAM adjusted with equation 6 ($T_{RCMJ1}$) is first normalised and standardised (Eq. 7).

***Eq. 7***

$$\frac{T_{RCMJ1sc,ji} - m_{RCMJ1sc,i}}{std_{RCMJ1sc,i}} = \varepsilon_{sc,ji}$$

where $T_{RCMJ1sc,ji}$ is daily temperature adjusted with Eq. 6 at day number *j* in month *i* in the scenario period *sc*. $m_{RCMJ1sc,i}$ is the mean monthly temperature in month *i* in the scenario period *sc*, $std_{RCMJ1sc,i}$ is the standard deviation based on daily values from month *i* in the scenario period *sc*, and $\varepsilon_{sc,ji}$ is the residual at day *j* in month *i* in the scenario period *sc*.

The mean monthly ratio between the scenario and control is used for standard deviation ($\gamma_T$) and absolute mean monthly change is used ($\beta_T$) (Eq. 8a and 8b).

***Eq. 8a***

$$\gamma_T = \frac{\sigma_{RCMJ1sc,i}}{\sigma_{RCMJ1ctrl,i}}$$

***Eq. 8b***

$$\beta_T = m_{RCMJ1sc,i} - m_{RCMJ1ctrl,i}$$

If we multiply the daily residuals with the observed standard deviation multiplied with $\gamma_T$ and add the observed mean value and $\beta_T$:

***Eq. 9***

$$\overset{\wedge\wedge}{T}_{RCMJ2sc,ji} = \varepsilon_{sc,ij} \times \left(\sigma_{obs,a} \times \gamma_T\right) + (m_{obs,i} + \beta_T)$$

We then force the mean value and variability for the control period to be reliably estimated and the mean differences in mean value and standard deviation is maintained.

# 4 Results

## 4.1 PRECIPITATION

The methodology described above is applied on daily precipitation from a transient model run (HIRHAM) in the time period 1980-2049 (section 2). The control period is the period 1980-1999. A new scenario period is defined for every 5 year, maintaining the 5 year trend in the scenario. First, daily precipitation is interpolated from HIRHAM (called RCM in the figures) to the selected station sites (Figure 1), then adjusted with equation 1 (RCMJ1). Iterations with equation 5 are performed until satisfactory estimates of the statistical moments were reached (RCMJ2). Mean monthly precipitation sum from the three datasets (RCM, RCMJ1, RCMJ2) together with mean monthly observed precipitation sum (OBS) at the selected locations within the control period show that precipitation amounts in the RCM dataset is wrongly simulated compared to OBS (Figure 2). The RCMJ1 dataset show better agreement; however there is still too large disagreement compared to observations for the adjusted time series to be reliable. The next empirical adjustment step (RCMJ2), 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 a similar pattern (Figure 3); the variability is not well reproduced with HIRHAM but is satisfactory adjusted with the empirical adjustment method outlined above (RCMJ2).

