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Adjustment of dynamically downscaled temperature and precipitation data in Norway

Report 20/02

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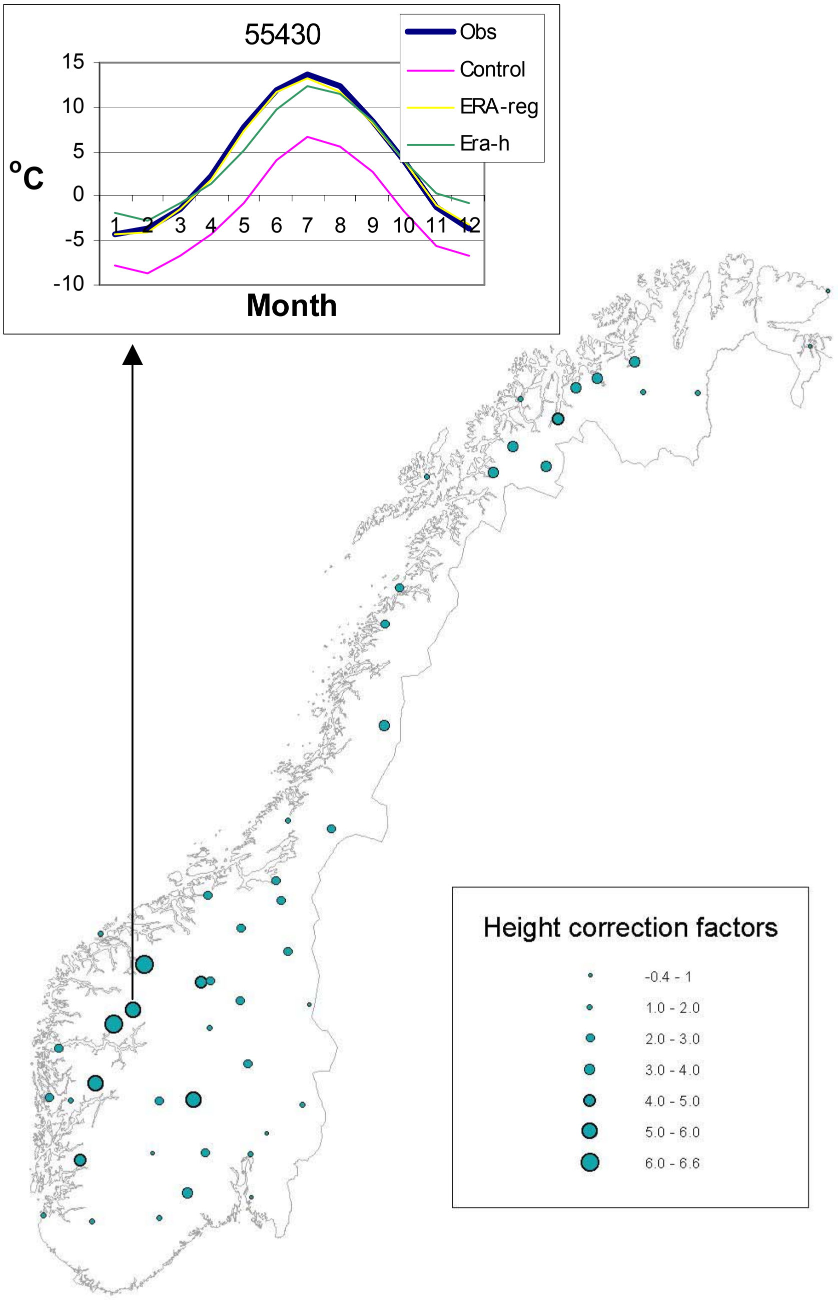

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SUMMARY:

Dynamically downscaled daily values of temperature and precipitation data for 55 sites in Norway are adjusted to represent the stations site. The precipitation data in the “control period” (1980-2000) and the “scenario period” (2021-2050) are adjusted with the mean monthly ratio between the ERA-15 data and the observed data for the same period (1979-1993). The temperature data are, for the same periods, adjusted with monthly regression equation between the ERA-15 data and the observed data for the same period (1979-1993). The temperature data are, at some selected stations, height corrected as well to be compared to the data adjusted with regression.

It is found that the precipitation data was satisfactory adjusted. The method may, however, be sophisticated with correcting with respect to weather type as well. The results from temperature data adjusted with regression was found to be biased as the increase in temperature in the scenario period was reduced. The height correction method was found to be a rather good adjustment method. There are, however, problems concerning the winter period. The adjustment methods and the adjusted temperature and precipitation data are described in the present report.

SIGNATURES:

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Torill Engen Skaugen	Eirik J. Førland
Scientist	Acting head of the Climatology Division

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1. Introduction

The global air temperature has increased during the last 150 years (IPCC, 2001). In Norway both annual air temperatures and precipitation have increased during the last 100 – 150 years (Førland et al, 2000). The global change in climate is, at least partly, thought to be caused by human induced greenhouse gasses. In the years to come, human activity will lead to further increase in the atmospheric concentration of greenhouse gasses. Temperature and precipitation scenarios are obtained by different global climate models and for various emission scenarios (IPCC, 2001). In the second phase of the Coupled Model Intercomparison Project (CMIP2; Meehl et al. 2000), results from 19 coupled climate models forced by the same CO_2 increase (1% per year) were compared. The different models give different scenarios for the future, but they all indicate that Norway will get a warmer climate, and most of them also indicate a wetter climate (Räisänen, 2001). The spatial resolution in these global models is, however, too coarse to give reliable results on a regional scale. In Norway, local and regional scenarios are studied in the Regional Climate Development Under Global Warming (RegClim). Information of the project is available at the Internet; http://www.nilu.no/regclim. One of the overall aims is to estimate probable changes in the regional climate in Northern Europe, bordering sea areas and major parts of the Arctic, given a global climate change.

The RegClim project has, up to now, worked mainly on the results from the global climate model of the MaxPlanck-Institut für Meteorologie in Hamburg (MPI) with the AOGCM[1] ECHAM4/OPYC3 with the GSDIO integration (Roeckner et al., 1999). In this integration, the concentration of greenhouse gases and sulphur aerosols have been specified according to the IPCC IS92a scenario (IPCC, 1992). This integration describes the climate development from 1860 up to 2050. Both expected increase in greenhouse gasses and direct and indirect effects of aerosols are accounted for as well as the change of the amount of ozon in the troposphere. The model gives a realistic description of the present climate in Norway and is therefore chosen as a basis for the downscaling of temperature and precipitation in Norway.

The results from ECHAM4/OPYC3 have a resolution of about 300x300 km^2. In RegClim both empirically and dynamically based techniques were used to downscale the AOGCM results to local scale. Empirical downscaling techniques involve identification of empirical links between observed local climate elements, and large-scale atmospheric fields. These relations are then used to estimate local climate from the large-scale fields produced by global climate models. So far the empirical downscaling in RegClim has been performed at monthly basis (Hanssen-Bauer et al, 2000, 2001, Benestad, 2000).

In dynamical downscaling, the results from a global climate model are used as input in a regional weather forecast model with finer resolution. In RegClim, the regional climate model (RCM) at MPI, HIRHAM, was applied. It is based on the dynamics of HIRLAM[2] and the

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[1] AOGCM means coupled atmospheric-ocean global general circulation model

[2] **HI**gh **R**esolution **L**imited **A**rea **M**odel. The project with this model started with the Nordic countries in 1985. Ireland, the Netherlands and Spain have later joined the project.

physics of ECHAM[3]. In RegClim it was run with a spatial resolution of 55x55 km^2 and a 6 hourly time resolution, over an area that covers Northern Europe, the northern North Atlantic and parts of the Arctic. Both the climate of today (1980-1999) and the climate of the future (2030-2049) were dynamically downscaled from the GSDIO scenario (Bjørge et. al, 2000). For evaluation purposes, HIRHAM was also run with “perfect boundaries”, applying observationally based re-analysed data from the ECMWF[4] during the period 1979-1993 (“ERA-15 data”) to define the boundary conditions. Comparison of results from this run and observations from Norwegian meteorological stations during the same period show that though temperature- and precipitation fields produced by HIRHAM are far more realistic than the fields produced by ECHAM4/OPYC3, the resolution is still too coarse to give values that are directly comparable to point observations.

Studies of potential climate change impacts often depend on meteorological input with fine resolution both in space and time. The presently available empirically downscaled climate scenarios have a coarse time scale, while the dynamically downscaled scenario has a too coarse spatial resolution for many impact studies. In the present study, methods are tested for further adjusting the dynamically downscaling results in order to make them comparable to site observations.

The observed and modelled data applied in the present study are described in chapter 2. The methods used to adjust the climate data to the station sites and the difficulties concerning these methods are described in chapter 3. The factors used to adjust the dynamically downscaled precipitation and temperature data are presented in chapter 4, and a summary of the work presented in this report are given in chapter 5.

The temperature and precipitation data presented in this report are used to simulate the runoff in selected catchments areas and look into the total runoff pattern of Norway (Roald et al., in preparation), and also to study the change in extreme precipitation events (Skaugen et al., 2002).

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[3] The atmospheric global climate model at MPI-Hamburg, based on an earlier version of the ECMWF model.

[4] European Centre for Medium-Range Weather Forecast

2. Data

2.1 Observational data

Climate data from 55 stations were applied to produce and evaluate adjustment factors for dynamically downscaled values of temperature and precipitation. The selection of stations was done with respect to existing calibrated HBV models and to geographical location (Roald et al., 2002). The aim was to obtain a station density net covering all regions of Norway. The locations of the selected stations are presented in Fig. 2.1, station information is given in Appendix A.

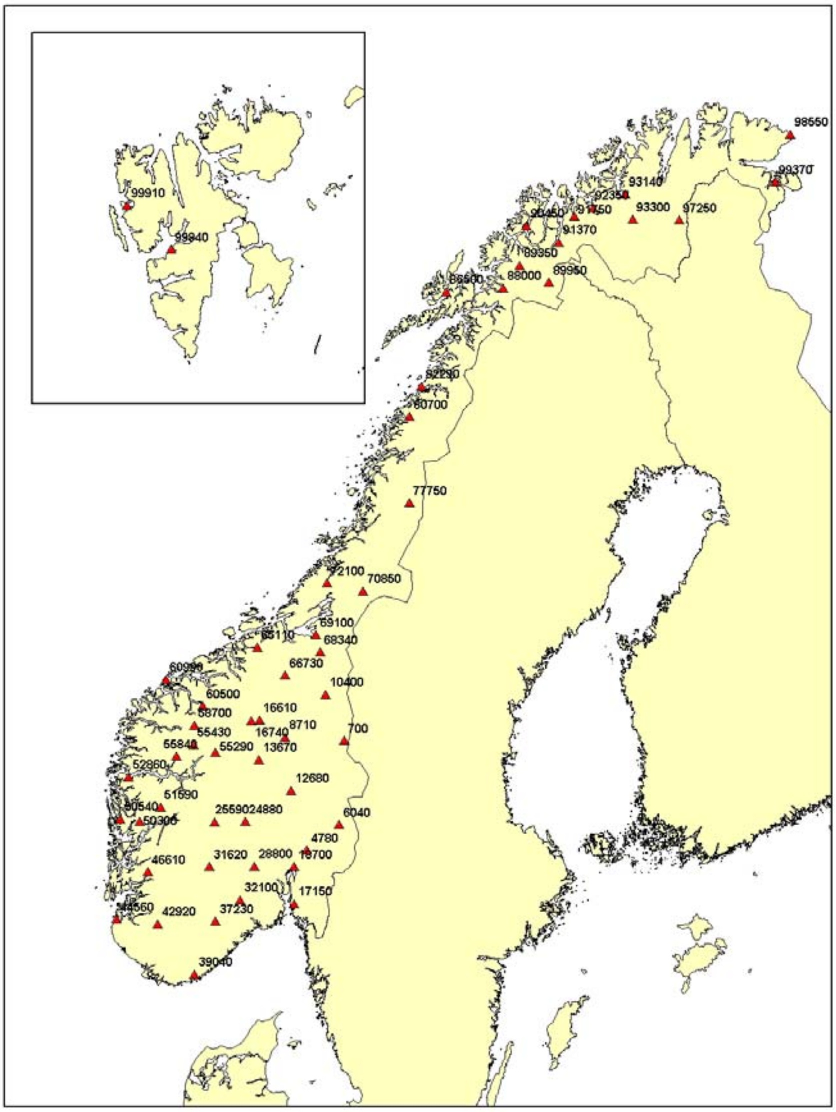

Figure 2.1 The sites of the selected precipitation and temperature observation stations.

2.2 Model data

Temperature and precipitation data were interpolated from the HIRHAM model with the bilinear interpolation method to the 55 station sites (Fig. 2.1). Model data from three HIRHAM runs were interpolated: The ECHAM4/OPYC3 downscaling was interpolated for the periods 1980-1999 ("control period") and 2030-2049 ("scenario period"). Additionally, the perfect boundary run (cf. Chapter1) from 1979-1993 ("verification period") using ERA-15 data as boundary conditions was interpolated.

3. Methods on adjusting the dynamically downscaled precipitation and temperature datasets

Precipitation and temperature data has been interpolated from the HIRHAM model (dynamically downscaled) with the bilinear interpolation method at 55 selected sites (cf. Chapter 2). As sorted out in chapter one, the HIRHAM model does not estimate the temperature and precipitation at the station sites properly. The dynamically downscaled temperature and precipitation data had to be adjusted.

If HIRHAM was able to reproduce observational data satisfactorily, the modelled temperature and precipitation values in the verification period (1979-1993) should be comparable with observations from the same period. Simple correlation analyses of daily values within different months shows that this is not the case (cf. Figs 4.1 and 4.7). This may have different causes. The terrain in the HIRHAM model is not properly accounted for, and the data should be adjusted to the real altitude prior to the comparison with observations. Further, the temperature and precipitation data from the dynamical downscaling, even though there has been a bilinear interpolation to specific sites, represent an area covering 55x55 km^2. Thus the values are still smoothened out compared to the at site values. There may also be difficulties concerning the model. Though the boundary conditions are given, there are possibilities of getting storm tracks and air pressure patterns that differ from the observed ones. There may of course be further difficulties with the models as well. Some of the deviations between modelled climate and observations (e.g. errors connected to topography) may be of systematic character. Such errors may be reduced by use of empirical adjustment factors.

Modelled and observed data during the verification period are applied to develop empirical adjustment factors. The temperature and precipitation datasets are sorted after months, as the adjustments probably show a seasonal variability. Each day for all January months of the ERA-15 dataset is compared, and mean value and variance at each station for every month is estimated both for the observed data and for the modelled data. The HIRHAM model simulates 30 days in each month through out the year.

3.1 Precipitation

The precipitation from the ERA-15 dataset is adjusted with the ratio between the ERA-15 mean monthly value and the observed mean monthly value for the data period (1979-1993) within each month. Thus there are twelve adjustment factors at each station to adjust the day-to-day precipitation.

Equation 3.1 $$Y = aX$$

where X is the downscaled precipitation and *a* is the adjustment factor.

3.2 Temperature

Two different approaches are applied for adjusting the downscaled temperature data. Linear regression is applied in order to get a good fit with the observed monthly average temperature. It is, however, realised that the linear regression reduces variance as well as systematic climate change signals compared to the direct results from the dynamical downscaling. Consequently, an alternative adjustment including only height correction is suggested.

Regression

The temperature from the ERA-15 dataset is adjusted with the regression coefficients (*a* and *b*) from the regression equation between the observed and downscaled daily temperatures from the ERA-15 period. The adjustment equation can be expressed as:

Equation 3.2 $$Y = aX + b$$

where X is the downscaled temperature, Y is the adjusted downscaled temperature, *a* and *b* are regression coefficients.

Elevation correction

The temperature from the downscaled dataset is, at selected stations, adjusted with 0.65 ^{o}C per 100 meter height difference between the model altitude at the station site and the station height. This compensated for a vertical temperature gradient of -0.65 ^{o}C per 100 m, which represents the average conditions fairly well. The adjustment was applied both for control- and scenario dataset, and the adjustment equation can be expressed as:

Equation 3.3 $$Y = X + b$$

where X is the downscaled temperature, b is the correction factor ($\Delta H * (-0.65)$) and Y is the adjusted downscaled temperature.

4. Adjusting the dynamically downscaled precipitation and temperature datasets

4.1 Precipitation

For each station the precipitation mean value and variance within each month are estimated based upon the ERA-15 dataset and the observations. These statistical moments are supposed to be equal, and even the day-to-day data is supposed to be comparable (cf. Chapter 3). The monthly correlation between daily observations and the ERA-15 dataset is shown in Fig. 4.1 (and Appendix B). The figure shows that the correlation is low. It is however better in the winter months than in the summer months. The drop in correlation during summer was to be expected because the convective precipitation in summer is rather inhomogeneously distributed in time and space and thus difficult to predict.

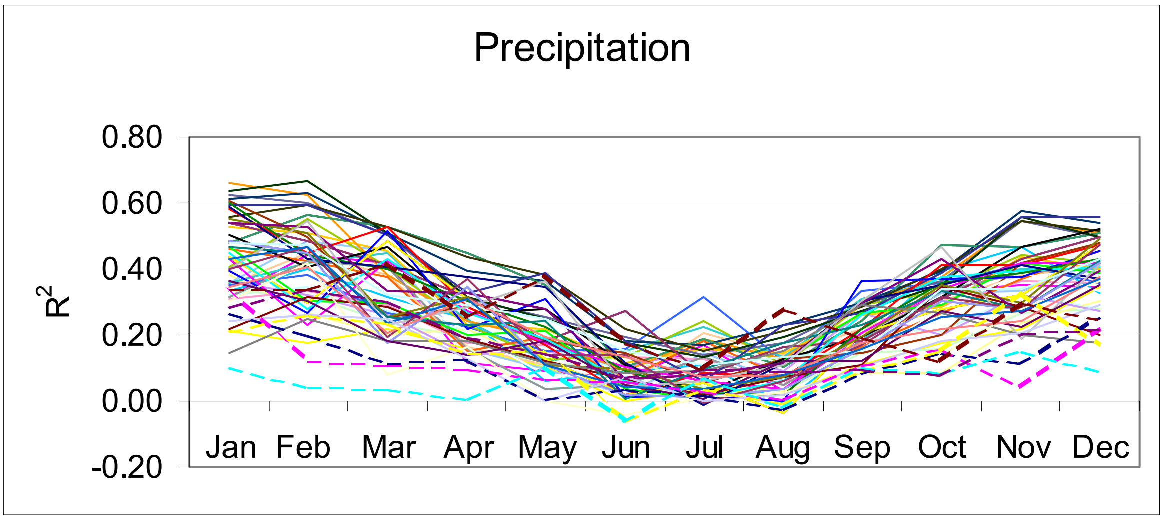

Figure 4.1 Monthly correlation between daily precipitation observations and the ERA-15 dataset (1979-1993).

