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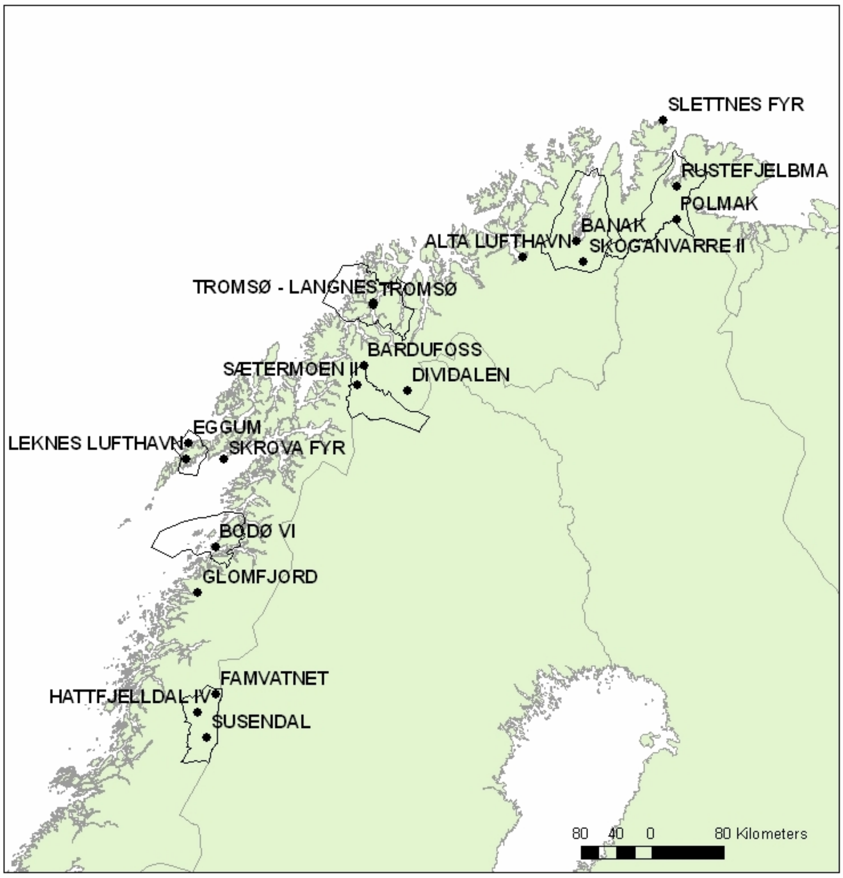
Climate

Climatic basis for vulnerability studies of the agricultural sector in selected municipalities in northern Norway

Inger Hanssen-Bauer, Hans Olav Hygen and Torill Engen Skaugen



Selected municipalities: Hattfjelldal, Bodø, Vestvågøy, Bardu, Tromsø, Porsanger, Tana

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Abstract

A large number of temperature and precipitation projections for the 21st century for the municipalities Hattfjelldal, Bodø, Vestvågøy, Bardu, Tromsø, Porsanger and Tana in northern Norway are presented and compared to historical climate observations in the same municipalities. Though temperatures have increased during the last 110 years in all municipalities, the projected trends for the 21st century are even larger. For precipitation, the projected increase is in general of the same magnitude as the increase which has been measured during the 20th century.

An example projection was used to calculate possible future changes in growing season, growing degree days and snow season towards 2021-2050 in the selected municipalities. An increase in growing season for grass of 1 to 4 weeks was calculated most places, while the increase in growing degree days varies from below 100 to above 200. The example scenario gave a 3 to 7 weeks reduced snow season towards the mid-century most places. A slightly smaller reduction was calculated in some mountain areas, and an even longer reduction in a few northern coastal localities. Local projections for frequencies of days when the temperature crosses 0 ^{o}C have not been produced. However, taking into consideration the presented temperature projections, this frequency will probably tend to decrease in autumn and spring (especially at coastal sites) and increase in winter (especially at inland sites).

It should be emphasized that there is considerable uncertainty concerning local future climate projections, and that the example projection mentioned above only shows one of several possible future developments.

Keywords

Climate statistics, climate change, growing season, snow season, Norwegian municipalities

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1 Background

Climatic change may lead to challenges, but also provide new opportunities for the agriculture sector in the Arctic (e.g. ACIA, 2005). To be prepared for challenges as well as possibilities, it is useful both to analyze the past and to make projections for the future climate conditions. The project ”Climate Change Vulnerability Capacity in the Agricultural Sector in Northern Norway”, which is conducted by Nordland Research Institute, and where CICERO, Bioforsk and met.no are contributors, aims at investigating the vulnerability capacity in selected municipalities in Northern Norway. This report gives some basic climate information for these municipalities.

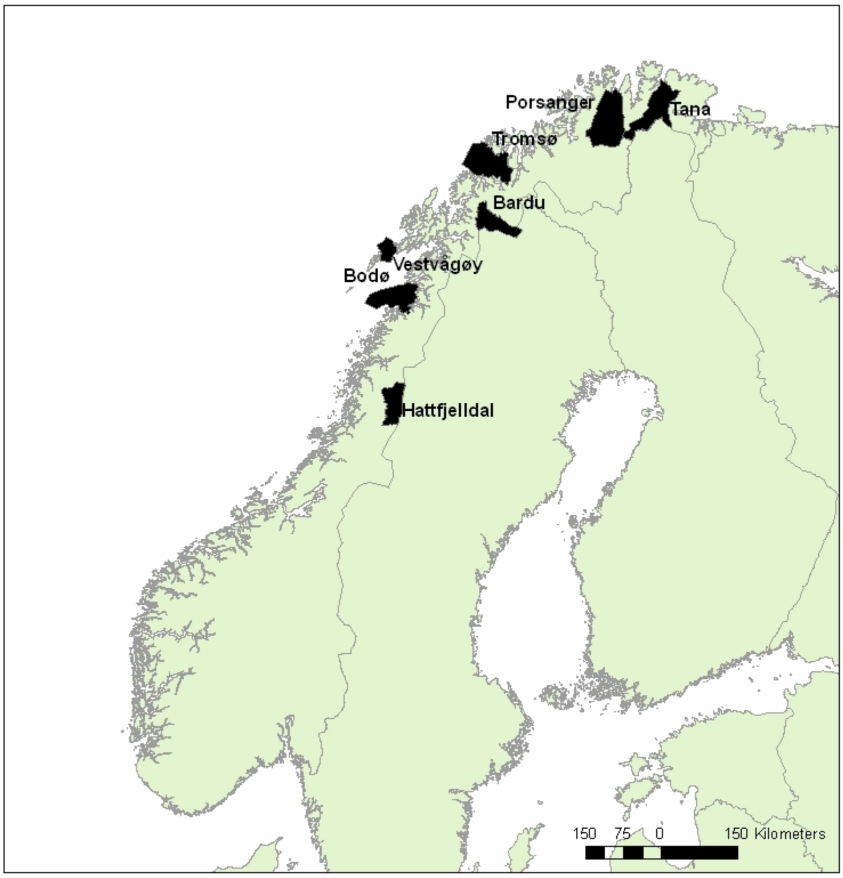
2 Research area and meteorological stations

The following seven municipalities were selected for this project (in order from south to north): Hattfjelldal, Bodø, Vestvågøy, Bardu, Tromsø, Porsanger and Tana (Figure 1 a)

The meteorological stations used to describe present and past climate in the municipalities (Figure 1 b) are listed in Table 1. Whenever possible, stations situated in the selected municipalities were used. However, additional stations from neighboring municipalities were applied when there was a lack of representative and sufficiently long high quality observational series in the actual municipalities.

Table 1. Meteorological stations applied in the present analyses. The columns give station number, station name, period of observations, altitude above sea level, municipality, latitude and longitude. The last 4 columns indicate if temperature (T) and/or precipitation (R) observations were applied to describe present and past climate, and if future projections have been calculated for T and/or R. The background colors indicate which municipality the stations were used to describe: Red=Hattfjelldal, Orang=Bodø, Yellow=Vestvågøy, Green=Bardu, Cyan=Tromsø, Blue=Porsanger, Purple=Tana

St. No	STATION NAME	PERIOD From	To	ALT. masl	MUNICIPALITY	LAT	LON	DATA USED Tobs	Robs	Tproj	Rproj
77650	HATTFJELLDAL	1962	1972	380	HATTFJELLDAL	65.6	14.0	Yes	-	-	-
77850	SUSENDAL	1895	-	265	HATTFJELLDAL	65.4	14.3	Yes	Yes	Yes	Yes
78770	FAMVATNET	1968	-	510	HATTFJELLDAL	65.8	14.5	Yes	Yes	-	-
80700	GLOMFJORD	1916	2010	39	MELØY	66.8	14.0	Yes	-	-	-
82290	BODØ	1953	-	11	BODØ	67.3	14.4	Yes	Yes	Yes	Yes
85380	SKROVA LIGHTH	1933	-	11	VÅGAN	68.2	14.7	Yes	Yes	-	-
85560	LEKNES AIRPORT	1972	-	26	VESTVÅGØY	68.2	13.6	-	Yes	-	-
86140	EGGUM	1994	2006	7	VESTVÅGØY	68.3	13.7	Yes	Yes	Yes	Yes
89350	BARDUFOSS	1940	-	76	MÅLSELV	69.1	18.5	Yes	Yes	-	-
89500	SÆTERMOEN	1952	-	114	BARDU	68.9	18.3	-	Yes	-	Yes
89950	DIVIDALEN	1912	2009	228	MÅLSELV	68.8	19.7	Yes	-	Yes	-
90450	TROMSØ	1920	-	100	TROMSØ	69.7	18.9	Yes	Yes	Yes	Yes
90490	TROMSØ - LANGN	1964	-	8	TROMSØ	69.7	18.9	Yes	Yes	-	-
93140	ALTA AIRPORT	1963		3	ALTA	70.0	23.4	Yes	-	-	-
95270	SKOGANVARRE	1955	1998	74	PORSANGER	69.8	25.1	Yes	Yes	Yes	-
95350	BANAK	1957	-	5	PORSANGER	70.1	25.0	Yes	Yes	-	Yes
96400	SLETTNES LIGHTH	1927	-	8	GAMVIK	71.1	28.2	Yes	-	-	-
96800	RUSTEFJELBMA	1951	-	10	DEATNU-TANA	70.4	28.2	Yes	Yes	Yes	-
96930	POLMAK	1980	1998	30	DEATNU-TANA	70.1	28.0	-	Yes	-	Yes



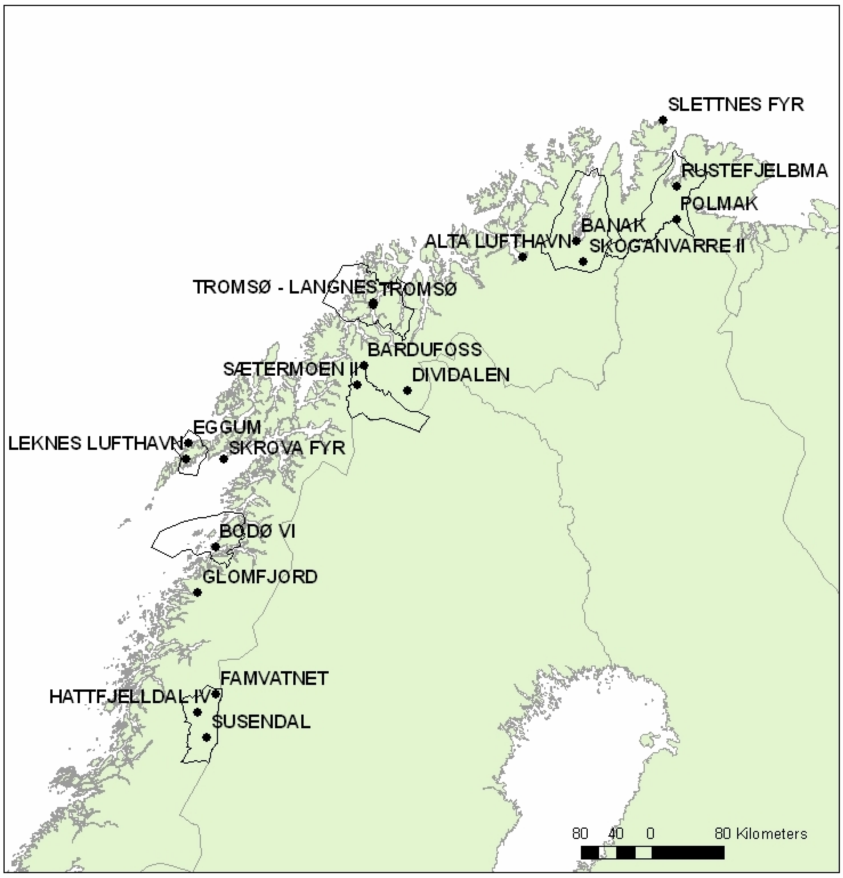


Figure 1. Maps showing location of a) municipalities, b) meteorological stations

3 Methods, data and definitions

The historical climate information is based upon analyses of data from the Norwegian Meteorological Institute's (met.no's) station network. The original climate data, the 1961-1990 climatology, and some homogenized time-series, are available through eKlima (http://eKlima.met.no). The long-term series of precipitation and temperature are, whenever available, homogenized series. In municipalities where no long time-series exist, locally adjusted regional series (Hanssen-Bauer 2005) have been used to prolong the observational series. The historical series are presented as annual/seasonal values. Based on these, we present so-called "lowpass-filtered series", where variability on 10-year and 30-year timescales are shown (Hanssen-Bauer and Nordli 1998). Linear trends are used to show changes on a 100 year timescale.

There are several definitions of *growing season* (Engen-Skaugen et al. 2007). In the present report, we use the term about the thermal growing season for grass, which is here defined as number of days per year with average temperature above 5 ^{o}C. *Growing degree day sum* is the annual sum of daily degree days above 5 ^{o}C. The *snow-season* is defined as the number of days when 50% or more of the ground is covered by snow.

The future projections given in the present report are based on Hanssen-Bauer et al. (2009). "High", "medium" and "low" projected linear trends for the 21st century were there given for temperature and precipitation, and for different Norwegian regions. These trends summarize the results from a large number of climate simulations (72 for temperature, 22 for precipitation) calculated from different emission scenarios (B2, A1b and A2), various global models and downscaling techniques. The "medium trend" gives the average of these ensembles, the "high" gives the 90 percentile, and the "low" the 10 percentile. Thus, it is not impossible that the future climate end up over "high" or below "low". At average, however, eight of ten projections typically show trends between the low and the high. Note that inter-annual and decadal scale variability is expected to occur around a future linear trend, and the projected trends only aim to show possible changes of long-term averages.

The future projections of growing season and snow conditions depend on more spatially detailed projections than the above mentioned ensembles. One scenario, valid for the period 2021-2050, is thus further elaborated as described by Engen-Skaugen (2007), and used to calculate growing- and – through a hydrological model – snow indices (Schuler et al 2005). As only one climate projection is applied in these calculations, these results should be considered only as an example of possible future developments, rather than as a prediction. The ensemble projections of temperature and precipitation still offer the possibility of judging the representativity of the example scenario.

4 Temperature and precipitation climatology in the area

Figure 2 shows the 1961-1990 average winter (Dec-Jan-Feb) and summer (Jun-Jul-Aug) temperature. During winter in Northern Norway, there is a strong gradient from a relatively mild coastal zone (average temperatures typically 0 to -5 ^{o}C) to cold inland areas (average below -10 ^{o}C in many localities). In summer, the contrasts are smaller, and the warmest sites (average above +10 ^{o}C) are found in some low altitude areas in inland and fiords, and also in the southernmost coastal areas, while mountain areas and the northern coast are the colder.

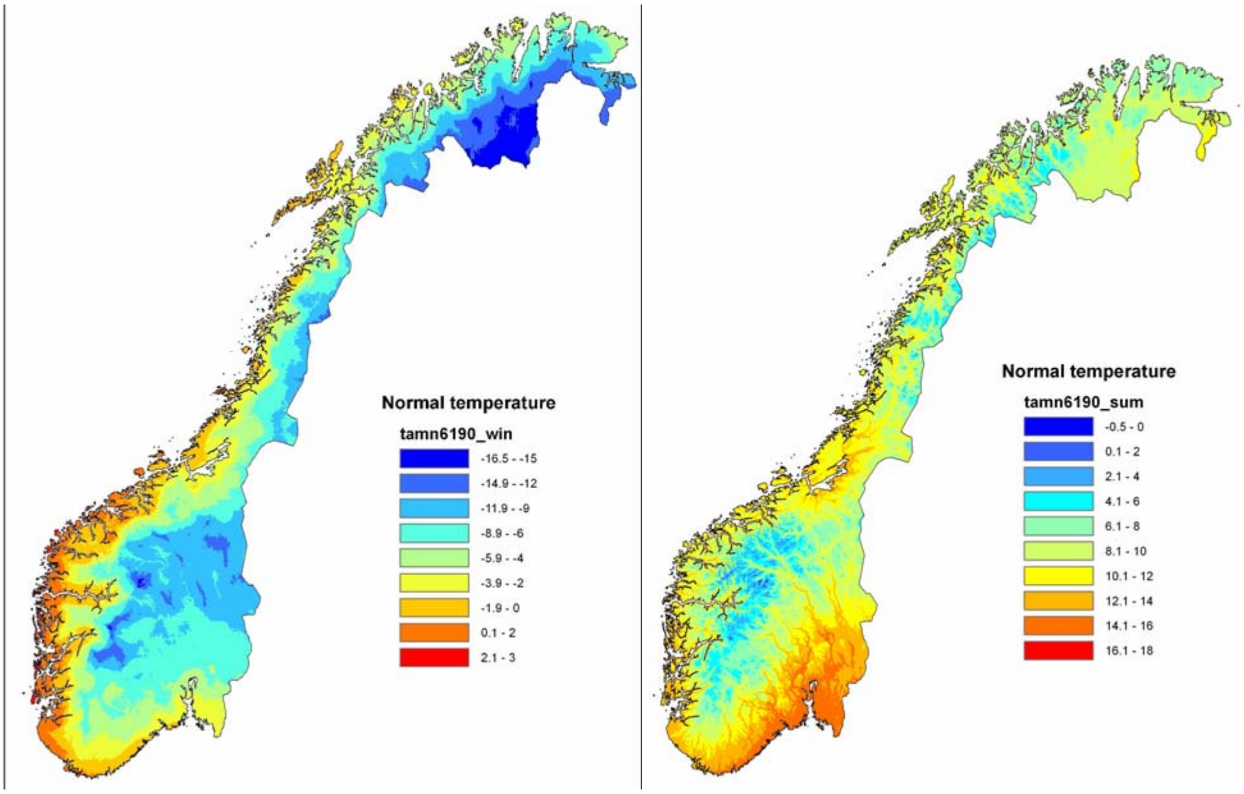


Figure 2 Average seasonal temperature 1961-1990 in Northern Norway. a) Winter, b) Summer

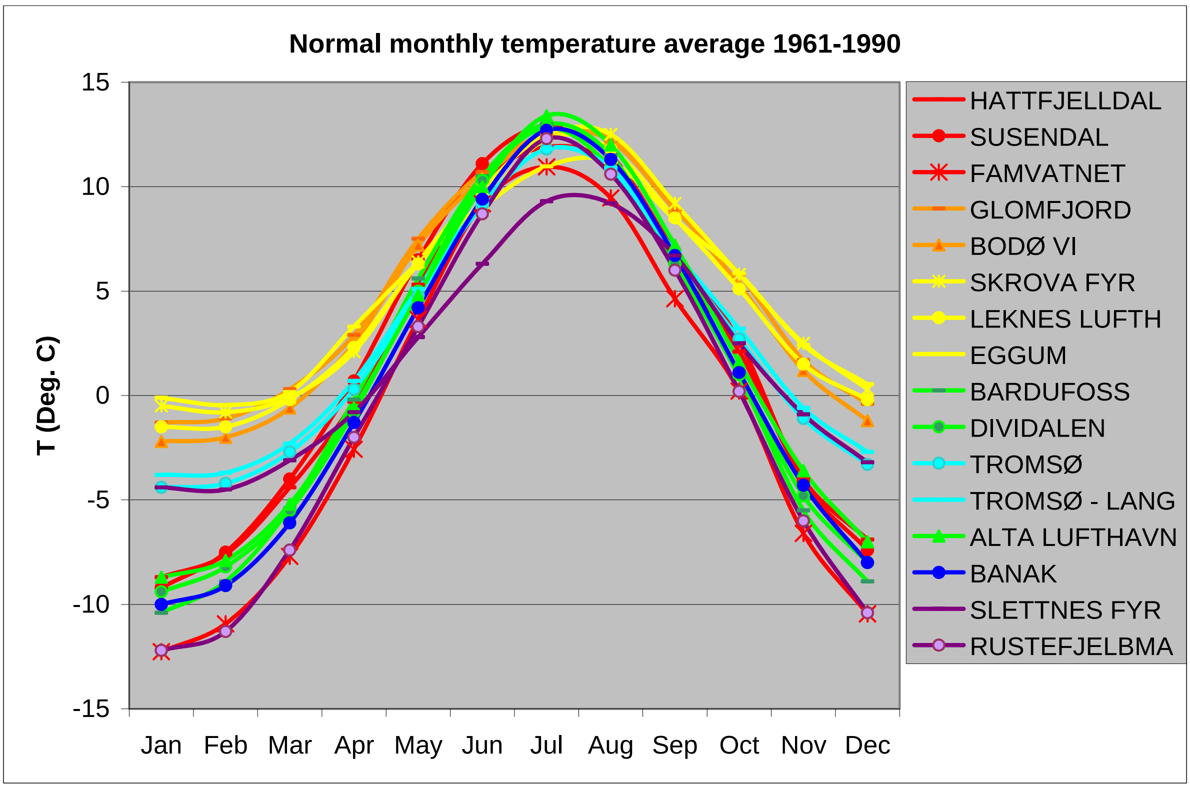
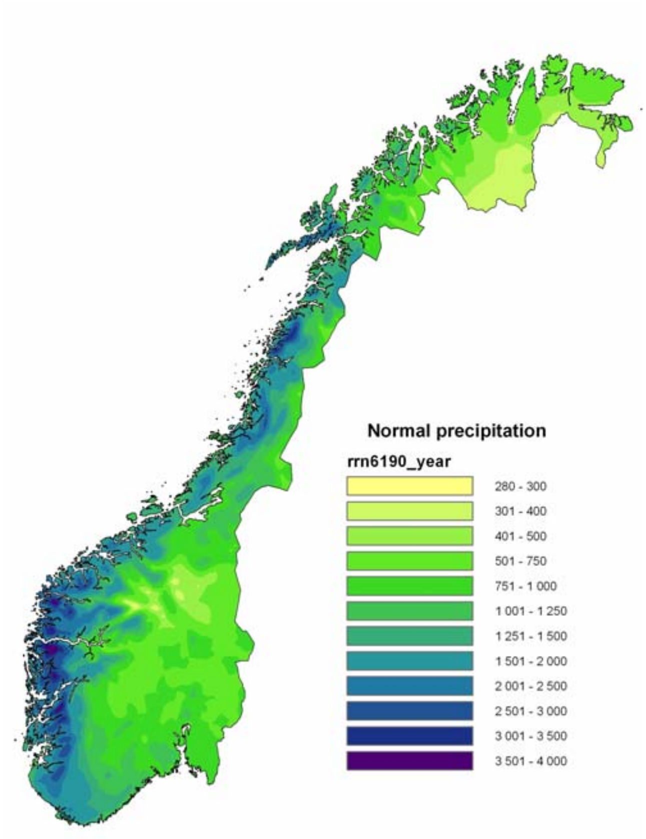


Figure 3 Monthly temperature average 1961-1990 at the selected meteorological stations.



This is seen also from the monthly 1961-1990 average temperatures for the selected temperature stations (Figure 3).

Inland stations as Hattfjelldal and Dividalen, and Rustefjelbma, which is situated in the inner part of a fiors, are considerable colder during winter than the coastal stations Bodø, Skrova and even Slettnes (the northernmost of all the stations). In summer, Slettnes is the coldest station. The differences between the other are rather small in summer, but note that spring and autumn are warmer at the southerly coastal stations.

Figure 4. Average annual precipitation 1961-1990

Figure 4 shows the average annual precipitation in Norway during 1961-1990. In Northern Norway the highest values (>2000 mm) are found along the west coast, especially in the southern part. The lowest values (300-400 mm) are found in the northern inland areas.

As for temperature, contrasts are larger in winter than in summer, as the arid northern inland areas have their maximum precipitation in summer, while the rainy west coast has precipitation minimum in late spring/early summer.

The average monthly precipitation for the period 1961-1990 for the selected precipitation stations confirms that the contrasts are larger in winter than in summer (Figure 5). Most of the stations show a precipitation maximum in autumn (October), and also rather high values during winter. Exceptions are the northernmost inland and inner fiord stations Dividalen, Skoganvarre, Banak, Rustefjelbma and Polmak, which have maximum in July. These are also the driest stations in the area.

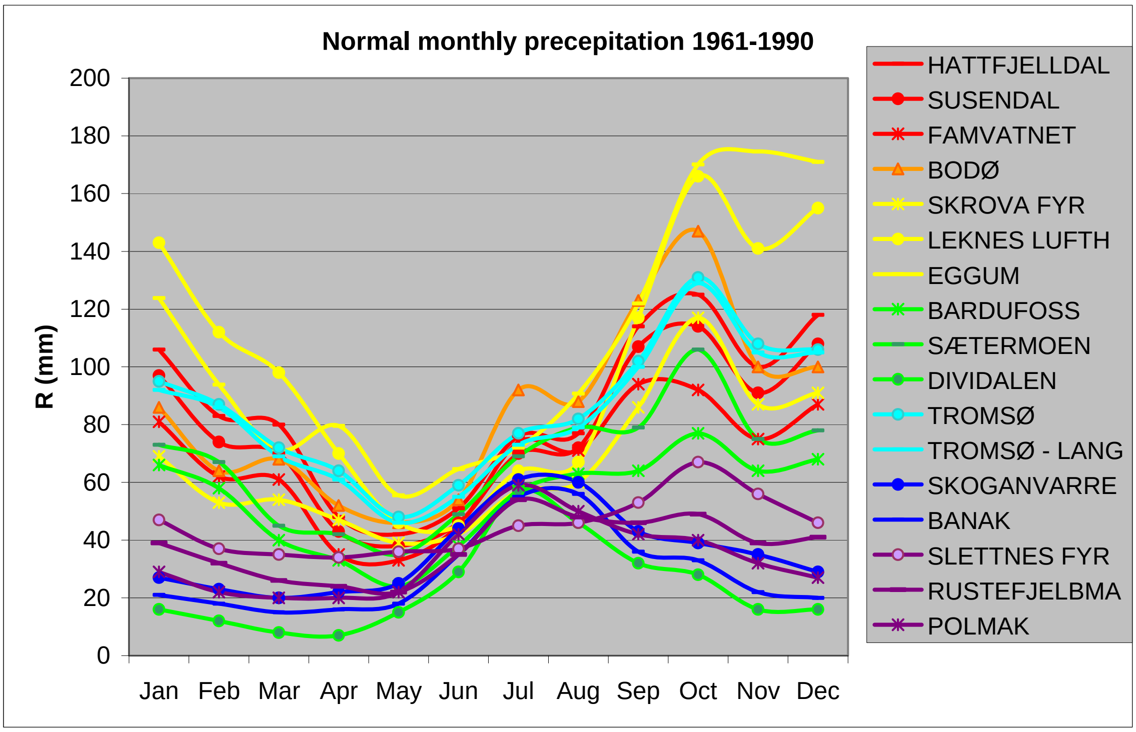


Figure 5 Monthly precipitation average 1961-1990 at the selected meteorological stations.

5 Climate in the individual municipalities

5.1 Hattfjelldal

Hattfjelldal is an inland municipality southeast in Nordland County (Fig. 1a), with snowy winters and relatively short summer. The area of Hattfjellfdal is 2683,2 km^2, of which much is occupied by mountainous terrain and lakes. Data from the three stations Susendal, Hattfjelldal and Famvatnet are used in the present analyses. Susendal (265 m.a.s.l.) is chosen as the main meteorological station in the municipality. The precipitation measurements at Susendal started in 1895, and though the temperature series only goes back to 1976, it has been possible to prolong the series of annual and seasonal temperature back to 1900 by using neighboring stations and a scaling technique .

5.1.1 Temperature

Figure 6 shows that January at average is the coldest month of the year, with a mean temperature of about -9 ^{o}C at Susendal. July is at average is the warmest month, with a mean temperature of about +13 ^{o}C. The variations around these mean temperatures are, however large, and the lowest minimum-temperature that has been measured at the station is about -40^{o}C, while the highest maximum-temperature is about +30^{o}C. There is thus a span of almost 70 ^{o}C from the lowest to the highest measured temperature. The average monthly temperature mean is above 0 ^{o}C from April to October, but frost nights may occur even in July.

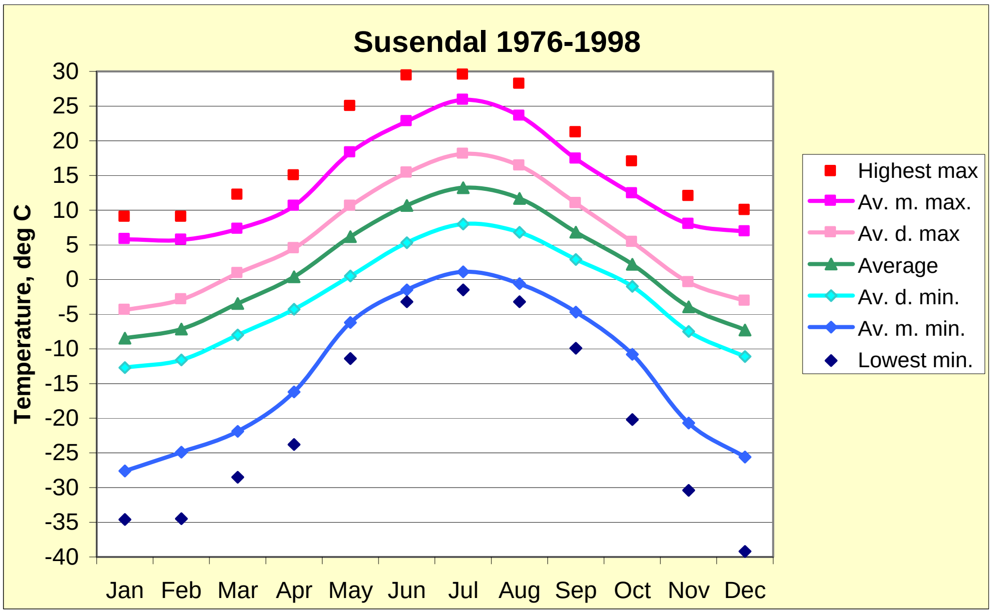


Figure 6. Monthly average and extreme temperatures at Susendal. ”Highest max.”/”Lowest min.” are the most extreme temperature measured in the specific month during the given time period, ”Av. m. max.”/ ”Av. m. min.” are the average monthly extremes, while “Av. d. max.”/ “Av. d. min.” are the average daily extremes. “Average” is the monthly mean.

Concerning geographical representativity of the temperature measurements at Susendal, it should be kept in mind that the altitude of this station is low compares to the average for the municipality, and that it is seen from Figures 3 that the higher situated station Famvatnet (510 m.a.s.l.) typically is 2-3.5 degrees colder at a monthly basis, with maximum difference in the early spring. Also the time-series of annual mean temperatures in Figure 7 illustrate that Famvatnet is colder than Susendal. Still, the series are highly correlated, thus years that are relatively cold at Susendal are also cold at Famvatnet.

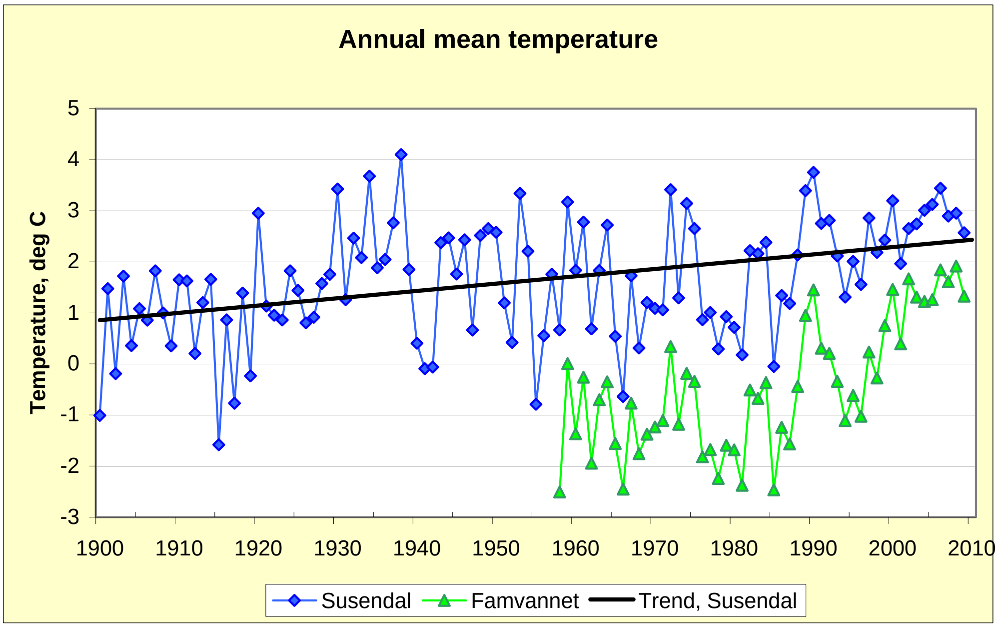


Figure 7. Annual mean temperature series for Susendal and Famvatnet. For Susendal, the linear trend from 1900 to 2009 is also shown.

The inter-annual temperature variation at Susendal is large: The lowest value in the 110 year long composite series is -1.6 ^{o}C in 1915, and the highest is + 4.1 ^{o}C in 1938. Even though the warmest year occurred in the first half of the series, the large number of mild years during the last couple of decades leads to a statistically significant positive trend in the series. The linear trend in Figure 7 is + 0.14 ^{o}C per decade, or about 1.5 ^{o}C over the 110 year period. All the seasonal trends are also positive over the period 1900 to 2009 (Table 2).

Table 2 also shows projected future temperature trends at Susendal. These trends are also shown in Figure 8. For definition of low, medium and high projections: See chapter 3 and Figure 8 label!

Note that though the observed trends during the 20^{th} century are well below the trends projected for the 21^{st} century, the annual and seasonal trends observed during the latest decades have been within or close to the range of projected trends (Figure 8).

Table 2. Observationally based temperature trends from 1900 to 2009, and medium, low and high projected trends for the 21^{st} century at Susendal.

SUSENDAL		Unit: ^{o}C per decade Ann	Win	Spr	Sum	Aut
Trends 1900 to 2009		+0.14	+0.16	+0.16	+0.09	+0.16
Projected trends from 1961-1990 to 2071-2100	Medium	+0.31	+0.38	+0.35	+0.20	+0.31
	Low	+0.20	+0.25	+0.24	+0.12	+0.20
	High	+0.42	+0.55	+0.47	+0.30	+0.41

One specific climate projection (“example projection”) is used to calculate possible changes in growing season and snow season towards the mid-century. Figure 8 shows that in Susendal, this example projection is close to the medium temperature projection in summer and autumn, between medium and low in spring, and even below the low one winter.