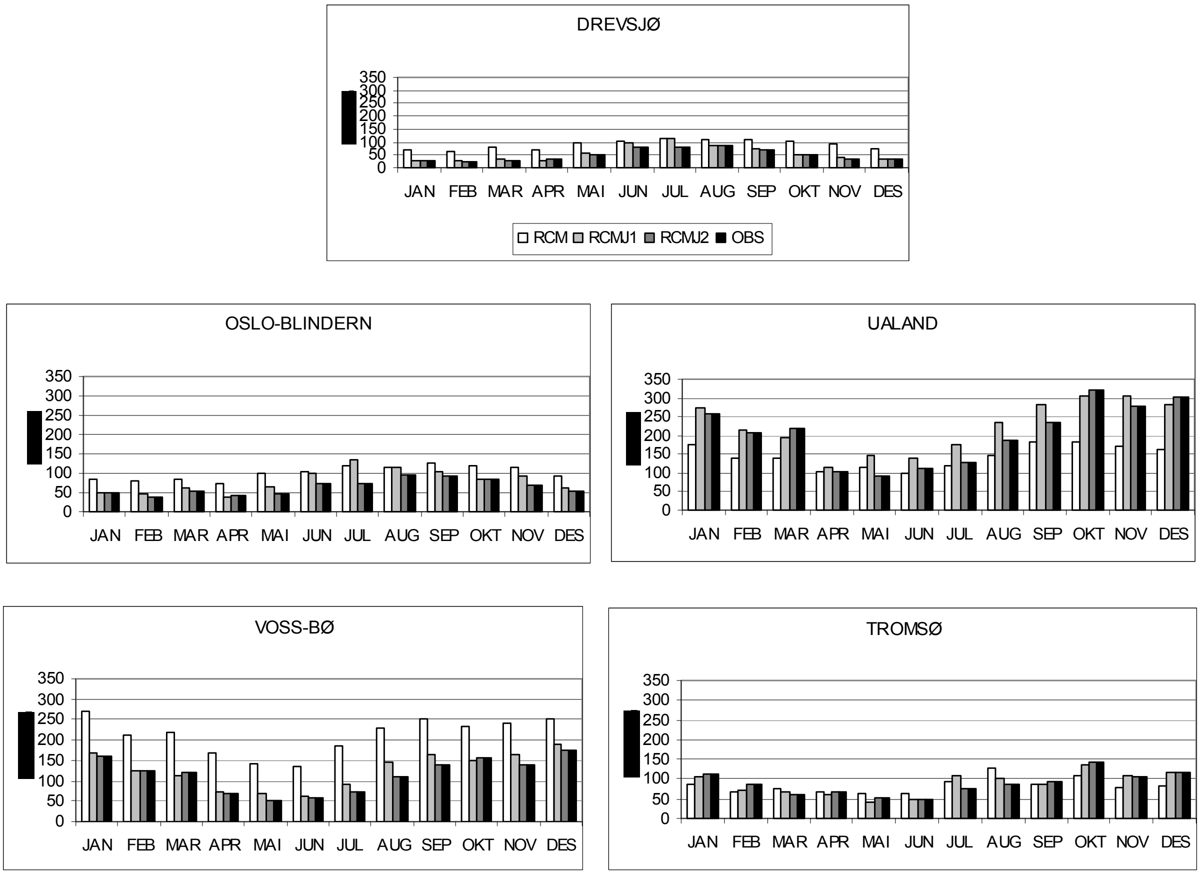

***Figure 2 Mean monthly precipitation sum at the selected stations interpolated from HIRHAM (RCM), adjusted with eq. 1 (RCMJ1), adjusted with eq. 2 and 3 (RCMJ2) and observed (OBS) for the control period (1980-1999).***

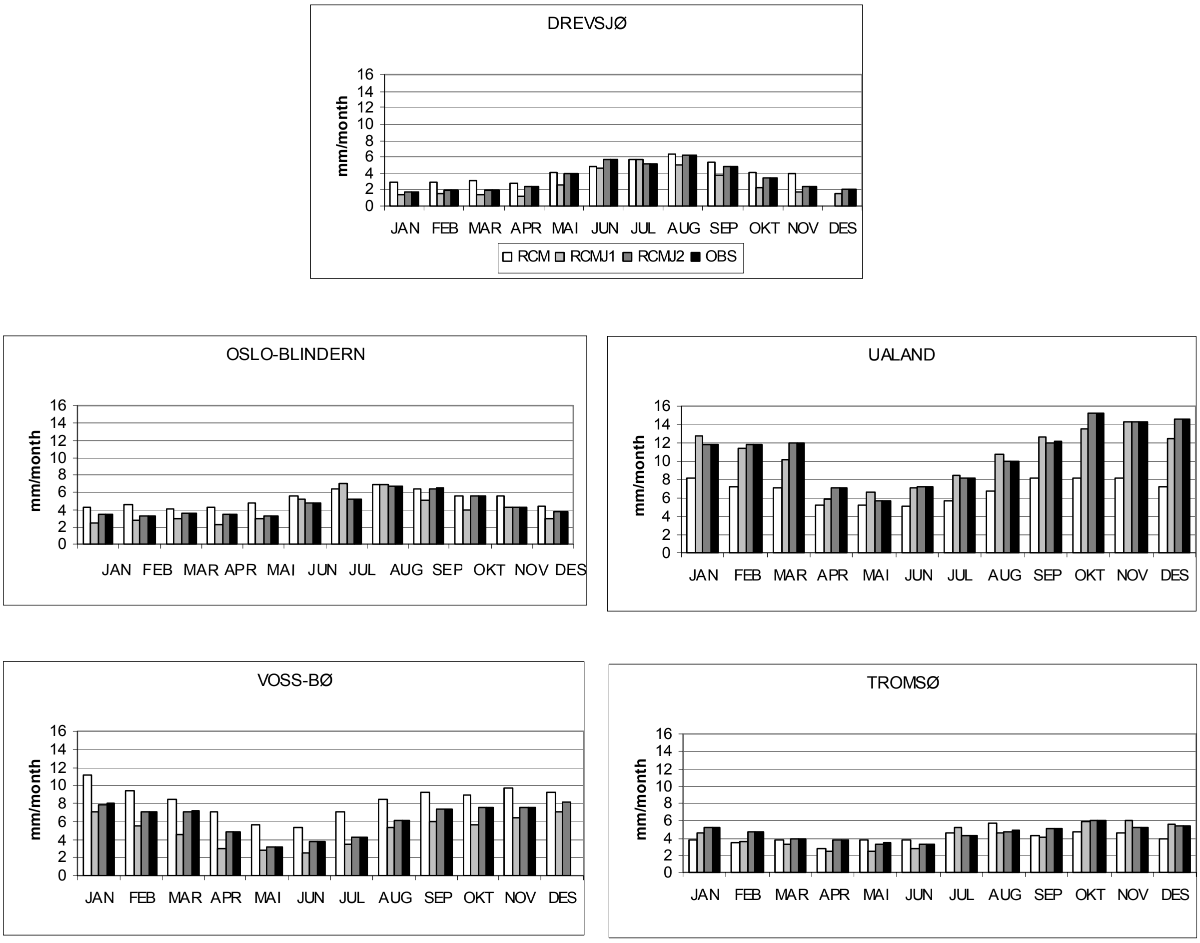

***Figure 3 Mean monthly standard deviation based on daily precipitation values at the selected stations interpolated from HIRHAM (RCM), adjusted with eq. 1 (RCMJ1), adjusted with eq. 2 and 3 (RCMJ2) and observed (OBS) for the control period (1980-1999).***

A well known problem with HIRHAM 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 in the RCM dataset is too large (Figure 4) both for number of days with precipitation > 0 mm, > 0.2 mm and >0.5 mm. After the adjustment (RCMJ2), the agreement between modelled and observed number of days with precipitation is improved.

