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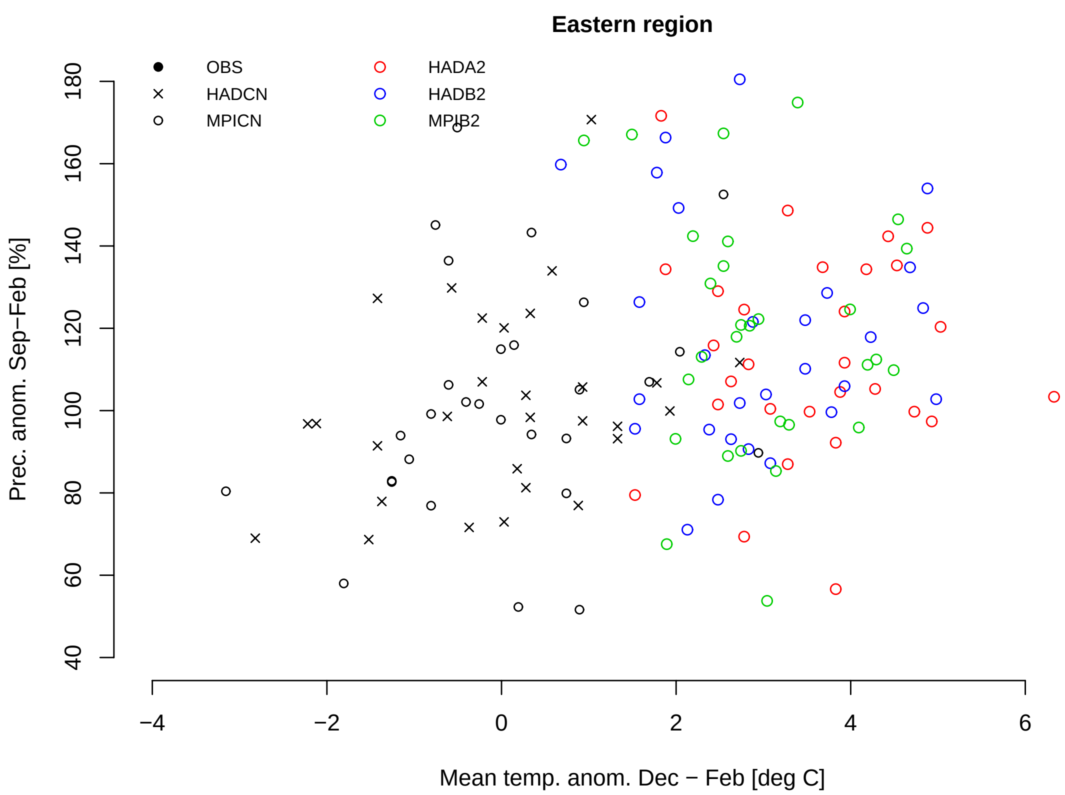
Climate

Energy demand and potential for hydropower production in Norway

Historic and future perspective

Torill Engen-Skaugen and Eirik J. Førland



Temperature and precipitation anomalies.

Towards a warmer climate

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report

Title	Date
Energy demand and potential for hydropower production in Norway Historic and future perspective	21.12.2007
Section	**Report no.**
Climatology Department	no. 14/07
Author(s)	**Classification**
Torill Engen-Skaugen and Eirik J. Førland	☒ Free ☐ Restricted
	ISSN 1503-8025
	e-ISSN 1503-8025
Client(s)	**Client's reference**
Norwegian Electricity Industry Association (EBL)	MKU_ 1.8_06 (EBL)
Norwegian Research Council / CICERO (coordinator for CELECT)	CELECT (NFR-Contract 178340/S30)

Abstract

The combination of dry autumns and low temperatures in the succeeding winter may lead to high prices on electricity and problems with energy supply in Norway. Heating Degree-Days (HDD) are commonly used as an indicator for energy demand for heating buildings. HDD sum anomalies for the latest 50-100 years are in this report presented together with the frequency of years with high demand for heating in combination with low hydro power potential and vice versa. Three scenarios for the period 2071-2100 are also analysed.

The main conclusion is that the demand for heating buildings has decreased during the latest decades and the hydro power potential has been high. Precipitation is projected to increase in Norway during the 21st century. The analyses show that winters with high HDD-values have a tendency to occur simultaneously in all regions in Norway. The scenario results indicate that dry autumns and relatively cold winters may occur in the future as well. The demand for heating buildings will however continue to decrease in the future (~30% for the period 2071-2100 relative to 1961-1990).

Keywords

Heating degree-days, precipitation anomalies, temperature anomalies, energy demand

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1 Introduction

Electricity demand for heating buildings in Norway increased dramatically after 1950 (Bøeng, 2005). Reasons for this are that el-supply before 1950 was not available in all regions in Norway, the quality of electric panel ovens was rather sparse at the time, and there was rationing of electricity during the 2nd world war. Norway has traditionally experienced low electricity prices and the supply has been sufficient. This is due to large annual and particularly autumn rainfalls that for most years have lead to full reservoirs in the beginning of the heating season[1]. The situation with high supply and low prices for electricity is now changing because of a) increasing electricity demand, b) deregulation of the Norwegian electricity marked and c) the epoch for developing hydroelectric power in Norway now more or less is ended.

Electricity supply in Norway is mainly based on hydropower production, and temperature is usually the most significant weather variable influencing electricity consumption for heating buildings. The potential for electricity production throughout the heating season is dependent of the availability of water in reservoirs at the beginning of the winter period. Large amounts of rain during autumn and winter will fill the reservoirs; dry conditions may lead to problems concerning reservoir filling. The demand for heating buildings is large when the winter and spring seasons are cold. People's electricity demand as a whole, though, may be analysed differently and is not considered here. Halvorsen and Larsen (2001) found that the household electricity consumption in the period 1976-1993 in Norway increased by an average of approximately 3% annually. Half of this increase is due to an increase in the number of households. The remainder is due to an increase in average consumption per household. Out door temperature is the main variable when it comes to heating (Johnsen, 2001; Pardo et al., 2002). Regional monthly and seasonal temperature and precipitation series are available for the Norwegian mainland from 1900 (www.met.no). A combination of these time series is here used as an indicator for the development of heating demand and potential for hydropower production in Norway.

Groisman et al (2003) found a statistically significant decrease in annual heating degree-days during the past 50 years of 6% over the entire Arctic-region, with a maximum absolute and relative reduction in heating degree-days over Western Canada and Alaska (9% and 8% per 50 years respectively). For Eurasia, significant reductions were found for Russia (6-7% per 50 years), indicating that there have been reduced heating costs in relative terms. Førland et al (2004), concluded that the heating season in the Nordic countries has been reduced during the latest decades, and that the available projections indicate a further reduction during the next 50 years.

Temperature anomalies for winter and spring from the monthly normal values (1961-1990) for five geographical regions in Norwegian are considered in combination with autumn and winter precipitation anomalies from the monthly normal values (1961-1990). Heating Degree-Days (HDD) are commonly used to deal with the non linearity of the temperature effect, indicating demand for heating (e.g. Kadioglu et al., 2001; Sarak and Satman, 2002; Moral-Carcedo and Vicéns-Otero, 2005). HDD sum anomalies are here presented together with the frequency of years with high demand for heating in combination with low hydro power potential (dry autumn and winter seasons in combination with cold winter and spring seasons) and vice versa (wet autumn and winter seasons in combination with warm winter and spring seasons).

The supply and demand of electricity in Norway is vulnerable to the climate, and consequently influenced by climate change. The HDD analyses are performed on three scenarios (2071-2100) to give a future perspective on potential for hydropower production and demand for heating buildings. These are based on the HadAM3H model from the Hadley centre, UK with SRES emission scenarios A2 and B2 (IPCC, 2000), and the ECHAM4/OPYC3 model from Max Planck Institute in Hamburg, Germany (Roeckner, 1999) with SRES emission scenario B2 (IPCC, 2000).

[1]The period of the year when people need to heat their buildings. It is here defined from the first day in the autumn when the mean daily temperature drops below 10 °C until it rises above 10 °C in spring (Section 3).

The price of electricity in the heating season is traditionally dependent on the reservoir filling, as well as the heating demand during winter and spring. In 2003 Norway experienced a near doubling of the electricity prices. Autumn 2002 and Winter 2003 is associated with small rainfall amounts and low degree of filling in the reservoirs. The electricity prices, however, are also dependent on the power market. The generation and sales activities of hydropower in Norway has been exposed to competition since 1991 and operates like a stock market. The present study is of relevance to energy prices although the price of electricity will not be considered specifically.

The temperature and precipitation regions together with temperature and precipitation anomalies series are presented in Section 2. Methods used are presented in Section 3. The results for the historical period are presented in Section 4. The future perspective is presented in Section 5. Discussion and concluding remarks are given in Section 6.

The present report is part of the projects “Klimaprediktabilitet på skala fra 0 til 100 år: konsekvenser for snømagasin, tilsig, flom, tørke og energiproduksjon“ (http://KlimaKraft.met.no) funded by the Norwegian Electricity Industry Association (EBL), reference number MKU_1.8_06, and the project “CELECT - Climate change impacts in the electricity sector” (NFR 178340/S30) funded by the Norwegian Research Council. The CELECT-project is coordinated by Gunnar Eskeland, CICERO (www.cicero.uio.no).

2 Data

2.1 Historical mean monthly temperature and precipitation time series

Homogeneous long-term variations of temperature and precipitation are interpolated to monthly grids with spatial resolution of 1 x 1 km^2 back to1900. The temperature and precipitation anomaly series in the present analysis are therefore established for five regions based on borders of Norwegian counties (Figure 1). The interpolation methods used are described in Hanssen-Bauer et al (2006). Regions with fairly homogeneous long-term variations of temperature and precipitation in Norway are established by Hanssen-Bauer and Nordli (1998) and Hanssen-Bauer and Førland (1998) respectively. See also Førland et al. (2000). The interpolated monthly temperature and precipitation grids show good agreement with the homogeneous time series representing the same time period. The agreement is poorer in the early years of the period. This is mainly due to sparse observational series. The historical time series are extracted from the gridded maps. They are updated every moth and can be downloaded from the met.no's web site: http://met.no/met/ver_100/index.html.

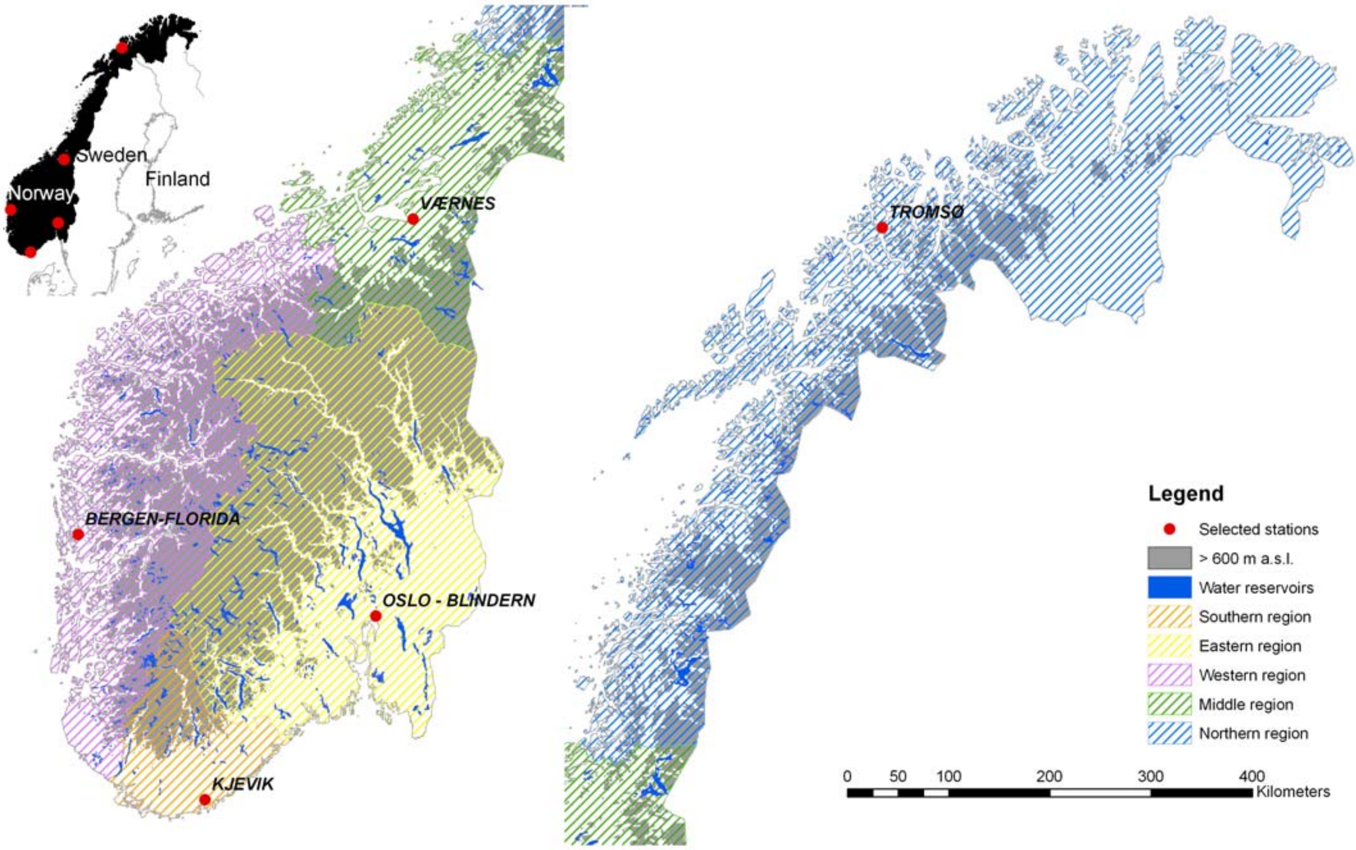

Figure 2.1. Geographical regions used in the analyses marked by colours in the Figure. The location of the weather stations used, 18700 Oslo-Blindern, 39040 Kjevik, 50540 Bergen-Florida, 69100 Værnes and 90450 Tromsø, are indicated in the figure. Also shown are water reservoirs as well as areas with altitude above 600 m a.s.l.