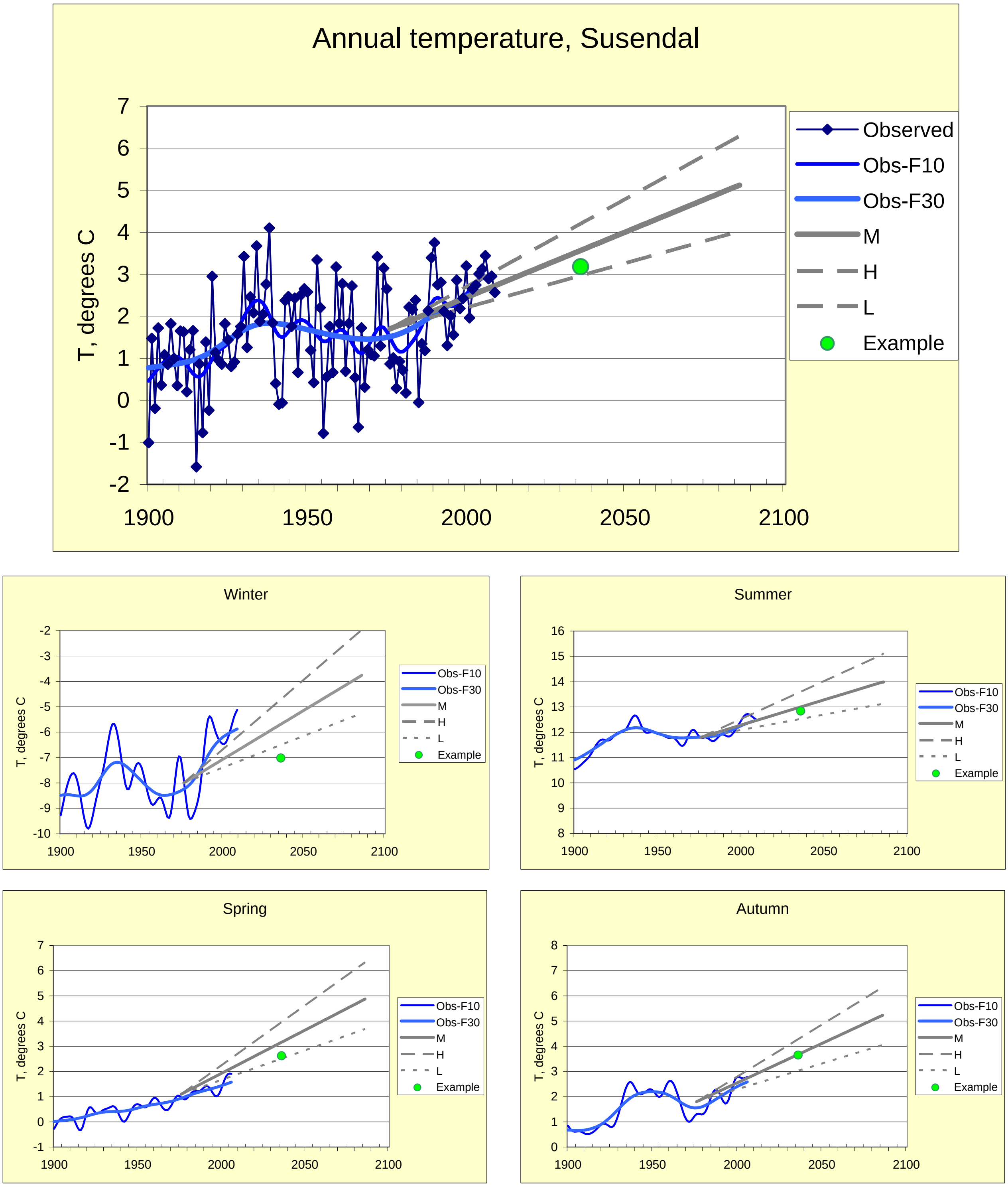


Figure 8. Historical temperature series and projected future trends at Susendal on annual and seasonal basis. The historical series are given as filtered curves showing variability on 10-year and 30-year timescales. The annual are also given as single values. The future trends are based upon 72 temperature projections. The medium trend (M) gives the average, the high (H) gives the 90 percentile, and the low (L) the 10 percentile of these projection. The example projection which is used for detailed calculations is shown as a green point.

5.1.2 Growing season

The thermal growing season for grass is defined in chapter 3. Figure 9, left panel, shows that in the period 1961-1990, some parts of Hattfjelldal had 4-5 months growing season, while other places had only 1-2 months.

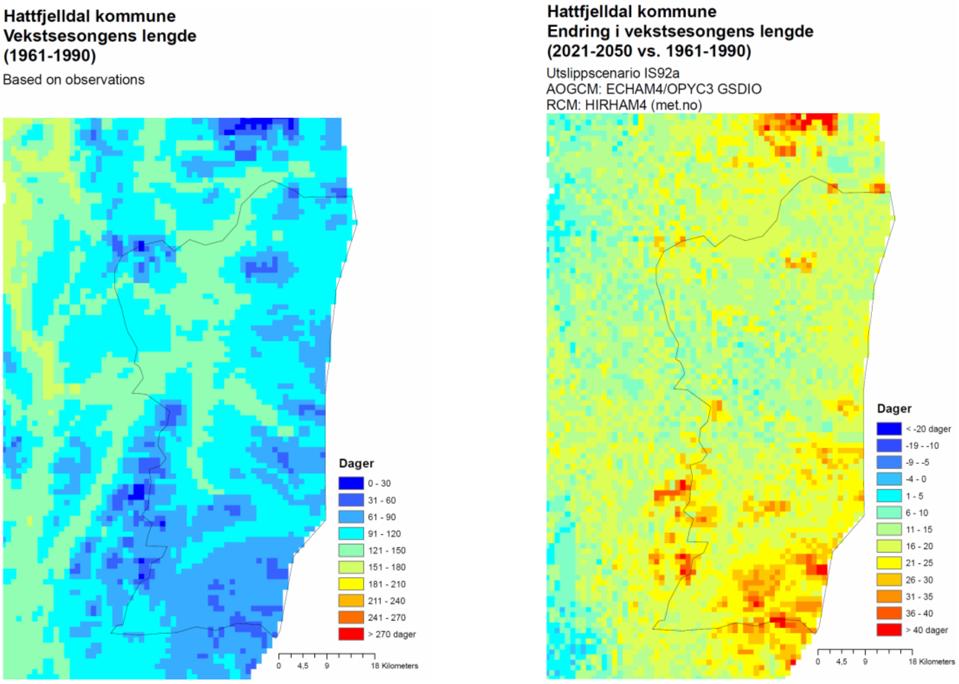


Figure 9. Average length of the growing season in the period 1961-1990 based upon observations (left), and projected change of the growing season from 1961-1990 to 2021-2050 (right) in Hattfjelldal municipality.

The growing season was shortest in the mountainous southern part of the municipality, while it was longest in some of the northwestern areas.

The example projection for the period 2021-2050 (right panel of Figure 9), shows an increase in the growing season of 1-3 weeks in most of the municipality, but 4-5 weeks in the southern areas. The increase is thus largest in areas where the growing season presently is shortest.

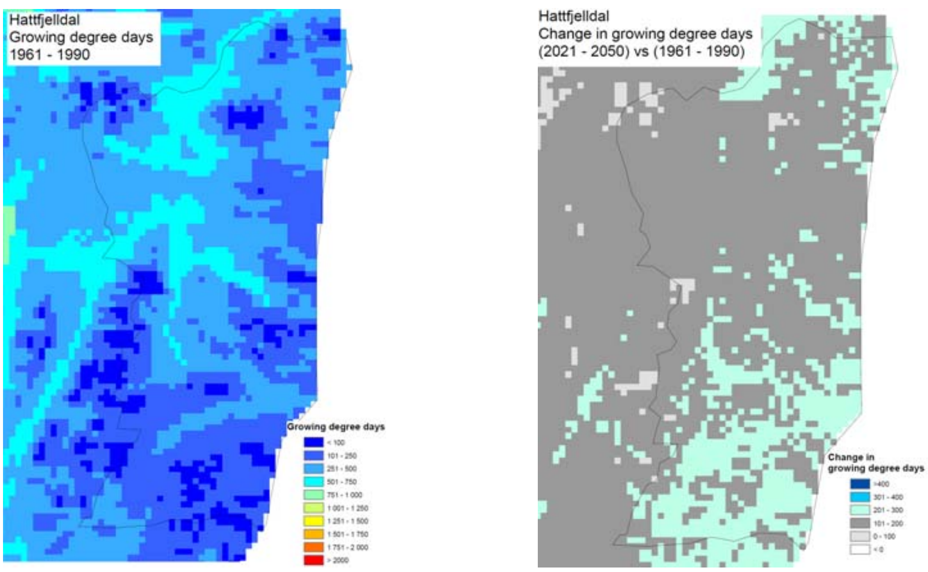


Figure 10. Average annual sum of growing degree days in the period 1961-1990 based upon observations (left), and projected changes from 1961-1990 to 2021-2050 (right) in Hattfjelldal municipality.

The 1961-1990 climatology for growing degree-days (Figure 10, left panel) show the same pattern as growing season, with lowest values (<250 over some areas) in the mountainous southern part of the municipality, and highest values (>500 in some valleys) in the northwestern areas.

The example projection for the period 2021-2050 (right panel of Figure 10), shows an increase in average sum of growing degree-days of 100-300 in most of the municipality. Again, the projected increase is largest in the southern areas.

5.1.3 Precipitation

The 1961-1990 normal annual precipitation at Susendal was 700 mm, while it was 810 mm at Famvatnet, where the altitude is higher. The monthly values at the two stations are rather similar in summer, while Famvatnet gets more precipitation during autumn and winter (Figure 11). As seen from Figures 4 and 5, Hattfjelldal gets less precipitation than more coastal areas in Nordland County, but more than inland areas in Finnmark. Susendal and Famvatnet both have precipitation maximum in autumn, and minimum in late spring.

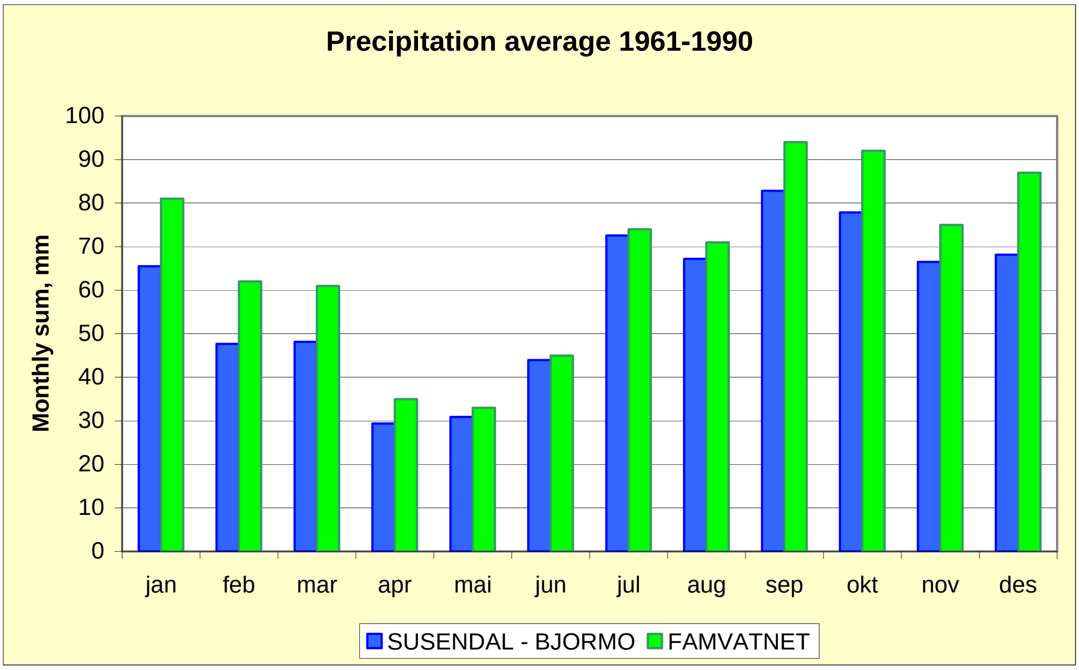


Figure 11. Average monthly precipitation sum for the period 1961-1990 at the stations Susendal and Famvatnet.

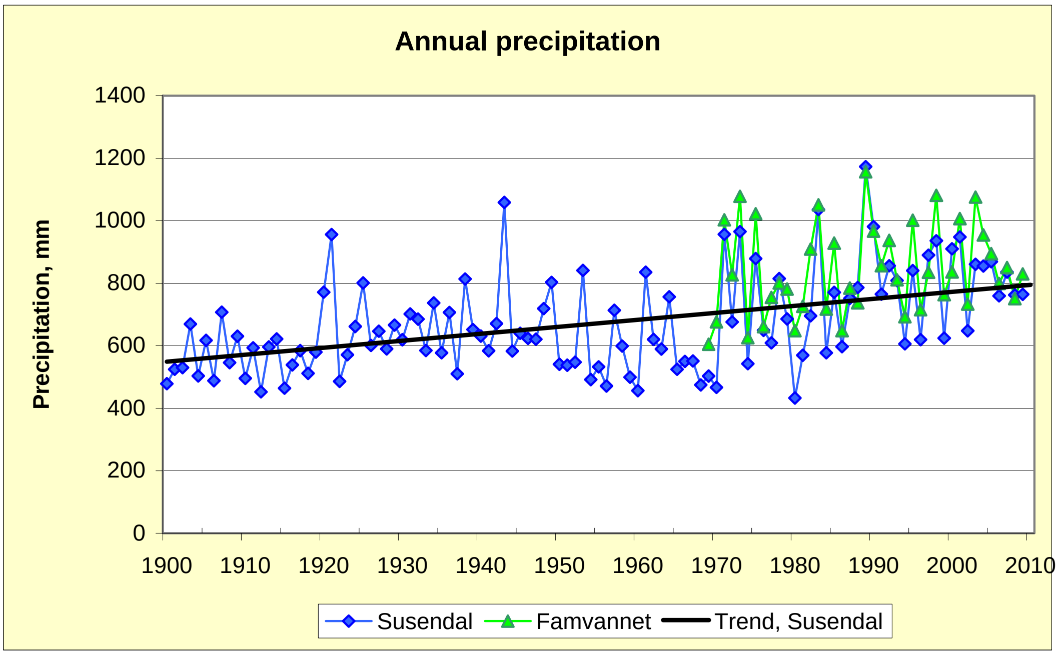


Figure 12 Annual precipitation series for Susendal and Famvatnet. For Susendal, the linear trend from 1900 to 2009 is also shown.

Table 3. Observationally based precipitation trends from 1900 to 2009, and medium, low and high projected trends for the 21st century at Susendal.

SUSENDAL		Unit: % per decade				
		Ann	Win	Spr	Sum	Aut
Trends 1900 to 2009		+3.2	+5.1	+3.5	+0.9	+3.3
Projected trends from 1961-1990 to 2071-2100	Medium	+2.0	+1.7	+2.1	+1.9	+2.6
	Low	+0.1	-1.1	+0.5	+0.7	+0.1
	High	+4.6	+3.3	+5.2	+3.3	+5.5

The annual precipitation at Susendal and Famvatnet are well correlated (Figure 12). The long series from Susendal shows a significant precipitation increase from 1900 to 2009. The linear trend gives an increase of 3.2% per decade, when measured relatively to the 1961-1990 average. Table 3 shows that some increase has taken place in all the seasons, though the increase in summer precipitation is not statistically significant.

In Figure 13, the historical precipitation series is combined with low, medium and high projection for the future. Table 3 and Figure 13 show that in winter, the observed precipitation trend during the last 110 years – and particularly during the latest decades – is larger than the trend projected for the future. This may indicate that most models underestimate the future precipitation trend in this area, but on the other hand, the precipitation increase the later years may be caused by natural variability and thus be of a temporary character. Anyway, it should be noted that the example projection which is used for projecting snow variables for the period 2021-2030 is rather low in winter, when compared with the observed winter precipitation the latest decades.

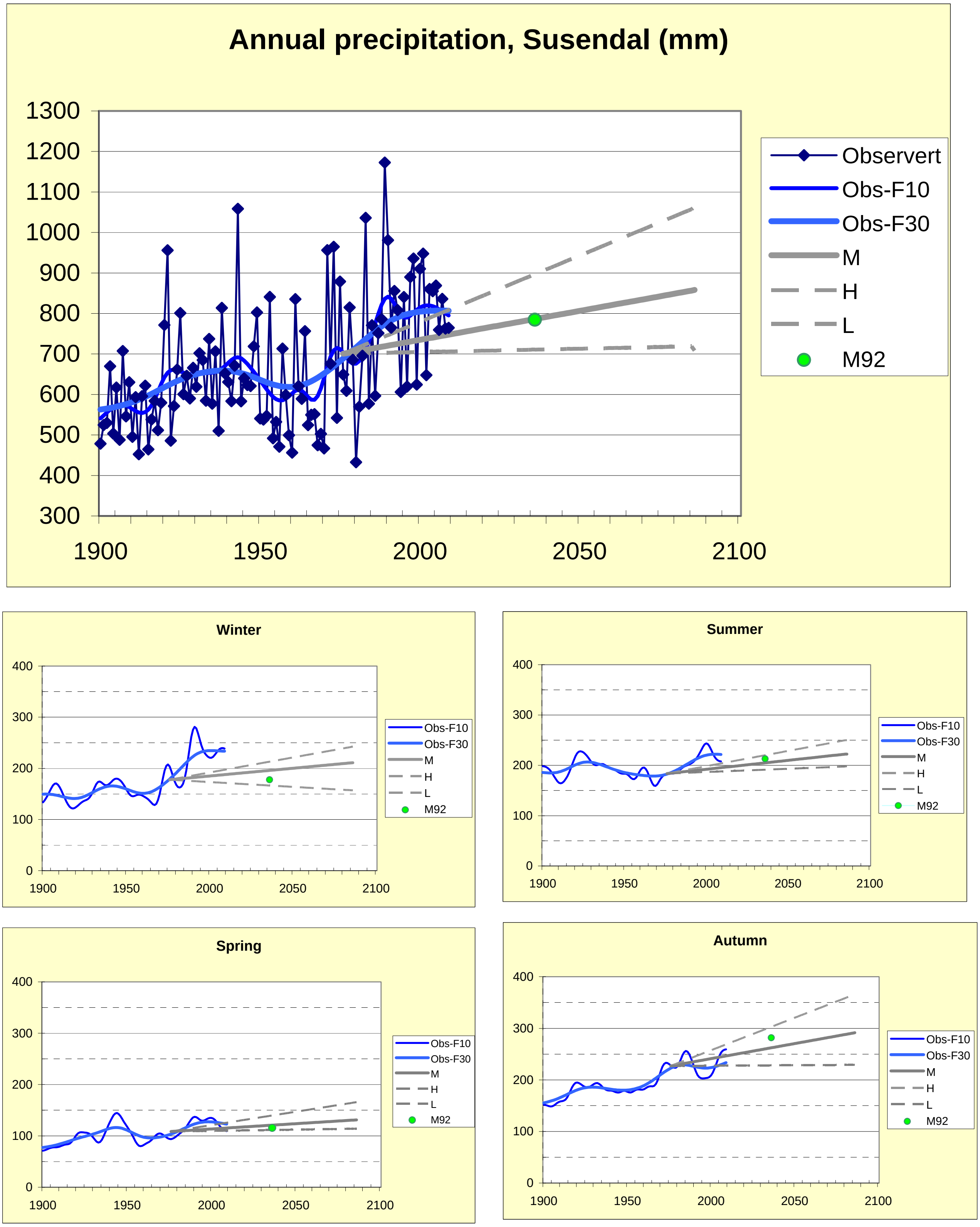


Figure 13. Historical precipitation series and projected future trends at Susendal on annual and seasonal basis. The historical series are given as filtered curves showing variability on 10-year and 30-year timescales. The annual series is also given as single values. The future trends are based upon 22 temperature projections. The medium trend (M) gives the average, the high (H) gives the 90 percentile, and the low (L) the 10 percentile of these projection. The example projection which is used for detailed calculations is shown as a green point.

5.1.4 *Snow season*

The length of the snow season at Susendal has the last 30-40 years varied between 5 and 7 months, (Figure 14, left panel). At Famvatnet, the snow season is typically 1 month longer than at Susendal (Figure 14, right panel). At both stations, there has been a tendency towards shorter snow season since the 1970s, though the interannual variability is large.

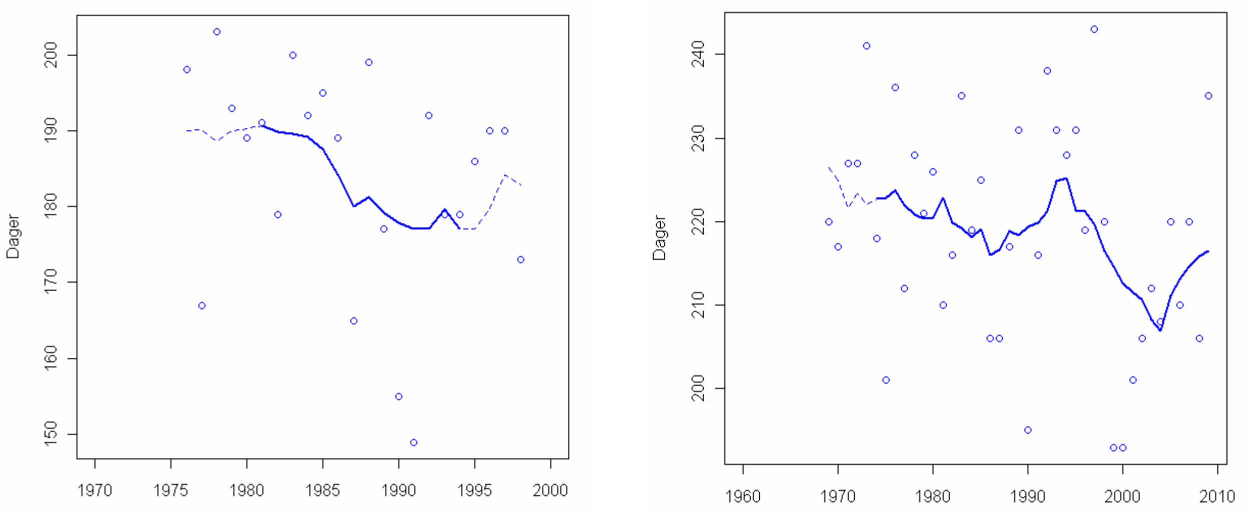


Figure 14. Number of days a year with 50% or more of the ground covered with snow at a) Susendal, b) Famvatnet

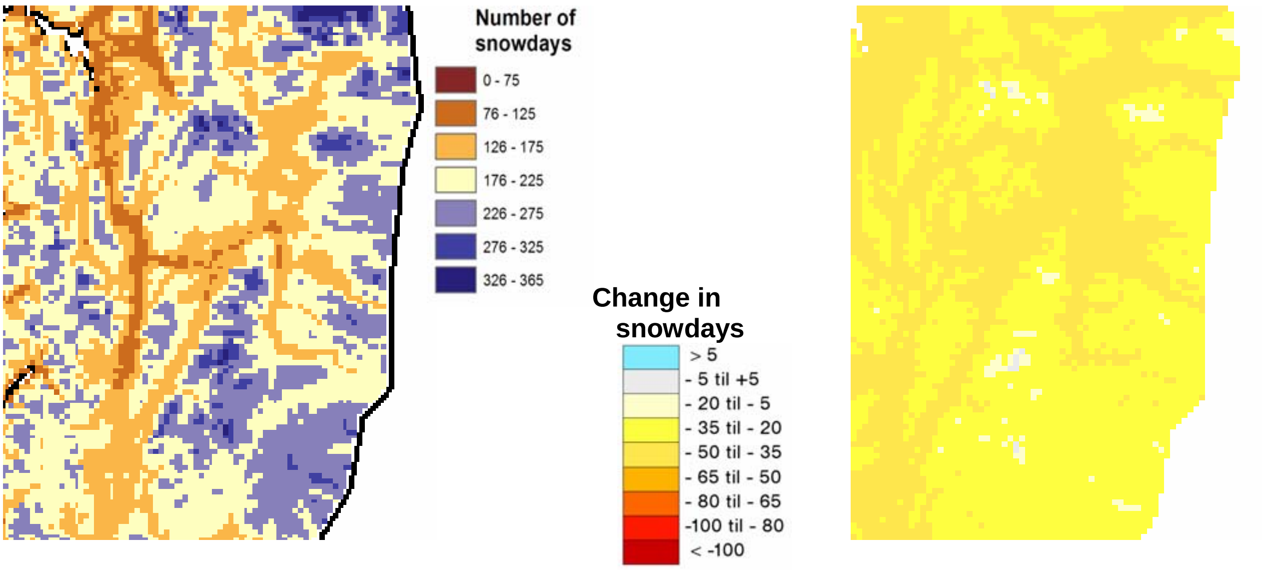


Figure 15. Number of days a year with 50% or more of the ground covered with snow in Hattfjelldal a) In the period 1961-1990, b) projected change to 2021-2050

The left panel of figure 15 shows that most of Hattfjelldal typically has a snow season between 5 and 8 months, though a few sites exist where the snow season is either shorter or longer. According to the right panel, the example scenario gives 3-7 weeks reduced snow season towards the mid-century. The largest decrease is projected in the areas which presently have relatively short snow season.

5.2 Bodø

Bodø is a coastal municipality in Nordland County, including several islands (Fig. 1a). The area of Bodø is 1310,3 km^2, and the altitude varies from 0 almost 1300 m a.s.l. The present main meteorological station in the municipality is Bodø IV (11 m a.s.l.), which started in 1953. In order to investigate the long-term climate variability, the Bodø IV series were combined with series from previous stations in the area. Data from the station Glomfjord (39 m.a.s.l.) were used for comparison, as the series from this station are long and reasonably homogeneous, and thus serve as a quality control.

5.2.1 Temperature

Concerning geographical representativity of the temperature measurements in Bodø, it should be kept in mind that the altitude of this station is low, and that mountain areas in the municipality certainly will have a colder winter climate.

Figure 16 shows that January and February at average are the coldest months of the year, with a mean temperature of about -2 ^{o}C at the the Bodø IV station. July is at average is the warmest month, with a mean temperature of about +12.5 ^{o}C. There is considerable variation around these mean temperatures, but the variation is smaller than at Susendal in the inland municipality Hattfjelldal. The lowest minimum-temperature that has been measured at the station in the period 1961-1990 is -18.5^{o}C, and thus more than 20 ^{o}C warmer than the similar value in Susendal. The highest maximum-temperature is +29^{o}C, and rather similar to Susendal. The average monthly temperature mean is above 0 ^{o}C from April to November, and in July and August there were no incidents of below zero temperatures in the period 1961-1990.

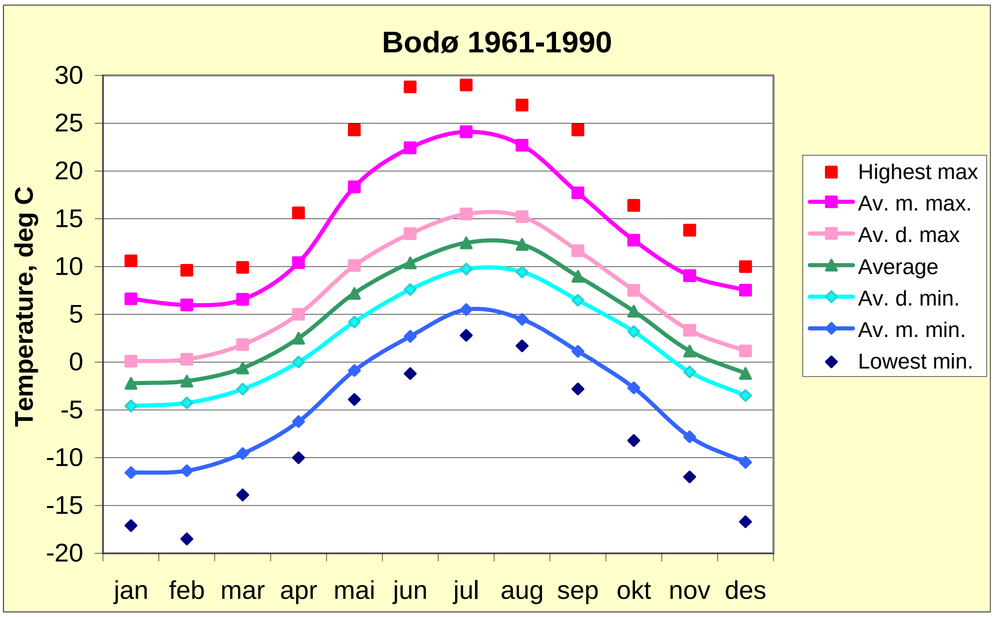


Figure 16. Monthly average and extreme temperatures at Bodø. "Highest max."/"Lowest min." are the most extreme temperature measured in the specific month during the given time period, "Av. m. max."/ "Av. m. min." are the average monthly extremes, while "Av. d. max."/ "Av. d. min." are the average daily extremes. "Average" is the monthly mean.

Figure 17 shows that the annual mean temperature in Bodø and Glomfjord are highly correlated, and that the trends in the series are similar. The inter-annual temperature variation in Bodø is considerable, but still much smaller than in Susendal: The lowest value in the 110 year long composite series is +2.3 ^{o}C in 1915, and the highest is + 6.1 ^{o}C in 1934. Even though the warmest year occurred in the first half of the series, the large number of mild years during the last couple of decades leads to a statistically significant positive trend in the series. The linear trend in Figure 17 is + 0.11 ^{o}C per decade, or about 1.2 ^{o}C over the 110 year period. All the seasonal trends are also positive over the period 1900 to 2009 (Table 4).

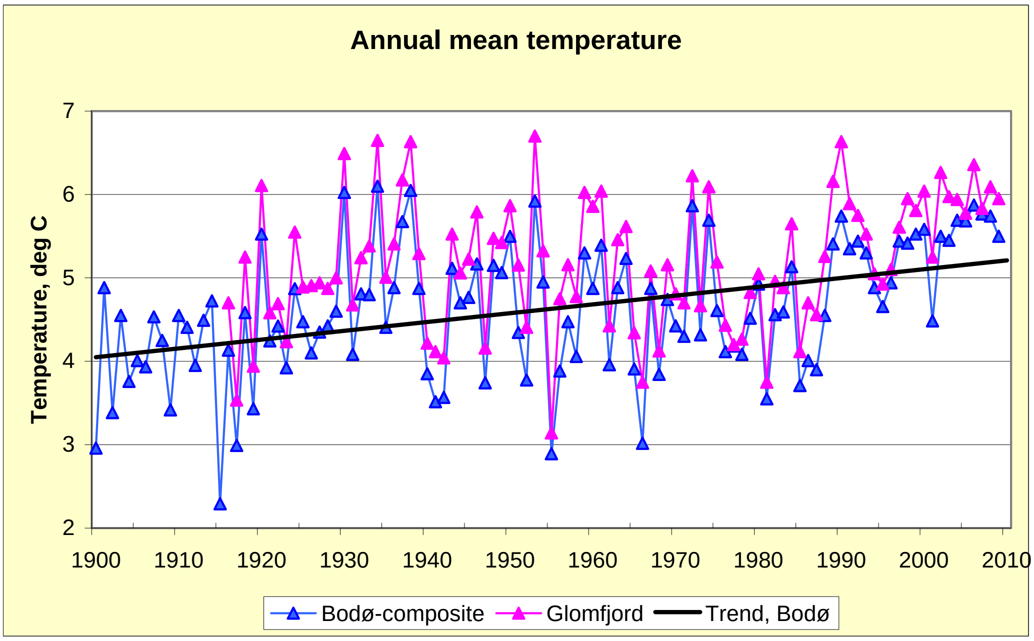


Figure 17. Annual mean temperature series for Bodø and Glomfjord. For Bodø, the linear trend from 1900 to 2009 is also shown.

Table 4. Observationally based temperature trends from 1900 to 2009, and medium, low and high projected trends for the 21st century in Bodø.

BODØ		Unit: ^{o}C per decade Ann	Win	Spr	Sum	Aut
Trends 1900 to 2009		+0.11	+0.10	+0.13	+0.08	+0.12
Projected trends from 1961-1990 to 2071-2100	Medium	+0.31	+0.38	+0.35	+0.20	+0.31
	Low	+0.20	+0.25	+0.24	+0.12	+0.20
	High	+0.42	+0.55	+0.47	+0.30	+0.41

Table 4 shows both observed historical and projected future temperature trends in Bodø. The future projected trends are also shown in Figure 19. For definition of low, medium and high projections: See chapter 3 and Figure 18 label! The projected temperature trends for the 21st century are definitely higher than those observed during the 20th century, however, the annual and seasonal trends which have been observed the latest decades are for the most within the projected range (Figure 18).

One specific climate projection ("example projection") is used to calculate possible changes in growing season and snow season towards the mid-century. Figure 18 shows that in Bodø, this example projection is close to the medium temperature projection in summer and autumn, close to the low in spring, and below the low one in winter.

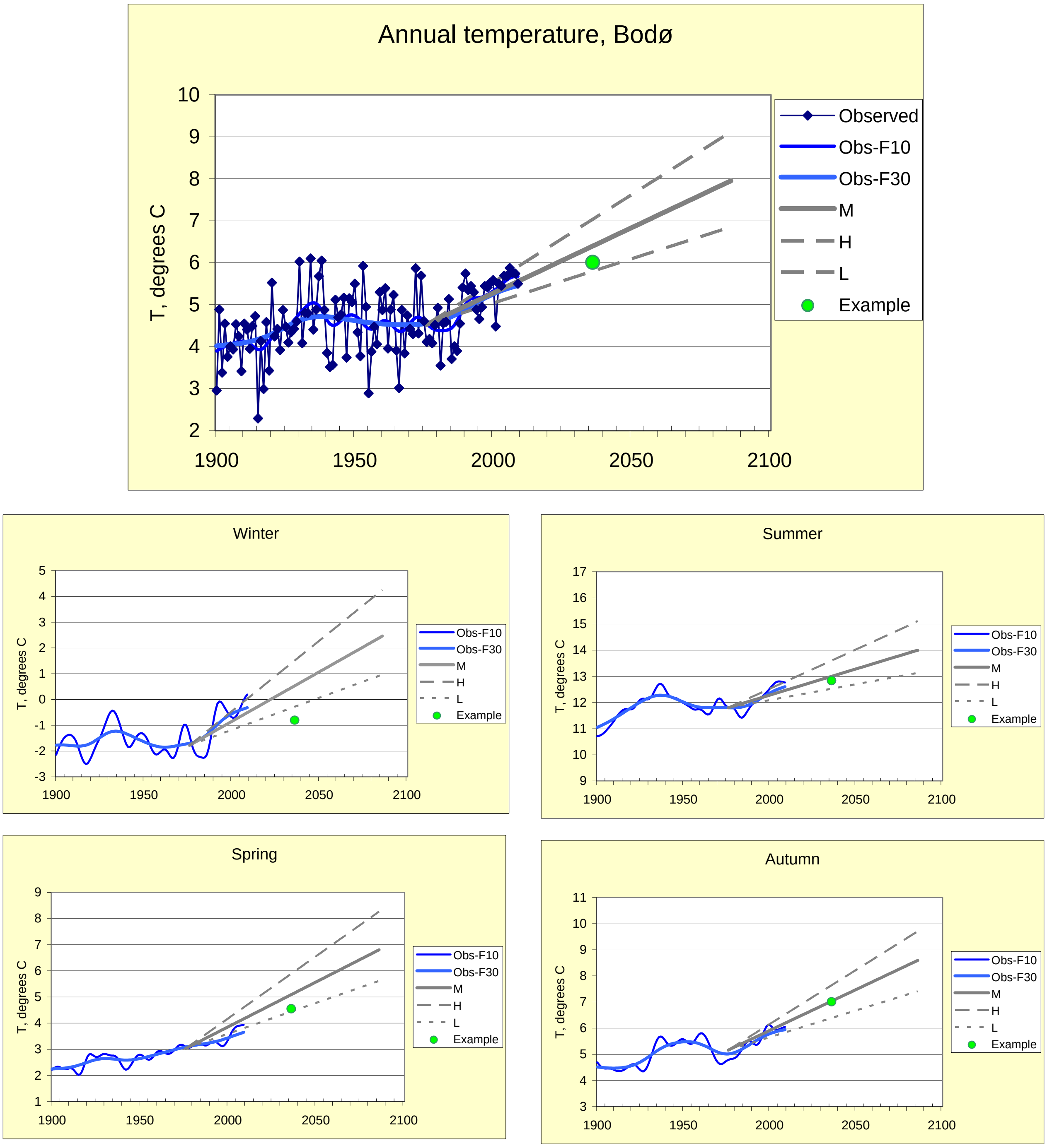


Figure 18. Historical temperature series and projected future trends at Bodø on annual and seasonal basis. The historical series are given as filtered curves showing variability on 10-year and 30-year timescales. The annual are also given as single values. The future trends are based upon 72 temperature projections. The medium trend (M) gives the average, the high (H) gives the 90 percentile, and the low (L) the 10 percentile of these projection. The example projection which is used for detailed calculations is shown as a green point.

