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

REPORT No. 02/02

T. E. Skaugen and O. E. Tveito

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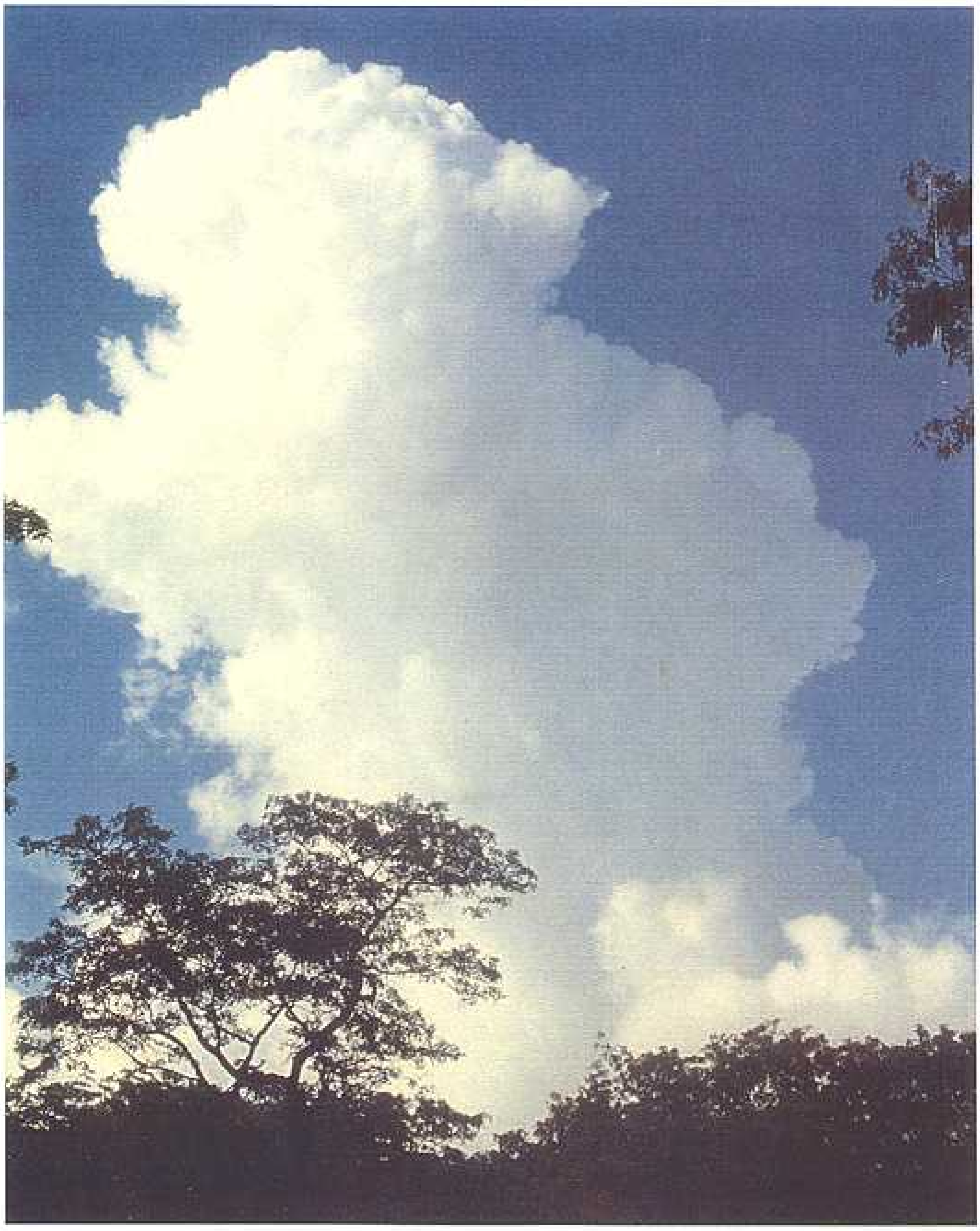

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Growing degree-days – Present conditions and scenario for the period 2021-2050

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SUMMARY:

This report presents a study of the change in the length of the growing season (GS) and the growing degree-days (GDD) in Norway due to temperature increase in Norway the last two decades (1981 – 2000), and expected temperature increase in the future (2021 - 2050) compared to the normal period (1961-1990).

Only minor differences in the length of the GS (<10%) and in the GDD value (<10%) for the last decades was found compared to the normal period, but overall the difference was positive. The minor changes are a consequence of that the temperature increase during last decades has been most prominent in wintertime when there was no defined GS.

The temperature is expected to increase in Norway during the next fifty years. Even though it is supposed to increase most in the wintertime, the expected temperature increase in the summertime (and spring and autumn) will lead to longer growing season all over the country. In Northern Norway the GDD will increase with between 30-100 % and at the coastal belt from Trondheimsfjorden to the Swedish boarder it will increase with up to 30 %. The GDD will increase with more than 100 % in the parts of the mountain area in Norway.

KEYWORDS:
Growing degree-days ((GDD), growing season (GS), temperature scenarios, Geographical information systems (GIS).

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1. Introduction

Growing season (GS) is the number of days from when the plants start to grow (BGS) in the spring until they end growing (EGS) in the autumn. Different crops grow at different time of the year, both because the air temperature differs with altitude, distance from the coast and with latitude, and because they react differently to the air temperature. Some crops are very sensitive to lower temperatures while others are resistant to colder climate. Longer GS can be beneficial for different crops, but may also lead to more insect and disease damage.

Many possible definitions of GS are available (Brinkman 1979). The number of days with daily mean air temperatures (2m) above a given threshold temperature is often used. The threshold temperature however differs with different plants. In this report, estimates of BGS, EGS and GS are based on thirty-year average of daily mean temperature. The temperature threshold used is 5 °C, which is the threshold temperature regarded as the growing season by the agricultural sector in Norway. This is because plant growth is insignificant at lower threshold temperatures (Aune, 1993; Carter, 1998; Gudem and Hovland, 1999).

Rötzer and Chmielewski (2001) used observations of average date of leaf unfolding of four different crops for mapping the length of GS in Europe. For the end of GS, the average dates of leaf fall of the same crops are used. The difference between the end and beginning defines the length of GS. A linear regression model is fitted to the observations to get an estimate of the GS when latitude, longitude and altitude are given. Rötzer and Chmielewski (2001) chose this phenophases because long time series with observation could be provided by International Phenological Gardens (IPGs) in Europe, and the fact that most vegetation becomes green and finishes growing in this period. The IPGs in Europe has genetically identical clones of trees and shrubs (Menzel and Fabian, 1999). However, only three locations of these IPGs, used by Rötzer and Chmielewski (2001), are located in Norway, which is a rather sparse basis of data. These are situated in Oslo, Trondheim and Bergen.

The temperature sum during the growing season, growing degree-days sum (GDD), is defined as the accumulated sum of ^{o}C between the daily mean temperature and a threshold temperature (5^{o}C) (Gudem and Hovland, 1999). Because the air temperature varies in space with altitude, latitude and distance from the coast, GDD decreases with the same parameters.

GDD is a good estimate on accumulated heat and is therefore a useful index of energy available for biological growth. Especially is this useful indication for growth potential in areas where temperature is a minimum factor such as Norway (Gudem and Hovland, 1999).

Annual temperatures 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 (Hanssen-Bauer and Nordli, 1998). After a period with decreasing temperatures from the 1930s, the annual temperature has increased in all parts of Norway since 1980. Førland et al. (2000) showed that the temperature in Norway increased during the last two decades (1980-1999) compared to the normal period. Climate change scenarios for Norway indicate that the tendency of increasing temperature will continue in the next decades (Hanssen-Bauer et al., 2000).

The aim of this report was to use one temperature scenario (Hanssen-Bauer et al., 2000) on the algorithms for GS and GDD to give an indication of how these parameters will change compared to the normal period 1961-1990. The influence in GS and GDD due to temperature increase in the last two decades of the twentieth century compared to the normal period is studied as well.

Temperature data used in the study are presented in chapter two. The methods used are presented in chapter three. The growing 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 four. The GDD is estimated for the same time periods, the results are presented in chapter five. A summary of the study is presented in chapter six.

Only one temperature scenario is used to establish BGS, EGS, GS and GDD. Obviously there are uncertainties concerning the BGS, EGS, GS and GDD scenarios. Some uncertainty considerations are therefore also given in chapter six.

2. Data

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 by 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[1)] (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 used (Tveito et al., 2000). For the twenty-year period, temperature stations with time series of more than 15 years are used (127-136 stations [2)]). 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 Arctic. The locations of the forty-six temperature stations on the Norwegian mainland 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

[2)] 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.

[1)]*Coupled atmospheric-ocean global general circulation models*

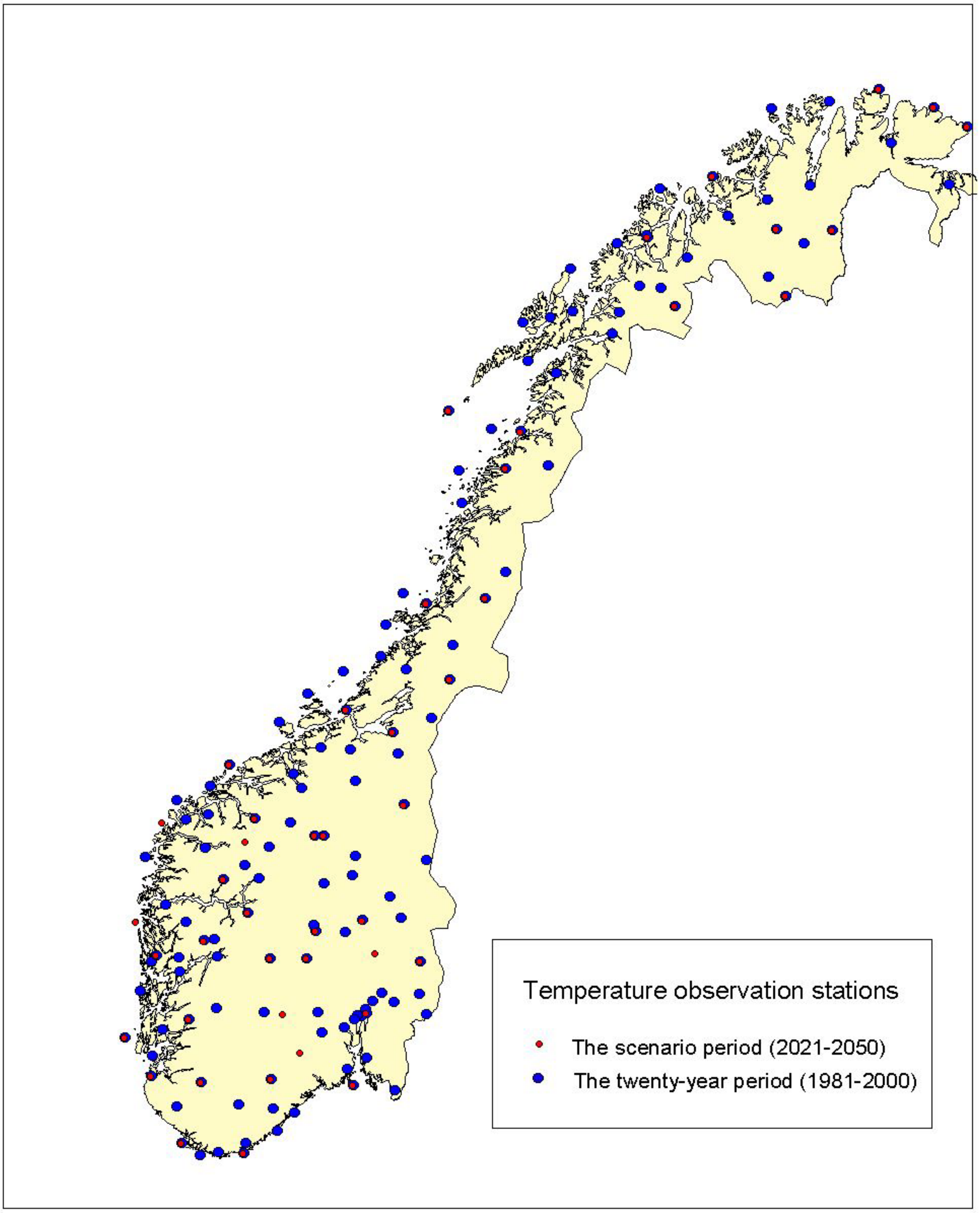

Figure 2.1 ***Temperature observation stations used for the twenty-year period 1981-2000 and for scenario period 2021-2050. The temperature observation stations used for the normal period are presented in Tveito et al. (2000).***

3. Methods

3.1 Estimation of daily mean temperature from monthly mean temperature.

To be able to estimate the growing season and the GDD, daily mean temperatures for the actual time period studied must be available. For historical time periods, such values can be obtained using the observed daily values. For the empirical downscaled scenarios of the future climate, only mean monthly temperature estimates are available. It is 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 not exceeds 0.001 ^{o}C, defined as the tolerancecriterion. 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. The method is used for the historical periods as well as for the scenario period.

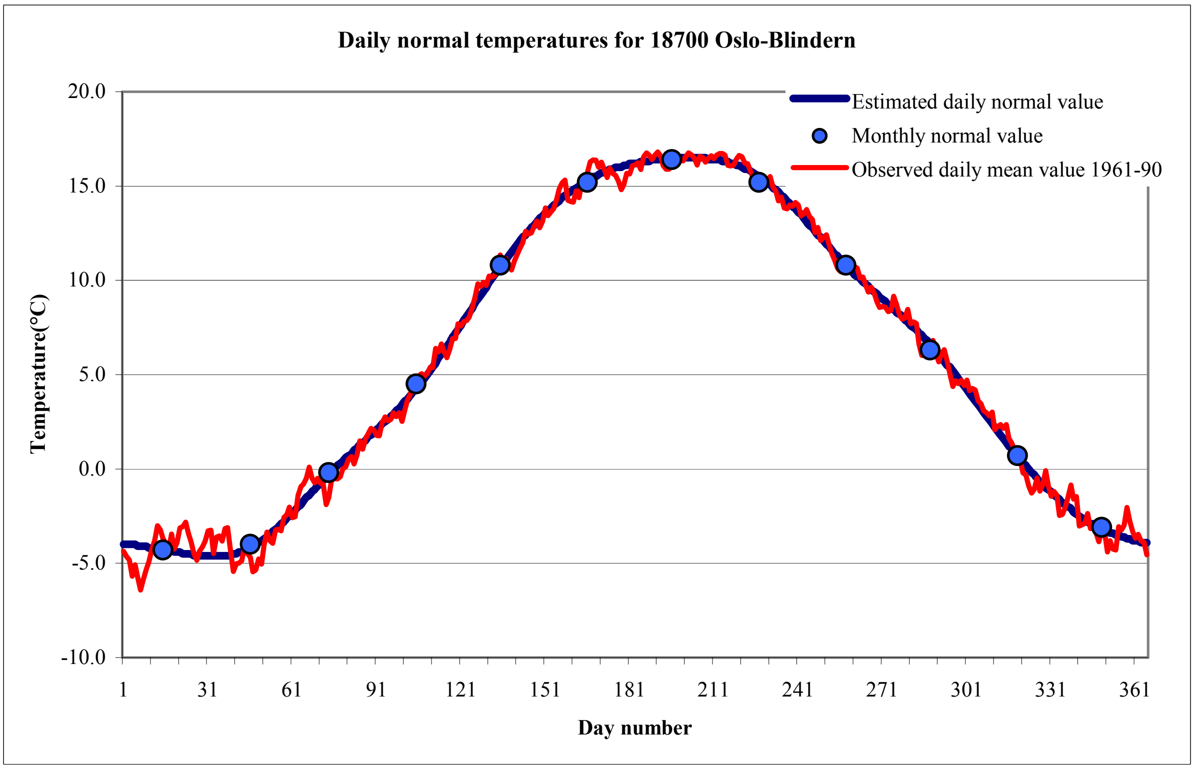

Figure 3.1 ***Observed daily mean temperature, estimated daily mean temperature and mean monthly temperature at 18700 Oslo – Blindern during 1961-90 (from Tveito et al., 2001).***

3.2 Spatial interpolation of temperature observations

Mean monthly temperature maps are established for the recent normal period (1961-1990) for Fennoscandia by Tveito et al. (2000). The maps are obtained by using the stochastic interpolation method residual kriging. The grid resolution is 1 x 1 km^2.

Interpolation of absolute temperature values is difficult due to sparse station density and large variability over short distances. This is in conflict with 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 topography is removed, and more robust estimates are obtained compared to interpolation of absolute temperature values.

Monthly 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 Calculating the length of growing season and the growing degree-days

GS is the period of the year when the daily mean temperature is above 5 °C (Aune, 1993). For each grid cell in the temperature map, a smoothed curve of daily mean temperatures is established based on the twelve mean monthly values (section 3.1). The beginning (BGS), end (EGS) and the length of GS can therefore be calculated for each cell in the grid.