2.2 Establishing historical temperature series representative to population

Regional area-weighted temperature series represent also large mountain areas in Norway and are thus too cold compared to areas where most people live. To make the series representative for the populated areas, the temperature series has been adjusted to represent large cities (temperature stations) within the geographical region. One temperature station is selected within each region; 18700 Oslo-Blindern is chosen for the South-Eastern region, 69100 Kjevik (Kristiansand) for the Southern region, 50540 Bergen-Florida for the Western region, 69100 Værnes (Trondheim) for the Middle region and 90450 Tromsø for the Northern region (Figure 2.1). Monthly normal values for temperature at the selected stations are presented in Table 2.1. The monthly temperature differences between the station normal and the normal representing the geographical region (Table 2.2) are added to the regional temperature series.

Table 2.1 Monthly normal temperatures (1961-1990) for the selected weather stations representing the geographical regions, [1] Southeast, [2] South [3] West, [4] Middle and [5] North.

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
18700-Oslo [1]	-4.3	-4.0	-0.2	4.5	10.8	15.2	16.4	15.2	10.8	6.3	0.7	-3.1
39040 Kjevik [2]	-1.7	-1.8	1.0	4.6	9.9	14.0	15.5	14.8	11.5	7.9	3.1	-0.1
50540 Bergen-Florida [3]	1.3	1.5	3.3	5.9	10.5	13.3	14.3	14.1	11.2	8.6	4.6	2.4
69100 Værnes [4]	-3.4	-2.5	0.1	3.6	9.1	12.5	13.7	13.3	9.5	5.7	0.5	-1.7
90450 Tromsø [5]	-4.4	-4.2	-2.7	0.3	4.8	9.1	11.8	10.8	6.7	2.7	-1.1	-3.3

Table 2.2 Difference[°C] in normal temperatures between station and area-weighted values.

Region	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Oslo [1]	4.7	4.9	4.6	4.8	5.9	6.1	5.6	4.4	4.5	4.2	4.5	4.4
Kristiansand [2]	2.0	2.4	2.7	3.0	3.6	3.8	3.6	2.7	3.1	2.9	2.4	2.3
Bergen [3]	3.8	4.4	5.2	5.5	5.7	5.4	4.9	4.2	4.7	4.8	4.7	4.1
Trondheim [4]	2.8	3.3	3.4	3.5	4.0	3.8	3.3	2.7	2.7	2.5	2.6	2.9
Tromsø [5]	4.5	4.3	3.8	2.9	2.5	2.2	2.0	1.6	1.8	2.5	3.6	4.3

2.3 Temperature and precipitation scenarios for the future (2071-2100)

Regional temperature and precipitation time series representing geographical regions are not established for scenarios for the future. Scenarios at one representative station within each geographical region are therefore used. These are the same stations as presented in Table 2.1. Temperature and precipitation are first interpolated from HIRHAM, the regional climate model at met.no (Bjørge et al, 2000). The data are adjusted with an empirical method to be representative for local temperature and precipitation conditions at specific locations (Engen-Skaugen, 2007; Engen-Skaugen et al., 2007). Three different scenarios are used, these are SRES emission scenarios A2 and B2 (IPCC, 2000) simulated with the global climate model HadAm3H at the Hadley centre, UK and SRES emission scenario B2 simulated with the global climate model ECHAM4/OPYC3 at the Max Planck Institute, Germany (Roeckner, 1999). All scenarios are run for a control period representing the time slice 1961-1990, and a scenario period representing the years 2071-2100.

3 Methods

3.1 Accumulated heating degree-day sum

The heating season is the period of the year when buildings need to be heated. The sums of heating degree-days closely correlate to energy consumption for heating, and have numerous other practical implications (Quayle and Diaz, 1980, Guttman and Lehman, 1992). The amount of energy for heating of buildings is also depending on other climatological factors (wind speed, radiation), as well as factors related to demographic changes, living standards, and building instructions (e.g. volume of heated buildings, preferred indoor temperatures, thermal insulation, etc.) (Venälänen et al., 2003). The heating season is in the present study defined as the period of the year when the smoothed daily mean temperature is below a threshold $\hat{T}$, while heating degree-days (HDD) are the sum of the difference between a base temperature T_{base} and the daily mean temperature T_i (Taylor, 1981):

(1) $$HDD = -\sum_{i=1}^{365}(T_i - Tbase), \ \ T_i \ < \hat{T}$$

(2) $$HDD = 0, \quad T_i \geq \hat{T}$$

In the USA, the base temperature T_{base} is 65F (Groisman et al., 2003) while in Norway T_{base} = 17°C and $\hat{T}$ =10°C (Skaugen and Tveito, 2002). The latter values are used in the present analysis.

Smoothed daily mean temperatures are obtained by interpolating from mean monthly temperature applying a cubic spline algorithm (Press et al, 1992). HDD is accumulated from the first day in the fall where the mean daily temperature dips below 10 °C until the first day in spring when it rise above 10 °C (heating season). The method is described in Skaugen and Tveito (2002). Normal HDD value (1961-1990) for the selected cities are presented in Table 6.1. Distributed normal HDD values for Norway are presented in Figure 3.1.

HDD time series with duration one, five, seven and 10 days are established based on daily mean temperature (derived from observations). Equation 1 and 2 is used to obtain the HDD time series. Time series of moving mean one, five, seven and 10 days HDD are estimated from the daily HDD time series.

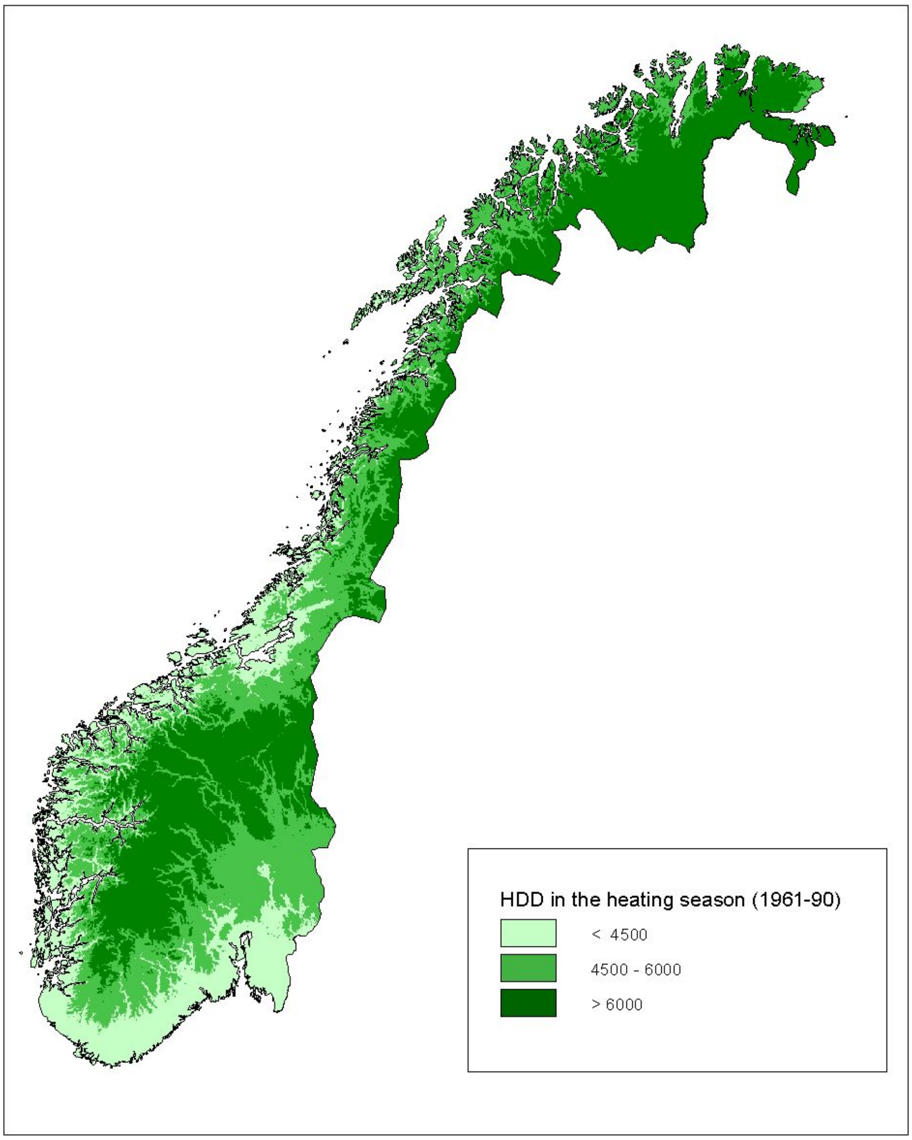

Figure 3.1. Mean annual accumulated heating degree-day sum *[°C]* within the heating season for the normal period 1961-1990 (from Skaugen andTveito, 2002).

4 Heating demand and hydropower potential during 1900-2007

Heating degree days (HDD) established for different durations are presented in Section 4.1. HDD-sums within the heating season are presented in Section 4.2.

4.1 Frequency distribution of mean daily HDD (1957-2007)

Frequency distribution of mean daily HDD throughout a year are established based on time series of daily temperature, with duration of 1, 5, 7 and 10 days, for the period January 1957 until November 2007. The median, 95 and 99 percentiles are presented in Tables 4.1-4.5 for Oslo, Kristiansand, Bergen, Trondheim and Tromsø respectively. A table presenting the highest HDD values within the period January 1957 until November 2007 for the five cities are presented in Appendix A, and is summarised in Table 4.6.

Table 4.1 Median, 95 and 99 percentiles of HDD per day with duration 1, 5, 7 and 10 days for the periods 1957-2007 and 1961-1990 for Oslo.

	1957-2007			1961-1990		
Duration	Median	95 percentile	99 percentile	Median	95 percentile	99 percentile
1 day	11	24.8	30.2	11.2	25.3	31.2
5 days	11	24	28.6	11.2	24.5	29.6
7 days	10.9	23.8	28.1	11.2	24.2	29.1
10 days	10.9	23.5	27.4	11.1	24.1	28.4

Table 4.2 Median, 95 and 99 percentiles of HDD per day with duration 1, 5, 7 and 10 days for the periods 1900-2007 and 1961-1990 for Kristiansand.

	1957-2007			1961-1990		
Duration	Median	95 percentile	99 percentile	Median	95 percentile	99 percentile
1 day	9.9	22.2	28.1	10.1	23	29.2
5 days	10	21.5	26.1	10.1	22.4	27
7 days	9.9	21.3	25.8	10	22.2	26.6
10 days	9.8	21	25.5	9.9	21.8	26.2

Table 4.3 Median, 95 and 99 percentiles of HDD per day with duration 1, 5, 7 and 10 days for the periods 1900-2007 and 1961-1990 for Bergen.

	1957-2007			1961-1990		
Duration	Median	95 percentile	99 percentile	Median	95 percentile	99 percentile
1 day	9.1	18.2	21.5	9.3	18.4	21.7
5 days	8.9	17.6	20.5	9.1	17.8	20.8
7 days	8.7	17.4	20.2	8.8	17.6	20.6
10 days	8.6	17.1	19.8	8.7	17.4	20.3

Table 4.4 Median, 95 and 99 percentiles of HDD per day with duration 1, 5, 7 and 10 days for the periods 1900-2007 and 1961-1990 for Trondheim.

	1957-2007			1961-1990		
Duration	Median	95 percentile	99 percentile	Median	95 percentile	99 percentile
1 day	11.3	24.4	31.1	11.4	25	31.6
5 days	11.5	23.4	28.5	11.5	23.9	28.7
7 days	11.5	23.1	27.7	11.6	23.5	27.8
10 days	11.5	22.7	26.8	11.6	23.2	27.2

Table 4.5 Median, 95 and 99 percentiles of HDD per day with duration 1, 5, 7 and 10 days for the periods 1900-2007 and 1961-1990 for Tromsø.