Number of days when the temperature crosses 0 °C at the Bodø IV station is at average around 15 in autumn, 30 in winter and 25 in spring (Figure 19). In winter, there has been a weak tendency towards higher values. In autumn and spring, there the tendency is opposite from about 1970.

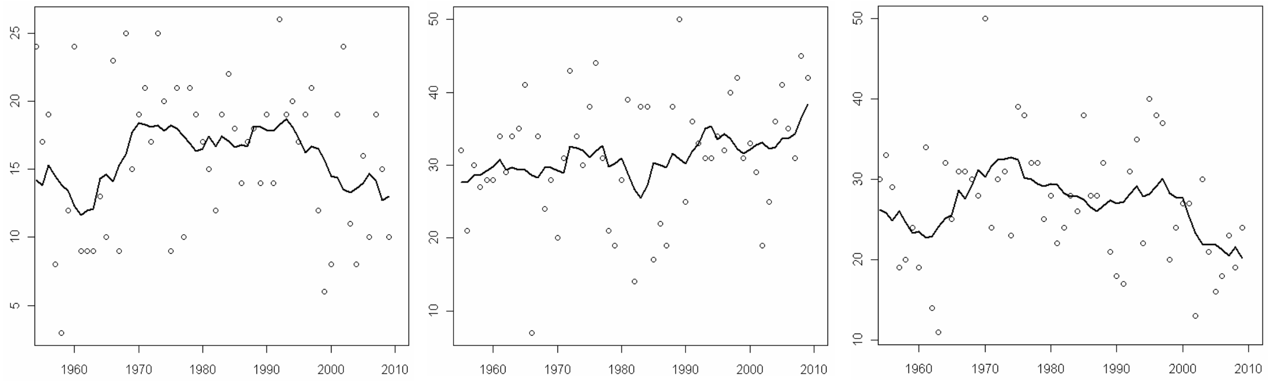


Figure 19. Number of days per season when the temperature has crossed 0 °C in Bodø. Left panel: Autumn (Sep-Nov), mid-panel: Winter (Dec-Feb), right panel: Spring (Mar-May)

This is consistent with positive temperature trends in all seasons, as the average winter temperature is presently below zero while average spring and autumn temperatures are above zero. Detailed future projections for frequencies of days when the temperature crosses 0 °C have not been produced. However, taking into considerations the temperature projections given in Figure 18, the average frequency will probably continue to decrease in spring and autumn, while it in winter may increase for a period, before it starts to decrease.

5.2.2 Growing season

The thermal growing season for grass is defined in chapter 3. Figure 20, left panel, shows that the growing season at the Bodø meteorological station typically has varied between 5 and almost 7 months, with an average around 6 months. Figure 21, left panel shows that the average growing season in Bodø municipality for the most varies from 3 to 6 months. The meteorological station is thus representative for the most favorable parts of the municipality (which is the coastal areas) concerning growing season. The Bodø measurements indicate that there has been a tendency towards longer growing season (Figure 20, left panel) and increased annual sum of growing degree days (Figure 20, right panel) during the last 50 years.

Figure 20. a) Left panel: Heating season (red) and growing season (blue) in Bodø for the period 1955-2009 given in number of days a year. b) Right panel: Annual sum og growing degree days in Bodø

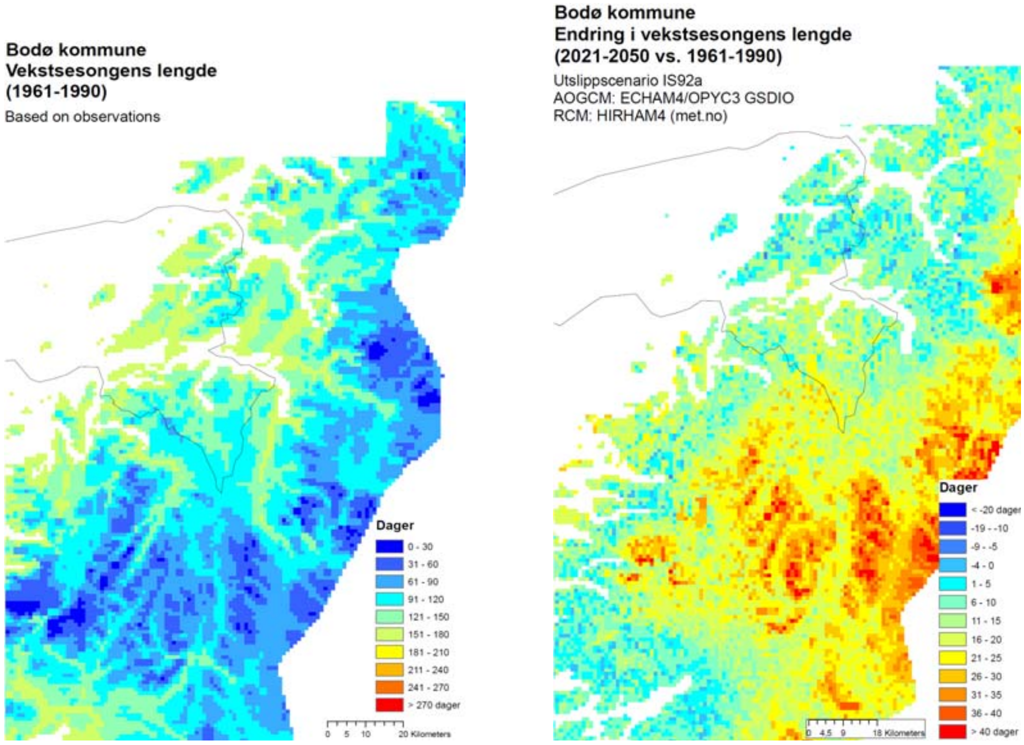


Figure 21. Average length of the growing season in the period 1961-1990 based upon observations (left), and projected change of the growing season from 1961-1990 to 2021-2050 (right) in Bodø municipality.

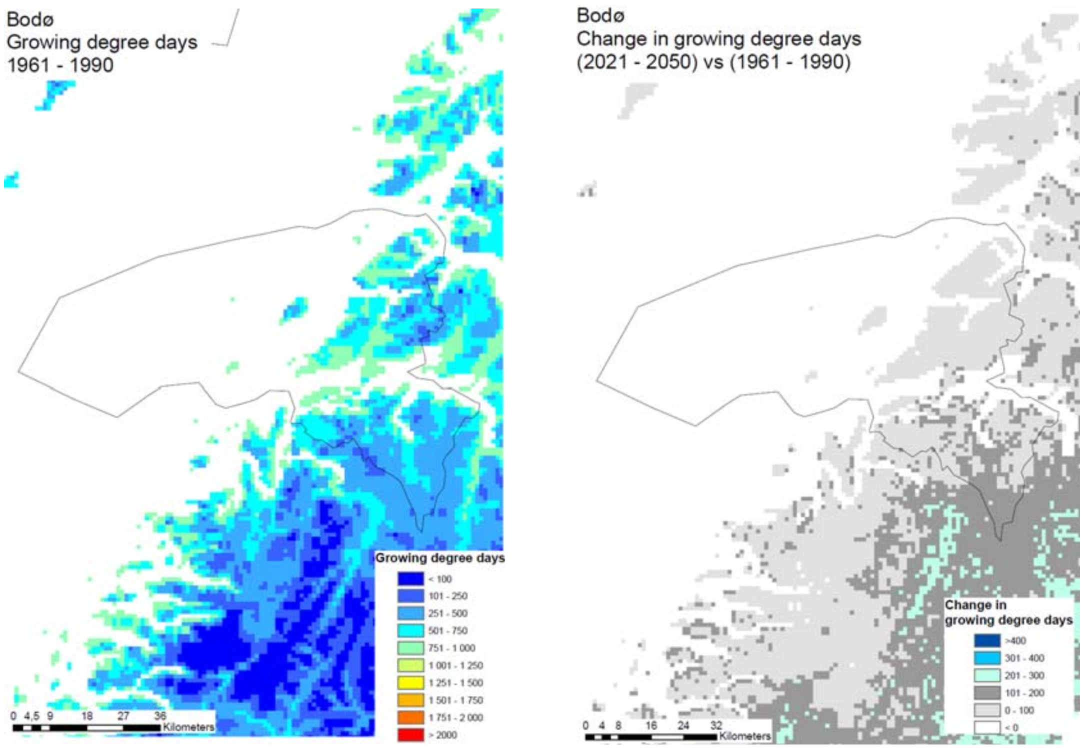


Figure 22. Average annual sum of growing degree days in the period 1961-1990 based upon observations (left), and projected changes from 1961-1990 to 2021-2050 (right) in Bodø municipality.

The example projection used to calculate growing season for 2021-2050 shows only small changes in growing season towards the mid-century in the coastal areas (Figure 21, right panel). The projected change is larger in fiords and inland areas, where there typically is projected a 2-3 weeks increase. Also concerning growing degree days (Figure 22), the projected increase is larger (>100) in the inland.

5.2.3 Precipitation

The 1961-1990 normal annual precipitation in Bodø was 1020 mm. The measurements show a precipitation maximum in October and a minimum in May (Figure 23), which is typical for the coastal stations (Figure 5). There is, however, also a small precipitation top in July.

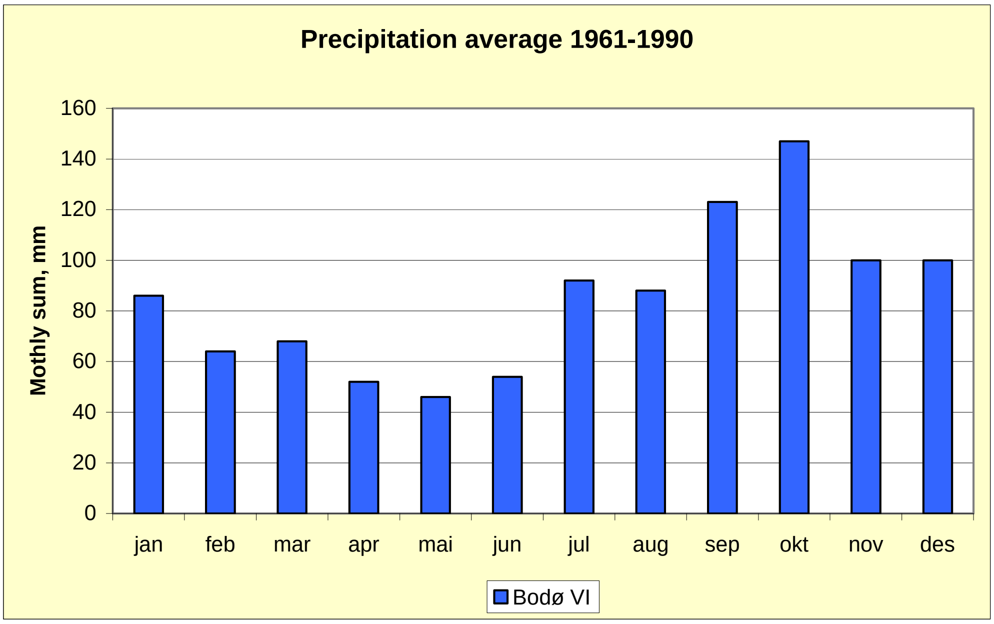


Figure 23. Average monthly precipitation sum for the period 1961-1990 at the station Bodø.

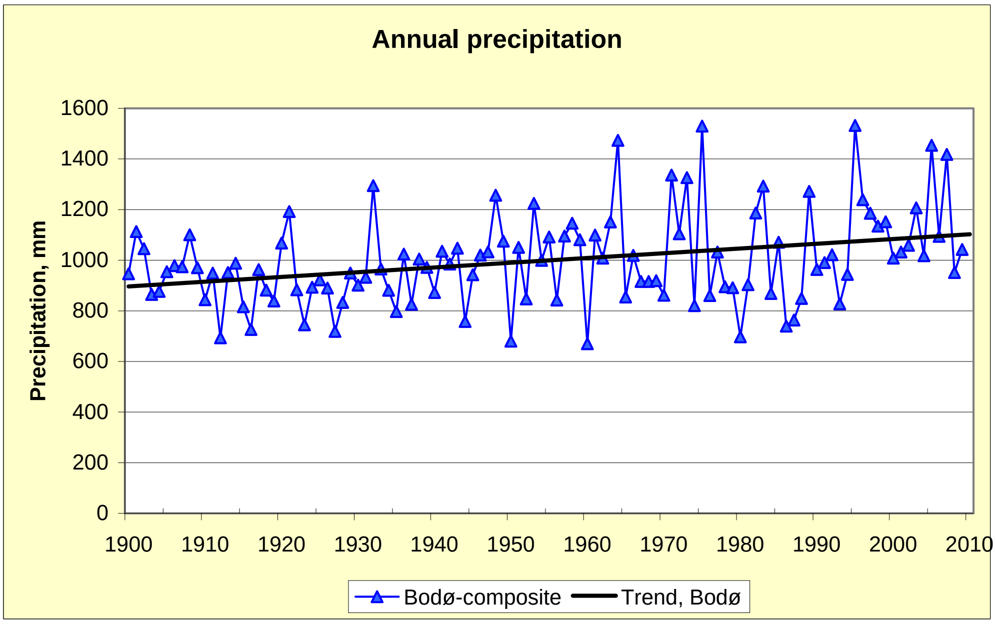


Figure 24 Annual precipitation series and linear trend from 1900 to 2009.

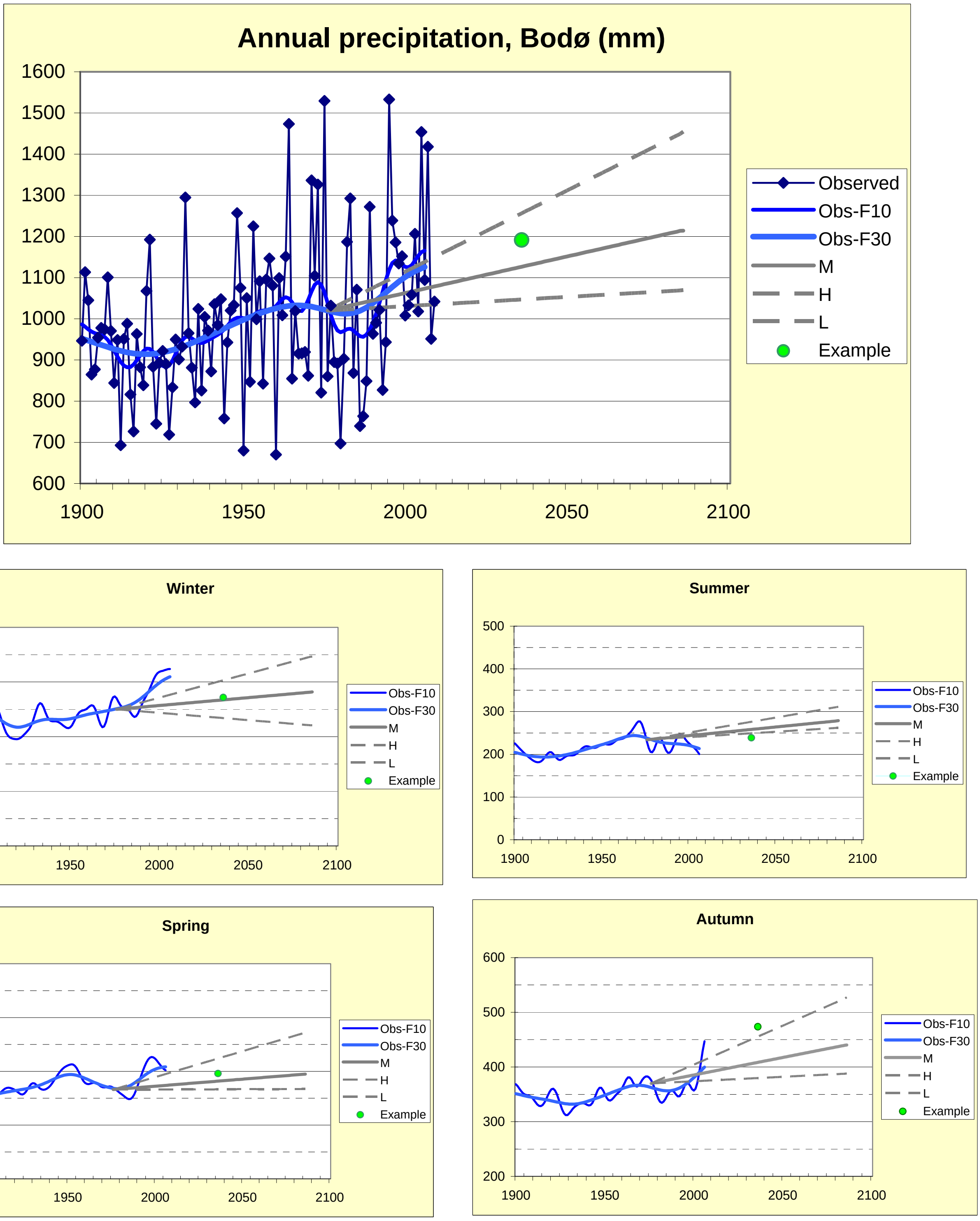


Figure 25. Historical precipitation series and projected future trends in Bodø on annual and seasonal basis. The historical series are given as filtered curves showing variability on 10-year and 30-year timescales. The annual series is also given as single values. The future trends are based upon 22 temperature projections. The medium trend (M) gives the average, the high (H) gives the 90 percentile, and the low (L) the 10 percentile of these projection. The example projection which is used for detailed calculations is shown as a green point.

The annual precipitation in Bodø has in the period 1900 to 2009 varied within the range 650 to 1550 mm (Figure 24). The series also shows a statistically significant increase during the period. The linear trend corresponds to an increase of 1.8% per decade, when measured relatively to the 1961-1990 average. Precipitation has increased in all seasons (Table 5), though the increase has been largest in winter-precipitation so far.

Table 5. Observationally based precipitation trends from 1900 to 2009, and medium, low and high projected trends for the 21st century in Bodø.

BODØ		Unit: % per decade Ann	Win	Spr	Sum	Aut
Trends 1900 to 2009		+1.8	+2.7	+2.3	+1.3	+1.4
Projected trends from 1961-1990 to 2071-2100	Medium	+1.8	+1.1	+1.6	+1.7	+2.4
	Low	+0.4	-1.1	+0.1	+1.1	+0.9
	High	+3.9	+3.5	+5.8	+3.0	+3.9

In Figure 25, the historical precipitation series are combined with low, medium and high projection for the future. Table 5 and Figure 25 show that in winter, the observed precipitation trend during the last 110 years – and particularly during the latest decades – is larger than the trend projected for the future. This may indicate that most models underestimate the future precipitation trend in this area, but, on the other hand, the precipitation increase the later years may be caused by natural variability and thus be of a temporary character. Anyway, it should be noted that the example projection which is used for projecting snow variables for the period 2021-2030 is rather low in winter, when compared with the observed winter precipitation the latest decades.

5.2.4 Snow season

The length of the snow season in Bodø varied from 1955 to 1990 between 40 and 160 days (Figure 26), while the average snow season is slightly below 4 months. There is a weak (not statistically significant) tendency for increasing length of the snow season during the period, which is caused by more winter precipitation, and not by an increased period of temperatures below 0 ^{o}C.

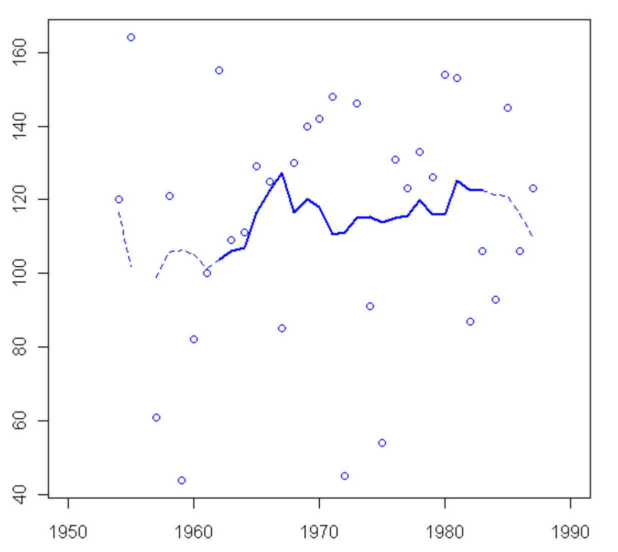


Figure 26. Number of days a year with 50% or more of the ground covered with snow in Bodø

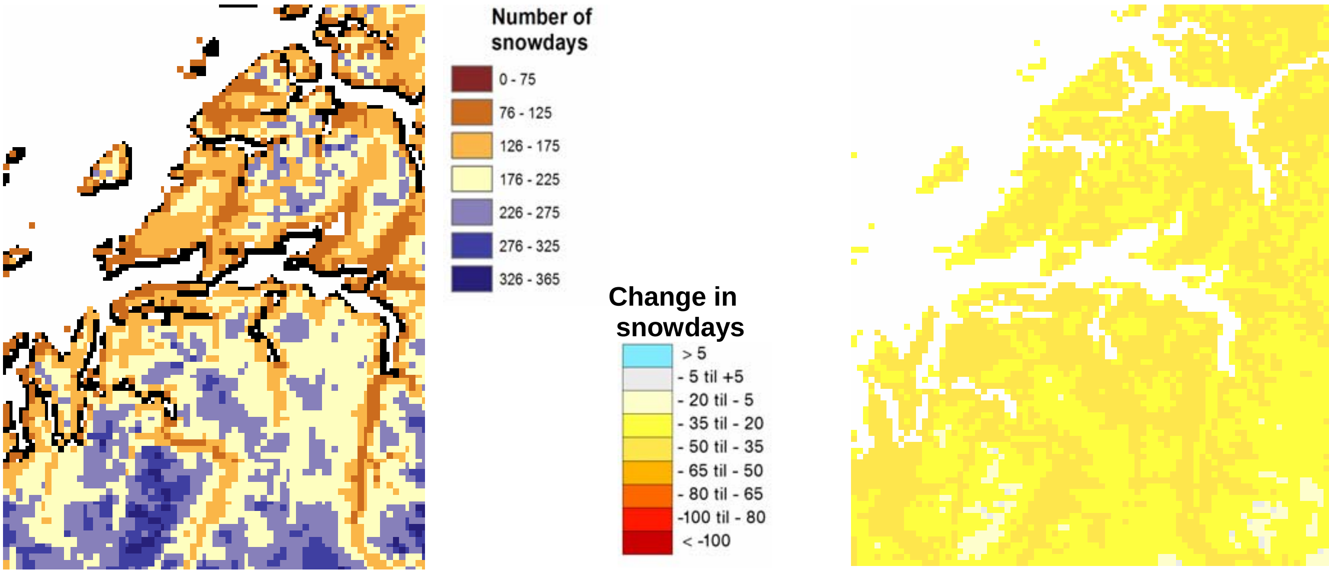


Figure 27. Number of days a year with 50% or more of the ground covered with snow in Bodø a) In the period 1961-1990, b) projected change to 2021-2050

The left panel of figure 27 indicates that low land areas in Bodø municipality have 3 to 6 months snow season (shortest season along the coast), while mountain areas can have 7 to 9 months. According to the right panel, the example scenario gives 3-7 weeks reduced snow season. The largest decrease is projected in the low land areas.

5.3 Vestvågøy

Vestvågøy is an island municipality outside the coast of Nordland County (Fig. 1a), with maritime climate. The area of Vestvågøy is 423,4 km^2. Data from the three stations Skrova Lighthouse, Leknes Airport and Eggum are used in the present analyses. Eggum (7 m.a.s.l. at the north-west coast of the island) is chosen as the main meteorological station in the municipality. Though the climate series from this station are fairly short, it was possible to possible to prolong the series of annual and seasonal temperature back to 1900 by using neighboring stations and a scaling technique. Leknes Airport (26 m.a.s.l.) is situated at the southern coast, and Skrova Lighthouse (11 m.a.s.l.) is situated east of Vestvågøy.

5.3.1 Temperature

Figure 28 shows that February at average is the coldest months of the year, with a mean temperature of about -1 ^{o}C at Skrova Lighthouse. July and August are at average is the warmest months, with a mean temperature of about +12.5 ^{o}C. There is considerable variation around these mean temperatures, but still smaller than in the inland municipality Hattfjelldal. The lowest minimum-temperature that has been measured at the station in the period 1961-1990 is -15^{o}C, and thus more than 20 ^{o}C warmer than the similar value in Hattfjelldal. The highest maximum-temperature is +29^{o}C, and rather similar to Hattfjelldal. The average monthly temperature mean is above 0 ^{o}C from April to December, and in July and August no below zero minimum temperatures were measured in the period 1961-1990.

Concerning geographical representativity of the temperature measurements at Vestvågøy, Figure 3 shows that Eggum, which is more exposed to the open sea, has similar winter temperatures, but a bit cooler summers than Skrova. Leknes, on the other hand, has similar summer temperatures, but is a bit colder in winter, as it is slightly less influenced by the maritime air. All the stations are situated at low altitude, and areas in the municipality with higher altitude will have a colder climate.

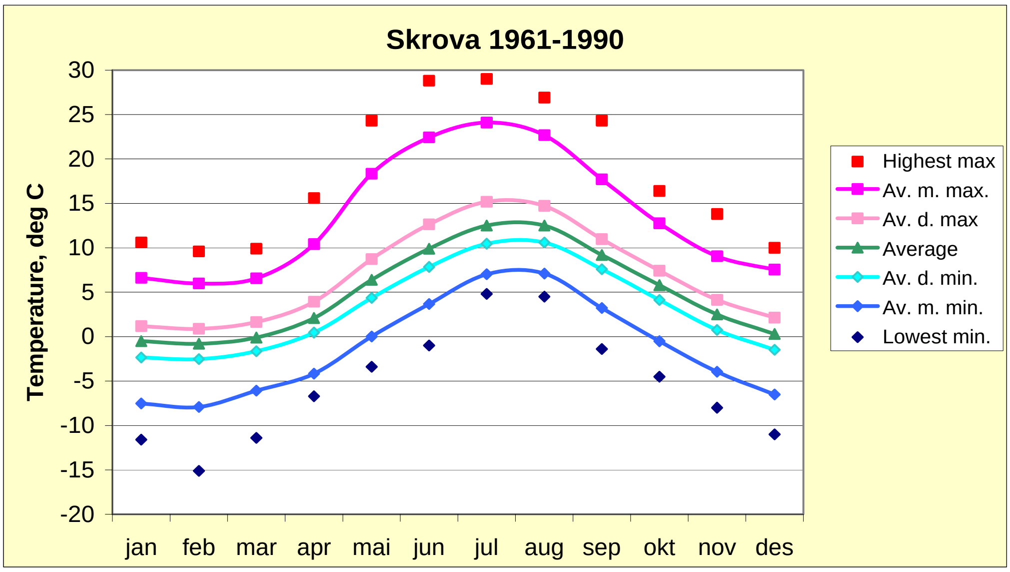


Figure 28. Monthly average and extreme temperatures at Skrova. "Highest max."/"Lowest min." are the most extreme temperature measured in the specific month during the given time period, "Av. m. max."/ "Av. m. min." are the average monthly extremes, while "Av. d. max."/ "Av. d. min." are the average daily extremes. "Average" is the monthly mean.

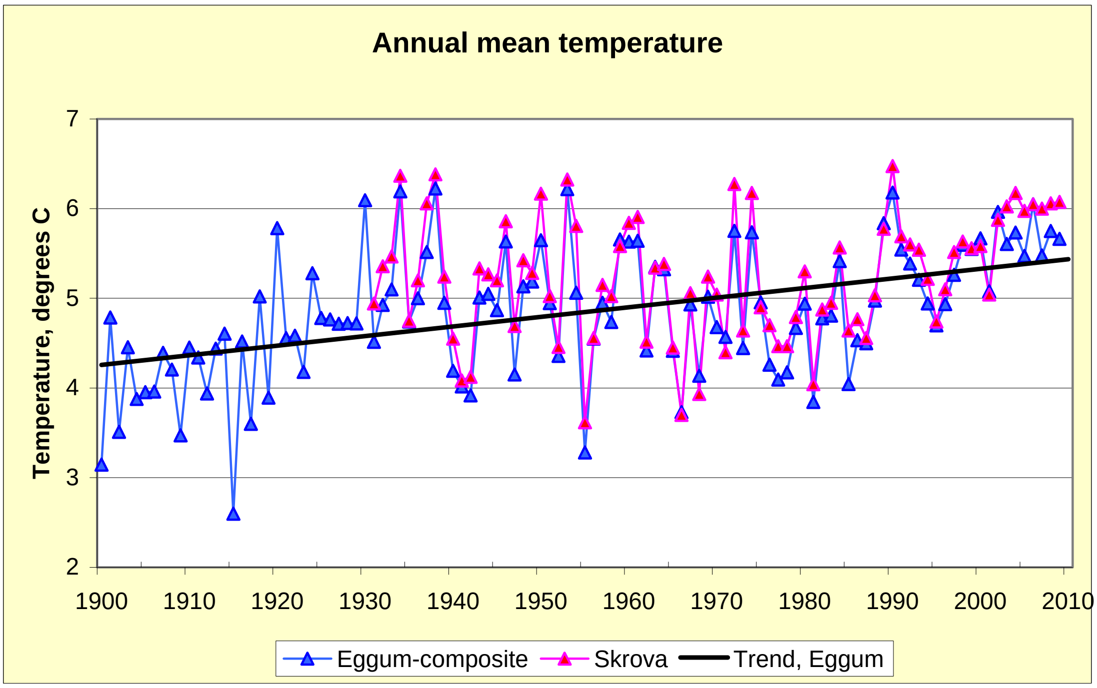


Figure 29. Annual mean temperature series for Eggum and Skrova. For Eggum, the linear trend from 1900 to 2009 is also shown.

The annual mean temperatures in Eggum and Skrova are highly correlated, and the trends in the series are similar (Figure 29). The inter-annual temperature variation in Eggum is similar to what was found in Bodø: The lowest value in the 110 year long composite series is +2.6 ^{o}C in 1915, and the highest is + 6.2 ^{o}C in 1938.

The large number of mild years during the last couple of decades leads to a statistically significant positive trend in the series, even though the year with the highest recorded annual mean temperature was 1938. The linear trend is + 0.11 ^{o}C per decade, or 1.2 ^{o}C over the 110 year period. All the seasonal trends are also positive over the period 1900 to 2009 (Table 6).

Table 6. Observationally based temperature trends from 1900 to 2009, and medium, low and high projected trends for the 21st century in Bodø.

EGGUM		Unit: ^{o}C per decade Ann	Win	Spr	Sum	Aut
Trends 1900 to 2009		+0.11	+0.09	+0.16	+0.06	+0.10
Projected trends from 1961-1990 to 2071-2100	Medium	+0.31	+0.38	+0.35	+0.20	+0.31
	Low	+0.20	+0.25	+0.24	+0.12	+0.20
	High	+0.42	+0.55	+0.47	+0.30	+0.41

Figure 30 and Table 6 shows both observed and projected temperature trends at Eggum. For definition of low, medium and high projections: See chapter 3 and Figure 30 label! The projected temperature trends for the 21t century are definitely higher than those observed during the 20th century, however, the annual and seasonal trends which have been observed the latest decades largely span from the low to the medium projected trends (Figure 30).

One specific climate projection ("example projection") is used to calculate possible changes in growing season and snow season towards the mid-century. Figure 30 shows that in Eggum, this example projection is close to the medium temperature projection in summer and autumn, close to the low in spring, and below the low one in winter.

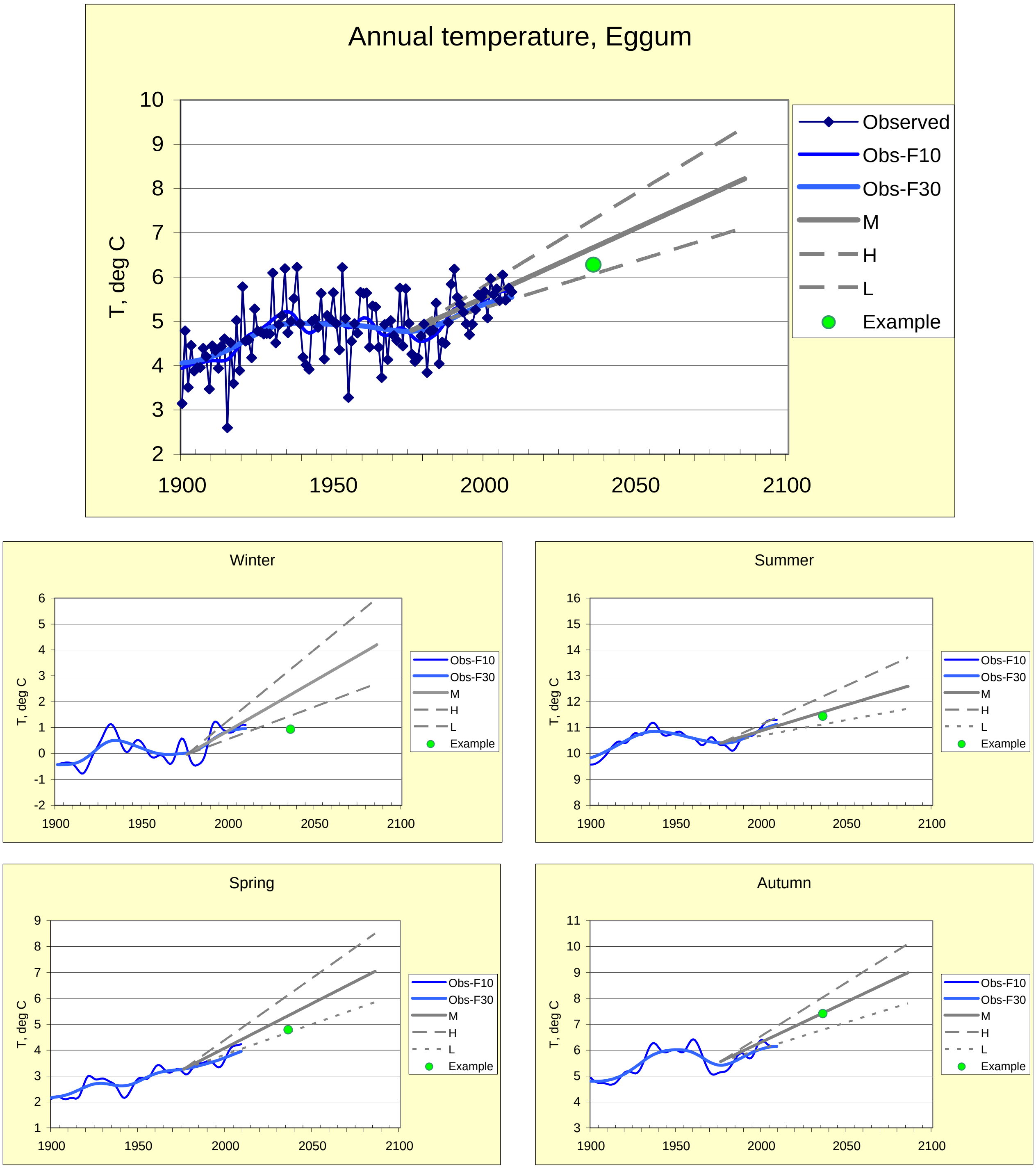


Figure 30. Historical temperature series and projected future trends at Eggum on annual and seasonal basis. The historical series are given as filtered curves showing variability on 10-year and 30-year timescales. The annual are also given as single values. The future trends are based upon 72 temperature projections. The medium trend (M) gives the average, the high (H) gives the 90 percentile, and the low (L) the 10 percentile of these projection. The example projection which is used for detailed calculations is shown as a green point.

