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Heating degree-days – Present conditions and scenario for the period 2021-2050

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Norwegian Meteorologica Institute (met.no)

SUMMARY:

This report presentes an impact study of the change in the length of the heating season and the heating degree-days (HDD) due to global warming. The time slice periods analysed is the recent standard normal period 1961-90, the twenty-year period 1981-2000 and the scenario period, 2021-2050.

The length of the heating season decreased with a few days for the costal area and some inland areas in the last twenty-year period compared to the normal period. It did however increase (with only a few days) for some areas too. The temperature within the heating season increased over the whole country, and thus the HDD in the heating season decreased (with 8 % at the most).

The temperatures for the scenario period are supposed to increase due to expected global warming, especially in the winter. This will lead to a decrease in the length of the heating season all over the country up to 2050. The HDD will decrease at the most with more than 20 % in costal areas.

KEYWORDS:

Heating degree-days, heating season, scenarios, Geographical information systems (GIS).

SIGNATURES:

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Project leader	Head of the DNMI Climatology Division

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1. Introduction

The heating season is the period of the year when we have to use electricity or fuel to heat our buildings. The length of this season depends on the air temperature, which again varies in space with altitude, latitude, distance from the coast etc. The heating degree-days (HDD) are the accumulated sum of ^{o}C between the daily mean temperature and a threshold temperature, which in Scandinavian countries is defined to be 17 ^{o}C (Johannessen, 1956). The HDD is a good estimate on accumulated cold and is therefore a useful index of heating energy consumption and thus to power production planning (Quayle & Diaz, 1980).

Annual temperatures and precipitation have increased during the last 100-150 years in Norway. The increase in annual temperatures since 1876 is between 0.4 to 1.2 ^{o}C in different regions. After a period with decreasing temperatures from the 1930s, the annual temperature has increased in all parts of Norway since 1980 (Hanssen-Bauer & Nordli, 1998). Førland et al. (2000) showed that the temperature in Norway increased during the last two decades (1980-1999) compared to the normal period (1961-1990). The largest increase occurred during the winter season. Climate change scenarios for Norway indicate that the tendency of increasing temperature and precipitation will continue in the next decades (Hanssen-Bauer et al., 2000 and Hanssen-Bauer et al., 2001).

This report presents a study of the change in the length of the heating season and the HDD in Norway due to global heating. The time slice periods analysed is the normal period 1961-90 (the reference period), the twenty-year period 1981-2000 and the scenario period, 2021-2050. The estimate for the scenario period is based on only one temperature scenario (chapter 2). Obviously there are uncertainties concerning this temperature scenario. The same parameters as presented in this report for Norway and the same time slices will be analysed for some selected cities in Fennoscandia in a report later this year.

Solar insolation contributes to the heating season in the way that the more solar radiation the less we need to heat our buildings. The heating of buildings due to solar radiation is of greater importance during the spring and summer than during the autumn and winter. The estimate of HDD is calculated within the heating season, which in this study is the time of the year when the temperatures are below 10 ^{o}C. The influence of the radiation will therefore be of less importance. (A report on estimates of monthly solar insolation in Norway, based on cloud cover observations, is in progress (Skaugen, 2002)).

Temperature data used in the study are presented in chapter two. The methods used are presented in chapter three. The heating season with its length, start and end for the normal period, the twenty-year period 1981-2000 and the scenario period 2021-2050 is presented in chapter 4. The HDD is estimated for the same time periods, the results are presented in chapter 5. A summary of the study is presented in chapter six.

2. Data

2.1 Temperature data used for Norway

For the last normal period 1961-90 and for the twenty-year period 1981-2000 temperature observations are used. For the scenario period 2021-2050, temperature data are calculated from the empirical downscaling of the GSDIO integration (a transient integration including effects of greenhouse-gases and tropospheric ozon, as well as direct and indirect effects of sulphur aerosols) with the Max-Planck-Institute climate model ECHAM4/OPYC3 (scenario data from the Max-Planck Institutes AOGCM which means coupled atmospheric-ocean global general circulation models) (Hanssen-Bauer et al., 2000). The empirical downscaling method involves the use of empirical links between large –scale fields and local variables to deduce estimates of the local variables.

The number of stations used for the three periods within Norway is tabulated in table 2.1. For the normal period, data for 421 stations are available (Tveito et al., 2000). For the twenty-year period, temperature stations with time series of more than 15 years are used (127-136 stations*). The locations of these stations are shown in Figure 2.1. Temperature estimates for the scenario period is carried out for fifty stations in Norway, four of these is located in the Svalbard area. The locations of the forty-six temperature main land stations used are shown in Figure 2.1.

Table 2.1 Number of temperature stations used in the analysis.

	Number of stations
1961-1990	421
1981-2000	127-136*
2021-2050	46

* Not all the stations satisfies the criterion of 15 years with observations in every month. For July, 127 stations satisfies the criterion, for September and October 136 stations satisfies the criterion.

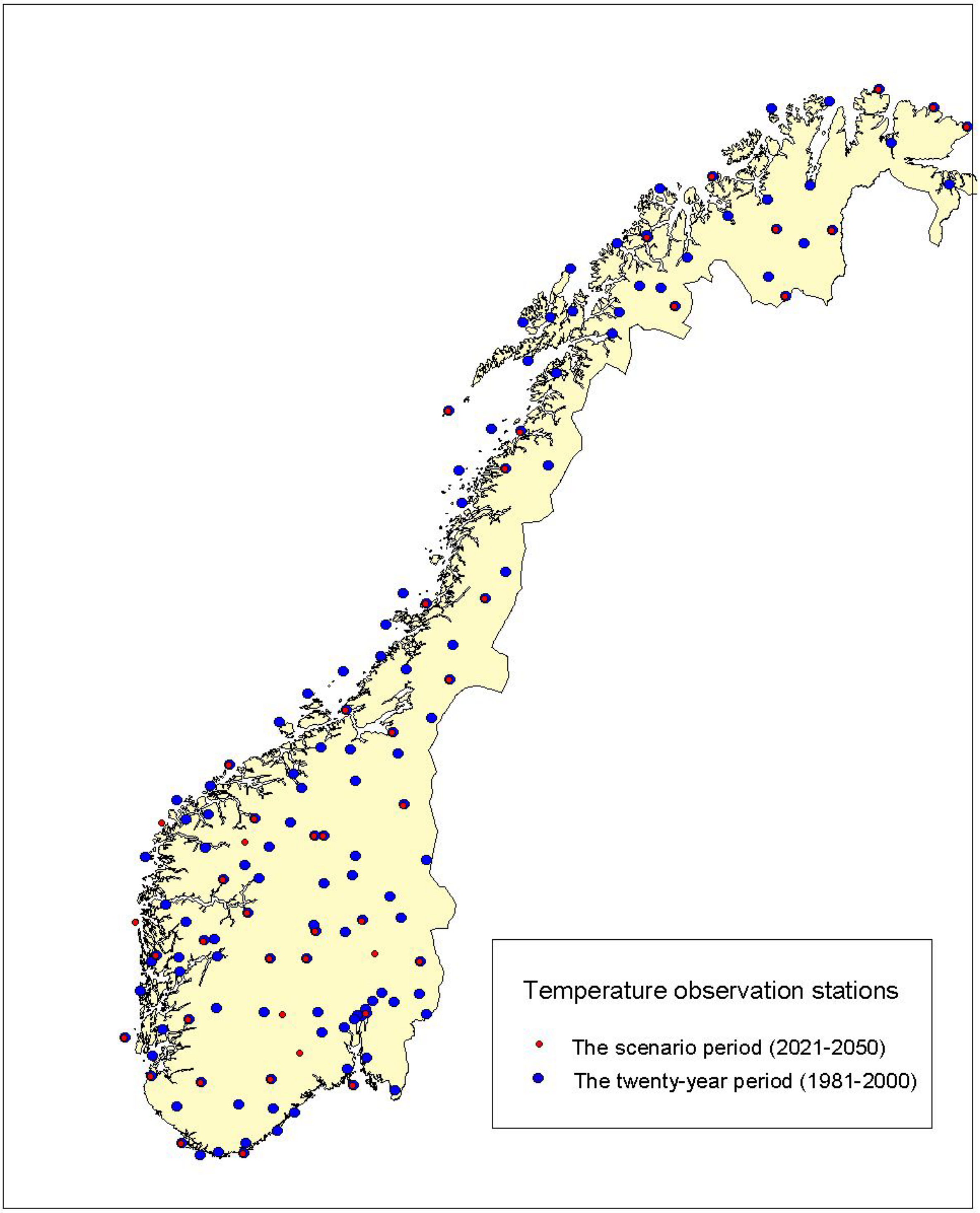

Figure 2.1 Temperature observation stations used for the twenty-year period 1981-2000 and for scenario period 2021-2050. The temperature observation stations used for the normal period are presented in Tveito et al. (2000).

3. Methods

3.1 Estimation of daily mean temperature from monthly mean temperature.

To be able to estimate the heating season and the HDD, daily mean temperatures for the actual time period studied have to be available. For historical time periods, such values can be obtained using the observed daily values. For the scenarios of the future climate daily temperatures are not available. It is however possible to estimate daily smoothed temperatures from monthly mean values. Such approach also ensures consistent values for all periods analysed. The smoothed daily mean temperature is interpolated from monthly mean temperature applying a cubic spline algorithm (Press et al., 1992). A constraint is added to the spline equation to ensure that the deviation between the gridded monthly mean temperature and the mean monthly temperature based on the estimated daily temperature values satisfies the tolerance criterion 0.001 ^{o}C. The amplitude of the spline curve was adjusted by shifting the positions of the monthly mean (default in the middle of the month). This is done iteratively until the tolerance criterion was fulfilled. As can be seen in Figure 3.1, the method reproduces the observed daily thirty-year means satisfactory (from Tveito et al., 2001). The method is used for the historical periods as well as for the scenario period.

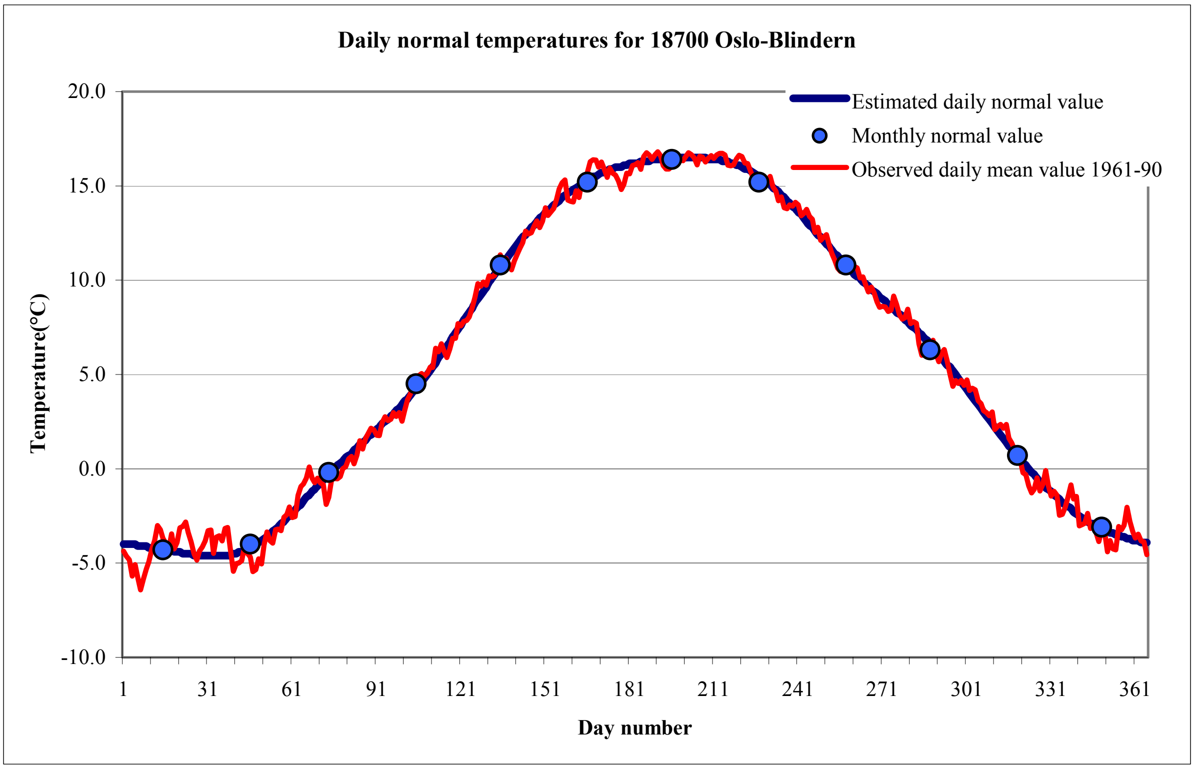

Figure 3.1 **Observed daily mean temperature, estimated daily mean temperature and mean monthly temperature at the temperature station 18700 Blindern (in Oslo).**

3.2 Spatial interpolation of temperature observations

Mean monthly temperature maps are established for the last normal period for Fennoscandia by Tveito et al. (2000). The maps are established from the temperature observations presented in chapter two. The maps are obtained by using a stochastic interpolation method called residual kriging. The grid resolution is 1 x 1 km^2.

Interpolation of absolute temperature values is difficult due to sparse station density and its large variability over short distances. This is in conflict with the assumptions using spatial interpolation methods that usually are based on the assumption of second order stationarity. By normalising the mean temperature values for the 1981-2000 and 2021-2050 periods, these assumptions are almost fulfilled. The normal value is subtracted from the mean temperature values for the respective periods, and the resulting residual value is used as the regionalized variable. By interpolating the residuals, the variability due to climatology is removed, and more robust estimates are obtained compared to interpolation of absolute temperature values.

Temperature maps for the twenty-year period and the scenario period are obtained by adding the residual maps for the respective periods to the temperature maps for the normal period. The maps are represented as grids in a Geographical Information System (GIS).

3.3 Calculation of the heating season

For each grid cell in the temperature map, a smoothed curve of daily mean temperatures is estimated based on the twelve monthly mean values (section 3.1). The heating season is calculated for each grid cell from the cells temperature curve. Solar radiation is supposed to be of greater importance in the fist half of the year than in the second half of the year. For this reason the heating season is traditionally defined as the period from the day the mean daily temperature falls below 11 ^{o}C during the autumn and until the day it rises above 9 ^{o}C during the spring (Johannessen, 1956). For some parts of the country, the temperature will rise above 9 ^{o}C during the summer, but never reach 11 ^{o}C. This area is shown as the grey shaded area in

Figure 3.2. The end of the heating season in this area will be defined, but the start of the season however will not be defined. To be able to define a heating season with a start and an end for all parts of the country, the threshold temperature in this study was set to 10 ^{o}C in both ends of the season.

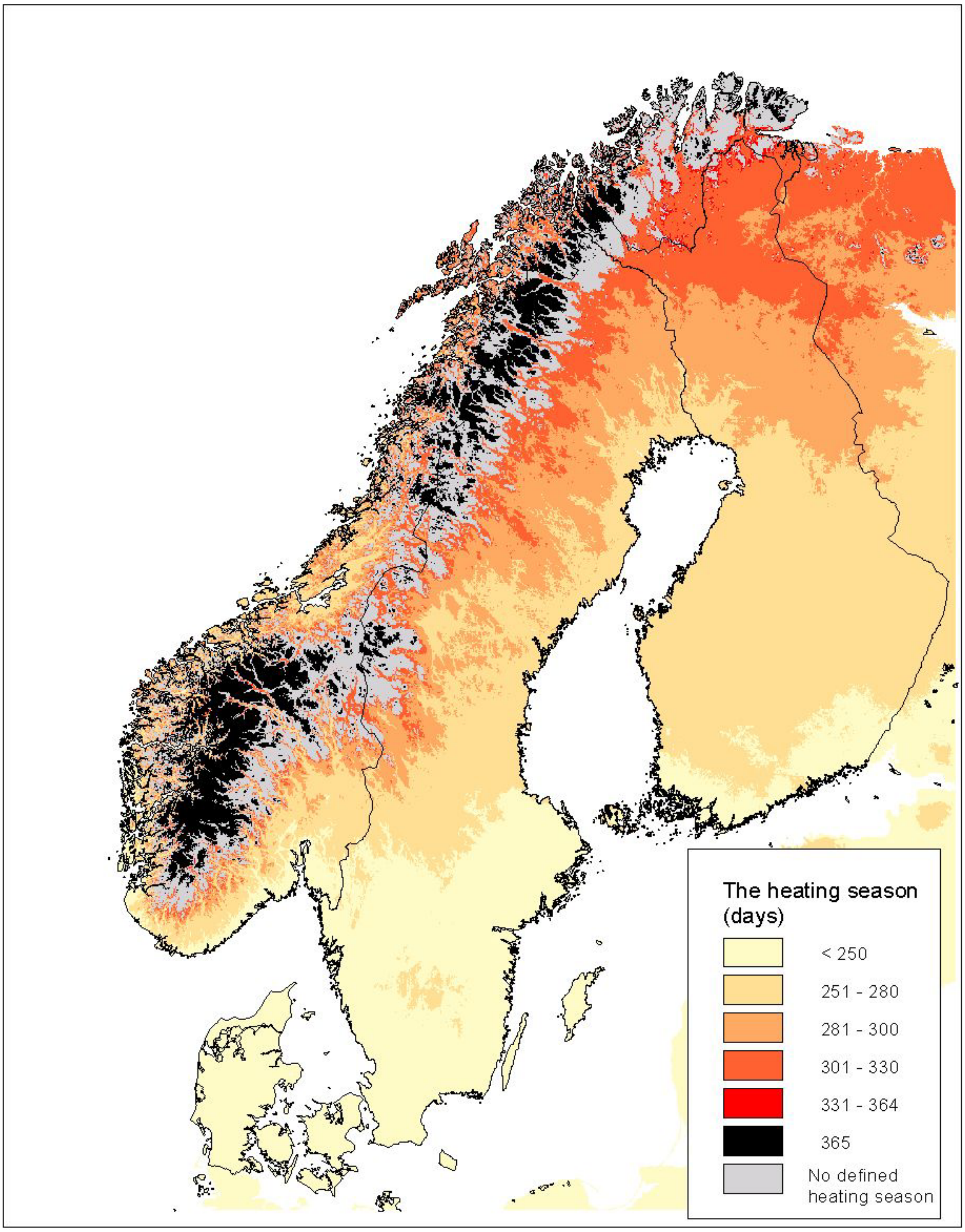

Figure 3.2 The heating season in Norway in the normal period 1961-1990. The grey shaded area is the part of Norway where the beginning of the heating season never was defined.

3.4 Calculation of the heating degree-days

The heating degree-days (HDD) are defined as the accumulated degree sum above a defined reference temperature, $\hat{T}$ (Taylor, 1981). Mathematically this can be expressed throughout the whole year (or within a defined season) as:

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

$$HDD = 0, T_i \geq \hat{T}$$

where T_i is the daily normal temperature for day number *i,* $\hat{T}$ is the reference temperature. In Scandinavian countries the reference temperature is 17 °C. The heating season is in this study the period of the year with mean daily temperature is below 10 °C (section 3.3).