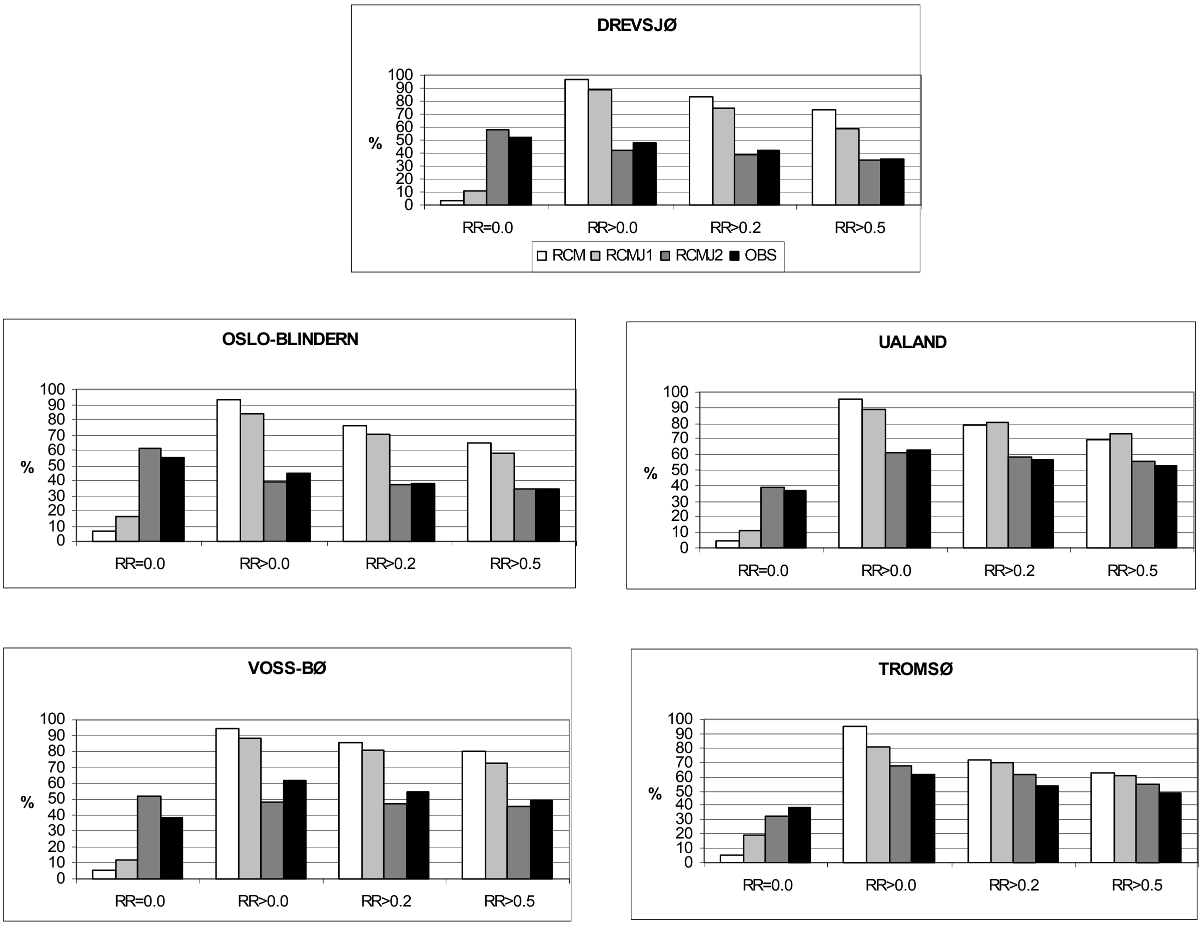

***Figure 4 Number of days with precipitation > 0.0 mm, >0.2 mm, > 0.5 mm and number of days without precipitation ( = 0.0 mm) at the selected stations interpolated from HIRHAM (RCM), adjusted with eq. 1 (RCMJ1), adjusted with eq. 2 and 3 (RCMJ2) and observed (OBS) for the control period (1980-1999).***

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 observed number of days with precipitation at the selected stations properly, at least on an average basis. The Figures 5 and 6 show that the adjusted precipitation (both RCMJ1 and RCMJ2) maintain 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.