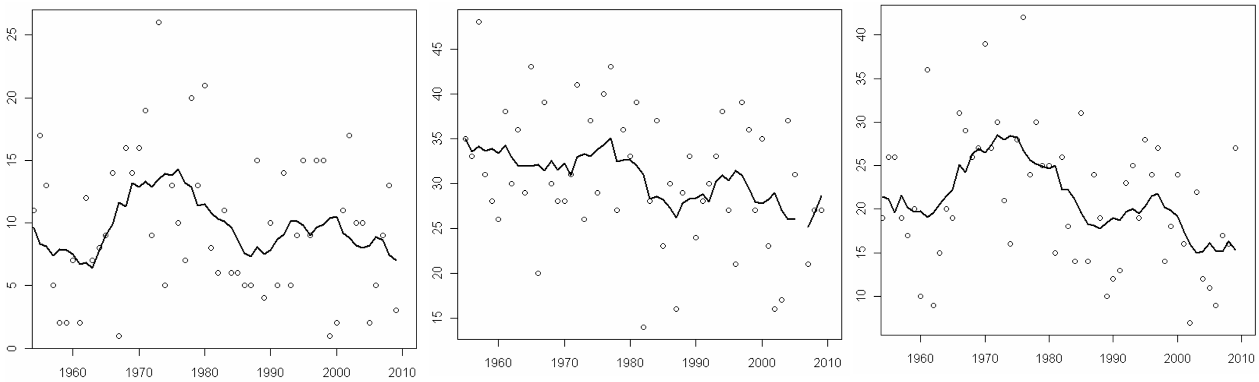


Figure 31. Number of days per season when the temperature has crossed 0 °C in Skrova. Left panel: Autumn (Sep-Nov), mid-panel: Winter (Dec-Feb), right panel: Spring (Mar-May)

Number of days when the temperature crosses 0 °C at the Skrova station is at average around 10 in autumn, 30 in winter and 20 in spring (Figure 31). From the 1970s, there seem to be a weak tendency towards lower values in all seasons. This is consistent with positive temperature trends in all seasons, as even the average winter temperature at average has been above zero during the later decades. Detailed future projections for frequencies of days when the temperature crosses 0 °C have not been produced. However, taking into considerations the temperature projections given in Figure 30, the average frequency will probably continue to decrease in all seasons.

5.3.2 Growing season

The thermal growing season for grass is defined in chapter 3. Figure 32, left panel, shows that the growing season at the Skrova meteorological station typically has varied between 4 and almost 7 months, with an average slightly below 6 months. The average annual number of growing degree days is about 900. The average growing season in Vestvågøy municipality for the most varies from 4 to 6 months (Figure 33, left panel). The Skrova station is thus representative for the most favorable parts of the municipality concerning growing season.

Measurements at the Skrova station indicate that there has been a tendency towards longer growing season (Figure 32a) and increased annual sum of growing degree days (Figure 32b) during the last 50 years.

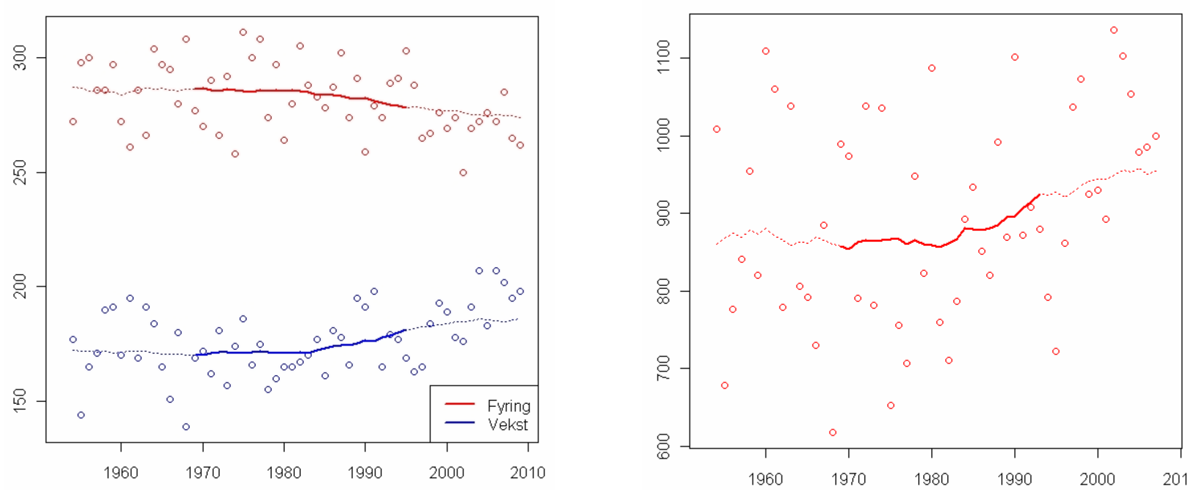


Figure 32. a) Left panel: Heating season (red) and growing season (blue) in Skrova for the period 1955-2009 given in number of days a year. b) Right panel: Annual sum og growing degree days in Skrova

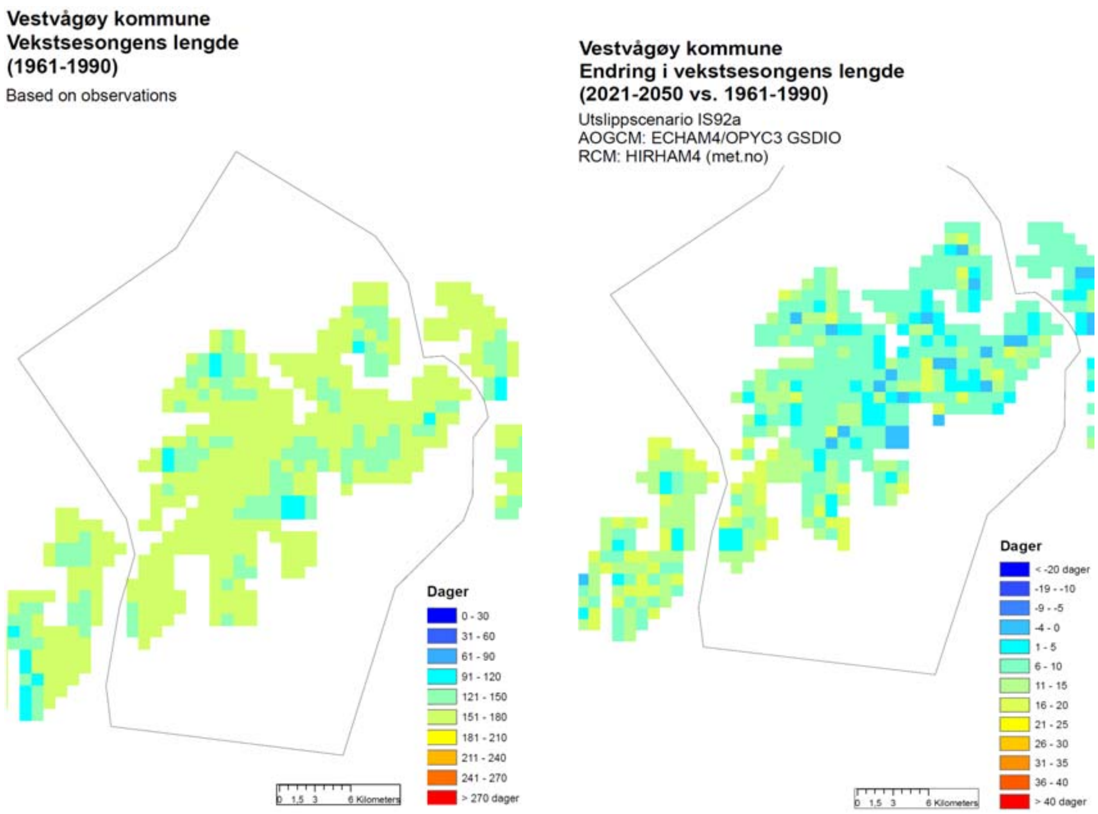


Figure 33. Average length of the growing season in the period 1961-1990 based upon observations (left), and projected change of the growing season from 1961-1990 to 2021-2050 (right) in Vestvågøy municipality.

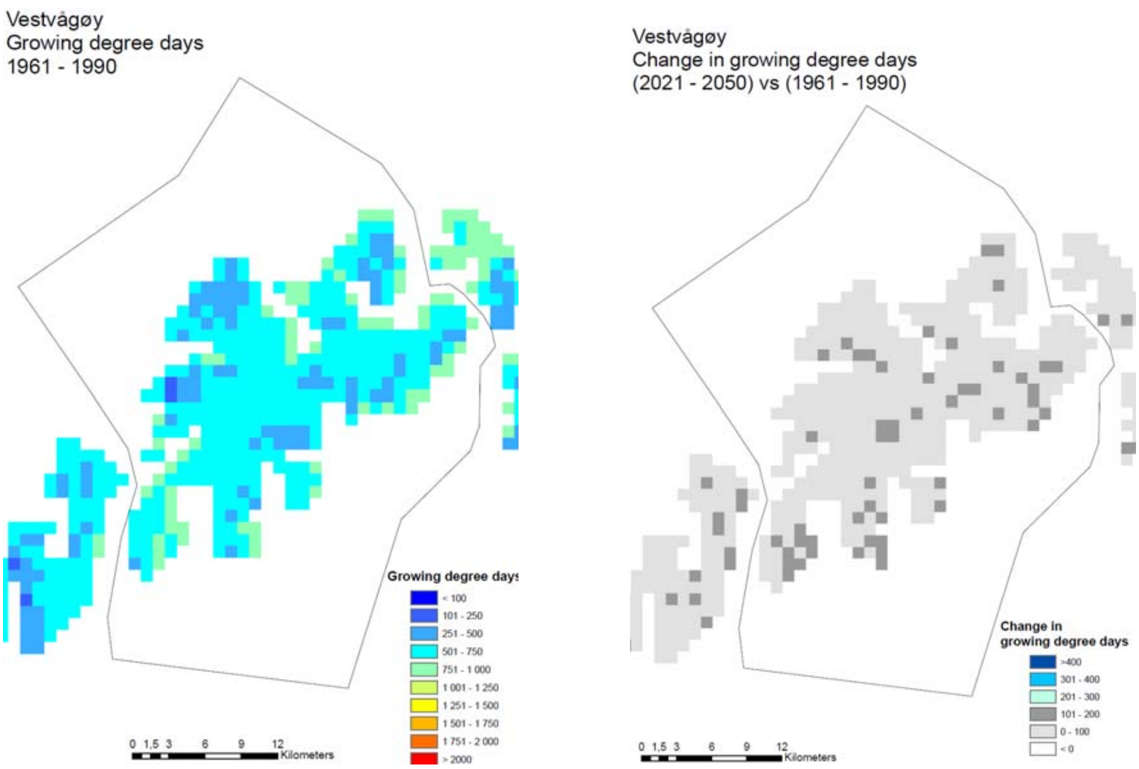


Figure 34. Average annual sum of growing degree days in the period 1961-1990 based upon observations (left), and projected changes from 1961-1990 to 2021-2050 (right) in Vestvågøy municipality.

The example projection used to calculate growing season for 2021-2050 shows an increase of about a week most places, though a few areas show 2-3 weeks increase, and other show very little change (Figure 33, right panel).

Concerning growing degree days, Figure 34 shows an increase of less than 100 most places, though the projected increase is 100 to 200 a few places.

5.3.3 Precipitation

The 1961-1990 normal annual precipitation at Eggum and Leknes were both between 1200 and 1300 mm. Both stations have precipitation minimum in late spring/early summer, and maximum in autumn. Eggum usually gets more precipitation than Leknes in summer and autumn, while Leknes gets slightly more in late winter and early spring (Figure 35).

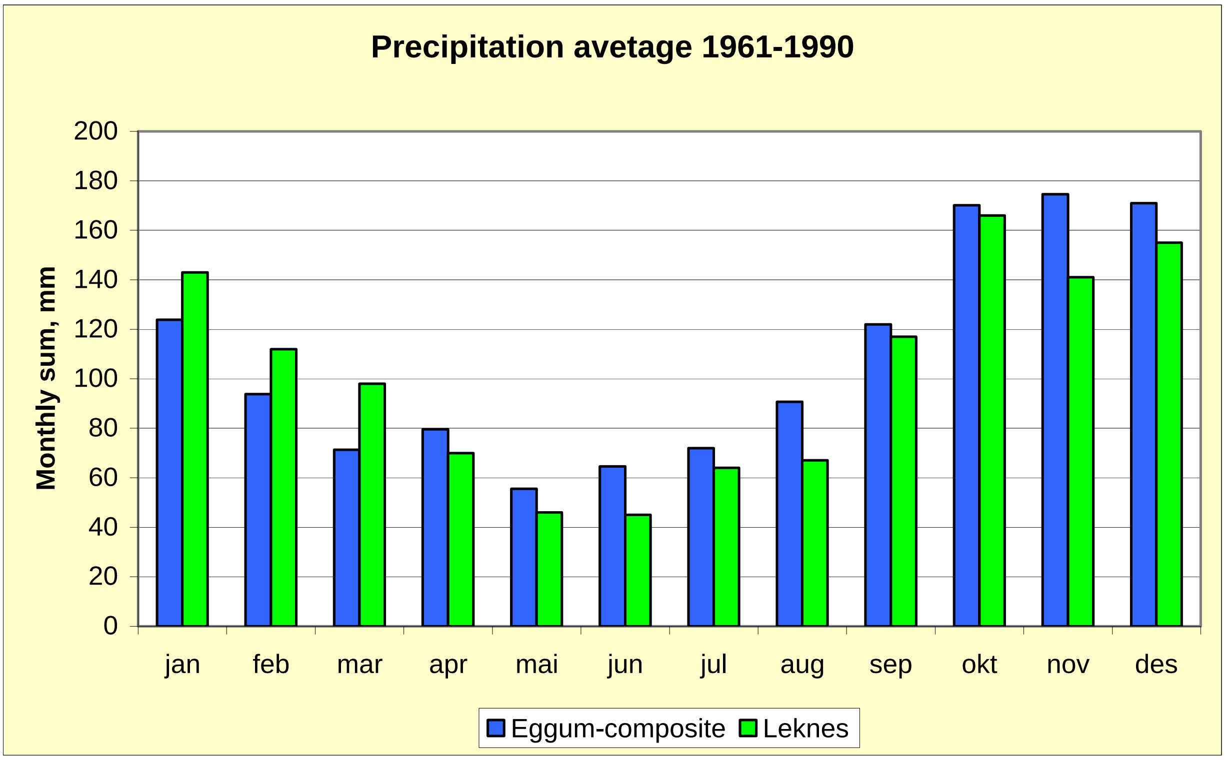


Figure 35. Average monthly precipitation sum for the period 1961-1990 at the stations Eggum and Leknes.

As seen from Figure 5, both these stations get more precipitation than Skrova, which is situated further to the east, and is to some degree sheltered from precipitation by the mountains in Lofoten and Vesterålen.

The annual precipitation at Eggum and Leknes are rather well correlated (Figure 36). The long composite series from Eggum shows a precipitation increase from 1900 to 2009. The linear trend gives an increase of 1.6% per decade, when measured relatively to the 1961-1990 average. Table 7 shows that the increase mainly has taken place in winter and spring.

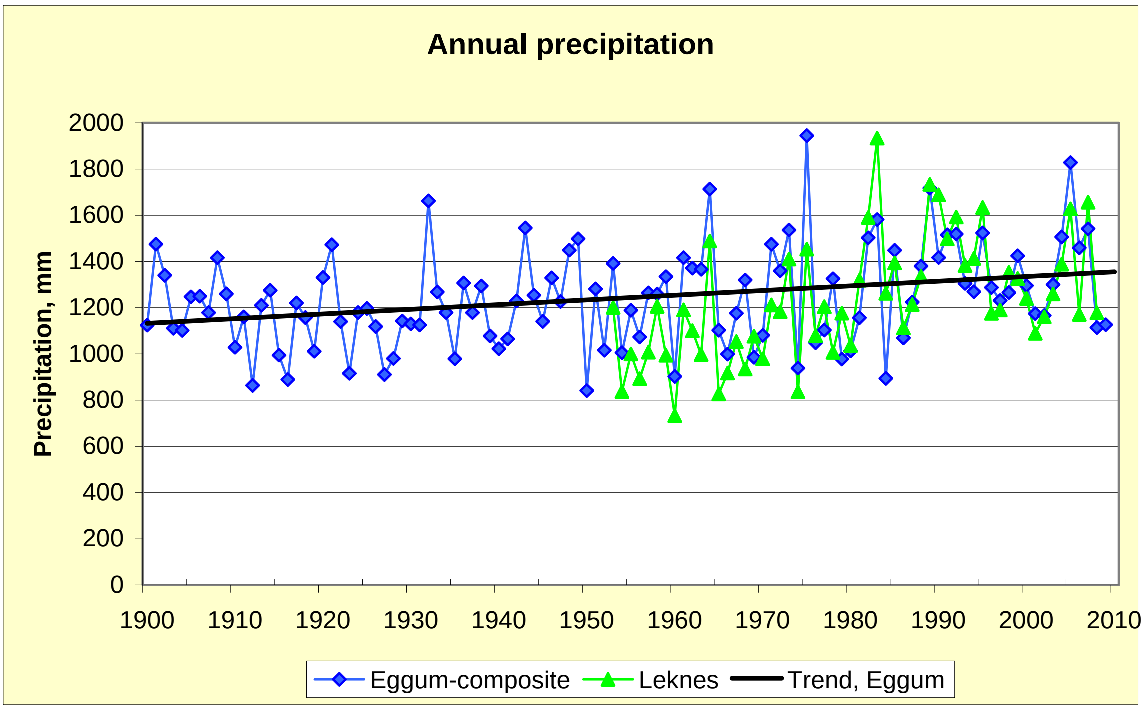


Figure 36 Annual precipitation series for Leknes and Eggum. For Eggum, the linear trend from 1900 to 2009 is also shown.

Table 7. Observationally based precipitation trends from 1900 to 2009, and medium, low and high projected trends for the 21st century at Eggum.

EGGUM		Unit: % per decade				
		Ann	Win	Spr	Sum	Aut
Trends 1900 to 2009		+1.6	+2.9	+2.4	+0.7	+0.4
Projected trends from 1961-1990 to 2071-2100	Medium	+1.8	+1.1	+1.6	+1.7	+2.4
	Low	+0.4	-1.1	+0.1	+1.1	+0.9
	High	+3.9	+3.5	+5.8	+3.0	+3.9

In Figure 37, the historical precipitation series is combined with low, medium and high projection for the future. Table 7 and Figure 37 show that in winter, the observed precipitation trend during the last 110 years – and particularly during the latest decades – is larger than the trend projected for the future. This may indicate that most models underestimate the future precipitation trend in this area. On the other hand, however, the precipitation increase the later years may be caused by natural variability and thus be of a temporary character. Anyway, it should be noted that the example projection which is used for projecting snow variables for the period 2021-2030 is rather low in winter, when compared with the observed winter precipitation the latest decades.

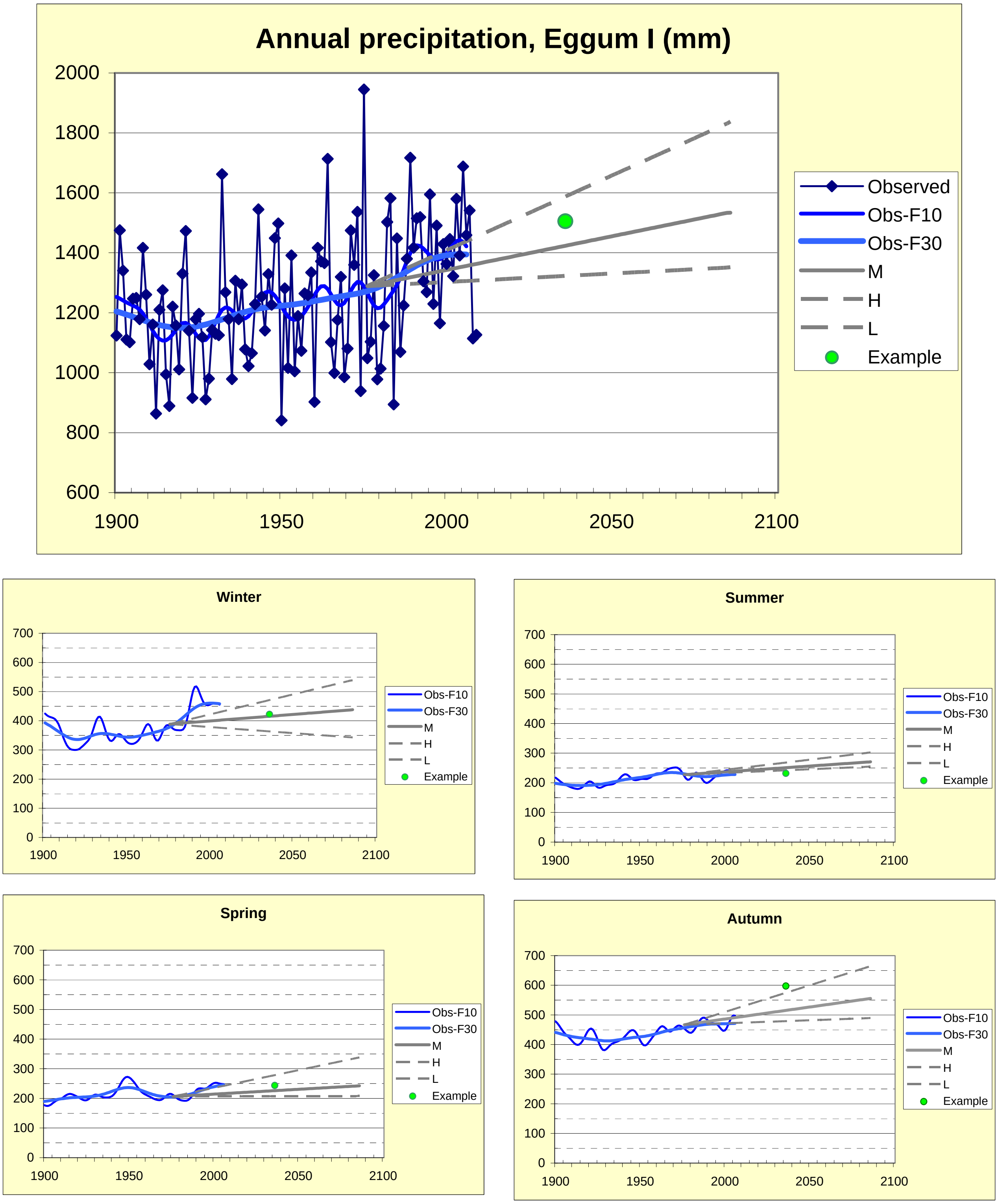


Figure 37. Historical precipitation series and projected future trends at Eggum on annual and seasonal basis. The historical series are given as filtered curves showing variability on 10-year and 30-year timescales. The annual series is also given as single values. The future trends are based upon 22 temperature projections. The medium trend (M) gives the average, the high (H) gives the 90 percentile, and the low (L) the 10 percentile of these projection. The example projection which is used for detailed calculations is shown as a green point.

5.3.4 Snow season

The length of the snow season at Skrova has the last 50 years varied between 1.5 and 5 months, with an average between 3 and 4 months (Figure 38). There has been a tendency towards shorter snow season since the late 1960s, though the interannual variability is large.

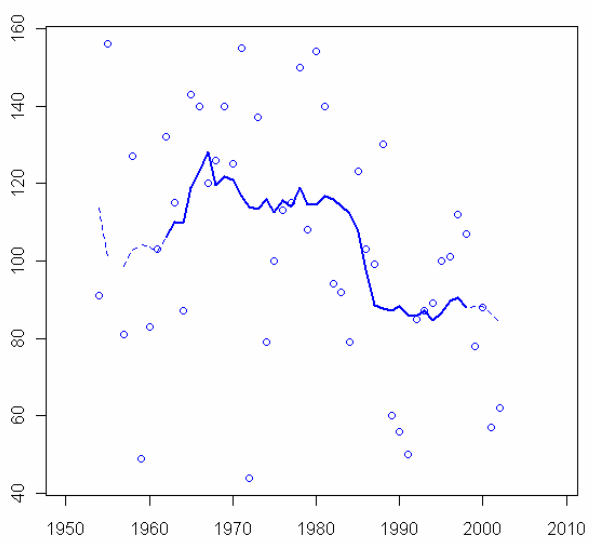


Figure 38. Number of days a year with 50% or more of the ground covered with snow at Skrova lighthouse

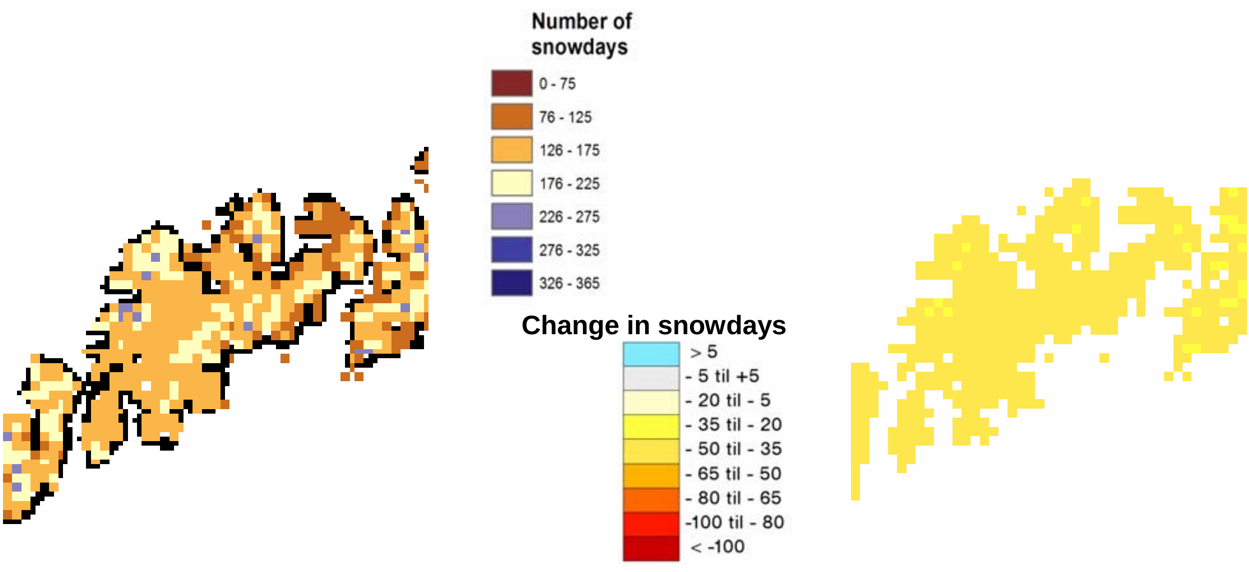


Figure 39. Number of days a year with 50% or more of the ground covered with snow at Vestvågøy a) In the period 1961-1990, b) projected change to 2021-2050

The left panel of Figure 39 shows that most of Vestvågøy typically has a snow season between 4 and 6 months. Skrova thus has somewhat shorter snow season than the average for the municipality. According to the right panel of Figure 39, the example scenario gives 5-7 weeks reduced snow season over most of Vestvågøy from 1961-1990 to 2021-2050.

5.4 Tromsø

Tromsø is a coastal municipality in Troms County (Fig. 1a), which partly is situated on the mainland, but also includes several islands. The area of Tromsø is 2 557 km², of which much is occupied by mountainous terrain. The municipaliy has several mountain peaks over 1000 m a.s.l. In the south-eastern part, there are peaks up to 1800 m a.s.l. The meteorological stations used in the present analyses are Tromsø (100 m.a.s.l.) and Tromsø-Langnes (8 m.a.s.l.), both situated on the Tromsø island, central in the municipality. They are thus representative for the coastal and low altitude areas of the municipality. The precipitation measurements at Tromsø started in 1926, and the temperature measurements in1920. However, measurements from other stations in the area has made it possible to prolong the series of annual and seasonal temperature and precipitation back to 1900.

5.4.1 Temperature

Figure 40 shows that January and February at average are the coldest months of the year, with a mean temperature of about -4.3 °C at the Tromsø station. July is at average is the warmest month, with a mean temperature of about +11.8 °C. There is considerable variation around these mean temperatures, but still much smaller than in the inland municipality Bardu. The lowest minimum-temperature that has been measured at the station in the period 1961-1990 is about -18.4°C, and thus similar to Bodø, and about 13 °C warmer than in Dividalen, Bardu. The highest maximum-temperature is +30.2°C, and similar to Dividalen. The average monthly temperature mean is above 0 °C from April (barely) to October, and in July and August there were no incidents of below zero temperatures in the period 1961-1990.

Concerning geographical representativity of the temperature measurements in Tromsø, it should be kept in mind that this is a station with relatively low altitude and with considerable maritime influence. Mountains and inland areas in the municipality will certainly have a colder winter climate. The station Dividalen in Bardu is probably more representative for inland areas.

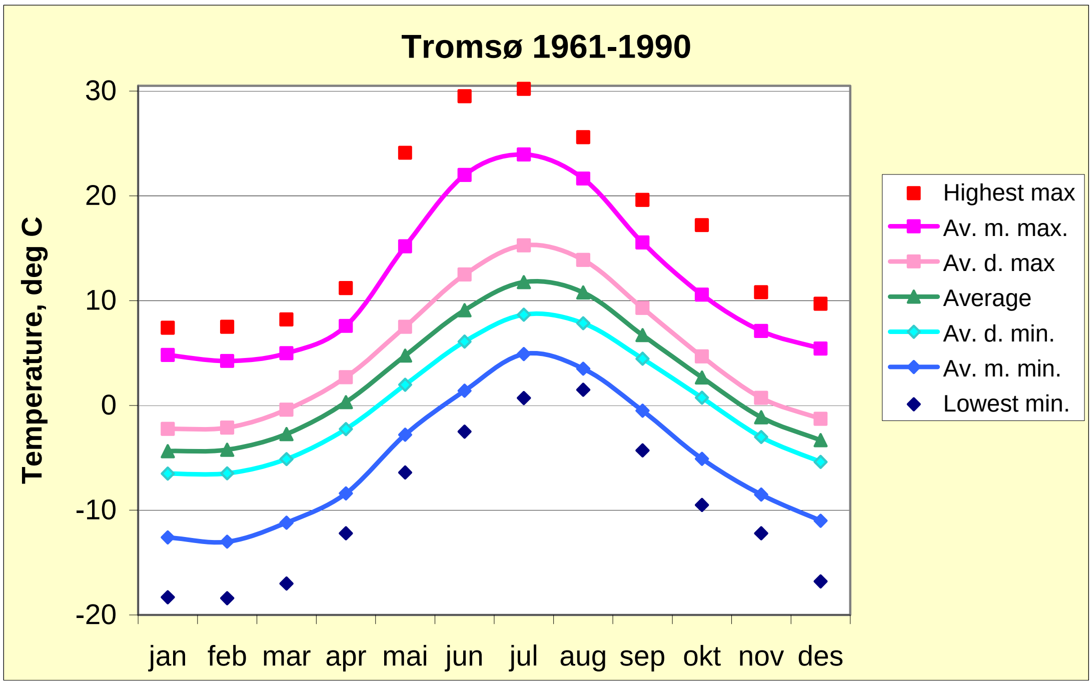


Figure 40. Monthly average and extreme temperatures at Tromsø. "Highest max."/"Lowest min." are the most extreme temperature measured in the specific month during the given time period, "Av. m. max."/ "Av. m. min." are the average monthly extremes, while "Av. d. max."/ "Av. d. min." are the average daily extremes. "Average" is the monthly mean.

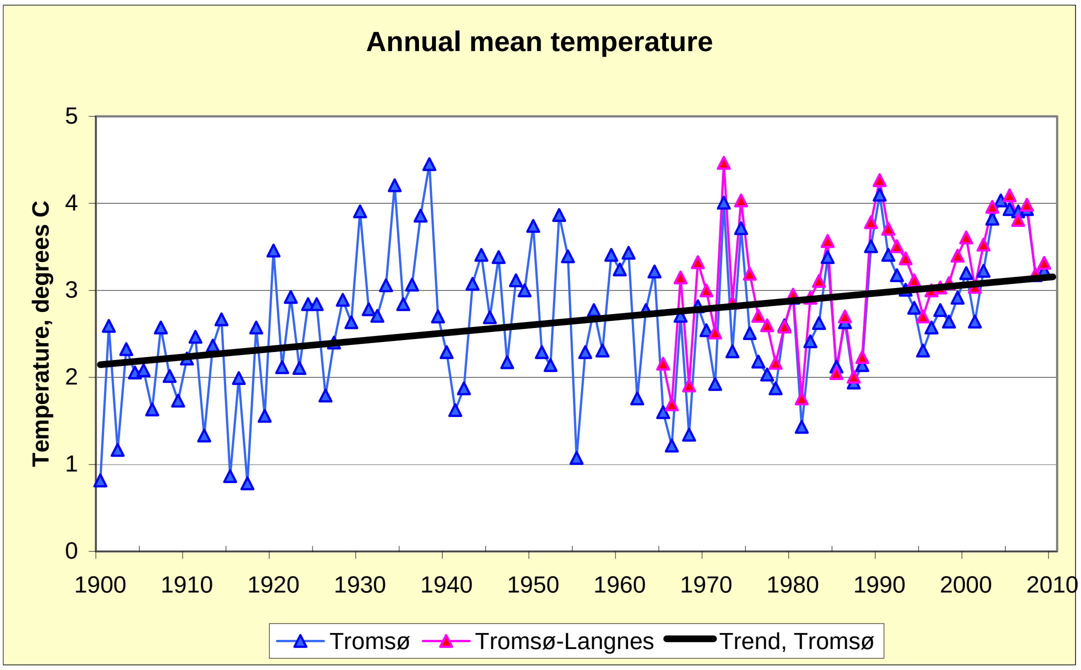


Figure 41. Annual mean temperature series for Tromsø and Tromsø-Langnes. For Tromsø, the linear trend from 1900 to 2009 is also shown.

Figure 41 shows that the annual mean temperature in Tromsø and Tromsø-Langenes are highly correlated, and the trends in the series seem to be similar. The inter-annual temperature variation in Tromsø is considerable: The lowest value in the 110 year long composite series is +0.8 ^{o}C in 1900, and the highest is + 4.5 ^{o}C in 1938. Even though the warmest year occurred in the first half of the series, the large number of mild years during the last couple of decades leads to a positive trend in the series. The linear trend in Figure 41 is + 0.09 ^{o}C per decade, or about 1 ^{o}C over the 110 year period. The trends for spring, summer and autumn are also positive over the period 1900 to 2009, while the winter temperatures show no trend (Table 8, first row).

Table 8. Observationally based temperature trends from 1900 to 2009, and medium, low and high projected trends for the 21st century in Bodø.

TROMSØ		Unit: ^{o}C per decade Ann	Win	Spr	Sum	Aut
Trends 1900 to 2009		+0.09	+0.00	+0.16	+0.14	+0.06
Projected trends from 1961-1990 to 2071-2100	Medium	+0.31	+0.38	+0.35	+0.20	+0.31
	Low	+0.20	+0.25	+0.24	+0.12	+0.20
	High	+0.42	+0.55	+0.47	+0.30	+0.41

Table 8 and Figure 42 show projected future temperature trends in Tromsø together with historical trends. For definition of low, medium and high future projections: See chapter 3 and Figure 42 label! The projected temperature trends for the 21t century are definitely higher than those observed during the 20th century, however, the annual and seasonal trends which have been observed the latest are more similar to the projected trends.