Taylor (1981) estimated the population-weighted heating degree-days. This means that the HDD is weighted with the population density. This is useful information, especially with the focus on power planning. Population-weighted HDD estimates are beyond the scope of the work reported here, but the estimates can be seen together with the population density map of Norway from 1999, Appendix A.

4. The heating season

4.1 The normal period 1961-1990

The start-, the end- and the length of the heating season are calculated for the normal period 1961-1990 for Norway (Figures 4.1-4.3). This is done as described in section 3.3 with the data presented in section 2.1.

The duration of the heating season increases with altitude (m. a. s. l.) and latitude from less than 240 days in the coastal area in the southwestern and southeastern part of Norway (Figure 4.1). In a belt from the Swedish border in the southeastern part of Norway along the coast to the Trondheimsfjord area, and in a tiny belt further north up to Lofoten, the heating season lasts from 240 to 290 days. This belt is widest in the southeast and gets thinner along the west coast and further north. It widens in the low altitude area around Trondheimfjorden. The red-orange areas in the map indicate that the heating season lasts from 290 up to 364 days of the normal year. This are the areas located at the high altitudes and in the north of Norway. In the high mountain areas and northernmost parts of the country, the temperature never exceeds 10 ^{o}C during the summer and thus the heating season is defined throughout the normal year (365 days).

In the area where the heating season lasts for less than 240 days, the heating season begins somewhere between late in September to early in October (Figure 4.2), and ends during the second half of May (Figure 4.3). The beginning and the end of the heating season show the same pattern as for the length of the heating season. The start of the heating season is distributed over a shorter period than the end of the season. A histogram of the start and the end of the heating season is presented in Appendix B, Figure 1. The histogram of the end of the heating season indicates that the distribution has two peaks. The first peak is around day number 140 (20.5), the second around day number 180 (29.6). Plot of the end of the heating season (Figure 4.3) with colours separated with the peaks are shown in Appendix B, Figure 3. The map shows that the country can be divided into two regions. A third region is the part of the country where the heating season lasts through out the year, this region is not accounted for in the histogram referred to. The first region is defined as a belt from the south-eastern part of Norway along the coast up to the Trondheimsfjord area, and some low altitude and costal areas in the north of Norway. In this area the heating season will end earlier than the other regions. A frequency diagram of the start and end of the heating season is shown in Appendix B, Figure 2.

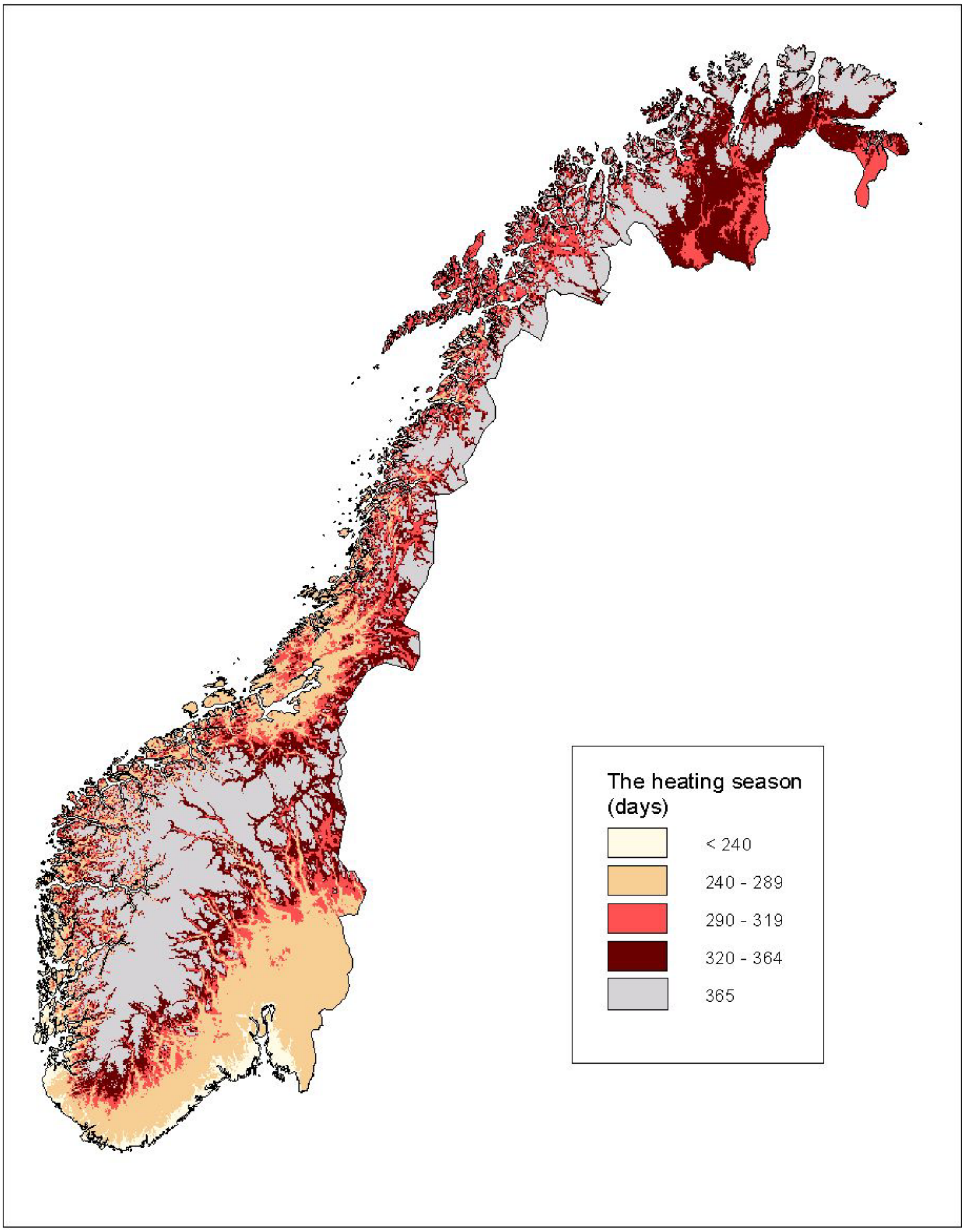

Figure 4.1 The length of the heating season in the normal period (1961-1990) in Norway.

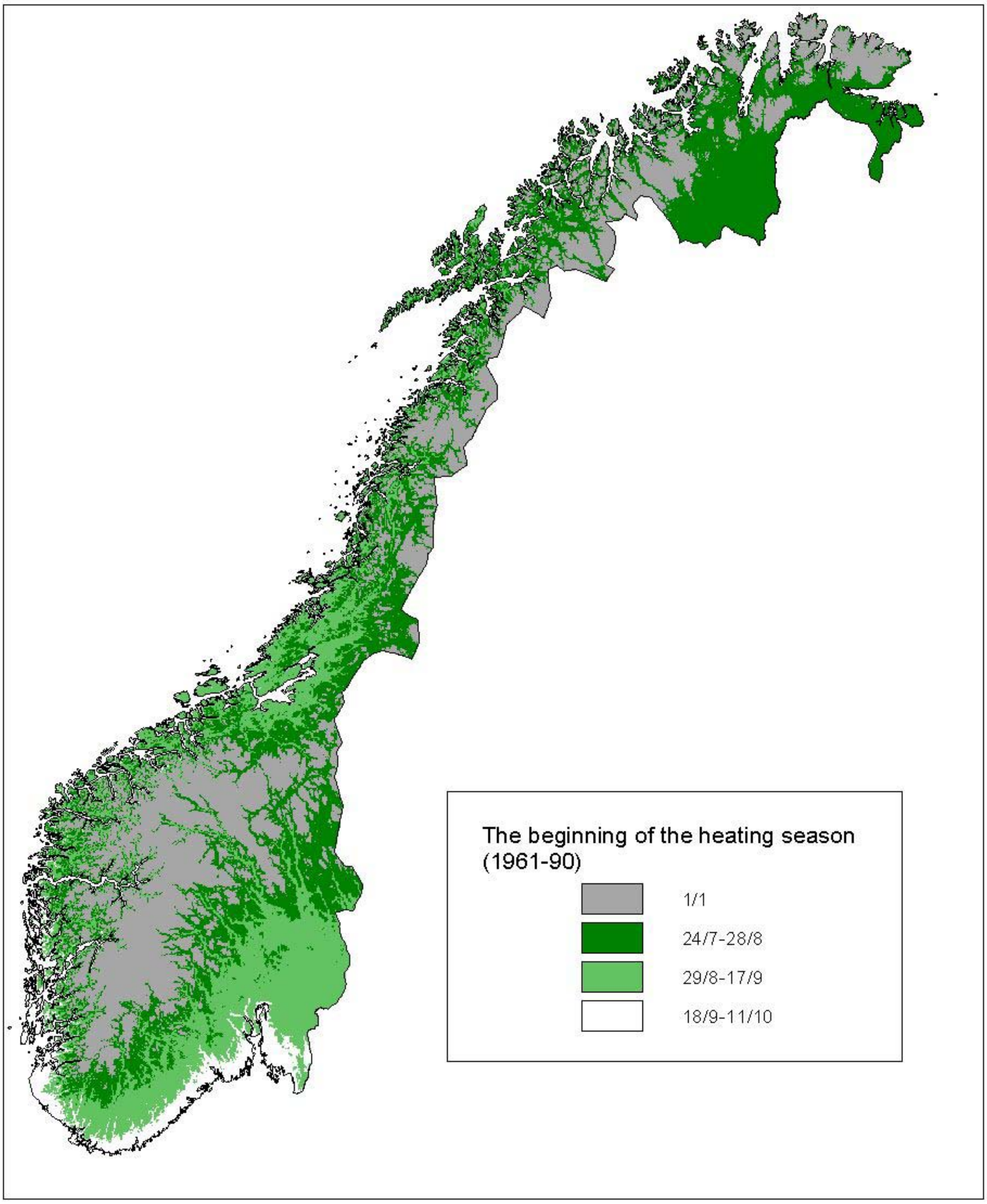

Figure 4.2 The start of the heating season in the normal period (1961-1990) in Norway.

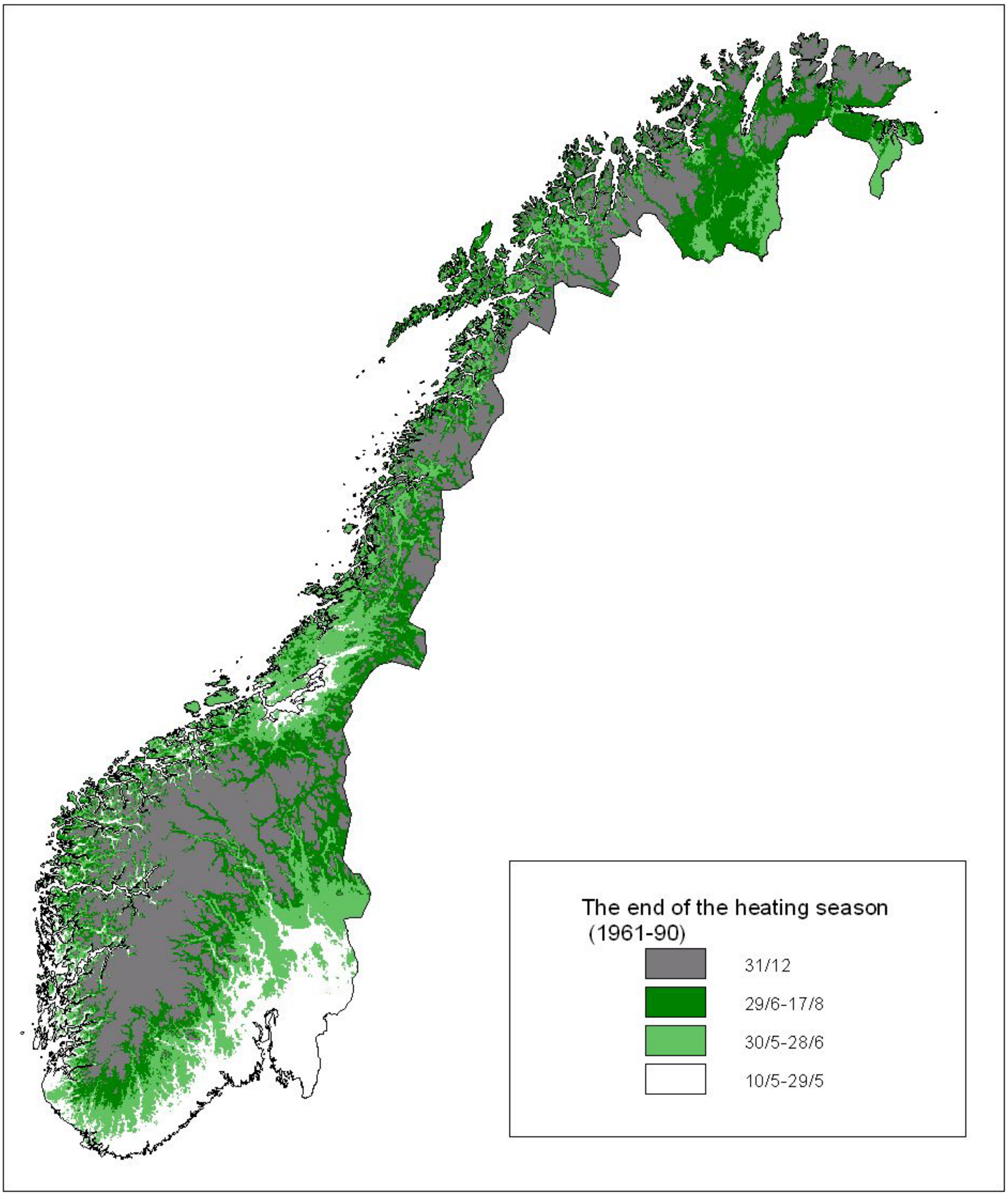

Figure 4.3 The end of the heating season in the normal period (1961-1990) in Norway.

4.2 The 20 year-period 1981-2000 compared to the normal period

Changes in the length-, the first- and the last day of the heating season between the twenty-year period (1981-2000) and the last normal period are calculated (chapter 3), and are presented as maps in Figure 4.4-4.6. This is done as described in section 3.3 with the data presented in section 2.1.

The grey area in Figure 4.4 indicates that there has been no change in the length of the heating season. A large part of this area is the high mountains and the northernmost part of the country, where the heating season lasts throughout the whole year. Compared to the normal period, the area where the heating season lasted the whole year decreased with ca 10 %. There are however areas where there was no change in the length of the heating season.

The blue shaded colours in Figure 4.4 indicate that the length of the heating season increased, and the yellow to red shaded colours indicate that the duration of the heating season decreased in the last twenty-year period compared to the normal period. The heating season decreased with less than 20 days in the costal areas and some inner parts of the country. Only minor areas decreased with more than 20 days. The length of the heating season did however also increase in some areas, although it was just with a few days. We know that the air temperature in general increased over the whole country for the last twenty years compared to the normal period (Førland et al., 2000). Analyses of the changes in temperature for the twenty-year period compared to the normal period show that the temperature in general increased in the winter, spring and autumn seasons (Figure 4.7). The summer temperature (June, July, August) however, which has an important influence of the beginning and end of the heating season, became lower in some areas. Daily mean temperature estimated from monthly mean temperatures for some chosen temperature stations (section 3.1) are presented in Appendix C. The location of the stations chosen is shown in Appendix C, Figure 1 (yellow dots). The daily mean temperatures for the different periods and with the threshold temperature 10 ^{o}C are shown in Appendix C, Figures 2-8. They show that the winter temperature (December, January and February) increased at all the selected stations. This is in accordance with Figure 4.7. The stations 08130 Evenstad (Appendix C Figure 4), 43500 Ualand - Bjuland (Appendix

C Figure 8) and 28800 Lyngdal i Nummedal (Appendix C Figure 5) are situated in the blue area, which means that the heating seasons length increased compared to the reference period. The end of the season was delayed with a few days. The change in the beginning of the season is minor. At the selected stations situated in the yellow shaded area, station 04440 Hakadal (Appendix C Figure 2), 36560 Nelaug (Appendix C Figure 7) and 04780 Gardermoen (Appendix C Figure 3), the heating season decreased. The change in the heating season occurred mainly at the end of the season. The beginning of the heating season had only minor (or none) changes. The station 33960 Haukeliseter (Appendix C Figure 6) is situated in the grey area, which is where the heating season lasts throughout the year. Even though the temperature increased during the winter, it did not rise above 10 ^{o}C during the summer, Appendix C Figure 6.

The changes in the spatially distributed start of the heating season compared to the normal period were within a few days. The start was delayed with only a few days, up to eight days at the Trondheimsfjord area, the area along the west coast and the western part of Nordland (Figure 4.5). Some areas had also an earlier start, which means that the heating season increased. The change in the end is also minor, within +/- 10 days (Figure 4.6). It seems, however, that the change in the end was larger than in the start of the season. The histogram of the start and the end of the heating season is shown in App. B, Figure 3 (and as a cumulative area frequency distribution in App. B Figure 4). The changes in the end are multiplied by –1 to be comparable with the changes of the beginning. Most of the changes in the end of the heating season were minor and situated around zero days.