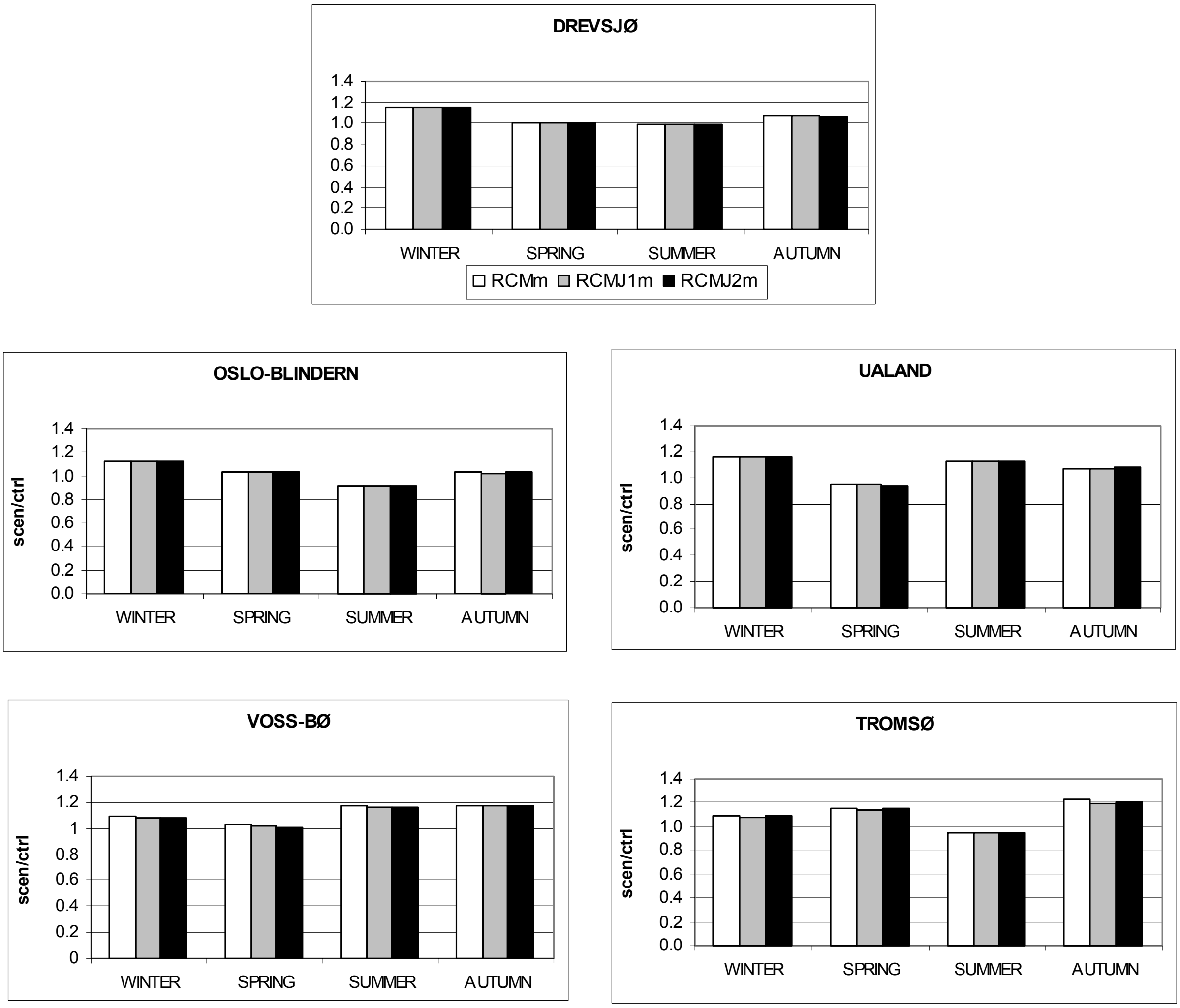

***Figure 5 Relative change in mean monthly precipitation at the selected stations interpolated from HIRHAM (RCM), adjusted with eq. 1 (RCMJ1), adjusted with eq. 2 and 3 (RCMJ2) and observed (OBS) for the control period (1980-1999).***