	1957-2007			1961-1990		
Duration	Median	95 percentile	99 percentile	Median	95 percentile	99 percentile
1 day	14.5	24.9	28	14.7	25.3	28.5
5 days	14.7	24.2	26.9	15	24.5	27.2
7 days	14.8	23.9	26.5	15.1	24.2	26.8
10 days	14.9	23.6	25.9	15.2	23.9	26.2

Table 4.6 Highest HDD-values recorded during 1957-2007 at the selected locations

	1 day		5 days		10 days	
Location	**Date**	**HDD**	**Date**	**HDD**	**Date**	**HDD**
Oslo	10.01.1987	39,0	07.01.1987	35,1	04.02.1966	32,9
Kristiansand	08.01.1982	40,9	05.01.1982	37,1	07.02.1966	32,4
Bergen	11.01.1987	31,8	10.01.1987	27,4	09.01.1987	24,2
Trondheim	10.01.1987	40,1	09.01.1987	37,7	06.01.1987	33,5
Tromsø	02.02.1966	33,8	30.01.1966	31,2	01.02.1966	29,4

Figure 4.1-4.5 shows that the highest median-values of HDD during 1900-2007 are found for Tromsø, and the lowest for Bergen. Western Norway also has the lowest 95 and 99 percentile values, while the southeastern region (Oslo) has the highest values. The exception is for 1 day duration, where the highest 99 percentile value is found for the Trondheim-region.

Table 4.6 reveals two periods since 1957 with particularly high heating demand; i.e. the shift between January/February in 1966 and the first part of January 1987. In the southernmost region, also the start of 1982 had high HDD-values for 1 and 5 days durations (More details are presented in Appendix A).

4.2 HDD within the heating season (1900-2007)

Regional mean autumn and winter precipitation anomalies for each year for the respective geographical region are established. The time series are considered together with annual mean winter and spring temperature anomalies for the respective geographical region (a) in Figures 4.1 – 4.5). The temperature (T) and precipitation (P) values are sorted and values for the 20 % and 80 % percentiles are found respectively. The dots within the blue lines in Figures a) are the years where T and P are equal to or lower than the 20% value (cold and dry years). These are indicating the years when the demand for heating buildings was high in combination with low hydro power potential. The dots within the red lines in the Figures are the years where T and P are equal to or higher than the 80% value (warm and wet years). These are indicating the years when the demand for heating buildings was low in combination with high hydro electrical power potential. These dots are zoomed in and presented with the actual year respectively in Figures b) and c). Heating Degree-Day (HDD) anomalies compared to the normal HDD value (1961-1990) of the region is presented in the figures as well (d)). The HDD sum for the years in b) and c) are marked with blue and red colour respectively.

Figure 4.6 show spread plots of the HDD for the period 1957-2007 indicating how the HDD varies between regions. Upper left of the Figure shows Southeast vs Middle parts of Norway, upper right show Southeast vs. Western parts, middle left show Middle vs. Northern parts, middle right show Southeast vs. Northern parts, lower left show Southern vs. Southeastern parts and lower right show Southern vs. Northern parts. The figure indicates that there is a high correlation in HDD-values between the regions; even between the southernmost and northernmost regions the correlations is 0.72 The strongest correlation (r2~0.95 and r2~0.92) is found between Southern and Southeastern parts and Southeastern and Western parts respectively.

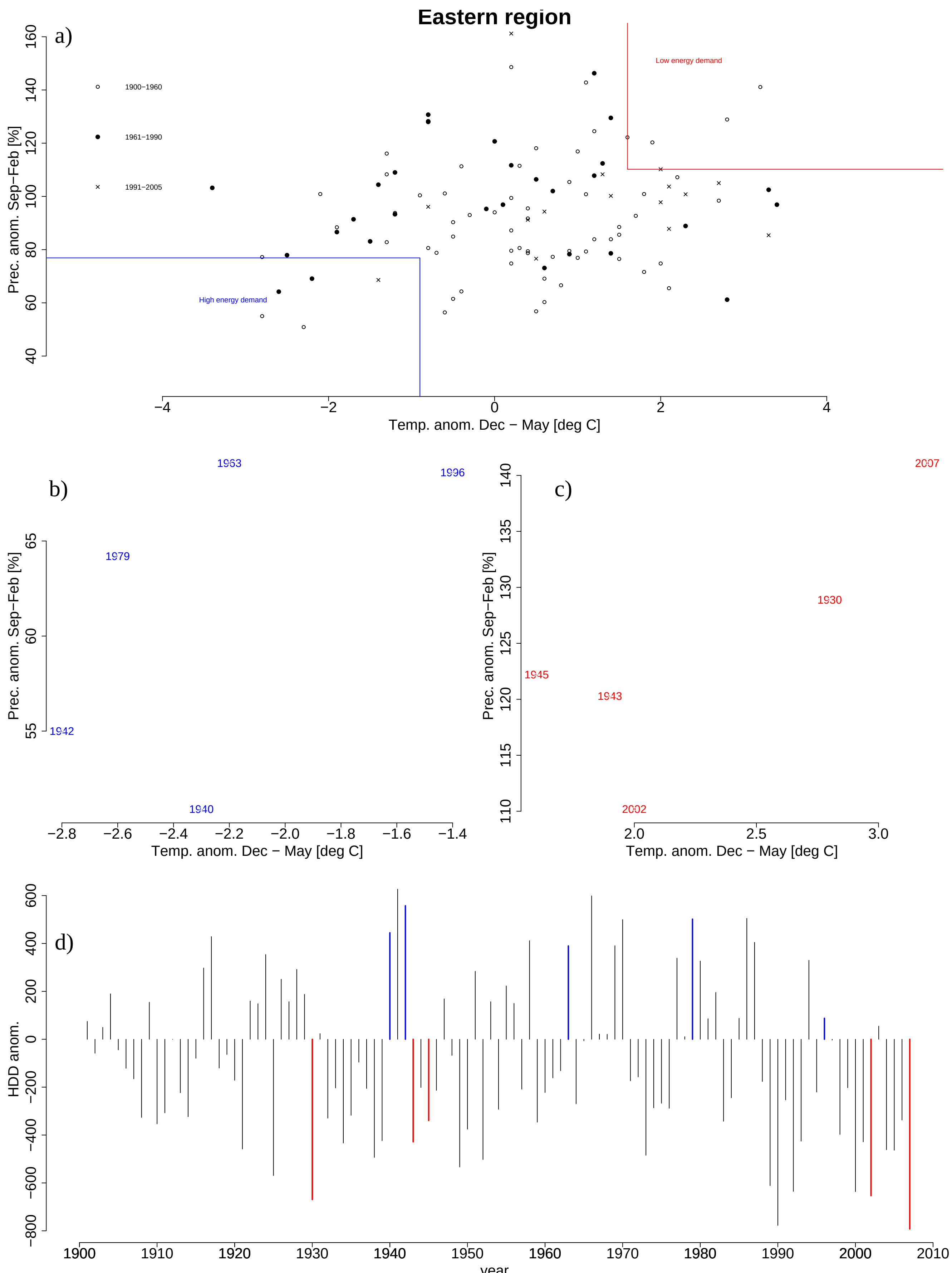

Figure 4.1 a) Winter and spring temperature anomalies in combination with precipitation sum anomalies for autumn and winter for the South-Eastern region within the period 1900-2007. b) Years with dry autumn and winter combined with cold winter and spring (blue columns in d). c) Years with wet autumn and winter combined with mild winter and spring (red columns in d)). d) Heating degree-day sum, anomalies from the regions mean heating degree-day value, for the normal period (1961-1990).

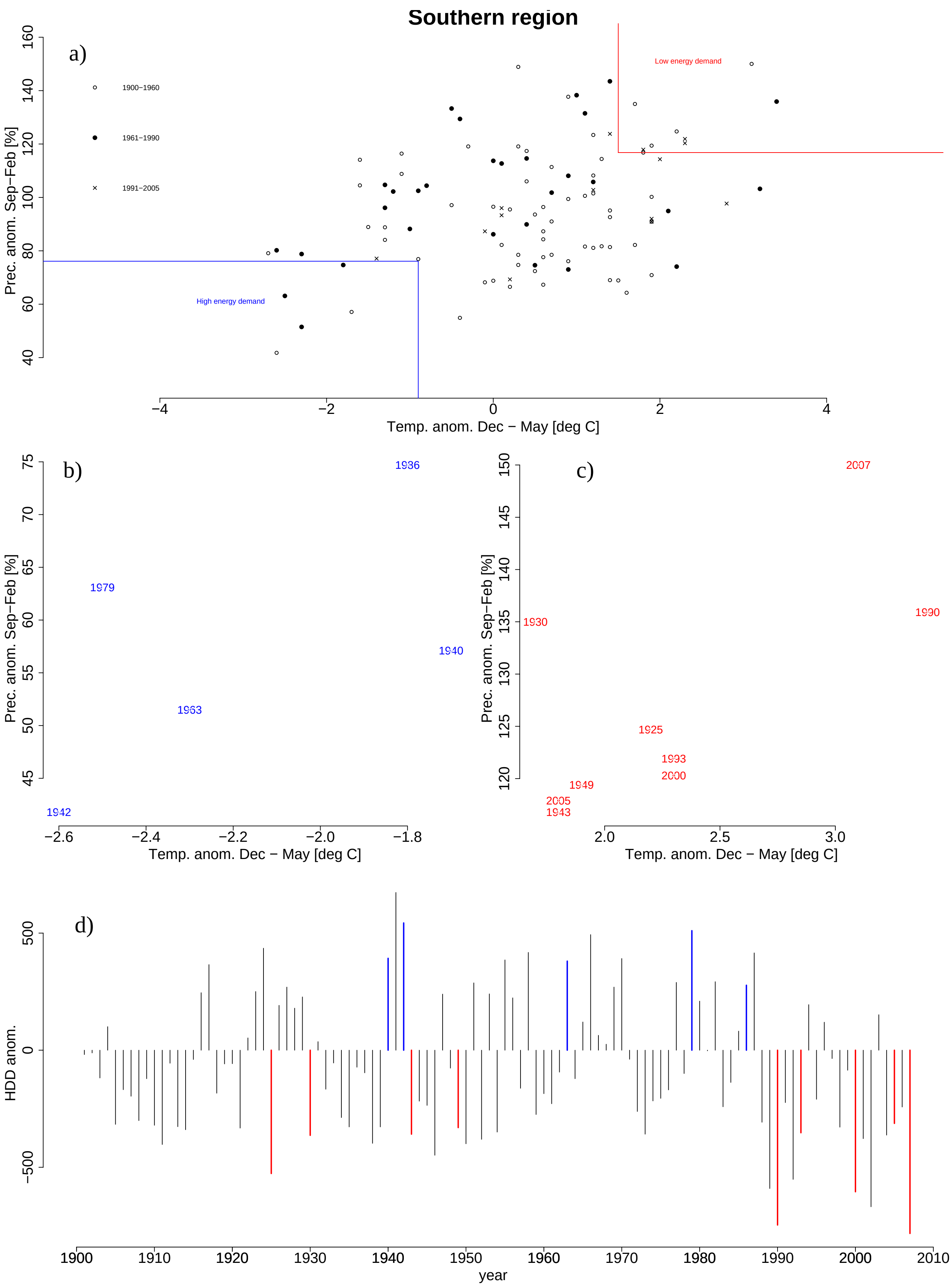

Figure 4.2 a) Winter and spring temperature anomalies in combination with precipitation sum anomalies for autumn and winter for the Southern region within the period 1900-2007. b) Years with dry autumn and winter combined with cold winter and spring (blue columns in d). c) Years with wet autumn and winter combined with mild winter and spring (red columns in d)). d) Heating degree-day sum, anomalies from the regions mean heating degree-day value, for the normal period (1961-1990).