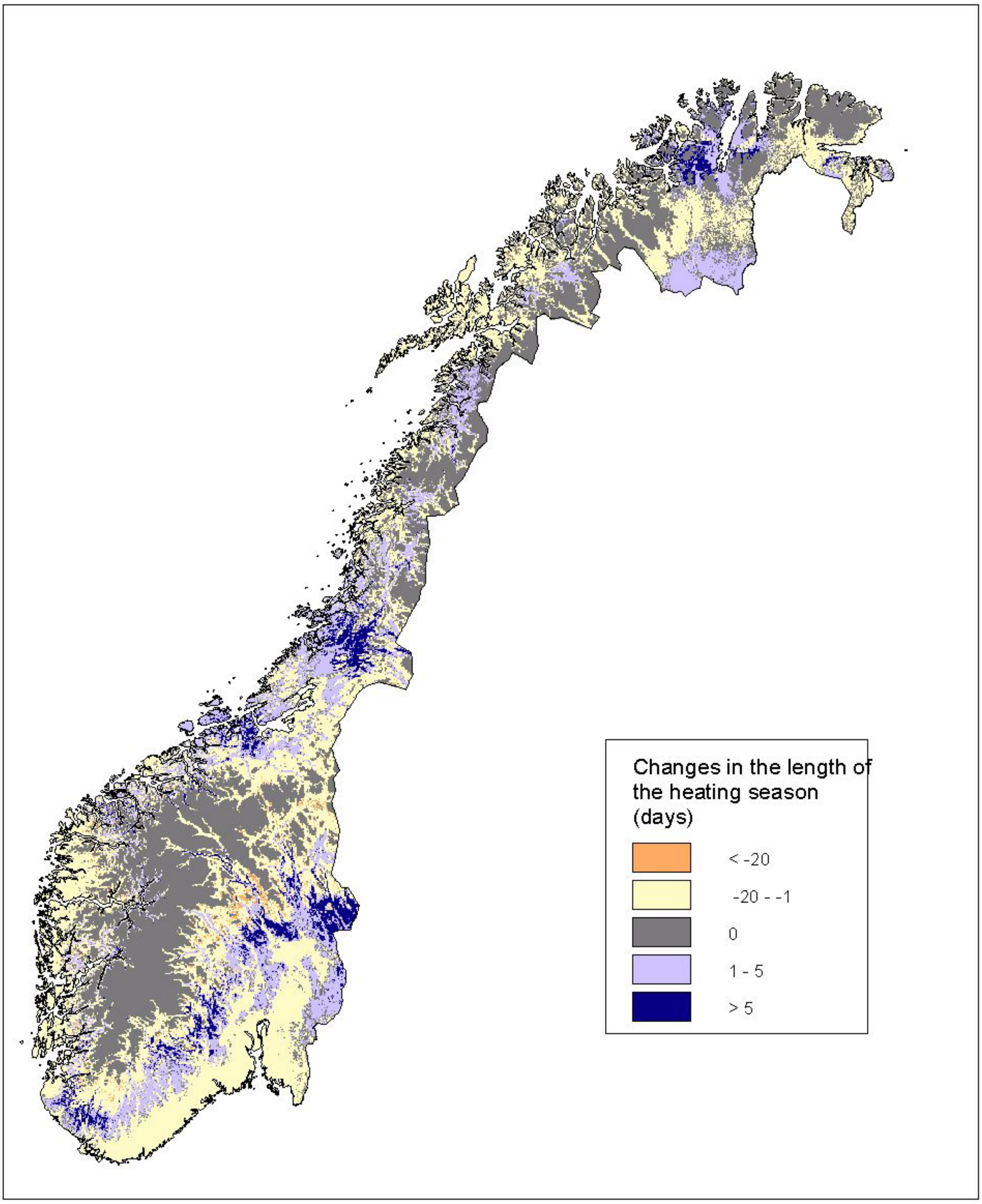

Figure 4.4 The changes of the length of the heating season between the twenty-year- (1981-2000) and the normal period (1961-1990) in actual days.

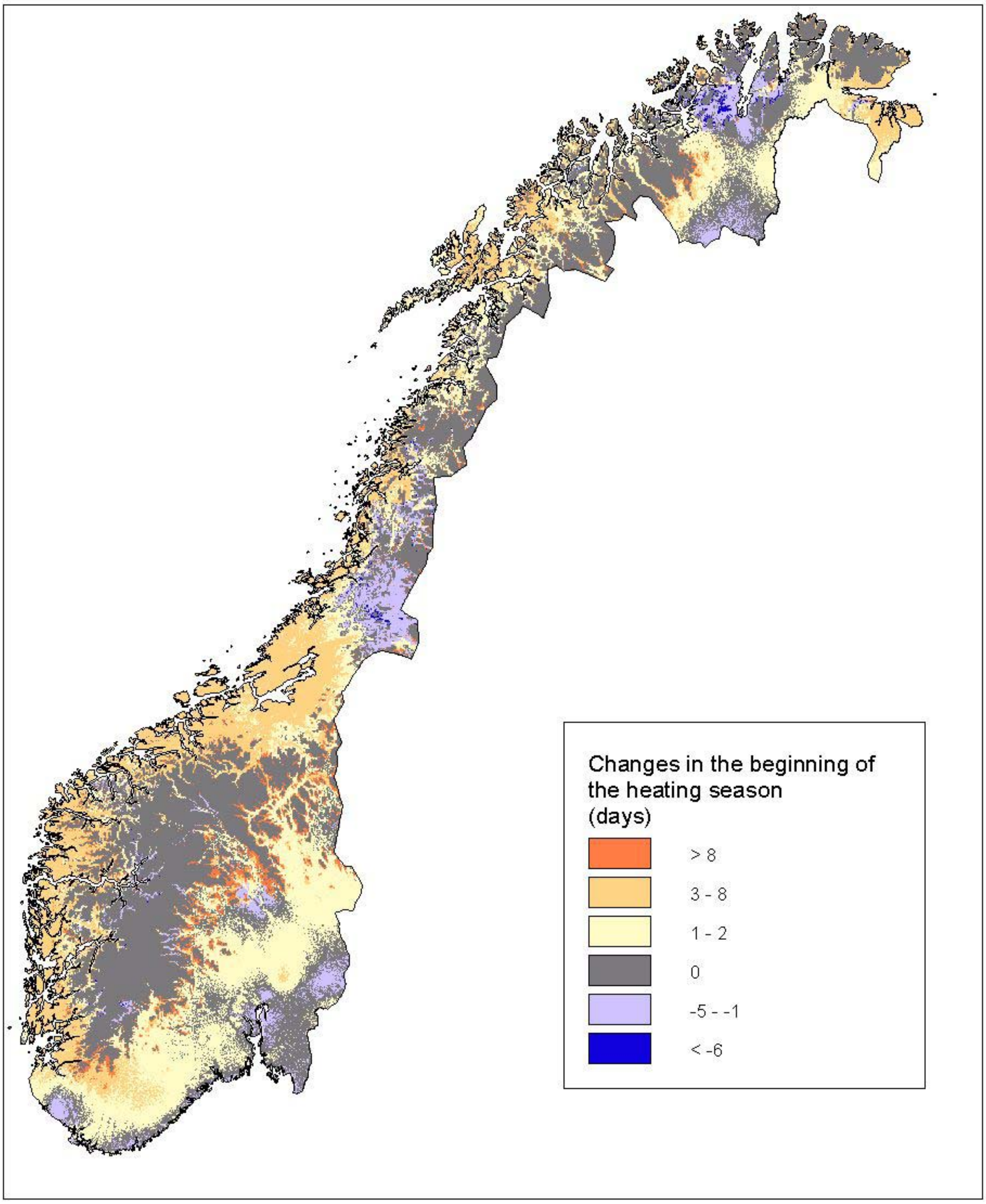

Figure 4.5 The changes of start of the heating season between the twenty-year- (1981-2000) and the normal period (1961-1990) in actual days.

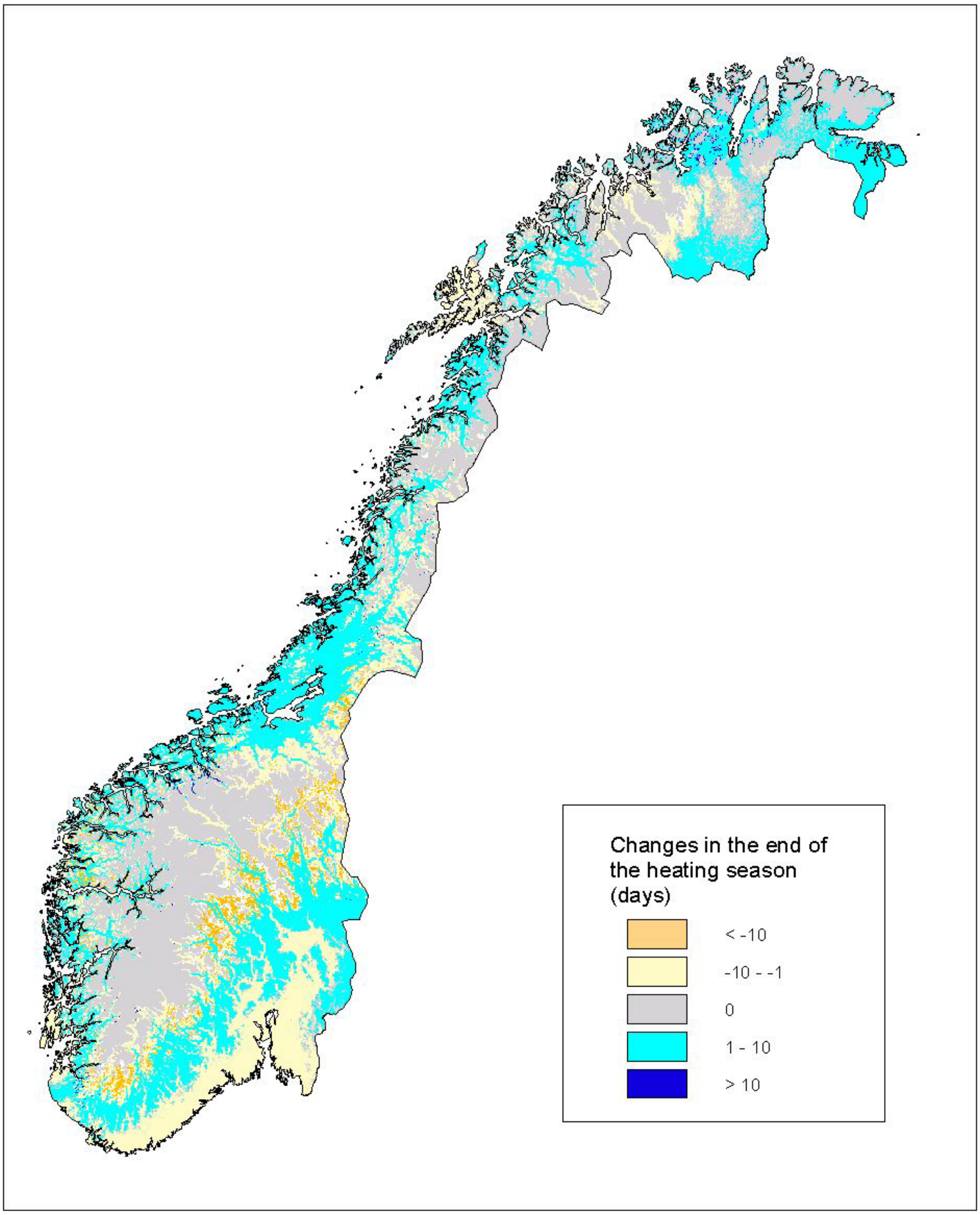

Figure 4.6 The changes of the end of the heating season between the twenty-year- (1981-2000) and the normal period (1961-1990) in actual days.

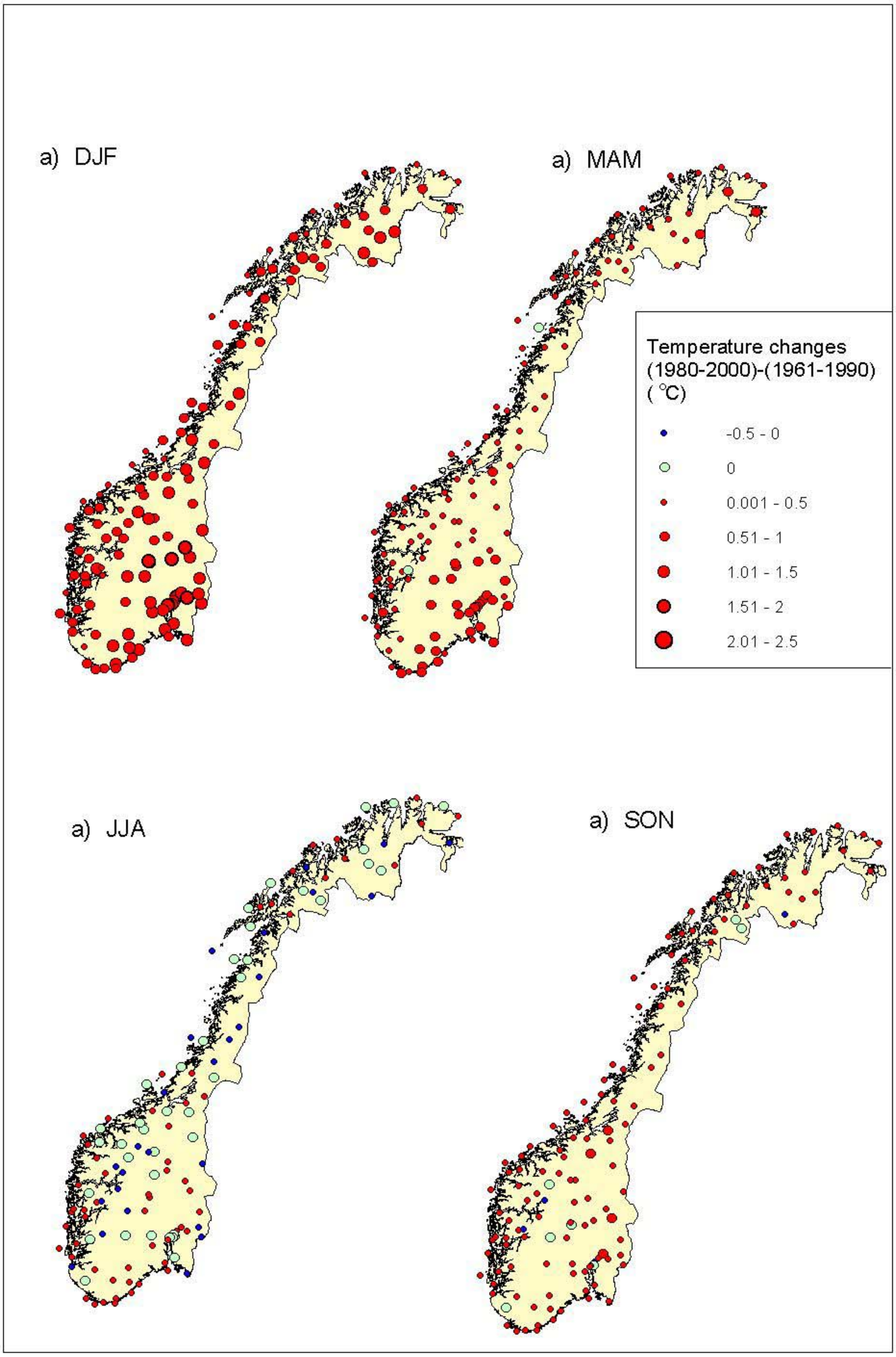

Figure 4.7 The changes of the observed temperature for the four seasons; winter (DJF), spring (MAM), summer (JJA) and autumn (SON) between the twenty-year-period (1981-2000) and the normal period (1961-1990).

4.3 The 30 year period 2021-2050 compared to the normal period

Temperature scenarios for the period 2021-2050 indicate that we will get a warmer climate in Norway in all seasons. The largest increase will occur in the winter season and will be most prominent in Northern Norway (Hanssen-Bauer et al., 2001). A consequence of this scenario is that the heating season will decrease all over the country (Figures 4.8-4.10).

The grey area in Figure 4.8 indicates where there will be no change in the length of the heating season. This is the high mountain area where the heating season lasts throughout the whole year. Compared to the normal period, this area will decrease with nearly 60 %.

In the southeastern part of Norway and the area around Trondheimsfjorden, the heating season will be up to 20 days shorter. For the costal part of the southwest, the coastal part of the Trondheimsfjord area and the inner part of Finnmarksvidda, the heating season will decrease with between 20 and 40 days. In the western part of the country, in the mountain areas and in the north the heating season will decrease with more than 40 days. The daily mean temperature curves (Appendix C) show that for all the selected stations, the heating season will decrease. The temperature increase will delay the beginning of the heating season and it will end earlier. The station situated in the grey shaded area (station 33960), where the length of the season is 365 days for both the normal period and during 1981-2000, will get a defined heating season in the scenario period.

The changes of the start- and end of the heating season in the scenario period compared to the normal period are presented respectively in Figure 4.9 and Figure 4.10. Positive values in Figure 4.9 means that the start of the heating season is delayed compared to the normal period. The same pattern as in Figure 4.8 can be recognised. The delay in the start of the heating season compared to the normal period is largest at the west coast and in the northern part of the country (with more than 16 days). Negative values in Figure 4.10 means that the heating season ends earlier compared to the normal period. The heating season ends earlier all over the country, at the most with more than 30 days at the west coast and in the northern part of Norway. The figure indicates that there are larger changes in the end of the season (in the spring) than in the beginning (in the autumn).

In Appendix B Figure 6, the histogram of the start and end of the heating season for the normal period are plotted together with the scenario period. The area where the heating season lasted through out the year in the normal period (the grey shaded area in figure 4.1) is excluded from the histogram for both periods. This is done to compare the two time periods (1961-1990 and 2021-2050). The diagram shows that the start of the heating season will be delayed with a few days, and it will start over a shorter period in time. The largest changes however are found in the end of the heating season. The distribution of the end of the heating season will be moved forward in time with a few days. The heating season will end much more simultaneously than the pattern we see for the normal period, especially for the second region that is the mountain area and the northern part of the country. The histogram of the changes of the start and end of the heating season in the scenario period compared to the normal period, Appendix B Figure 7, show that the change in the start is delayed with around 8 days. It is however delayed with up to 35 days at the most (the costal area in the west and the north). The changes of the end are separated in the two regions (the same regions as described in section 2.1), and it is less simultaneous compared to the normal period. The cumulative frequency diagram are shown in Figure 8, App. B

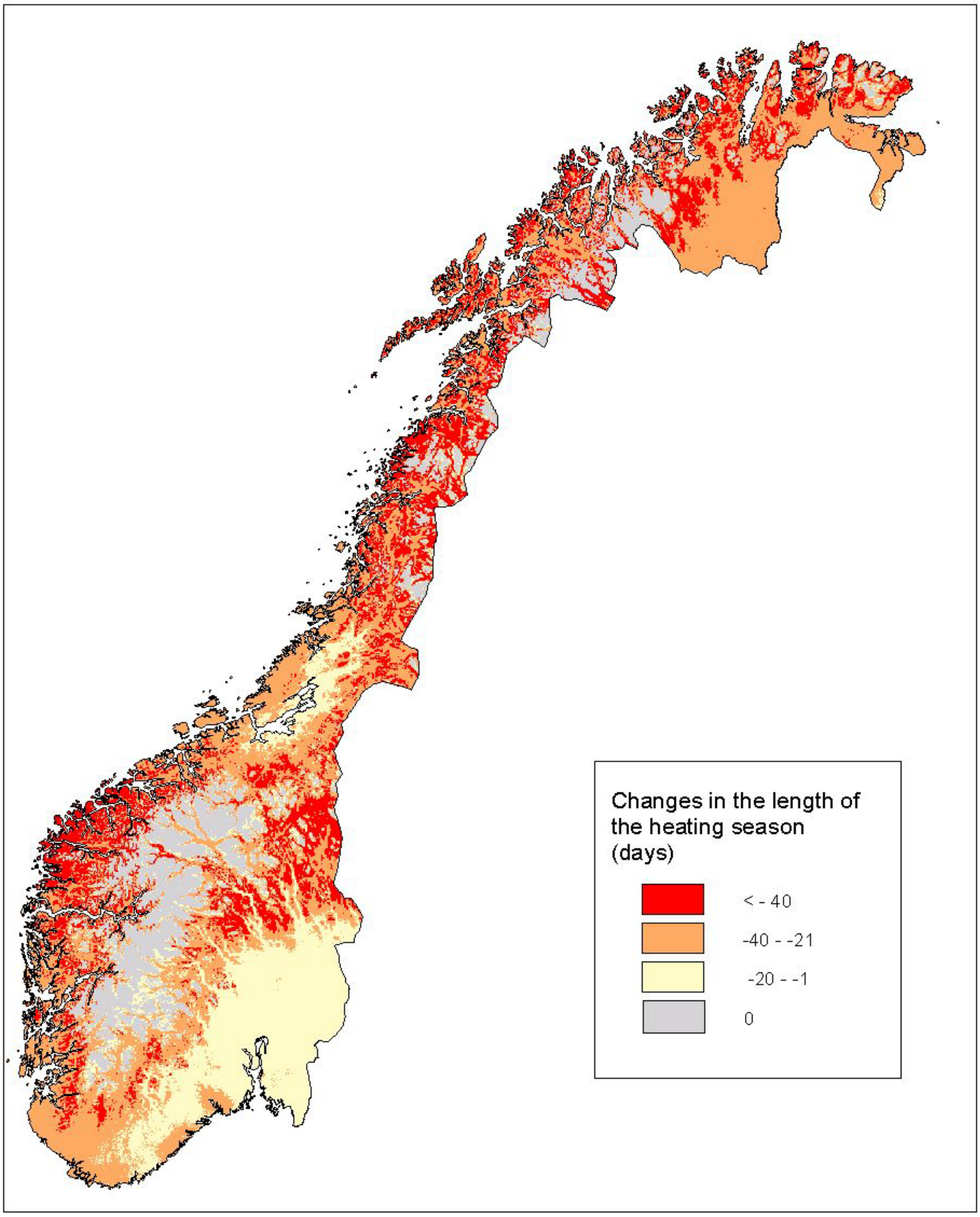

Figure 4.8 The changes of the length of the heating season between the scenario period (2021-2050) and the normal period (1961-1990) in actual days.