The growing degree-days (GDD) are defined as the accumulated degree sum above a defined reference temperature (Gudem and Hovland, 1999). Mathematically this can be expressed throughout the whole year (or within a defined season) as:

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

$$GDD = 0, T_i < \hat{T}$$

where T_i is the daily normal temperature for day number *i,* $\hat{T}$ is the threshold temperature.

4. Growing season (GS)

4.1 The normal period 1961-1990

The length, start (BGS) and end (EGS) of the GS are calculated for the normal period (1961-1990) for Norway (Figure 4.1- 4.3). This is done as described in section 3.3 with the temperature data presented in chapter 2.

The duration of the GS decreases with altitude (m a. s. l.) and latitude in accordance with the temperature gradient (Figure 4.1). In the northern part of Norway, the duration of GS for the normal period varied between 50 – 150 days. In a large part of Finnmark, the GS lasted between 100-125 days (yellow area in figure 4.1). For the rest of Finnmark the GS lasted less than 100 days. In the coastal area from the Trondheimsfjord area to Lofoten, it lasted up to 150 days. In this area the length of the GS decreased towards the mountainous area in the east. In the coastal area in the southwestern and southeastern part of Norway from the Swedish border to the Trondheimsfjord area, the GS lasted between 150 and 200 days. Only a narrow zone at the southwestern coast had values exceeding 200 days. In large parts of the mountain area in southern Norway, the GS lasted between 100-150 days. The area where the GS was shortest, less than 50 days, was the high mountain area in the western part of Norway. Only 1436 km^2 in the high mountain area in the western part of Norway had no defined GS in the normal period (light blue area in Figure 4.1) (Appendix A, Table 1).

The spatial distribution of BGS in the normal period is presented in Figure 4.2. The GS in the blue area in the figure had the earliest start, from April 11. to May 5. This area is the coastal belt from the Swedish border to the Trondheimfjord area. In a belt from the mountain area in the south, the Lofoten area and parts of Finnmark, BGS was from May 6. to June 2. (the green area in the figure). In the high mountain area and in the northern part of Norway, BGS started from June 3 until the end of June (the red area in the figure). The pink area in the figure represents the part of Norway where the daily mean air temperature raised above 5 ^{o}C late in the summer, from July to August. The white area in figure 4.2 represents the area that had no defined GS.

BGS is presented as histogram in Appendix A, Figure 1. The histogram shows that in the normal period, BGS was ranging in an interval from day number 101 (11/4) to day number 227 (15/8), a period of more than 120 days. Two marked peaks are shown in the histogram. These are from the earliest start (April 11., day number 101) to May 18 (day number 138), which coincides with the blue, and parts of the green area in figure 4.2. The second peak represents the rest of the green area and the red area in figure 4.2, in this area the GS begins within a shorter time period. The tail of the histogram shows that the GS began late, July – August (day number 182 - 227), at minor areas, this represents the pink area in figure 4.2.

The spatial distribution of EGS in the normal period is shown in Figure 4.3. The red region in figure 4.3 ended over a period from day number 205 (24/7) to 260 (17/9). This area had the shortest GS in the country and corresponds to the area that had the latest BGS. The high mountain area and a belt in the northern Norway, ended during September-October over a period from day number 261 (18/9) to day number 286 (13/10) (green area in the figure). In the coastal area from the Swedish border to the Trondheimsfjord area, the GS ends latest over a period from the middle of October (14/10) to late in November (29/11) (day number 287-333). This is the blue area in figure 4.3.

The spatial distribution of the end of the growing season is also shown as histogram in Appendix A, figure 1. The first peak in the histogram refers to the red and green area. The last peak refers to the area that had the longest growing season (figure 4.1), the blue area in figure 4.3.

As can be seen from the histogram, there are some areas where the GS ends when it starts some other place and vice versa. These are the very small areas where the GS is shortest. In the Nordland county there area a few areas where the daily mean temperature rise above 5 ^{o}C at day number 197 (16/7) and falls below this threshold temperature at day number 210 (29/7). In the high mountains in southern Norway, the first day with temperature above the threshold is day number 225 (13/8) and it falls below at day number 228 (16/8). These are the areas with hardly no GS at all, these areas is shown at the end of the tail of the BGS-histogram and at the very fist part of the EGS-histogram (Appendix A, figure 1).

BGS and EGS are presented as cumulative frequency curves in Appendix A, figure 5. The curves show that the beginning of GS started over a period from day number 100 (10/4), and most of the total area (90%) had its start before day number 170 (19/6), a period of ca 70 days. The curves show as well that nearly the whole country (96.6 %) had a start of the GS after day number 190 (9/7). Only a very small amount of the country (0.4%) had EGS before day number 230 (18/8).

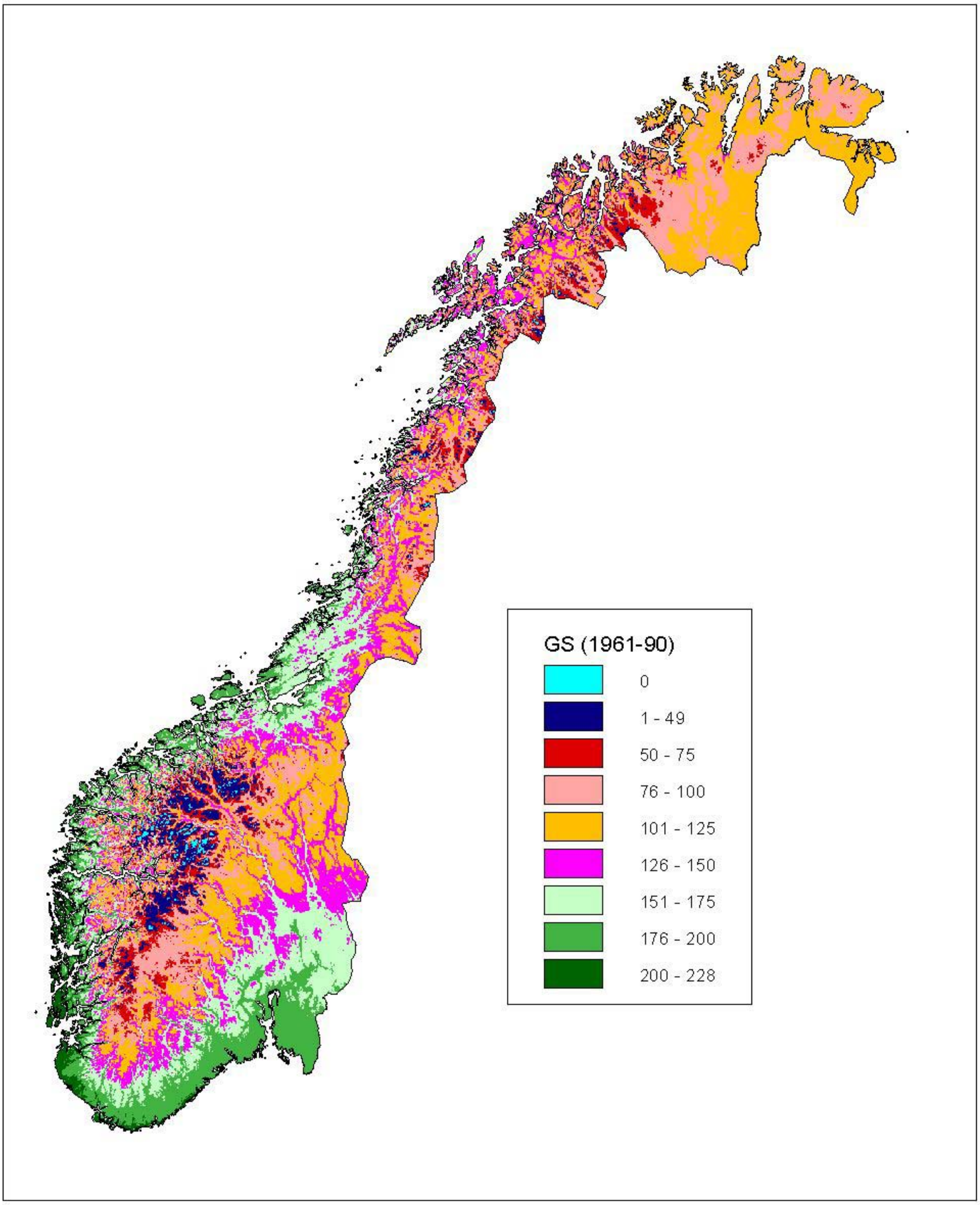

Figure 4.1 The length of the growing season for the normal period 1961-1990.

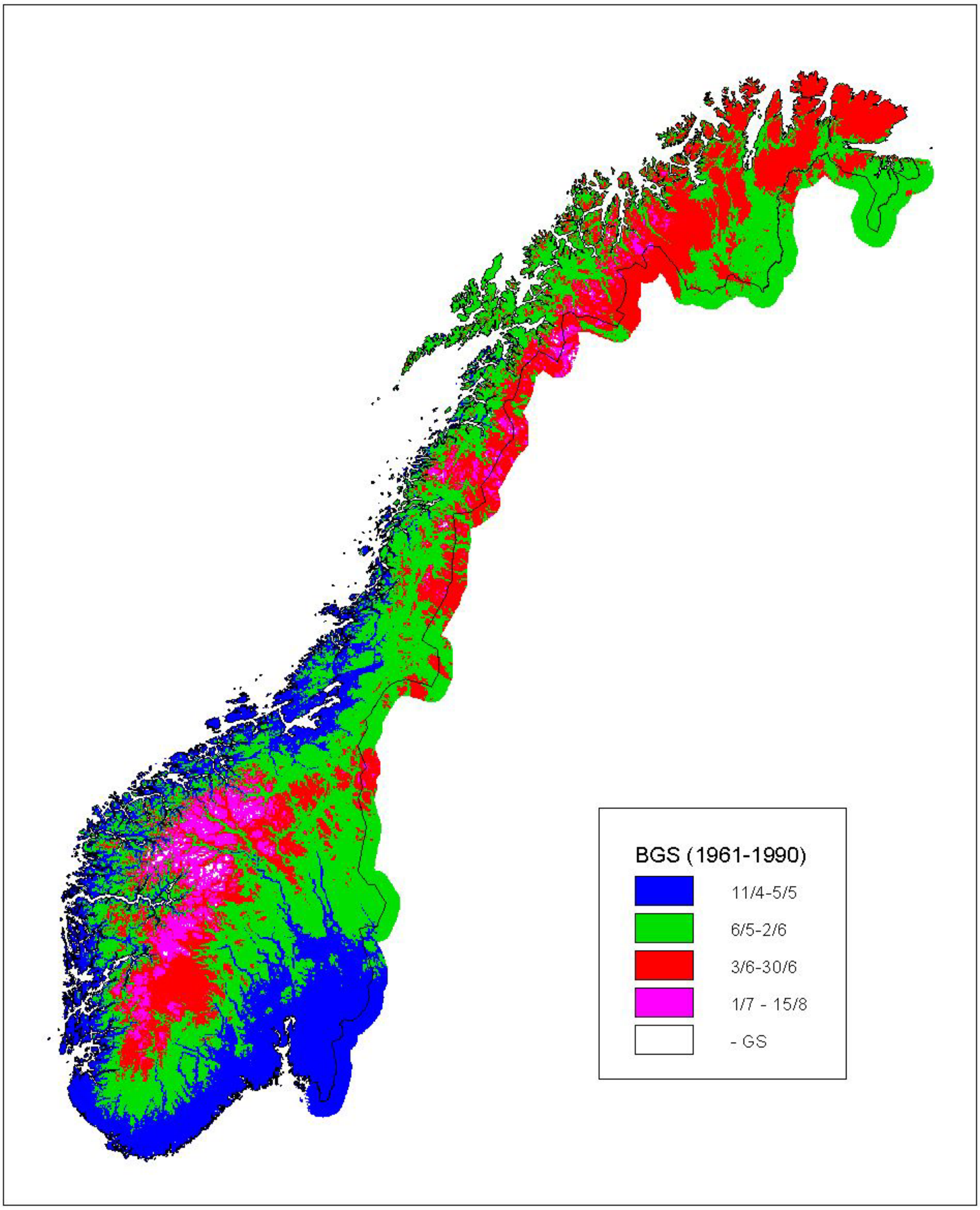

Figure 4.2 The beginning of the growing season for the normal period 1961-1990.

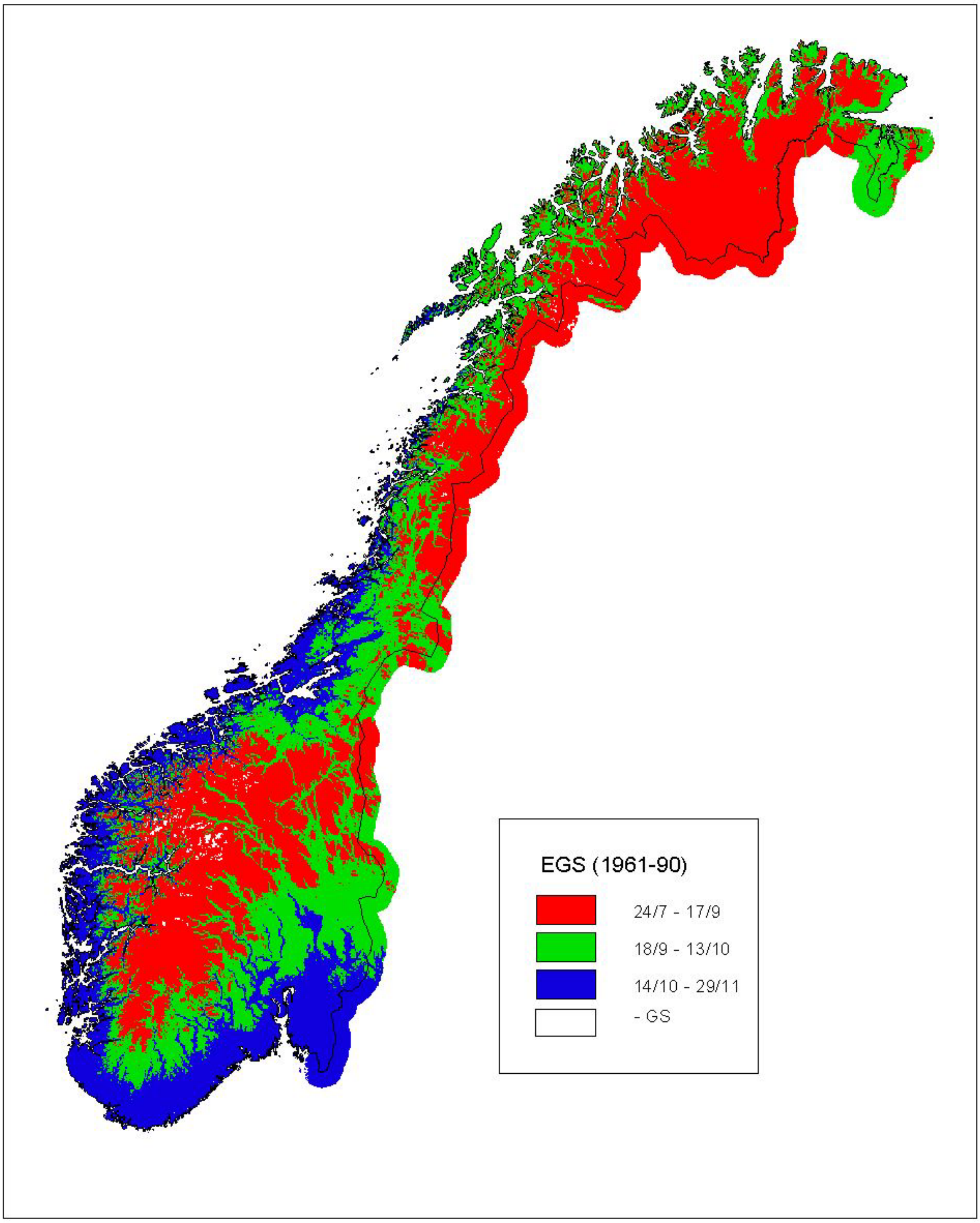

Figure 4.3 The end of the growing season for the normal period 1961-1990.

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

Differences in length, start (BGS) and end (EGS) of GS between the twenty-year period (1981-2000) and the last normal period area presented in Figure 4.4-4.6

There was only a few days difference in the length of the GS in the twenty-year period compared to the normal period (Figure 4.4). In the southcoast area, the southeastern part of the country and the Trondheimfjord area, the average length of the GS lasted up to 5 days longer for the last twenty-year period. In the eastern part of Finnmark and the coastal area of northern Norway the same difference were found (less than 5 days). Only small areas had an increase in the GS with more than 5 days. However, there is a rather large area of Norway where the GS was shorter (less than 5 days) compared to the normal period (blue area in figure 4.4).