One specific climate projection (“example projection”) is used to calculate possible changes in growing season and snow season towards the mid-century. Figure 42 shows that in Tromsø, this example projection is close to the medium temperature projection in summer and autumn, between medium and low in spring, and even below the low one winter.

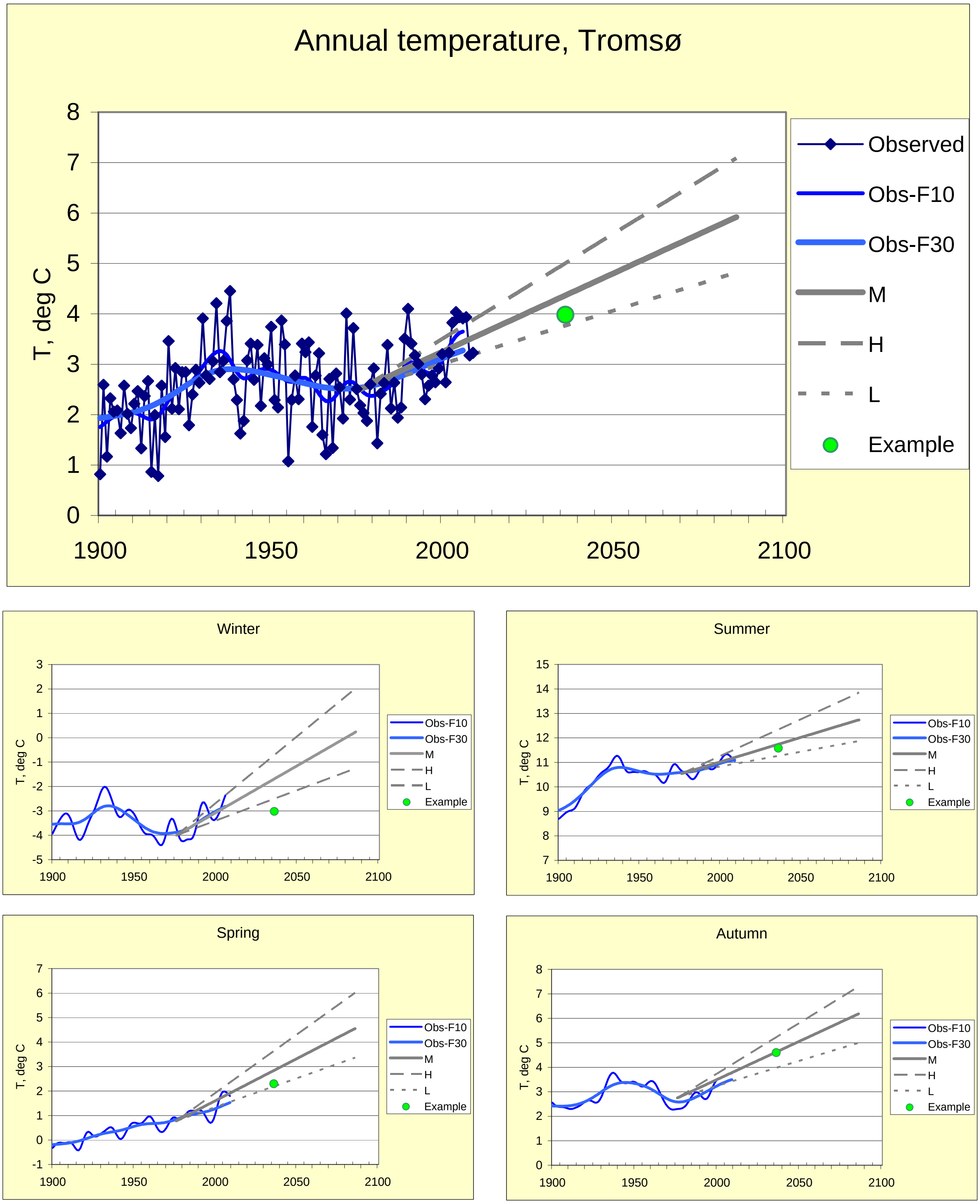


Figure 42. Historical temperature series and projected future trends at Tromsø on annual and seasonal basis. The historical series are given as filtered curves showing variability on 10-year and 30-year timescales. The annual are also given as single values. The future trends are based upon 72 temperature projections. The medium trend (M) gives the average, the high (H) gives the 90 percentile, and the low (L) the 10 percentile of these projection. The example projection which is used for detailed calculations is shown as a green point.

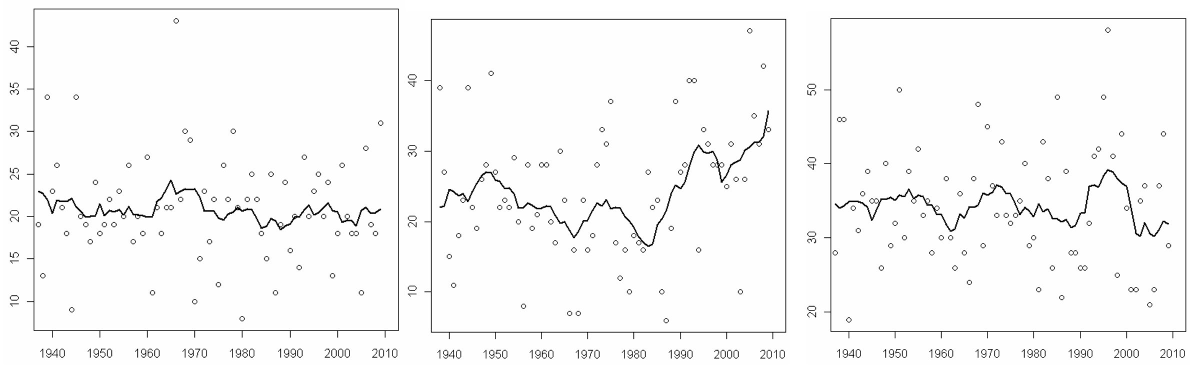


Figure 43. Number of days per season when the temperature has crossed 0 °C in Tromsø

Number of days when the temperature crosses 0 °C at the Tromsø station is at average around 20 in autumn, 30 in winter and 35 in spring (Figure 43). In winter, there has been a marked tendency towards higher values the latest decades – which is consistent with the increasing winter temperatures during this period. In autumn and spring, there variability is large, but the trends are weak. Detailed future projections for frequencies of days when the temperature crosses 0 °C have not been produced. However, taking into considerations the temperature projections given in Figure 42, the frequency will probably decrease in autumn and spring, and increase in winter at the Tromsø station.

5.4.2 Growing season

The thermal growing season for grass is defined in chapter 3. Figure 44, left panel, shows that the growing season at the Tromsø meteorological station typically has varied between 4 and 5 months, with an average around 4 1/2 months. Figure 45, left panel shows that the average growing season in the municipality for the most varies from 3 to 5 months, though the mountain areas have shorter growing season. Concerning growing season, the meteorological station Tromsø is representative for the most favorable parts of the municipality, which are the coastal areas and valleys.

Measurements at the Tromø station indicate that there was a negative trend in growing season (Figure 44a) and growing degree days (Figure 44b) from the 1940s to the 1960s, while there has been a weak positive trend during the last 50 years, .

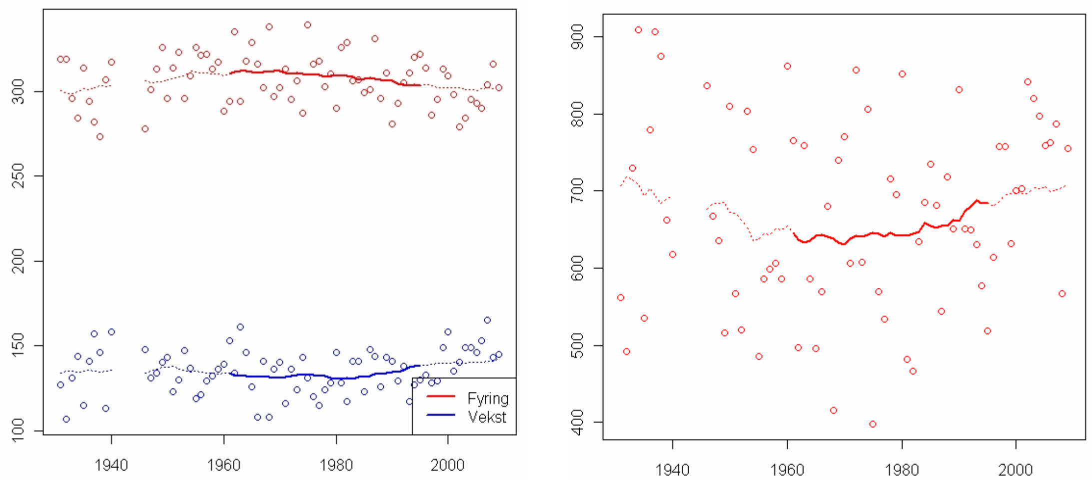


Figure 44. a) Left panel: Heating season (red) and growing season (blue) in Tromsø for the period 1955-2009 given in number of days a year. b) Right panel: Annual sum og growing degree days in Tromsø

The example projection used to calculate growing season for 2021-2050 shows only small changes in growing season towards the mid-century in the mountain areas (Figure 45, right panel). In coastal areas and low altitude valleys, the projected increase is typically around 2 weeks.

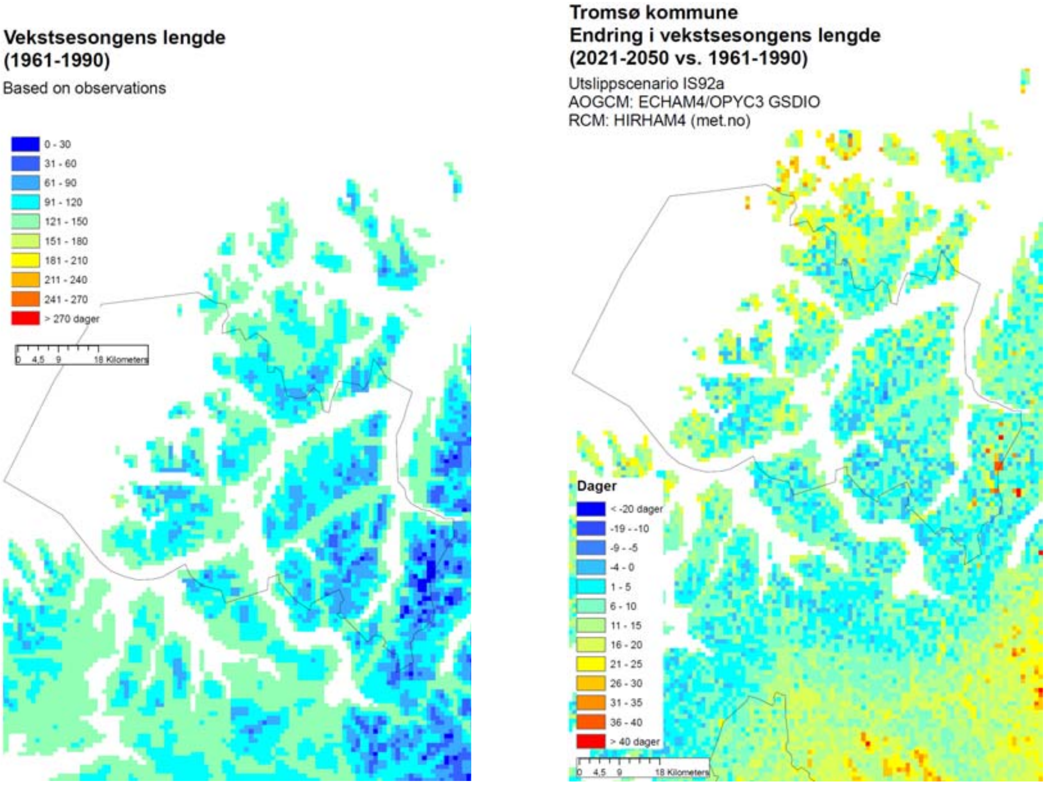


Figure 45. Average length of the growing season in the period 1961-1990 based upon observations (left), and projected change of the growing season from 1961-1990 to 2021-2050 (right) in Tromsø municipality.

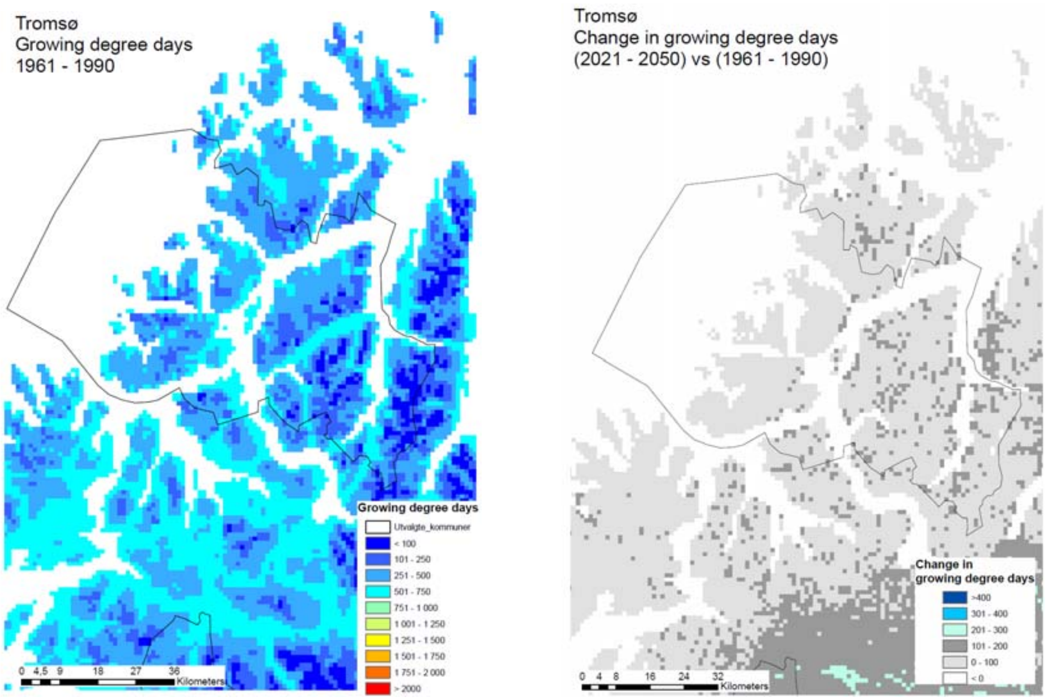


Figure 46. Average annual sum of growing degree days in the period 1961-1990 based upon observations (left), and projected changes from 1961-1990 to 2021-2050 (right) in Tromsø municipality.

5.4.3 Precipitation

The 1961-1990 normal annual precipitation at the Tromsø sation was 1030 mm, while it was 1000 mm at Tromsø-Langnes, where the altitude is lower. Both stations show a precipitation maximum in autumn, and a minimum in late spring (Figure 47). As seen from Figures 4 and 5, Tromsø gets about as much precipitation as Bodø, though Tromsø gets slightly more in winter and less in summer and autumn.

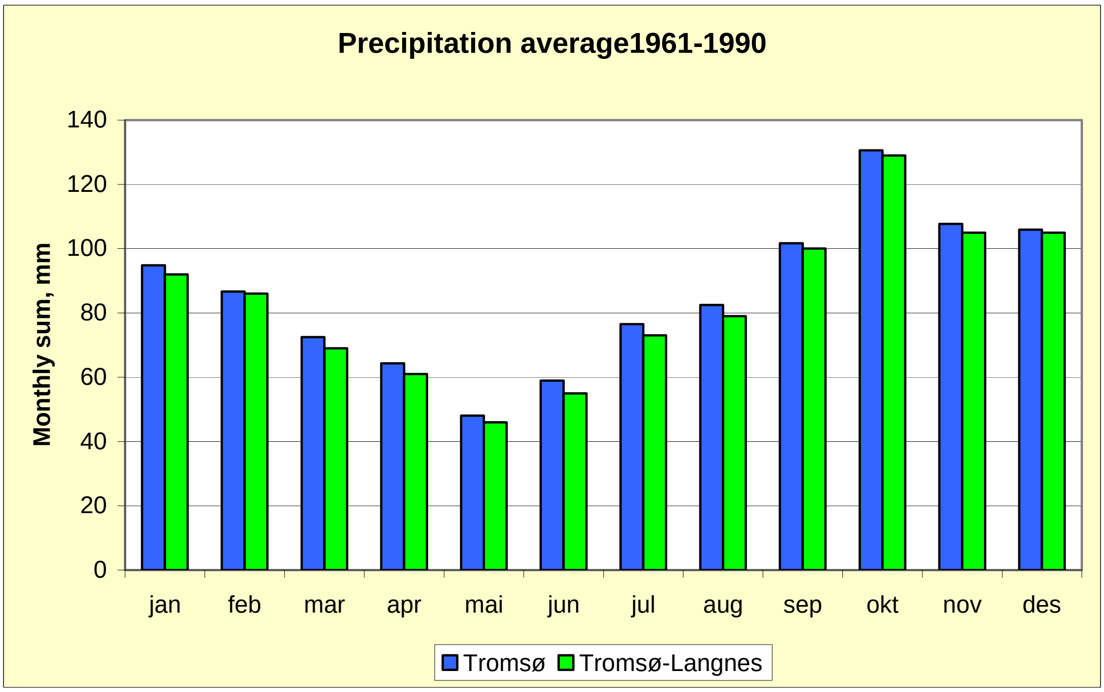


Figure 47. Average monthly precipitation sum for the period 1961-1990 at the stations Tromsø and Tromsø - Langnes.

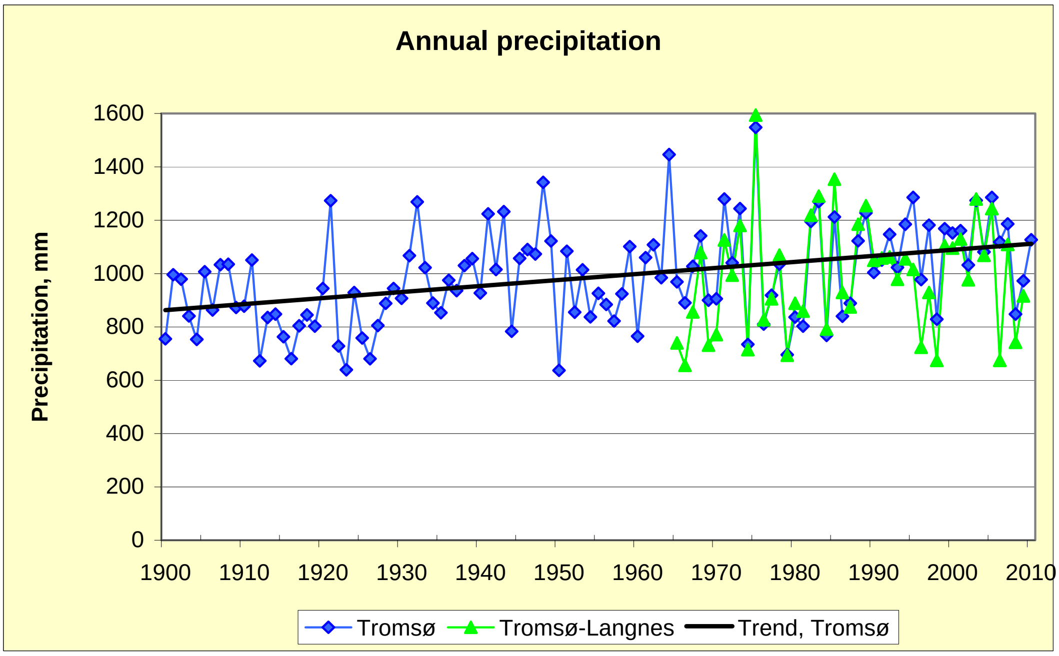


Figure 48 Annual precipitation series for Tromsø and Tromsø-Langnes. For Tromsø, the linear trend from 1900 to 2009 is also shown.

The annual precipitation at Tromsø and Tromsø-Langnes are well correlated (Figure 48). The long series from Tromsø shows a precipitation increased from 1900 to 2009. The linear trend gives an increase of 2.2 % per decade (% of the 1961-1990 average). The total precipitation increase from 1900 to 2009 was thus about 24%. Table 9 shows that some increase has taken place in all the seasons, though the increase in winter precipitation is the larger.

Table 9. Observationally based precipitation trends from 1900 to 2009, and medium, low and high projected trends for the 21st century at Tromsø.

TROMSØ		Unit: % per decade Ann	Win	Spr	Sum	Aut
Trends 1900 to 2009		+2.2	+3.6	+1.9	+2.8	+1.0
Projected trends from 1961-1990 to 2071-2100	Medium	+1.8	+1.1	+1.6	+1.7	+2.4
	Low	+0.4	-1.1	+0.1	+1.1	+0.9
	High	+3.9	+3.5	+5.8	+3.0	+3.9

In Figure 49, the historical precipitation series is combined with low, medium and high projection for the future. Table 9 and Figure 49 show that in winter, the observed precipitation trend during the last 110 years – and particularly during the latest decades – is larger than the trend projected for the future. This may indicate that models tend to underestimate the antropogenic effect on precipitation in this area. On the other hand, the increase in winter precipitation during the later years may be more or less attributed to natural variability, and thus not totally result from antropogenic forcing.

Anyway, the example projection which is used for projecting snow variables for the period 2021-2050 (green point in Figure 49) is rather close to what we have seen the last 30 years concerning total winter precipitation, though it is close to the medium of the projection values. Note that the example projection for autumn precipitation, on the other hand, is relatively high compared to present values (and also compared to the average projection).

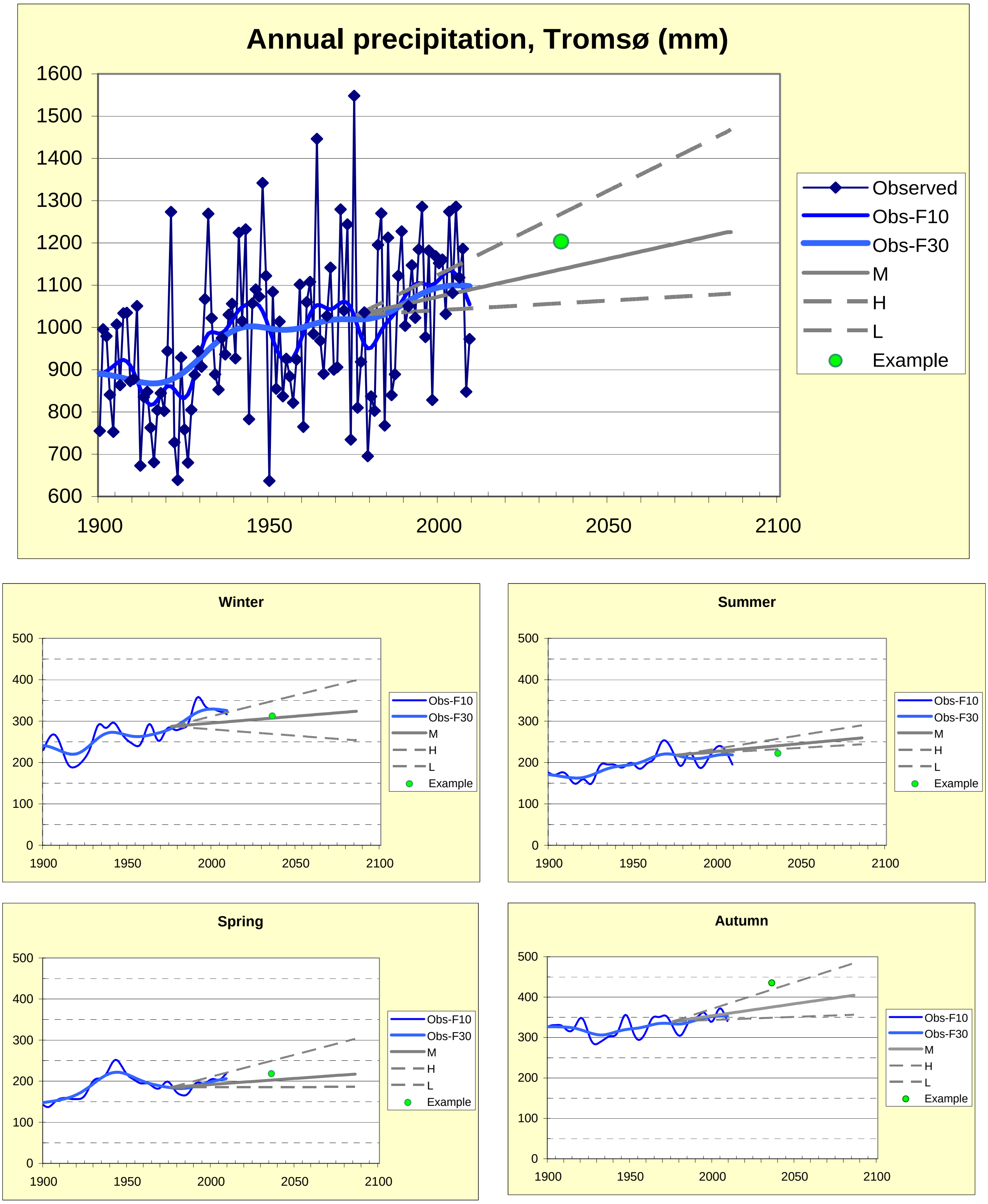


Figure 49. Historical precipitation series and projected future trends at Tromsø on annual and seasonal basis. The historical series are given as filtered curves showing variability on 10-year and 30-year timescales. The annual series is also given as single values. The future trends are based upon 22 temperature projections. The medium trend (M) gives the average, the high (H) gives the 90 percentile, and the low (L) the 10 percentile of these projection. The example projection which is used for detailed calculations is shown as a green point.

5.4.4 Snow season

The length of the snow season at the Tromsø station has the last 60 years varied between 5,5 and 8 months, with an average around 6,5 months (Figure 50). There seem to have been a change from positive to negative trend in snow season length around 1970. The inter-annual variability is large, however.

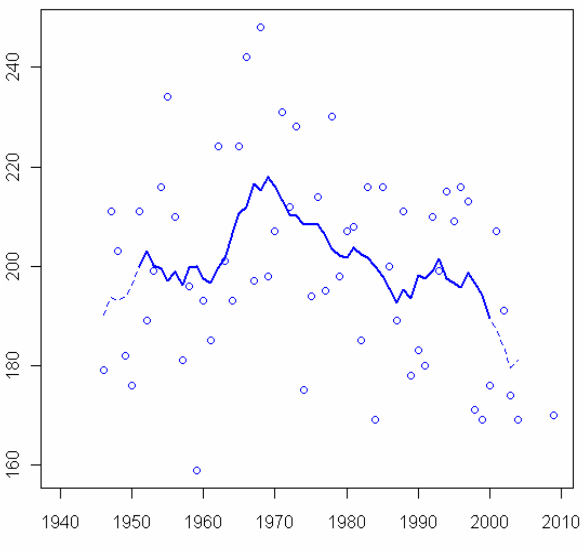


Figure 50. Number of days a year with 50% or more of the ground covered with snow at in Tromsø

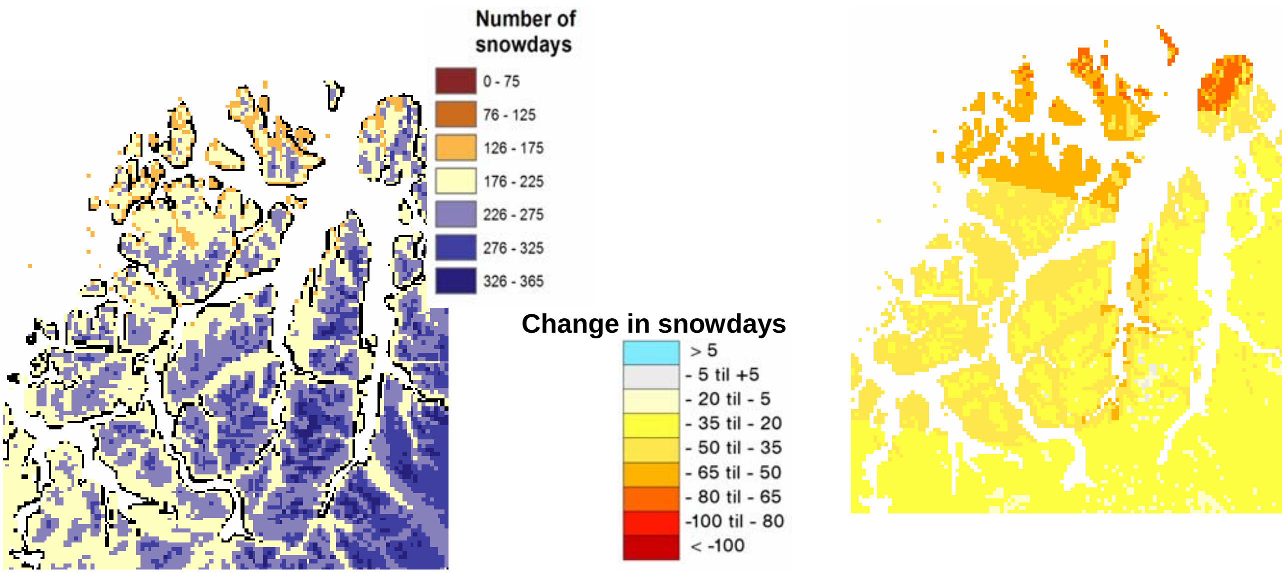


Figure 51. ***Number of days a year with 50% or more of the ground covered with snow in Tromsø municipality a) In the period 1961-1990, b) projected change to 2021-2070***

The left panel of figure 51 shows that most of Tromsø municipality typically has a snow season between 5 and 8 months, though a few sites exist where the snow season is longer. According to the right panel, the example scenario gives 3-7 weeks reduced snow season most places. The largest decrease is projected in coastal areas and valleys, while the projected reduction is smaller in the mountain areas.

5.5 Bardu

Bardu is an inland municipality south in Troms County (Fig. 1a), and the winters are considerably colder here than along the coast. The area of Bardu is 2704 km^2, of which much is occupied by mountainous terrain with peaks up to 1500 m a.s.l. Data from the three stations Bardufoss (76 m.a.s.l.), Sætermoen (114 m.a.s.l.) and Dividalen (228 m.a.s.l.) are used in the present analyses. Sætermoen is the only one which is situated in Bardu, but as only precipitation is measured there, data from stations in the neighbor municipality Målselv are also used. Sætermoen and Bardu are representative of the western part of the municipality, while Dividalen is representative for the eastern, and most continental part of the municipality. All stations are representative for valleys rather than mountain areas.

5.5.1 Temperature

Figure 52 shows that January at average is the coldest months of the year, with a mean temperature of -9.3 ^{o}C at the the Dividalen station. July is at average is the warmest month, with a mean temperature of about +12.7 ^{o}C. There is considerable variation around these mean temperatures. The lowest minimum-temperature that has been measured at the station in the period 1961-1990 is about -31.7^{o}C, and the highest maximum-temperature is +30.8 ^{o}C. The average monthly temperature mean is above 0 ^{o}C from May to October, but below zero minimum temperatures have occurred in all months of the year. The temperature measurements at Dividalen are probably representative for the inland valleys in the area. The mountain areas will usually be colder, at least during spring, summer and autumn.

Figure 53 shows that the annual mean temperature in Dividalen and Bardu are highly correlated, and the trends in the series seem to be similar. The inter-annual temperature variation in Dividalen is considerable: The lowest value in the 110 year long composite series is -2 ^{o}C in 1915, and the highest is + 3.1 ^{o}C in 1938. Even though the warmest year occurred in the first half of the series, the large number of mild years during the last couple of decades leads to a statistically significant positive trend in the series. The linear trend in Figure 53 is + 0.12 ^{o}C per decade, or about 1.3 ^{o}C over the 110 year period. All the seasonal trends are also positive over the period 1900 to 2009 (Table 10). The largest temperature increase has occurred during spring.

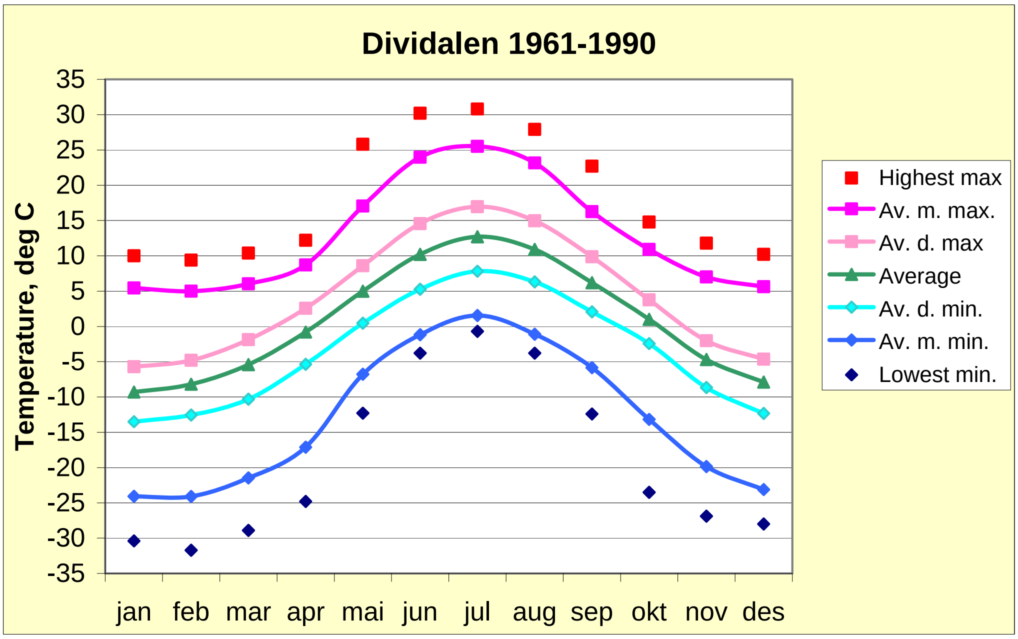


Figure 52. Monthly average and extreme temperatures at Dividalen. "Highest max."/"Lowest min." are the most extreme temperature measured in the specific month during the given time period, "Av. m. max."/ "Av. m. min." are the average monthly extremes, while "Av. d. max."/ "Av. d. min." are the average daily extremes. "Average" is the monthly mean.

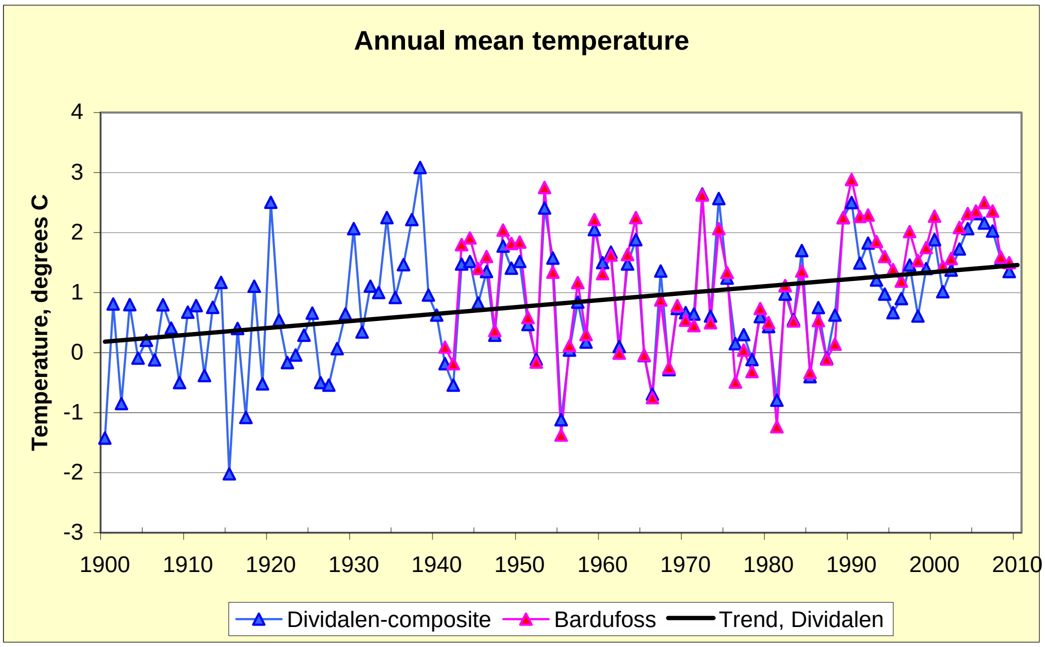


Figure 53. Annual mean temperature series for Dividalen and Bardufoss. For Dividalen, the linear trend from 1900 to 2009 is also shown.