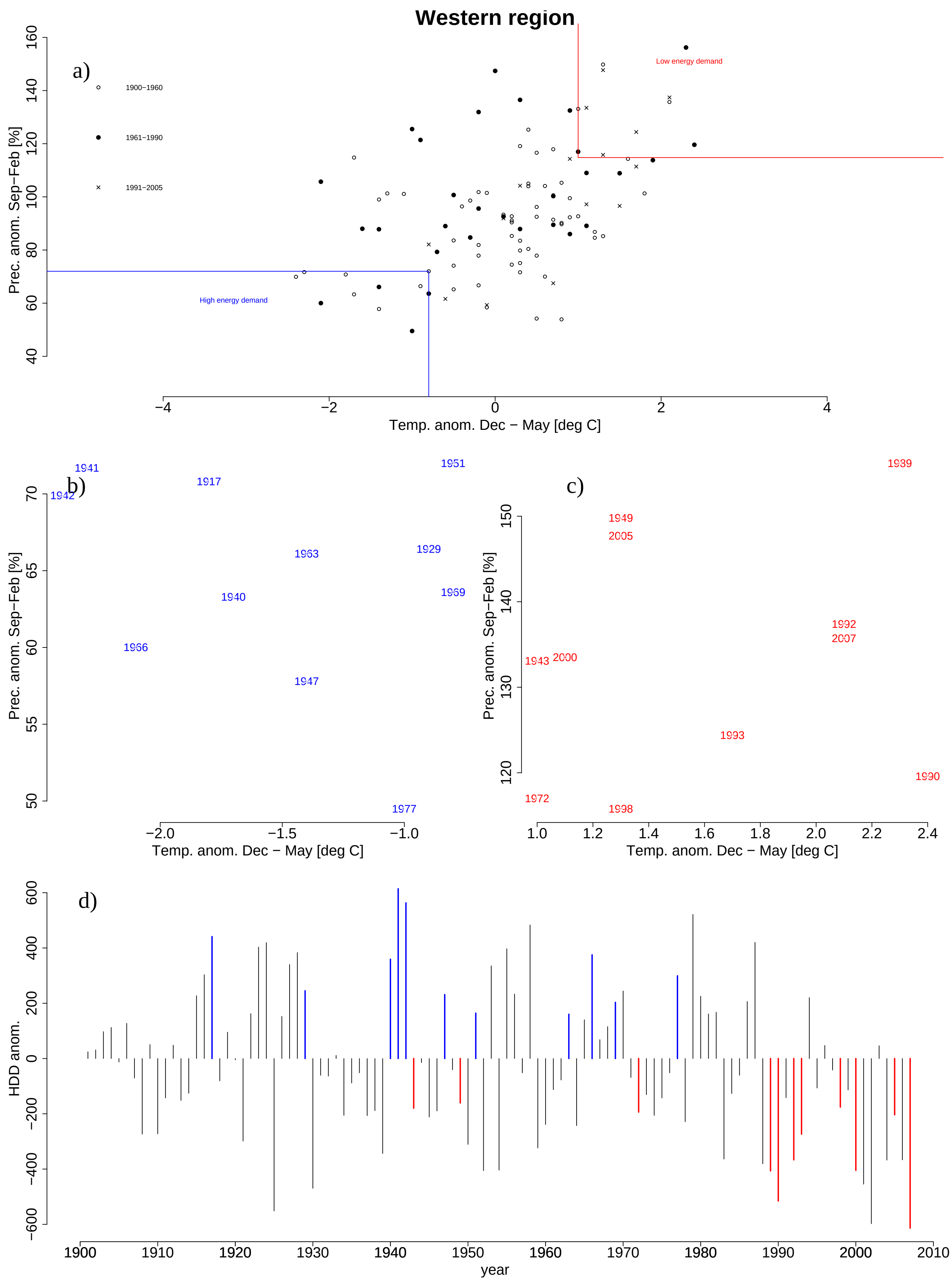

Figure 4.3 a) Winter and spring temperature anomalies in combination with precipitation sum anomalies for autumn and winter for the Western region within the period 1900-2007. b) Years with dry autumn and winter combined with cold winter and spring (blue columns in d). c) Years with wet autumn and winter combined with mild winter and spring (red columns in d)). d) Heating degree-day sum, anomalies from the regions mean heating degree-day value, for the normal period (1961-1990).

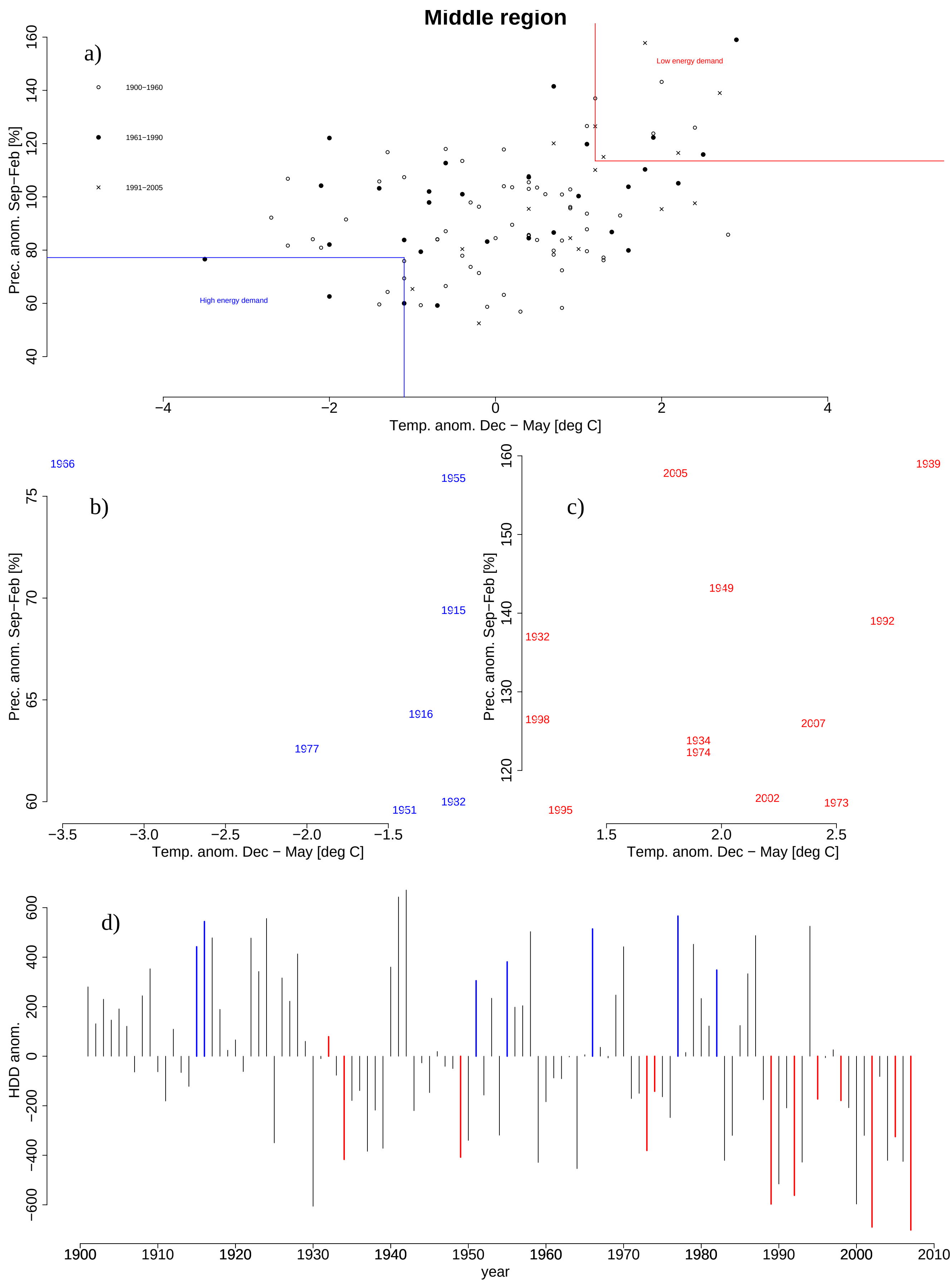

Figure 4.4 a) Winter and spring temperature anomalies in combination with precipitation sum anomalies for autumn and winter for the Middle region within the period 1900-2007. b) Years with dry autumn and winter combined with cold winter and spring (blue columns in d). c) Years with wet autumn and winter combined with mild winter and spring (red columns in d)). d) Heating degree-day sum, anomalies from the regions mean heating degree-day value, for the normal period (1961-1990).

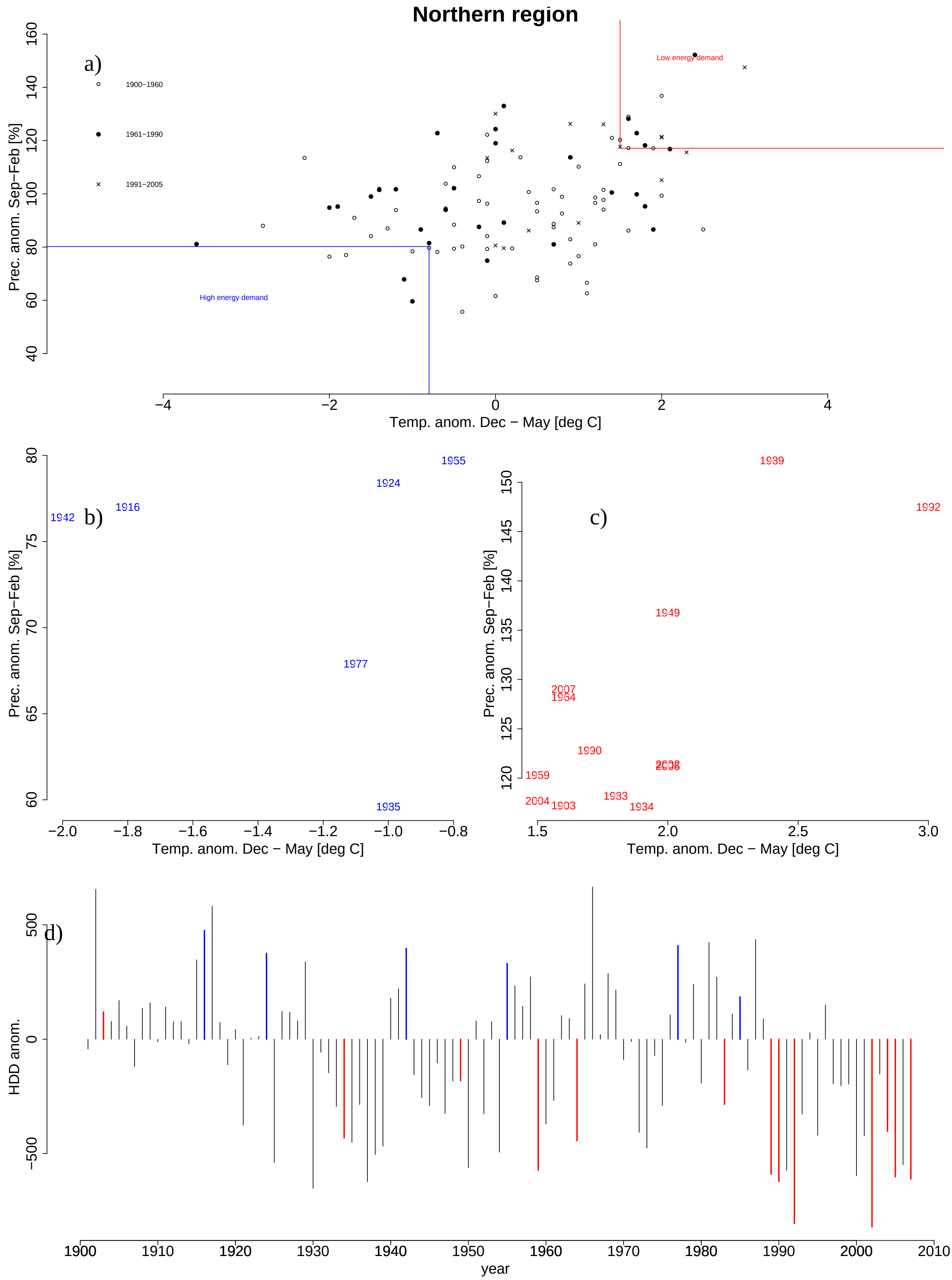

Figure 4.5 a) Winter and spring temperature anomalies in combination with precipitation sum anomalies for autumn and winter for the Northern region within the period 1900-2007. b) Years with dry autumn and winter combined with cold winter and spring (blue columns in d). c) Years with wet autumn and winter combined with mild winter and spring (red columns in d)). d) Heating degree-day sum, anomalies from the regions mean heating degree-day value, for the normal period (1961-1990).