It is a well-known effect of general circulation models such as the HIRHAM model that it, because of smoothening of the terrain, simulates small amounts of precipitation on days where there should have been no precipitation. To take this into account, daily precipitation is set to 0 mm when the model simulates precipitation less than 0.2 mm. This adjustment was applied both during the ERA 15 period, the control period and the scenario period. The threshold, however, should perhaps have been higher.

The control- and the scenario datasets are then adjusted with the ratio between the observed data and the mean monthly ERA-15 dataset for the same period (cf. Chapter 3). The mean annual value and the standard deviation for the control period at the stations studied (cf.

Chapter 2) are presented in Appendix C. These statistical moments should be comparable to the observed values (given that 20 year is a sufficiently long period to define climatology).

Appendix C shows rather large differences in the mean value between the observed dataset and the modelled data in the control period. The adjusted dataset shows, as is to be expected, more similar values to the observed dataset even though there are still some differences. The adjusted dataset is thus improved with respect to the mean value. Concerning the standard deviation, the effect of the adjustment is more random. Because the adjustment factors tend to be less than one at all stations, it was found that the variance for almost all the stations was reduced in the adjusted data compared to the unadjusted data (Appendix C).

The factors used to adjust the ERA-15 precipitation data are shown in Table 4.1. Geographically the factors are shown in the Figures 4.2, 4.3 and 4.4. The adjustmentfactor at selected stations are presented graphically as well (Fig. 4.5). If the adjustment factor is larger (smaller) than 1, the mean monthly precipitation value is modelled too low (high). If the adjustment factor is equal to 1 the mean monthly precipitation is perfectly modelled.

The figures and table show that, in some areas along the west coast, the adjustment factors are larger than one in most months. The reason is probably that the model underestimates the orographic enhancement of precipitation in the precipitation maximum zone. In summer, areas with adjustment factors larger than one are also found in other coastal parts of southern Norway. This may indicate that convective precipitation is underestimated by the model. Most of the adjustment factors are still below 1. The low values in the precipitation minimum zone leeward of mountain areas are probably partly caused by orographic effects that are not properly resolved in the model. However, climate models also show a more general tendency to over estimate precipitation at high latitudes. This may be caused by modelling problems, but it may also reflect problems connected to measuring precipitation at high latitudes.

The change in precipitation in the scenario period compared to the control period are obtained by the ratio between the two periods (Førland et al., 2000). The change in precipitation from control to scenario period is, as excepted, similar for the adjusted precipitation data as for the original HIRHAM precipitation (Eq. 3.1).

Table 4.1 The factors used to adjust the HIRHAM precipitation data for the control and scenario period.

Stnr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
700	0.53	0.53	0.46	0.46	0.58	1.06	1.05	0.94	0.70	0.66	0.52	0.50
4780	0.85	0.81	0.79	0.65	0.73	1.11	1.32	1.20	0.90	0.95	0.91	0.80
6040	0.58	0.51	0.57	0.56	0.61	1.22	1.23	0.93	0.71	0.72	0.64	0.60
8710	0.59	0.49	0.44	0.38	0.47	0.82	0.86	0.84	0.56	0.68	0.66	0.52
10400	0.52	0.56	0.40	0.38	0.47	0.78	0.87	0.79	0.57	0.45	0.49	0.46
12680	0.68	0.66	0.55	0.35	0.41	0.70	0.80	0.81	0.66	0.75	0.72	0.63
13670	0.66	0.49	0.47	0.41	0.48	0.69	0.80	0.76	0.50	0.57	0.59	0.45
16610	0.40	0.43	0.36	0.27	0.36	0.64	0.82	0.75	0.45	0.47	0.37	0.36
16740	0.39	0.34	0.25	0.25	0.29	0.53	0.71	0.60	0.33	0.42	0.37	0.39
17150	0.82	0.74	0.81	0.59	0.80	1.24	1.68	1.45	0.89	1.07	0.88	0.80
18700	0.68	0.62	0.70	0.53	0.62	0.99	1.36	1.33	0.88	0.81	0.76	0.70
24880	0.49	0.37	0.29	0.25	0.43	0.53	0.73	0.73	0.44	0.57	0.44	0.36
25590	0.98	0.64	0.72	0.57	0.61	0.71	0.83	0.80	0.61	0.90	0.71	0.73
28800	0.68	0.60	0.56	0.45	0.65	0.82	1.08	0.93	0.59	0.87	0.65	0.55
31620	1.25	0.80	0.70	0.48	0.63	0.70	0.89	0.90	0.72	0.90	0.75	0.73
32100	0.48	0.47	0.44	0.32	0.76	0.69	1.02	1.12	0.78	0.87	0.56	0.50
37230	0.80	0.65	0.56	0.48	0.78	0.63	1.03	1.16	0.75	1.10	0.79	0.67
39040	1.19	0.85	0.96	0.71	1.14	1.02	1.52	1.61	1.17	1.35	1.19	1.03
42920	1.38	1.16	0.98	0.82	1.00	1.04	1.38	1.26	1.31	1.56	1.25	1.26
44560	0.57	0.55	0.56	0.65	0.84	0.89	1.01	0.93	0.92	0.91	0.81	0.62
46610	1.06	1.08	0.94	0.97	1.02	0.93	1.06	1.11	1.20	1.20	1.21	1.17
50300	1.04	1.11	1.06	1.21	1.34	1.21	1.33	1.19	1.49	1.32	1.25	1.22
50540	0.67	0.79	0.84	0.97	0.95	0.88	1.03	0.92	1.03	0.94	0.98	0.88
51590	0.57	0.57	0.50	0.50	0.52	0.53	0.60	0.59	0.71	0.65	0.64	0.65
52860	1.34	1.43	1.20	1.37	1.16	1.06	1.17	1.14	1.64	1.44	1.46	1.43
55290	0.73	0.59	0.57	0.55	0.54	0.68	1.15	0.99	1.00	0.94	0.66	0.59
55430	0.89	0.83	0.79	0.62	0.63	0.63	0.76	0.74	0.93	1.03	0.99	0.92
55840	1.01	1.06	0.88	0.88	0.74	0.67	0.83	0.83	1.18	1.07	1.09	1.08
58700	0.69	0.71	0.56	0.61	0.42	0.52	0.61	0.59	0.71	0.73	0.65	0.72

60500	0.58	0.56	0.46	0.44	0.33	0.37	0.50	0.41	0.46	0.50	0.57	0.57
60990	0.69	0.92	0.69	0.76	0.65	0.69	0.75	0.82	1.00	0.85	0.89	0.75
65110	1.09	1.33	0.81	0.86	0.92	0.84	0.87	0.84	1.10	1.24	1.25	1.21
66730	0.53	1.00	0.50	0.45	0.49	0.79	0.97	0.75	0.54	0.48	0.61	0.54
68340	0.47	0.56	0.42	0.47	0.66	0.91	0.97	0.76	0.70	0.53	0.47	0.49
69100	0.51	0.57	0.43	0.50	0.58	0.71	0.82	0.69	0.65	0.53	0.45	0.54
70850	0.74	0.75	0.57	0.61	0.67	0.94	1.15	0.73	0.83	0.66	0.61	0.68
72100	1.02	1.03	0.77	1.03	0.91	0.81	0.93	0.85	0.99	0.94	1.07	1.04
77750	0.89	0.74	0.54	0.52	0.53	0.62	0.73	0.64	0.73	0.72	0.71	0.67
80700	1.20	1.12	0.92	1.08	1.07	1.09	1.54	1.10	1.27	1.31	1.38	1.20
82290	0.50	0.47	0.47	0.45	0.59	0.55	0.85	0.58	0.60	0.60	0.61	0.56
86500	1.09	1.09	0.88	1.02	0.92	0.66	0.92	0.63	0.75	1.10	1.28	1.24
88000	0.86	0.84	0.53	0.38	0.64	0.46	0.86	0.66	0.64	0.74	0.69	0.89
89350	0.53	0.45	0.31	0.29	0.34	0.33	0.65	0.53	0.43	0.48	0.55	0.54
89950	0.22	0.16	0.11	0.10	0.31	0.49	0.99	0.59	0.39	0.30	0.24	0.26
90450	0.90	0.80	0.62	0.68	0.63	0.56	0.87	0.63	0.68	0.84	0.98	0.97
91370	0.54	0.39	0.24	0.30	0.32	0.40	0.88	0.53	0.30	0.57	0.48	0.48
91750	0.69	0.61	0.40	0.44	0.55	0.59	0.88	0.66	0.65	0.78	0.70	0.78
92350	0.47	0.40	0.32	0.31	0.45	0.45	0.74	0.62	0.49	0.55	0.49	0.56
93140	0.51	0.42	0.36	0.30	0.42	0.45	0.77	0.51	0.53	0.45	0.58	0.55
93300	0.62	0.56	0.57	0.47	0.58	0.80	1.12	0.79	0.73	0.60	0.73	0.60
97250	0.37	0.28	0.32	0.32	0.57	0.78	1.27	0.71	0.61	0.50	0.49	0.37
98550	0.85	0.80	0.68	0.65	0.73	0.94	1.29	0.93	0.71	0.78	0.91	0.73
99370	0.86	0.69	0.61	0.67	0.54	0.94	1.14	0.82	0.67	0.58	0.80	0.67
99840	0.45	0.52	0.59	0.43	0.23	0.39	0.49	0.79	0.40	0.26	0.38	0.31
99910	1.00	0.95	1.36	0.99	0.54	0.71	0.81	1.42	1.24	0.68	0.91	0.86

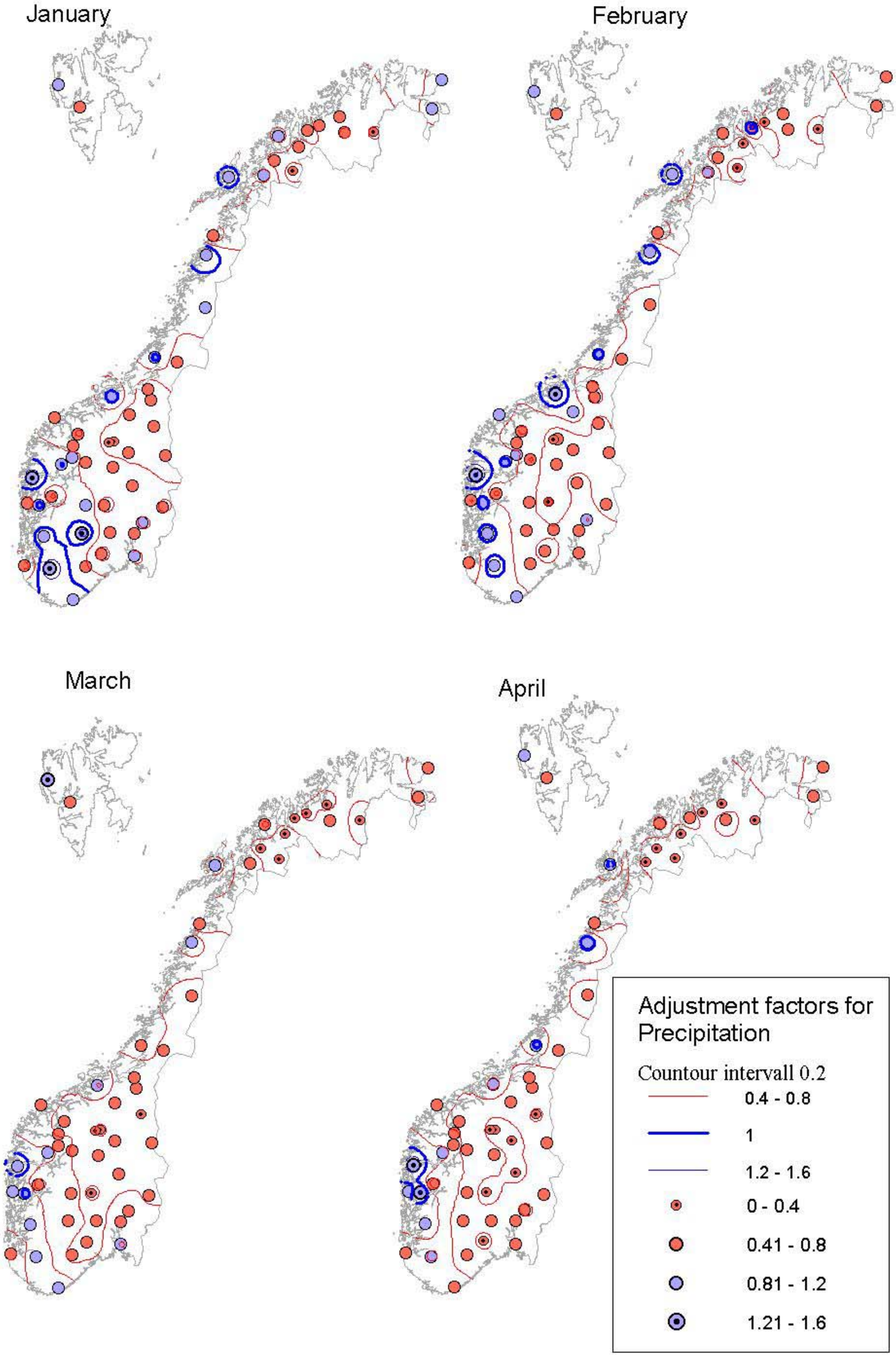

Figure 4.2 Factors used to adjust the dynamical downscaled precipitation data (January-April).

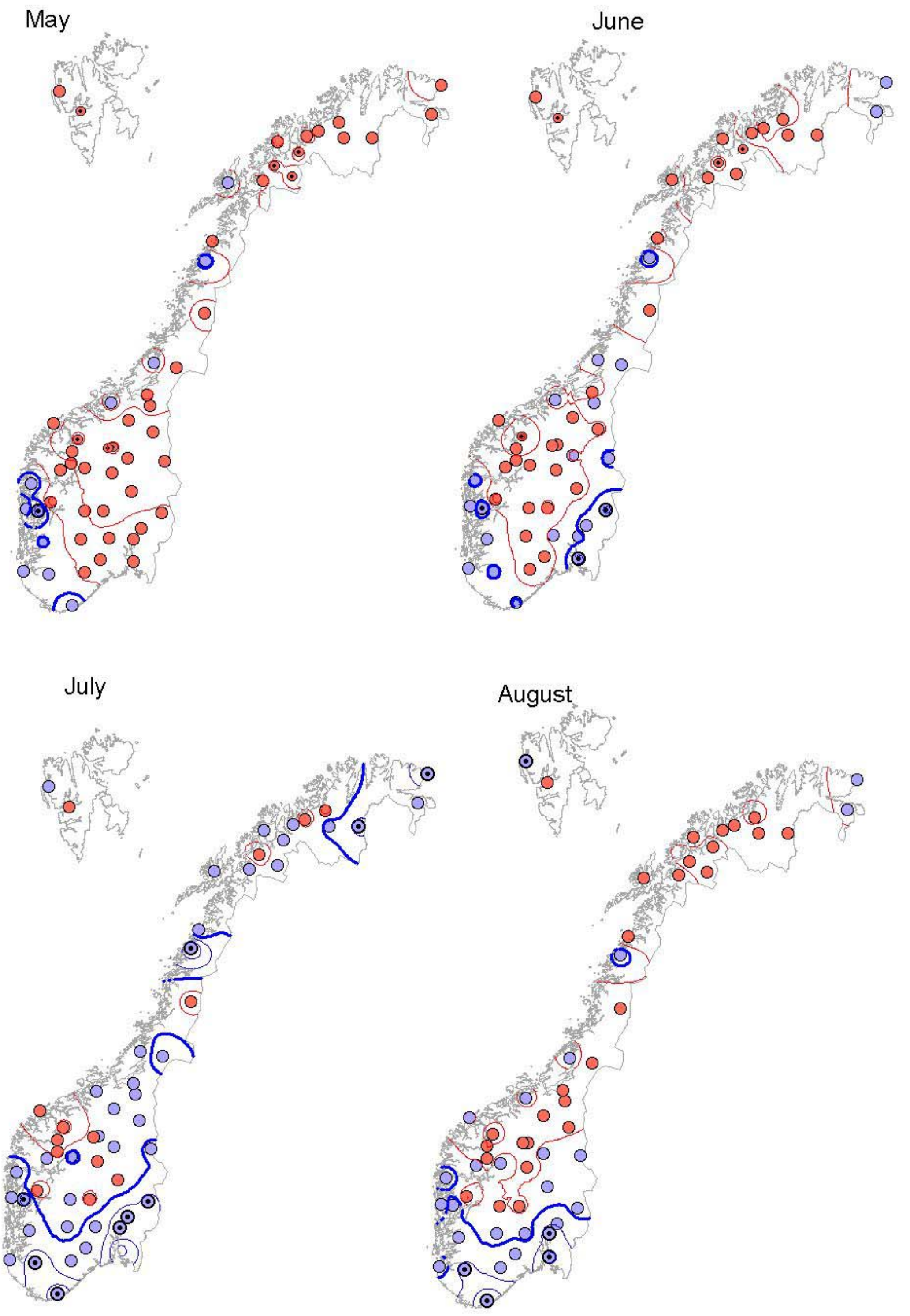

Figure 4.3 Factors used to adjust the dynamical downscaled precipitation data (May-August).

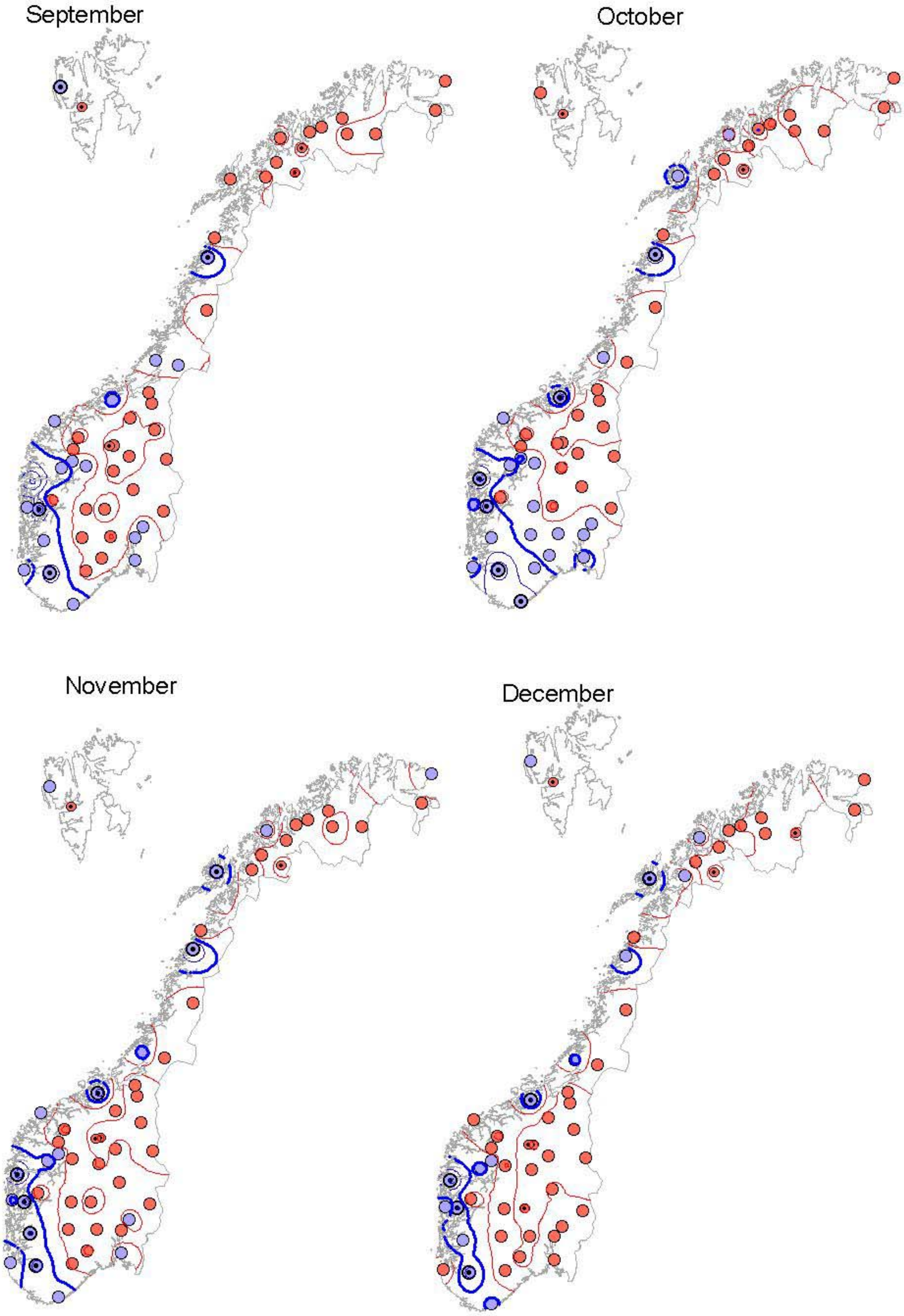

Figure 4.4 Factors used to adjust the dynamical downscaled precipitation data (September-December).