Table 10. Observationally based temperature trends from 1900 to 2009, and medium, low and high projected trends for the 21st century in Dividalen.

DIVIDALEN		Unit: °C per decade Ann	Win	Spr	Sum	Aut
Trends 1900 to 2009		+0.12	+0.08	+0.18	+0.11	+0.10
Projected trends from 1961-1990 to 2071-2100	Medium	+0.31	+0.38	+0.35	+0.20	+0.31
	Low	+0.20	+0.25	+0.24	+0.12	+0.20
	High	+0.42	+0.55	+0.47	+0.30	+0.41

Table 10 and Figure 54 show projected future temperature trends in Dividalen together with historical trends. For definition of low, medium and high future projections: See chapter 3 and Figure 54 label! The projected temperature trends for the 21t century are definitely higher than those observed during the 20th century, however, the annual and seasonal trends which have been observed the latest decades largely span from the low to the medium projected trends.

One specific climate projection ("example projection") is used to calculate possible changes in growing season and snow season towards the mid-century. Figure 54 shows that in Dividalen, this example projection is close to the medium temperature projection in summer and autumn, close to the low one in spring, and even below the low winter.

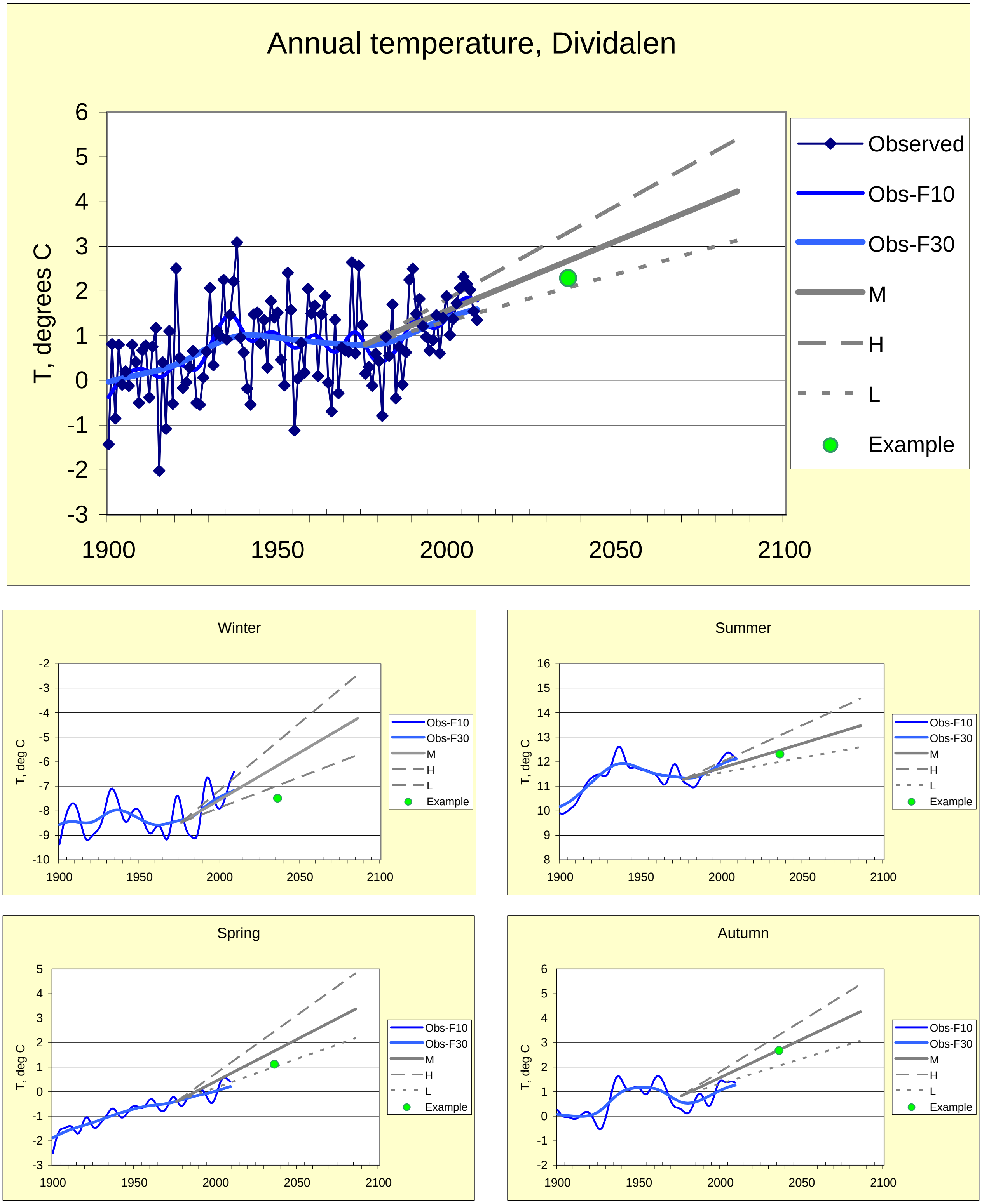


Figure 54. Historical temperature series and projected future trends at Dividalen on annual and seasonal basis. The historical series are given as filtered curves showing variability on 10-year and 30-year timescales. The annual are also given as single values. The future trends are based upon 72 temperature projections. The medium trend (M) gives the average, the high (H) gives the 90 percentile, and the low (L) the 10 percentile of these projection. The example projection which is used for detailed calculations is shown as a green point.

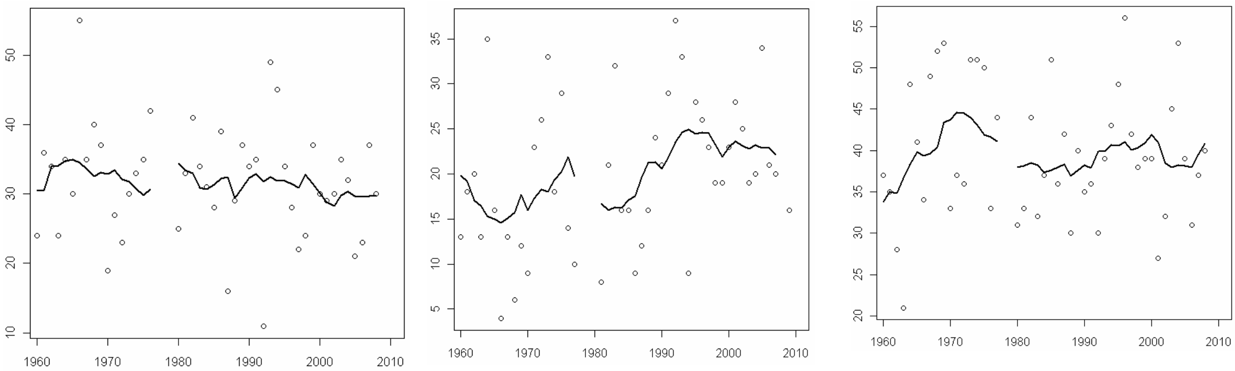


Figure 55. Number of days per season when the temperature has crossed 0 °C in Dividalen

Number of days when the temperature crosses 0 °C at the Dividalen station is at average around 30 in autumn, 20 in winter and 40 in spring (Figure 55). The last two decades, days when temperature crosses 0 °C seem to have become more frequent during the winter season. In autumn and spring, there variability is large, but the trends are weak.

Detailed future projections for frequencies of days when the temperature crosses 0 °C have not been produced. However, taking into considerations the temperature projections given in Figure 54, the frequency will probably decrease in autumn and spring, and increase in winter at the Dividalen station.

5.5.2 Growing season

The thermal growing season for grass is defined in chapter 3. Figure 56 shows that the growing season at the Dividalen meteorological station typically has varied between 3.5 and 5 months, with an average around 4.5 months. Figure 57, left panel shows that the average growing season in Bardu municipality for the most varies from 2 to 5 months, though mountain peaks have even shorter growing season. The meteorological station Dividalen is thus representative for the most favorable parts of the municipality (which are the valleys) concerning growing season.

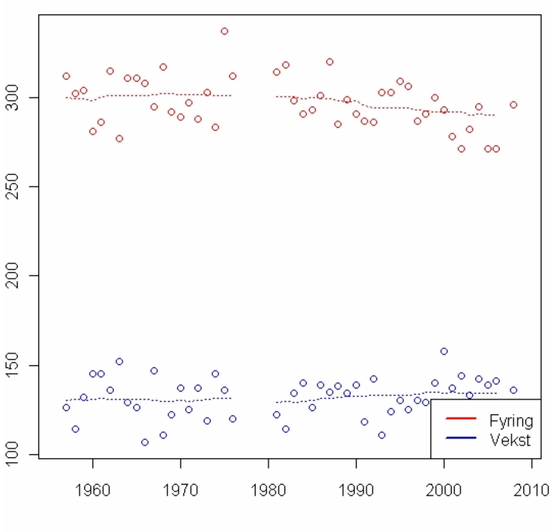


Figure 56. Heating season (red) and growing season (blue) in Dividalen for the period 1955-2009 given in number of days a year.

The example projection used to calculate growing season for 2021-2050 shows 2-4 weeks increase in the growing season in large parts of the municipality towards the mid-century in the (Figure 57, right panel). The projected change in growing degree days is 100-300 in most of the area (Figur 58, right panel).

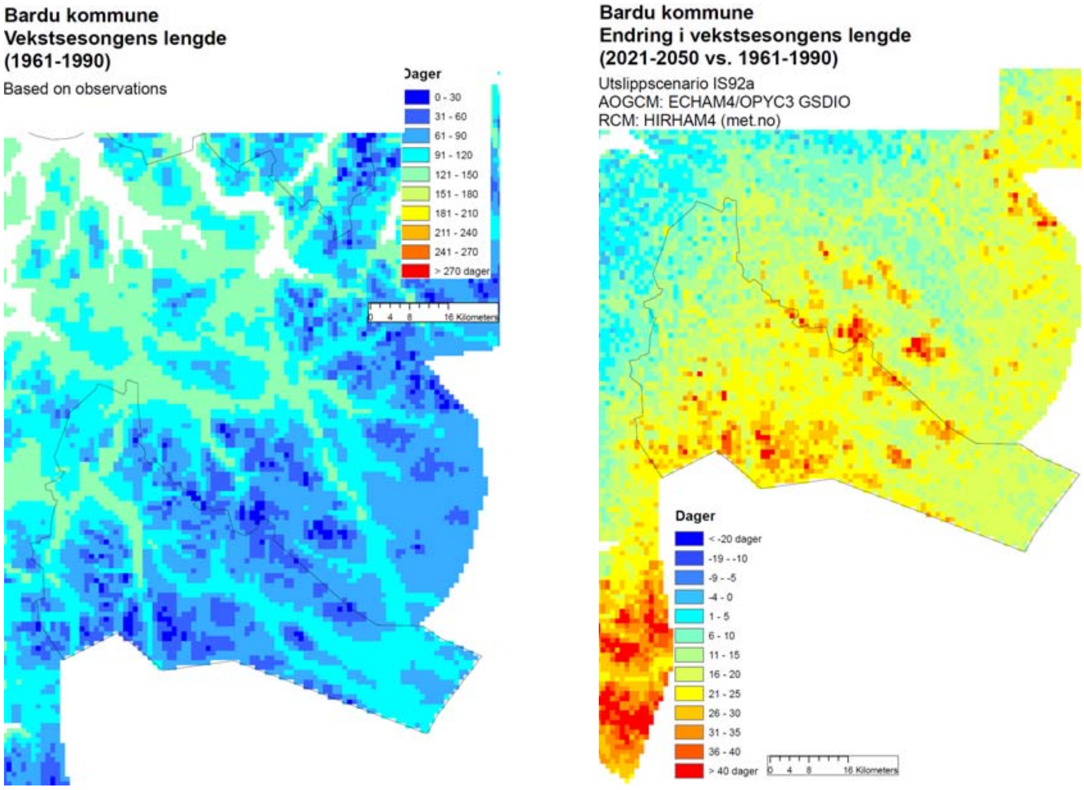


Figure 57. Average length of the growing season in the period 1961-1990 based upon observations (left), and projected change of the growing season from 1961-1990 to 2021-2050 (right) in Bardu municipality.

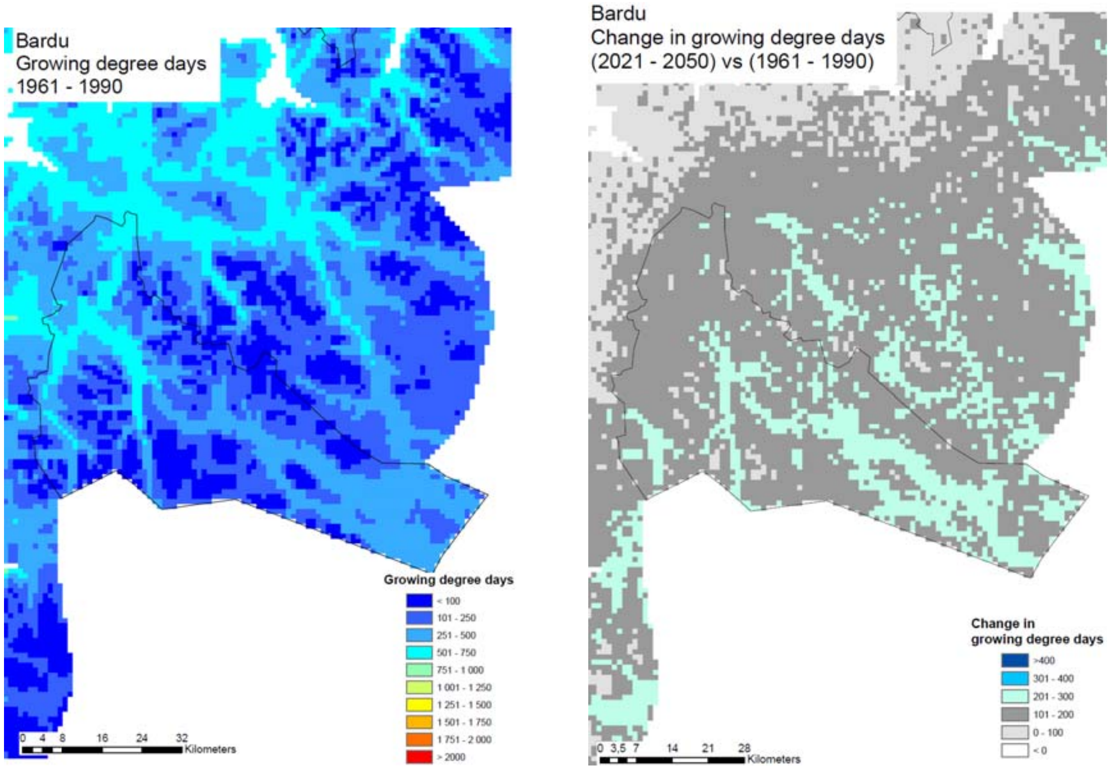


Figure 58. Average annual sum of growing degree days in the period 1961-1990 based upon observations (left), and projected changes from 1961-1990 to 2021-2050 (right) in Bardu municipality.

5.5.3 Precipitation

The 1961-1990 normal annual precipitation at Sætermoen was 797 mm, while it was 652 mm at Bardufoss, and only 282 at the Dividalen, which is situated further east and further inland than the other stations. Figure 59 shows that Sætermoen and Bardufoss follow the "west coast pattern" with precipitation maximum in autumn, rather high values during winter, and minimum in late spring, while Dividalen has precipitation maximum in summer and a very low minimum in spring. At average, Dividalen gets less precipitation than Sætermoen in all months, but the difference is rather small in summer.

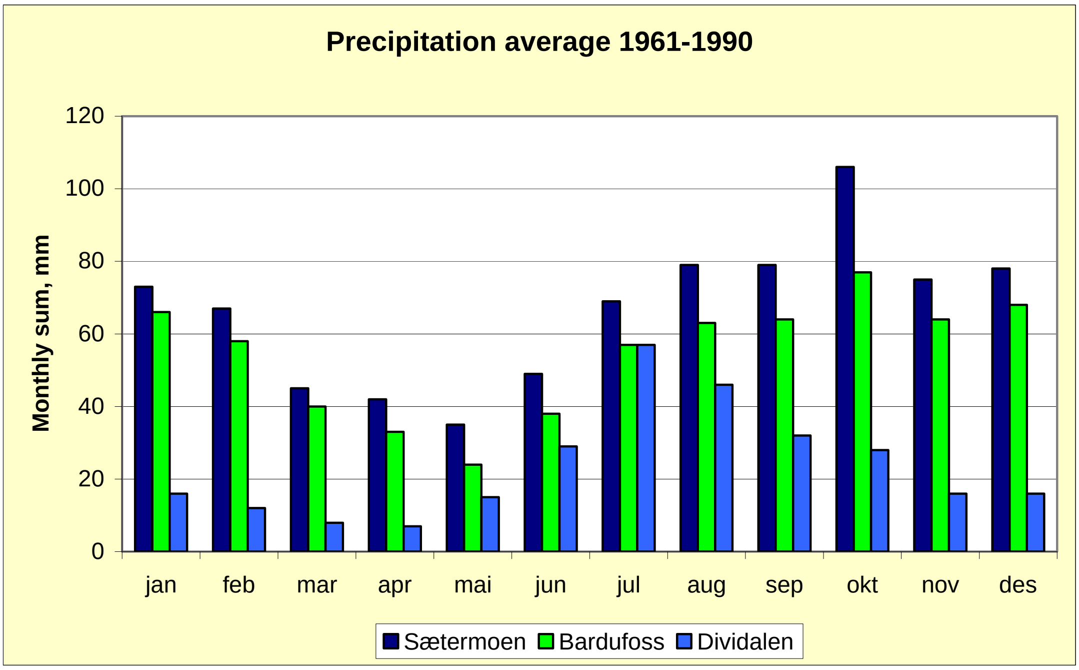


Figure 59. Average monthly precipitation sum for the period 1961-1990 at the stations Sætermoen, Bardufoss and Dividalen.

The annual precipitation at Særetmoen and Bardufoss are well correlated (Figure 60). The long series from Sætermoen shows a significant positive precipitation increase from 1900 to 2009. The linear trend gives an increase of 2.9% per decade, when measured relatively to the 1961-1990 average. Table 11 shows that some increase has taken place in all the seasons, though the increase in winter precipitation is the larger.

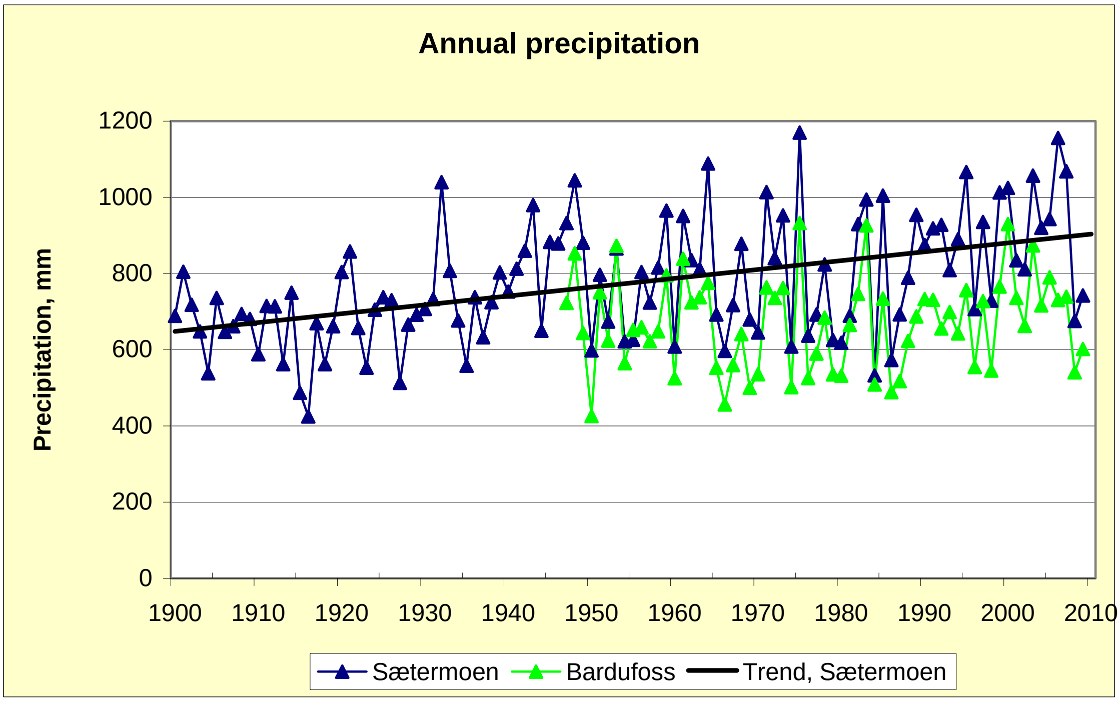


Figure 60 Annual precipitation series for Sætermoen and Bardufoss. For Sætermoen, the linear trend from 1900 to 2009 is also shown.

In Figure 61, the historical precipitation series is combined with low, medium and high projection for the future. Table 11 and Figure 61 show that in winter, the observed precipitation trend during the last 110 years – and particularly during the latest decades – is larger than the trend projected for the future. This may indicate that models tend to underestimate the antropogenic effect on precipitation in this area. On the other hand, the increase in winter precipitation during the later years may be more or less attributed to natural variability, and thus not totally result from antropogenic forcing.

Anyway, the example projection which is used for projecting snow variables for the period 2021-2050 (green point in Figure 61) is rather close to what we have seen the last 30 years concerning total winter precipitation, though it is close to the medium of the projection values. Thus, the projection for changes in the length snow season does not take into account a possible increase in winter precipitation relatively to the present level.

Table 11. Observationally based precipitation trends from 1900 to 2009, and medium, low and high projected trends for the 21st century at Sætermoen.

SÆTERMOEN		Unit: % per decade				
		Ann	Win	Spr	Sum	Aut
Trends 1900 to 2009		+2.9	+4.1	+1.5	+3.1	+2.6
Projected trends from 1961-1990 to 2071-2100	Medium	+1.8	+1.1	+1.6	+1.7	+2.4
	Low	+0.4	-1.1	+0.1	+1.1	+0.9
	High	+3.9	+3.5	+5.8	+3.0	+3.9

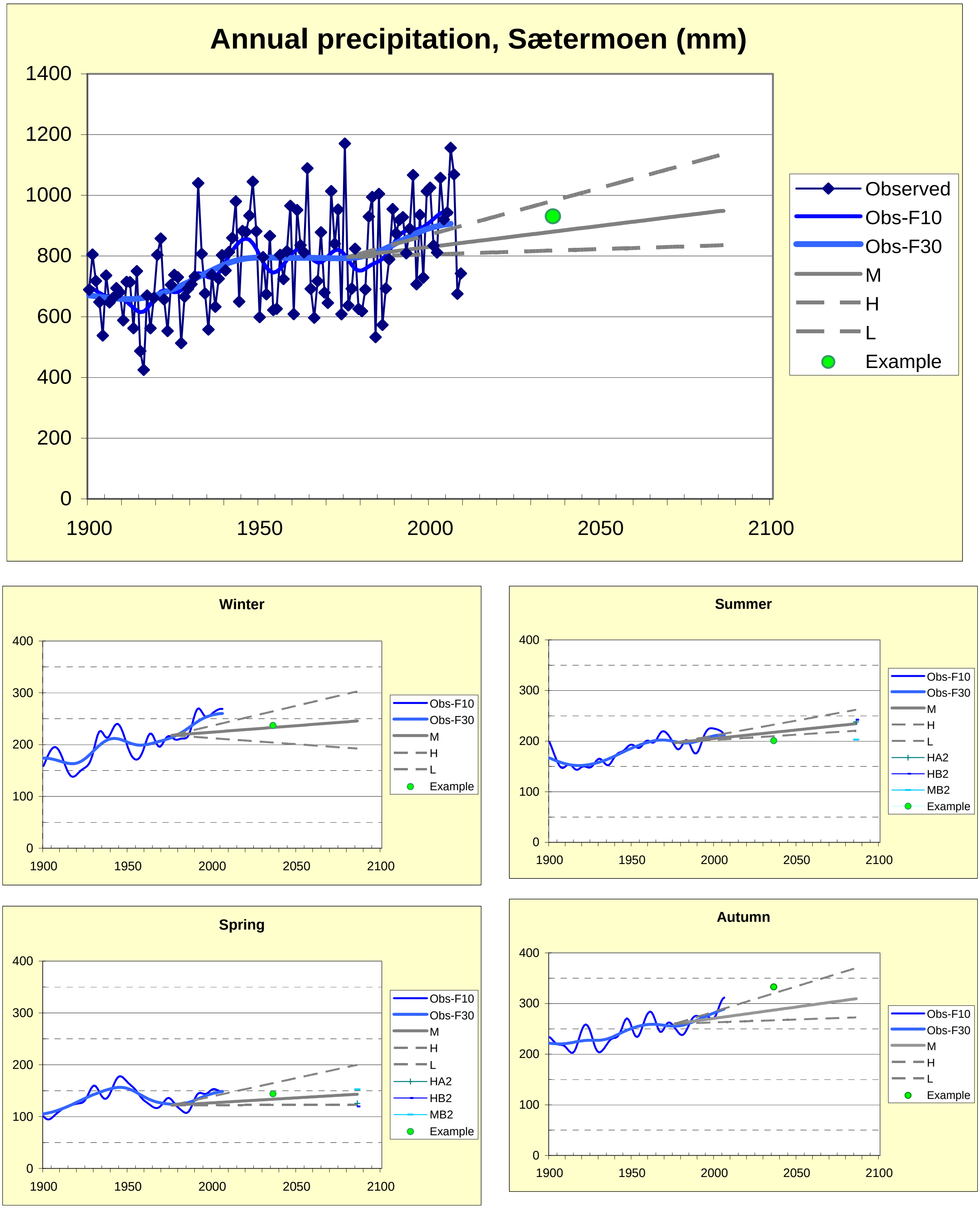


Figure 61. Historical precipitation series and projected future trends at Sætermoen on annual and seasonal basis. The historical series are given as filtered curves showing variability on 10-year and 30-year timescales. The annual series is also given as single values. The future trends are based upon 22 temperature projections. The medium trend (M) gives the average, the high (H) gives the 90 percentile, and the low (L) the 10 percentile of these projection. The example projection which is used for detailed calculations is shown as a green point.

5.5.4 Snow season

The length of the snow season at Sætermoen has the last 50 years varied between 5 and 8 months, and at Dividalen between 3 and 8 months (Figure 62). The averages are about 6.5 and 6 months, respectively. The Dividalen series show a clear trend towards shorter snow season from the 1960s, while this trend is less evident at Sætermoen.

Figure 62. Number of days a year with 50% or more of the ground covered with snow at a) Sætermoen, b) Dividalen

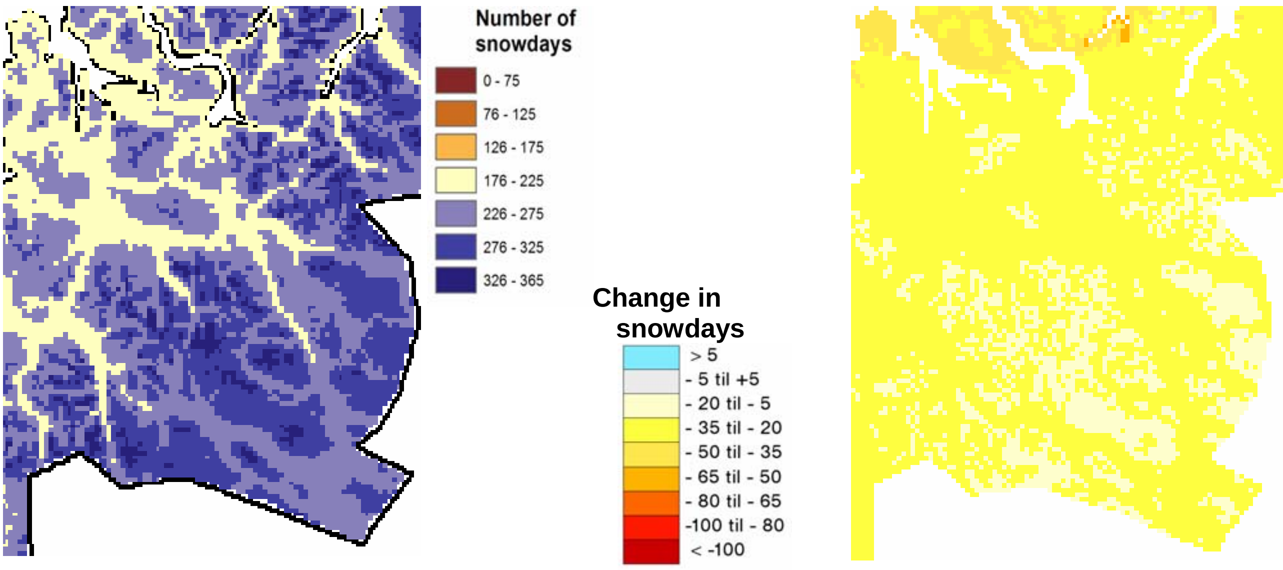


Figure 63. Number of days a year with 50% or more of the ground covered with snow in Bardu municipality a) In the period 1961-1990, b) projected change to 2021-2070

The left panel of figure 63 shows that most of Bardu typically has a snow season between 6 and 9 months, and that the stations represent the areas with shorter snow season in the municipality. According to the right panel, the example scenario gives 2-5 weeks reduced snow season in 2021-2050. The largest decrease is projected in the areas which presently have relatively short snow season.

5.6 Porsanger

Porsanger is a fiord municipality in Finnmark County (Fig. 1a), including a long shoreline to the Porsanger fiord, but also rivers, lakes, valleys and mountains with a few peaks above 1000 m a.s.l. The area of Porsanger is 4873 km². Data from the meteorological stations Banak (5 m a.s.l.) and Skoganvarre (74 m a.s.l.) are used in the present analyses. Though both stations started in the 1950s, it has been possible to prolong the temperature series from Skoganvarre and the precipitation series from Banak back to 1900 by using neighboring stations and a scaling technique.

5.6.1 Temperature

Figure 64 shows that January at average is the coldest months of the year, with a mean temperature of -10 ^{o}C at the Banak station. July is at average is the warmest month, with a mean temperature of +12.7 ^{o}C. There is considerable variation around these mean temperatures. The lowest minimum-temperature that has been measured at the station in the period 1961-1990 is about -33.6^{o}C. The highest maximum-temperature is +33^{o}C. The average monthly temperature mean is above 0 ^{o}C from May to October, but July is the only month with no incidents of minimum temperature below zero temperatures in the period 1961-1990.

Concerning geographical representativity of the temperature measurements at Banak, it should be kept in mind that the altitude of this station is low, and the distance to the fiord is rather short. Winter temperatures in are expected to be lower in mountain areas and further inland. On the other hand, areas even closer to the fiord and further out towards the fiord mouth will have milder winters. In summer, the temperatures are more homogeneous, but still the mountain areas will be cooler.

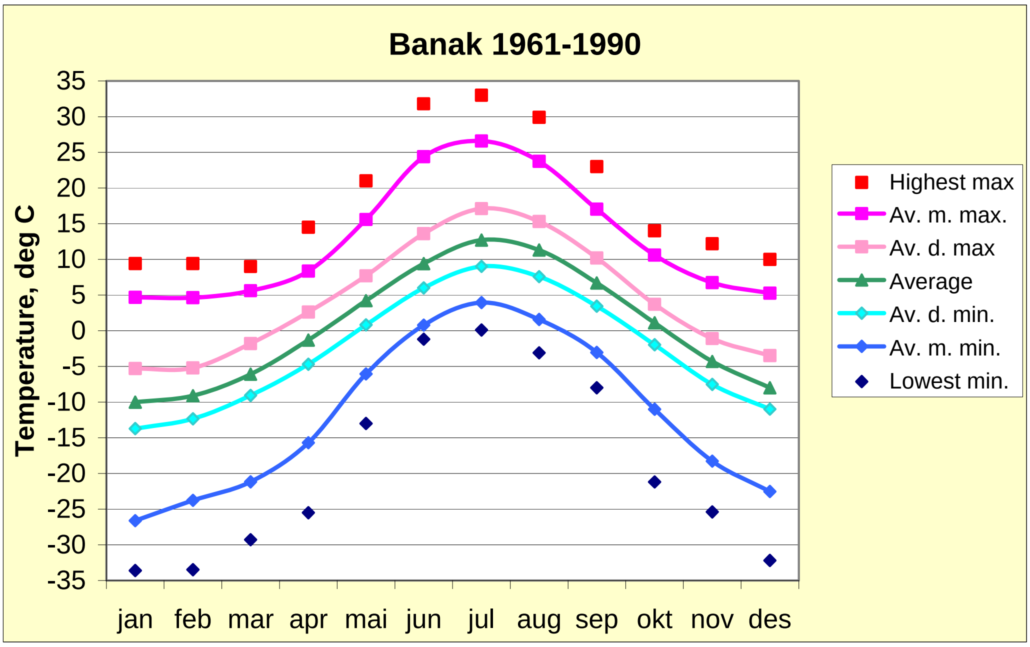


Figure 64. Monthly average and extreme temperatures at Banak. "Highest max."/"Lowest min." are the most extreme temperature measured in the specific month during the given time period, "Av. m. max."/ "Av. m. min." are the average monthly extremes, while "Av. d. max."/ "Av. d. min." are the average daily extremes. "Average" is the monthly mean.

Figure 65 shows that the annual mean temperature in Banak and Skoganvarre are highly correlated, though Skoganvarre, being less exposed to maritime influence than Banak, is at average a couple of degrees colder.

The inter-annual temperature variation in Banak is considerable: The lowest value in the 110 year long composite series is -4.34^{o}C in 1902, and the highest is +1.83 ^{o}C in 1938. Even though the warmest year occurred in the first half of the series, the large number of mild years during the last couple of decades leads to a positive trend in the series. The linear trend in Figure 65 is + 0.11 ^{o}C per decade, or about 1.2 ^{o}C over the 110 year period. All the seasonal trends are also positive over the period 1900 to 2009 (Table 12), but the largest trend is found in spring temperatures.