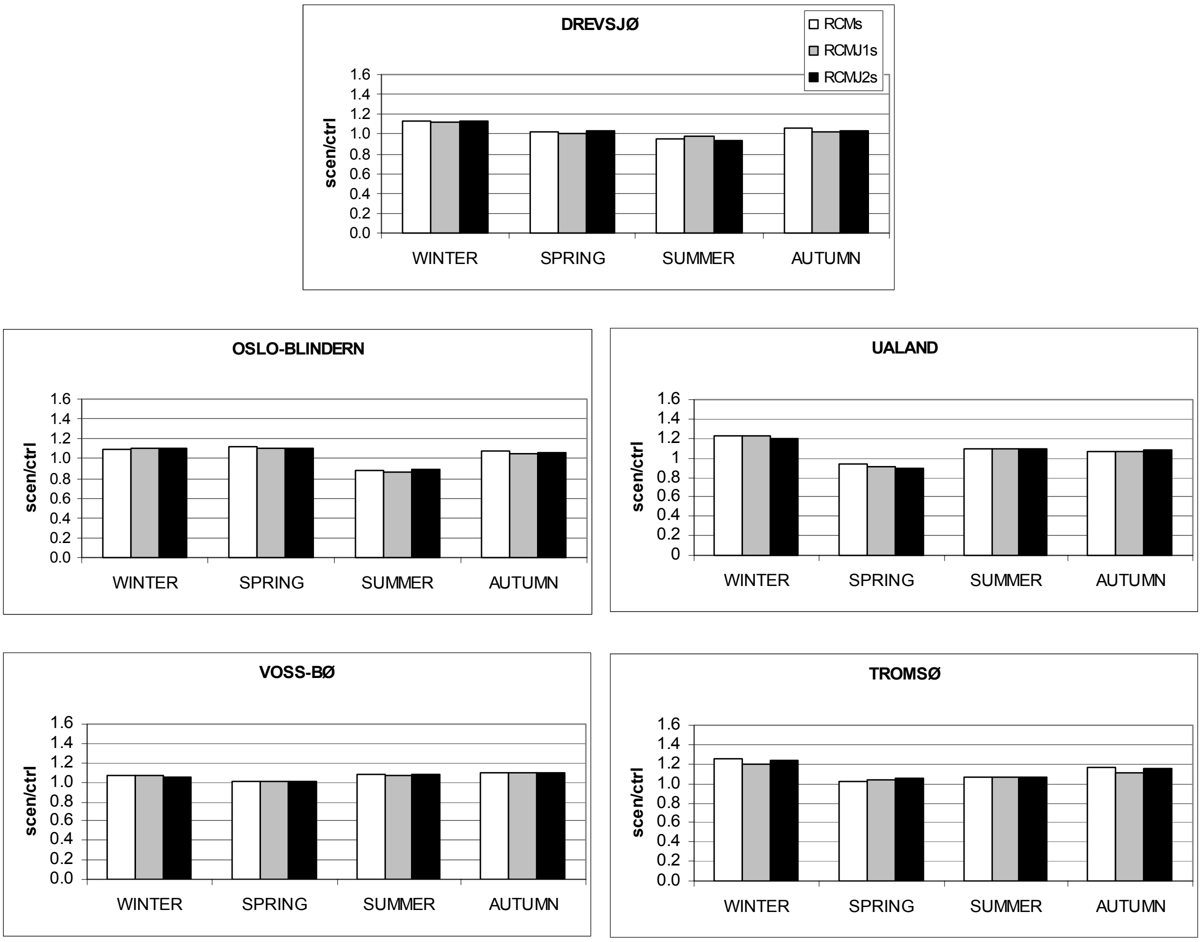

***Figure 6 Relative change in standard deviation based on daily precipitation at the selected stations interpolated from HIRHAM (RCM), adjusted with eq. 1 (RCMJ1), adjusted with eq. 2 and 3 (RCMJ2) and observed (OBS) for the control period (1980-1999).***

## 4.2 TEMPERATURE

Refinement of daily temperature values (section 2) is performed on interpolated temperature data from HIRHAM (RCM) to selected station sites (Section 2) on the transient run (1980-2049). A new scenario period is defined every 5 year, maintaining the 5 year trend in the scenario. Observations for the control period (1980-1999) were used to validate the methodology. Data from the regional climate model (RCM) is first adjusted with Eq. 6 (RCMJ1). The RCMJ1 temperature data is then adjusted with equation 5 (RCMJ2) and compared to observations in the control period (OBS). Both mean monthly temperatures and mean monthly standard deviation based on daily values show perfect agreement (Figures 7 and 8 respectively). The RCMJ2 (and RCMJ1) temperature data maintain the absolute mean monthly change in temperature, and absolute change in standard deviation based on daily temperature values obtained by HIRHAM (Figure 9 and 10 respectively). The selected scenario projects a future warming at all the selected stations, especially in the north. The trend is maintained.