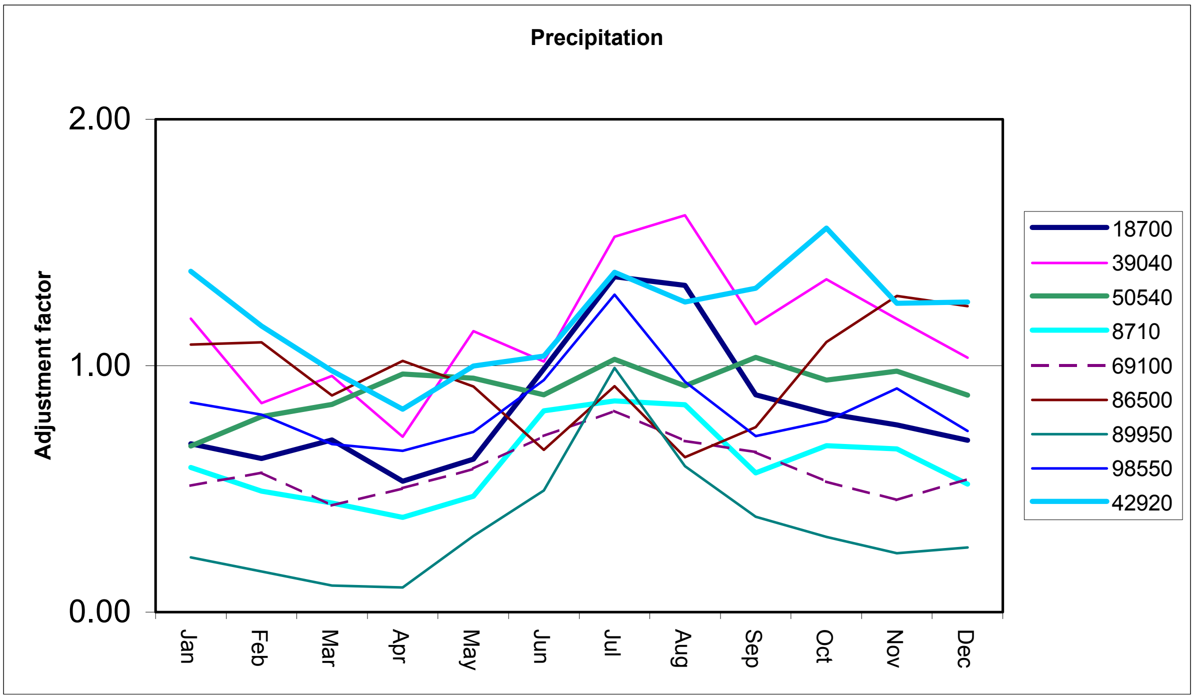

Figure 4.5 Adjustment factors for precipitation through out the year. The stations represent different parts of Norway.

4.2 Temperature

4.2.1 Adjustment with regression

The correlation between the observed and modelled temperature in the ERA-15 period is shown in Fig. 4.6 (and Appendix D). The dataset is better correlated than the precipitation data (Fig. 4.1). This is mainly because temperature variations are more continuous than precipitation variations both in time and space. However, a drop in correlation during summer is found in this dataset as well. This may be caused by more convective air masses which make the model prediction more difficult.

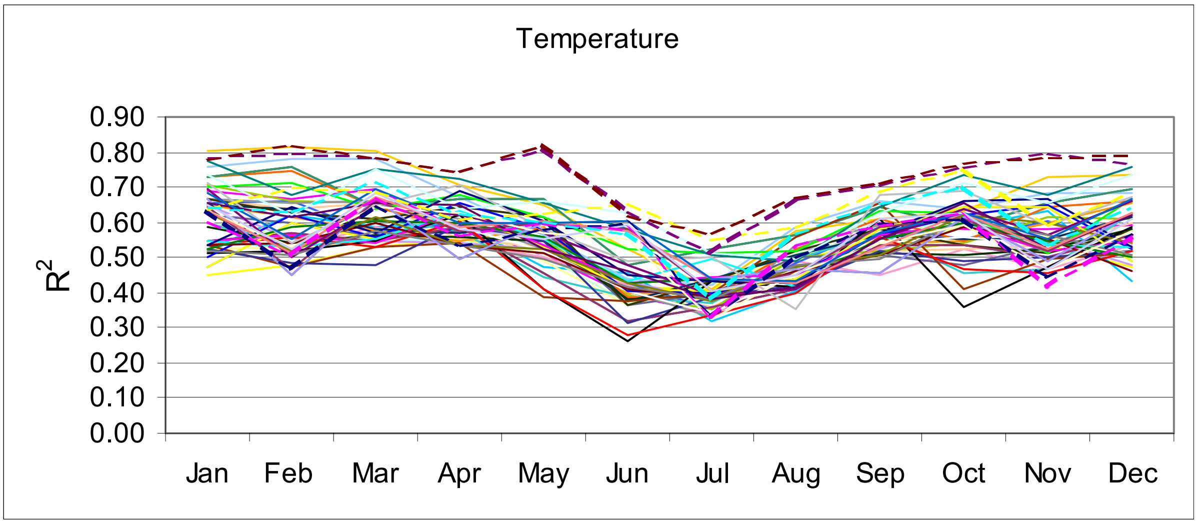

Figure 4.6 The monthly correlation between the observed temperature and the ERA-15 temperature dataset based on daily values from 55 stations during 1979-1993.

The temperature data are adjusted according to Eq. 3.2 (cf. Chapter 3). The mean monthly temperature value and standard deviation are supposed to be comparable for observations and ERA-15 values. The annual mean value and standard deviation of daily values are tabulated in Appendix E. The mean monthly values show rather large differences between the observed and the modelled dataset for the control period. The adjusted model data have mean values similar to the observed dataset.

The basic idea behind using regression was that the coeffisient b should represent systematic difference (caused by difference in altitude) while a would reflect local temperature conditions (inversions etc.). There are, however, difficulties concerning the adjustment of the temperature data with regression. When studying the difference between the scenario period and the control period, the temperature increase is changed with a factor corresponding to the regression coefficient *a*: (a*scenario+b)-(a*control+b) = a*(scenario-control). This would have been a minor problem if the factor *a* had varied around 1 for the different stations and for different seasons. It was, however, found that *a* always was less than one, thus the temperature difference reported by Bjørge et al. (2000) was reduced. The reduction in temperature change between the scenario period and the control period is presented in Fig. 4.7.

As for precipitation the adjustment tends to reduce the variance compared to the unadjusted data (Appendix E), and in most cases this reduction is not in accordance with the observations.

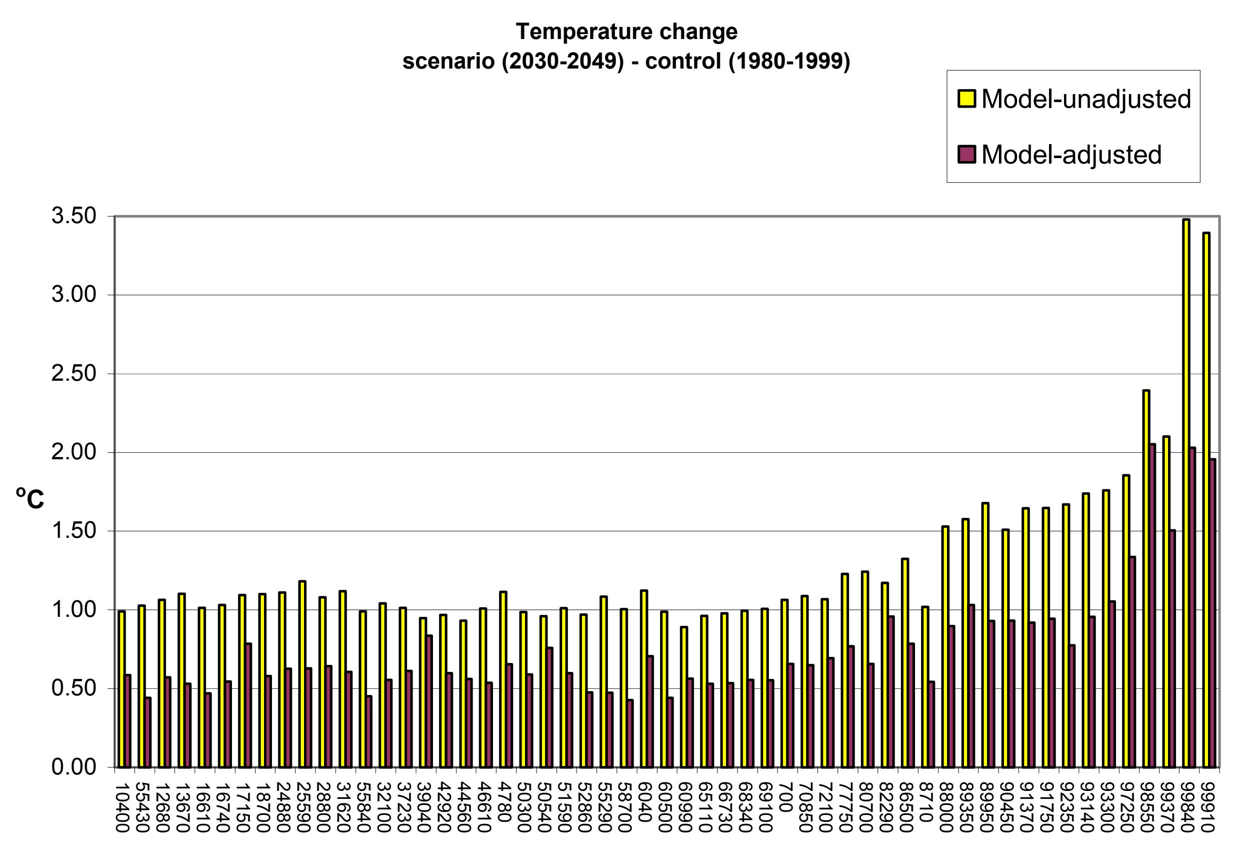

Figure 4.7 The change in temperature at each station in the scenario period compared to the control period for the unadjusted and the adjusted data. The figure shows that the change is reduced in the adjusted data.

The regression factors *a* and *b* (see Eq. 3.2) used to adjust the ERA-15 air temperature data are shown in Table 4.2. The basic thought is that the *a* and *b* factors may represent the gradient correction and the height correction respectively. However, as the correction factors result from regression analyses, they are also affected with noise.

The regression factors are plotted on maps to see if they contain geographical patterns. Regression factor *a* is shown in the Figs. 4.8, 4.9, 4.10 and 4.11, while *b* is shown in the Figures 4.12, 4.13, 4.14 and 4.15. The factor *a* is at minimum during summer (Figs. 4.9-4.10), when the correlation between observed and modelled values in the ERA-period also is low (cf. Fig. 4.6). This may indicate that the low values result from noise rather than systematic spatial variations which the model does not take care of. In winter, the values of *a* are generally higher than during summer. In mountainous areas the values are still relatively low. This may reflect problems connected to modelling winter temperatures in complex terrain.

The factor *b* is mainly positive in the period April through October. This results partly from the fact that most stations are situated at lower altitude than the model topography at the same position, so that the model at average is somewhat too cold at most stations (Appendix E). Additionally, the *b* value has to compensate for the reduction in average value caused by the low values of *a* during summer. In winter, *b* tends to be negative in inland areas. This may reflect the fact that the model does not resolve ground inversions properly, and that the model consequently tends to be too warm at inversion exposed sites during the winter.

Table 4.2 Monthly regression factors a and b (Eq. 3.1).

Stnr	jan		feb		mar		apr		mai		jun		jul		aug		sept		oct		nov		dec	
	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b
700	0.73	-4.1	0.75	-3.2	0.81	-1.0	0.63	0.3	0.49	3.9	0.38	6.6	0.38	7.9	0.40	6.7	0.46	3.8	0.69	0.9	0.70	-1.3	0.72	-4.1
4780	0.70	-1.8	0.80	-1.4	0.74	0.6	0.48	2.4	0.47	6.1	0.37	9.1	0.29	11.2	0.49	7.4	0.55	4.8	0.64	2.3	0.48	0.1	0.70	-1.6
6040	0.80	-2.1	0.87	-1.2	0.80	1.2	0.49	2.7	0.49	6.3	0.36	9.3	0.30	10.9	0.41	8.4	0.53	4.8	0.64	2.2	0.60	-0.1	0.79	-1.8
8710	0.66	-3.3	0.61	-2.1	0.59	0.0	0.56	1.5	0.42	4.7	0.32	7.2	0.32	8.5	0.37	7.2	0.43	4.9	0.67	2.2	0.60	-0.7	0.73	-2.5
10400	0.63	-4.7	0.70	-3.0	0.62	-0.7	0.61	1.5	0.46	4.7	0.37	7.0	0.39	8.1	0.42	7.0	0.52	4.6	0.77	1.9	0.70	-0.9	0.76	-3.4
12680	0.61	-2.6	0.67	-0.9	0.59	1.2	0.53	3.0	0.40	7.2	0.40	9.4	0.29	11.6	0.33	9.6	0.52	5.6	0.56	3.3	0.59	1.1	0.47	-3.0
13670	0.52	-3.0	0.45	-3.0	0.44	-1.6	0.54	1.3	0.49	4.6	0.35	7.0	0.36	8.2	0.42	6.5	0.49	4.0	0.62	1.5	0.43	-1.9	0.51	-3.1
16610	0.54	-2.5	0.52	-2.4	0.46	-1.9	0.64	1.0	0.52	4.1	0.06	6.4	0.40	7.2	0.41	6.2	0.22	3.8	0.62	1.8	0.47	-1.4	0.53	-2.5
16740	0.60	-2.1	0.59	-1.2	0.50	0.6	0.66	3.8	0.47	6.6	0.29	8.7	0.38	9.5	0.40	8.4	0.48	5.9	0.64	3.4	0.55	0.2	0.61	-1.7
17150	0.88	0.2	0.88	0.5	0.82	1.3	0.63	2.5	0.55	5.6	0.42	8.4	0.39	9.7	0.61	5.7	0.72	3.1	0.72	2.2	0.65	1.2	0.86	0.3
18700	0.62	-0.1	0.65	0.1	0.66	1.8	0.49	3.6	0.45	7.2	0.34	10.1	0.28	12.1	0.42	9.2	0.52	6.0	0.57	3.7	0.45	1.7	0.63	0.2
24880	0.83	-2.3	0.71	-1.8	0.66	2.5	0.49	4.4	0.42	7.9	0.35	10.8	0.29	12.5	0.42	9.5	0.43	6.6	0.63	3.3	0.54	-1.2	0.79	-2.7
25590	0.68	-0.5	0.54	-1.4	0.54	-0.5	0.58	1.6	0.46	4.5	0.35	7.3	0.33	8.7	0.43	6.9	0.48	4.5	0.63	2.6	0.51	-0.3	0.55	-1.4
28800	0.89	-1.0	0.78	-0.8	0.76	1.3	0.50	2.6	0.48	6.0	0.35	8.9	0.31	10.6	0.42	7.9	0.49	5.0	0.59	2.5	0.56	-0.4	0.86	-1.2
31620	0.64	-1.7	0.65	-1.5	0.56	-1.4	0.73	0.1	0.50	2.8	0.35	6.1	0.33	7.7	0.43	5.9	0.48	3.7	0.51	1.9	0.49	-0.6	0.53	-2.0
32100	0.75	-2.1	0.66	-2.3	0.66	1.4	0.51	4.0	0.40	7.6	0.32	10.8	0.30	12.1	0.43	9.1	0.52	5.8	0.52	3.9	0.42	0.5	0.82	-1.1
37230	0.82	0.9	0.87	0.4	0.77	1.7	0.52	2.9	0.48	6.0	0.35	9.3	0.31	11.2	0.46	8.2	0.47	6.2	0.55	3.8	0.54	2.1	0.70	1.3
39040	1.12	0.0	1.07	0.4	0.92	1.3	0.85	1.9	0.82	3.4	0.65	5.5	0.50	8.3	0.73	4.4	0.74	3.3	0.78	1.9	0.84	0.8	1.09	-0.4
42920	0.86	-0.3	0.80	-0.6	0.65	0.2	0.49	1.1	0.52	3.8	0.34	0.3	0.36	8.3	0.38	7.3	0.49	4.9	0.54	3.0	0.59	0.8	0.89	0.2
44560	0.77	1.8	0.75	1.8	0.60	2.6	0.54	3.5	0.53	5.4	0.29	8.8	0.34	9.6	0.42	8.7	0.56	6.2	0.54	5.1	0.60	3.4	0.73	2.2
46610	0.71	2.1	0.63	2.2	0.48	3.5	0.55	5.3	0.50	7.8	0.28	10.9	0.35	11.1	0.39	10.1	0.43	7.9	0.48	5.9	0.51	3.3	0.63	2.4
50300	0.76	0.6	0.68	0.6	0.63	1.4	0.62	2.5	0.56	4.5	0.33	7.7	0.47	7.2	0.44	7.1	0.56	4.7	0.56	3.6	0.55	1.7	0.74	0.7
50540	0.83	2.1	0.75	2.4	0.70	3.2	0.90	4.0	0.98	4.3	0.66	6.6	0.87	4.3	0.70	6.0	0.79	4.2	0.71	4.2	0.72	3.0	0.85	2.0
51590	0.89	1.8	0.72	1.6	0.58	3.6	0.63	5.5	0.50	8.0	0.30	10.8	0.35	11.1	0.37	10.0	0.47	7.3	0.56	5.2	0.60	2.9	0.76	1.9
52860	0.57	3.0	0.52	2.8	0.52	3.3	0.60	4.0	0.50	5.9	0.25	9.6	0.36	9.4	0.36	9.3	0.53	6.3	0.51	5.5	0.40	4.3	0.50	3.2
55290	0.45	-6.2	0.37	-6.6	0.41	-6.1	0.60	-2.6	0.43	0.0	0.27	2.7	0.36	3.7	0.45	2.8	0.62	0.5	0.41	-1.4	0.38	-4.4	0.43	-5.5
55430	0.55	0.0	0.53	0.5	0.50	2.0	0.54	4.2	0.45	7.7	0.22	10.9	0.30	11.2	0.28	10.1	0.40	7.2	0.46	4.8	0.40	1.3	0.54	0.4
55840	0.59	1.3	0.52	1.3	0.42	2.8	0.56	5.6	0.47	8.6	0.21	11.9	0.30	12.0	0.28	11.1	0.41	8.2	0.48	5.6	0.45	2.9	0.52	1.5
58700	0.40	2.2	0.45	3.0	0.44	4.1	0.66	6.3	0.48	9.1	0.18	11.4	0.42	10.7	0.32	10.7	0.57	8.0	0.39	7.0	0.38	4.4	0.43	2.9
60500	0.48	4.1	0.53	4.9	0.50	6.0	0.68	7.6	0.37	9.4	0.17	11.3	0.24	12.1	0.28	11.5	0.53	9.0	0.54	7.9	0.44	5.9	0.45	4.2
60990	0.66	2.4	0.66	2.5	0.62	2.8	0.75	3.0	0.71	4.0	0.53	5.6	0.58	6.1	0.47	7.7	0.71	4.7	0.67	4.3	0.50	3.8	0.67	2.5
65110	0.55	0.4	0.64	1.4	0.50	1.7	0.66	2.8	0.54	5.3	0.35	8.0	0.40	8.9	0.37	8.7	0.57	5.5	0.68	3.4	0.55	2.4	0.50	0.8
66730	0.48	-1.8	0.59	0.0	0.53	0.8	0.71	2.5	0.53	5.0	0.36	7.1	0.42	7.7	0.39	7.3	0.60	4.6	0.77	2.9	0.56	1.1	0.49	-1.2