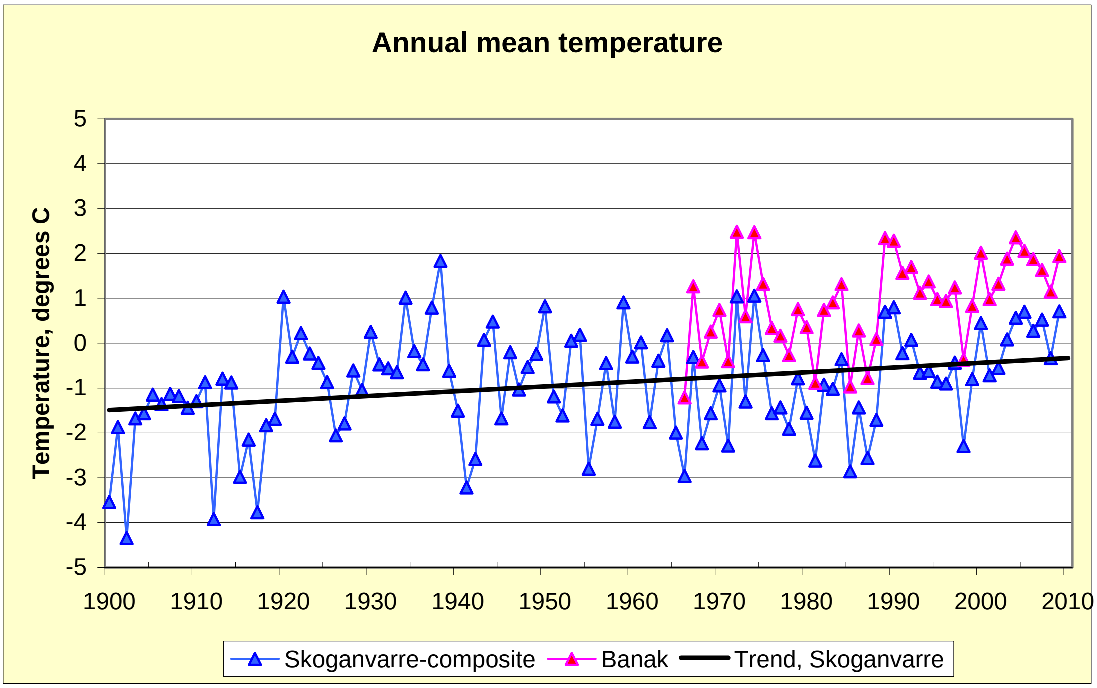


Figure 65. Annual mean temperature series for Skoganvarre and Banak. For Skoganvarre, the linear trend from 1900 to 2009 is also shown.

Table 12. Observationally based temperature trends from 1900 to 2009, and medium, low and high projected trends for the 21st century in Skoganvarre.

SKOGANVARRE		Unit: ^{o}C per decade Ann	Win	Spr	Sum	Aut
Trends 1900 to 2009		+0.11	+0.09	+0.17	+0.10	+0.07
Projected trends from 1961-1990 to 2071-2100	Medium	+0.38	+0.48	+0.39	+0.25	+0.37
	Low	+0.28	+0.33	+0.27	+0.15	+0.26
	High	+0.47	+0.64	+0.53	+0.37	+0.50

Table 12 and Figure 66 show projected future temperature trends in Skoganvarre together with historical trends. For definition of low, medium and high future projections: See chapter 3 and Figure 66 label! The projected temperature trends for the 21t century are definitely higher than those observed during the 20th century, however, the annual and seasonal trends which have been observed the latest decades largely span from the low to the medium projected trends.

One specific climate projection ("example projection") is used to calculate possible changes in growing season and snow season towards the mid-century (green points). Figure 66 shows that in Skoganvarre, this example projection is close to the medium temperature projection in summer and winter, between medium and low in spring, and even between medium and high in autumn.

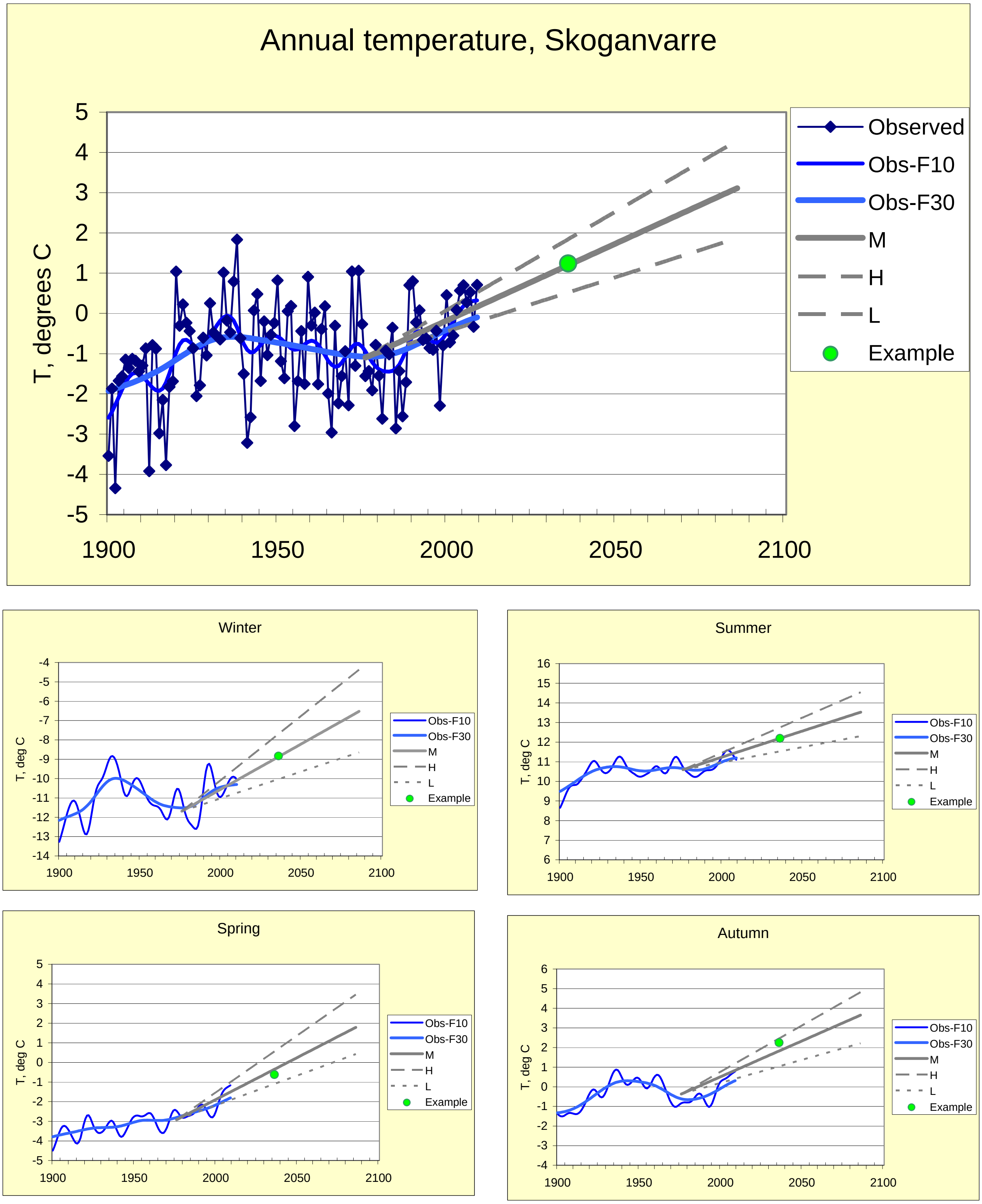


Figure 66. Historical temperature series and projected future trends at Skoganvarre on annual and seasonal basis. The historical series are given as filtered curves showing variability on 10-year and 30-year timescales. The annual are also given as single values. The future trends are based upon 72 temperature projections. The medium trend (M) gives the average, the high (H) gives the 90 percentile, and the low (L) the 10 percentile of these projection. The example projection which is used for detailed calculations is shown as a green point.

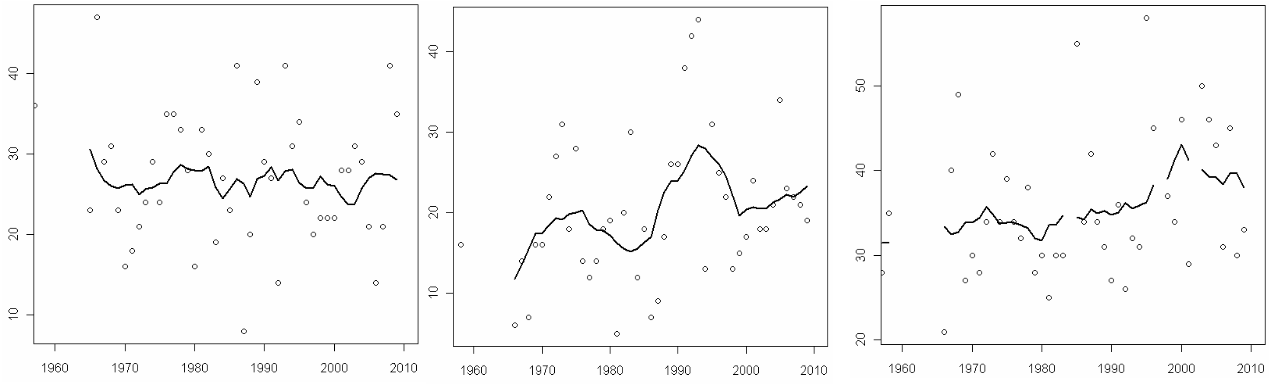


Figure 67. Number of days per season when the temperature has crossed 0 °C in Banak

Number of days when the temperature crosses 0 °C at the Banak station is at average around 25 in autumn, 20 in winter and 35 in spring (Figure 67). The variability is large, but there seem to be a small tendency towards more frequent days when temperature crosses 0 °C in winter and spring.

Detailed future projections for frequencies of days when the temperature crosses 0 °C have not been produced. However, taking into considerations the temperature projections given in Figure 66, the frequency will probably decrease in autumn and increase in winter at the Banak and Skoganvarre stations toward the mid-century. In spring, the frequency will probably increase temporarily and then decrease later in the century.

5.6.2 Growing season

The thermal growing season for grass is defined in chapter 3. Figure 68, left panel, shows that the growing season at the Banak meteorological station typically has varied between 3 and 5 months, with an average around 4 months. Figure 20, left panel shows that the average growing season in Porsanger municipality for the most varies from 2 to 5 months. The meteorological station Banak is thus representative for rather favorable parts of the municipality concerning growing season.

Measurements at the Banak station indicate that there has been a weak tendency towards longer growing season (Figure 68a) and increased annual sum of growing degree days (Figure 68b) during in Banak from the 1970s.

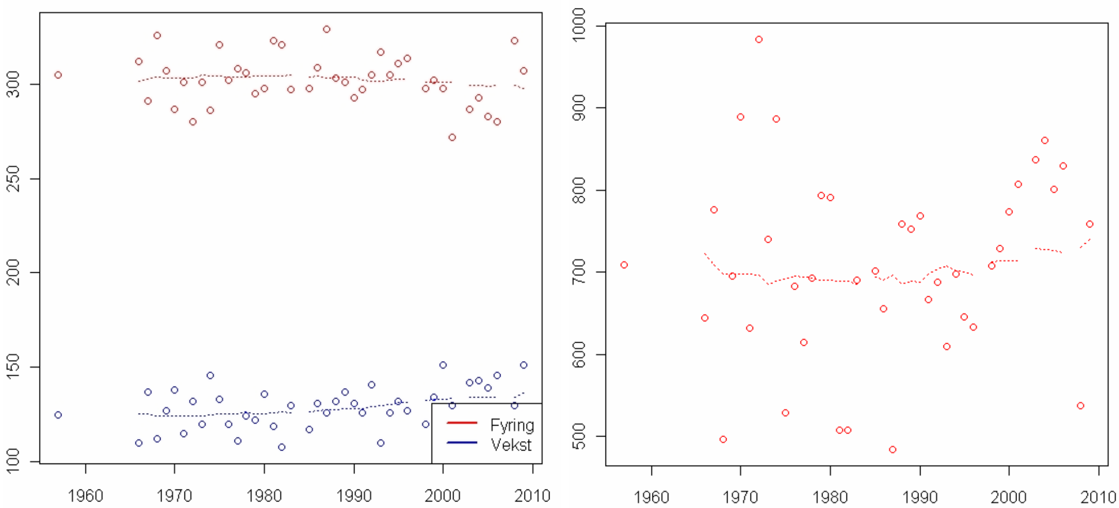


Figure 68. a) Left panel: Heating season (red) and growing season (blue) in Banak for the period 1955-2009 given in number of days a year. b) Right panel: Annual sum og growing degree days in Banak

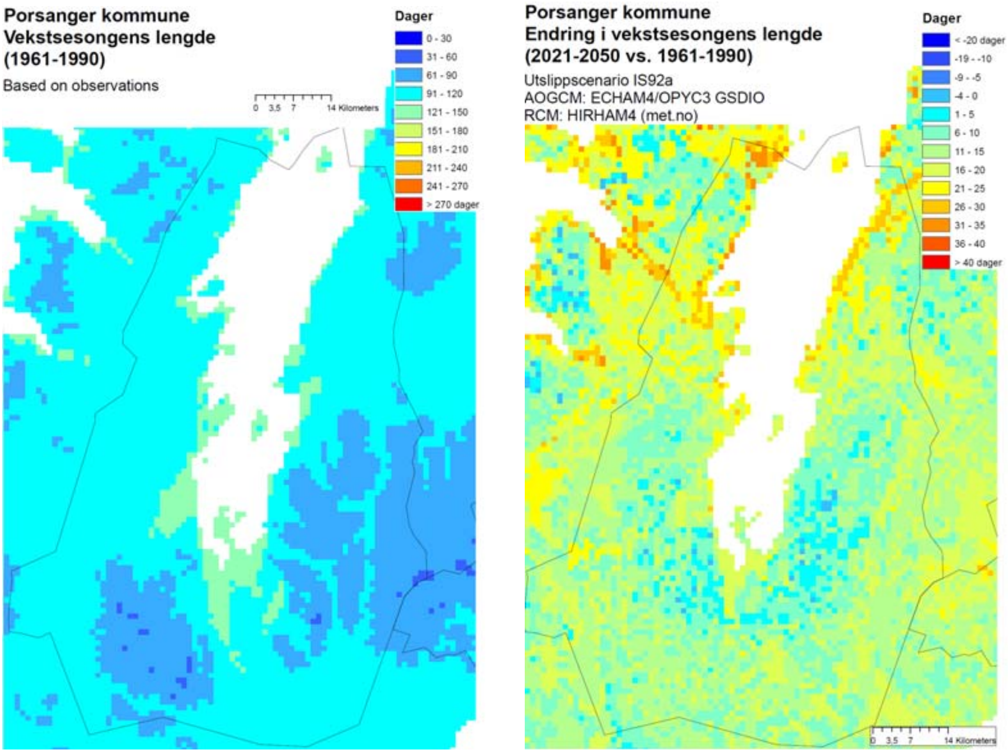


Figure 69. Average length of the growing season in the period 1961-1990 based upon observations (left), and projected change of the growing season from 1961-1990 to 2021-2050 (right) in Porsanger municipality.

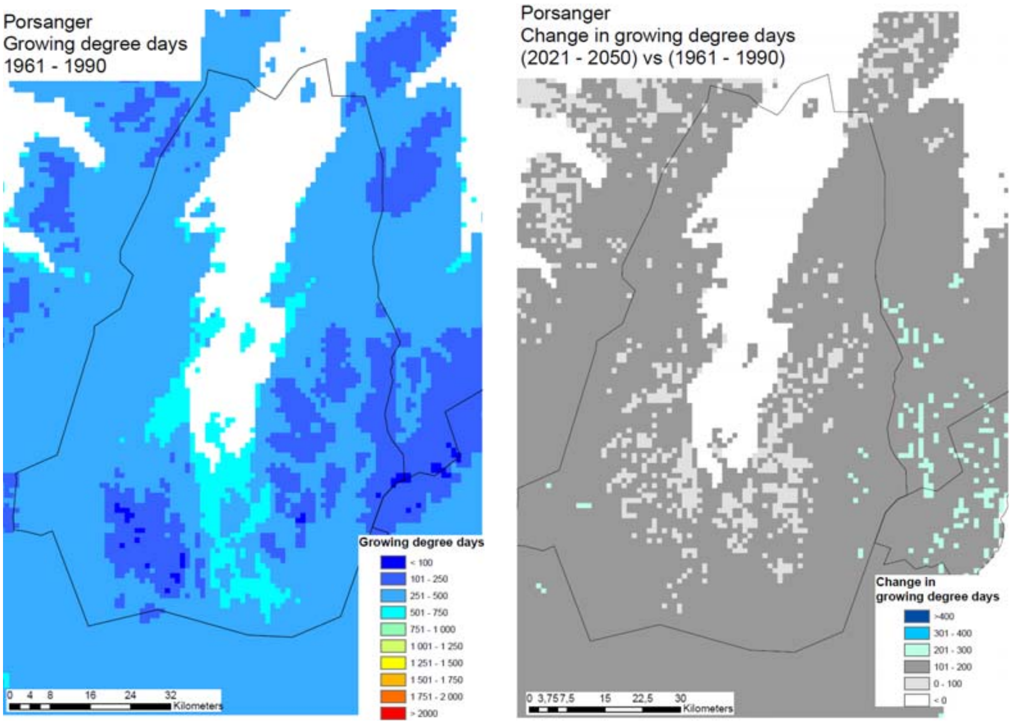


Figure 70. Average annual growing degree days in the period 1961-1990 based upon observations (left), and projected changes from 1961-1990 to 2021-2050 (right) in Porsanger municipality.

The example projection used to calculate growing season for 2021-2050 shows only small changes in growing season in the mountain areas, but 2-3 weeks along the coast in the inner part of the fiord, and even 4 weeks at the coast further out in the fiord (Figure 69, right panel). The projected change is larger in fiords and inland areas, where there typically is projected a 2-3 weeks increase. Typical increase in growing degree days is between 100 and 200 ((Figure 70, right panel).

5.6.3 Precipitation

The 1961-1990 normal annual precipitation at Skoganvarre was 427 mm, while it was 345 mm at Banak, where the altitude is higher. The average monthly values are higher at Skoganvarre than at Banak in all months, but the stations show the same seasonal pattern with minimum in spring and maximum in summer (Figure 71). As seen from Figures 4, this is typical for the inland and inner fiord stations in Finnmark county.

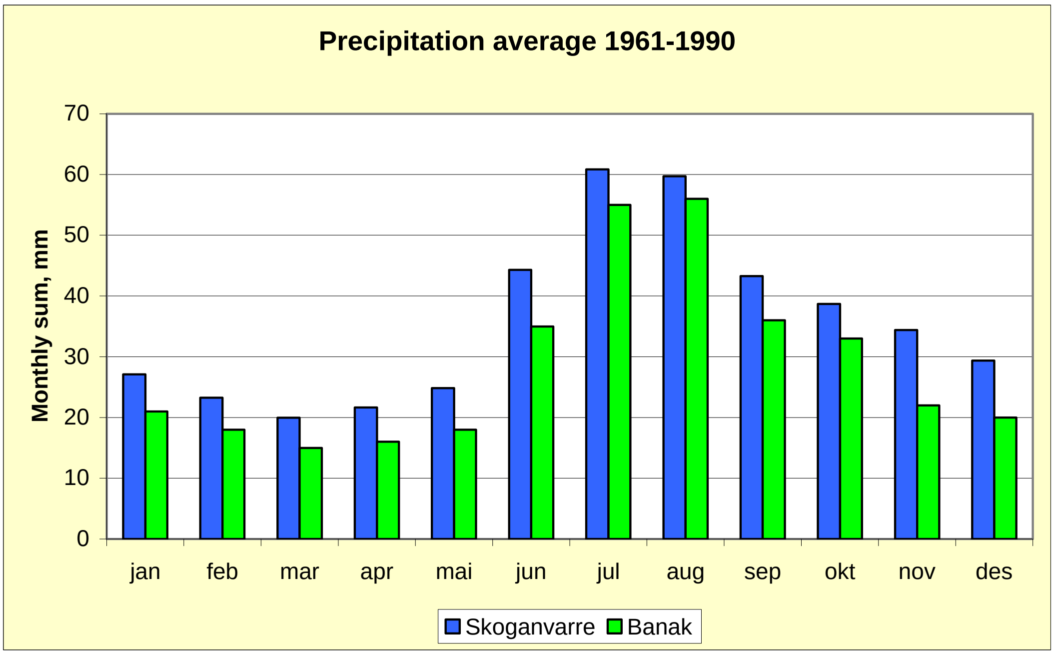


Figure 71. Average monthly precipitation sum for the period 1961-1990 at the stations Skoganvarre and Banak.

The annual precipitation at Skoganvarre and Banak are well correlated (Figure 72). The long series from Banak shows an increase from 1900 to 2009. The linear trend gives an increase of 1.8% per decade, when measured relatively to the 1961-1990 average. Table 13 shows that some increase has taken place in all the seasons, though the increase was largest in winter and spring.

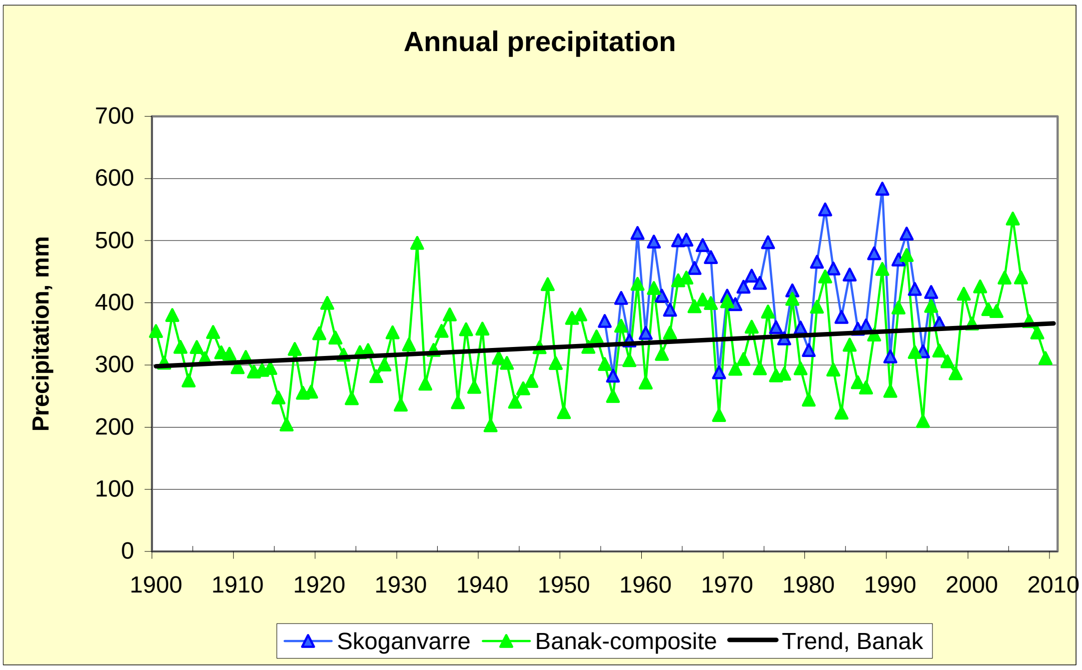


Figure 72 Annual precipitation series for Skoganvarre and Banak. For Banak, the linear trend from 1900 to 2009 is also shown.

In Figure 73, the historical precipitation series is combined with low, medium and high projection for the future. Table 13 and Figure 73 show that in winter, the observed precipitation trend during the last 110 years is similar to the "high" projection for the future. The trend during the latest decades is even higher. This may indicate that models tend to underestimate the antropogenic effect on precipitation in this area. On the other hand, the increase in winter precipitation during the later years may be more or less attributed to natural variability, and thus not totally result from antropogenic forcing.

Anyway, the example projection which is used for projecting snow variables for the period 2021-2050 (green point in Figure 73) is rather close to the 1961-1990 average concerning both annual and seasonal precipitation. Compared to other precipitation projections, the example projection is low. Thus, the projection for changes in the length snow season based upon this example, does not take into account a possible increase in winter precipitation.

Table 13. Observationally based precipitation trends from 1900 to 2009, and medium, low and high projected trends for the 21st century at Susendal.

BANAK		Unit: % per decade				
		Ann	Win	Spr	Sum	Aut
Trends 1900 to 2009		+1.8	+2.9	+2.9	+1.2	+1.7
Projected trends from 1961-1990 to 2071-2100	Medium	+1.5	+1.4	+1.5	+1.2	+2.1
	Low	+0.6	+0.1	+0.3	+0.4	+0.9
	High	+2.5	+3.3	+3.7	+1.9	+3.4

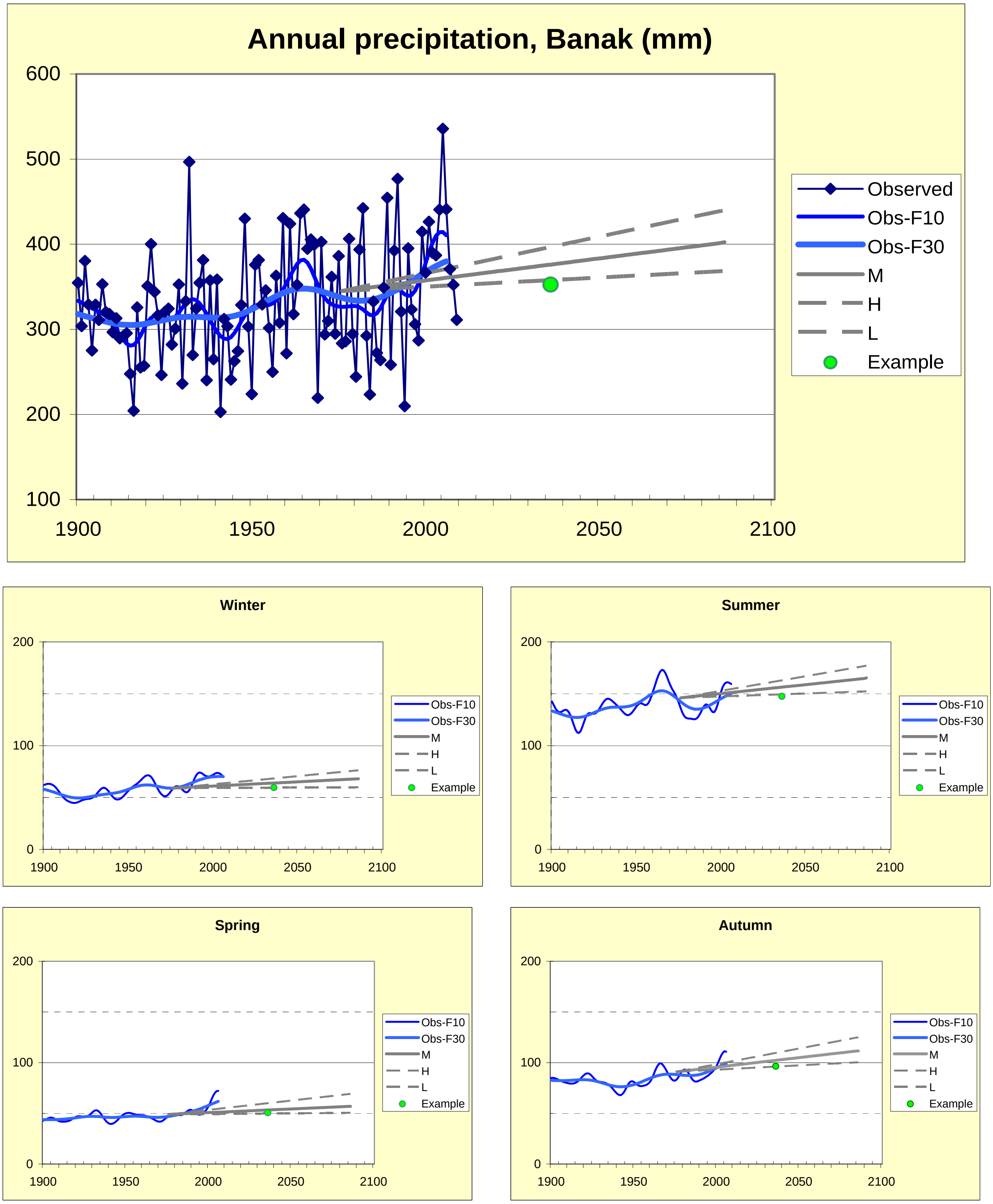


Figure 73. Historical precipitation series and projected future trends at Banak on annual and seasonal basis. The historical series are given as filtered curves showing variability on 10-year and 30-year timescales. The annual series is also given as single values. The future trends are based upon 22 temperature projections. The medium trend (M) gives the average, the high (H) gives the 90 percentile, and the low (L) the 10 percentile of these projection. The example projection which is used for detailed calculations is shown as a green point.

5.6.4 Snow season

The length of the snow season at Skoganvarre has the last 50 years varied between 5.5 and 8 months, with an average of around 6.5 months (Figure 74). The interannual variability is large, and there is no clear trend in the series.

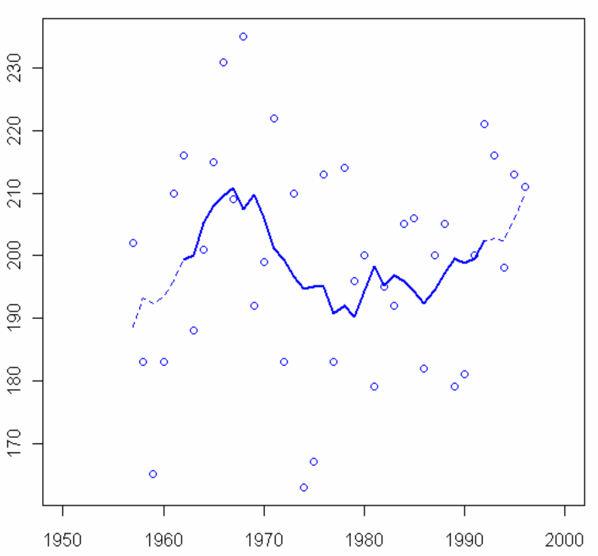


Figure 74. Number of days a year with 50% or more of the ground covered with snow at Skoganvarre

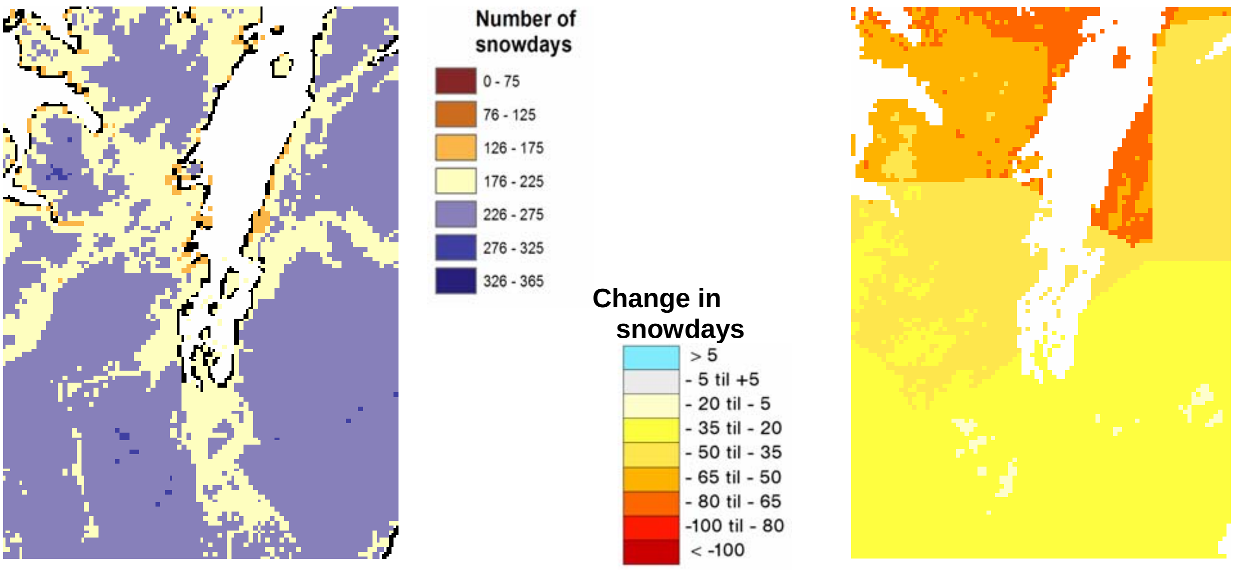


Figure 75. Number of days a year with 50% or more of the ground covered with snow in Porsanger a) In the period 1961-1990, b) projected change to 2021-2070

The left panel of figure 75 shows that Porsanger municipality typically has a snow season between 5 and 9 months. According to the right panel, the example scenario gives a 3-5 weeks reduced snow season in the southern part of the municipality, while coastal areas in the outer part of the fiord may have a 10 weeks reduction of the snow season.

5.7 Tana

Tana is a fiord and inland municipality east in Finnmark County (Fig. 1a). The area of Tana is 4 049.7 km^2, including the coastline of the inner part of Tanafiord, but also rivers, lakes, valleys and mountains with a couple of peaks above 1000 m a.s.l. Data from the stations Rustefjelbma (8 m a.s.l.) and Polmak (10 m a.s.l.) are used in the present analyses. Data from Sletnes lighthouse, which is not situated in the municipality but at the coast outside the Tana fiord, is used to illustrate temperature conditions at sites exposed to open ocean. Though the Rustefjelbma station started in 1951 and there are large gaps in the Polmak precipitation series, it has been possible to prolong the Rustefjelbma temperature series and the Polmak precipitation series back to 1900 by using neighboring stations and scaling technique.

5.7.1 Temperature

Figure 76 shows that January at average are the coldest months of the year, with a mean temperature of about -12 ^{o}C at the the Rustefjelbma station. July is at average is the warmest month, with a mean temperature of +12.3 ^{o}C. There is considerable variation around these mean temperatures. The lowest minimum-temperature that has been measured at the station in the period 1961-1990 is -44^{o}C. The highest maximum-temperature is about +32^{o}C, and the temperature range at Rustefjelbma thus exceeds 75 ^{o}C. The average monthly temperature mean is above 0 ^{o}C from Mayl to October (barely), but all months of the year have had incidents of below zero temperatures in the period 1961-1990.

Concerning geographical representativity of the temperature measurements at Rustefjelbma, it should be kept in mind that the station is situated relatively near the fiord. Inland areas in the municipality will be colder in winter. On the other hand, coastal areas further out the fiord are considerably milder in winter, but cooler in summer.

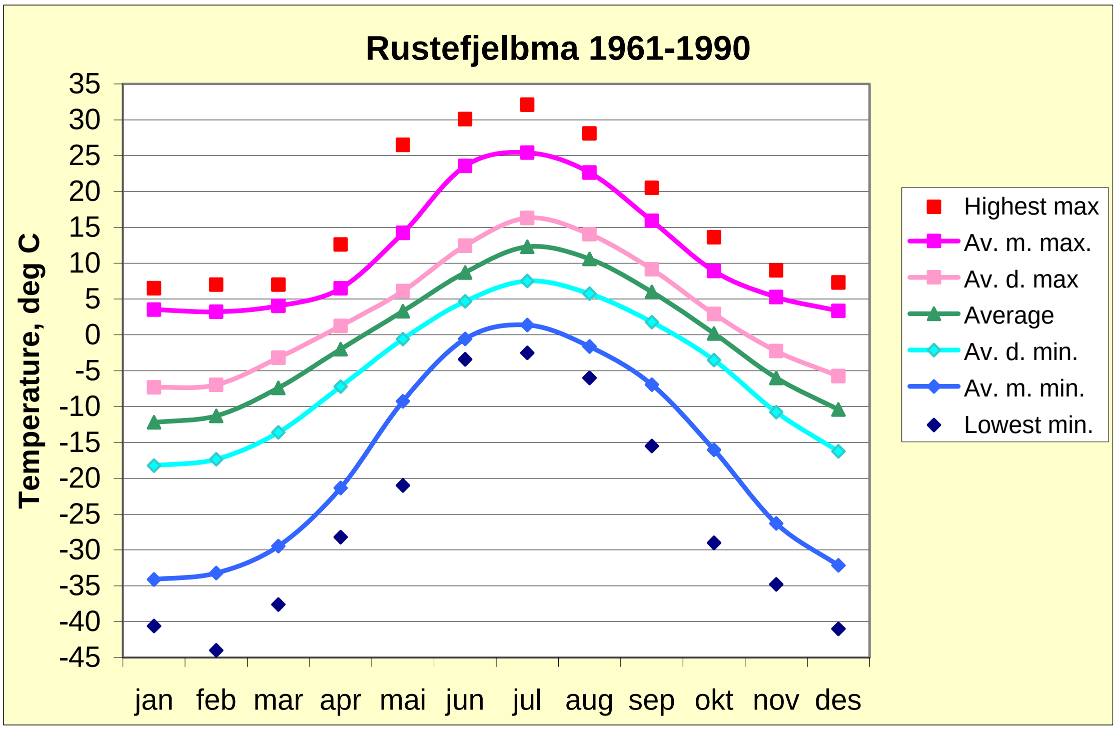


Figure 76. Monthly average and extreme temperatures at Rustefjelbma. "Highest max."/"Lowest min." are the most extreme temperature measured in the specific month during the given time period, "Av. m. max."/ "Av. m. min." are the average monthly extremes, while "Av. d. max."/ "Av. d. min." are the average daily extremes. "Average" is the monthly mean.