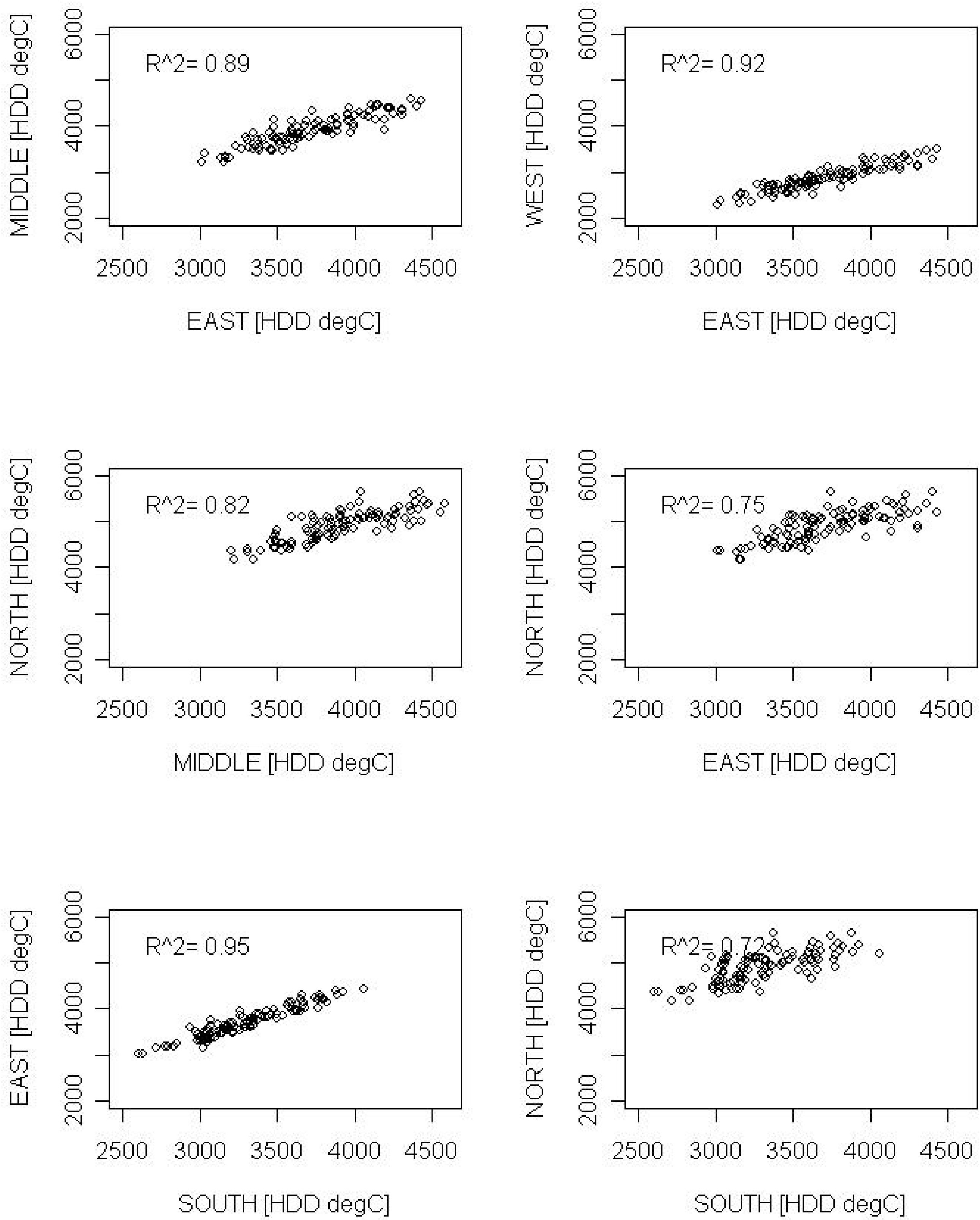

Figure 4.6 Spread plot of HDD [°C] in Norway from 1901-2007; Southeastern vs. Middle part of Norway (upper left), Southeastern vs. Western part of Norway (upper right), Middle vs. Northern part of Norway (middle left), Southeastern vs. Northern parts of Norway (middle right), Southern vs. Southeastern parts of Norway (lower left) and Southern vs. Northern parts of Norway (lower right). Th correlation coefficient (R^2) is presented in the figure.

5 A future perspective (2071-2100) for heating demand and hydropower potential

Analyses of future scenarios are based on the HadAM3H model from the Hadley centre, UK with SRES emission scenarios A2 and B2 (IPCC, 2000), and the ECHAM4/OPYC3 model from Max Planck Institute, Germany (Roeckner, 1999) with SRES emission scenario B2 (IPCC, 2000) (see section 2.3).

5.1 Future change in frequency distribution of mean daily HDD

Median, 95 and 99 percentile of mean daily HDD with duration of one, five, seven and ten days respectively are established from time series of daily temperature for five locations in Norway; Oslo, Kristiansand, Bergen, Trondheim and Tromsø. Future change in median, 95 and 99 percentile of mean daily HDD for these durations are estimated for three scenarios; HADA2, HADB2 and MPIB2. The estimates are established for the period 2071-2100 relative to the normal period (1961-1990) and are presented in the Figures 5.1-5.5 for the selected cities. The data presented in the figures are listed in tables in Appendix B (Table B1 – B5).

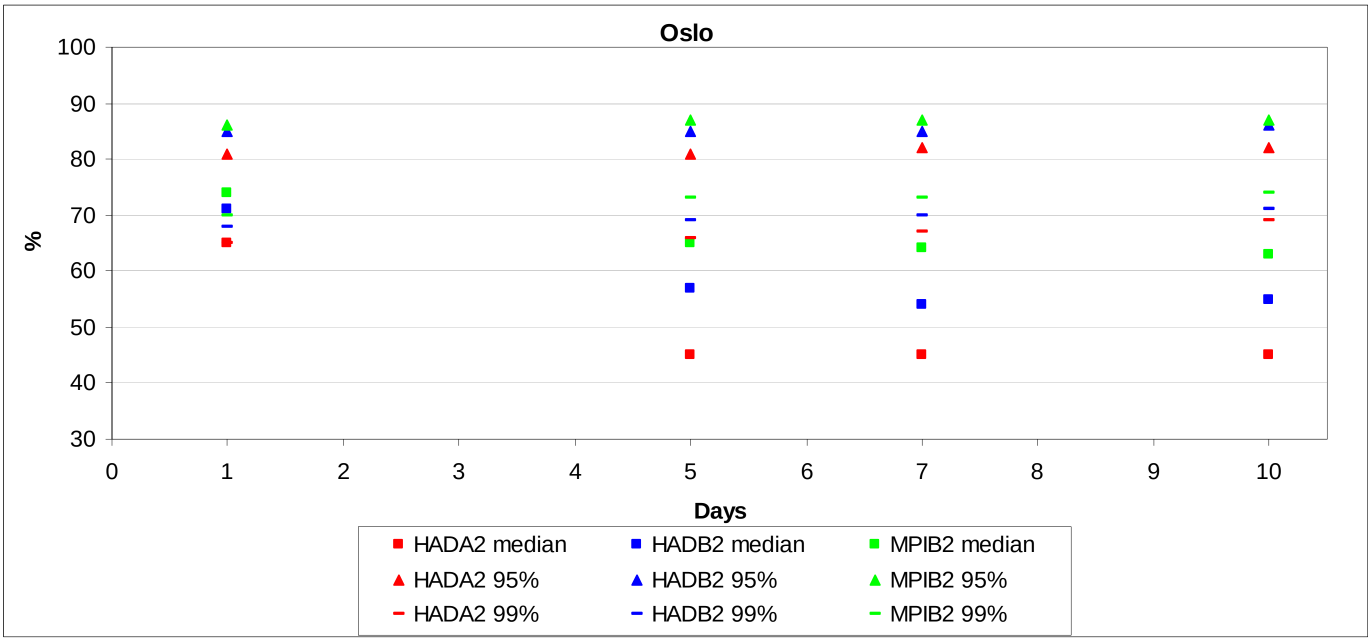

Figure 5.1 Change in Median, 95 and 99 percentiles of HDD per day with duration 1, 5, 7 and 10 days from 1961-1990 to 2071-2100 for Oslo. The changes are expressed as ratios (%) between future and present climate. Three scenarios are presented, HadA2, HADB2 and MPIB2.

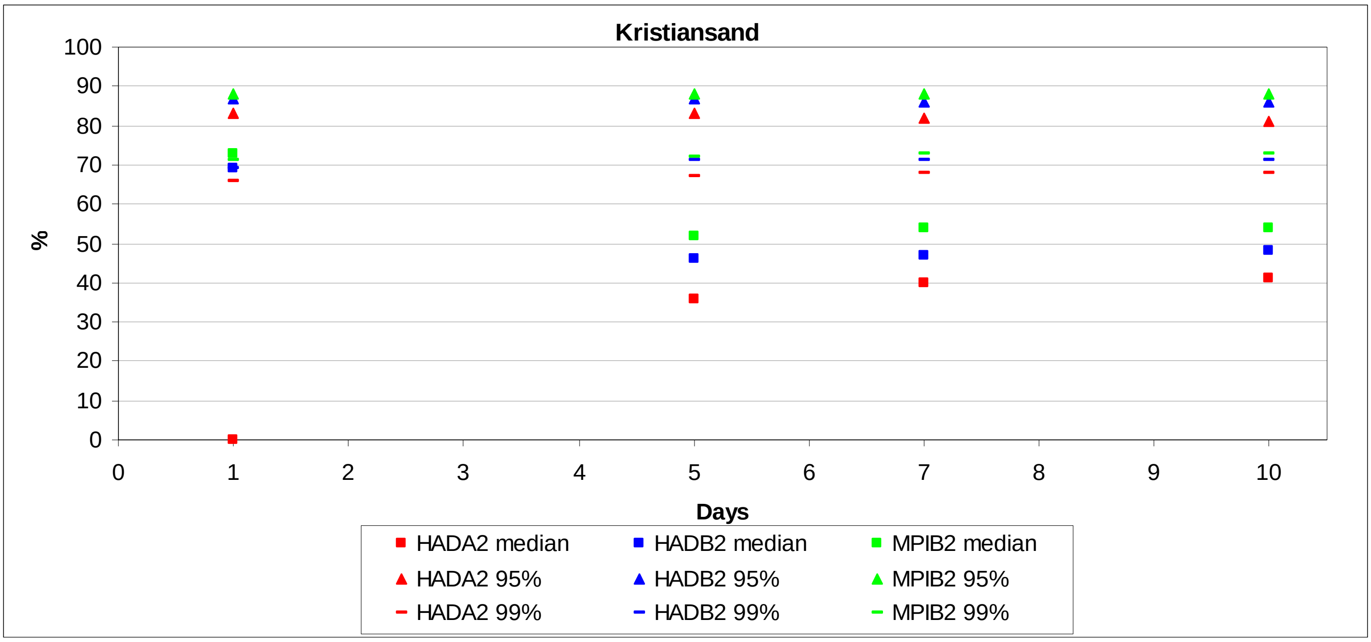

Figure 5.2 Change in Median, 95 and 99 percentiles of HDD per day with duration 1, 5, 7 and 10 days from 1961-1990 to 2071-2100 for Kristiansand. The changes are expressed as ratios (%) between future and present climate. Three scenarios are presented, HadA2, HADB2 and MPIB2.

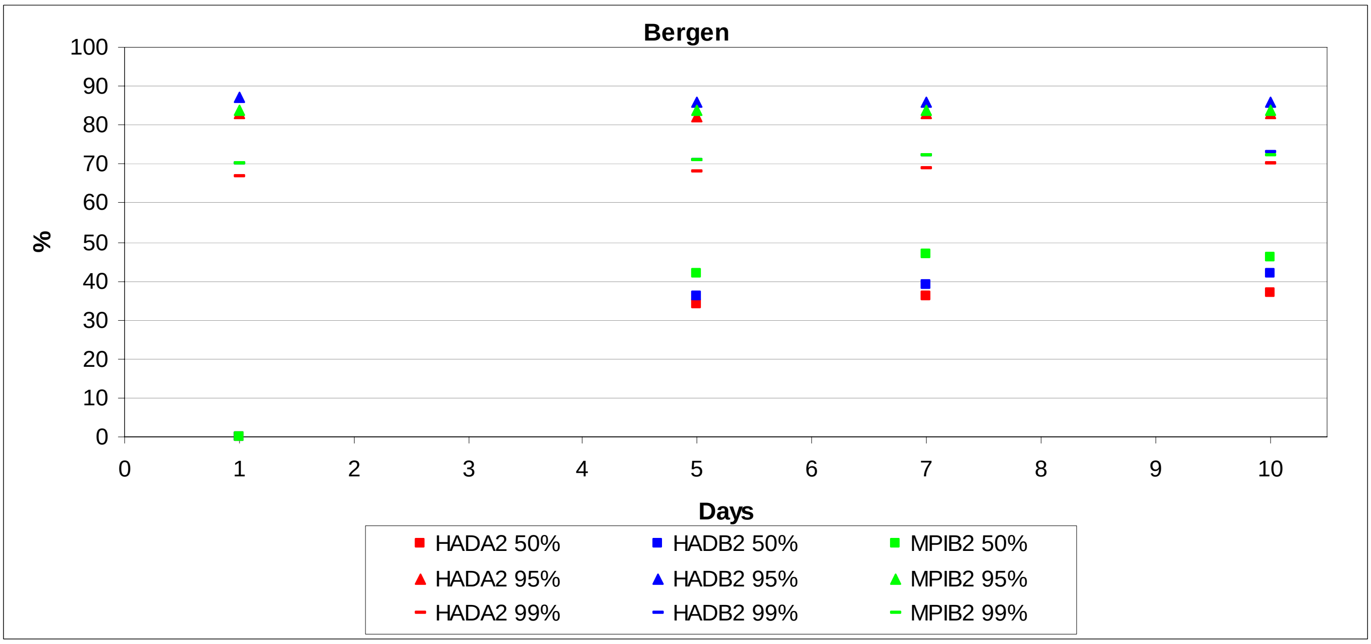

Figure 5.3 Change in Median, 95 and 99 percentiles of HDD per day with duration 1, 5, 7 and 10 days from 1961-1990 to 2071-2100 for Bergen. The changes are expressed as ratios (%) between future and present climate. Three scenarios are presented, HadA2, HADB2 and MPIB2.