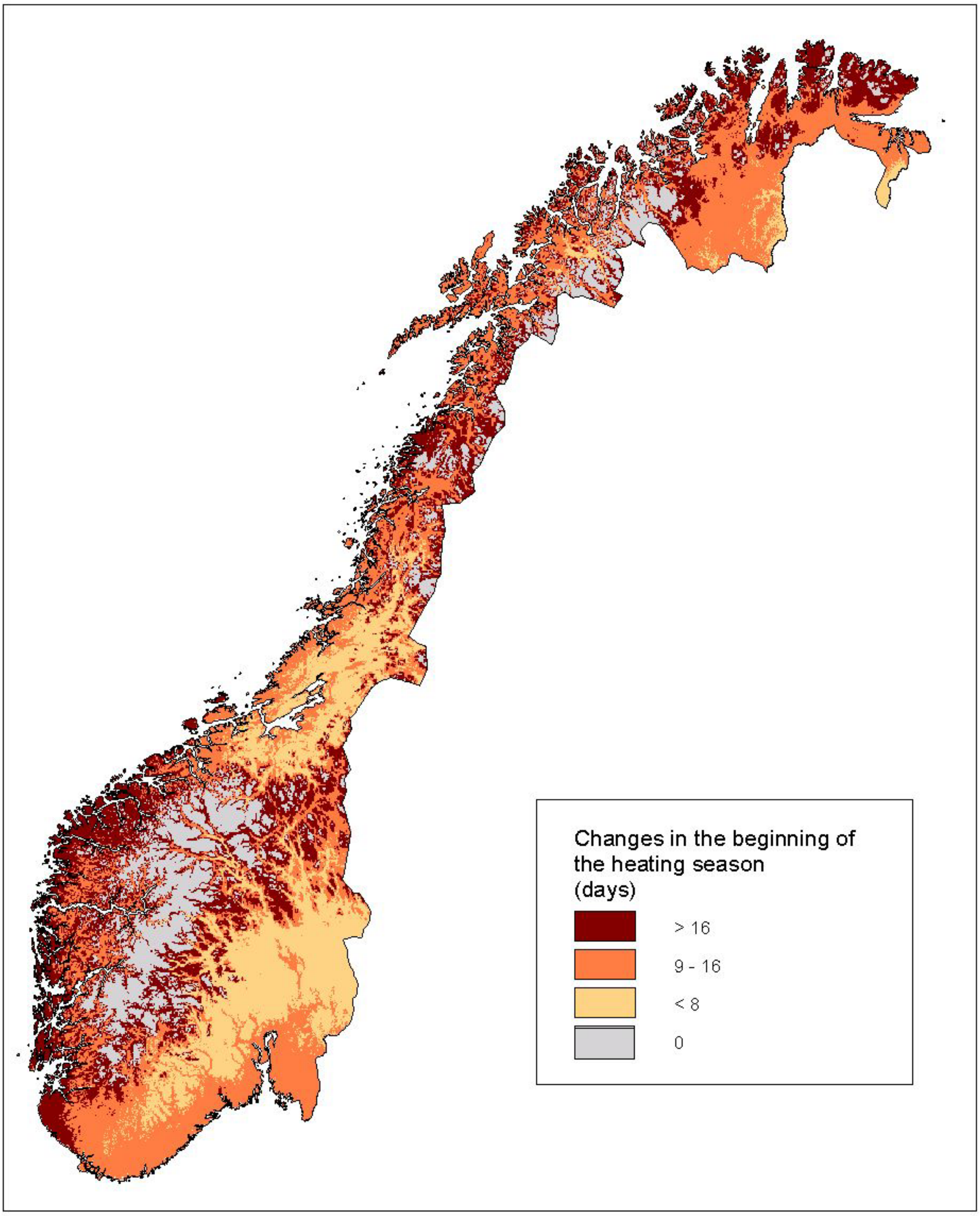

Figure 4.9 The changes of start of the heating season between the scenario period (2021-2050) and the normal period (1960-1990) in actual days.

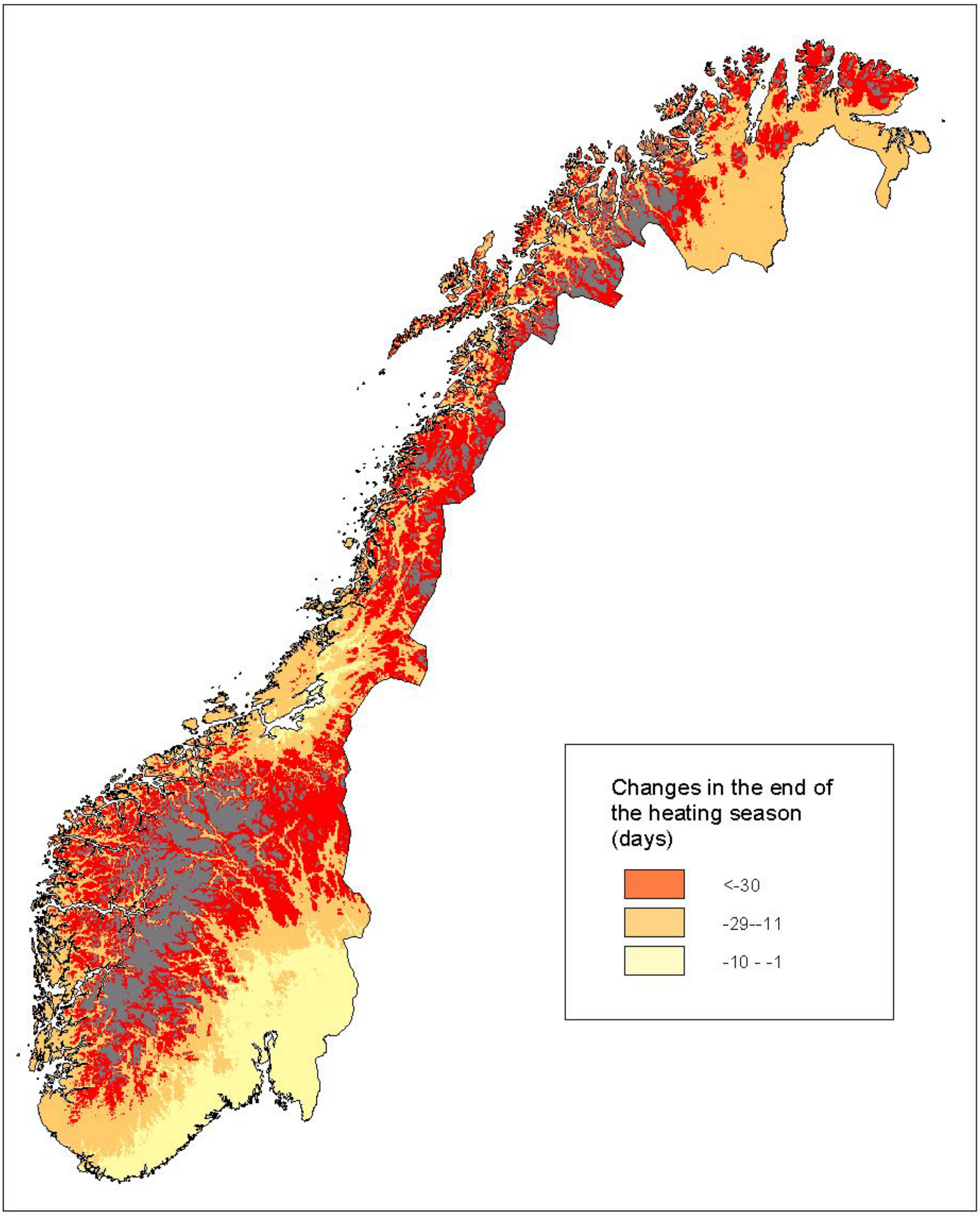

Figure 4.10 **The changes of the end of the heating season between the scenario period (2021-2050) and the normal period (1960-1990) in actual days.**

5. The heating degree-days (HDD)

5.1 The normal period 1961-1990

The heating degree-days (HDD) within the heating season are the accumulated sum of °C between the daily mean temperature and a threshold temperature, which in the Scandinavian countries is defined to be 17 ^{o}C (section 3.4). The HDD is a useful index of heating energy consumption (Quayle & Diaz, 1980). The HDDs are calculated within the heating season for the normal period 1961-1990, the results are presented in Figure 5.1. The temperature data used are presented in section 2.1

Solar insolation contributes to the heating season in the way that the more solar radiation the less we need to heat our buildings. The heating of buildings due to solar radiation is supposed to be of larger importance during the spring and summer than during the autumn and winter. The estimate of HDD is calculated within the heating period, which here is defined as the time of the year when the temperatures are below 10 ^{o}C. The influence of radiation in the estimates presented here will therefore be of less importance.

The HDD increase with negative °C. For Norway this means that the HDD increases with altitude and latitude. The distributed HDD map over Norway (Figure 5.1) is divided into three regions. The first region is the belt along the coast from the Trondheimsfjord area to the Swedish boarder. This belt has a rather linear distributed increase in HDD according to the area, ranging from less than 3000 and up to 4500 ^{o}C (Appendix D Figure 1). The next region has almost the same amount of area within each HDD-value, ranging from 4500 to 6000. This area is the high land area from the Swedish border in the east within the belt between the high mountain area and the first region. From Trondheimsfjorden the belt gets thinner along the coast up to Finnmark. The third region, with the highest estimates of HDD, more than 6000 ^{o}C, coincides with the high mountain areas and Finnmarksvidda.

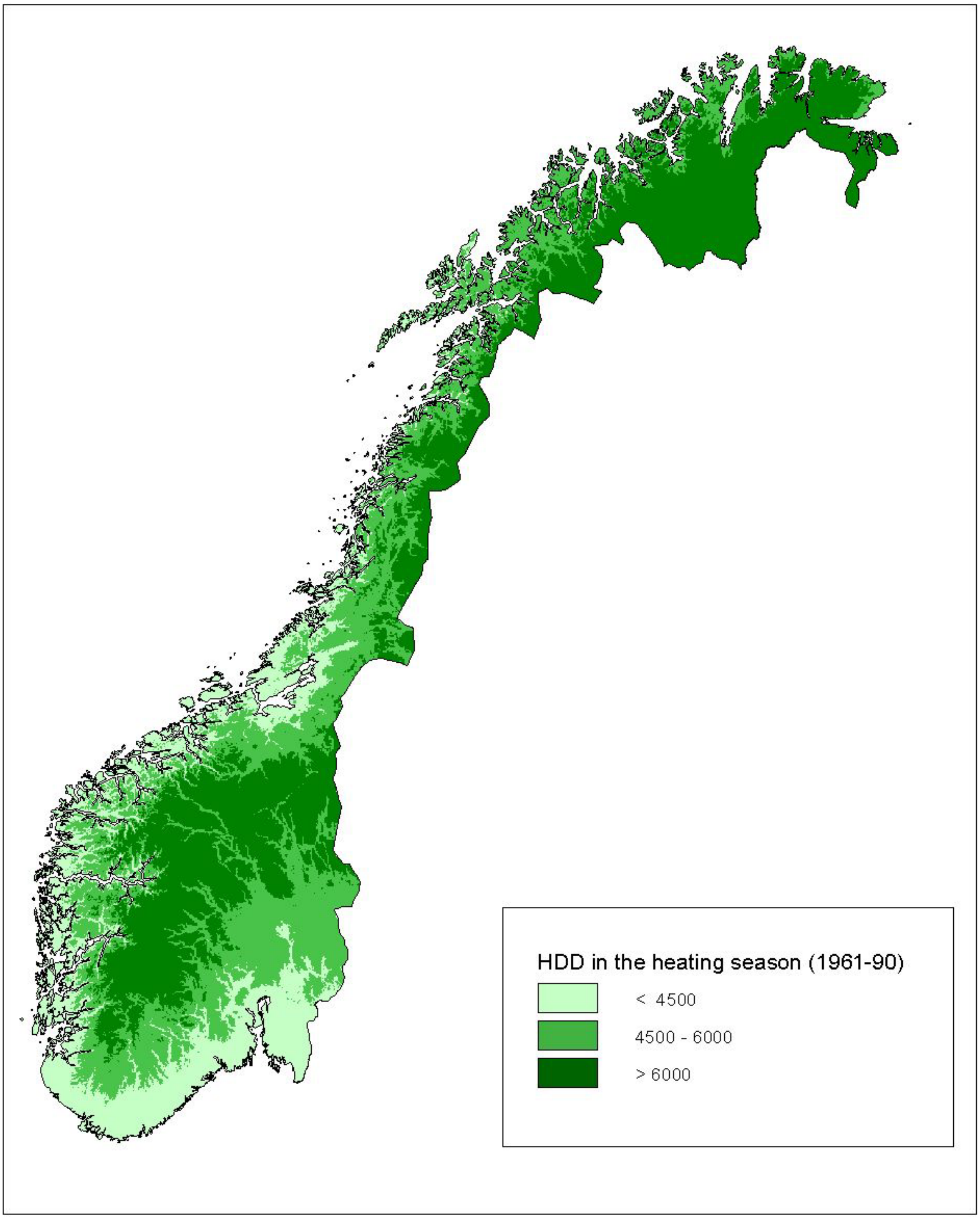

Figure 5.1 The HDD in the heating season in the normal period 1961-1990 in ^oC.

5.2 The 20 year-period 1981-2000 compared to the normal period

The changes of the HDD for the 20-year period 1981-2000 compared to the normal period are presented in Figure 5.2. The temperature data used are presented in section 2.1. In Figure 5.3, the changes are shown in percent

The HDD decreased over the whole country during the twenty-year period compared to the normal period. This was to be expected since the winter temperature increased during the period compared to the normal period (Førland et al., 2000, Figure 4.8 and appendix C). The greatest reduction in HDD, up to 400 ^{o}C, occurred in the same area that had the largest increase in temperature during wintertime, the southeastern part of the country. The Figures show that this area, which have the largest changes in ^{o}C, also in general show the largest changes in percent, up to 8 % (Figure 5.3). The histogram of the area distribution of the changes is presented in Appendix D, Figure 2. As can be seen from Figure 5.2 and the histogram in Appendix D (Figure 2), the largest area has a change in HDD between –100 and –200.

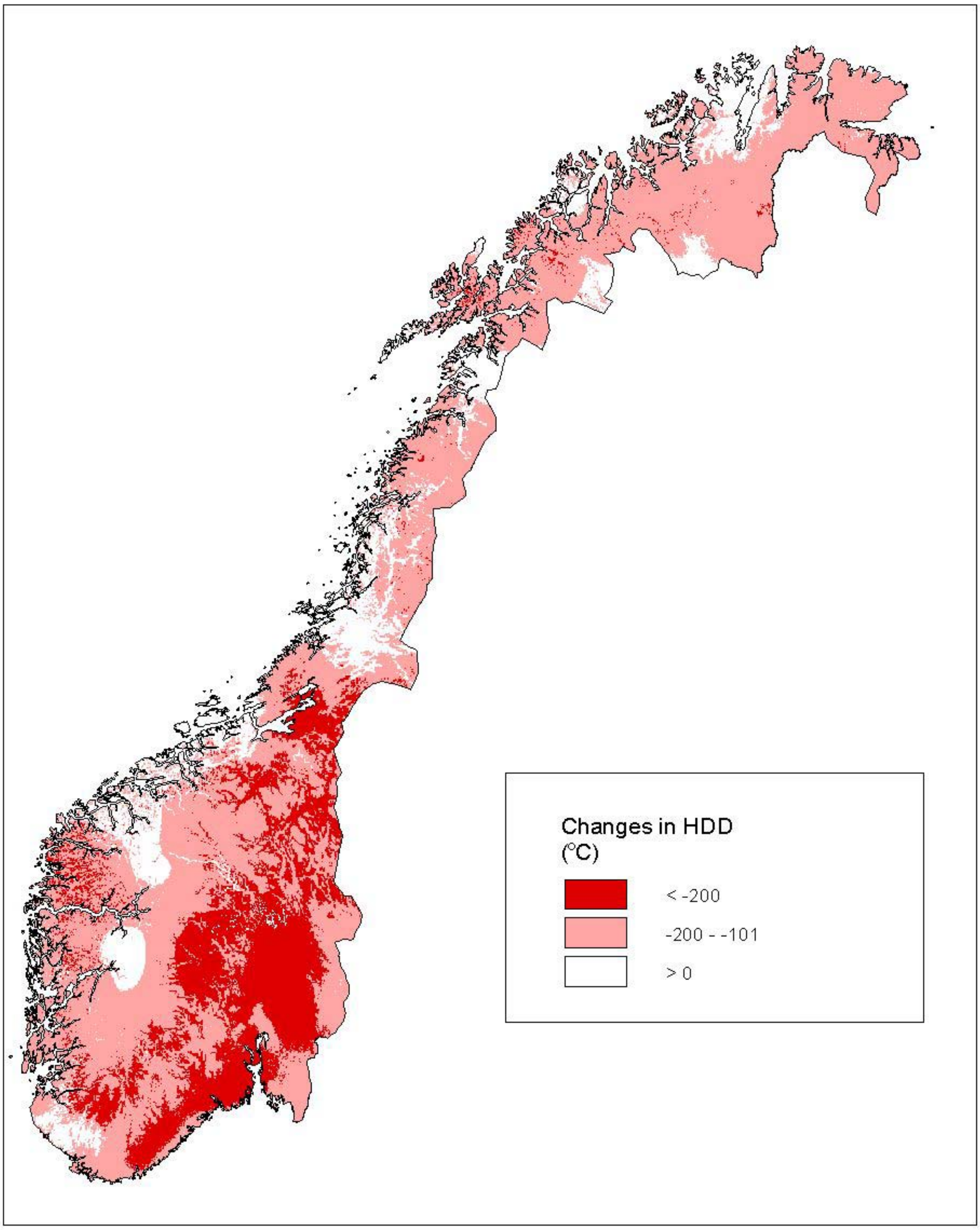

Figure 5.2 The changes of the HDD in the heating season between the twenty-year period (1981-2000) and the normal period (1961-1990) in ^{o}C.