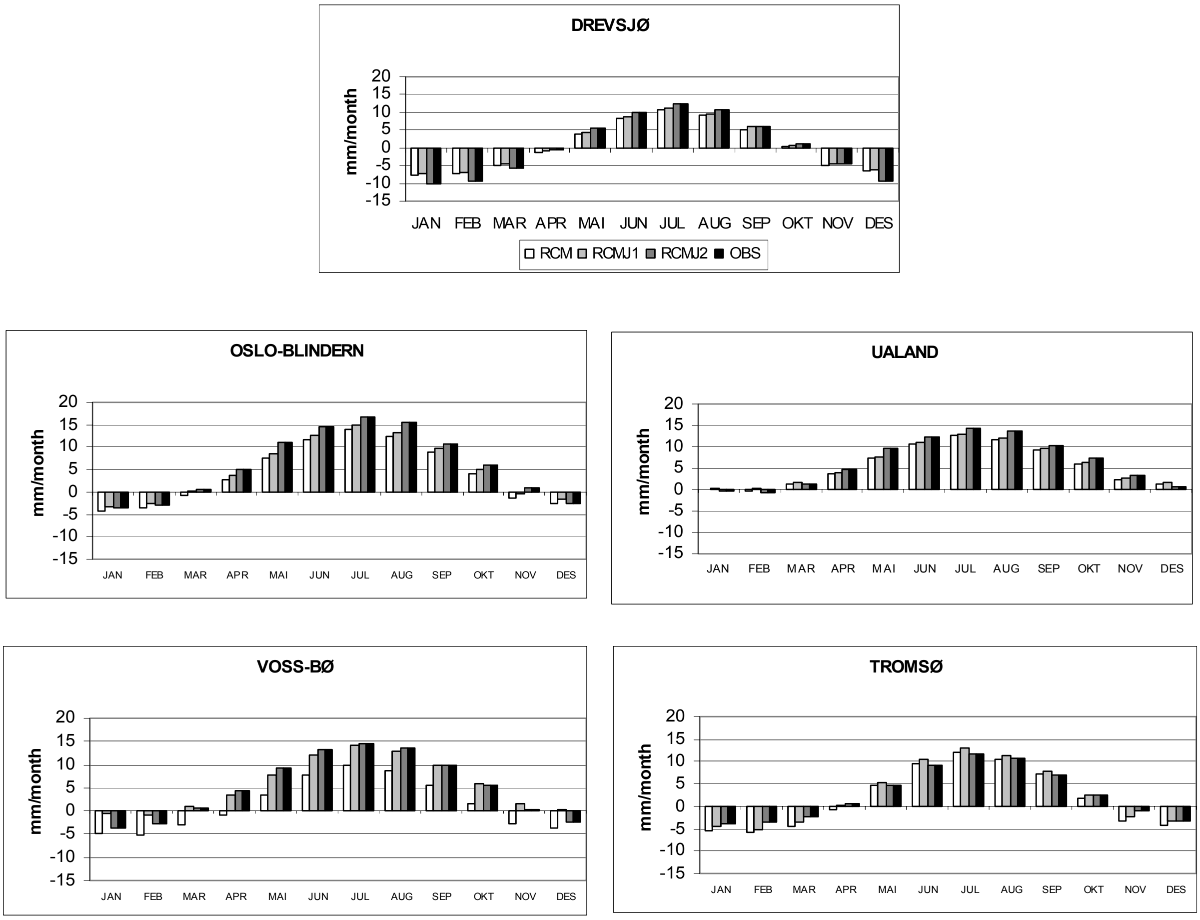

*Figure 7 Mean monthly temperature value at the selected stations interpolated (RCM), adjustment 1 (RCMJ1), adjustment 2 (RCMJ2) and observed (OBS) for the control period (1980-1999).*