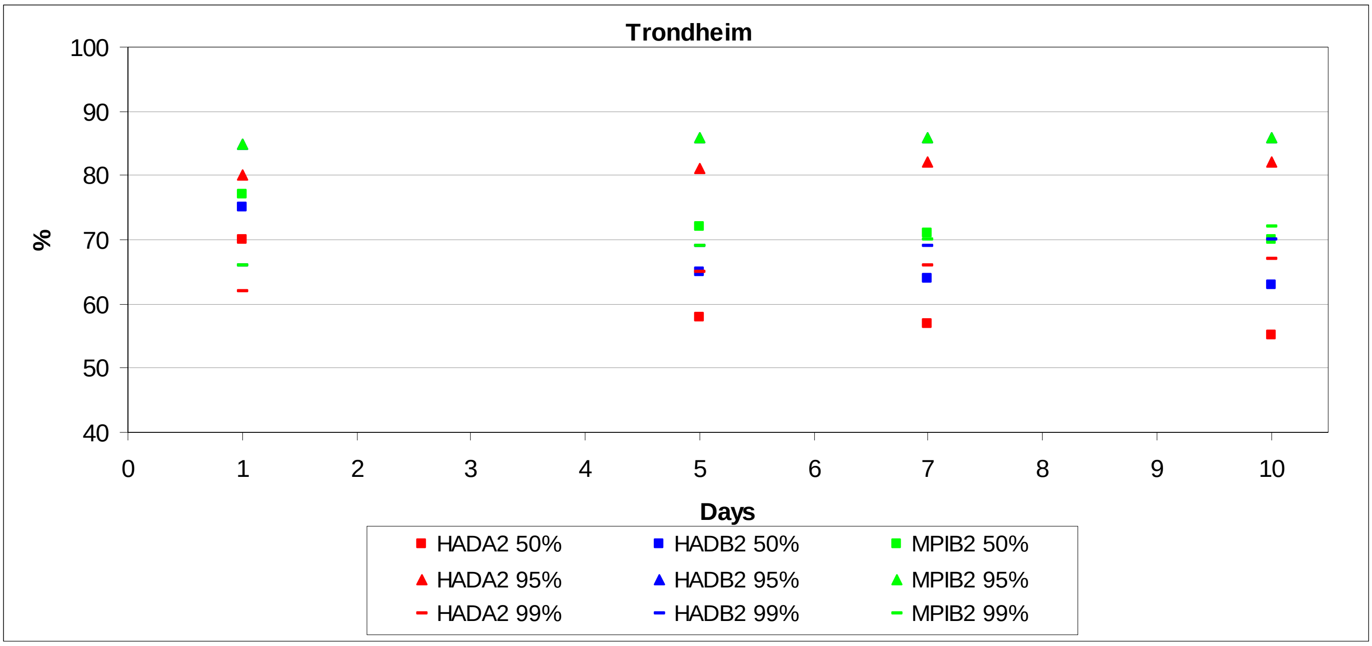

Figure 5.4 Change in Median, 95 and 99 percentiles of HDD per day with duration 1, 5, 7 and 10 days from 1961-1990 to 2071-2100 for Trondheim. The changes are expressed as ratios (%) between future and present climate. Three scenarios are presented, HadA2, HADB2 and MPIB2.

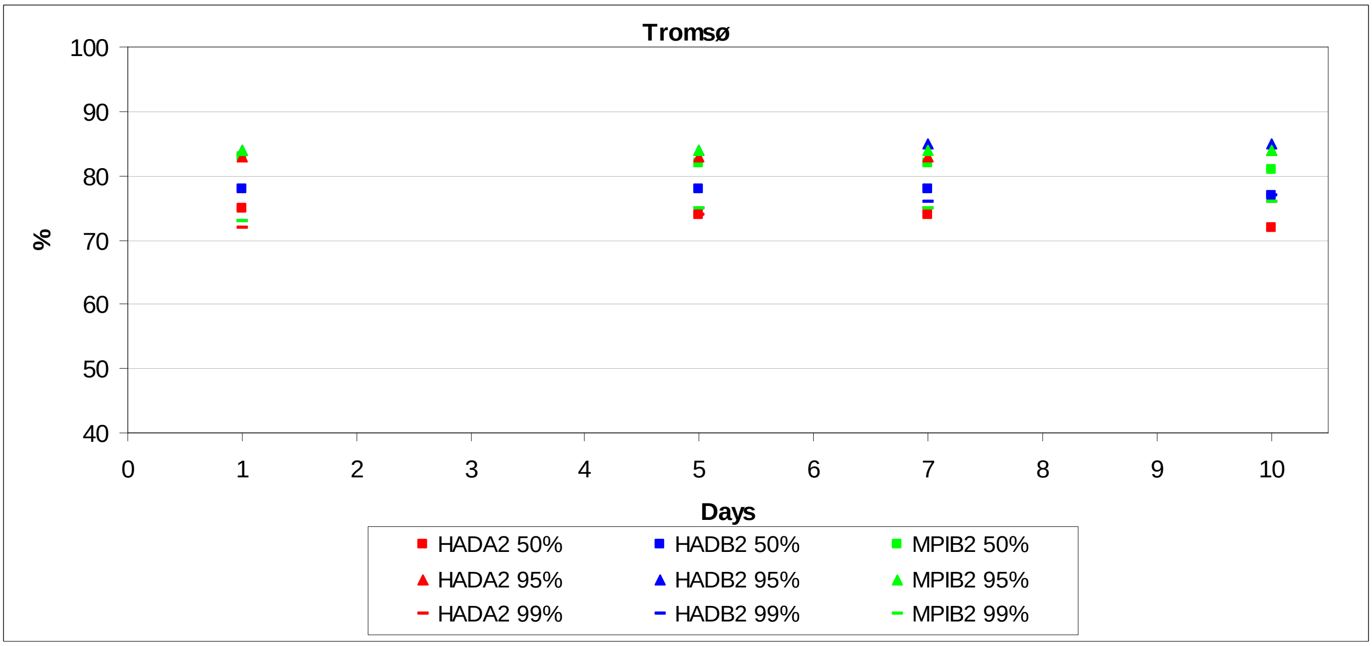

Figure 5.5 Change in Median, 95 and 99 percentiles of HDD per day with duration 1, 5, 7 and 10 days from 1961-1990 to 2071-2100 for Tromsø. The changes are expressed as ratios (%) between future and present climate. Three scenarios are presented, HadA2, HADB2 and MPIB2.

5.2 Future change in HDD-sum within the heating season

In Figures 5.6-5.10, the same combination of temperature and precipitation anomalies as in Figures 4.1a-4.5a are given for the control period (1961-1990) and for the future scenarios together with observations for the normal period 1961-1990 (see Figures 5.1-5.5a). Future change in HDD-sum within the heating season for the period 2071-2100 relative to the period 1961-1990 are presented in Table 5.1. Three projections for the future are presented (HADA2, HADB2, MPIB2). Results in Table 5.1 are based on time series of mean daily temperatures. The start of the heating season are defined as the first day when the four-day HDD mean drops below 10 °C after day no 190 (middle of July). The end of the heating season is defined as the first day in spring when the four-day HDD mean exceeds 10 °C. The definitions are used in Førland et al. (2004).

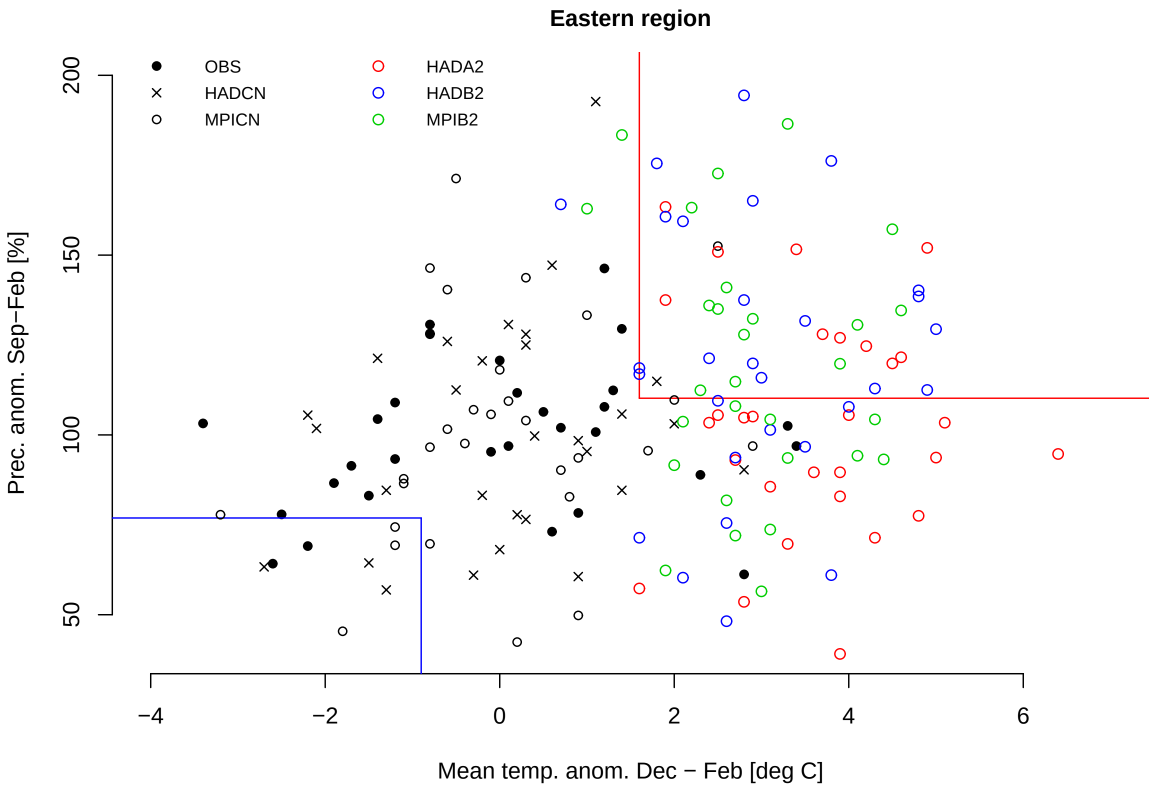

Figure 5.6 Mean winter and spring temperature in combination with precipitation sums for autumn and winter for the South-Eastern region within the period 1961-1990 for observations, for the HadAM3H and ECHAM4/OPYC3 control runs and three scenarios for the future period 2071-2100.

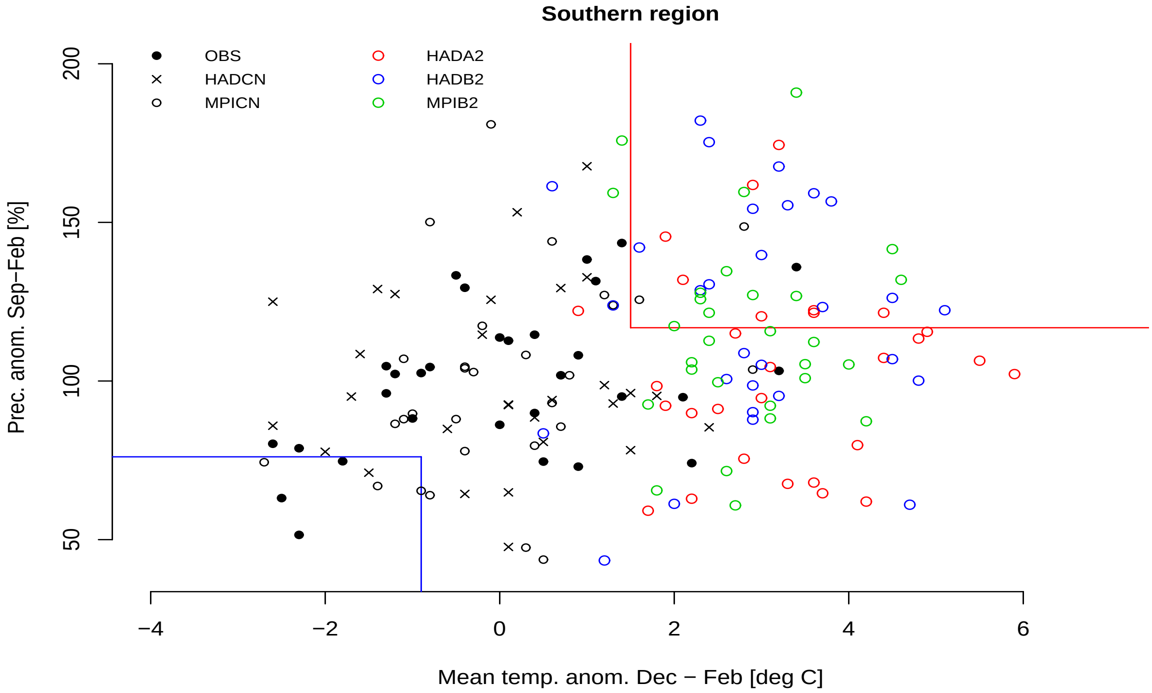

Figure 5.7 Mean winter and spring temperature in combination with precipitation sums for autumn and winter for the Southern region within the period 1961-1990 for observations, for the HadAM3H and ECHAM4/OPYC3 control runs and three scenarios for the future period 2071-2100.