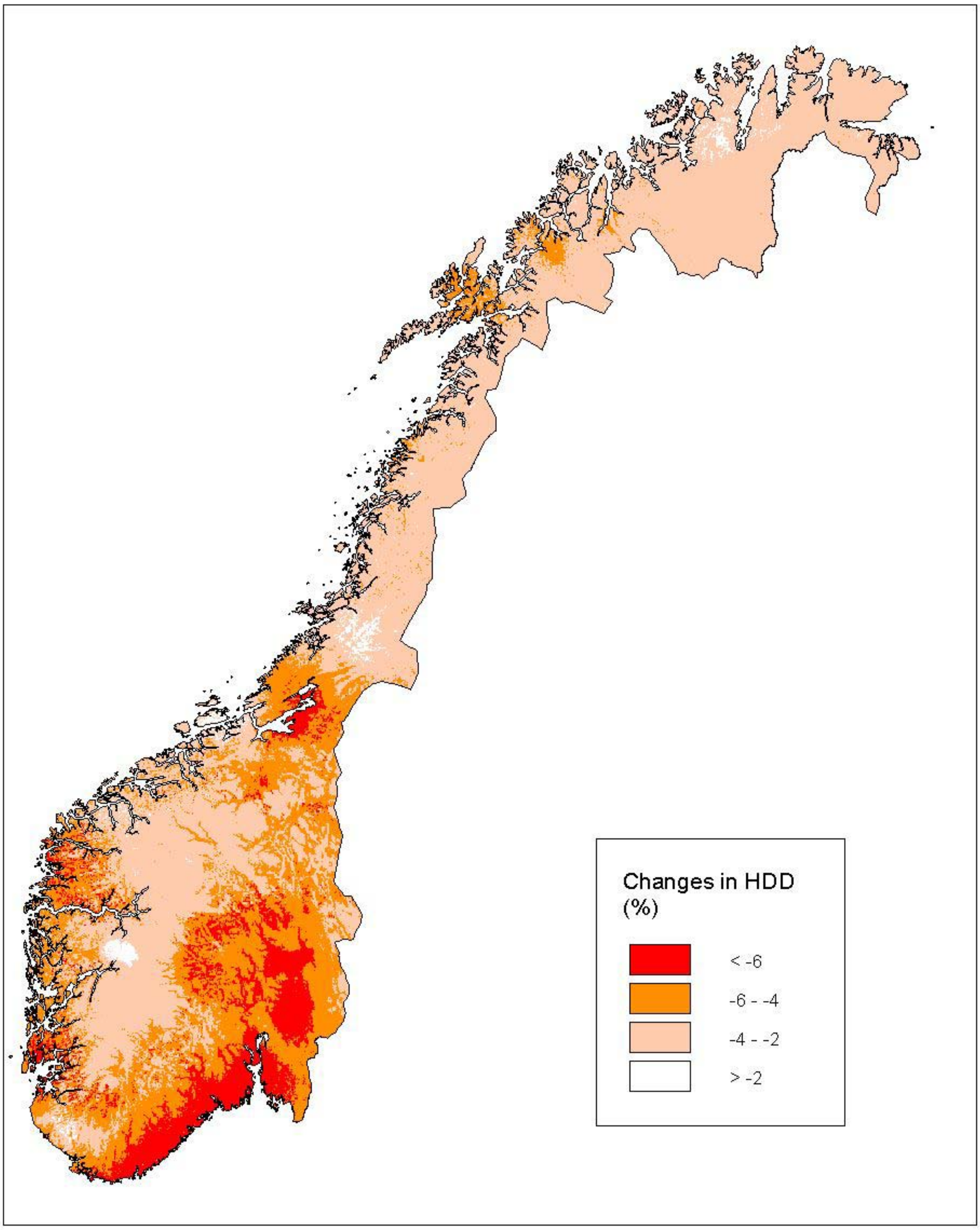

Figure 5.3 The spatial distribution of the changes of the HDD in the heating season between the twenty-year period (1981-2000) and the normal period (1961-1990) in percent.

5.3 The 30 year period 2021-2050 compared to the normal period

The changes of the HDD for the scenario period 2021-2050 compared to the normal period are presented as HDD (^{o}C) in Figure 5.4. The temperature data used are presented in section 2.1. In Figure 5.5, the changes are shown in percent.

As a consequence of increasing temperatures, especially in wintertime, the HDD is supposed to decrease all over the country. The changes in HDD separates Norway into four regions where the reduction in HDD is ranging from less than 650 to more than 1000 (as shown in Figure 5.4). The regions are (1) a belt along the coastal part of southeastern Norway and the Trondheimfjord area, (2) a rather large part of southern Norway, (3) parts of the mountainarea of Norway and (4) parts of northern Norway and Finnmarksvidda. The histogram of the area distributed changes in HDD (Appendix D Figure 3) show the same regional pattern.

The changes in HDD in percent are largest along the west coast and the costal line in the northern part of Norway, where the HDD will decrease with more than 20 %. In the eastern part of the country and the Trondheimfjord area, the reduction in HDD is expected to be between 10 and 15 %. Finnmarksvidda will have a reduction in HDD between 15-20 %. In the high mountain area in the south of Norway, the decrease is smallest, less than 10 %.

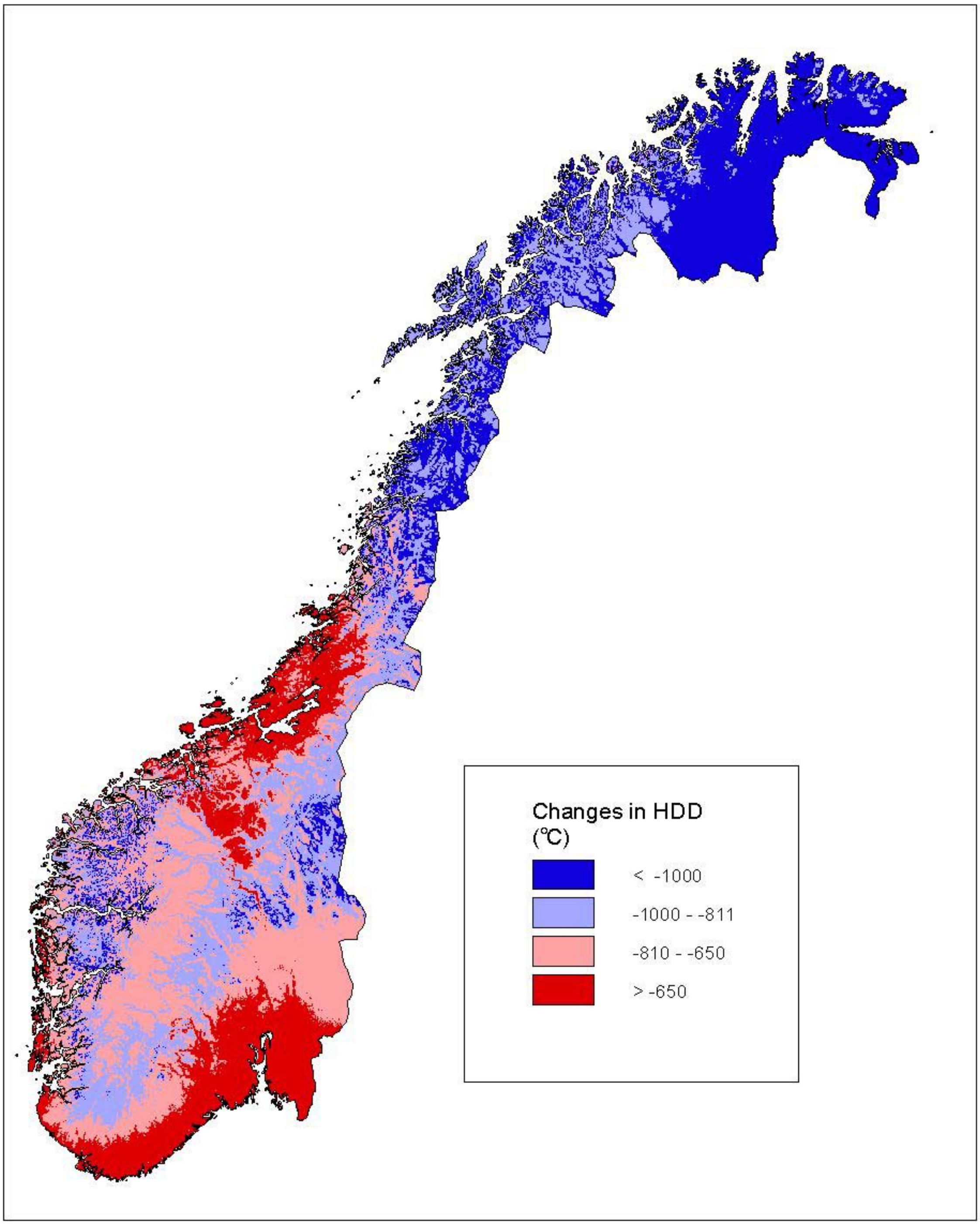

Figure 5.4 The spatial distribution of the changes of the day degree HDD in the heating season between the scenario period (2021-2050) and the normal period (1961-1990) in ^{o}C.

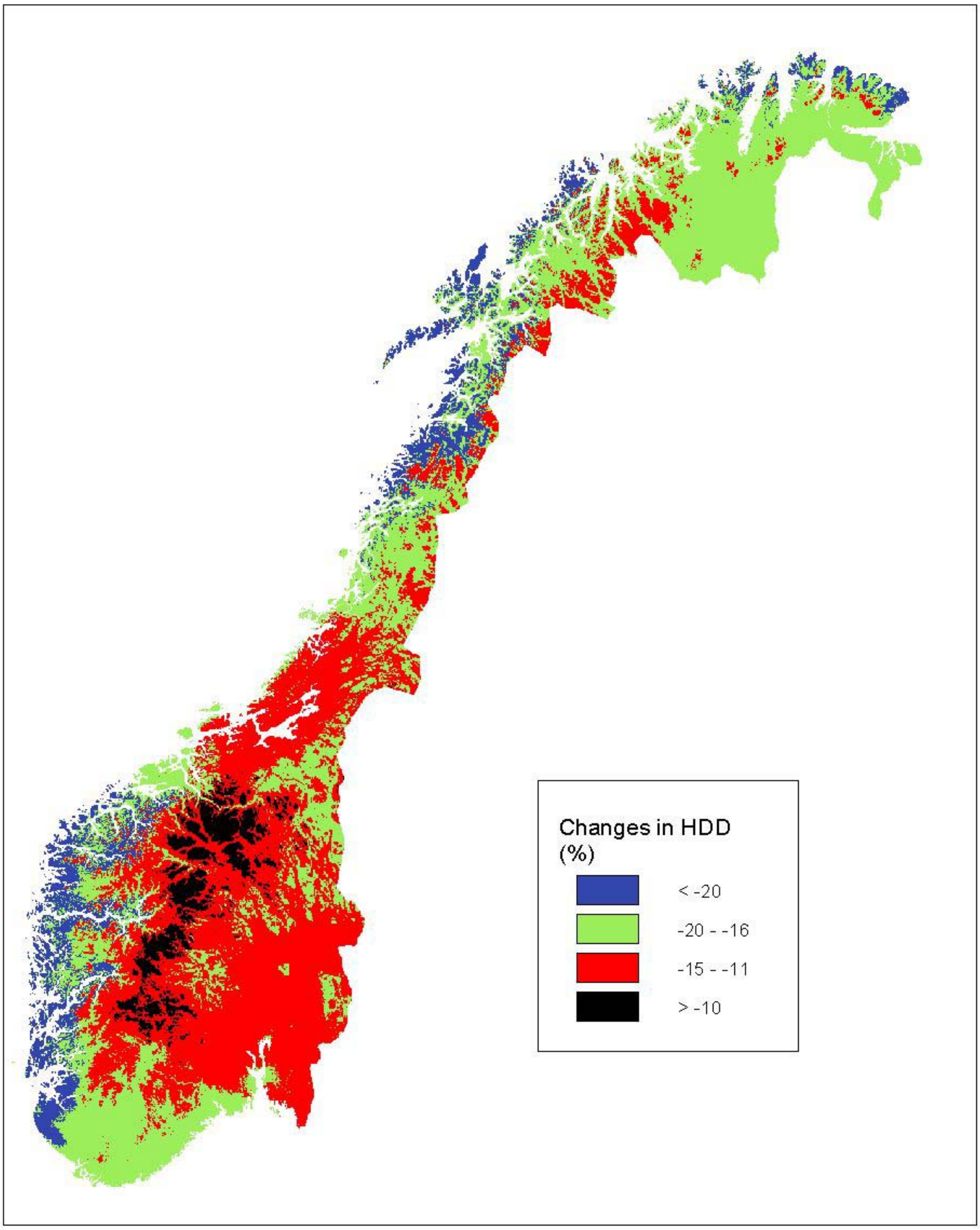

Figure 5.5 The spatial distribution of the changes of the HDD in the heating season between the scenario period (2021-2050) and the normal period (1961-1990) in percent.

6. Discussion and summary

6.1 Uncertainty considerations

The results of the study presented in this report are concerned with some uncertainties, e.g.:

1. Due to the criterion of at least 15 years of observations, we use less than half **the number of stations** to describe the twenty-year period compared to the normal period. For the scenario period, even less, only forty-six, temperature series are available. Therefore, parts of the variability in the spatial distribution of the heating season and the HDD may not be accounted for.
2. **Only one** AOGCM is used. Different AOGCMs project different temperature scenarios for Norway (Räisänen, 2001), however all models indicate a warming in Norway during the next 50-100 years.
3. There are uncertainties concerning **the empirical downscaling** method used.
4. In the end there are uncertainties concerning **the spatial interpolation method** used.

6.2 The heating season

The normal heating season (1961-1990) varies from less than 240 days in the coastal lowland up to 365 days in the high mountain areas and the northernmost part of Norway. The heating season ends over a longer period than it begins. The end of the season can be divided into two regions (three with the area where the heating season lasts for 365 days). In the first region, southern Norway with the lowland area around the Trondheimsfjord area, the heating season ends earlier than in the second area, the mountain area and the north of Norway.

The twenty-year period 1981-2000 show only minor changes in the heating season compared to the normal period. The heating season changed with only a few days, and for parts of the country it actually increased with just a few days. The changes were larger in the end than in the start of the heating season.

For the period 2021-2050 scenario show that the temperature will increase, and thereby result in a reduced heating season. The results show that the heating season will decrease with more than 40 days in the western part of the country and in the mountain area. In the coastal part of the southwestern area and the inner part of Finnmarksvidda, the heating season will decrease with between 20 and 40 days compared to the normal period. The smallest changes will occur in the southeastern part of Norway and in the Trondheimsfjord area were the heating season will be less than 20 days shorter.

The spatial distribution of the changes of the end of the heating season compared to the start of the season is less simultaneous in time. The end of the heating season can be divided into two separate regions, the first region is the lowland area in southern Norway where the season ends earlier than the second region, the mountain area and the northern Norway. A third region is the high mountain area where the heating season lasts through out the year.

6.3 The heating degree-days

The heating degree-days (HDD) in the heating season for the normal period varies from less than 4500 in the southern coastal area to more than 6000 in the high mountain area and in northern Norway.

The temperature during winter increased in the twenty-year period 1981-2000, and, even though the length of the heating season did not change much, the HDD decrease with up to 8 % compared to the normal period.

For the scenario period, the HDD decreased with more than 20 % at the west coast and the coastal area in Finnmark. In the eastern part of the country and the Trondheimfjord area, the scenarios indicates a reduction in HDD between 10 and 15 %. Finnmarksvidda will have a reduction in HDD of between 15-20 %. In the high mountain area in the southern Norway, the decrease is smallest, less than 10 %.

7. References

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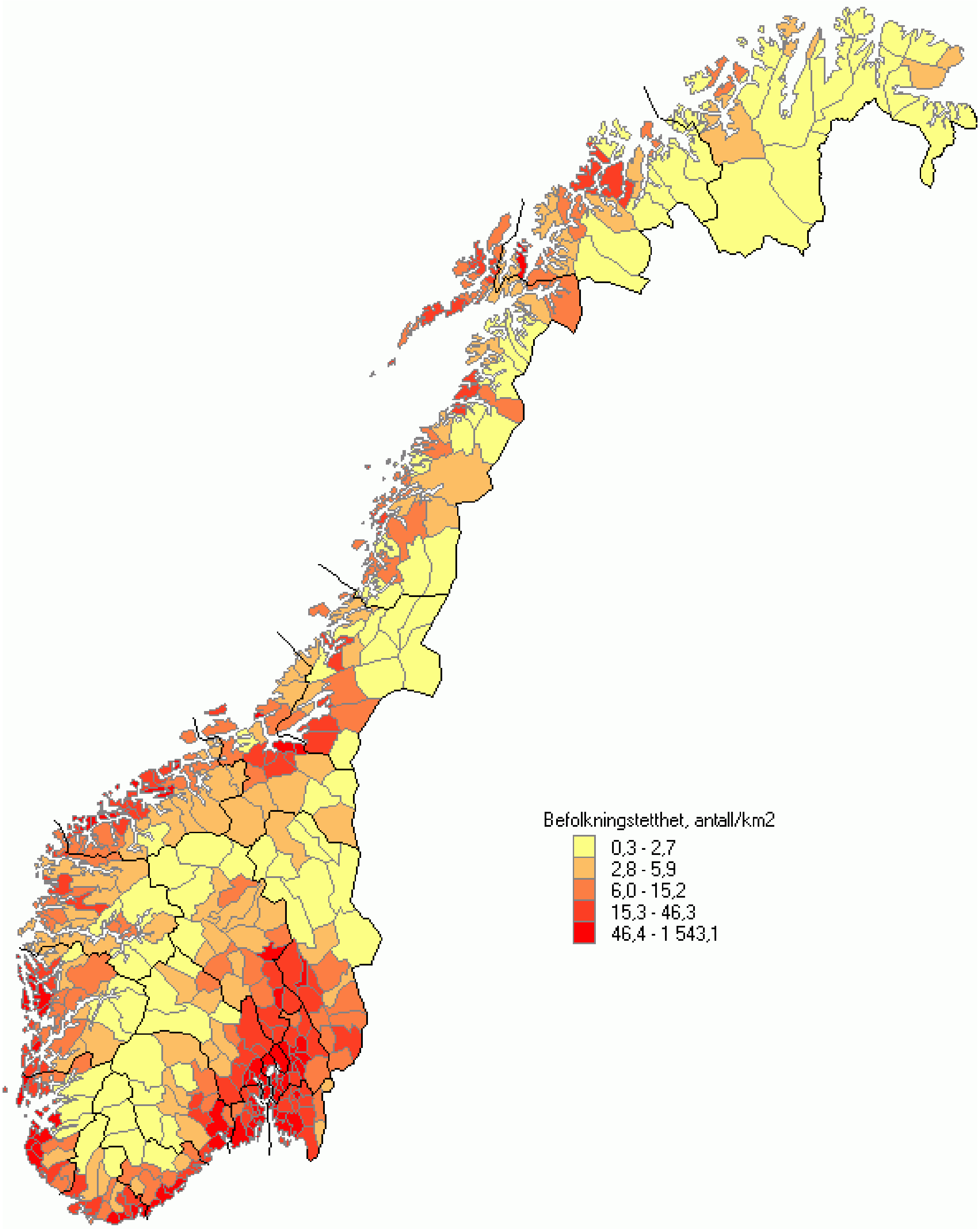
APPENDIX

Appendix A Population density in Norway



Population density (persons/km^2) in Norway in 1999. The map is downloaded from www.ssb.no.