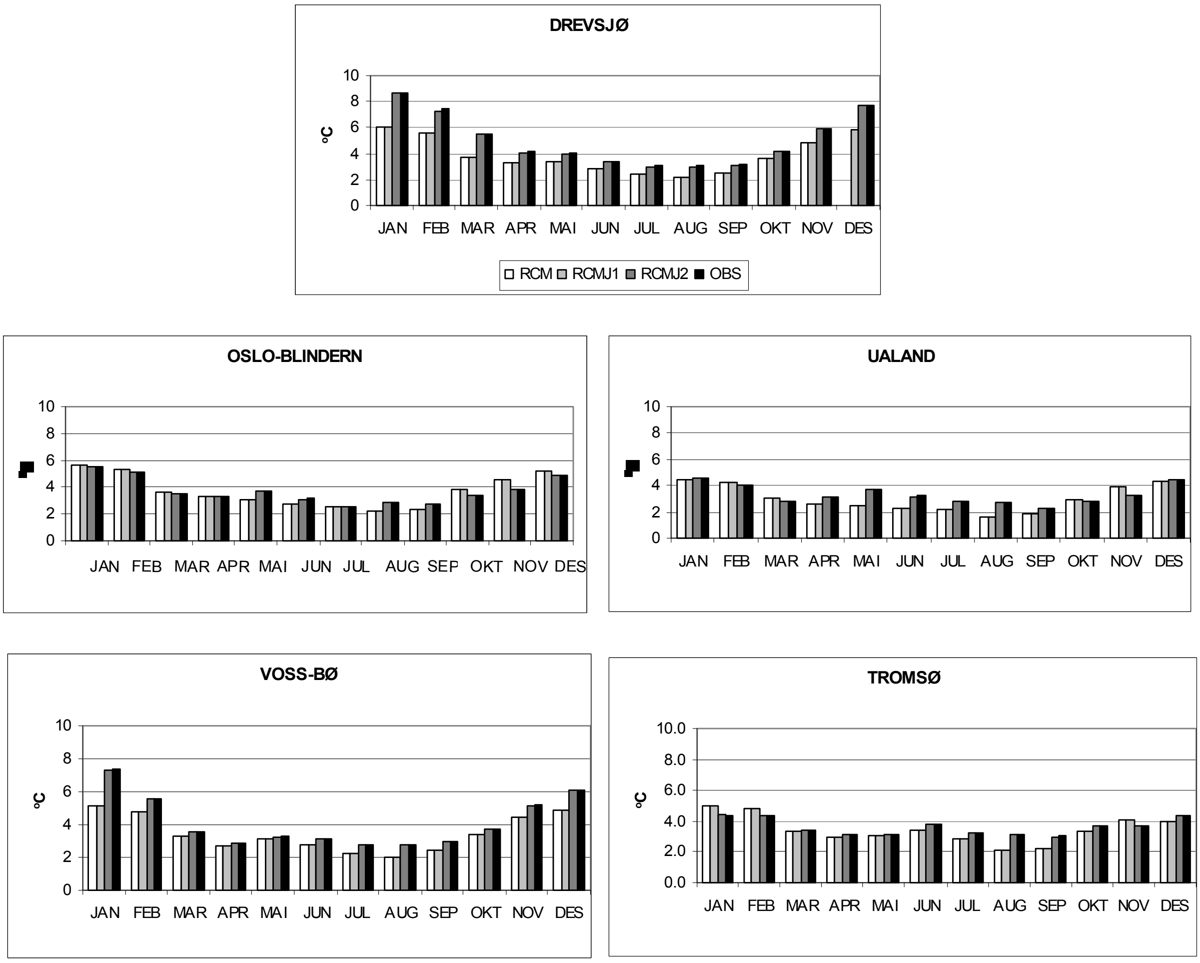

***Figure 8 Standard deviation based on daily temperature values at the selected stations interpolated from HIRHAM (RCM), adjusted with eq. 1 (RCMJ1), adjusted with eq. 2 and 3 (RCMJ2) and observed (OBS) for the control period (1980-1999).***

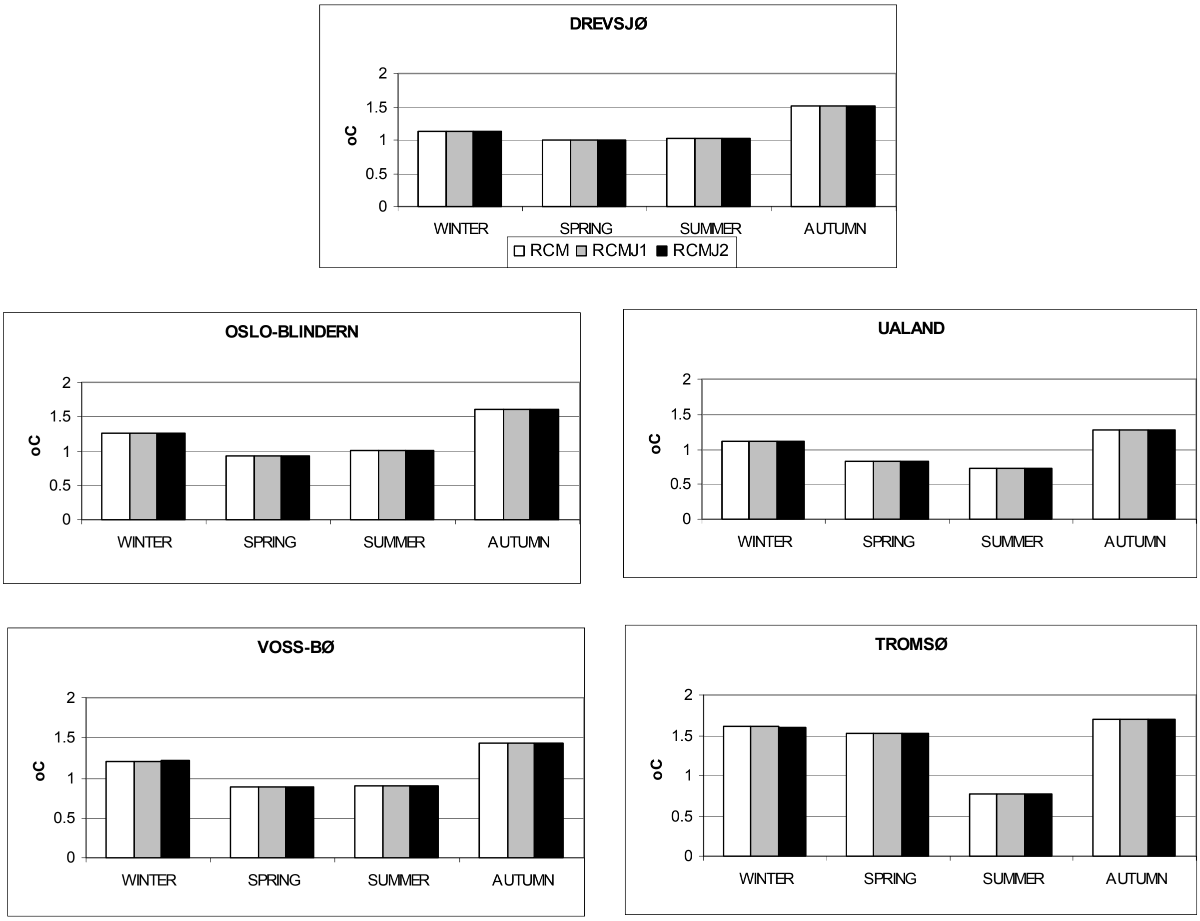

*Figure 9 Absolute change in mean monthly temperature value at the selected stations interpolated from HIRHAM (RCM), adjusted with eq. 1 (RCMJ1), adjusted with eq. 2 and 3 (RCMJ2) and observed (OBS) for the control period (1980-1999).*