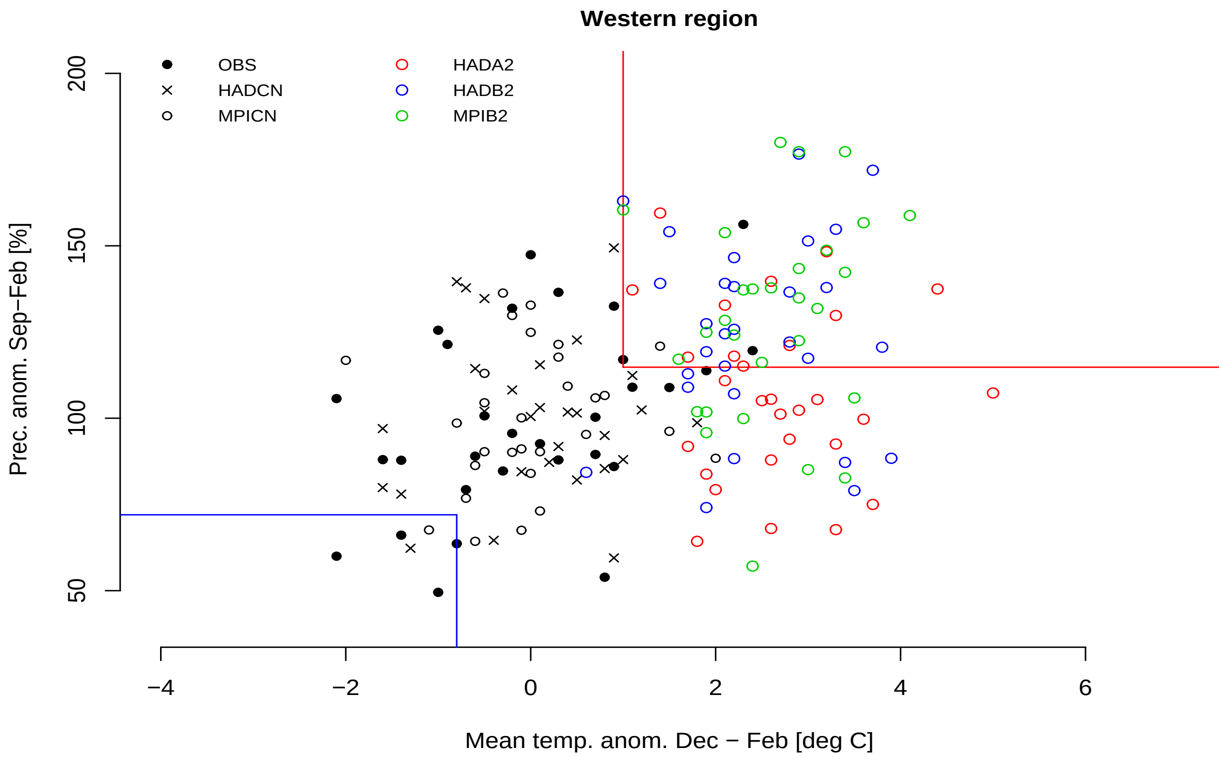

Figure 5.8 Mean winter and spring temperature in combination with precipitation sums for autumn and winter for the Western region within the period 1961-1990 for observations, for the HadAM3H and ECHAM4/OPYC3 control runs and three scenarios for the future period 2071-2100

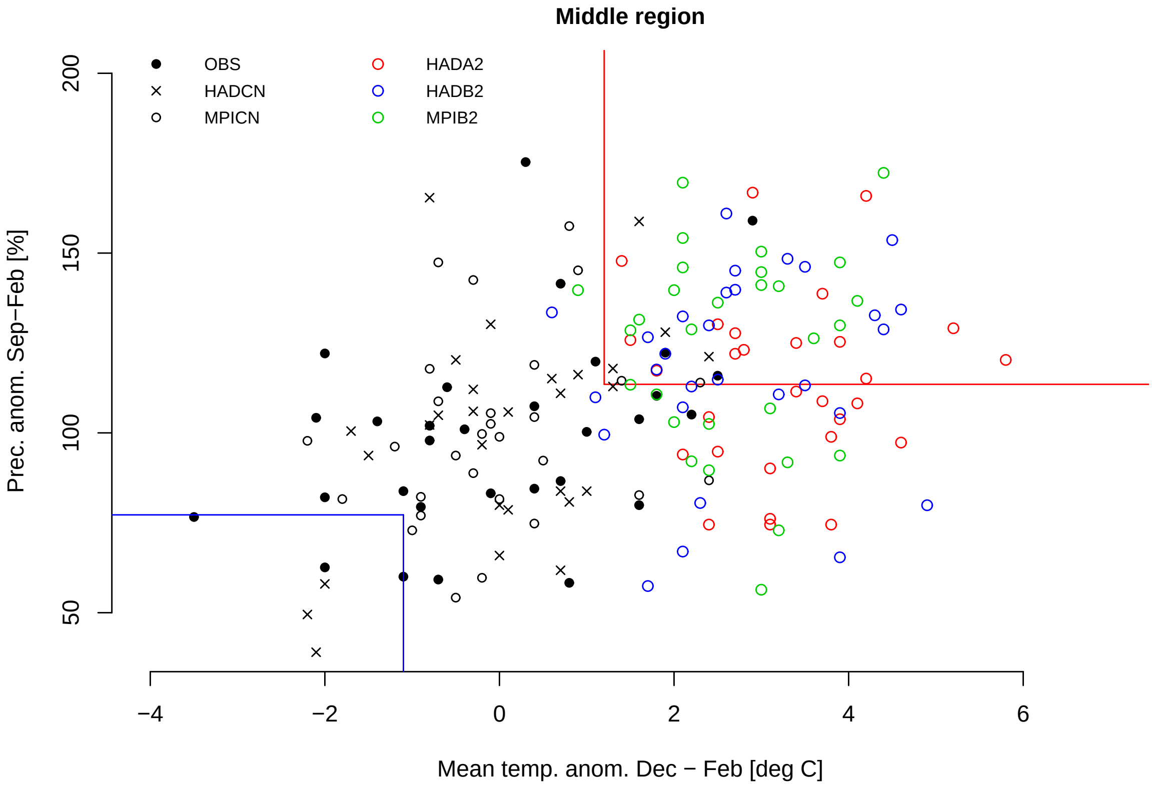

Figure 5.9 Mean winter and spring temperature in combination with precipitation sums for autumn and winter for the Middle region within the period 1961-1990 for observations, for the HadAM3H and ECHAM4/OPYC3 control runs and three scenarios for the future period 2071-2100

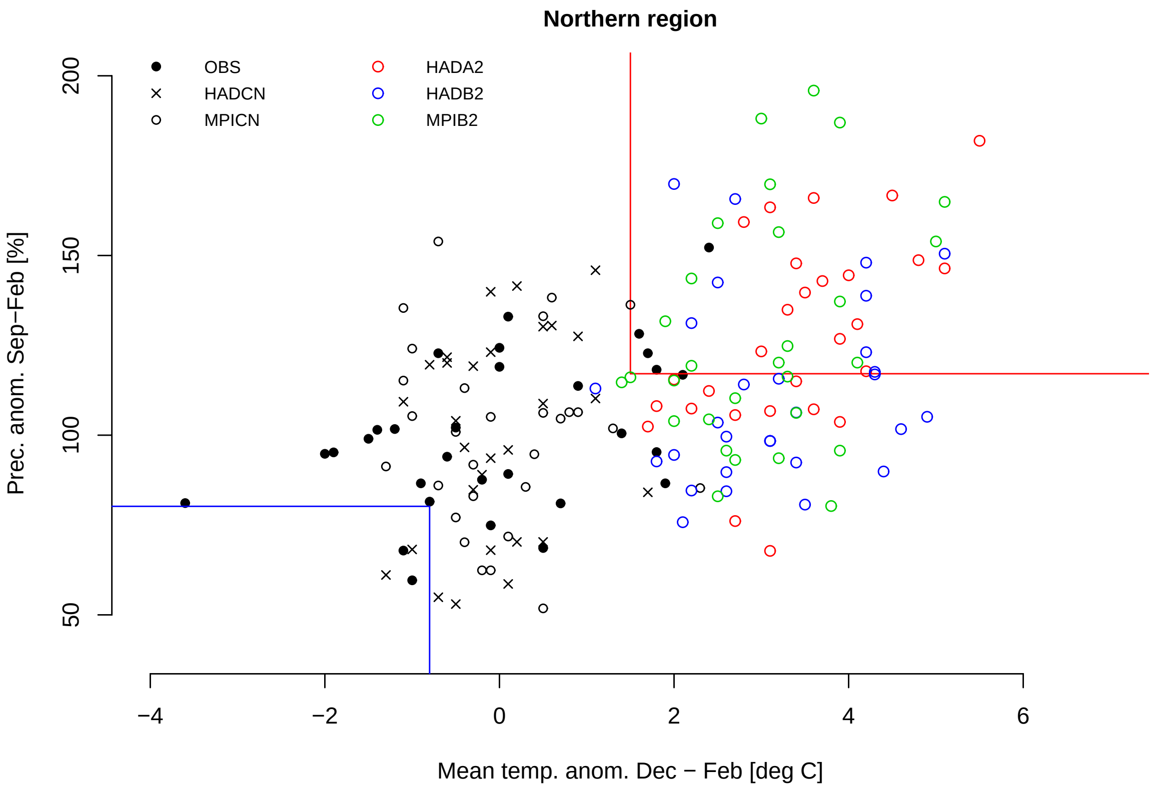

Figure 5.10 Mean winter and spring temperature in combination with precipitation sums for autumn and winter for the Northern region within the period 1961-1990 for observations, for the HadAM3H and ECHAM4/OPYC3 control runs and three scenarios for the future period 2071-2100

Table 5.1 Heating Degree-Day sum [°C] for the normal period (1961-1990) and projected change expressed as ratio [%] between future and present climate. Changes are shown for three scenarios for each of the selected cities.

Selected City	HDD (1961-1990)	HDD [%] HADA2 (2071-2100)/(1961-1990)	HDD [%] HADB2 (2071-2100)/(1961-1990)	HDD [%] MPIB2 (2071-2100)/(1961-1990)
Oslo	3700	0.70	0.73	0.75
Kristiansand	3300	0.67	0.71	0.73
Bergen	2750	0.66	0.70	0.66
Trondheim	3750	0.69	0.73	0.73
Tromsø	4900	0.71	0.74	0.78

6 Discussion and concluding remarks

6.1 The historical period (1961-1990)

Figure 4.1a shows December to May temperature anomalies against September to February precipitation anomalies and represents Southeastern parts of Norway (see Figure 2.1). The period 1900-2007 is presented with different symbols for the years 1900-1960, 1961-1990 (the normal period), and 1991-2005 respectively. The most extreme years (coinciding 20 and 80 percentiles for temperature and temperature resp.) are placed within the blue and red lines in Figure 4.1-4.5b; blue indicates very high energy demand combined with low hydro power potential, red indicates low energy demand combined with high hydro power potential.

Figure 4.1a -b shows that Southeastern parts of Norway has experienced five cold and dry years (blue years), two of these before 1960, one after 1990. Some of these years are documented in history and recalled in people's memory. E.g. the 2nd World war years was a hard experience for the Norwegian people, the cold and dry years (1940-1942) made the existence even harder. In 1963, 1979 and 1996, the winter and spring was cold in combination with dry autumn and winter. In February 1966 and January 1987 Oslo experienced the highest 1, 5, 7 and 10 days heating demand (Table 4.6 and Appendix A). Percentiles (Median, 95 and 99) of daily HDD for Oslo for the period 1900-2007 and the normal period 1961-1990 are presented in Table 4.1. The Table shows that the values are slightly higher for the normal period than for the whole period. Five years are categorised as having low energy demand in combination with high potential for hydropower energy. Three of these years are registered before 1960, two after 1990. In 1972-1973 there were restrictions on electric power consumption due to the oil crises. The winter these years was luckily warmer than normal.

Figure 4.1d presents the HDD sum anomalies for the whole period (1900-2007). The figure gives an indication of the energy demand for heating buildings during winter. The years commented on as blue and red are marked in the figure. The figure shows that there have been periods with low heating demand before, e.g. around 1910, 1930ies or 1970ies. It is shown, though, as documented in Groisman et al. (2003) and Førland et al. (2004), that there has been an increase in negative anomalies since 1990. The largest negative HDD anomalies appeared after 1989, the lowest demand ever in this region was registered in 2007. This was also a wet year with high hydro power production potential.

The results are here referred to as "the hydrological year" which means autumn for the year before and the spring for the present year. E.g. results for the year 1996 will be autumn 1995 considered together with winter and spring 1996. The results will therefore not coincide with other studies that consider the year as a whole, like in Bøeng (2005).

The Southern, Western, Middle and Northern parts of Norway (Figs. 4.2-4.5) show similar patterns as the Eastern region. These regions have experienced a larger number of years with low energy demand in combination with high hydro power potential during the last twenty years (Figs. 4.2, 4.3, 4.4 and 4.6 respectively). The early 2nd World War years were cold (high energy demand) in all regions. Winter and spring season in 1966 was very cold in all regions. In all regions, except in the southeast and south, the cold seasons were combined with dry autumn and winter. Winter and spring in 1989 was extremely warm. In most pars of the country (except southeastern and southern parts) the autumn and winter was very wet as well. Figures 4.1d - 4.5d show large similarities in timeseries of HDD anomalies for all regions. This is also shown in Figure 4.6; when there is high heating demand in the Northern region there is also high heating demand in middle and eastern regions. The same are shown with eastern vs. middle parts and for eastern vs. western parts.