Appendix B The start and end of the heating season in Norway

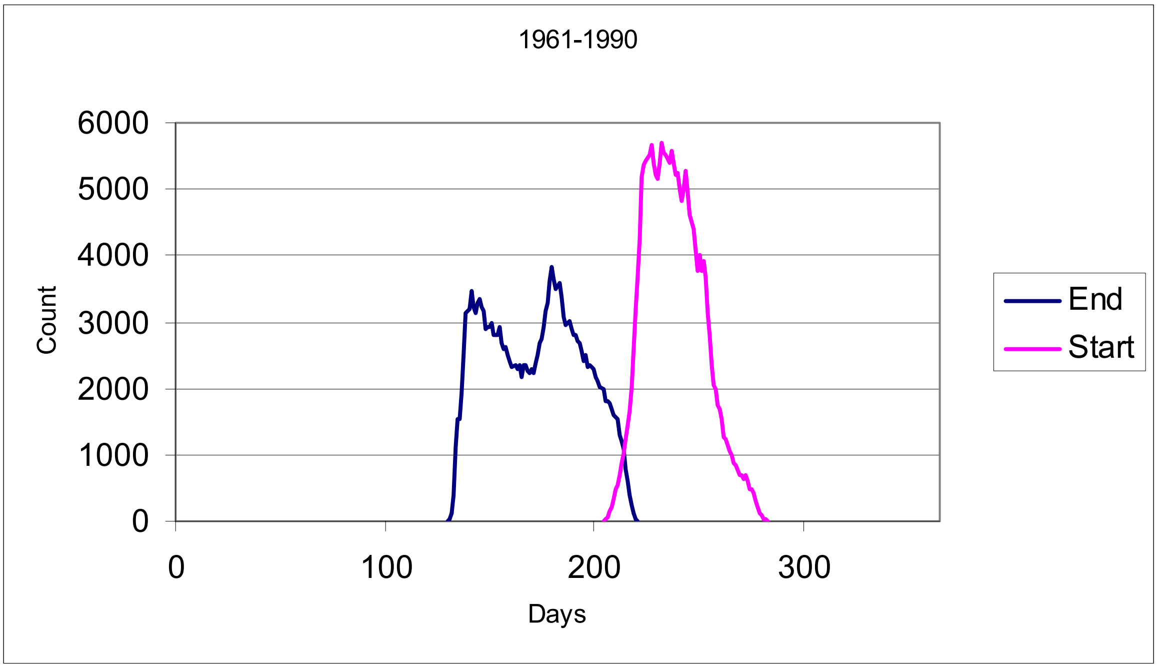


Figure 1 The histogram of the area distributed start and end of the heating season over Norway in the normal period (figure 4.2 and 4.3). (Count referrers to number of pixels (1 * 1km^2) in the grid.

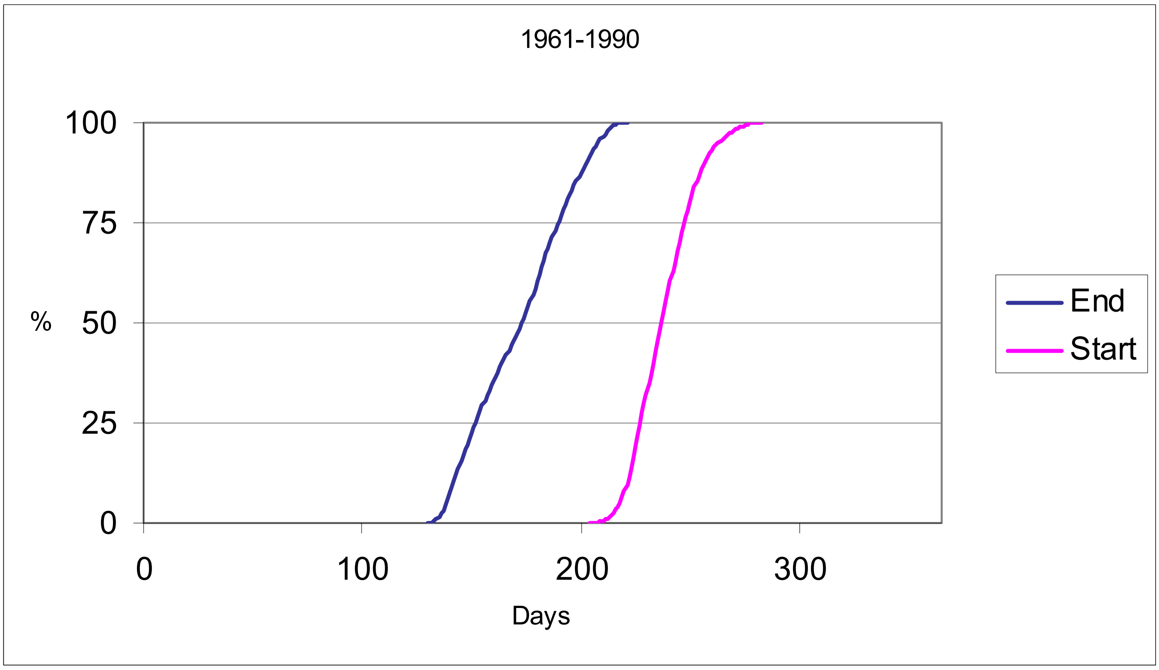


Figure 2 The cumulative frequency area distribution of the start and end of the heating season over Norway in the normal period (figure 4.2 and 4.3).

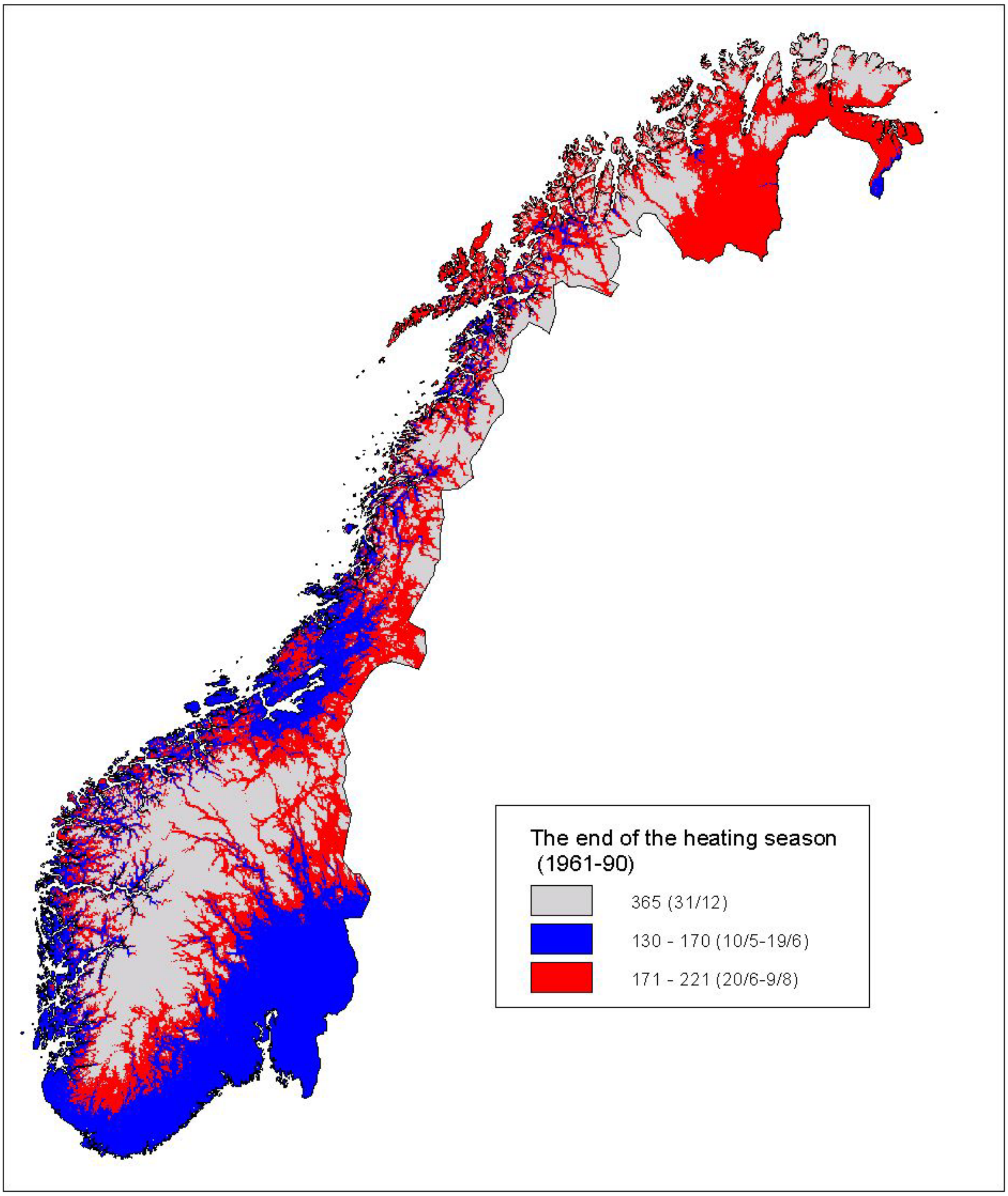


Figure 3 The three regions of the end of the heating season for the normal period. The regions are divided from the distribution of the histogram (App. D, figure 1).

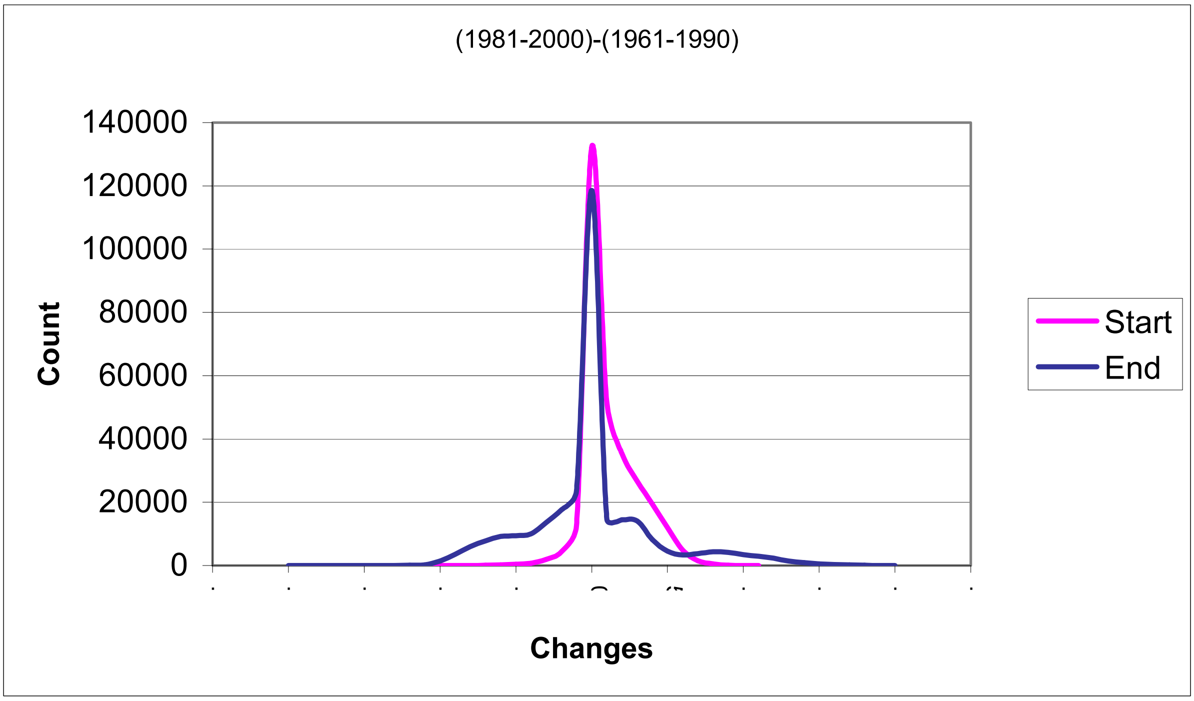


Figure 4 The histogram of the area-distributed anomalies in the start and end of the heating season over Norway in the twenty-year period 1981-2000 compared to the normal period (figure 4.2 and 4.3). The region where the heating season lasts 365 days is not shown in the diagram (Count referrers to number of pixels (1 * 1km^2) in the grid.

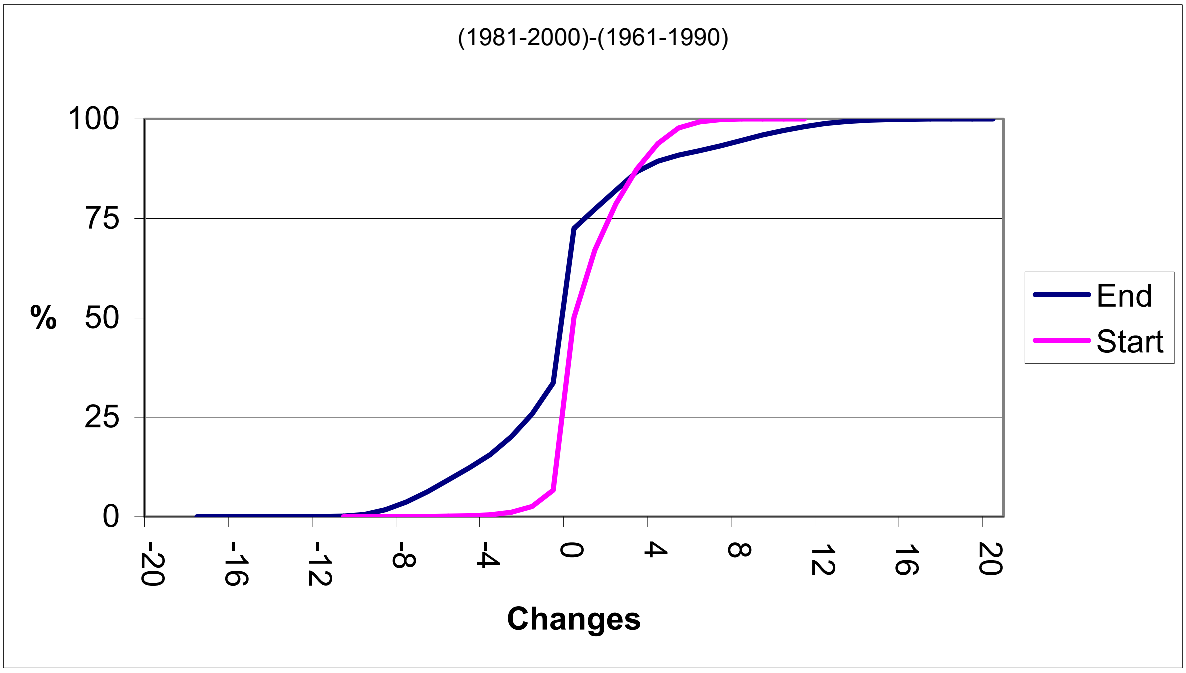


Figure 5 The cumulative frequency area-distributed anomalies in the start and end of the heating season over Norway in the twenty-year period 1981-2000 compared to the normal period (figure 4.2 and 4.3).

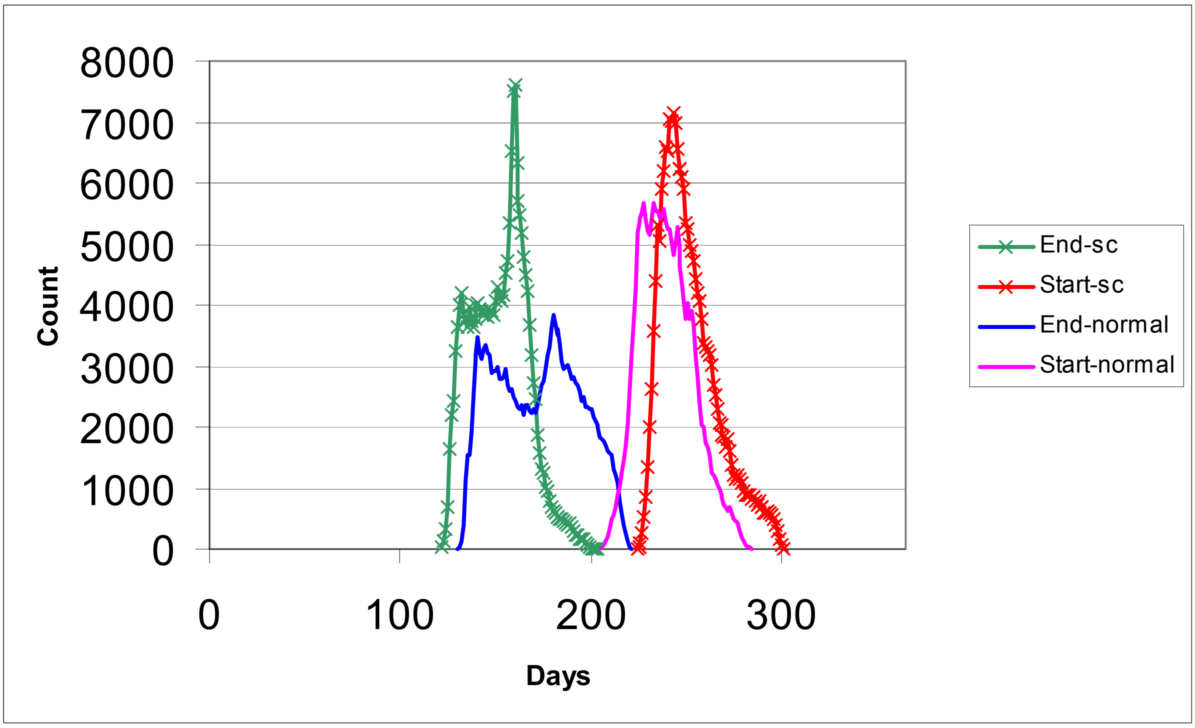


Figure 6 The histogram of the area distributed start and end of the heating season over Norway in the normal period (App. D, figure 1) together with the histogram of the area distributed start and end for the scenario period, 2021-2050. The region where the heating season lasts 365 days in the normal period is not shown in the diagram (Count referrers to number of pixels (1 * 1km^2) in the grid). 20% of the region that had heating season for 365 days is supposed to have a period without heating within the scenario period. This area is however not counted for in the histograms shown above.