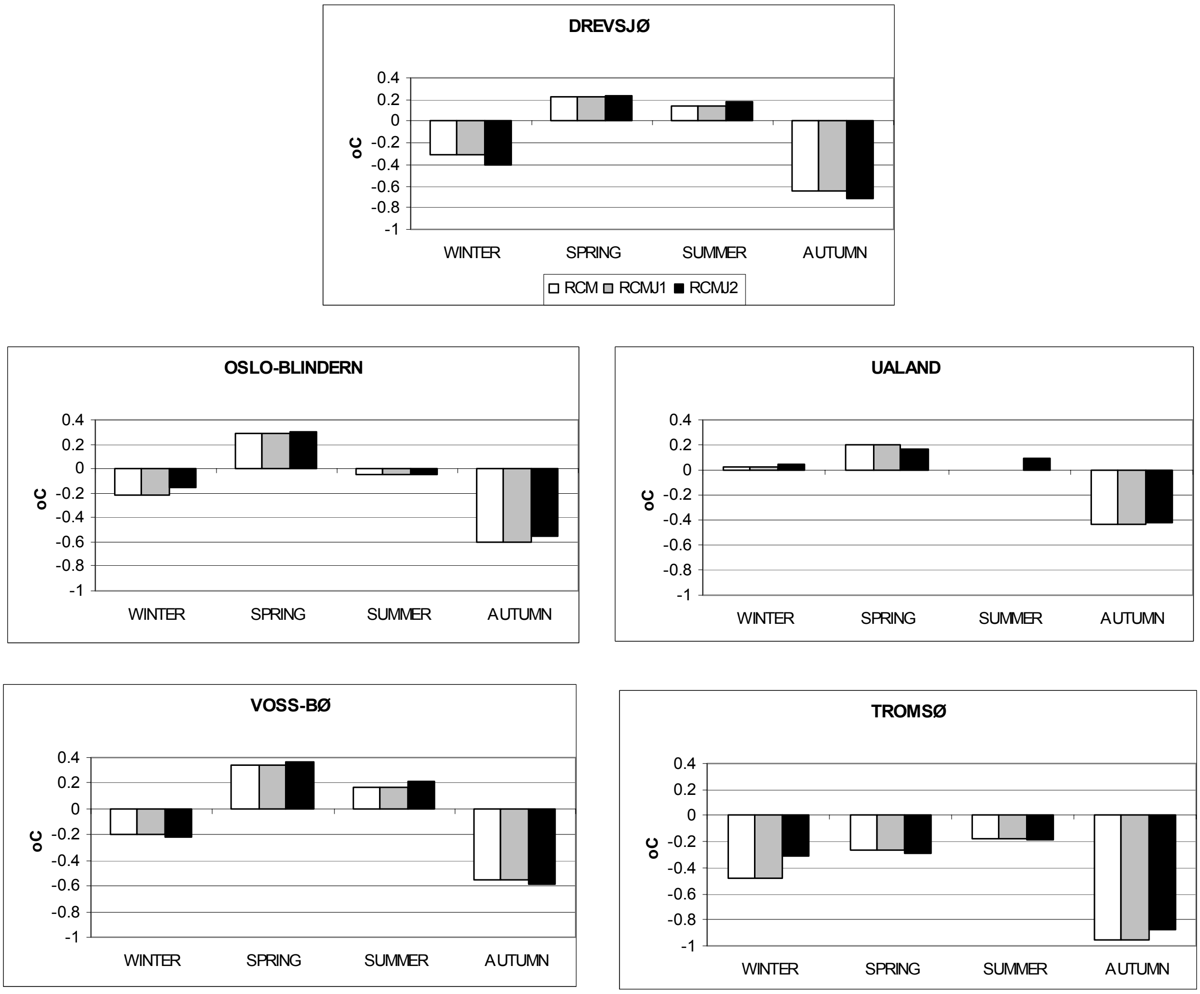

***Figure 10 Absolute change in mean monthly standard deviation based on daily temperature values at the selected stations interpolated from HIRHAM (RCM), adjusted with eq. 1 (RCMJ1), adjusted with eq. 2 and 3 (RCMJ2) and observed (OBS) for the control period (1980-1999).***

# 5 Applicability for impact research

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) on an average level. It is shown that HIRHAM 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 HIRHAM 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 intact after the adjustment and the adjusted precipitation and temperature data from the control period reproduce the same statistics as for the observed climate, which ideally should be expected by HIRHAM. Thus, it is possible to use the adjusted scenario data as transient time series input to effect models. In the current study, a new scenario period is defined every 5 year maintaining the 5 year trend in the scenario data.

The method outlined in the present paper is a rather simple empirical adjustment method that requires observations of precipitation and temperature at the selected stations. It should, however, be stressed that the uncertainty connected to AOGCMs and regional climate models of projections of the future climate are the same after the adjustment.

# 6 Summary and conclusions

Realistic downscaling of AOGCMs are important for impact studied. However, the resolution is too coarse either in space (dynamical downscaling) or in time (empirical downscaling). Thus, the need for further adjustments is crucial for the scenarios obtained with regional climate models to be used locally as transient time series. An advantage of the empirical refinement method presented here is that it is simple and the need for computer resources is limited. The adjustment of dynamically downscaled daily precipitation data does reproduce the variability of historical records and mean monthly values on an average basis well, and the trend obtained with the regional climate model, in this case HIRHAM, is maintained after the adjustment.

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## Notes

1 The RCM at MPI, based on HIRLAM (HIgh Resolution Limited Area Model) dynamics and ECHAM physics.

2 European Centre for Medium-Range Weather Forecast

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