The results of the historical development of people's energy demand for heating combined with hydro power potential the same winter show rather good agreement with historical documentation (e.g. the early war years and 1966). It is also shown that the two latest decades have experienced warmer winters with less heating demand. The hydro power potential has also increased due to wet autumn and winter seasons. The present study analyses temperature and precipitation series representing concurrent geographical regions in Norway. The energy demand for instance in Oslo depends just on the temperature in Oslo. The hydro power potential, however, depends of the available water draining to the reservoirs and the power transmission net in Norway. As shown in Figure 2.1, large amounts of Norwegian water reservoirs are located in the south western part of the country, and above ~600 m a.s.l. The results may be improved if these concerns were taken into account in the calculation of precipitation anomalies. On the other hand; the regional temperature and precipitation series represent large regions and are therefore only valid for a region as a whole.

6.2 A future perspective (2071-2100)

Scenarios for the future in Norway show that temperature will increase all over the country with an annual increase of ~3-3.5 °C (www.regclim.met.no). The increase is found to be largest in autumn and winter. Annual precipitation is projected to increase, especially during winter. Mean heating demand for the scenario period 2071-2100 is projected to decrease with ~ 20-30 % relative to the normal period (1961-1990) (Table 5.1).

Temperature and precipitation anomalies based on observations for the normal period (1961-1990) are presented in Figures 5.6-5.10 for the South-Eastern, Southern, Western, Middle and Northern regions respectively. Precipitation and temperature anomalies for the two control runs (representing the years 1961-1990), HADCN and MPICN, are presented in the figures as well together with anomalies for three scenarios for the future years 2071-2100. We have to keep in mind that the anomalies for the five model-runs (control and scenario) represents the selected stations (Figure 2.1) while observed anomalies represents the whole region. The figures show that the modelled combination of temperature and precipitation anomalies has captured the historic variability rather well for all regions. This is a good quality check of the modelled data.

Figure 5.1-5.5 indicates that the median, 95 and 99 percentiles of daily HDD with duration 1, 5, 7 and 10 days will decrease. Similar pattern is found for all the cities analysed. The median will decrease most (~30-100%). For Bergen and Kristiansand, for some scenarios the 1 day median HDD is projected to be zero in the 2071-2100 period;- i.e. the mean daily temperature will be larger than 10 °C in more than 50% of the days. The 95 percentile is projected to decrease with ~ 20 % while a reduction of ~30-40 % is projected for the 99 percentile.
The precipitation anomalies for the three scenarios show more or less the same spread as for the control period. The model projects a few larger precipitation anomalies than experienced in the normal period for the South-Eastern, Southern, Western and Northern regions. All regions show a marked increase in positive temperature anomalies. All temperature anomalies for the scenario period are above the red line that defines the 20 % warmest years for the period 1900-2007. The figures show that dry autumn and winter seasons also may occur in the future. Years with low hydropower production potential may therefore be a problem in future as well. The demand for heating, though, will be substantially reduced. This is emphasized in Figures 5.6 – 5.7 and Table 5.1.

6.3 Concluding remarks

- An increase in the frequency of years with mild winter and spring is observed the latest decades. The latest years have experienced the lowest HDD since 1900.
- The combination of mild winter and spring and wet autumn and winter season seems to increase the latest twenty years.
- There has been a decrease in the frequency of years with cold winter and spring season combined with dry autumn and winter.

- There is a high inter-correlation between the regions in years with high/low energy demand for heating. There is even high correlation (r~0.72) between the southernmost and northernmost regions.
- The scenarios indicate that dry autumn and winter seasons will occur also in the future. Because of increasing temperatures during winter and spring, the energy demand for heating buildings will be substantially reduced up to 2071-2100.
- The frequency distribution of daily HDD based on scenarios indicate a reduction in number of days with heating of buildings in the future (2071-2100).

Acknowledgement

This work was conducted as part of the projects "Klimaprediktabilitet på skala fra 0 til 100 år: konsekvenser for snømagasin, tilsig, flom, tørke og energiproduksjon" funded by Norwegian Electricity Industry Association (EBL) (MKU-1.8_06) and the CELECT project (**C**limate change impacts in the **ELECT**ricity sector) funded in part by the Research Council of Norway 2002**–**2004 (ref nr 178340/S30). The authors would like to thank Astrid Voksø, Norwegian Water Resources and Energy Directorate (NVE) for providing digital geographical boundaries of Norwegian Water Reservoirs.

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APPENDIX A

The highest registered HDD values within the period January 1957 until November 2007 for Oslo, Bergen, Kristiansand, Trondheim and Tromsø are presented in the Table. The highest values are selected from three time periods; the whole time period 1957-2007, the first period 1957-1980 and the last period 1981-2007. The estimates are selected from one day HDD, five, seven and ten days mean daily HDD. The first day of the period are presented in the table. No indicates if there has been more than one episode of the actual HDD value.

Location	Duration	Time period	Date	HDD
Oslo	1	obs(1957-2007)	10.01.1987	39
Oslo	1	obs(1957-1980)	09.02.1966	38.2
Oslo	1	obs(1981-2007)	10.01.1987	39
Oslo	5	obs(1957-2007)	07.01.1987	35.1
Oslo	5	obs(1957-1980)	08.02.1966	34.4
Oslo	5	obs(1981-2007)	07.01.1987	35.1
Oslo	7	obs(1957-2007)	07.02.1966	34
Oslo	7	obs(1957-1980)	07.02.1966	34
Oslo	7	obs(1981-2007)	07.01.1987	33.8
Oslo	10	obs(1957-2007)	04.02.1966	32.9
Oslo	10	obs(1957-1980)	04.02.1966	32.9
Oslo	10	obs(1981-2007)	04.01.1987	32.5
Bergen	1	obs(1957-2007)	11.01.1987	31.8
Bergen	1	obs(1957-1980)	31.12.1978	29.2
Bergen	1	obs(1981-2007)	11.01.1987	31.8
Bergen	5	obs(1957-2007)	10.01.1987	27.4
Bergen	5	obs(1957-1980)	29.12.1978	27
Bergen	5	obs(1981-2007)	10.01.1987	27.4
Bergen	7	obs(1957-2007)	10.01.1987	26.2
Bergen	7	obs(1957-1980)	28.12.1978	25.5
Bergen	7	obs(1981-2007)	10.01.1987	26.2
Bergen	10	obs(1957-2007)	09.01.1987	24.2
Bergen	10	obs(1957-1980)	25.12.1978	23.8
Bergen	10	obs(1981-2007)	09.01.1987	24.2
Kristiansand	1	obs(1957-2007)	08.01.1982	40.9
Kristiansand	1	obs(1957-1980)	10.02.1966	39.1
Kristiansand	1	obs(1981-2007)	08.01.1982	40.9
Kristiansand	5	obs(1957-2007)	05.01.1982	37.1
Kristiansand	5	obs(1957-1980)	08.02.1966	36.2
Kristiansand	5	obs(1981-2007)	05.01.1982	37.1
Kristiansand	7	obs(1957-2007)	07.02.1966	34.3
Kristiansand	7	obs(1957-1980)	07.02.1966	34.3
Kristiansand	7	obs(1981-2007)	04.01.1982	33.6
Kristiansand	10	obs(1957-2007)	07.02.1966	32.4
Kristiansand	10	obs(1957-1980)	07.02.1966	32.4
Kristiansand	10	obs(1981-2007)	03.01.1982	30.9
Trondheim	1	obs(1957-2007)	10.01.1987	40.1
Trondheim	1	obs(1957-1980)	11.01.1968	38.3
Trondheim	1	obs(1981-2007)	10.01.1987	40.1
Trondheim	5	obs(1957-2007)	09.01.1987	37.7
Trondheim	5	obs(1957-1980)	22.02.1958	34.2
Trondheim	5	obs(1981-2007)	09.01.1987	37.7
Trondheim	7	obs(1957-2007)	08.01.1987	35.9
Trondheim	7	obs(1957-1980)	26.12.1978	33
Trondheim	7	obs(1981-2007)	08.01.1987	35.9
Trondheim	10	obs(1957-2007)	06.01.1987	33.5
Trondheim	10	obs(1957-1980)	03.02.1966	32.1

Trondheim	10	obs(1981-2007)	06.01.1987	33.5
Tromsø	1	obs(1957-2007)	02.02.1966	33.8
Tromsø	1	obs(1957-1980)	02.02.1966	33.8
Tromsø	1	obs(1981-2007)	09.01.1987	33.1
Tromsø	5	obs(1957-2007)	30.01.1966	31.2
Tromsø	5	obs(1957-1980)	30.01.1966	31.2
Tromsø	5	obs(1981-2007)	06.01.1987	30.7
Tromsø	7	obs(1957-2007)	29.01.1966	30.3
Tromsø	7	obs(1957-1980)	29.01.1966	30.3
Tromsø	7	obs(1981-2007)	04.01.1987	30
Tromsø	10	obs(1957-2007)	01.02.1966	29.4
Tromsø	10	obs(1957-1980)	01.02.1966	29.4
Tromsø	10	obs(1981-2007)	01.01.1987	29.4

APPENDIX B

Table B1 Change in Median, 95 and 99 percentiles of HDD per day with duration 1, 5, 7 and 10 days from 1961-1990 to 2071-2100 for Oslo. The changes are expressed as ratios (%) between future and present climate. Three scenarios are presented, HadA2, HADB2 and MPIB2.

Duration	HADA2 50%	HADB2 50%	MPIB2 50%	HADA2 95%	HADB2 95%	MPIB2 95%	HADA2 99%	HADB2 99%	MPIB2 99%
1 day	0.65	0.71	0.74	0.81	0.85	0.86	0.65	0.68	0.7
5 days	0.45	0.57	0.65	0.81	0.85	0.87	0.66	0.69	0.72
7 days	0.45	0.54	0.64	0.82	0.85	0.87	0.67	0.7	0.73
10 days	0.45	0.55	0.63	0.82	0.86	0.87	0.69	0.71	0.74

Table B2 Change in Median, 95 and 99 percentiles of HDD per day with duration 1, 5, 7 and 10 days from 1961-1990 to 2071-2100 for Kristiansand. The changes are expressed as ratios (%) between future and present climate. Three scenarios are presented, HadA2, HADB2 and MPIB2.

Duration	HADA2 50%	HADB2 50%	MPIB2 50%	HADA2 95%	HADB2 95%	MPIB2 95%	HADA2 99%	HADB2 99%	MPIB2 99%
1 day	0	0.69	0.73	0.83	0.87	0.88	0.66	0.69	0.71
5 days	0.36	0.46	0.52	0.83	0.87	0.88	0.67	0.71	0.72
7 days	0.4	0.47	0.54	0.82	0.86	0.88	0.68	0.71	0.73
10 days	0.41	0.48	0.54	0.81	0.86	0.88	0.68	0.71	0.73

Table B3 Change in Median, 95 and 99 percentiles of HDD per day with duration 1, 5, 7 and 10 days from 1961-1990 to 2071-2100 for Bergen. The changes are expressed as ratios (%) between future and present climate. Three scenarios are presented, HadA2, HADB2 and MPIB2.

Duration	HADA2 50%	HADB2 50%	MPIB2 50%	HADA2 95%	HADB2 95%	MPIB2 95%	HADA2 99%	HADB2 99%	MPIB2 99%
1 day	0	0	0	0.83	0.87	0.84	0.67	0.7	0.7
5 days	0.34	0.36	0.42	0.82	0.86	0.84	0.68	0.71	0.71
7 days	0.36	0.39	0.47	0.83	0.86	0.84	0.69	0.72	0.72
10 days	0.37	0.42	0.46	0.83	0.86	0.84	0.7	0.73	0.72

Table B4 Change in Median, 95 and 99 percentiles of HDD per day with duration 1, 5, 7 and 10 days from 1961-1990 to 2071-2100 for Trondheim. The changes are expressed as ratios (%) between future and present climate. Three scenarios are presented, HadA2, HADB2 and MPIB2.Trondheim

Duration	HADA2 50%	HADB2 50%	MPIB2 50%	HADA2 95%	HADB2 95%	MPIB2 95%	HADA2 99%	HADB2 99%	MPIB2 99%
1 day	0.7	0.75	0.77	0.8	0.85	0.85	0.62	0.66	0.66
5 days	0.58	0.65	0.72	0.81	0.86	0.86	0.65	0.69	0.69
7 days	0.57	0.64	0.71	0.82	0.86	0.86	0.66	0.69	0.7
10 days	0.55	0.63	0.7	0.82	0.86	0.86	0.67	0.7	0.72

Table B5 Change in Median, 95 and 99 percentiles of HDD per day with duration 1, 5, 7 and 10 days from 1961-1990 to 2071-2100 for Tromso. The changes are expressed as ratios (%) between future and present climate. Three scenarios are presented, HadA2, HADB2 and MPIB2.Trondheim.

Duration	HADA2 50%	HADB2 50%	MPIB2 50%	HADA2 95%	HADB2 95%	MPIB2 95%	HADA2 99%	HADB2 99%	MPIB2 99%
1 day	0.75	0.78	0.83	0.83	0.84	0.84	0.72	0.73	0.73
5 days	0.74	0.78	0.82	0.83	0.84	0.84	0.74	0.75	0.75
7 days	0.74	0.78	0.82	0.83	0.85	0.84	0.75	0.76	0.75
10 days	0.72	0.77	0.81	0.84	0.85	0.84	0.76	0.77	0.76