68340	0.55 0.4	0.60 1.1	0.50 1.9	0.66 3.5	0.56 6.1	0.40 7.7	0.47 8.5	0.41 8.5	0.59 6.0	0.70 4.1	0.50 2.1	0.54 0.5
69100	0.59 1.0	0.60 1.7	0.51 3.2	0.56 4.6	0.52 6.9	0.38 9.0	0.46 9.3	0.38 9.9	0.56 6.9	0.71 4.6	0.52 3.0	0.56 1.4
70850	0.62 -1.3	0.65 -0.3	0.61 1.1	0.60 2.6	0.56 5.3	0.44 7.5	0.47 8.2	0.43 8.0	0.60 5.2	0.71 3.0	0.61 0.8	0.58 -1.1
72100	0.66 -1.5	0.75 0.0	0.58 0.6	0.72 1.5	0.67 3.6	0.46 6.8	0.46 7.6	0.41 7.7	0.66 3.8	0.79 1.6	0.66 0.6	0.63 -1.1
77750	0.80 -0.8	0.66 -1.0	0.67 1.0	0.64 3.0	0.58 6.1	0.39 8.1	0.34 9.9	0.43 8.1	0.54 5.4	0.78 3.0	0.70 0.6	0.69 -1.6
80700	0.56 2.9	0.45 2.3	0.53 3.3	0.67 4.5	0.56 6.0	0.43 7.1	0.36 9.1	0.40 8.7	0.60 6.4	0.69 5.1	0.51 3.8	0.55 2.7
82290	0.83 1.4	0.82 1.4	0.75 1.9	0.87 3.6	0.99 4.2	0.79 4.7	0.73 5.6	0.66 6.2	0.78 4.5	0.93 2.6	0.78 2.1	0.87 1.4
86500	0.66 1.2	0.62 0.4	0.53 1.0	0.77 1.6	0.56 3.6	0.45 5.7	0.47 6.8	0.38 8.1	0.79 3.6	0.74 2.8	0.56 1.8	0.67 0.5
88000	0.69 0.8	0.56 0.0	0.59 1.8	0.48 3.2	0.60 6.6	0.51 7.4	0.36 10.2	0.50 8.4	0.53 5.6	0.85 3.3	0.60 0.6	0.74 0.7
89350	0.82 -1.6	0.67 -2.5	0.66 -0.3	0.58 2.7	0.57 5.4	0.52 7.0	0.36 9.8	0.47 8.0	0.63 4.7	0.84 2.3	0.70 -1.5	0.87 -1.7
89950	0.64 -1.1	0.58 -1.3	0.56 -0.1	0.62 3.0	0.58 5.9	0.48 7.5	0.27 10.3	0.41 8.1	0.59 5.6	0.71 3.3	0.51 -0.9	0.57 -2.0
90450	0.59 0.5	0.58 0.3	0.58 1.0	0.60 2.4	0.63 3.7	0.62 4.8	0.54 6.7	0.57 6.1	0.70 4.0	0.81 2.5	0.61 1.2	0.66 0.6
91370	0.66 1.6	0.68 1.6	0.56 2.0	0.63 4.5	0.49 6.8	0.34 8.9	0.30 10.8	0.37 9.5	0.59 6.6	0.86 5.1	0.54 2.0	0.60 1.2
91750	0.66 -0.5	0.59 -1.1	0.59 0.6	0.57 3.2	0.52 5.2	0.46 6.8	0.37 9.3	0.41 8.4	0.57 5.8	0.84 3.3	0.58 -0.3	0.69 -0.7
92350	0.50 1.3	0.46 0.7	0.49 1.6	0.51 3.4	0.45 5.0	0.42 6.4	0.32 9.2	0.35 8.7	0.51 6.6	0.62 4.7	0.45 2.0	0.50 1.3
93140	0.64 -0.7	0.56 -1.1	0.58 0.1	0.55 2.7	0.48 4.7	0.46 6.6	0.35 10.0	0.42 8.8	0.62 5.9	0.77 3.4	0.51 -0.4	0.63 -1.0
93300	0.67 -5.0	0.53 -6.3	0.63 -4.0	0.58 -0.9	0.56 2.0	0.57 4.3	0.32 8.2	0.48 5.7	0.64 3.3	0.89 0.2	0.58 -4.3	0.69 -5.4
97250	0.83 -5.9	0.74 -5.6	0.80 -2.7	0.68 0.8	0.56 3.6	0.56 5.8	0.31 9.8	0.57 5.9	0.69 3.6	1.02 0.8	0.73 -4.5	0.92 -6.2
98550	0.71 -2.1	0.92 -1.6	0.76 -1.1	0.80 0.2	0.84 0.9	1.01 0.5	0.87 1.8	0.91 1.2	0.91 1.1	1.12 -0.8	0.77 -1.3	0.83 -2.0
99370	0.74 -3.6	0.76 -2.5	0.74 -1.5	0.74 0.8	0.60 2.1	0.64 3.3	0.47 6.7	0.74 3.6	0.70 3.3	0.89 1.1	0.66 -1.8	0.91 -2.4
99840	0.57 0.0	0.68 1.4	0.69 1.5	0.66 0.5	0.67 0.7	1.00 3.5	0.44 5.4	0.54 5.1	0.47 3.7	0.45 1.5	0.53 1.2	0.57 0.4
99910	0.54 -0.5	0.66 0.9	0.65 0.7	0.64 0.0	0.76 0.8	0.85 2.7	0.42 4.3	0.55 3.9	0.61 3.1	0.53 1.3	0.51 0.2	0.56 -0.1

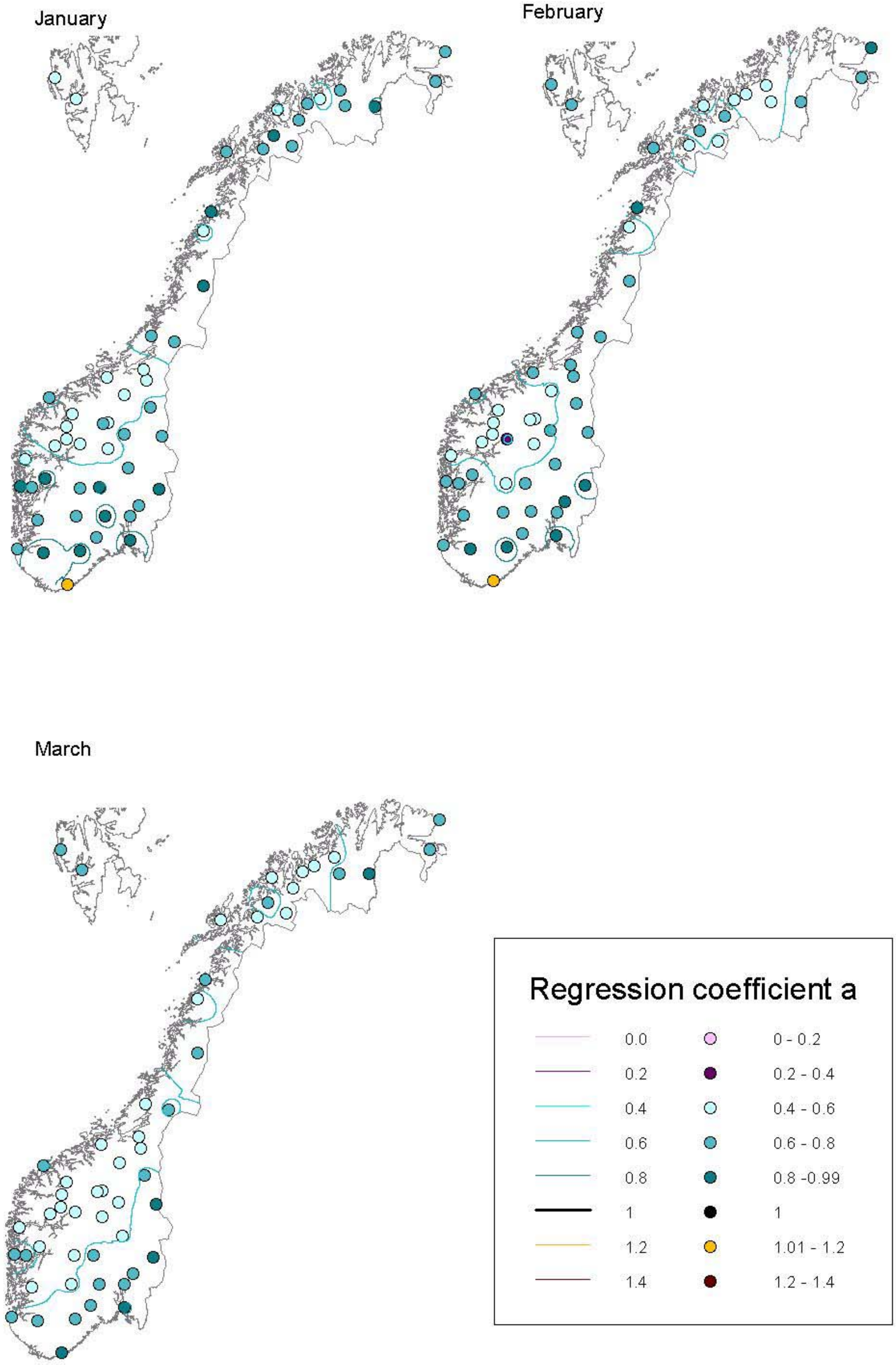

Figure 4.8 The regression factor a used to adjust the ERA-15 air temperature data to be consistent with the observed data within the same time period (January-March).

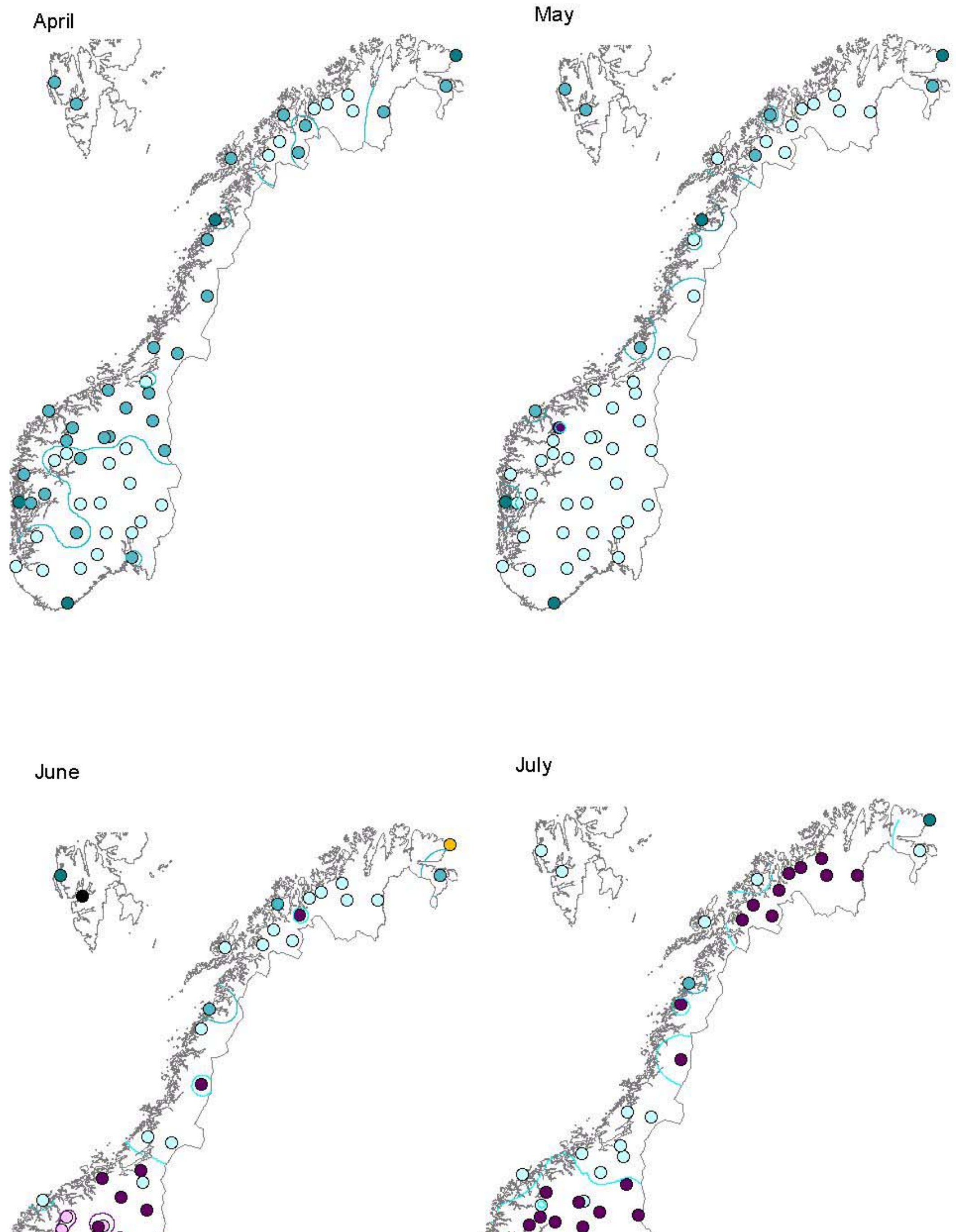

Figure 4.9 The regression factor a used to adjust the ERA-15 air temperature data to be consistent with the observed data within the same time period (April-July).

Figure 4.10 The regression factor a used to adjust the ERA-15 air temperature data to be consistent with the observed data within the same time period (August - November).

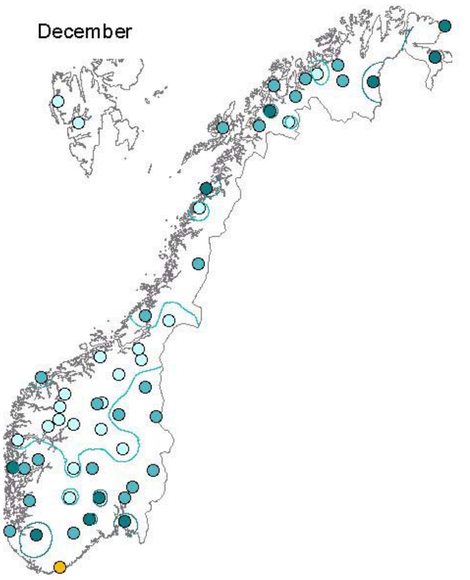

Figure 4.11 The regression factor a used to adjust the ERA-15 air temperature data to be consistent with the observed data within the same time period (December).

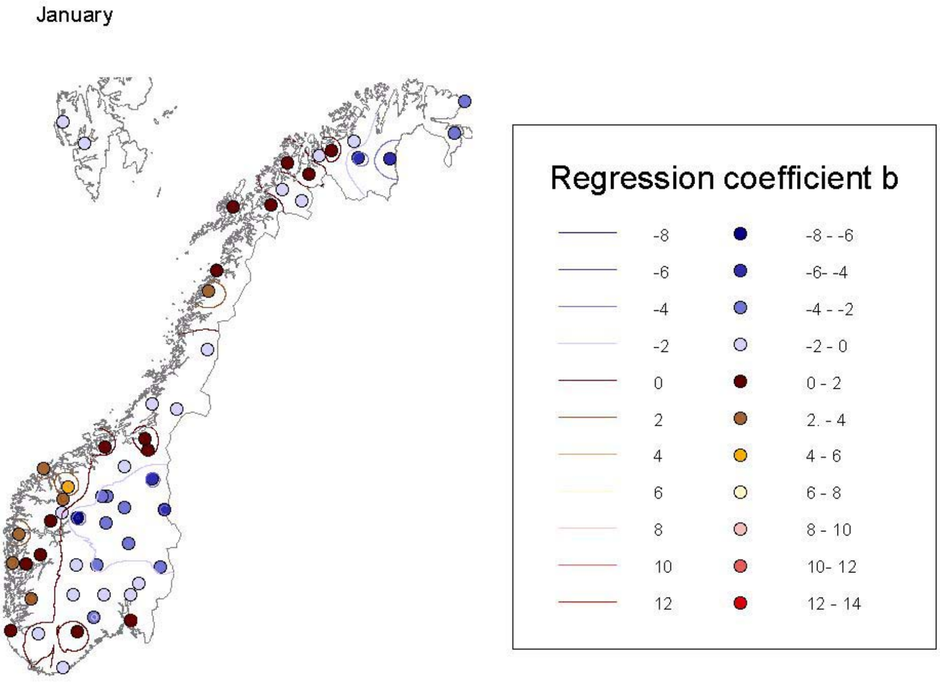

Figure 4.12 The regression factor b used to adjust the ERA-15 air temperature data to be consistent with the observed data within the same time period (January).