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 GS in the mountain areas and in northern Norway, 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 B. The location of the stations chosen is shown in Appendix B, Figure 1 (yellow dots). The daily mean temperatures for the three different periods and with the threshold temperature 5 ^{o}C are shown in Appendix B, Figures 2-4. The figures show that the winter temperature (December, January and February) increased at all the selected stations in the twenty-year period (1981-2000) compared to the normal period. This is in accordance with Figure 4.7. The station 33960 Haukeliseter (Appendix B Figure 3) is situated in the blue area, which means that the length of the GS decreased compared to the reference period. The figure show that the daily mean temperature curve rose above 5 °C only a few days later compared to the normal period, thus the GS started a day or two later. The delay in the start was larger than the delay in the end, so the total length of the GS for the station 33960 was a few days shorter compared to the normal period. The station 06040 Flisa (Appendix B, figure 3) is situated in the yellow area, which means that the growing season increased with a few days (<5 days) in the twenty-year period (1981-2000) compared to the normal period. The figure shows that the temperature rose above 5 °C a few days earlier compared to the reference period where there was no change in EGS. The station 43500 Ualand-Bjuland (Appendix B, figure 4) is also situated in the yellow area. The figure shows that the temperature rose above 5 °C a few days earlier in the spring in the twenty-year period (1981-2000) compared to the normal period. There are only minor changes in the end of the growing season.

The timing of BGS did not change markedly (Figure 4.5). Most of the difference was within +- 5 days. The blue areas in the figure indicate that the BGS started earlier. The area-distributed differences in BGS are also presented as histogram in Appendix A, figure 2. There are two peaks in the histogram. The peak to the right refers to the red, and parts of the blue area in figure 4.5, where the difference in the BGS was between –1 – 4 days. The tail of the histogram covers the area where the difference was from 5 to 16 days (light red area in figure 4.5). The peak to the left is between –1 to –5 (earlier start). The right tail covers the area where the difference was advanced with between 6 to 25 days (only minor areas, light blue area in figure 4.5).

The same pattern can be seen in Figure 4.6 for the spatial distribution of the difference in EGS. The red areas in the figure indicate that the GS ended earlier (mostly between 1 and 5 days, but up to 7 days for minor areas. The blue area indicates that the GS ended later (mostly between 0 to 5 days, but also up to 17 days for minor areas). The spatial distributed differences in the EGS are also presented as histogram in Appendix A, figure 2. The change is multiplied by –1 to be comparable with the change in the start of the growing season. As can be seen, the histogram has only one peak centered on -1 day (this means 1 day since the values are multiplied by –1). Together the difference in BGS and EGS lead to the change in the length of the GS. The histogram (Appendix 1, figure 2) shows that most of the country had a delay in EGS and had an earlier start. In overall this leads to a longer GS for most of the country, although it was only lengthened with a few days (ct. figure 4.4).

In Appendix A, figure 5, the cumulative frequency distributed curve of the BGS and EGS for the 1981-2000 period together with the normal period is shown. As can be seen, the difference in these parameters is minor. Some of the area that had no GS in the normal period did have a defined GS in the 1981-2000 period. The area was minor for the normal period, and was further reduced with 18 % (Appendix A, table 1). This area is removed from the diagram.

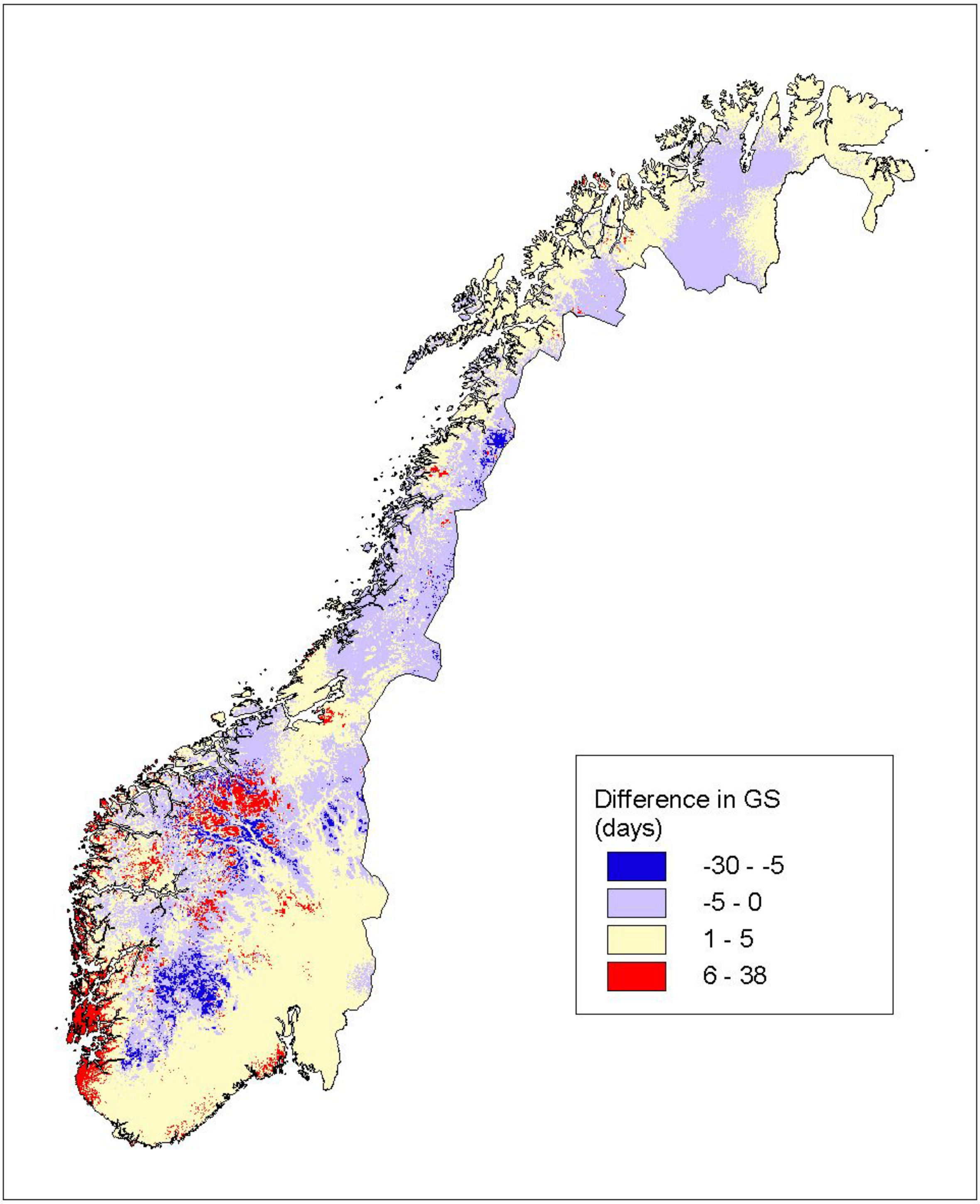

Figure 4.4 Differences in growing season for the twenty-year period 1981-2000 compared to the normal period 1961-1990.

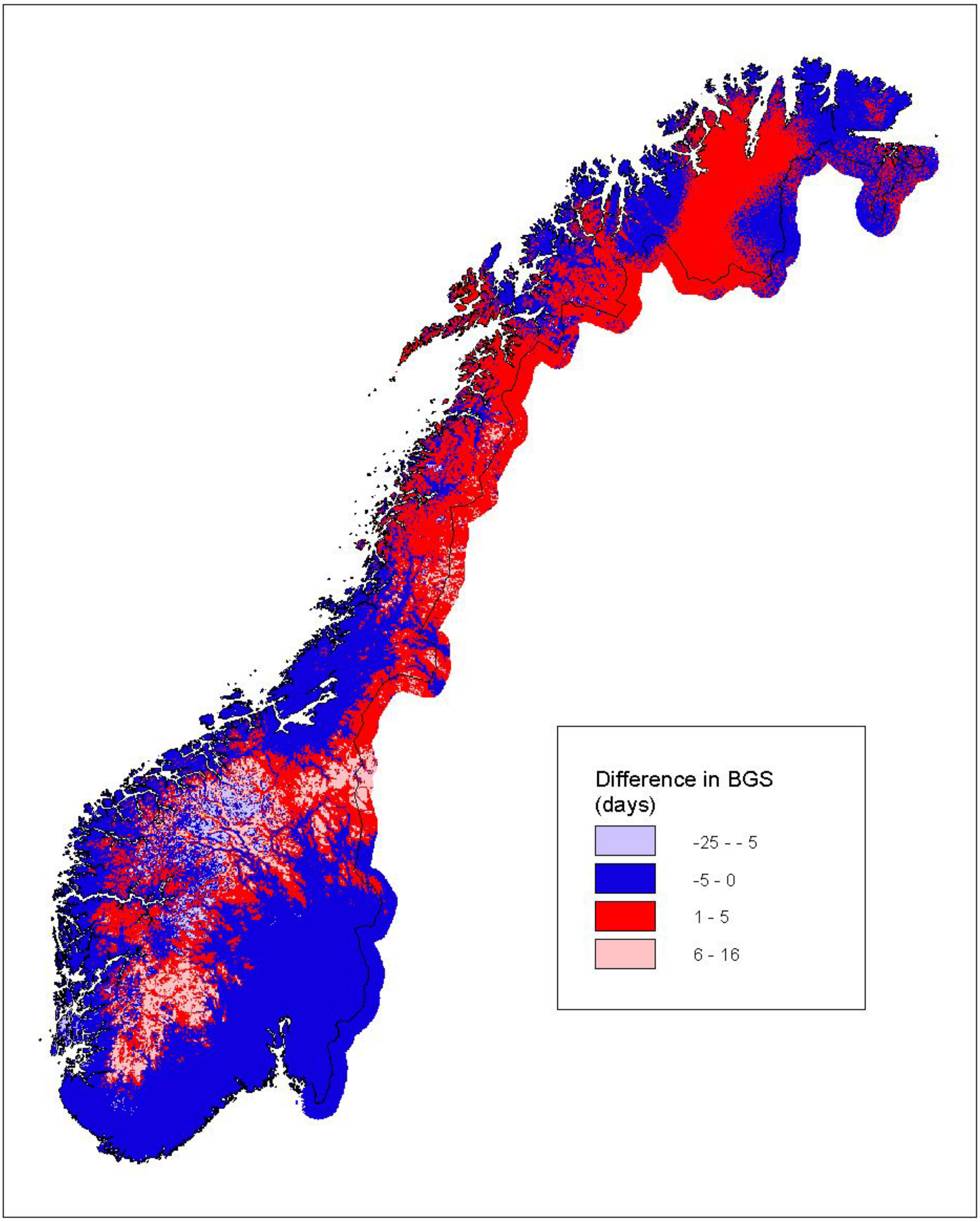

Figure 4.5 Difference in beginning of the growing season for the twenty-year period 1981-2000 compared to the normal period 1961-1990.

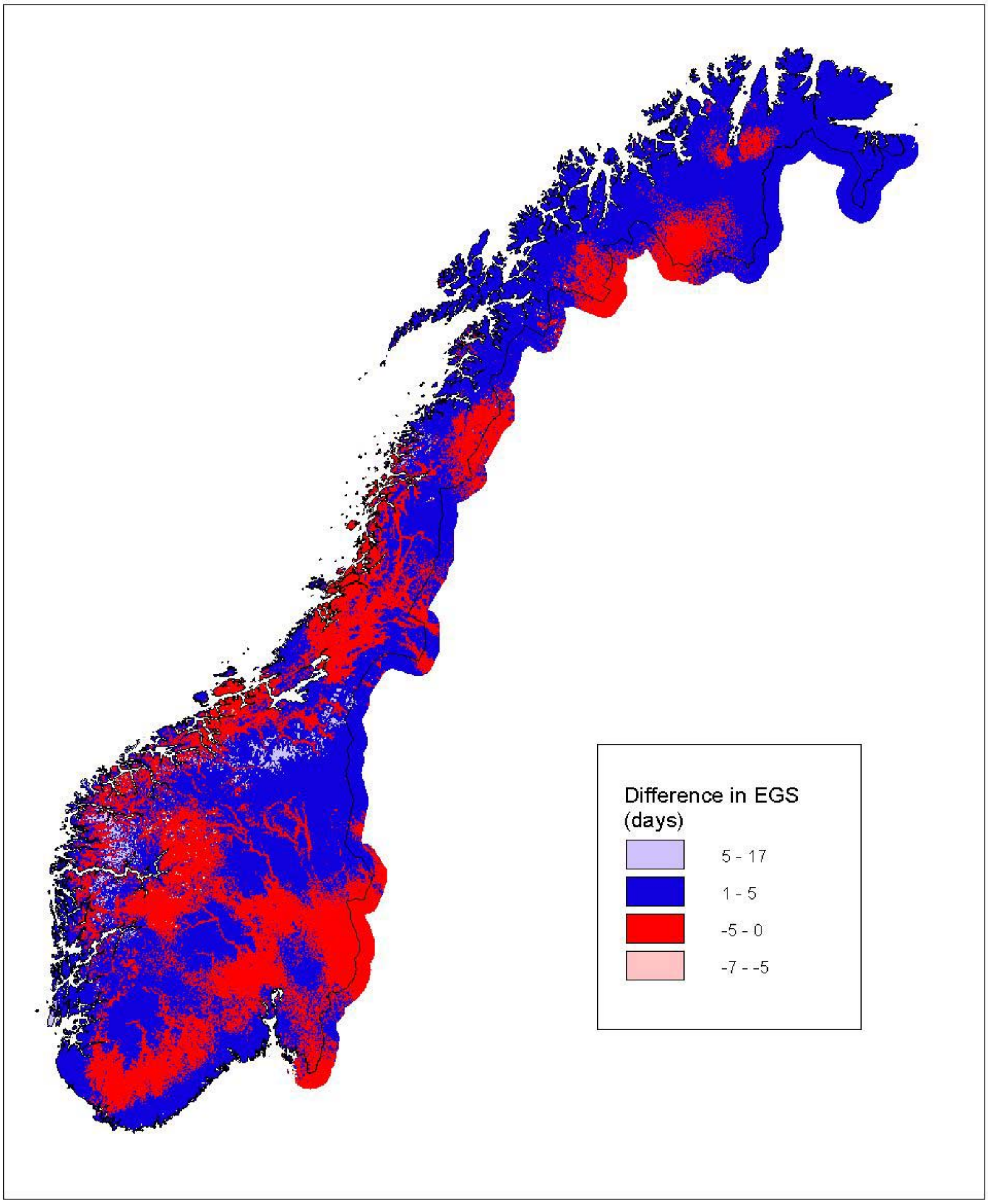

Figure 4.6 Difference in end of the growing season for the twenty-year period 1981-2000 compared to the normal period 1961-1990.

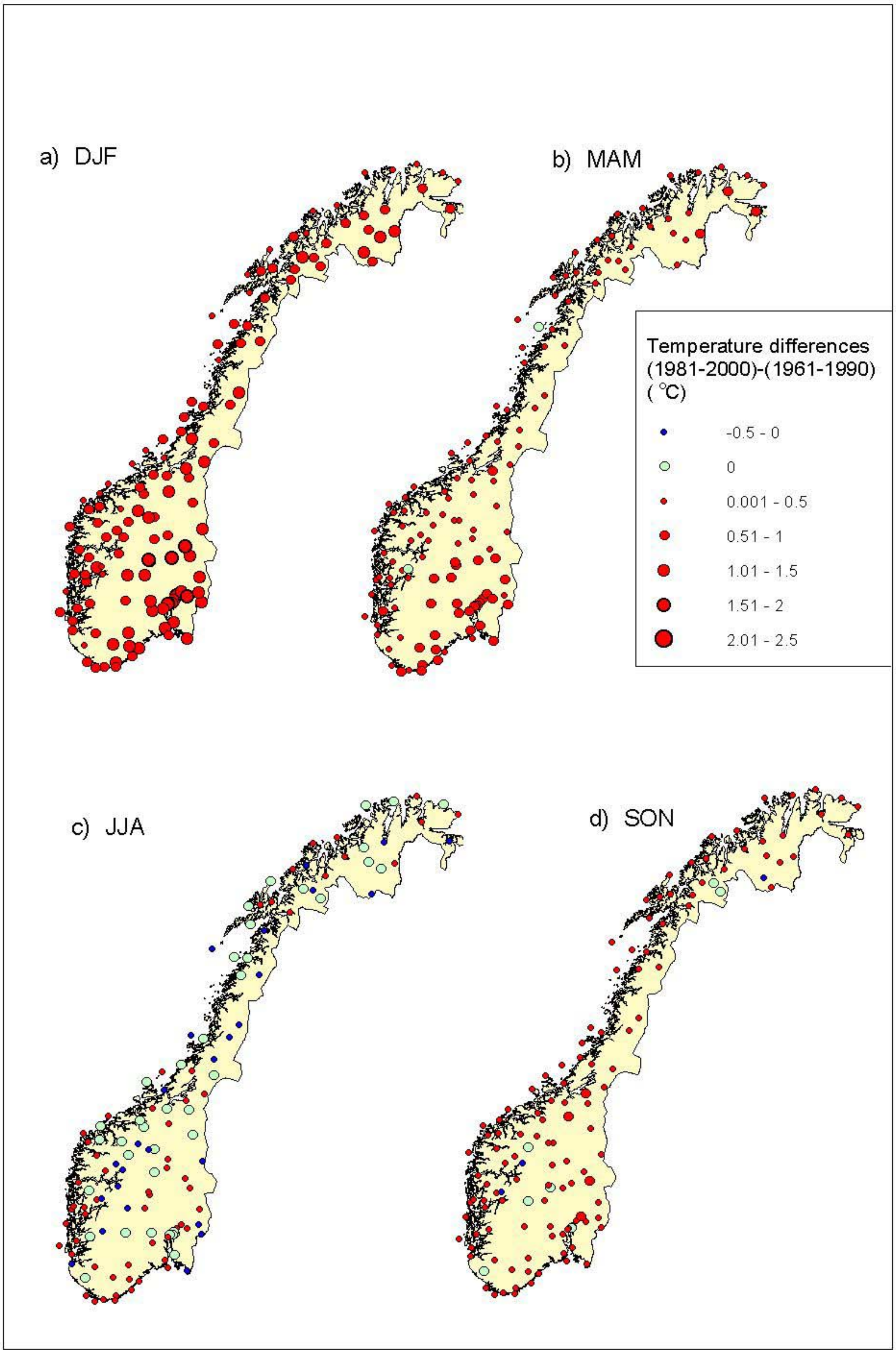

Figure 4.7 Difference in observed temperatures for the four seasons; winter (DJF), spring (MAM), summer (JJA) and autumn (SON) between the twenty-year- (1981-2000) and the normal period (1960-1990).