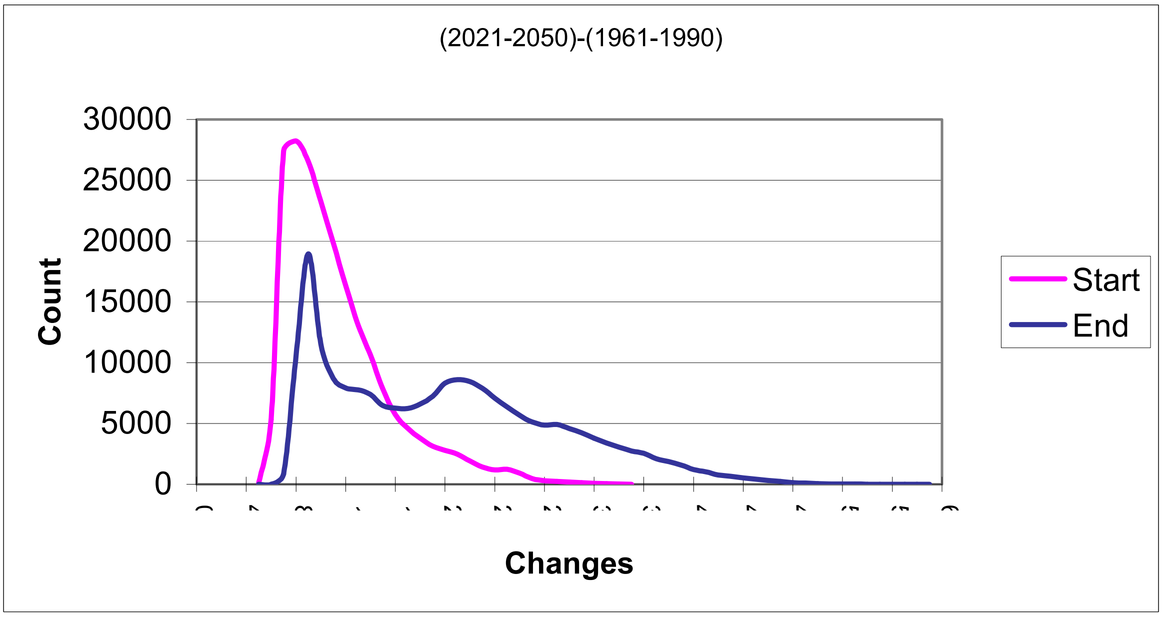


Figure 7 The histogram of the area-distributed anomalies in the start and end of the heating season over Norway in the scenario period 2021-2050 compared to the normal period (figure 4.10 and 4.11). (Count referrers to number of pixels (1 * 1km^2) in the grid.

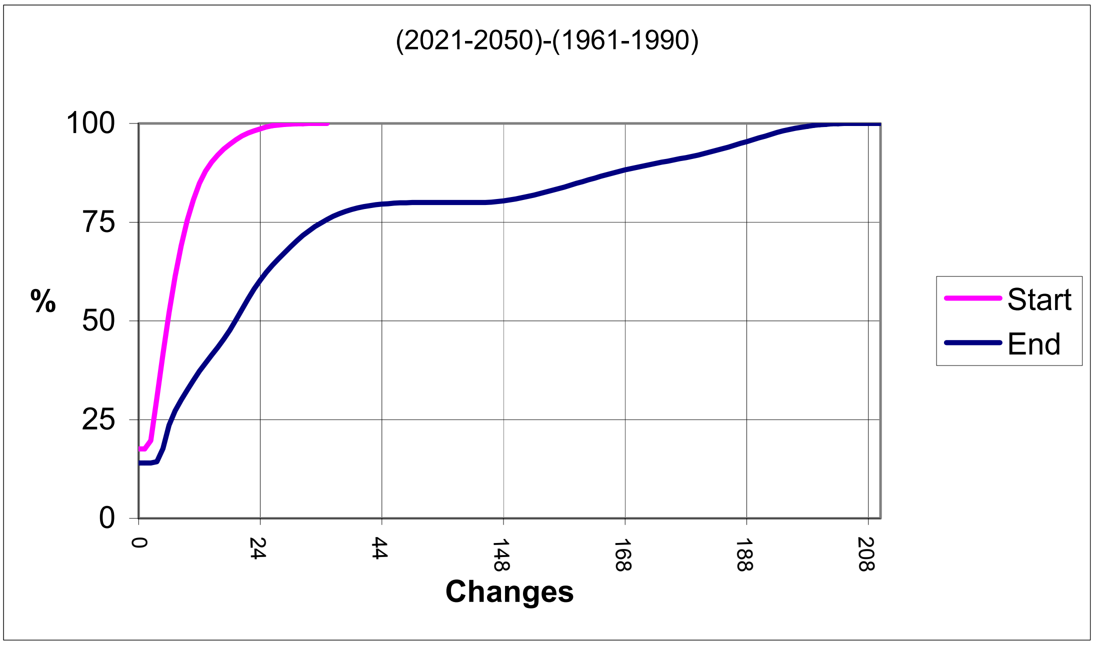


Figure 8 The cumulative frequency area-distributed anomalies in the start and end of the heating season over Norway in the scenario period 2021-2050 compared to the normal period (figure 4.10 and 4.11)

Appendix C Daily main temperature estimates for some selected locations

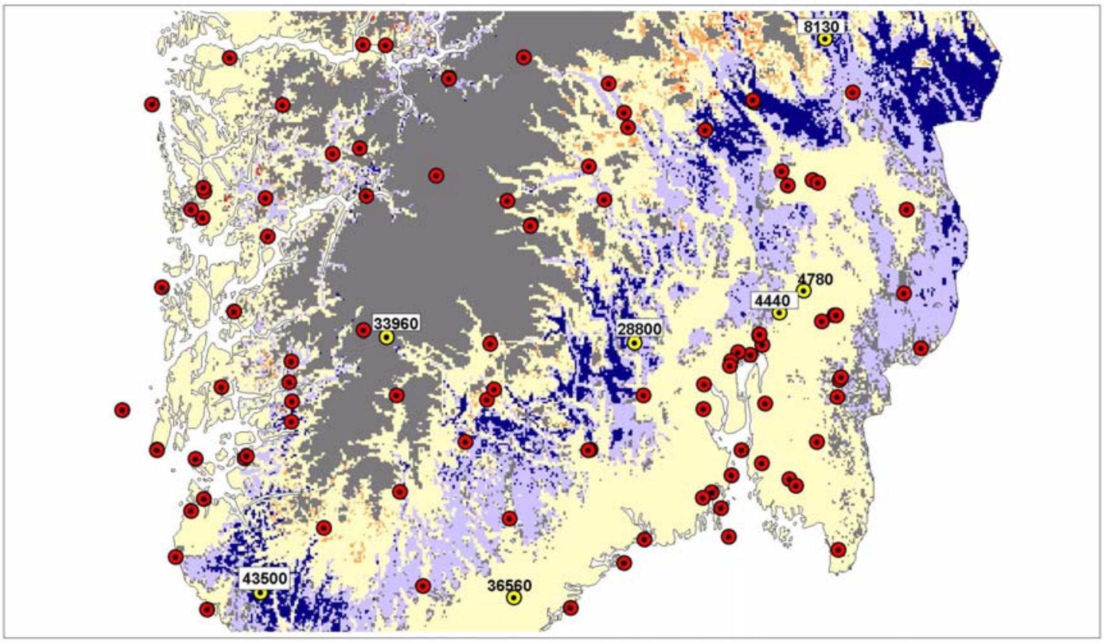


Figure 1 The sites of temperature stations in southern Norway on a extent of the spatially distributed map of the 1981-2000 period compared to the normal period (figure 4.5). The yellow dots indicate the selected stations.

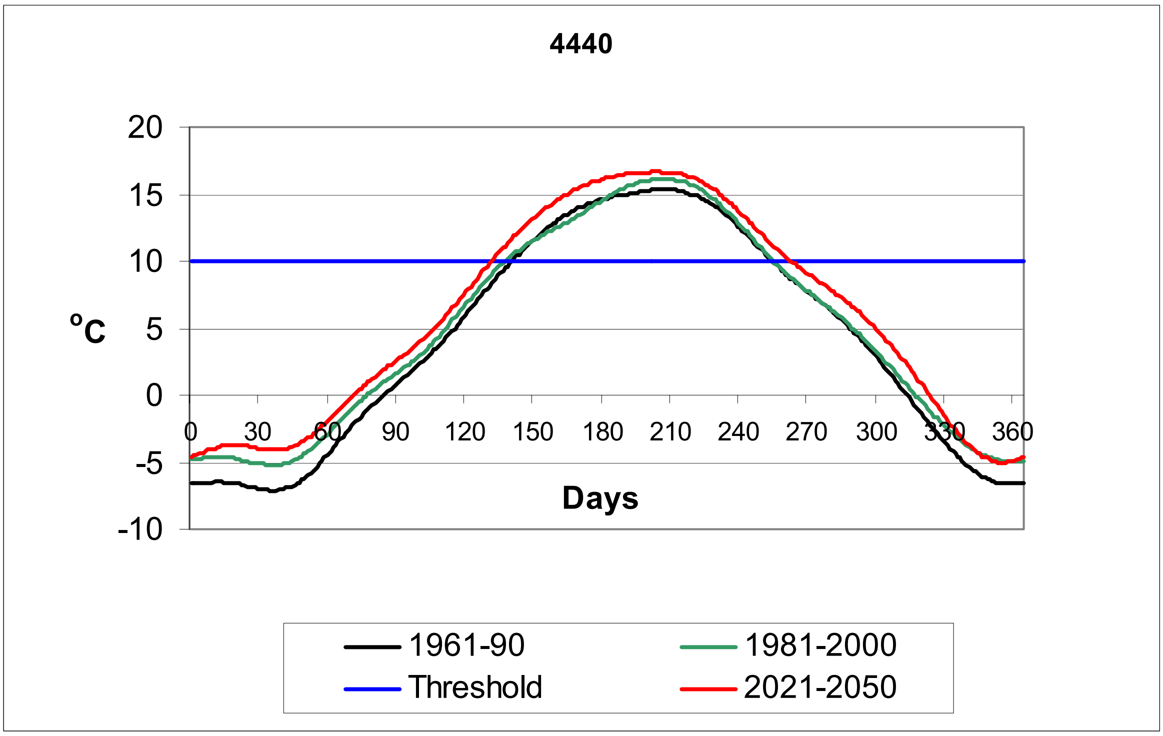


Figure 2 Estimated daily mean temperature at the observation station 4440 Hakadal for the normal period, the twenty-year period and the scenario period.

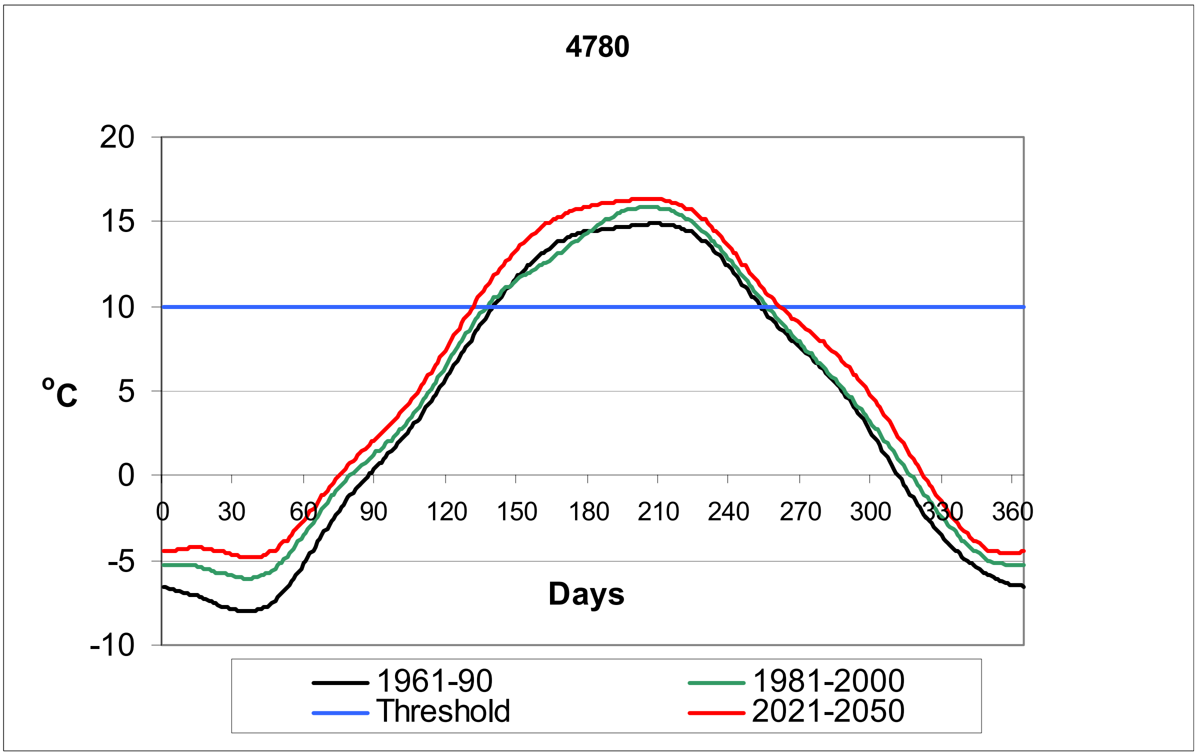


Figure 3 **Estimated daily mean temperature at the observation station 4780 Gardermoen for the normal period, the twenty-year period and the scenario period.**

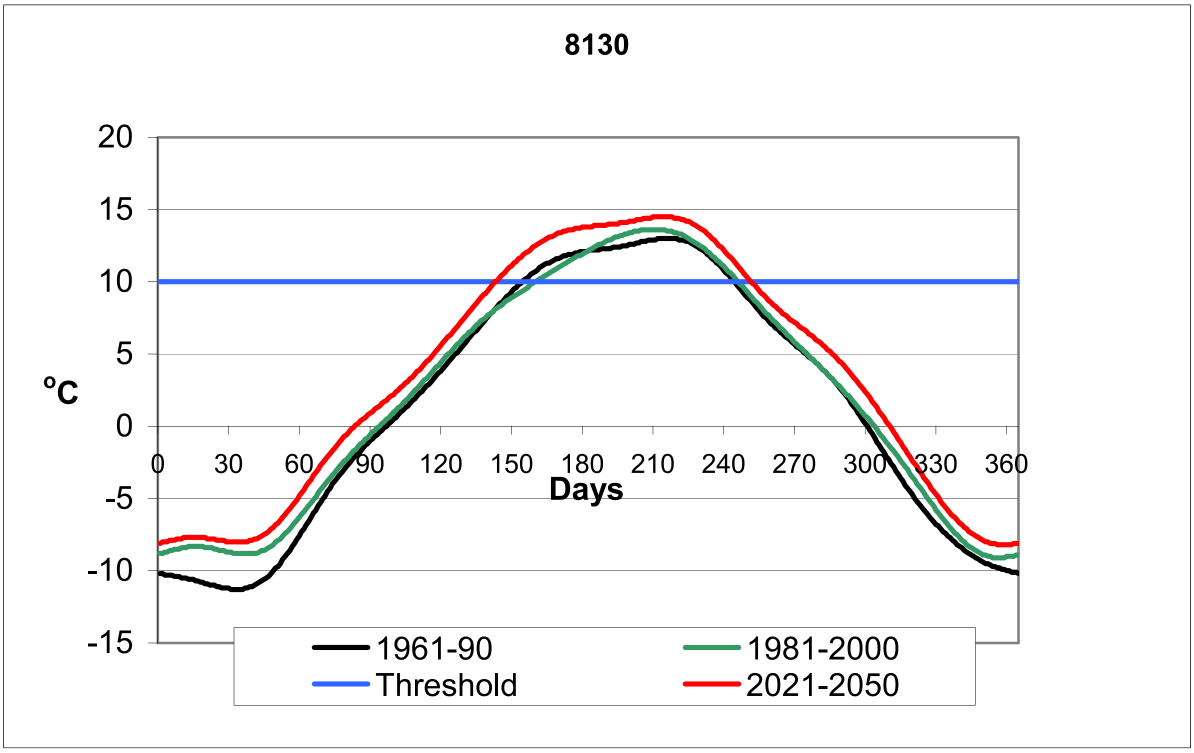


Figure 4 **Estimated daily mean temperature at the observation station 8130 Evenstad for the normal period, the twenty-year period and the scenario period.**