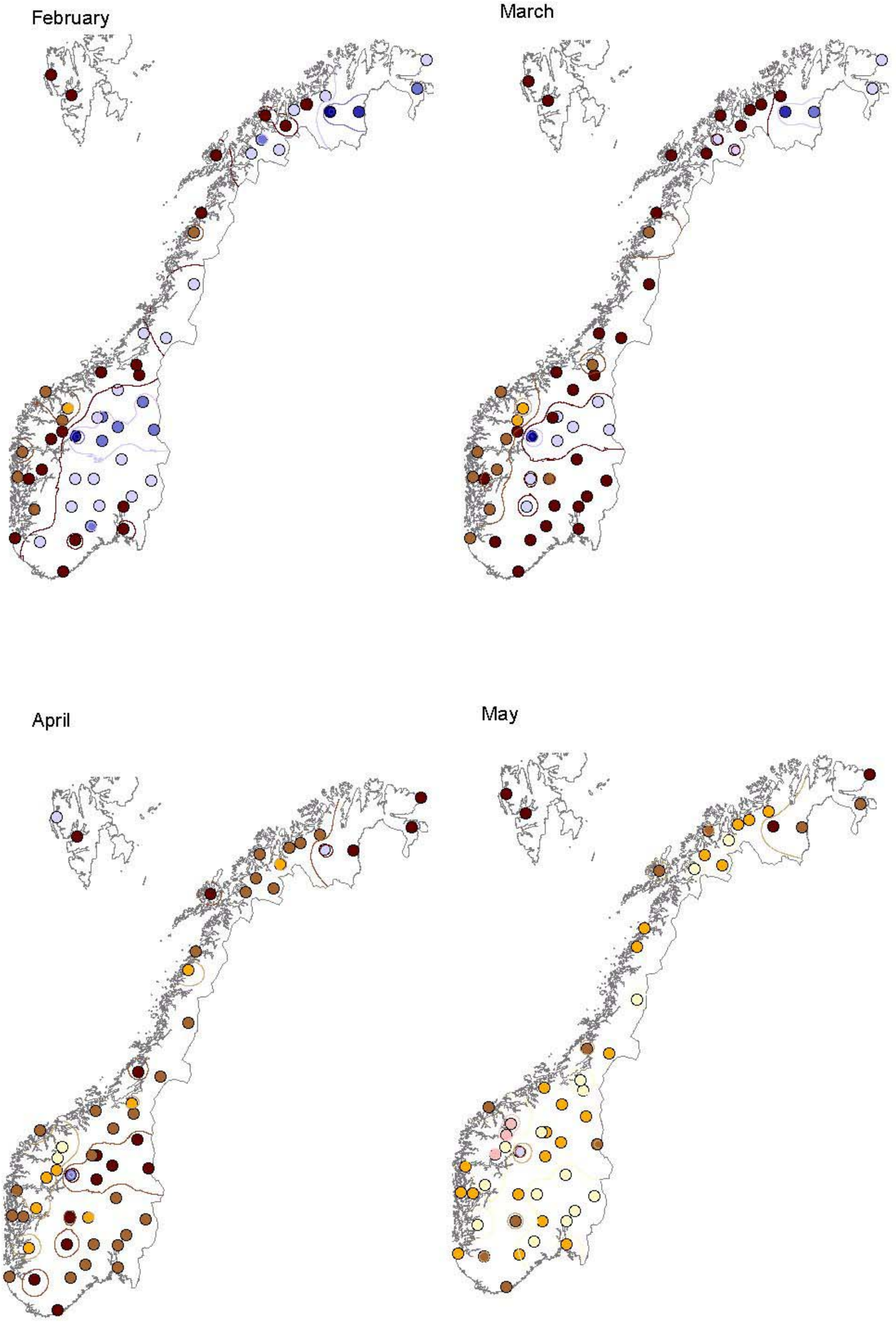

Figure 4.13 The regression factor b used to adjust the ERA-15 air temperature data to be consistent with the observed data within the same time period (February – May)

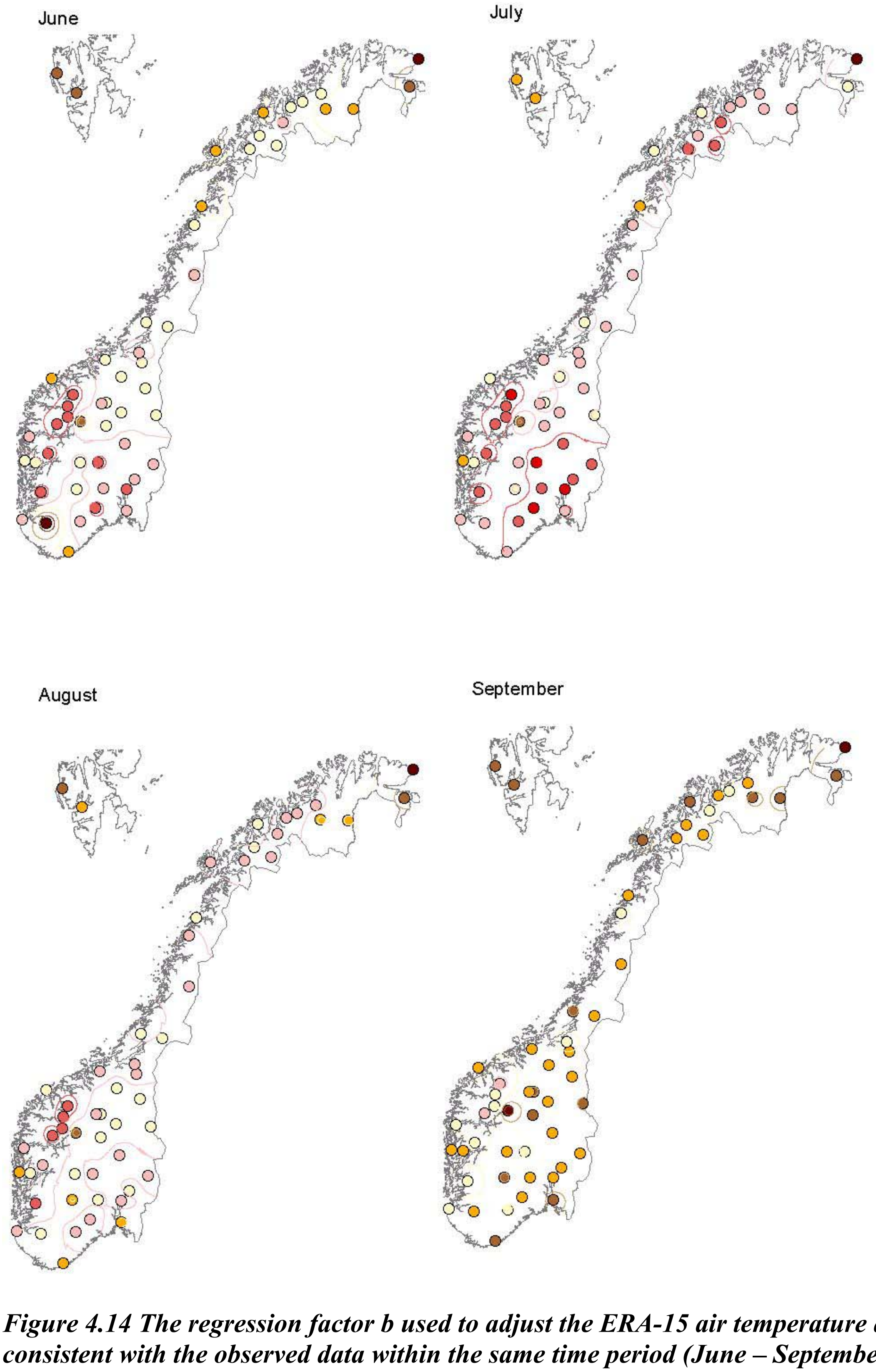

Figure 4.14 The regression factor b used to adjust the ERA-15 air temperature data to be consistent with the observed data within the same time period (June – September)

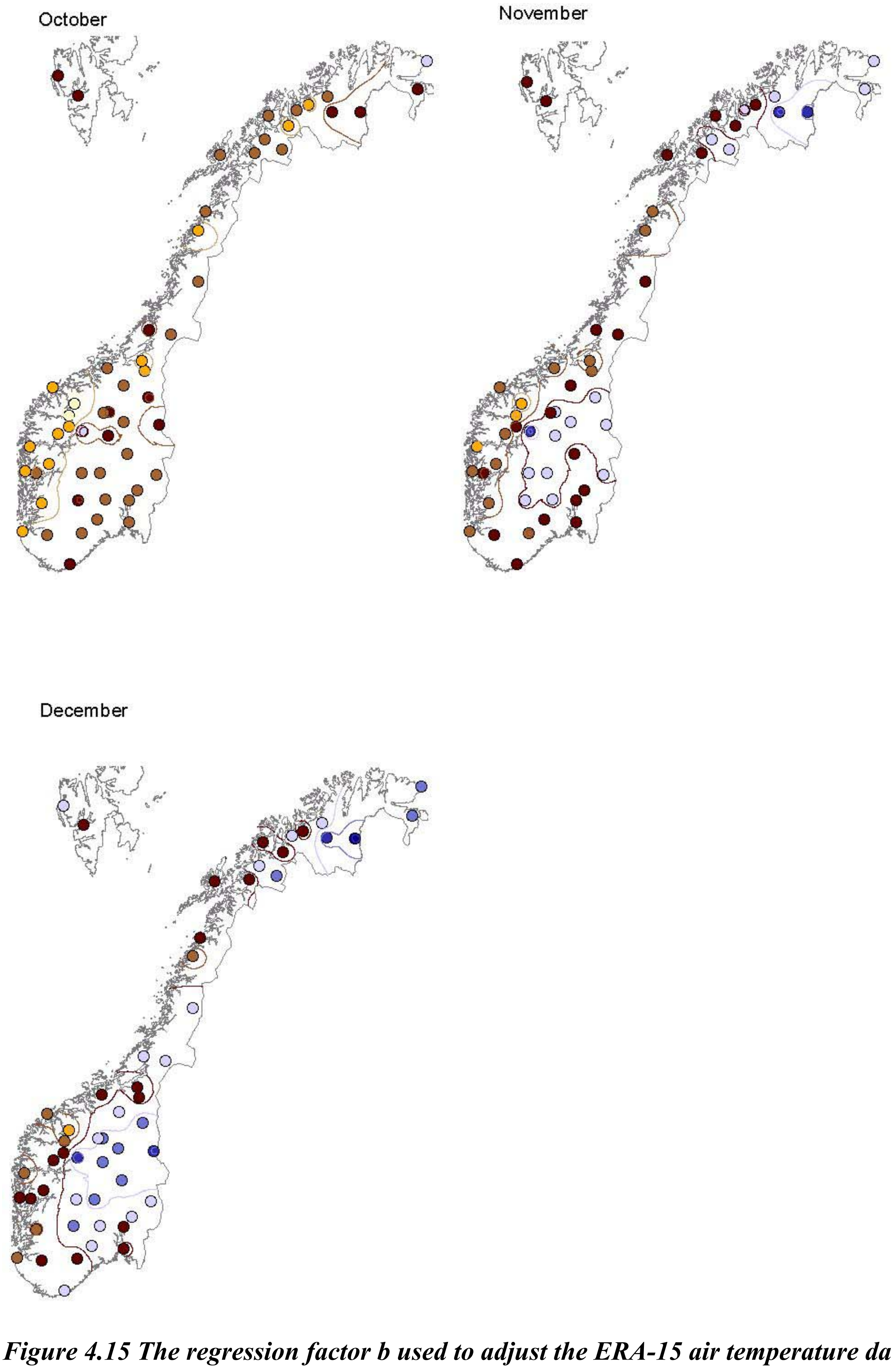

Figure 4.15 The regression factor b used to adjust the ERA-15 air temperature data to be consistent with the observed data within the same time period (October - December).

4.2.2 Adjustment with fixed elevation correction

As an alternative to the regression based adjustment (which reduces the temperature variability and change), the temperature data are adjusted with respect to height correction (cd Section 3.1.2). Using fixed height correction to adjust the temperature data at the station site will keep the temperature change as reported by Bjørge et al. (2001). The variance will not be adjusted. The correction factors are presented in Fig. 4.16 and in Table 4.3. A majority of the factors are positive, as most stations are situated below the altitude of the model topography. This reflects the fact that most stations are situated in valleys, even in mountainous terrain. The factors tend to be large in areas with large differences in altitude (inner fiord areas in western Norway and mountain areas in Nordland/Troms). This is a confirmation of the problems with the smoothened terrain represented in the model (resolution of 55x55 km^2).

The height corrections on temperature are applied at some selected stations. The mean monthly height corrected temperature data are presented together with the mean monthly observed temperature data (Figs. 4.17-4.26). The mean monthly uncorrected temperature data from the control period and the data corrected with regression for the same period are presented in the diagrams as well.

The figure shows that the regression corrected temperature data obtains the best fit to the observed mean monthly temperature data. (The mean value for the modelled data in the control period may be compared with the mean value for observations). The mean monthly height corrected value leads to rather good estimates compared to the observed data as well. The correction shows rather good fit during summer. In winter, however, there are problems concerning temperature inversions at inland valley stations (e.g. Figs. 4.17, 4.21 and 4.22). The height adjusted model is not able to reproduce the low winter temperature at these stations. There are also discrepancies at several coastal stations (e.g. Figs. 4.19, 4.20 and 4.23), probably because small differences between model topography and real terrain concerning distance to coast may lead to significant differences in annual temperature amplitude. The present resolution of the HIRHAM model is still too coarse to solve these problems. The temperature data adjusted with regression deals with these winter phenomena as far as the average value under the present climate conditions is concerned. We know, however, that the regression based adjustment at most stations reduces the modelled day-to-day variability to well below the observed level. Modelled systematic changes from the present climate will be reduced in a similar way. For climate change studies, the height adjustment should thus be applied rather than the regression based adjustment.

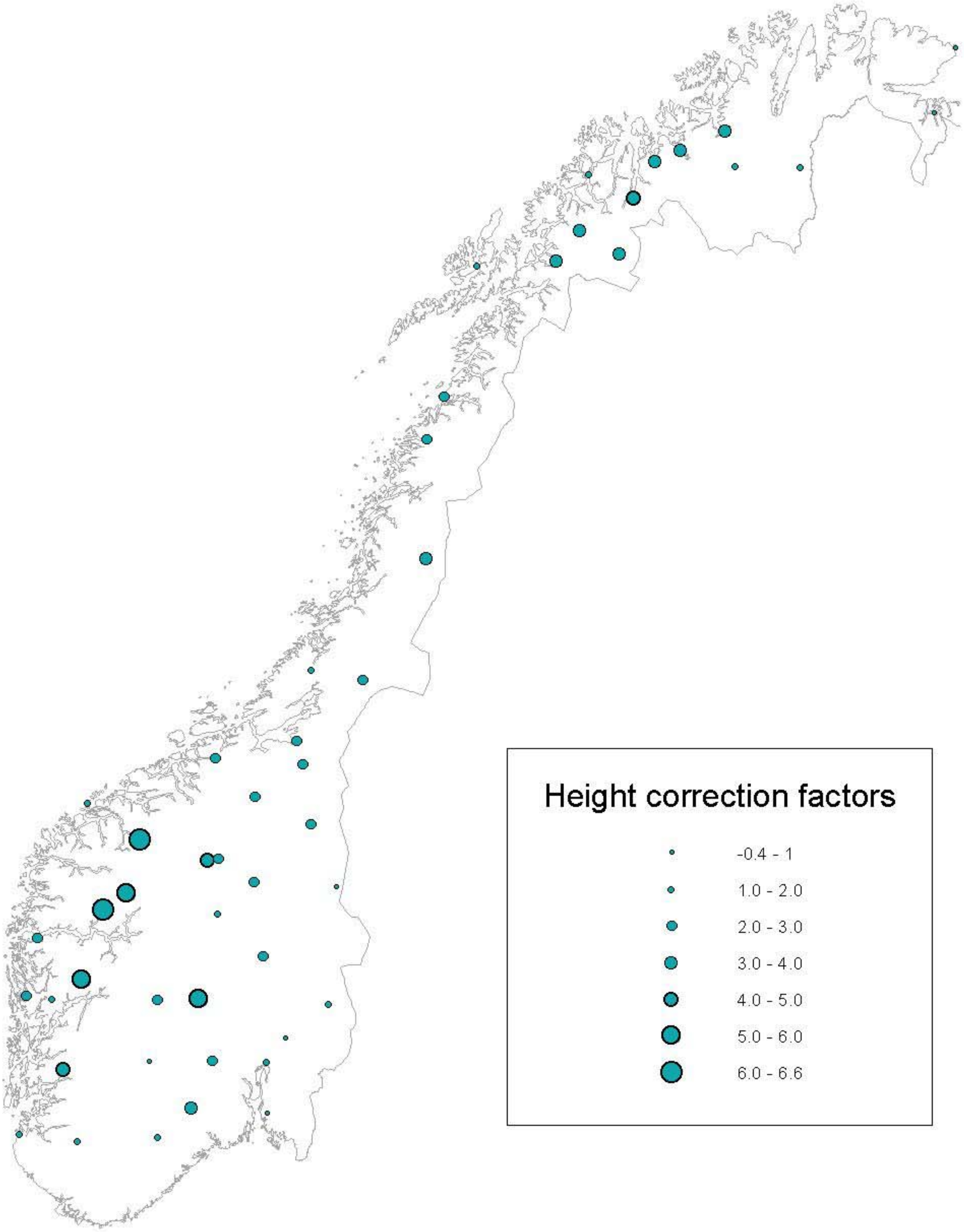

Figure 4.16 The correction factors of temperature (^{o}C) with respect to height

Table 4.3 ***H_S is station elevation, H_M is model elevation and ΔH is the difference between the H_M and H_S. C is the correction factors of temperature with respect to height, $C = 0.65 * \Delta H$.***

Station number	H_S	H_M	ΔH	C
700	672	820	148	0.96
4780	202	332	130	0.85
6040	184	431	247	1.61
8710	739	1092	353	2.29
10400	628	940	312	2.03
12680	270	728	458	2.98
13670	890	1174	284	1.85
16610	972	1295	323	2.10
16740	626	1321	695	4.52
17150	40	127	87	0.57
18700	94	311	217	1.41
24880	165	972	807	5.25
25590	810	1262	452	2.94
28800	288	624	336	2.18
31620	977	1088	111	0.72
32100	26	518	492	3.20
37230	252	540	288	1.87
39040	12	166	154	1.00
42920	500	684	184	1.20
44560	7	212	205	1.33
46610	5	727	722	4.69
50300	408	656	248	1.61
50540	12	329	317	2.06
51590	125	949	824	5.36
52860	38	414	376	2.44
55290	1413	1348	-65	-0.42
55430	324	1223	899	5.84