4.3 Scenario period 2021-2050 compared to the normal period

Temperature scenarios for the period 2021-2050 indicate 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 the increasing temperatures is that the GS will increase all over the country (Figure 4.8).

The length of the GS will increase with less than 20 days in the eastern part of Finnmarksvidda, the Trondheimfjord area and the Oslofjord area. In the southern part of the country, the mountain area in the south and the coastal area further north, the GS will increase with between 20-30 days. In the coastal part of Finnmark, the area from Trøndelag to Lofoten, and the high mountain area in the weastern part of Norway, GS will increase with between 30 and 40 days. The green area in figure 4.7, the change in GS will be more than 40 days (up to 87 days). The area where GS was not defined in the normal period is reduced with 95 % (Appendix A table 1).

The spatial distribution of BGS is shown in figure 4.9. The figure shows that for almost the whole country, the change in BGS is within twenty days. The pink area in Figure 4.9 is supposed to have the largest change in BGS, up to 58 days. The yellow area in figure 4.9 where the BGS is supposed to be delayed with between 150 to 226, refers to the area that had no GS in the normal period.

The histogram of the area distribution BGS in the scenario period together with the BGS of the normal period is shown in Appendix A figure 3. The diagram shows that the spatial distribution of BGS will be earlier compared to the normal period. The histogram of the spatial distribution of the change in BGS in the scenario period compared to the BGS in the normal period is shown in Appendix A, figure 4. The histogram shows that the peak of the change in BGS is moved between 0 and 15 days earlier, centred around 10 days. The tail of the histogram shows that in minor areas, the BGS will be between 16 – 58 days earlier. The cumulative frequency curve for the BGS (and EGS) for the scenario period is presented together with the same parameter for the normal period (Appendix A figure 5), green curves, and shows the same pattern that is presented in figures 3 and 4 (App. A).

The spatial distribution of EGS is shown in figure 4.10. The figure shows that for almost the whole country, the change in EGS is within twenty days. The pink area in Figure 4.10 is supposed to have the largest change in BGS, up to 45 days. This is the western part of the country parts of Nordland county. The yellow area in figure 4.9 where the BGS is supposed to be delayed with between 207 to 249, refers to the area that had no GS in the normal period.

The histogram of the area distribution EGS in the scenario period together with the EGS of the normal period is shown in Appendix A figure 3. The diagram shows that the spatial distribution of EGS will be delayed compared to the normal period. The histogram of the spatial distribution of the change in EGS in the scenario period compared to the EGS in the normal period is shown together with the change in BGS in Appendix A, figure 4. The change in EGS is multiplied with –1 to be comparable with the changes in BGS. The same can be seen for EGS as for BGS, although the change in EGS is supposed to be a bit more distributed. The peak is not centred around 10 days, but over a period of 10 – 15 days. The tail of the histogram shows that for minor areas the change in EGS will be more than 20 days (up to 45) delayed, which refers to the pink area in figure 4.10.

Appendix B figures 2 - 4 shows that the daily mean temperature curve will rise above 5 °C earlier and drop below 5 °C later than the normal period, which means that the growing season will increase at all the selected stations.

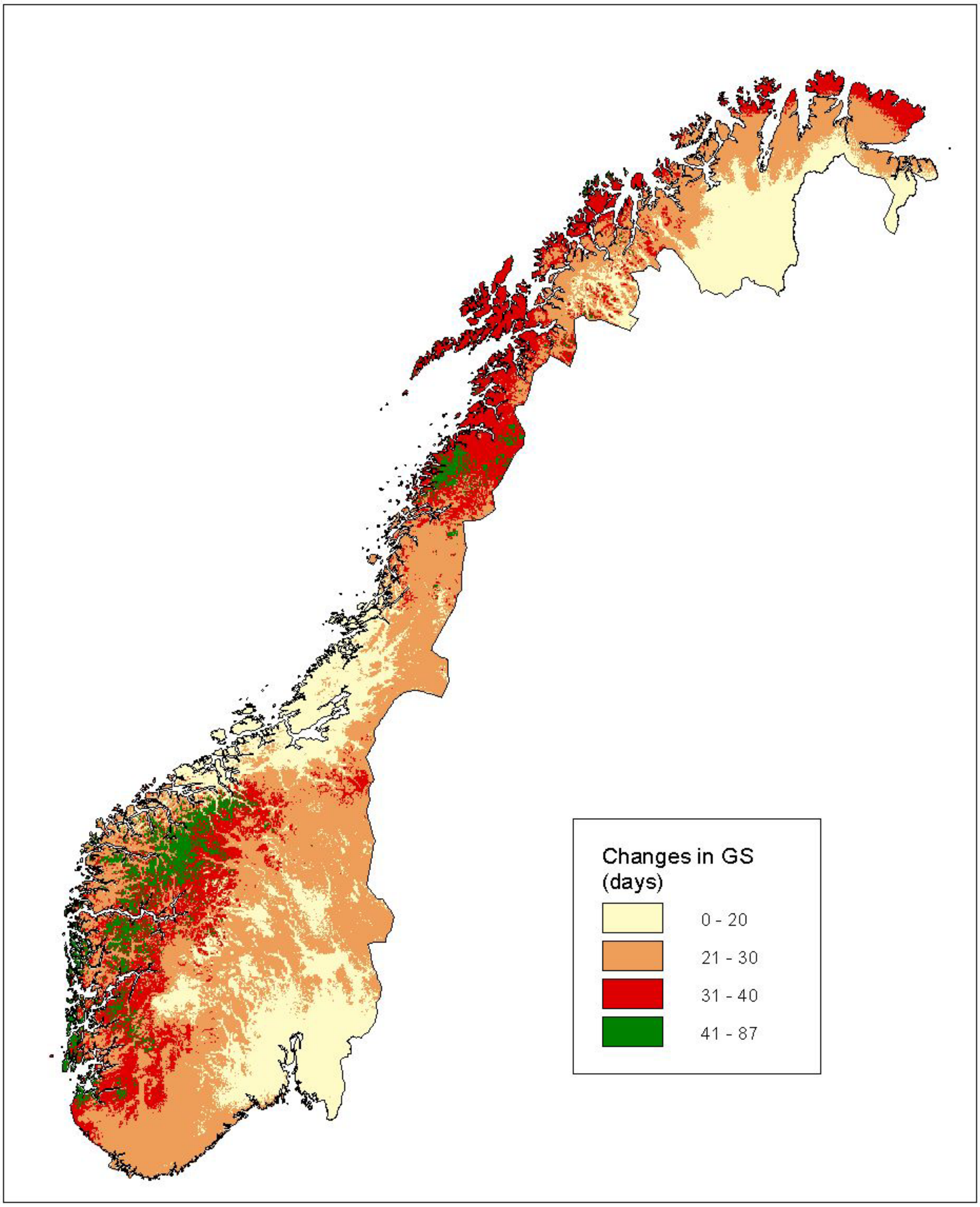

Figure 4.8 Change in the growing season for the scenario period 2021-2050 compared to the normal period 1961-1990.

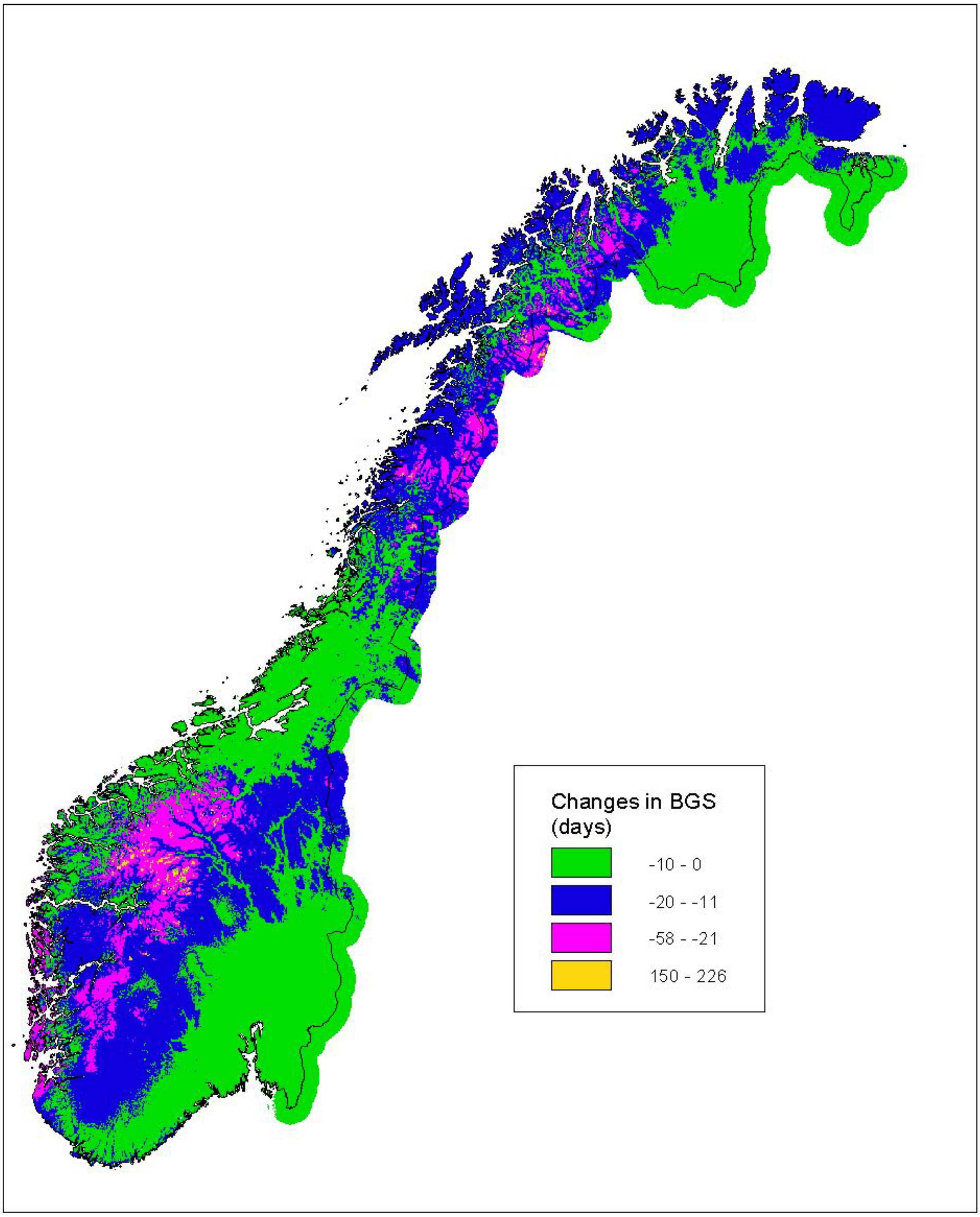

Figure 4.9 ***Change in beginning of the growing season for the scenario period 2021-2050 compared to the normal period 1961-1990. The yellow area in the figure where the BGS is supposed to be delayed with between 150 – 226 days refers to the area that had no GS in the normal period.***

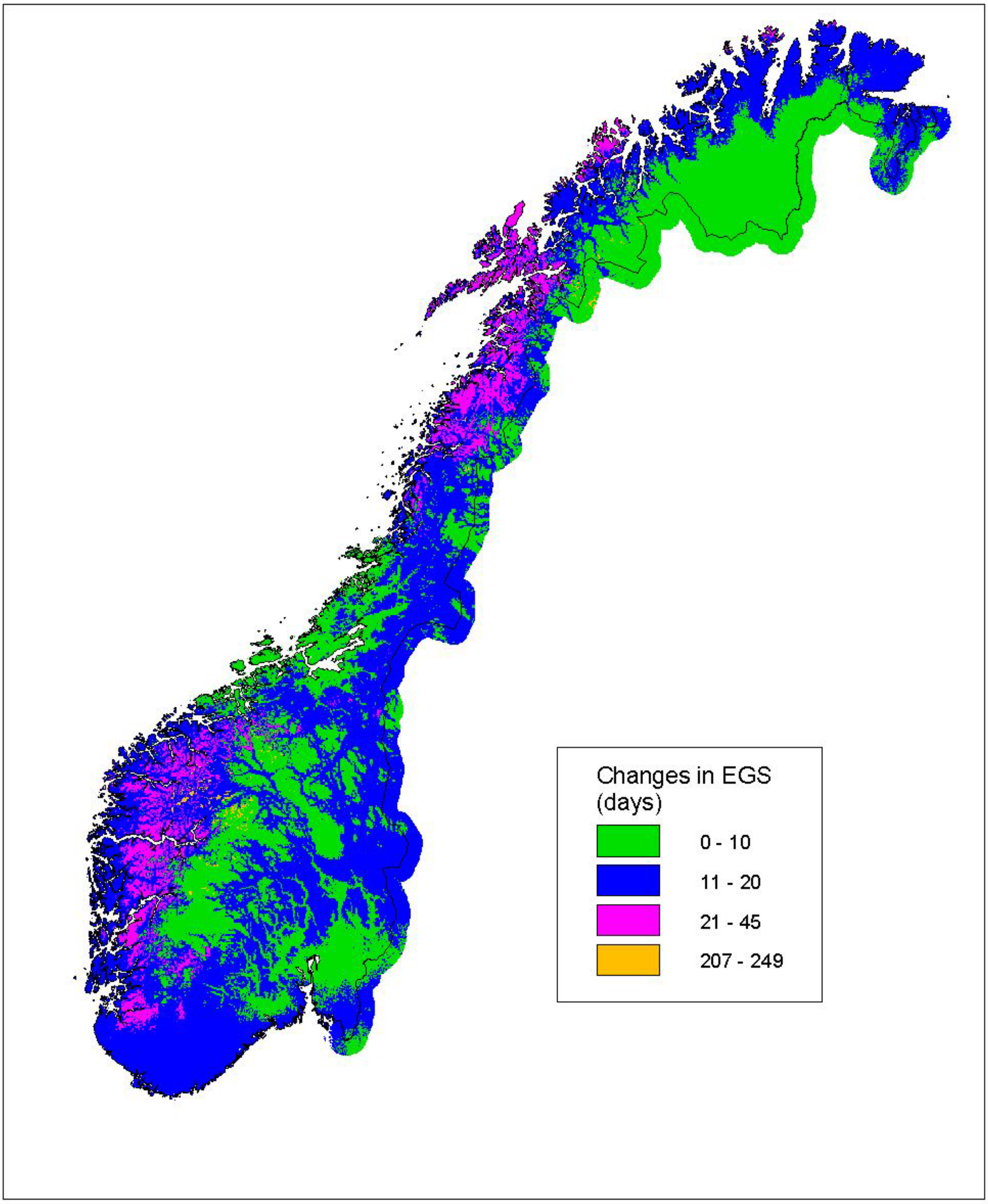

Figure 4.10 Change in the end of the growing season for the scenario period 2021-2050 compared to the normal period 1961-1990. The ice green area in figure 4.9 where the end of the growing season is supposed to be delayed with between 207 – 249 days refers to the area that had no growing season in the normal period.

5. Growing degree-days (GDD)

5.1 The normal period 1961-1990

The growing degree-days in Norway (GDD) during the GS are calculated as described in section 3.4 for Norway for the normal period (1961-1990), Figure 5.1.

The GDD values correspond with the length of the GS and with the temperature within the season. The area at the southwestern and southeastern coast of Norway had the largest GDD value, from 1200 – 1514 °C (light green area in figure 5.1). In a belt along the coast, from the Swedish border in the east to the area around Trondheimsfjorden, the GDD values were between 700 and 1200 °C (the green colour area in figure 5.1). This belt continues in a tiny area along the coast to Lofoten. The mountain area in the south of Norway, the costal part of the northern Norway, and Finnmark had GDD values between 200 and 700. The high mountain area had the lowest GDD estimate, less than 200.

The histogram of the area distribution of the GDD within the GS in the normal period is presented in appendix C, figure 1. The area with the lowest GDD correspond to the grey area in figure 5.1, the area with the highest values correspond to the light green area in figure 5.1. The peak between 200°C and 600 °C correspond to the high mountain area in the south and the northern part of the country.