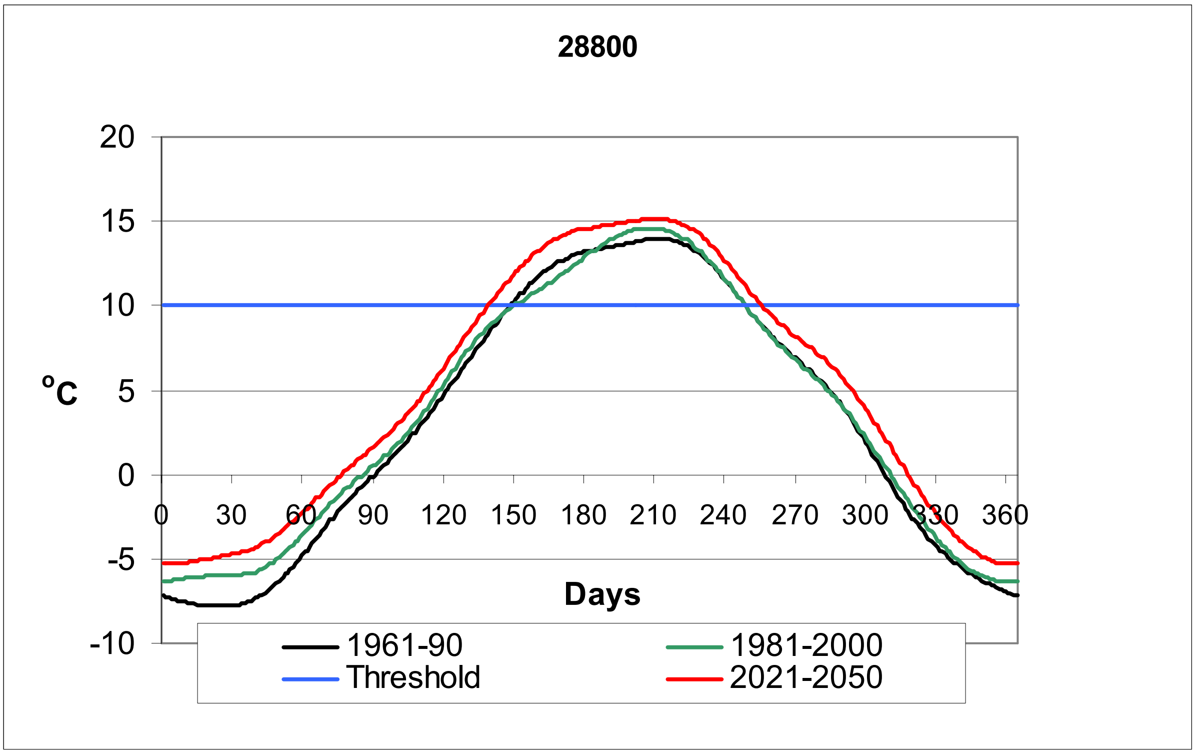


Figure 5 **Estimated daily mean temperature at the observation station 28800 Lyngdal I Nummedal for the normal period, the twenty-year period and the scenario period.**

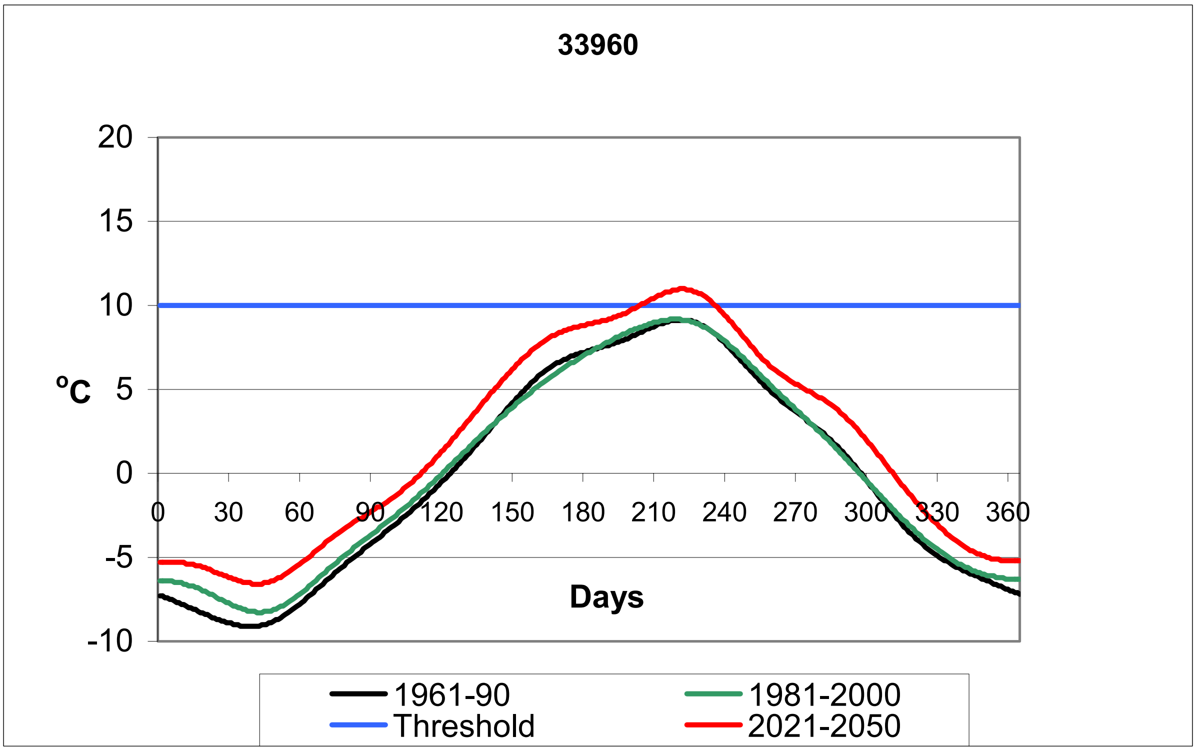


Figure 6 **Estimated daily mean temperature at the observation station 33960 Haukeliseter for the normal period, the twenty-year period and the scenario period.**

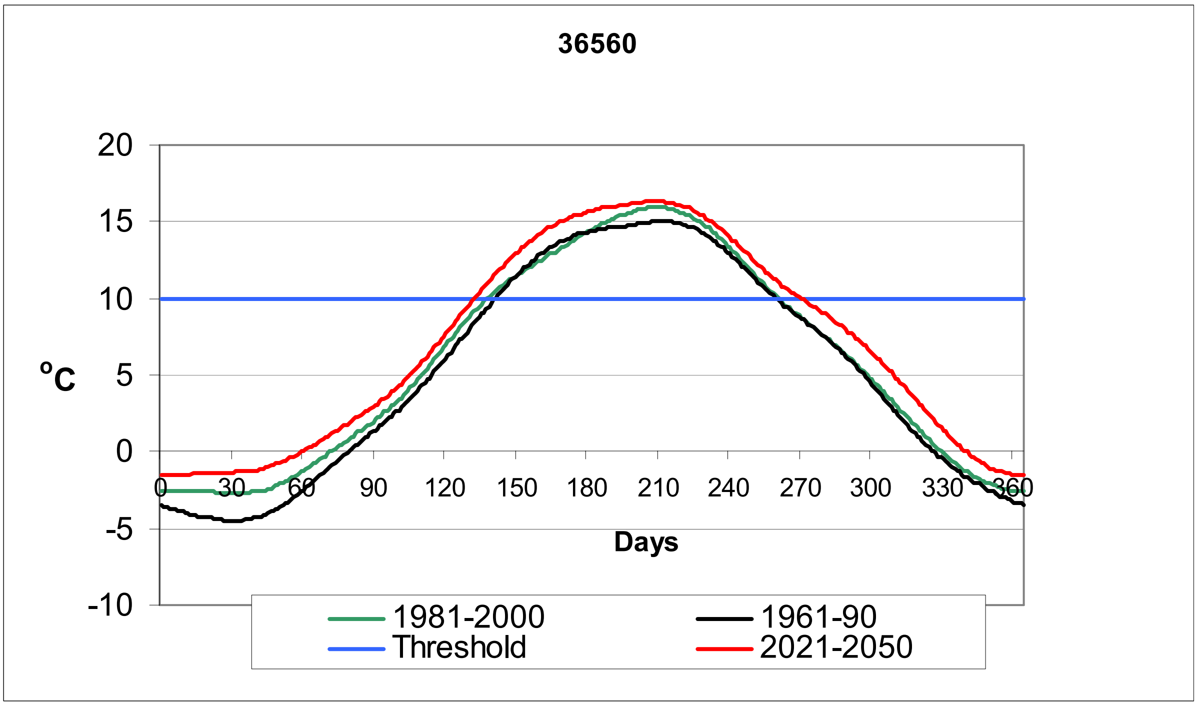


Figure 7 Estimated daily mean temperature at the observation station 36560 Nelaug for the normal period, the twenty-year period and the scenario period.

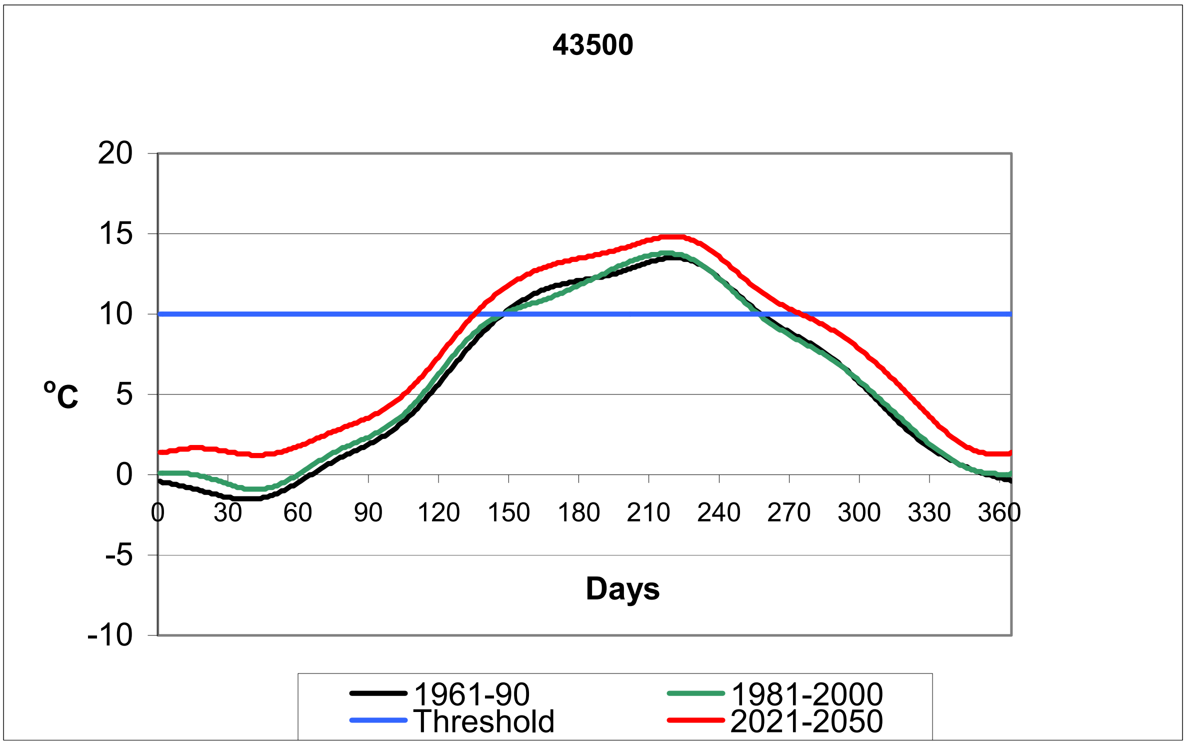


Figure 8 Estimated daily mean temperature at the observation station 43500 Ualand-Bjuland for the normal period, the twenty-year period and the scenario period.

Appendix D Area distribution of the HDD in Norway

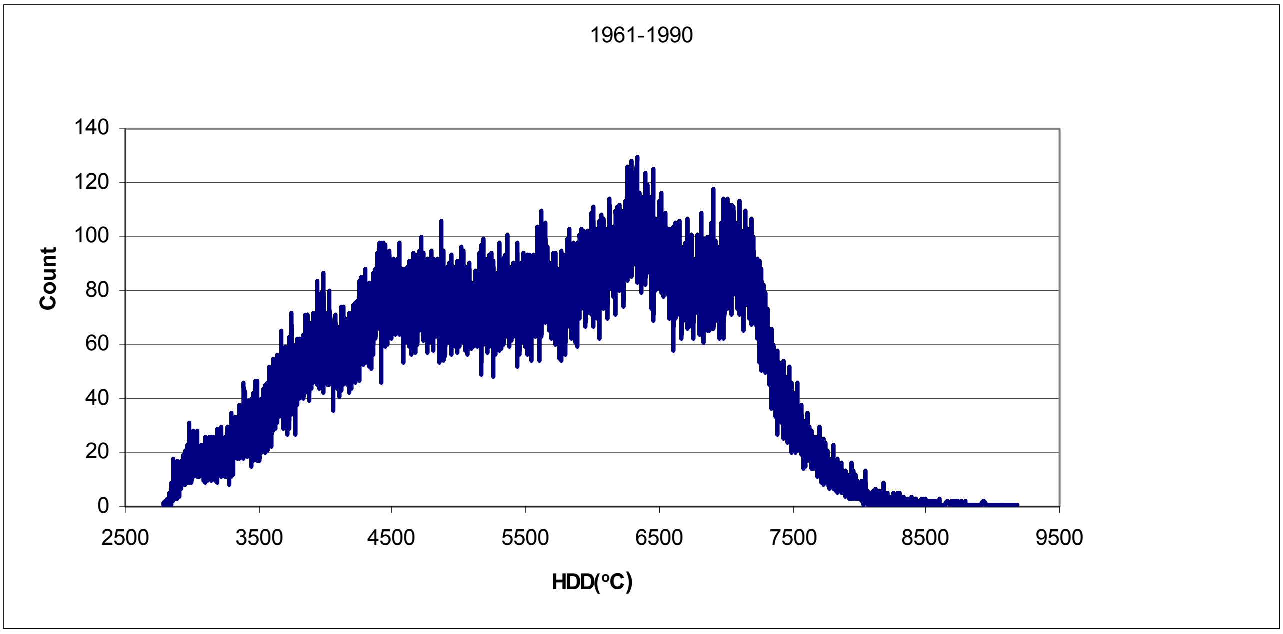


Figure 1 **Histogram of the area distribution of the HDD in Norway for the normal period.**

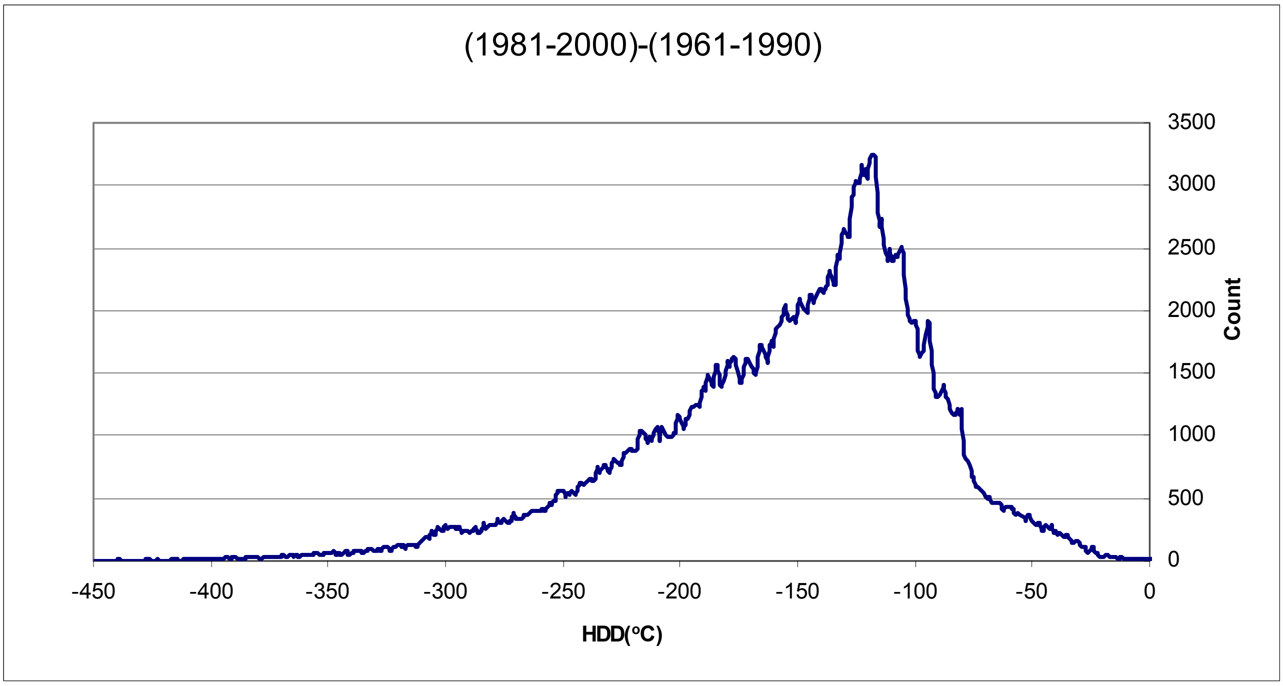


Figure 2 **Histogram of the area distribution of the changes in Norway for twenty-year period compared to the normal period.**

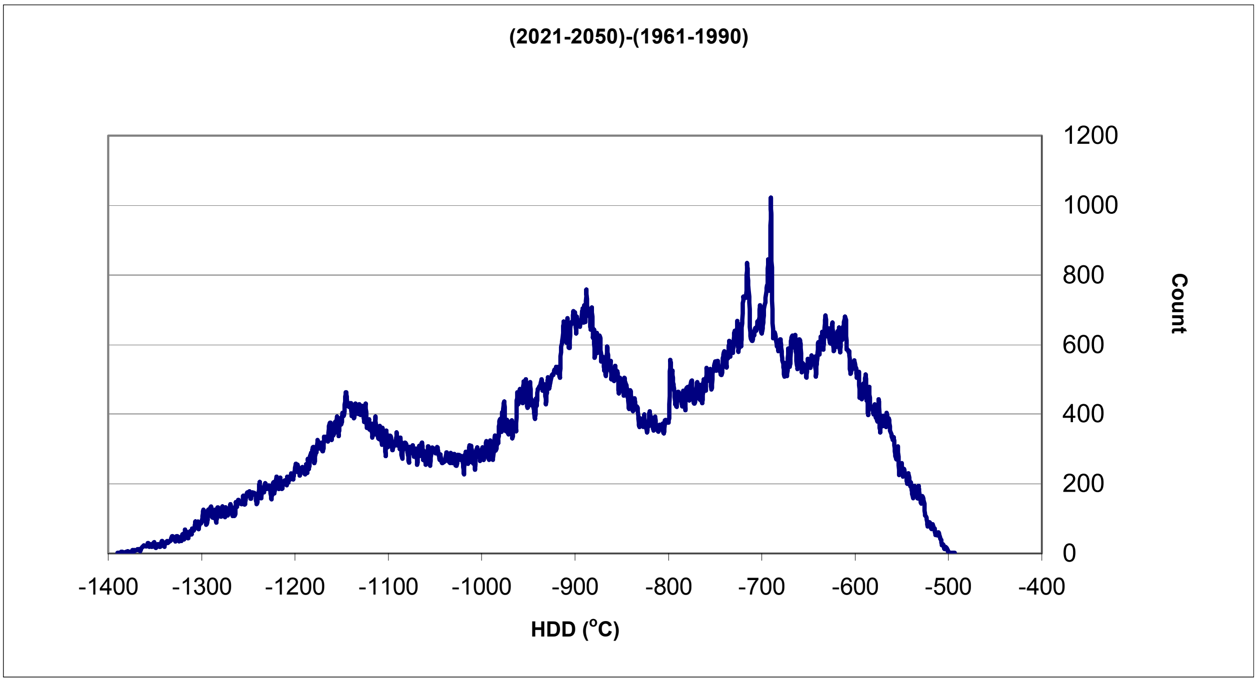


Figure 3 Histogram of the area distribution of the changes in Norway for scenario period compared to the normal period.