55840	10	1020	1010	6.57
58700	201	1125	924	6.01
60500	15	1019	1004	6.53
60990	22	270	248	1.61
65110	47	393	346	2.25
66730	475	860	385	2.50
68340	242	647	405	2.63
69100	12	473	461	3.00
70850	195	519	324	2.11
72100	86	264	178	1.16
77750	265	759	494	3.21
80700	39	483	444	2.89
82290	11	343	332	2.16
86500	3	172	169	1.10
88000	22	596	574	3.73
89350	76	564	488	3.17
89950	228	821	593	3.85
90450	100	343	243	1.58
91370	8	726	718	4.67
91750	1	557	556	3.61
92350	6	565	559	3.63
93140	3	490	487	3.17
93300	374	550	176	1.14
97250	129	396	267	1.74
98550	14	89	75	0.49
99370	89	178	89	0.58
99840	28	498	470	3.06
99910	8	403	395	2.57

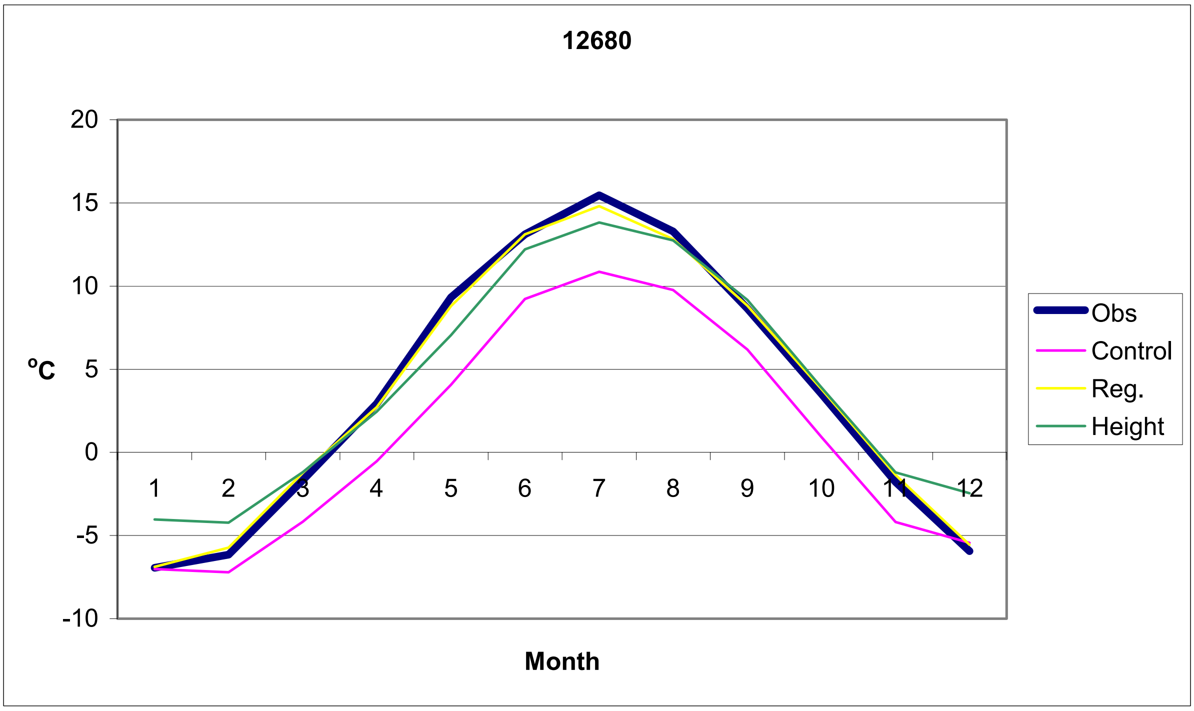

Figure 4.17 Mean monthly air temperature at station 12680-Lillehammer, observed values for the period 1980-1999 together with control data, the adjusted control data with regression and the adjusted control data with height correction.

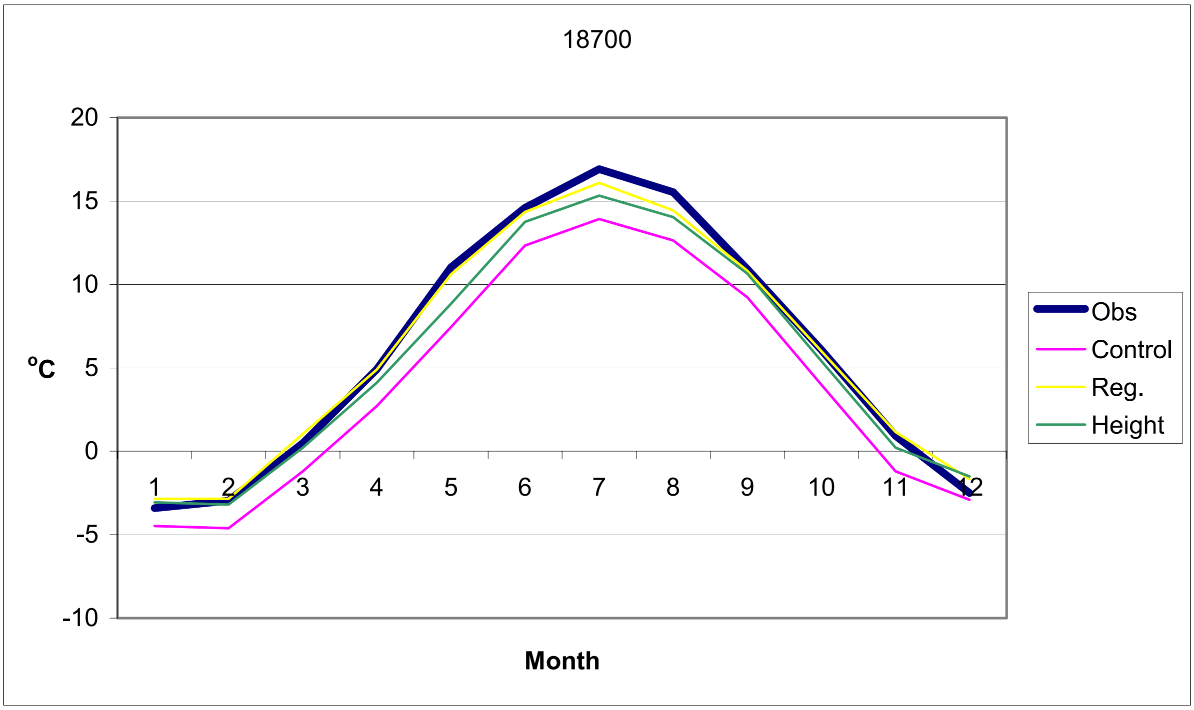

Figure 4.18. Mean monthly air temperature at station 18700 Oslo-Blindern, observed values for the period 1980-1999 together with control data, the adjusted control data with regression and the adjusted control data with height correction.

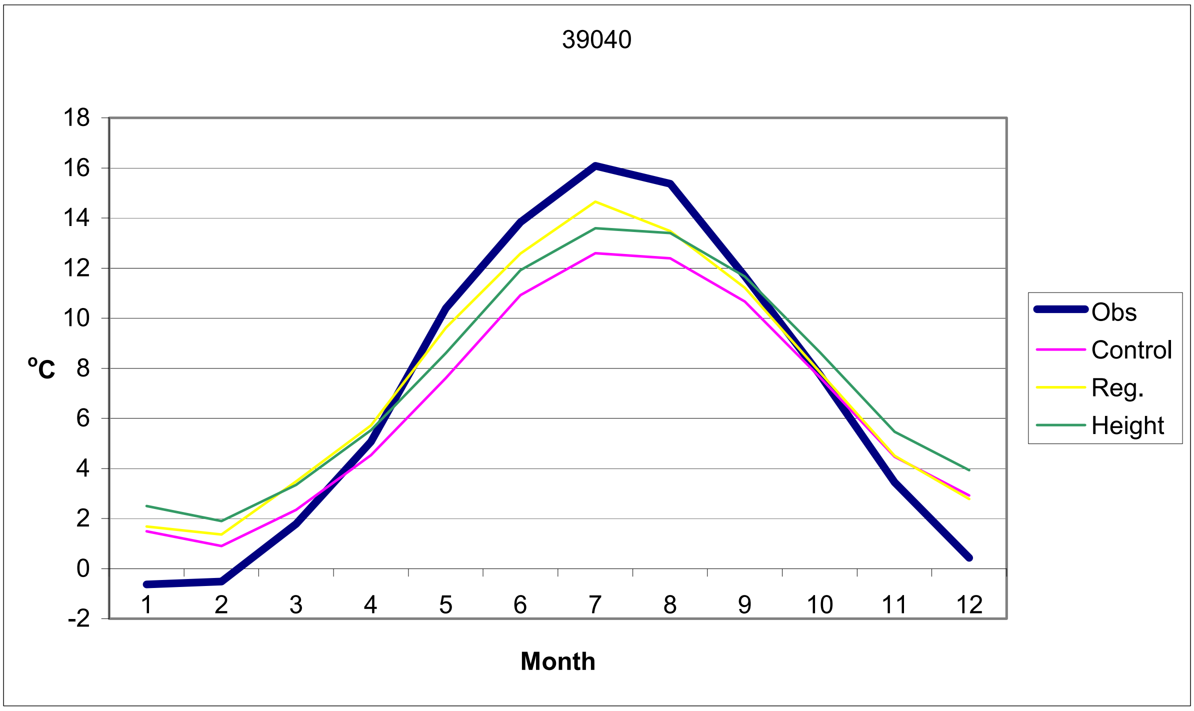

Figure 4.19. Mean monthly air temperature at station 39040 Kjevik, observed values for the period 1980-1999 together with control data, the adjusted control data with regression and the adjusted control data with height correction.

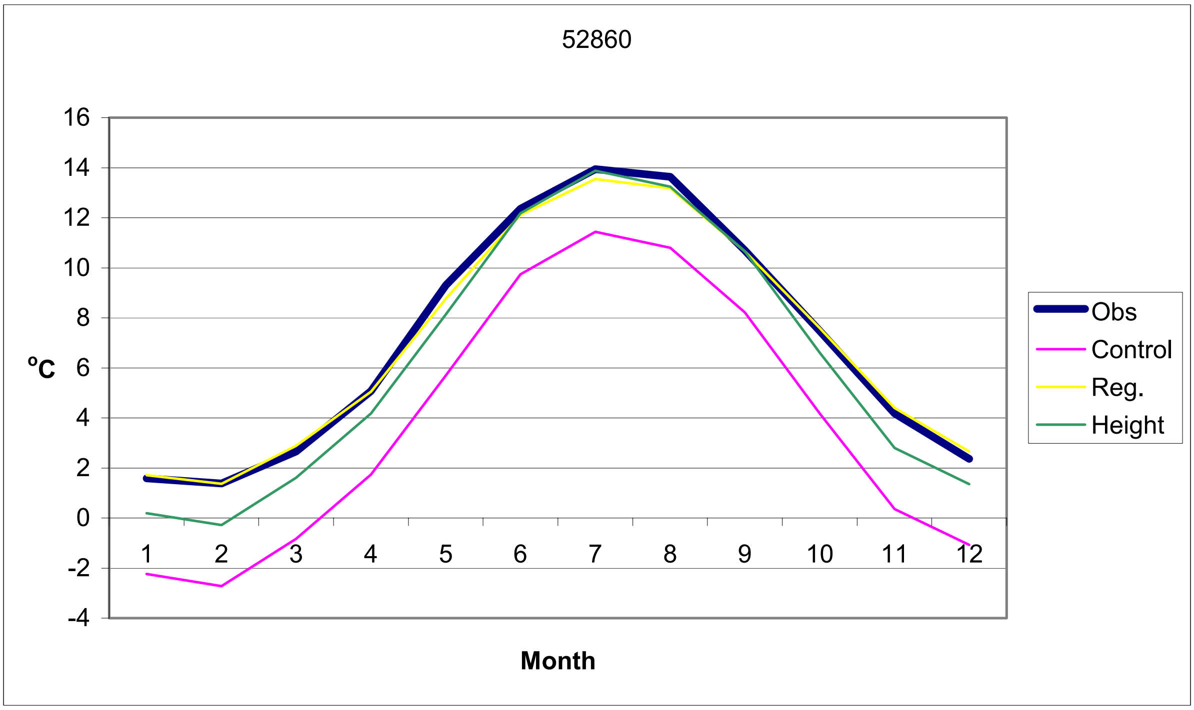

Figure 4.20 Mean monthly air temperature at station 52860 Takle, observed values for the period 1980-1999 together with control data, the adjusted control data with regression and the adjusted control data with height correction.

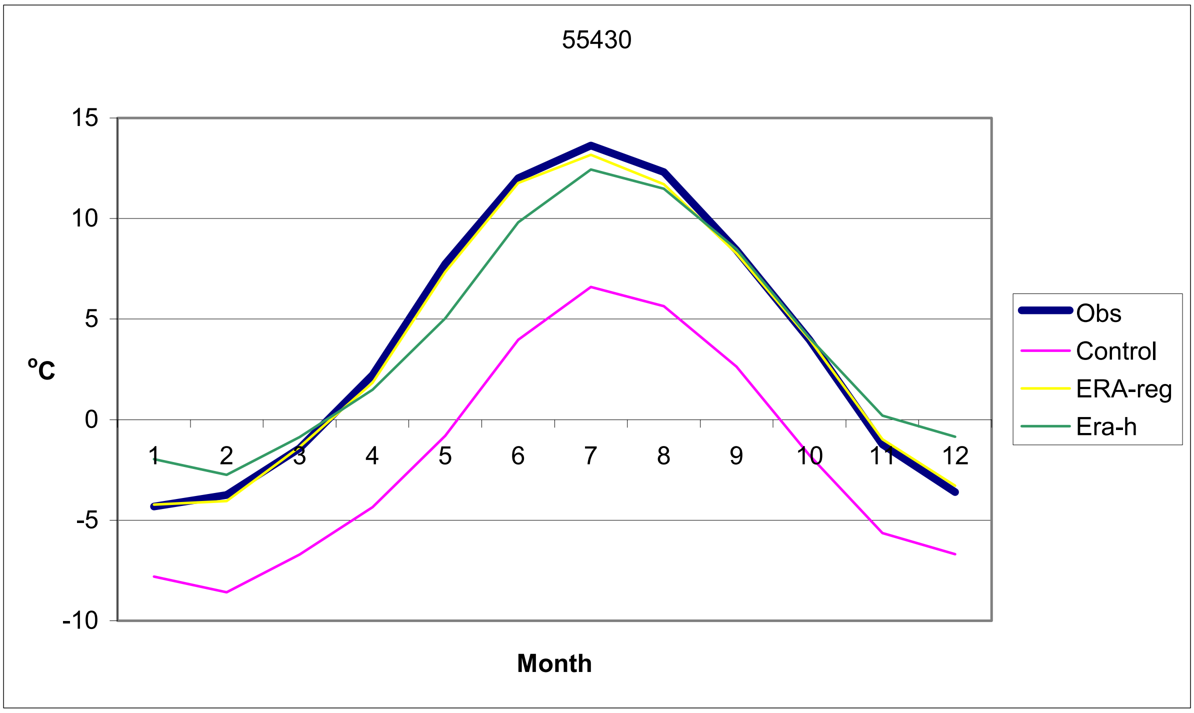

Figure 4.21 Mean monthly air temperature at station 55430 Bjørkehaug i Jostedalen, observed values for the period 1980-1999 together with control data, the adjusted control data with regression and the adjusted control data with height correction.

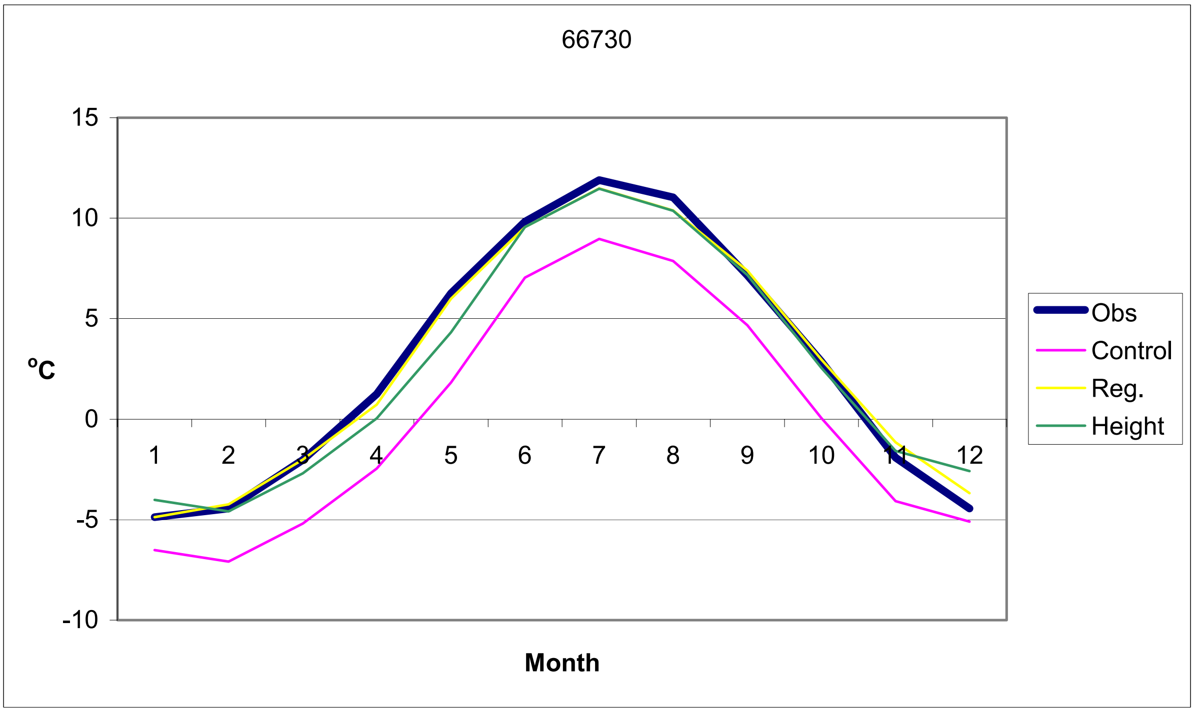

Figure 4.22. Mean monthly air temperature at station 66730 Berkåk Lyngholt, observed values for the period 1980-1999 together with control data, the adjusted control data with regression and the adjusted control data with height correction.