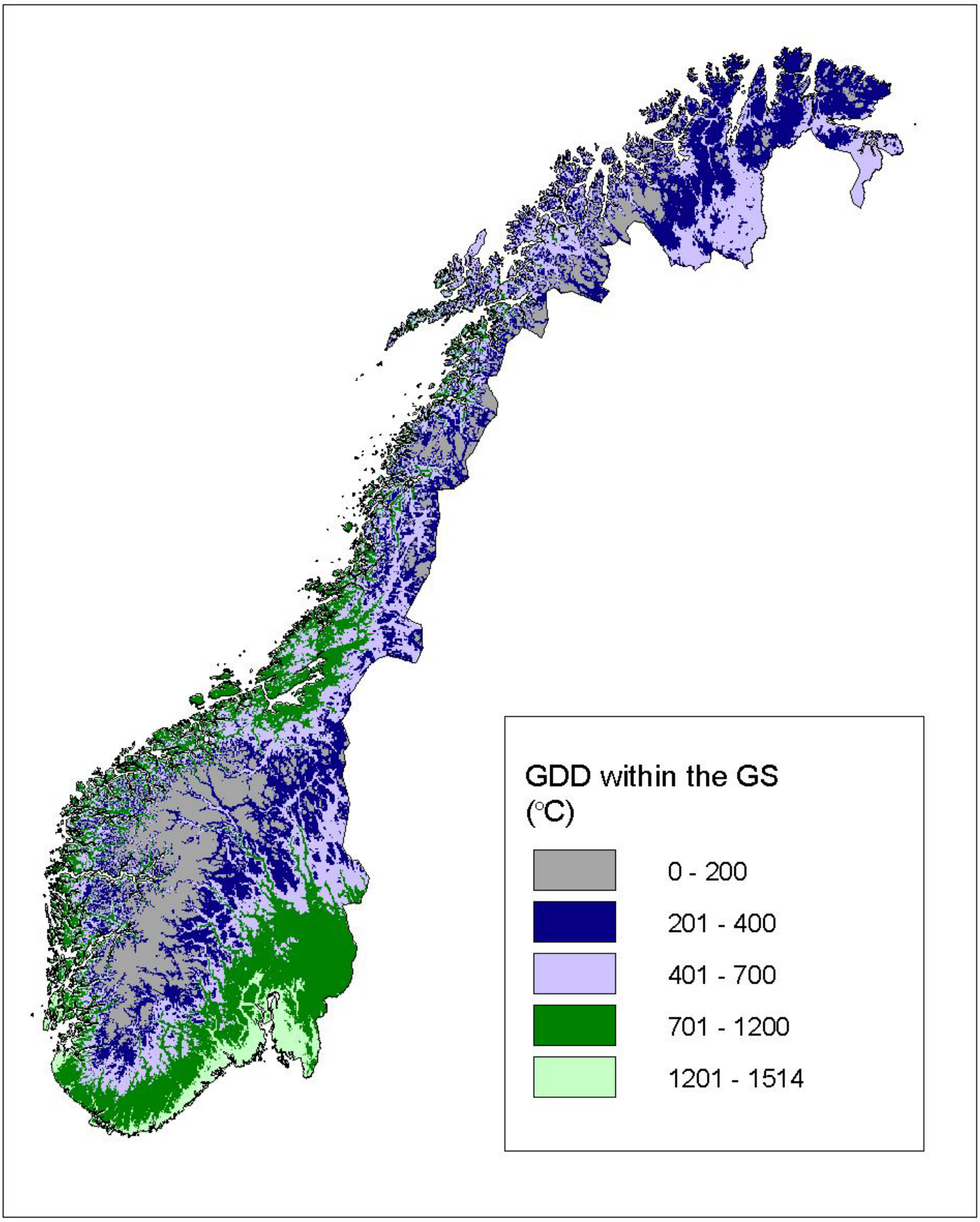

Figure 5.1 Growing degree-days within the growing season in the normal period 1961-1990

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

The differences in GDD 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. The differences in GDD in percent are shown in figure 5.3.

Figure 5.2 shows that the difference in GDD in the twenty-year period (1981-2000) compared to the normal period were rather small. Only at the southeastern and southwestern coast and a few other places in Norway, the change was larger than 30 °C. Some parts of the country had a decrease in summer temperature (ct. Figure 4.7). The areas that had a minor decrease in GDD correspond to these areas. In the rest of the country the change in GDD was up to 30 °C during the growing season.

The histogram of the differences in GDD in the twenty-year period (1981-2000) compared to the normal period is presented in appendix C, figure 2. The difference in GDD was positive for most of the country, and the peak of the histogram is centred around 5 °C. The same information is given as cumulative frequency curve as well, Appendix C figure 4. As can be seen from the curve (pink line), the largest part of the country (81 %) had a positive change compared to the normal period although it was minor. The GDD value for the period 1981-2000 is presented as cumulative frequency curve in Appendix C figure 5. The figure shows clearly that the change in GDD between the two periods was small.

In figure 5.3 the differences in the GDD in the twenty-year period (1981-2000) compared to the normal period are shown in percent. The figure shows that the largest increase (>10 %) was in the high mountain area. This is because the GS in this area was very short in the normal period, and consequently only a few days increase in the length of the growing season will lead to a large percentage change. For most of the country, the increase in GDD in the twenty-year period (1981-2000) compared to the normal period, was between 0 and 10 %. The same area where there was a decrease in GDD in °C (figure 5.2), had a decrease in GDD of less than 10 %. The white area in figure 5.3 appears because there were no defined GS in the normal period in this area. Hence there will be no defined percentage estimate in this area.

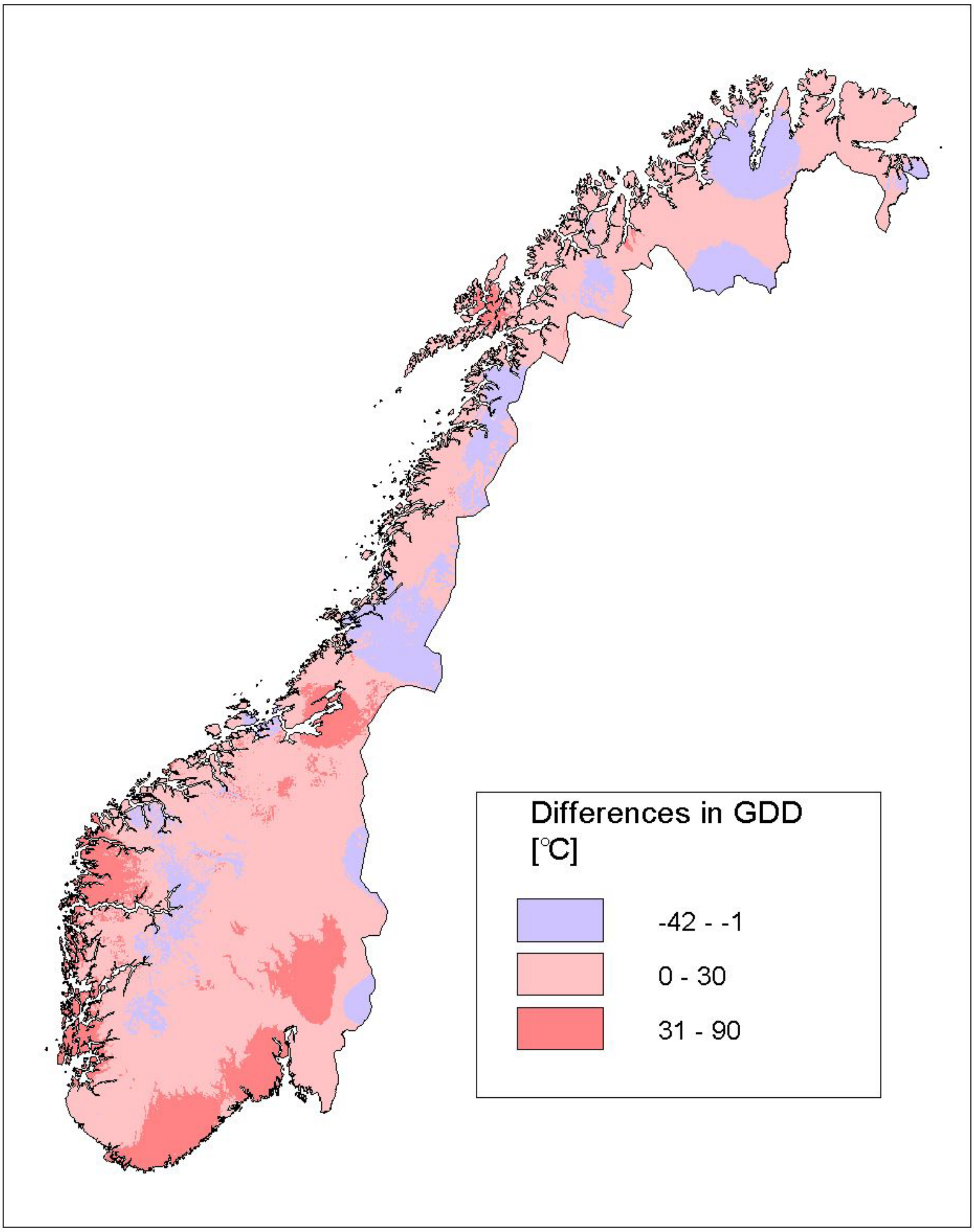

Figure 5.2 Differences in growing degree-days [°C] in the twenty-year period (1981-2000) compared to the normal period (1961-1990).

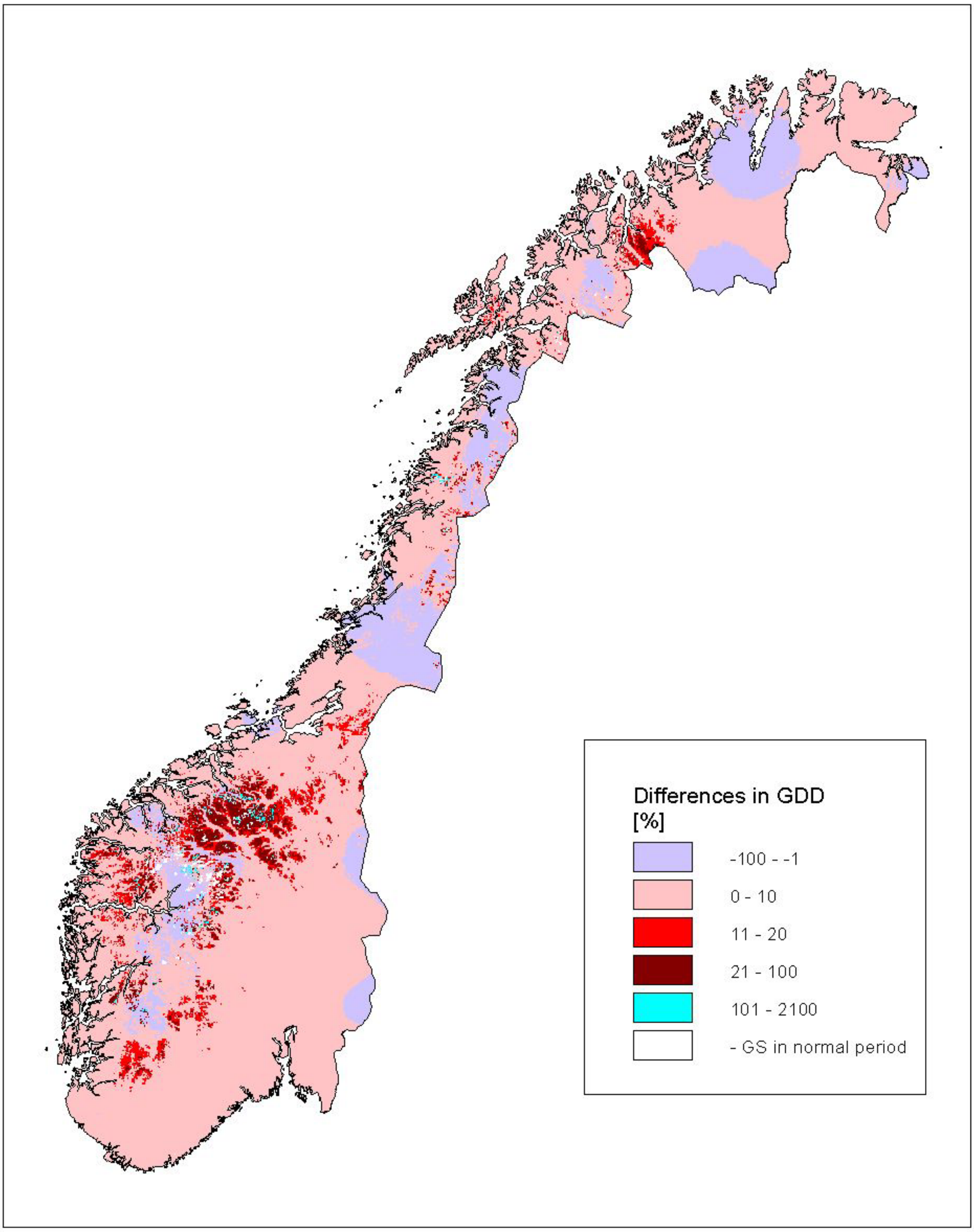

Figure 5.3 ***Differences in growing degree-days [%] in the twenty-year period (1981-2000) compared to the normal period (1961-1990).***

5.3 Scenario period 2021-2050 compared to the normal period

The changes in the GDD for the scenario period 2021-2050 compared to the normal period are presented in Figure 5.4. The temperature data used are presented in section 2.1. In Figure 5.5, the same changes are shown in percent.

The change in GDD in figure 5.4 is ranging from 0 to 481 ^{o}C. The largest increase is found along the westcoast (dark blue aera in figure 5.4). Large parts of Finnmarksvidda, the Trondheimsfjord area and the eastern part of southern Norway are supposed to have an increase in GDD between 200 and 300 ^{o}C (light blue area in figure 5.4). The high mountain areas will have the smallest change in GDD, less than 200 ^{o}C (grey area in figure 5.4).

The spatial distribution of the change in the GDD in the scenario period compared to the normal period is presented in Appendix C figure 3. The histogram is centred around 230 °C. The part of the histogram that is less than 200 ^{o}C represents the grey area in the figure, the part between 200 ^{o}C and 300 ^{o}C represents the light blue area in figure 5.4., and the part that is larger than 200 ^{o}C represents the blue area in the figure. As can be seen of the histogram as well as Figure 5.4, is that the largest part of the country will have an increase in GDD between 200 and 300 ^{o}C.

The cumulative frequency curve of the change in GDD in the scenario period compared to the normal period is presented in Appendix C figure 4 (blue line). The curve shows that the GDD estimate for the scenario period will increase markedly compared to the normal period. The cumulative frequency diagram of GDD value in the periods studied is presented in Appendix C figure 5, which shows the same results, that the GDD will increase in the future.

In figure 5.5, the changes in the GDD in the scenario period compared to the normal period is shown in percent. The area around the Trondheimsfjord and in a tiny belt from the west along the coast that widens further east to the Swedish border, the scenario indicate an increase in GDD of between 19 and 30 %. Increase in GDD up to 100 % will be found in mountain area and northern Norway. The area where the change is larger than 100 % is the high mountain area where the growing season was short in the normal period. A few days increase in the growing season will in this area consequentially lead to a large change in percent. The area in the high mountain area that had no GS is markedly reduced.

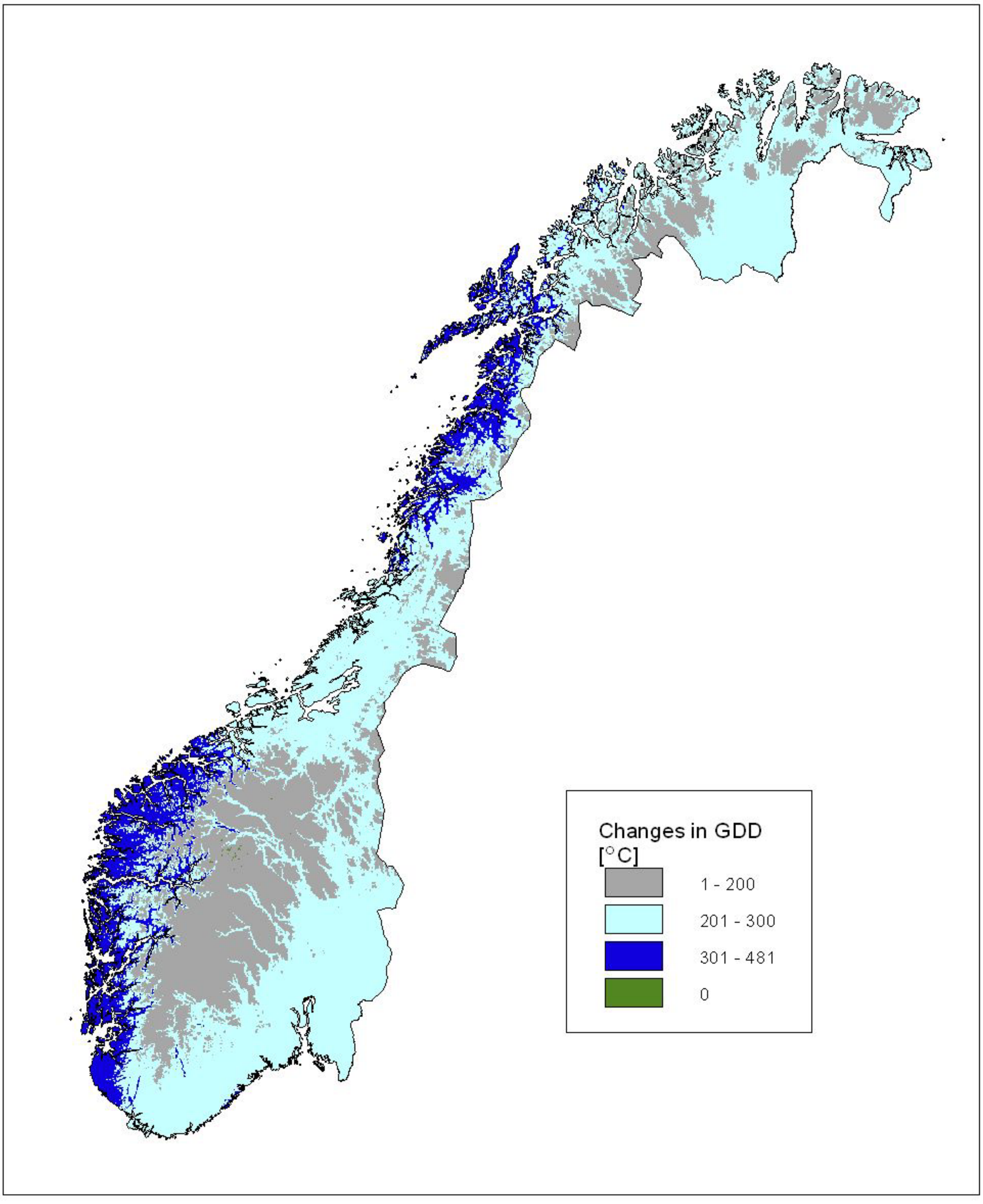

Figure 5.4 The change in the growing degree-days [°C] in the scenario period (2021-2050) compared to the normal period (1961-1990).

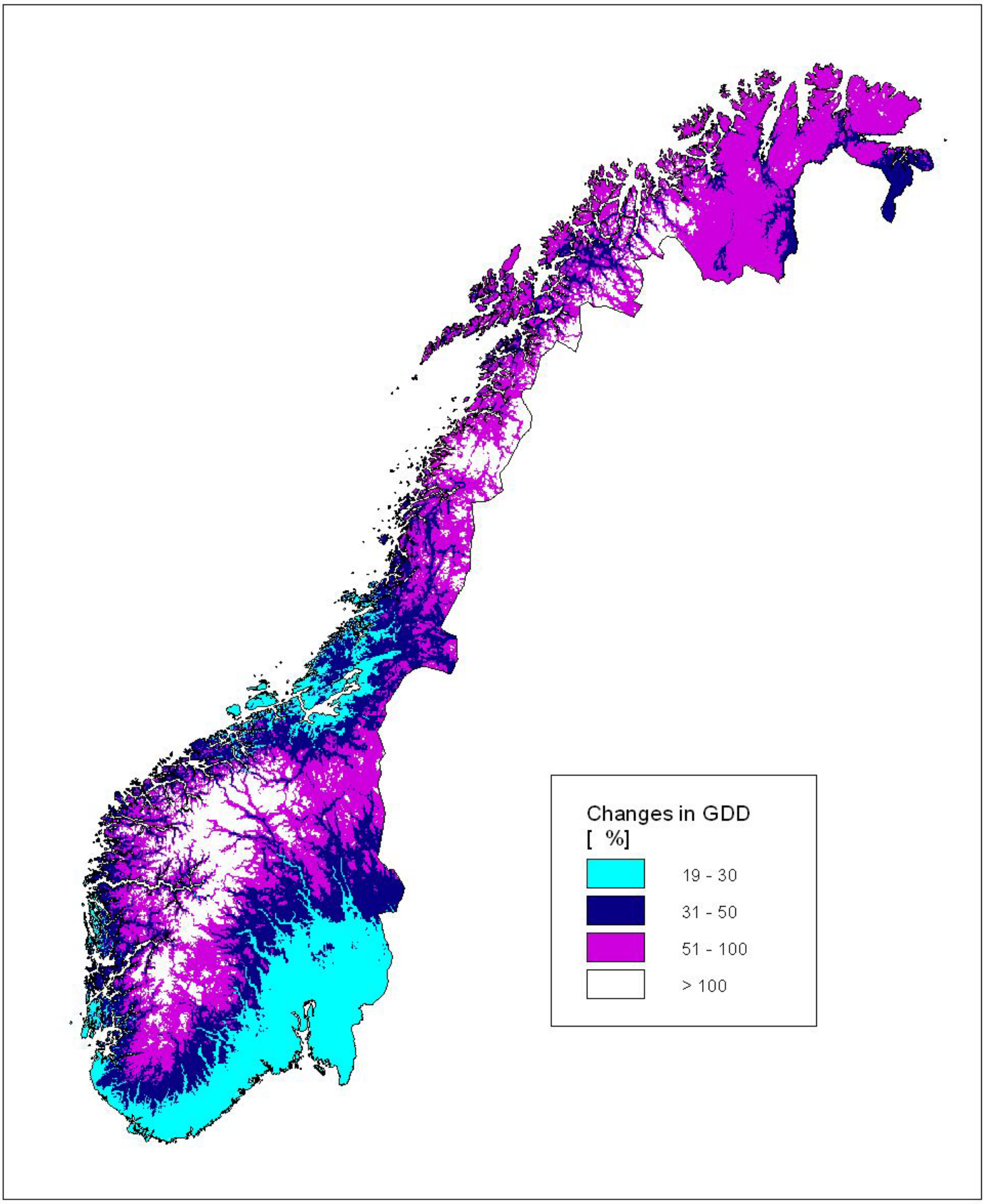

Figure 5.5 The change in the growing degree-days [%] in the scenario period (2021-2050) compared to the normal period (1961-1990).

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 GS and GDD 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 Growing season

The length of the growing season (GS) varies with altitude, latitude and with the temperature gradient. GS varied from less than 50 days in the high mountain area in the southern Norway to more than 200 days in a narrow zone in the soutwestern coast of the country in the normal period (1961-1990). The start of the GS began between the middle of April (coastal area in the south) to the middle of August. The end (EGS) was between end of July until the end of November. The duration of the GS in the area from the Trondheimfjord to the Swedish border was between 150 to 200 days. This is the southern, coastal, lowland of Norway. In this area it started before 5. May, and ended from the end of October and through out November. GS decreases with altitude, latitude, and distance from coast. The eastern part of Northern Norway and the high mountain area in southern Norway had the shortest GS, between 0 and 125 days. BGS in this area started between June and the middle of August, it ended between the end of July until the middle of September.

Rötzer and Chmielewski (2001) have developed a map of the average length of the GS covering Europe in the period 1961-1998. BGS and EGS were based on regression analysis of observations of leaf unfolding and leaf fall at different International Phenological Gardens (IPSs) in Europe. Three of these are situated in Norway, in Bergen, Oslo and Trondheim. The map shows the same pattern as presented in this report. They found that the area in a belt along the southern coast up to the Trondheimfjord area, the GS lasted between ca 160 – 180 days. The shortest GS was in the high mountain area and in the northern Norway, where the GS lasted from 120 –160 days (decreasing with altitude, latitude and distance from the coast). The BGS was from the beginning of May through out June. The EGS was between October to the beginning of November. Rötzer and Chmielewski (2001) used a different method defining the GS, but the results shows the same pattern as the study presented here even though they fount that the GS starts and ends over a shorter time period. There are also differences in the length of the GS in the reference period. Rötzer and Chmielewski (2001) found that the GS was shorter along the coast and longer in the north and in the high land of Norway compared to the study presented here. In the work presented in this report, we use the normal period (1961-1990) as the reference period to estimate the GS, Rötzer and Chmielewski (2001) use the period 1961-1998. The different time period make the two maps of average length of growing season incomparable. It is interesting, however, to see that the two methods lead to the same spatial pattern concerning the length of the growing season.

The difference in GS in the twenty-year period (1981-2000) compared to the normal period, was less than 10 days for most of the country. For some areas the GS was shorter (<5days) during 1981-2000 than the normal period. This is due to the decrease in mean temperature in this period compared to the normal period. The difference in the start of the season was within +/- 5 days for most parts of the country. The same pattern can be seen for the end of the season.

Even though there was found only minor differences in the thirty-year average GS value in the last decades compared to the normal period, there may have been large individual year-to-year differences. Chmielewski and Rötzer (2002) have mapped the anomaly pattern of the

BGS for Europe every year from 1969-1998 in relation to long-term mean. They show that the anomaly in the BGS in Norway was delayed in the years from 1981 to 1988. There was only small advance in the BGS in northern Norway in the years 1983 and1984. The period from 1989 to 1998 the BGS did advance compared to the (1969 – 1998)-average. The years 1995 to 1997 had some areas with delay in BGS. Chmielewski and Rötzer (2002) used observations of unfolding leaf from the IPGs in Europe to develop the spatial distribution of the BGS. They did not use the same reference period as in this study, the resulting maps is therefore not direct comparable with the maps presented here. However, they found that the BGS was strongly correlated to air temperature in the way that uniform temperature anomalies will lead to either advance or delay of BGS.

The largest temperature increase in the scenario period is found to be in the winter period, but there will also be temperature increase during the spring, summer and autumn months. This will lead to a longer GS all over the country in the scenario period (2021-2050) compared to the normal period. Finnmarksvidda, the Trondheimfjord area and the Oslofjord area will have an increase in the growing season of less than 20 days. The BGS in this area will advance with up to 10 days. The EGS will be delayed with up to 10 days, but in some area near the Oslofjord area, it will be delayed with up to 20 days. The western part of the country, parts of Nordland and the northernmost coast of Norway will have the largest increase, between 30 and 87 days. The rest of the country will have an increase in GS from 20 to 30 days.

The cumulative frequency curves in figure 5 (Appendix A), shows that for 50 % of the total area in Norway, the GS starts before day number 145 (25/5). For the scenario period, the day that the GS had started for 50 % of the country, has advanced with 11 days (to day number 134 (14/5). For the EGS, the curves show that 50% of the total area had the GS before day number 263 (20/9) in the normal period. For the scenario period, this day was delayed with 15 days to day number 279 (6/10). The GS will thus be almost four weeks (26 days) longer for 50 % of the country. The map of average length of the growing season over the period 1961-1998 covering Europe (Rötzer and Chmielewski, 2001) shows that countries like southern Great Britain, the Netherlands and northern Germany had an average growing season from ca 200 to 210 days in the period 1961-1998. Taking this into account, we are supposed to have an average length of the growing season along in the scenario period along the southern coast of Norway as it is to day in the European countries mentioned above.

6.3 Growing degree-days

GDD, in the normal period (1961-1990) varied from less than 200 to more than 1200 °C over the country depending on the length of the growing season and the temperature within the growing season. A belt in the southern area from the Swedish boarder to the Trondheimfjord area, and a thiny belt along the coast from here to Lofoten had the largest GDD within the growing season, more than 700 °C. In the mountain area in the south and the northern Norway, the GDD estimate was less than 700 °C.

The change in the growing degree-days, GDD, in the twenty-year period (1981-2000) compared to the normal period, was minor. The change was largest in the southern part of the country. For some parts of the country, the GDD estimate did decrease compared to the normal period because the mean temperature in the summer season decreased for some stations (figure 4.7). The increase in GDD was for most parts of the country less than 10 %. Only a minor area had an increase in the GDD of more than 10 %. For the area that had a reduction in the GDD, the change was mostly less than 3 %.

The largest change in GDD in the scenario period compared to the normal period is supposed to be between 300 and 480 ^{o}C at the western and parts of the northern coast of Norway. The high mountain area and parts of northern Norway, the change will be less than 200 ^{o}C. The largest change in percentage, however, does not correspond to the largest change in degree-sum. The change in the GDD in the southeastern Norway and the area around the Trondheimsfjord is supposed to be less than 30 %. Most of the mountain area in the southern Norway, and the northern Norway, there is supposed to be a change in the GDD between 30 – 100 %. The growing degree-days, GDD, in the scenario period (2021-2050) compared to the normal period, is supposed to be more than 100 % longer in the high mountain area in the southwestern and northern Norway. The large percentage is mostly because the growing season in this area in the normal period was short, and rather moderate changes in the growing season will affect the growing season and the GDD percentage estimate in a markedly way.

The growing degree-days (GDD) are a good indicator of energy available for biological growth during the growing season. An increase in GDD may for instance lead to heavier growth of the crops already present, and to the presence of more temperature sensitive crops.

Marked increase in GS and GDD, as the scenario indicates, may also result in more insects and plant disease damage.

7. References

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8. Appendix

Appendix A The beginning and end of the growing season in Norway

Appendix B Daily main temperature estimates for some selected locations

Appendix C Area distribution of the GDD in Norway

Appendix A The beginning and end of the growing season in Norway

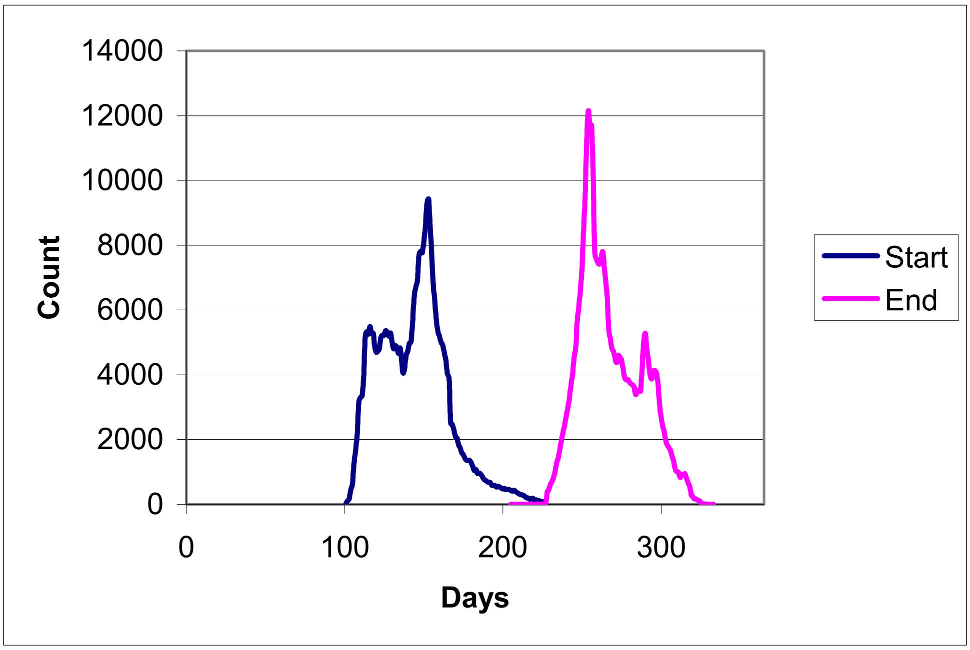

Figure 1 The histogram of the area distributed start and end of the growing season over Norway in the normal period (figure 4.2 and 4.3). (Count refers to number of pixels (1 * 1km2) in the grid).

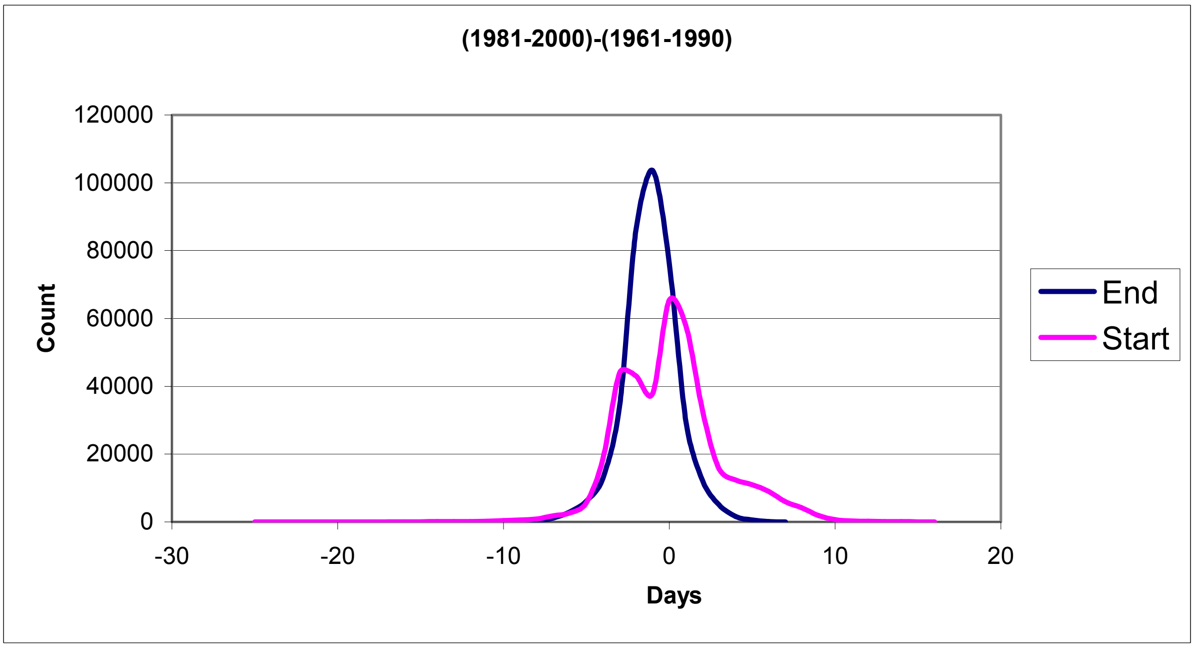

Figure 2 Histogram of the area-distributed changes in the BGS and EGS over Norway in the twenty-year period 1981-2000 compared to the normal period (figure 4.5 and 4.6). (Count refers to number of pixels (1 * 1km^2) in the grid). The area that had no GS in the normal period was reduced with 18 %. The data from this area is removed from the diagram.