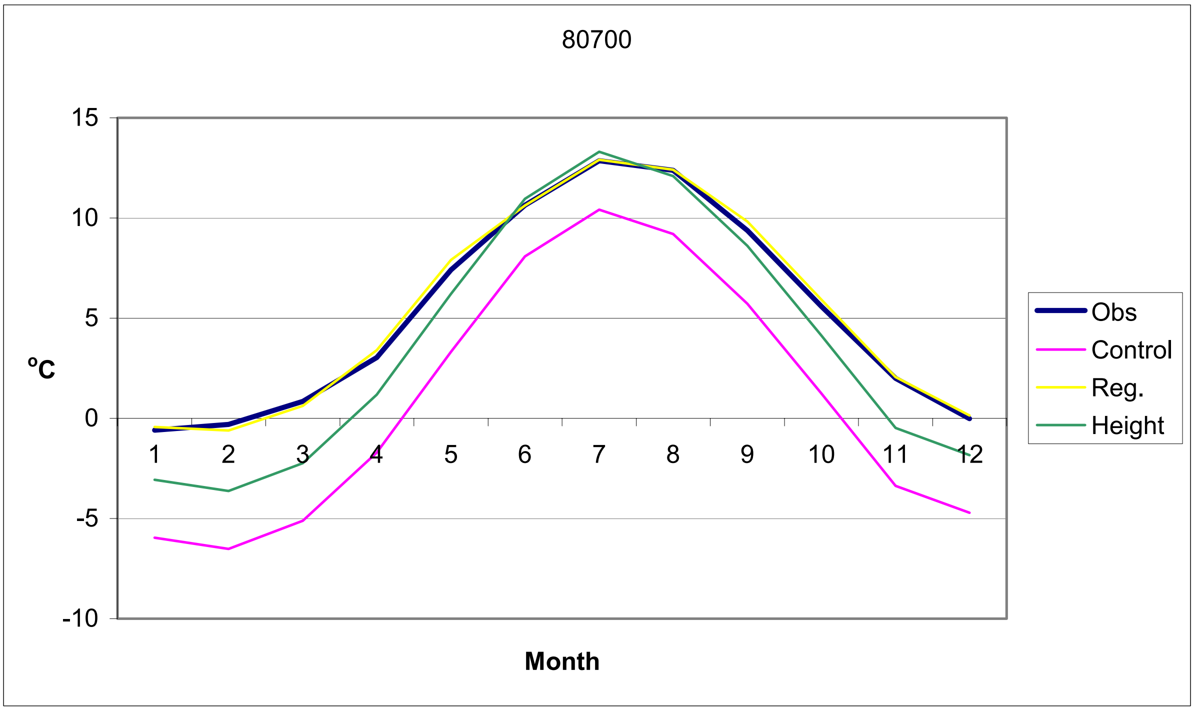

Figure 4.23 Mean monthly air temperature at station 80700 Glomfjord, observed values for the period 1980-1999 together with control data, the adjusted control data with regression and the adjusted control data with height correction.

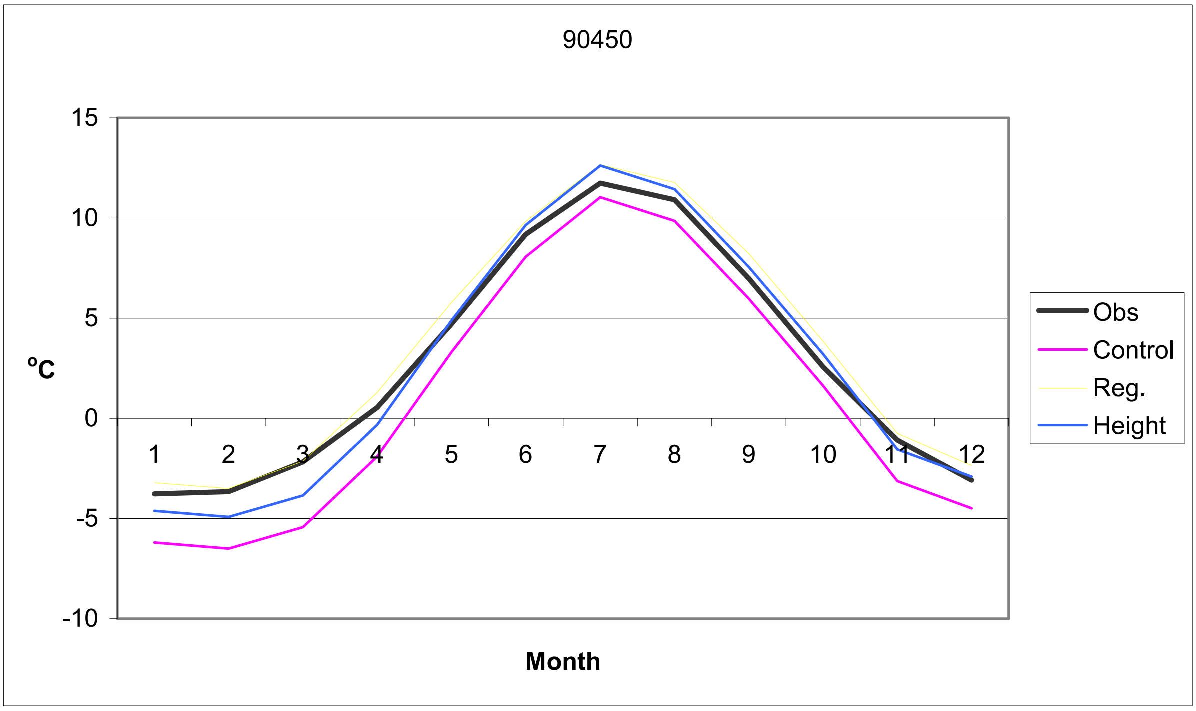

Figure 4.24 Mean monthly air temperature at station 90450 Tromsø, observed values for the period 1980-1999 together with control data, the adjusted control data with regression and the adjusted control data with height correction.

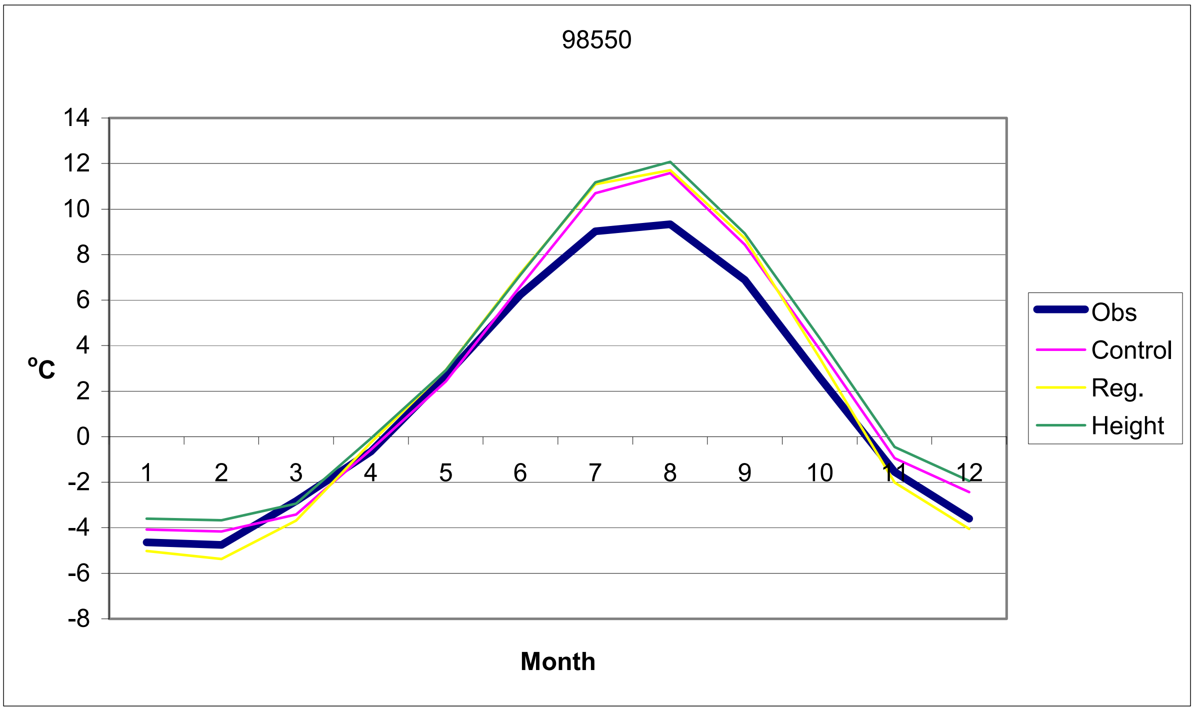

Figure 4.25 Mean monthly air temperature at station 98550 Vardø, observed values for the period 1980-1999 together with control data, the adjusted control data with regression and the adjusted control data with height correction.

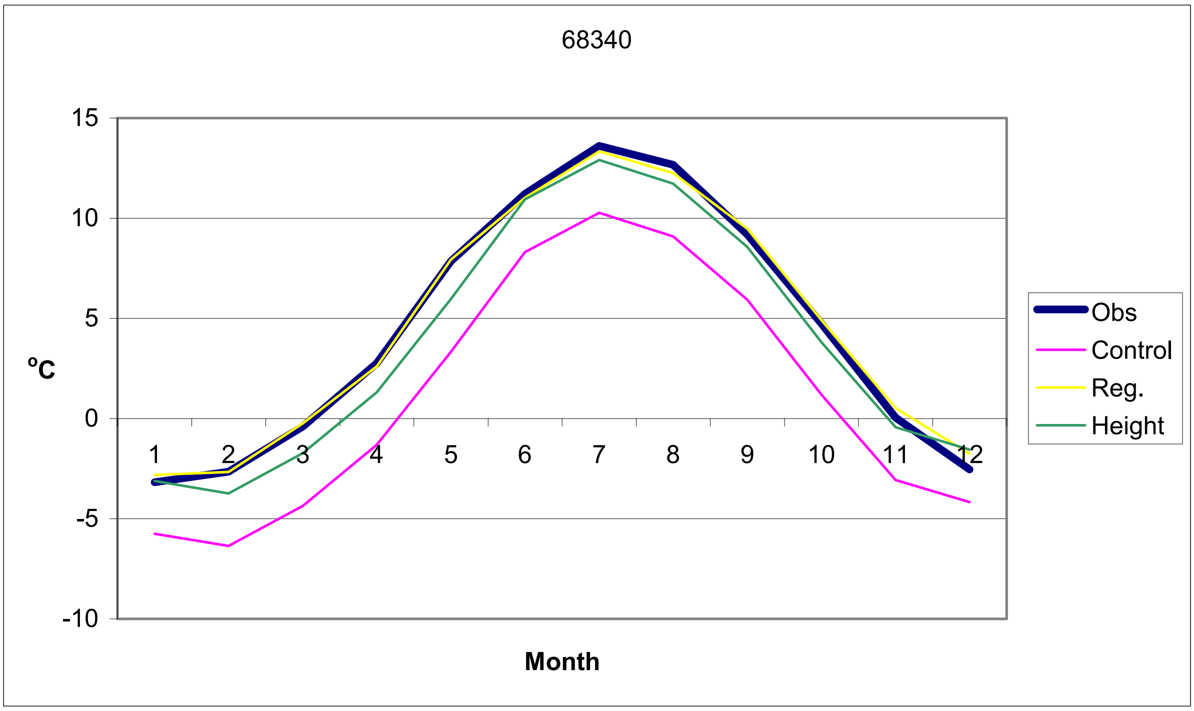

Figure 4.26 Mean monthly air temperature at station 68340 Selbu-Stubbe, observed values for the period 1980-1999 together with control data, the adjusted control data with regression and the adjusted control data with height correction.

5. Discussion and conclusions

5.1 Precipitation

Dynamically downscaled precipitation from the HIRHAM model was adjusted to represent station sites. The modelled data represent grid squares of 55x55 km^2 and are therefore smoothened compared to point observations. The adjustment factors are greater than one at stations in the precipitation maximum zone along the western and north-western coast, implying that precipitation is underestimated in these regions. In the eastern parts of Norway, the adjustment factors are lower than one most of the year. The lowest values are found in the precipitation minimum zone, indicating that the model overestimates the precipitation values in the "rain shadow". The adjustment factors also show a seasonal cycle: The factors are generally highest during summer and lowest during spring. The fact that the model estimates some rainfall on days with no precipitation is accounted for as precipitation is set equal to 0 for days with precipitation less or equal to 0.2 mm.

The adjustment of the precipitation data for the control period has lead to more realistic monthly mean values for the control period, and probably also for the scenario period. As most factors are <1, the adjustment also affected the variance of the daily precipitation. At about 50% of the stations it led to an improvement as compared to observations. The ratio between precipitation during the scenario period and the control period is the same for unadjusted and adjusted model data.

The western part of Norway receive most precipitation during the year (> 4000 mm) because of the maritime climate and the high mountains that lead to orographic precipitation. The model does not count properly for the orographic effects, thus the adjustment factors are larger than one in this area most of the year. In the coastal area in the east, the factors are >1 in July and August. This is a period dominated by convective precipitation, which is rather difficult to predict. The adjustment factor is >1 in the coastal area in Nordland in Sept. - Dec. In July the factors at the northernmost part of the country and at Finnmarksvidda is >1. The inland and high mountain parts of southern Norway have adjustment factors less than one through out the year. It increases towards east and is at the largest during spring.

The presently suggested method for adjustment of HIRHAM precipitation data is considered as satisfactory concerning average conditions. For considering precipitation distributions, however, the method would probably need refinement. The precipitation adjustment factors compensate in some average way for the limited spatial resolution of HIRHAM. By allowing the factor to vary from month to month, a typical seasonal variability is also accounted for. The adjustment factor should, however, ideally depend on type of weather (wind direction etc.) as well. The adjustment factors may be seen in conjunction with weather type and difficulties with forecasting problems concerning the different weather types. Tveito (2002) has studied the difference between the modelled precipitation (from the HIRLAM model) and the observed values compared to wind direction. Tveito has studied the variance and correlation between the data as well. Tveito found that the size of the estimated error is strongly dependent on wind direction or type of weather.

It is concluded that the adjustment factors for precipitation are found to be satisfactory. They can however, become more sophisticated, e.g. to get the variance adjusted satisfactory as well as the mean value. Further studies should therefore be performed to optimalize the adjustment factors on the modelled precipitation from the HIRHAM model.

5.2 Temperature

Two approaches were made to adjust dynamically downscaled temperatures from the HIRHAM model to represent station sites. One approach was based upon linear regression between downscaled and observed temperatures during the validation period (1979-1993). This method led to reasonable adjustment of mean temperatures in the control period (1980-1999). However, the variance was reduced at a majority of the stations, and at most stations the adjustment increased the difference between modelled and observed variance in daily temperatures. Also temperature changes were affected by the adjustment, and the projected change from control to scenario period was systematically reduced. The method can thus not be recommended for assessing local climate change.

The second approach was to adjust the modelled temperatures only for the difference between the real station altitude and the smoothed topography of the model. Adjustment factors corresponding to a temperature gradient of –0.65 per 100 m were applied. The adjustment factors improved the average values at all stations for most months, and without affecting the variance. At stations exposed for ground inversions, the adjustment was less satisfactory during winter months. Improvement concerning monthly mean values would probably be achieved by introducing an empirical temperature gradient rather than applying –0.65 per 100 m during winter. In order to improve the adjustment of single values it would, however, be necessary to allow the adjustment factor to vary with weather situation.

It is concluded that the altitude correction method is acceptable, though it may be refined e.g. by applying weather classification.

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Appendix A Station information.

Station number	Station name	Elevation (m.a.s.l.)
700	Drevsjø	672
4780	Gardermoen	202
6040	Flisa	184
8710	Sørnesset	739
10400	Røros	628
12680	Lillehammer - Sæthereng	270
13670	Skåbu - Storslåen	890
16610	Fokstua	972
16740	Kjøremsgrende	626
17150	Rygge	40
18700	Oslo – Blindern	94
24880	Nesbyen – Skoglund	165
25590	Geilo – Geilostølen	810
28800	Lyngdal i Nummedal	288
31620	Møsstrans	977
32100	Gvarv	26
37230	Tveitsund	252
39040	Kjevik	12
42920	Sirdal - Tjørhom	500
44560	Sola	7
46610	Sauda	5
50300	Kvamskogen	408
50540	Bergen - Florida	12
51590	Voss - Bø	125
52860	Takle	38
55290	Sognefjell	1413
55430	Bjørkehaug i Jostedal	324
55840	Fjærland - Skarestad	10

58700	Oppstryn	201
60500	Tafjord	15
60990	Vigra	22
65110	Vinjeøra	47
66730	Berkåk-Lyngholt	475
68340	Selbu-Stubbe	242
69100	Værnes	12
70850	Kjøbli i Snåsa	195
72100	Namdalseid	86
77750	Susendal-Bjormo	265
80700	Glomfjord	39
82290	Bodø	11
86500	Sortland	3
88000	Tennevoll	22
89350	Bardufoss	76
89950	Dividalen	228
90450	Tromsø	100
91370	Skibotn - Melå	8
91750	Nordreisa	1
92350	Nordstraum i Kvænangen	6
93140	Alta Lufthavn	3
93300	Suolovuopmi	374
97250	Karasjok	129
98550	Vardø	14
99370	Kirkenes lufthavn	89
99840	Svalbard lufthavn	28
99910	Ny-Ålesund	8

Appendix B Correlation between observed and modelled (ERA-15) daily precipitation.