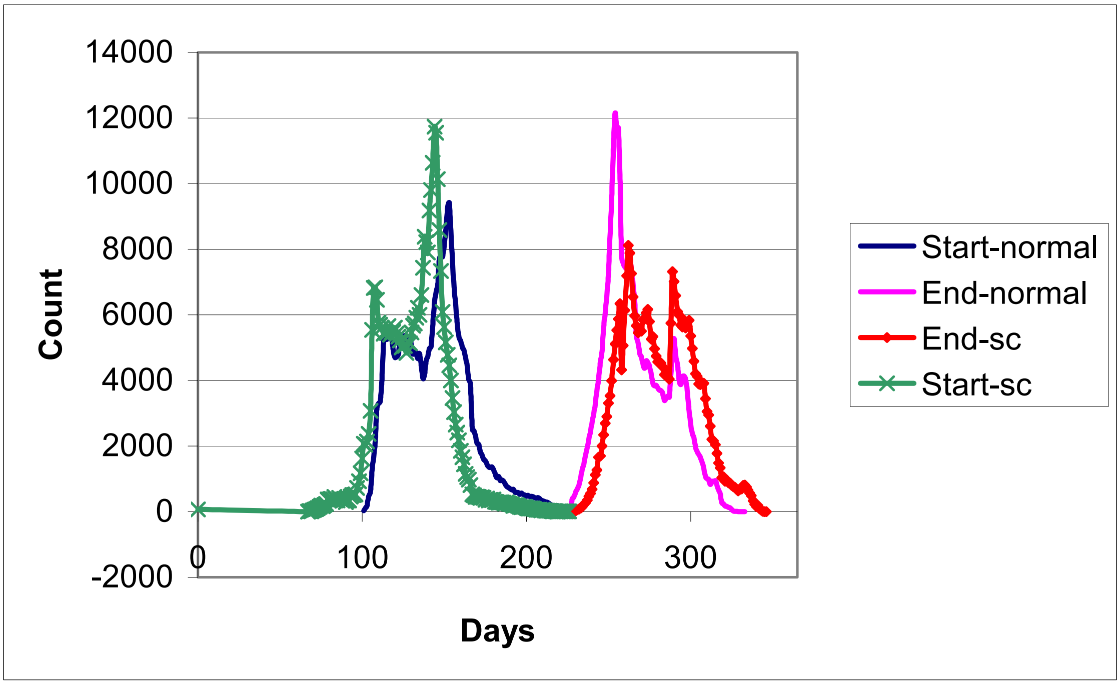

Figure 3 ***Histogram of the area distributed start and end of the growing season over Norway in the normal period (App. D, figure 1) together with the histogram of the area distributed start and end for the scenario period, 2021-2050 (figure 4.9 and 4.10). (Count refers to number of pixels (1 * 1km²) in the grid).***

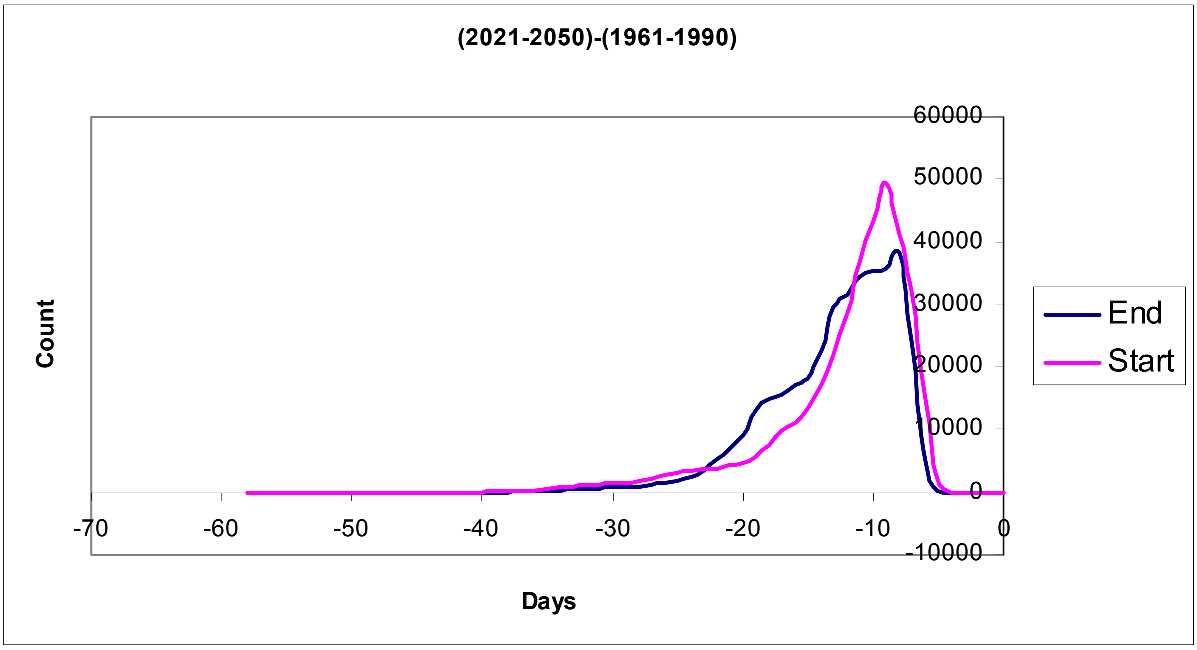

Figure 4 ***Histogram of the area-distributed changes in the start and end of the growing season over Norway in the scenario period 2021-2050 compared to the normal period (figure 4.9 and 4.10). (Count refers to number of pixels (1 * 1km²) in the grid). The area that had no GS in the normal period was reduced with 95 %. The data from this area is removed from the diagram.***

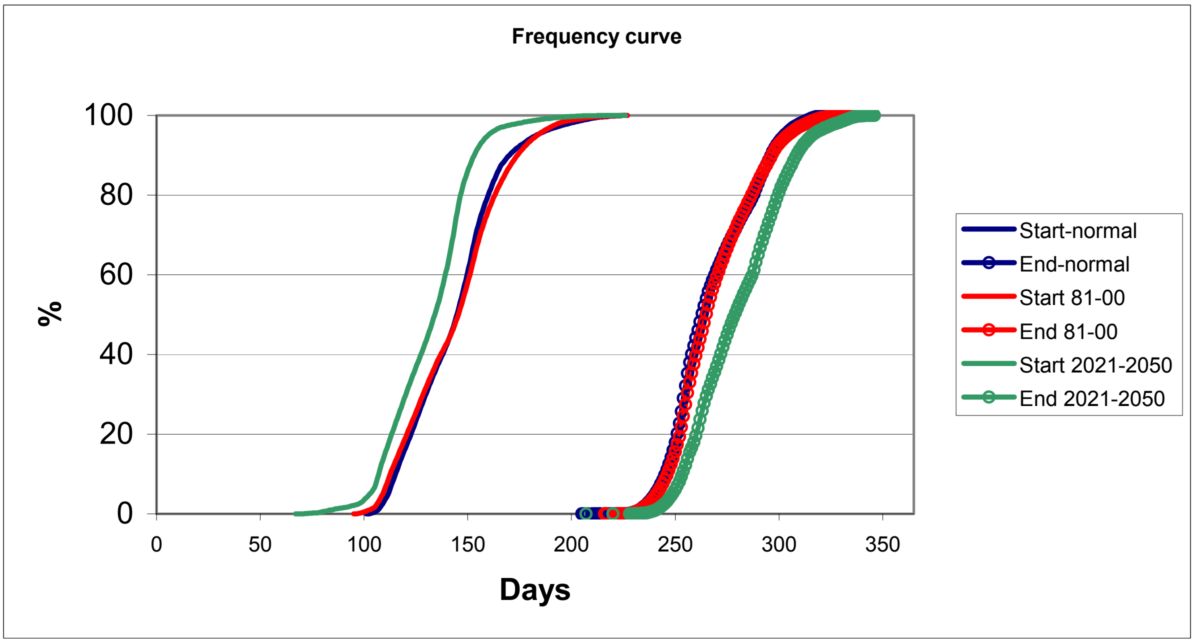

Figure 5 Cumulative frequency curve of the beginning and end of the growing season for the three periods studiet,1961-1990, 1981-2000 and 2021-2050.

Table 1 Number of pixels in the maps covering the beginning and end in Norway for the three periods studied, 1961-1990, 1981-2000 and 2021-2050.

	Start			End		
No. of pixels	61-90	81-00	2021-2050	61-90	81-00	2021-2050
=0	1436	1174	68	1436	1174	68
%	100	18	95	100	18	95
>0	372612	372874	373980	372612	372874	373980
Total	374048	374048	374048	374048	374048	374048

Appendix B   Daily mean temperature estimates for some selected locations

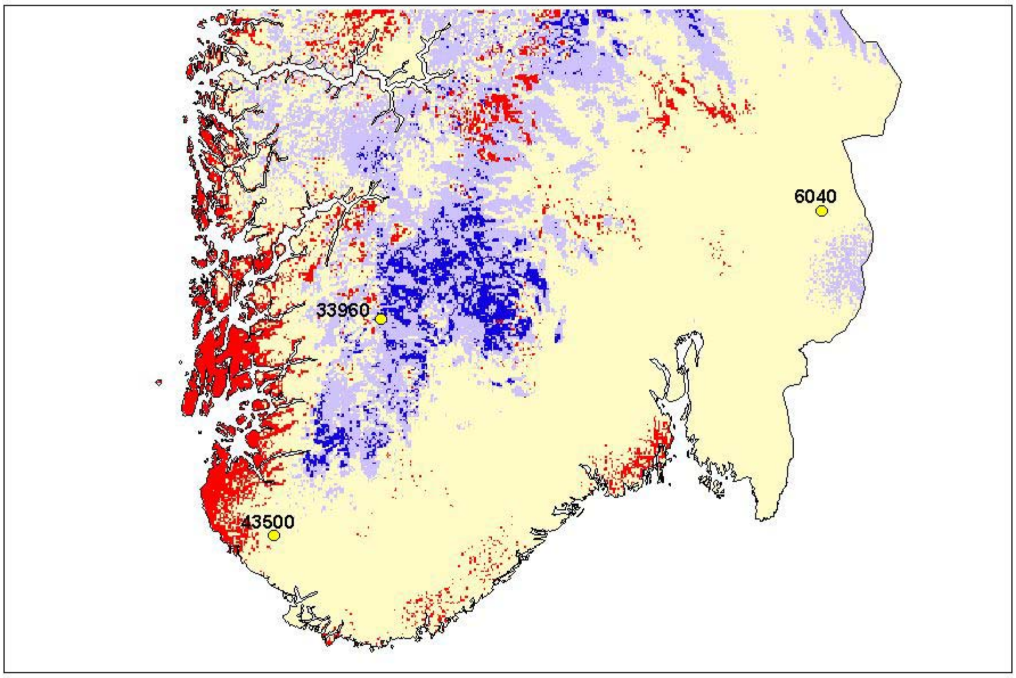

Figure 1 ***The sites of the selected temperature stations in southern Norway. The sites are presented together with the map of the difference in growing season in the period 1981-2000 period compared to the normal period (figure 4.4). The yellow dots indicate the selected stations.***

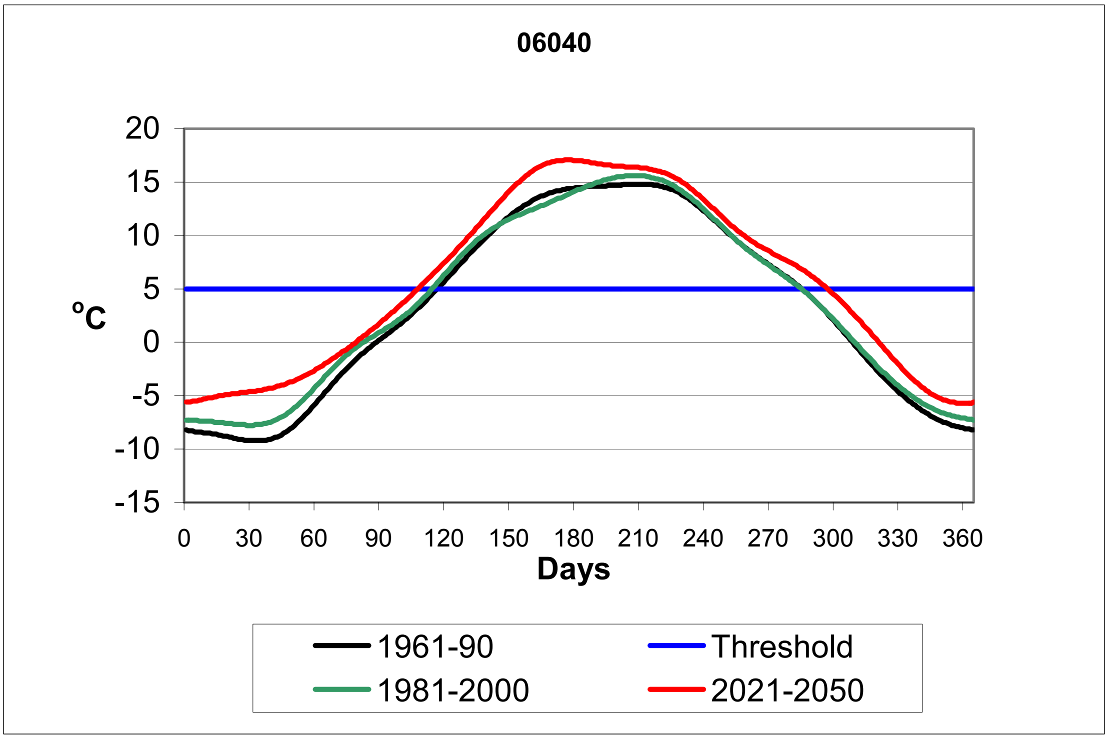

Figure 2 ***Estimated daily mean temperature at the observation station 06040 Flisa for the normal period, the twenty-year period and the scenario period.***

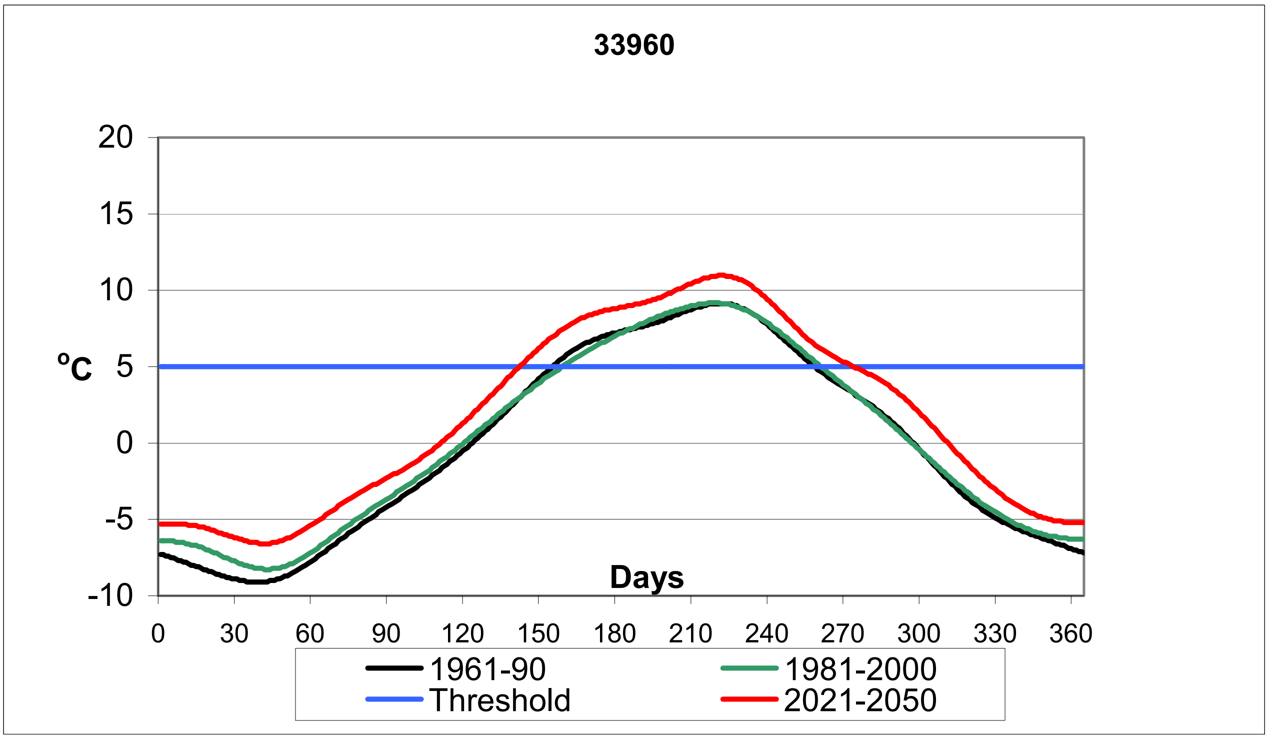

Figure 3 Estimated daily mean temperature at the observation station 33960 Haukeliseter for the normal period, the twenty-year period and the scenario period.

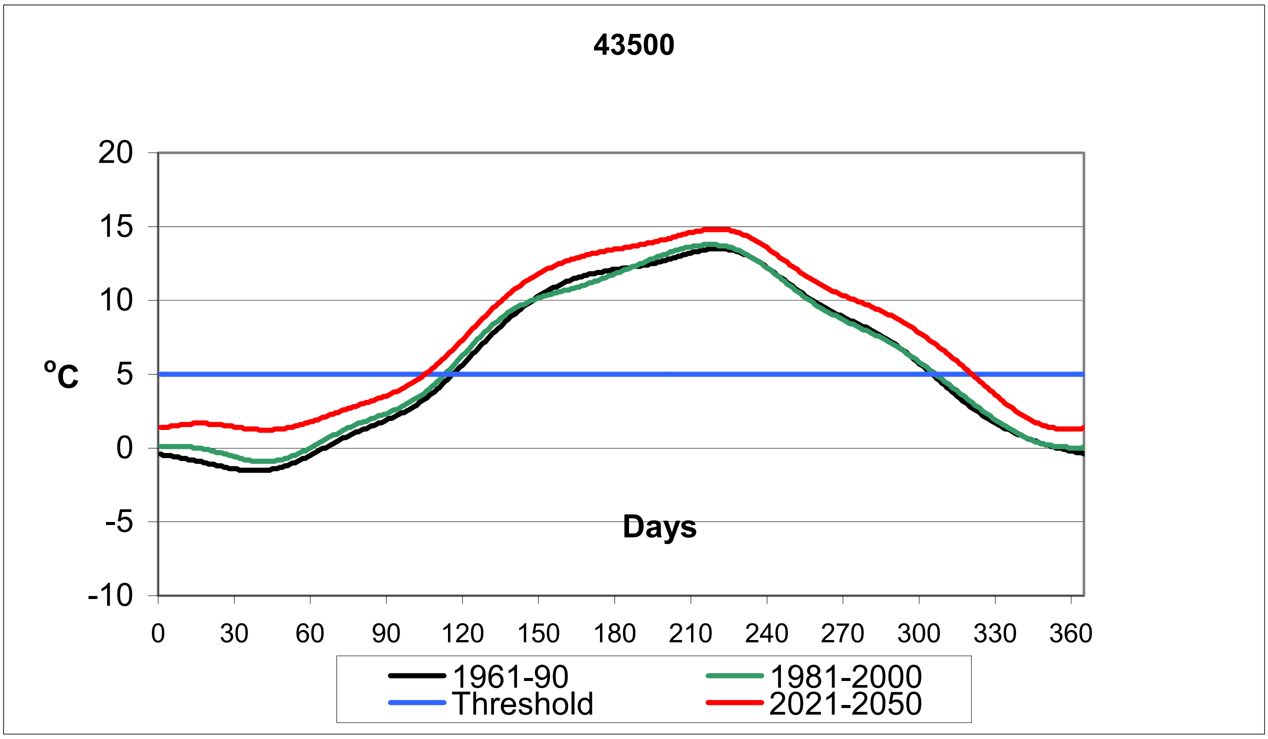

Figure 4 Estimated daily mean temperature at the observation station 43500 Ualand-Bjuland for the normal period, the twenty-year period and the scenario period.

Appendix C Area distribution of the GDD in Norway

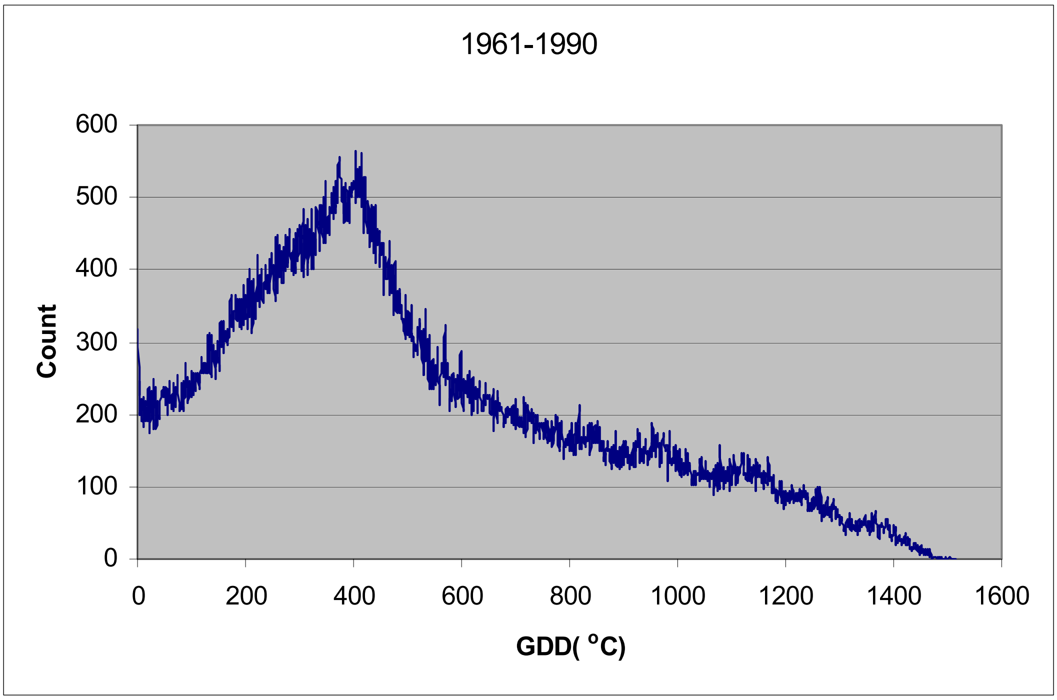

Figure 1 Histogram of the area distribution of the GDD in Norway for the normal period.

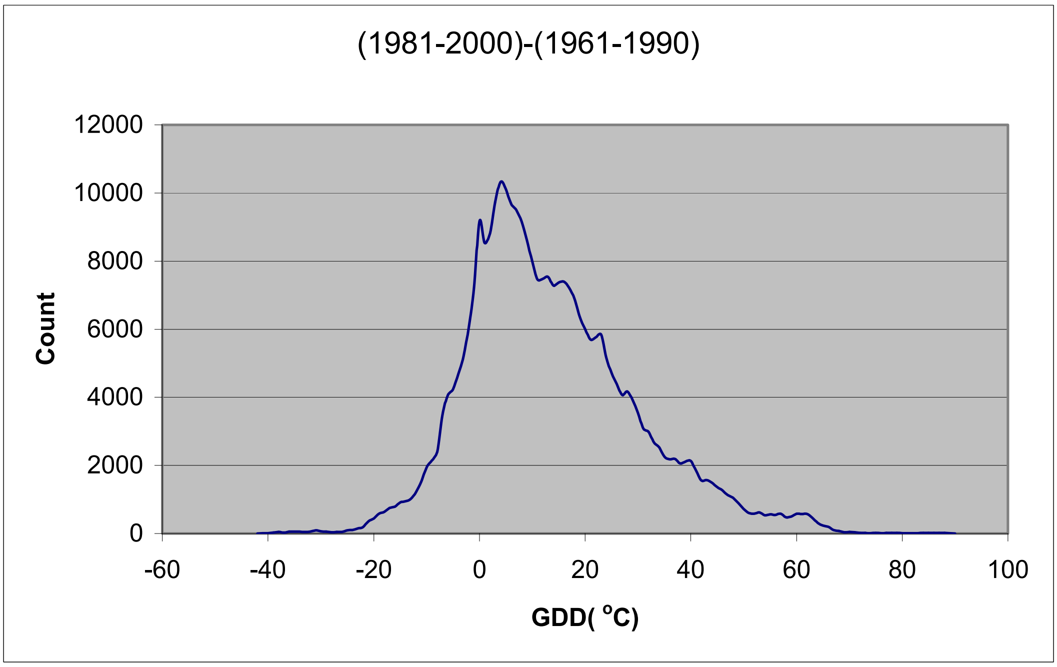

Figure 2 Histogram of the area distribution of the changes in GDD in Norway for the twenty-year period compared to the normal period.

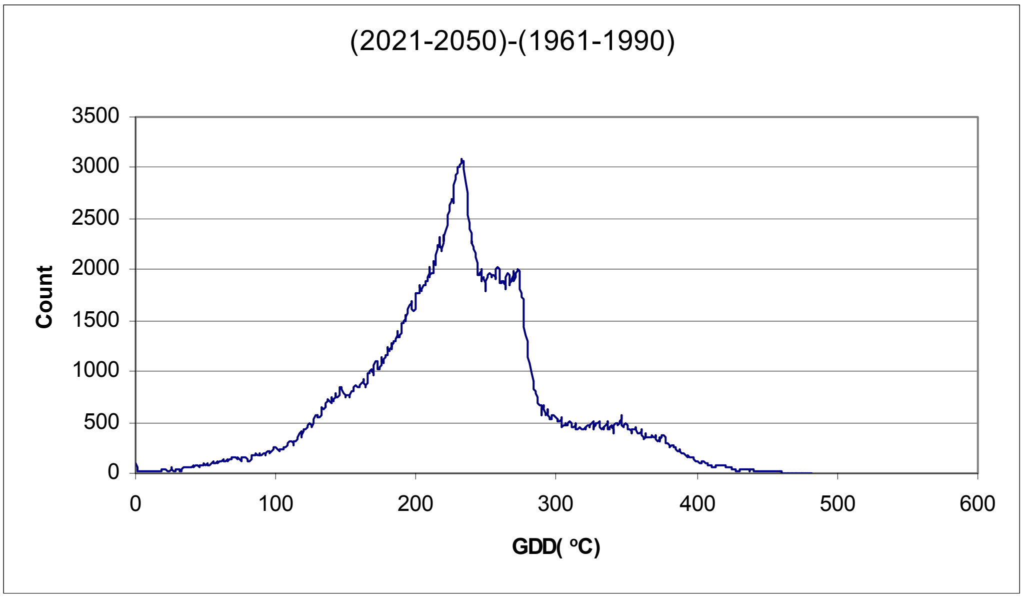

Figure 3 Histogram of the area distribution of the changes in GDD in Norway for the scenario period compared to the normal period.

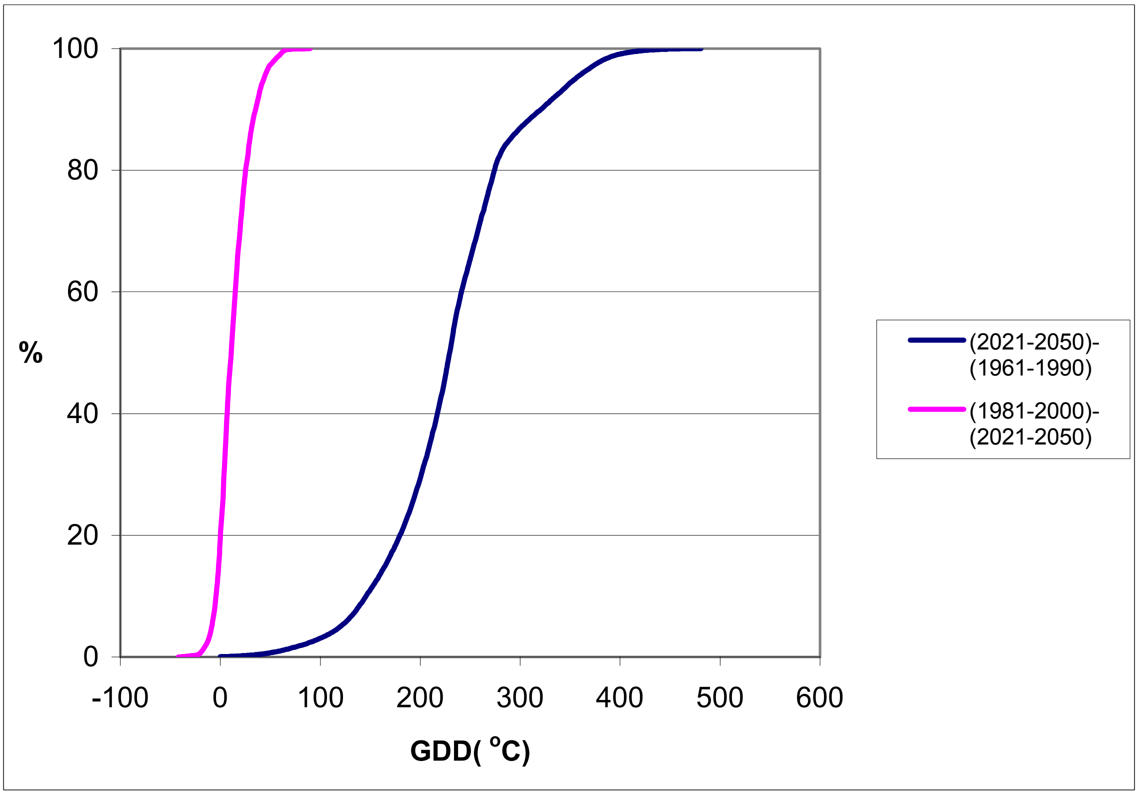

Figure 4 Cumulative frequency curve of the area distribution of the changes in GDD in Norway for the twenty-year period (1981-2000) and the scenario period compared to the normal period.

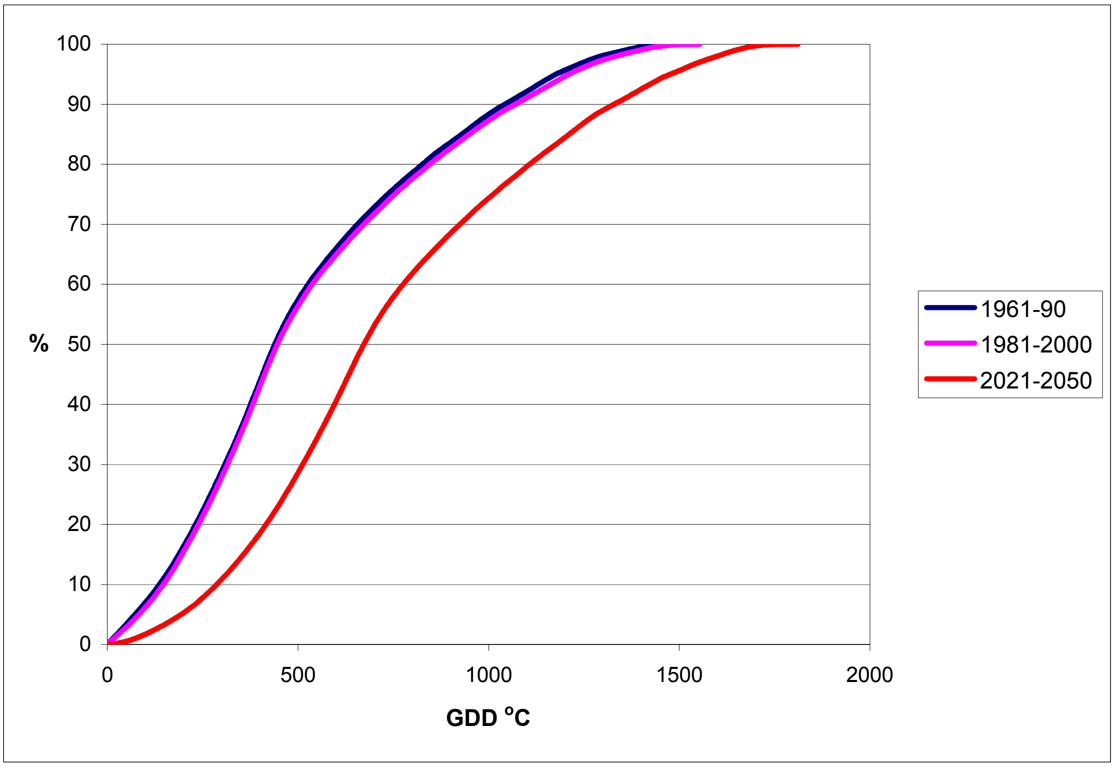

Figure 5 **Cumulative frequency curves of the area distribution of the GDD in Norway in the normal period (1961-1990), the twenty-year period (1981-2000) and the scenario period.**