Stnr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
700	0.22	0.31	0.28	0.19	0.12	0.07	0.02	0.07	0.11	0.34	0.28	0.20
4780	0.31	0.43	0.41	0.16	0.04	0.05	0.13	0.05	0.18	0.33	0.39	0.41
6040	0.26	0.37	0.33	0.21	0.08	0.07	0.10	-0.02	0.13	0.28	0.39	0.34
8710	0.15	0.25	0.18	0.18	0.11	0.08	0.09	0.15	0.29	0.27	0.20	0.18
10400	0.21	0.18	0.22	0.16	0.11	0.00	0.04	0.02	0.11	0.18	0.22	0.35
12680	0.33	0.40	0.32	0.25	0.06	0.09	0.11	-0.00	0.18	0.39	0.47	0.33
13670	0.32	0.35	0.27	0.21	0.17	0.09	0.05	0.07	0.22	0.21	0.32	0.28
16610	0.33	0.32	0.24	0.19	0.10	0.14	0.04	0.03	0.14	0.16	0.27	0.28
16740	0.38	0.27	0.20	0.22	0.11	0.05	0.06	0.03	0.09	0.09	0.24	0.30
17150	0.36	0.49	0.46	0.16	0.10	0.02	0.15	0.06	0.19	0.33	0.33	0.43
18700	0.31	0.44	0.42	0.12	0.09	0.07	0.17	0.03	0.20	0.33	0.35	0.35
24880	0.31	0.33	0.29	0.17	0.17	0.13	0.13	0.05	0.26	0.29	0.36	0.36
25590	0.37	0.32	0.26	0.14	0.15	0.11	0.16	0.09	0.26	0.20	0.32	0.27
28800	0.35	0.45	0.38	0.16	0.11	0.05	0.20	0.14	0.22	0.30	0.38	0.41
31620	0.35	0.38	0.27	0.22	0.15	0.16	0.31	0.12	0.33	0.36	0.41	0.36
32100	0.36	0.42	0.45	0.25	0.12	0.15	0.23	0.13	0.31	0.37	0.40	0.40
37230	0.40	0.55	0.40	0.23	0.13	0.14	0.24	0.11	0.29	0.33	0.45	0.42
39040	0.53	0.51	0.46	0.23	0.22	0.11	0.16	0.14	0.26	0.28	0.44	0.40
42920	0.66	0.62	0.38	0.24	0.19	0.09	0.19	0.13	0.29	0.37	0.55	0.51
44560	0.46	0.42	0.38	0.15	0.19	0.06	0.18	0.07	0.17	0.27	0.37	0.45
46610	0.62	0.60	0.50	0.31	0.25	0.19	0.14	0.17	0.29	0.36	0.55	0.49
50300	0.61	0.63	0.51	0.39	0.36	0.18	0.17	0.23	0.30	0.40	0.57	0.54
50540	0.48	0.56	0.53	0.45	0.35	0.11	0.19	0.10	0.24	0.47	0.47	0.51
51590	0.64	0.67	0.51	0.32	0.25	0.18	0.13	0.20	0.27	0.35	0.56	0.49
52860	0.56	0.59	0.53	0.43	0.38	0.22	0.15	0.22	0.29	0.40	0.54	0.52
55290	0.60	0.50	0.25	0.29	0.18	0.14	0.05	0.13	0.15	0.20	0.42	0.48
55430	0.54	0.49	0.41	0.31	0.18	0.27	0.08	0.17	0.18	0.31	0.43	0.49
55840	0.59	0.59	0.50	0.33	0.39	0.18	0.06	0.23	0.27	0.39	0.56	0.55
58700	0.50	0.41	0.47	0.27	0.28	0.11	0.03	0.13	0.19	0.32	0.47	0.52
60500	0.58	0.45	0.53	0.29	0.17	0.02	0.09	0.08	0.22	0.41	0.41	0.47
60990	0.47	0.30	0.29	0.20	0.21	0.04	0.00	0.12	0.27	0.29	0.42	0.39

65110	0.39	0.27	0.52	0.22	0.31	0.01	0.02	-0.00	0.36	0.37	0.38	0.45
66730	0.43	0.30	0.48	0.31	0.13	0.02	0.06	-0.03	0.21	0.28	0.32	0.47
68340	0.43	0.23	0.42	0.27	0.18	0.10	0.06	0.03	0.21	0.34	0.42	0.42
69100	0.45	0.28	0.43	0.27	0.19	0.06	0.01	0.06	0.26	0.38	0.40	0.41
70850	0.60	0.44	0.40	0.30	0.23	0.09	0.03	0.02	0.22	0.36	0.39	0.43
72100	0.59	0.43	0.41	0.37	0.34	0.11	-0.01	0.11	0.30	0.35	0.41	0.37
77750	0.55	0.51	0.25	0.32	0.11	0.10	0.03	0.07	0.20	0.35	0.29	0.49
80700	0.54	0.53	0.33	0.32	0.28	0.07	0.08	0.12	0.29	0.43	0.27	0.40
82290	0.46	0.45	0.25	0.23	0.24	0.01	0.10	0.17	0.23	0.33	0.28	0.42
86500	0.40	0.54	0.23	0.28	0.36	0.04	0.06	0.11	0.30	0.47	0.19	0.41
88000	0.48	0.45	0.18	0.34	0.11	0.02	0.01	0.04	0.16	0.31	0.28	0.42
89350	0.40	0.46	0.19	0.37	0.14	0.14	-0.01	0.06	0.17	0.31	0.28	0.47
89950	0.30	0.42	0.08	0.16	0.00	-0.04	0.01	0.02	0.10	0.14	0.28	0.36
90450	0.48	0.47	0.32	0.29	0.25	0.15	0.11	0.13	0.15	0.34	0.34	0.43
91370	0.36	0.30	0.18	0.14	0.18	0.05	0.01	0.12	0.12	0.27	0.23	0.35
91750	0.35	0.40	0.21	0.31	0.20	0.13	0.07	0.08	0.17	0.22	0.24	0.38
92350	0.43	0.47	0.24	0.31	0.11	0.04	0.04	0.08	0.16	0.26	0.27	0.37
93140	0.24	0.26	0.25	0.13	0.00	0.08	0.00	0.02	0.10	0.18	0.20	0.29
93300	0.27	0.20	0.12	0.13	0.01	0.04	0.02	-0.02	0.09	0.15	0.11	0.25
97250	0.34	0.12	0.11	0.10	0.07	0.06	0.03	0.01	0.11	0.16	0.04	0.22
98550	0.21	0.26	0.24	0.14	0.15	-0.06	0.04	-0.01	0.09	0.15	0.33	0.17
99370	0.10	0.04	0.04	0.01	0.11	-0.06	0.07	-0.02	0.10	0.08	0.15	0.09
99840	0.28	0.34	0.30	0.19	0.14	0.07	0.10	0.09	0.09	0.08	0.21	0.22
99910	0.34	0.34	0.42	0.25	0.38	0.18	0.10	0.28	0.19	0.12	0.30	0.25

Appendix C Mean annual precipitation for the control period [mm/day].

Station	Mean value			Standard deviation of daily values		
Number	Obs.	Mod.	Adjusted mod.	Obs.	Mod.	Adjusted mod.
700	1.6	2.8	2.0	3.9	4.1	3.2
4780	2.3	3.1	2.9	4.9	5.1	5.1
6040	1.8	2.9	2.2	4.0	4.5	3.8
8710	1.6	2.9	1.9	3.7	3.9	2.8
10400	1.4	2.9	1.6	3.1	3.6	2.4
12680	1.9	3.4	2.2	4.3	5.3	3.7
13670	1.5	3.2	1.9	3.7	4.6	3.0
16610	1.3	3.2	1.5	2.9	3.5	2.0
16740	1.2	3.4	1.4	3.0	3.6	1.7
17150	2.3	3.0	3.0	5.0	5.4	5.9
18700	2.1	3.2	2.8	4.7	5.4	5.2
24880	1.4	3.6	1.8	4.0	4.6	3.4
25590	2.0	3.2	2.4	4.0	4.6	3.4
28800	2.2	3.8	2.8	4.8	6.1	4.8
31620	2.3	3.6	2.8	4.2	5.3	4.3
32100	2.2	4.2	3.0	5.1	6.9	5.6
37230	2.7	4.2	3.4	6.1	7.0	6.0
39040	3.5	3.7	4.4	7.6	6.3	7.8
42920	5.2	4.9	6.0	9.0	7.0	8.9
44560	3.4	5.1	3.9	5.9	7.7	5.9
46610	6.4	6.8	7.4	10.9	8.8	9.9
50300	9.2	8.6	10.6	14.2	11.5	14.0
50540	6.6	8.1	7.3	10.6	11.1	10.0
51590	3.8	7.1	4.2	6.6	8.8	5.3
52860	9.1	7.7	10.3	15.8	11.0	15.1
55290	2.5	4.0	3.0	4.2	4.2	3.5
55430	-	5.5	4.6	-	6.0	5.2

55840	-	6.8	6.5	-	7.7	7.7
58700	-	6.2	4.0	-	6.8	4.5
60500	2.8	6.6	3.2	5.9	7.7	4.0
60990	3.8	5.9	4.7	6.2	7.6	6.2
65110	4.3	4.6	4.8	7.5	6.3	6.6
66730	2.3	4.1	2.6	4.6	4.6	3.2
68340	2.6	4.7	2.9	4.6	5.4	3.7
69100	2.4	4.8	3.8	4.4	5.8	4.9
70850	2.8	4.2	3.1	4.9	5.2	4.0
72100	3.6	4.3	4.1	5.8	6.1	5.9
77750	2.8	4.3	2.9	6.3	5.3	3.8
80700	5.7	4.8	5.7	10.5	7.3	8.8
82290	2.8	5.0	2.8	5.2	7.3	4.1
86500	3.8	3.4	3.3	6.6	5.6	5.8
88000	2.7	3.9	2.7	5.4	4.4	3.2
89350	1.8	3.8	1.7	3.5	5.2	2.6
89950	-	2.5	0.8	-	3.0	1.4
90450	2.9	3.6	2.8	4.8	5.2	4.1
91370	-	3.1	1.4	-	3.9	1.9
91750	1.9	2.9	1.9	3.8	3.9	2.7
92350	1.2	2.7	1.3	2.8	3.5	1.9
93140	1.1	2.3	1.1	2.5	3.1	1.7
93300	1.3	2.1	1.4	2.9	2.9	2.4
97250	1.0	2.0	1.2	2.7	2.8	2.2
98550	1.7	2.1	1.8	3.4	2.9	2.7
99370	1.2	1.8	1.4	3.0	2.8	2.5
99840	0.5	1.4	0.6	1.6	2.5	1.1
99910	1.1	1.2	1.2	3.2	2.3	2.3

Appendix D Correlation coefficient between observed and interpolated (from ERA-15) daily temperatures.

Stnr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
700	0.53	0.54	0.60	0.53	0.51	0.41	0.39	0.46	0.51	0.59	0.55	0.46
4780	0.66	0.66	0.66	0.61	0.52	0.40	0.33	0.53	0.59	0.62	0.54	0.56
6040	0.62	0.62	0.65	0.58	0.52	0.40	0.34	0.45	0.54	0.56	0.53	0.51
8710	0.52	0.51	0.57	0.54	0.50	0.42	0.38	0.48	0.50	0.61	0.57	0.51
10400	0.45	0.48	0.53	0.55	0.51	0.42	0.41	0.49	0.55	0.60	0.54	0.47
12680	0.52	0.62	0.59	0.60	0.47	0.46	0.32	0.40	0.56	0.59	0.63	0.43
13670	0.60	0.55	0.55	0.55	0.51	0.41	0.39	0.52	0.55	0.62	0.54	0.53
16610	0.60	0.56	0.54	0.60	0.51	0.37	0.43	0.51	0.56	0.60	0.55	0.53
16740	0.52	0.53	0.54	0.61	0.49	0.36	0.42	0.51	0.54	0.58	0.56	0.50
17150	0.76	0.78	0.78	0.67	0.56	0.44	0.42	0.59	0.66	0.64	0.68	0.68
18700	0.69	0.67	0.69	0.58	0.50	0.40	0.34	0.48	0.60	0.58	0.58	0.60
24880	0.60	0.53	0.59	0.54	0.50	0.42	0.33	0.49	0.45	0.52	0.47	0.53
25590	0.65	0.55	0.54	0.54	0.53	0.43	0.38	0.52	0.52	0.60	0.55	0.48
28800	0.66	0.64	0.65	0.55	0.53	0.41	0.36	0.46	0.52	0.53	0.53	0.60
31620	0.66	0.66	0.57	0.60	0.56	0.42	0.35	0.48	0.59	0.55	0.60	0.53
32100	0.60	0.53	0.61	0.58	0.44	0.39	0.37	0.50	0.57	0.46	0.46	0.63
37230	0.71	0.66	0.65	0.58	0.55	0.39	0.35	0.50	0.52	0.54	0.62	0.61
39040	0.80	0.82	0.80	0.70	0.65	0.52	0.41	0.58	0.61	0.63	0.73	0.73
42920	0.65	0.61	0.57	0.55	0.59	0.40	0.40	0.46	0.54	0.55	0.60	0.66
44560	0.73	0.75	0.64	0.58	0.58	0.38	0.39	0.52	0.61	0.55	0.64	0.66
46610	0.62	0.60	0.56	0.58	0.58	0.36	0.40	0.50	0.50	0.48	0.54	0.62
50300	0.65	0.64	0.58	0.57	0.61	0.38	0.44	0.51	0.56	0.55	0.55	0.61
50540	0.73	0.76	0.65	0.66	0.67	0.48	0.52	0.57	0.64	0.59	0.66	0.70
51590	0.59	0.54	0.56	0.56	0.55	0.38	0.39	0.47	0.51	0.51	0.52	0.58
52860	0.67	0.63	0.61	0.64	0.61	0.36	0.43	0.52	0.58	0.54	0.51	0.58
55290	0.53	0.47	0.53	0.54	0.39	0.38	0.40	0.56	0.65	0.41	0.49	0.51
55430	0.55	0.57	0.54	0.59	0.46	0.32	0.36	0.41	0.54	0.54	0.50	0.56
55840	0.53	0.48	0.48	0.59	0.55	0.31	0.39	0.42	0.52	0.49	0.50	0.52
58700	0.51	0.52	0.54	0.62	0.41	0.26	0.43	0.42	0.61	0.36	0.47	0.59
60500	0.53	0.56	0.53	0.61	0.41	0.28	0.34	0.40	0.56	0.47	0.45	0.52

60990	0.70	0.71	0.64	0.68	0.61	0.52	0.51	0.52	0.63	0.63	0.52	0.67
65110	0.50	0.62	0.56	0.66	0.58	0.40	0.40	0.46	0.57	0.62	0.65	0.52
66730	0.47	0.60	0.55	0.63	0.53	0.41	0.41	0.44	0.58	0.64	0.64	0.49
68340	0.55	0.56	0.54	0.63	0.54	0.43	0.44	0.45	0.57	0.59	0.52	0.54
69100	0.54	0.53	0.55	0.63	0.55	0.43	0.50	0.42	0.55	0.60	0.54	0.53
70850	0.53	0.59	0.60	0.60	0.56	0.43	0.44	0.43	0.55	0.60	0.55	0.50
72100	0.53	0.65	0.57	0.69	0.60	0.45	0.44	0.43	0.57	0.66	0.67	0.53
77750	0.63	0.52	0.61	0.54	0.53	0.43	0.37	0.47	0.51	0.62	0.60	0.54
80700	0.70	0.50	0.65	0.62	0.57	0.48	0.39	0.41	0.55	0.64	0.56	0.66
82290	0.77	0.68	0.75	0.72	0.65	0.58	0.51	0.49	0.64	0.73	0.68	0.76
86500	0.71	0.54	0.65	0.71	0.58	0.49	0.50	0.35	0.68	0.69	0.59	0.67
88000	0.67	0.45	0.67	0.49	0.60	0.58	0.44	0.47	0.46	0.62	0.49	0.63
89350	0.64	0.47	0.66	0.58	0.60	0.58	0.40	0.45	0.59	0.61	0.52	0.63
89950	0.63	0.53	0.64	0.63	0.57	0.55	0.32	0.46	0.54	0.59	0.47	0.58
90450	0.74	0.62	0.75	0.64	0.66	0.63	0.51	0.49	0.63	0.71	0.66	0.74
91370	0.66	0.61	0.65	0.65	0.53	0.46	0.38	0.41	0.55	0.65	0.52	0.62
91750	0.63	0.51	0.67	0.59	0.61	0.57	0.44	0.42	0.53	0.63	0.52	0.63
92350	0.68	0.55	0.70	0.60	0.60	0.61	0.44	0.44	0.57	0.63	0.55	0.66
93140	0.65	0.52	0.68	0.58	0.55	0.59	0.40	0.45	0.61	0.63	0.47	0.61
93300	0.63	0.47	0.65	0.54	0.58	0.60	0.33	0.50	0.60	0.61	0.44	0.57
97250	0.61	0.51	0.67	0.56	0.60	0.58	0.32	0.54	0.59	0.63	0.42	0.56
98550	0.64	0.70	0.69	0.61	0.63	0.66	0.55	0.59	0.69	0.75	0.59	0.69
99370	0.64	0.63	0.72	0.63	0.60	0.57	0.38	0.57	0.66	0.70	0.53	0.65
99840	0.79	0.80	0.79	0.75	0.81	0.63	0.52	0.67	0.71	0.76	0.80	0.77
99910	0.78	0.82	0.79	0.75	0.82	0.62	0.57	0.67	0.71	0.77	0.78	0.79

Appendix E Mean annual temperature values for the control period [^{O}C].

Stnr	Mean value			Standard deviation of daily values		
	Obs.	Mod.	Adjusted mod.	Obs.	Mod.	Adjusted mod.
700	0.4	0.0	0.4	9.6	7.8	8.2
4780	4.5	3.6	4.4	9.0	7.9	7.8
6040	3.8	2.7	3.8	9.7	8.1	8.3
8710	1.3	-1.3	0.8	8.8	7.4	7.5
10400	0.7	-0.7	0.7	9.6	7.4	8.0
12680	3.8	1.0	3.6	8.9	7.8	8.0
13670	0.9	-1.7	0.7	8.0	7.6	7.0
16610	0.2	-2.7	-0.1	7.8	7.1	6.5
16740	1.8	-2.9	1.5	8.5	7.1	7.4
17150	6.1	5.3	6.1	8.1	7.2	6.8
18700	6.1	4.0	6.0	8.2	7.8	7.2
24880	3.4	0.0	3.2	8.0	7.4	6.8
25590	1.3	-2.0	1.2	8.0	7.4	6.8
28800	3.8	2.3	3.7	8.8	7.3	7.5
31620	0.9	-0.7	0.8	7.6	7.3	6.6
32100	4.9	3.1	5.0	9.2	7.0	7.7
37230	5.5	3.2	5.4	7.8	7.1	6.8
39040	7.1	6.5	7.4	7.1	4.9	5.2
42920	3.5	2.3	2.9	7.5	6.5	5.9
44560	7.7	6.0	7.6	5.7	5.6	4.8
46610	6.6	1.7	6.3	6.9	6.6	6.0
50300	4.5	2.5	4.4	6.4	6.1	5.5
50540	7.9	5.4	8.1	5.6	5.2	5.1
51590	5.3	0.0	5.0	7.8	6.5	6.7
52860	7.1	3.8	7.0	5.5	6.2	4.7
55290	-3.3	-3.4	-3.5	7.4	7.0	6.2
55430	-	-2.0	3.7	-	6.6	6.6

55840	-	-0.9	5.1	-	6.3	6.3
58700	-	-1.8	5.6	-	6.2	5.4
60500	7.0	-0.6	7.1	6.0	6.3	4.9
60990	7.1	5.9	7.7	4.8	4.5	3.9
65110	3.2	5.4	0.0	6.4	5.6	0.0
66730	2.7	0.0	2.9	7.3	6.9	6.0
68340	4.4	1.1	4.6	7.4	7.0	6.2
69100	5.7	2.2	6.0	7.3	7.0	6.2
70850	3.4	1.2	3.6	8.2	7.4	7.1
72100	4.1	3.3	4.2	7.5	6.8	6.5
77750	2.0	-1.4	1.8	9.2	8.1	8.1
80700	5.3	0.9	5.4	6.2	7.2	5.4
82290	4.9	3.0	5.6	6.3	5.6	5.7
86500	4.4	3.0	4.6	6.1	6.7	5.7
88000	2.7	-1.0	3.0	8.3	6.9	6.4
89350	1.2	-1.0	1.3	9.7	8.2	8.7
89950	-	-3.5	0.7	-	8.8	8.2
90450	2.8	1.0	3.5	6.7	7.2	6.2
91370	-	-2.9	2.6	-	8.4	7.4
91750	1.6	-1.4	2.0	8.7	8.4	7.8
92350	3.0	-1.6	3.2	6.9	8.5	6.3
93140	1.6	-1.7	1.8	8.9	9.0	8.1
93300	-2.1	-2.3	-2.0	10.6	9.3	9.5
97250	-2.0	-1.6	-1.7	12.6	9.5	11.1
98550	1.6	2.3	2.1	5.9	6.1	6.5
99370	-0.3	-0.2	0.2	9.5	8.6	8.7
99840	-5.9	-10.9	-4.5	9.6	13.0	9.2
99910	-5.8	-8.9	-3.9	8.7	11.6	8.0