Figure 77 shows that the annual mean temperature in Rustefjelbma and Sletnes lighthouse are highly correlated, though Sletnes at average is 2 degrees warmer (which is caused by considerably milder winters at Sletnes, while the summer temperature at Sletnes actually are lower than at Rustefjelbma, c.f. Figure 3) . The inter-annual temperature variation in Rustefjelbma is considerable: The lowest value in the 110 year long composite series is -3.8 °C in 1902, and the highest is + 2.2 °C in 1938. Even though the warmest year occurred in the first half of the series, the large number of mild years during the last couple of decades leads to a positive trend in the series. The linear trend in Figure 77 is + 0.11 °C per decade, or about 1.2 °C over the 110 year period. Note that the average annual mean temperature at Rustefjelbma has changed from below to above freezing temperature, according to the linear trend. All the seasonal trends are also positive over the period 1900 to 2009 (Table 14).

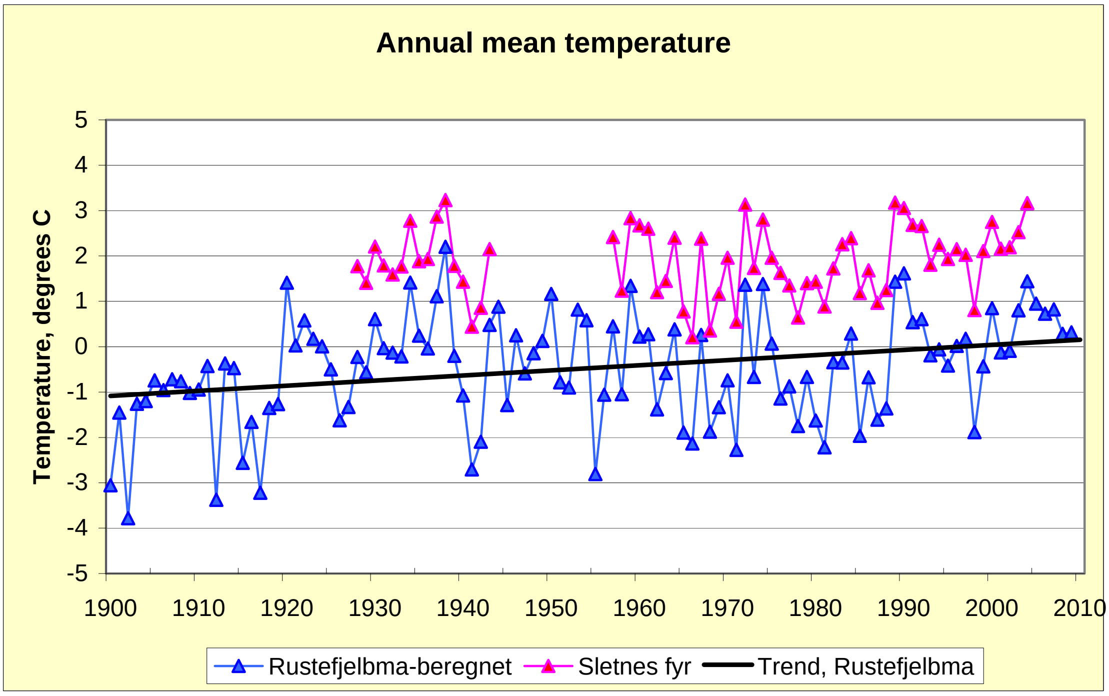


Figure 77. Annual mean temperature series for Rustefjelbma and Sletnes lighthouse. For Rustefjelbma, the linear trend from 1900 to 2009 is also shown.

Table 14. Observationally based temperature trends from 1900 to 2009, and medium, low and high projected trends for the 21st century in Bodø.

RUSTEFJELBMA		Unit: °C per decade				
		Ann	Win	Spr	Sum	Aut
Trends 1900 to 2009		+0.11	+0.10	+0.17	+0.11	+0.08
Projected trends from 1961-1990 to 2071-2100	Medium	+0.38	+0.47	+0.43	+0.26	+0.36
	Low	+0.27	+0.27	+0.30	+0.15	+0.24
	High	+0.49	+0.68	+0.58	+0.37	+0.47

Table 14 and Figure 78 show projected future temperature trends in Rustefjelbma together with historical trends. For definition of low, medium and high future projections: See chapter 3 and Figure 42 label! The projected temperature trends for the 21t century are definitely higher than those observed during the 20th century, however, the annual and seasonal trends which have been observed the latest decades largely span from the low to the medium projected trends.

One specific climate projection ("example projection") is used to calculate possible changes in growing season and snow season towards the mid-century (green points). Figure 78 shows that in Rustefjelbma, this example projection is close to the medium temperature projection in summer and winter, between medium and low in spring, and between medium and high in autumn.

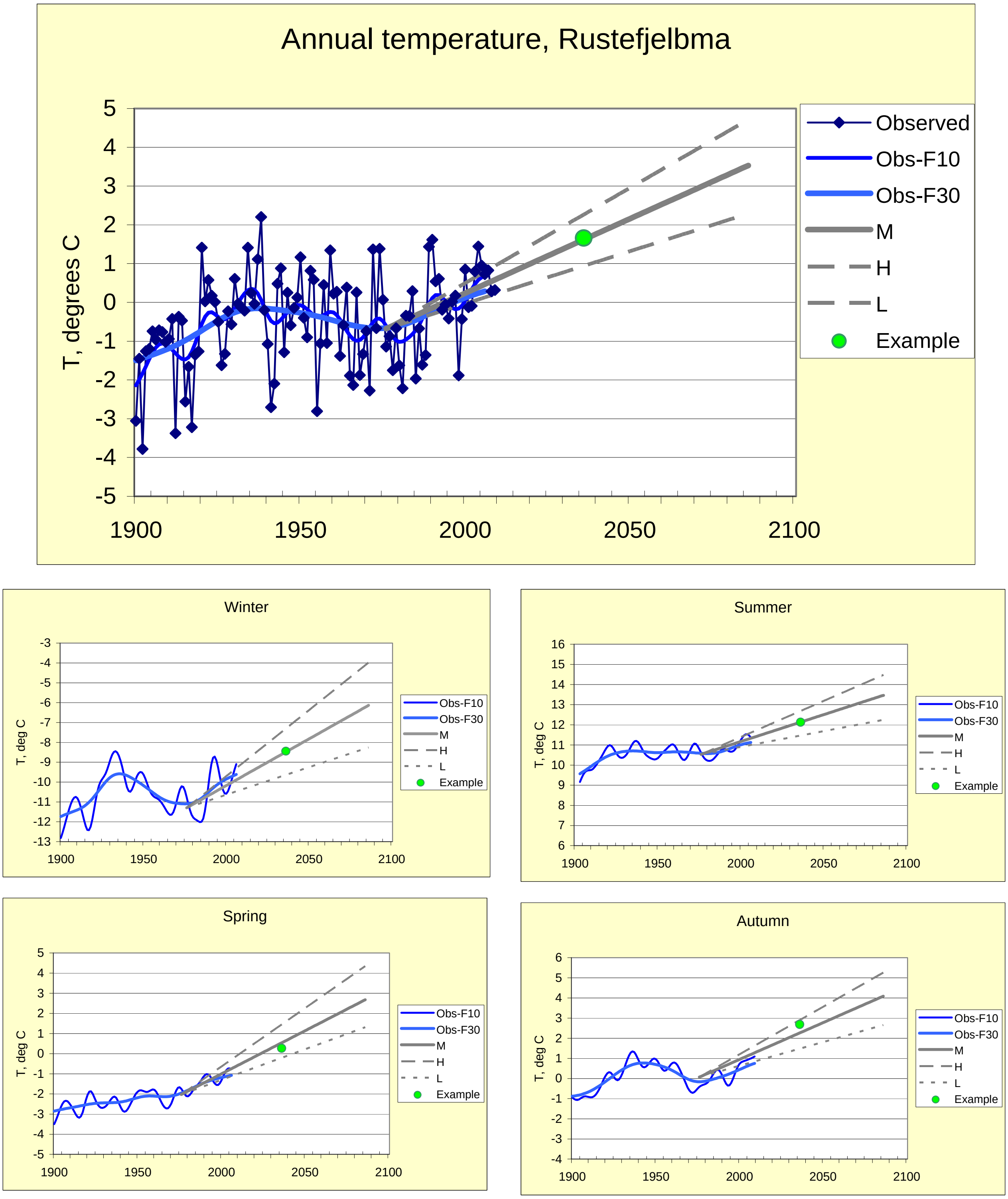


Figure 78. Historical temperature series and projected future trends at Rustefjelbma on annual and seasonal basis. The historical series are given as filtered curves showing variability on 10-year and 30-year timescales. The annual are also given as single values. The future trends are based upon 72 temperature projections. The medium trend (M) gives the average, the high (H) gives the 90 percentile, and the low (L) the 10 percentile of these projection. The example projection which is used for detailed calculations is shown as a green point.

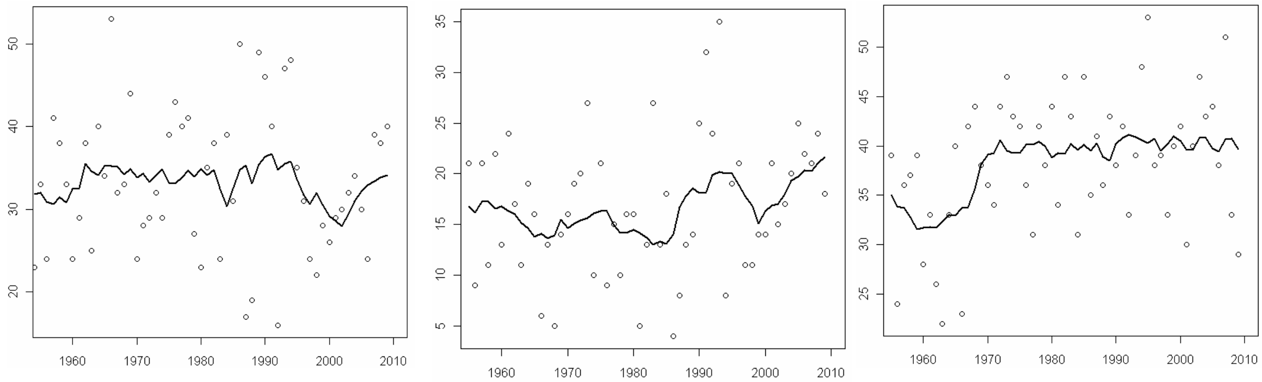


Figure 79. Number of days per season when the temperature has crossed 0 °C in Rustefjelbma

Number of days when the temperature crosses 0 °C at the Rustefjelbma station has the latest 50 years at average been around 30-35 in autumn, 15-20 in winter and 35-40 in spring (Figure 79). The variability is large, but there seem to be a small tendency towards more frequent days when temperature crosses 0 °C in winter.

Detailed future projections for frequencies of days when the temperature crosses 0 °C have not been produced. However, taking into considerations the temperature projections given in Figure 78, the frequency will probably decrease in autumn and increase in winter at the Rustefjelbma station. In spring, the frequency may increase temporarily before it stars to decrease.

5.7.2 Growing season

The thermal growing season for grass is defined in chapter 3. Figure 80, left panel, shows that the growing season at the Rustefjelbma meteorological station typically has varied between 3 and almost 5 months, with an average around 4 months. Figure 81, left panel shows that the average growing season in Tana municipality largely varies from 2 to 4 months. The meteorological station is thus representative for the most favorable parts of the municipality.

Measurements at the Rustefjelbma station indicate that there has been a weak tendency towards longer growing season (Figure 80a) and increased annual sum of growing degree days (Figure 80b) during the last 40 years in Rustefjelbma.

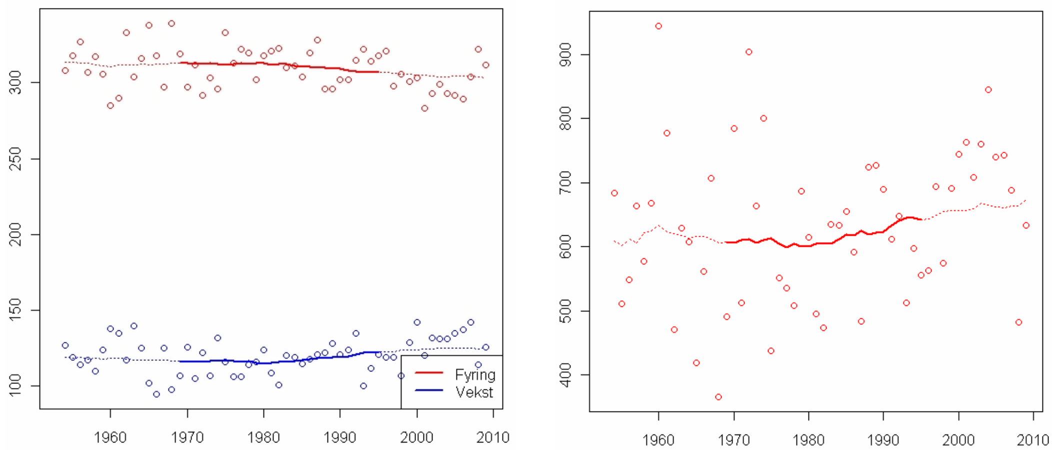


Figure 80. a) Left panel: Heating season (red) and growing season (blue) in Rustefjelbma for the period 1955-2009 given in number of days a year. b) Right panel: Annual sum og growing degree days in Rustefjelbma

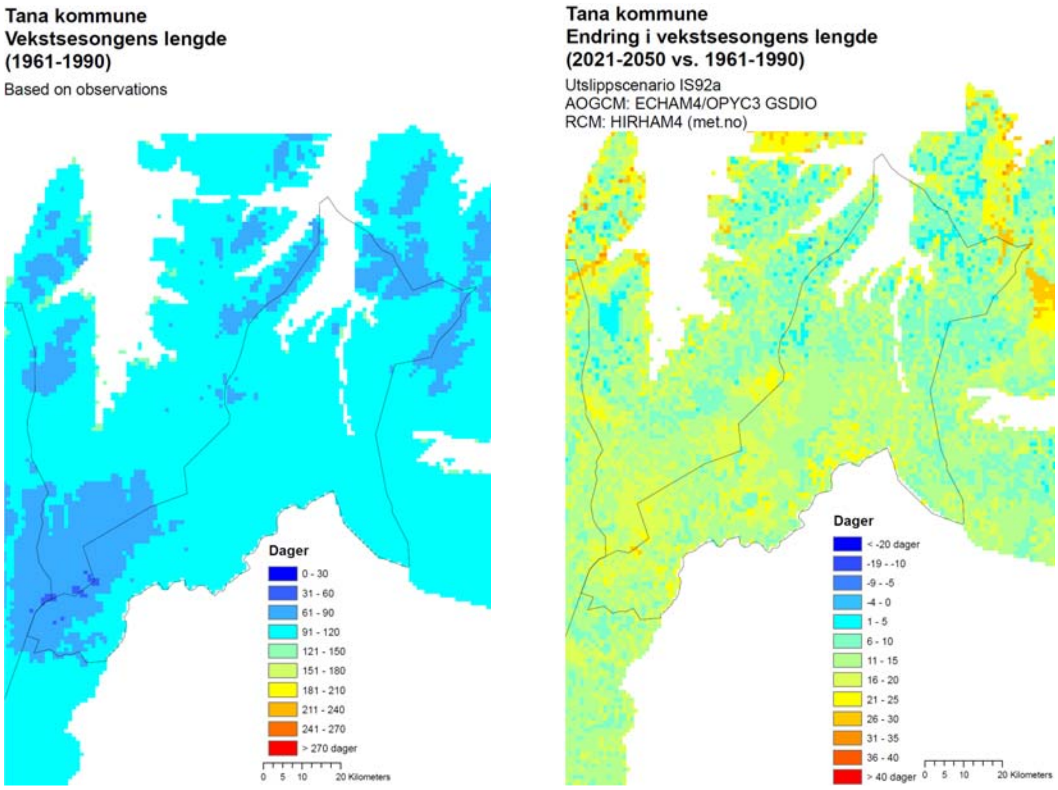


Figure 81. Average length of the growing season in the period 1961-1990 based upon observations (left), and projected change of the growing season from 1961-1990 to 2021-2050 (right) in Tana municipality.

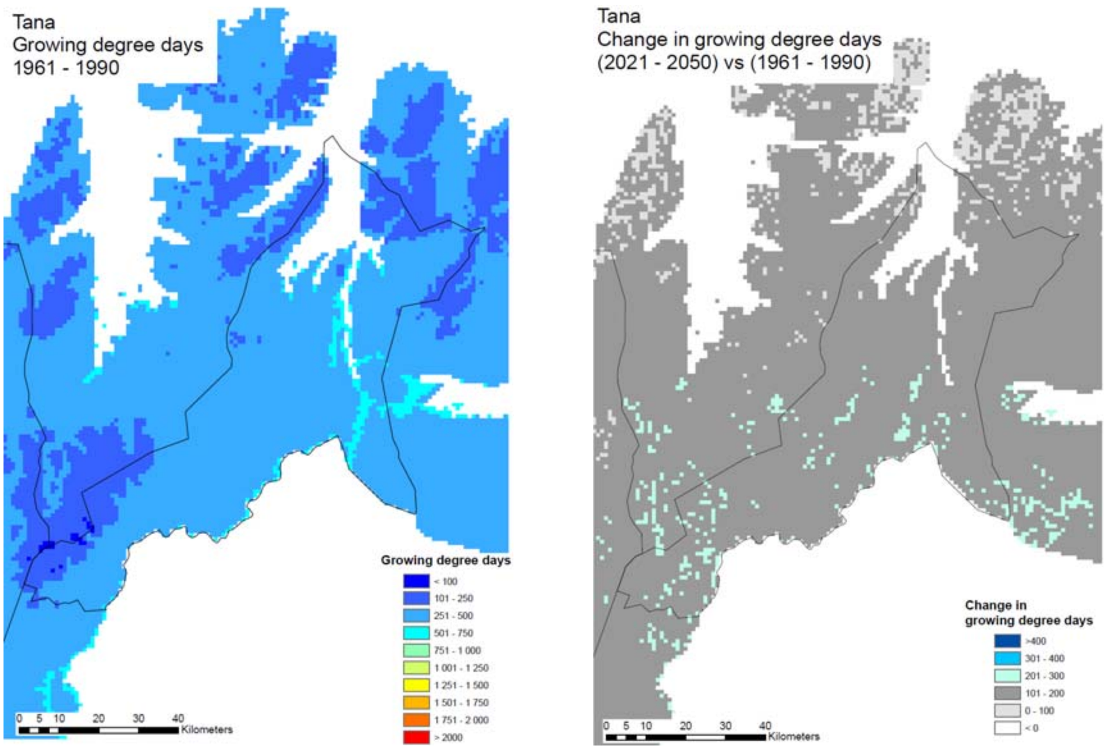


Figure 82. Average annual growing degree days in the period 1961-1990 (left), and projected changes from 1961-1990 to 2021-2050 (right) in Tana municipality.

The example projection used to calculate growing season for 2021-2050 shows 1-2 weeks increased growing season in most of the municipality, though the increase may be 3 weeks in some inland areas (Figure 81, right panel). The example projection gives a 100 to 200 increase in growing degree days over most of the municipality (Figure 82, right panel).

5.7.3 Precipitation

The 1961-1990 normal annual precipitation at Rustefjelbma was 455 mm, while it was 405 mm at Polmak, which is situated further inland. Both stations have maximum precipitation in summer and minimum in spring. Polmak has a higher maximum in summer, while Rustefjelbma at average has more precipitation in the other seasons (Figure 83).

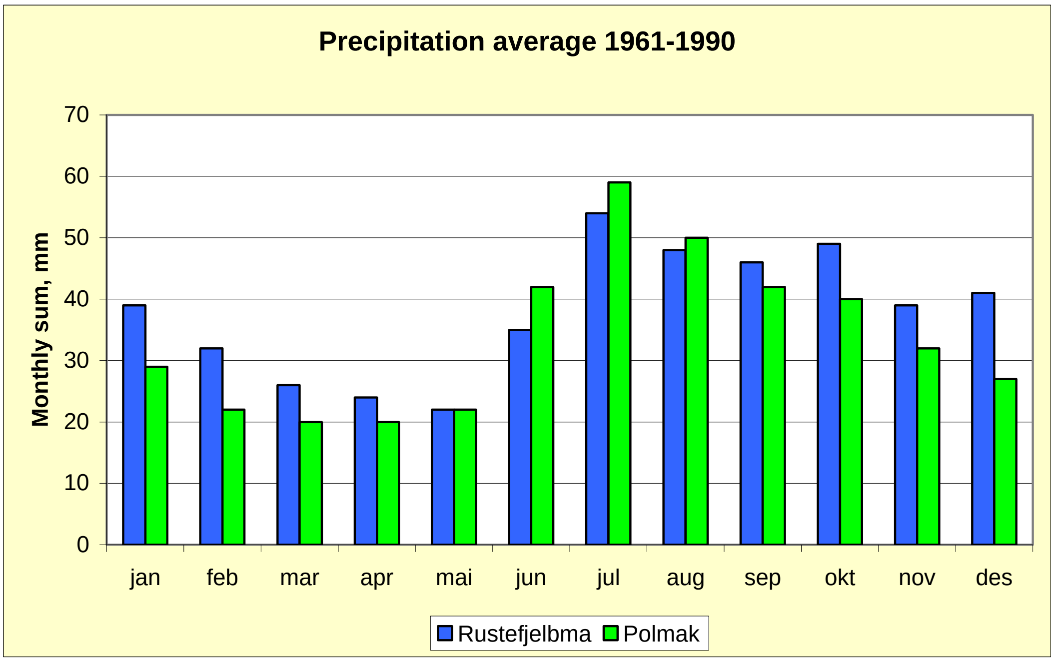


Figure 83. Average monthly precipitation sum for the period 1961-1990 at the stations Rustefjelbma and Polmak.

The annual precipitation at Rustefjelbma and Polmak are well correlated (Figure 84). The long series from Rustefjelbma shows a significant precipitation increase from 1900 to 2009. The linear trend gives an increase of 2.2% per decade, when measured relatively to the 1961-1990 average. Table 15 shows that some increase has taken place in all the seasons, though the increase in winter precipitation is the larger.

Table 15. Observationally based precipitation trends from 1900 to 2009, and medium, low and high projected trends for the 21st century at Susendal.

RUSTEFJELBMA		Unit: % per decade				
		Ann	Win	Spr	Sum	Aut
Trends 1900 to 2009		+2.2	+3.1	+2.6	+2.6	+1.8
Projected trends from 1961-1990 to 2071-2100	Medium	+1.5	+1.4	+1.5	+1.2	+2.1
	Low	+0.6	+0.1	+0.3	+0.4	+0.9
	High	+2.5	+3.3	+3.7	+1.9	+3.4

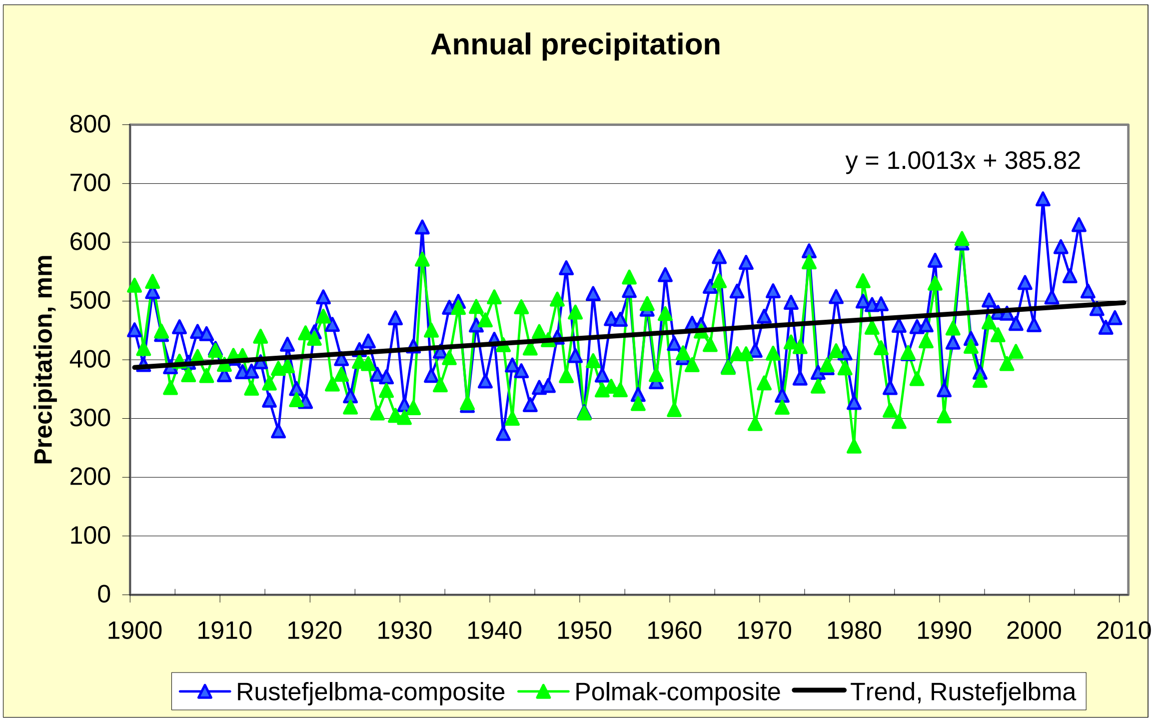


Figure 84 Annual precipitation series for Rustefjelbma and Polmak. For Rustefjelbma, the linear trend from 1900 to 2009 is also shown.

In Figure 85, the historical precipitation series is combined with low, medium and high projection for the future. Table 15 and Figure 85 show that in winter and summer, the observed precipitation trend during the last 110 years – and particularly during the latest decades – is larger than the trend projected for the future. This may indicate that models tend to underestimate the antropogenic effect on precipitation in this area. On the other hand, the increase in precipitation during the later years may be more or less attributed to natural variability, and thus not totally result from antropogenic forcing.

Anyway, the example projection which is used for projecting snow variables for the period 2021-2050 (green point in Figure 85) is rather close to the 1961-1990 average concerning winter precipitation. Thus, the projection for changes in the length snow season does not take into account a possible increase in winter precipitation.

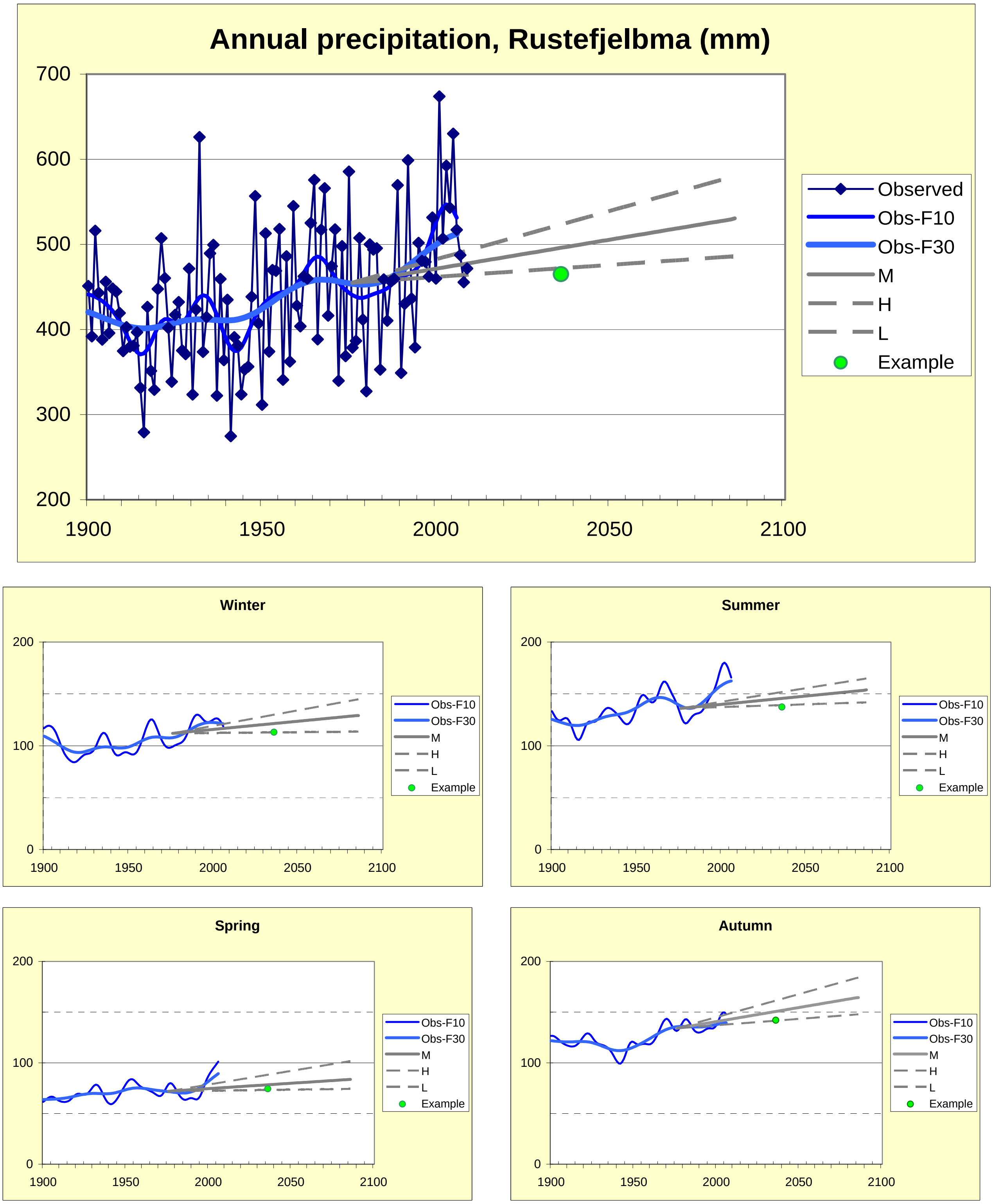


Figure 85. Historical precipitation series and projected future trends at Rustefjelbma on annual and seasonal basis. The historical series are given as filtered curves showing variability on 10-year and 30-year timescales. The annual series is also given as single values. The future trends are based upon 22 temperature projections. The medium trend (M) gives the average, the high (H) gives the 90 percentile, and the low (L) the 10 percentile of these projection. The example projection which is used for detailed calculations is shown as a green point.

5.7.4 Snow season

The length of the snow season at Rustefjelbma has the last 50 years varied between 6 and 8 months, with an average around 7 months (Figure 86). There has been a tendency towards shorter snow season since the 1970s, though the interannual variability is large.

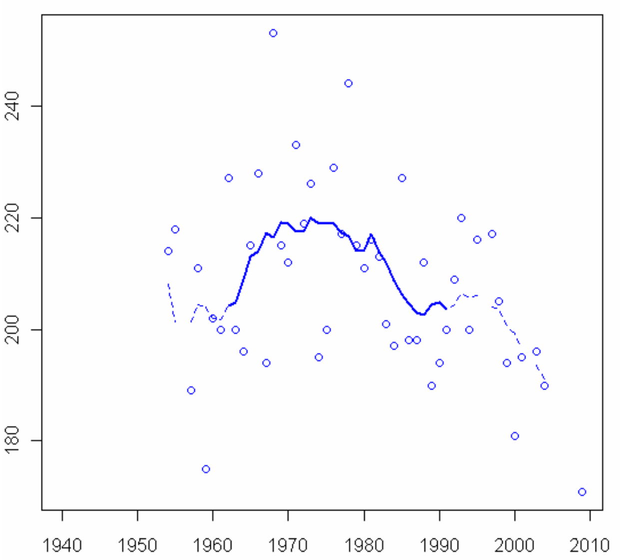
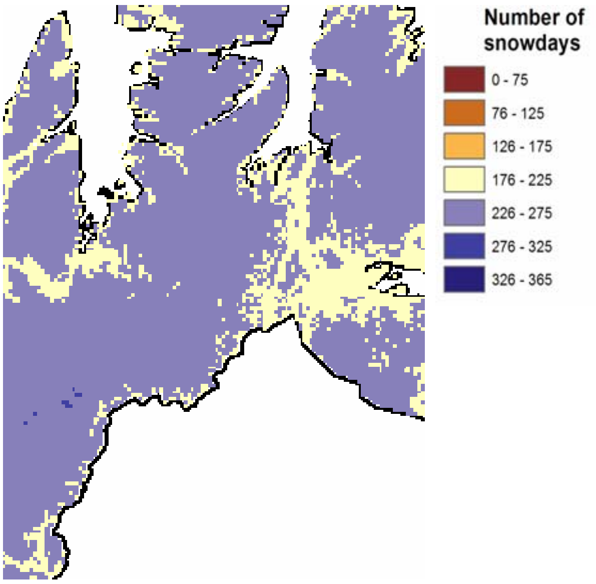


Figure 86. Number of days a year with 50% or more of the ground covered with snow at Rustefjelbma



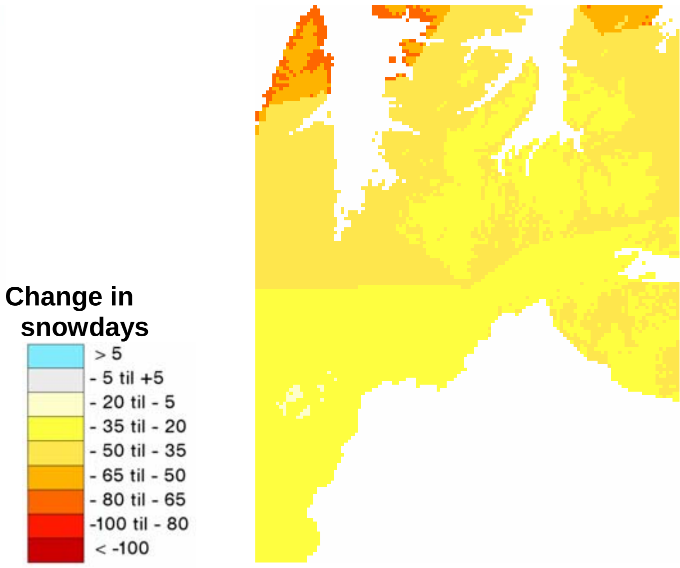


Figure 87. Number of days a year with 50% or more of the ground covered with snow in Tana municipality a) in the period 1961-1990, b) projected change to 2021-2050

The left panel of figure 87 shows that most of Tana municipality typically has a snow season between 6 and 8 months. According to the right panel, the example scenario gives 3-7 weeks reduced snow season towards the mid-century.

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6 Summary

Comparison of historical climate data from 1900 to 2009 and a large number of climate projections for the 21st century for the municipalities Hattfjelldal, Bodø, Vestvågøy, Bardu, Tromsø, Porsanger and Tana in northern Norway, show that though temperatures have increased during the last 110 years in all municipalities, the projected trends for the 21st century are even larger.

An example projection which, for all municipalities except the two northernmost, is rather low for winter and spring temperature, was used to calculate possible future changes in growing season. This projection gives an increase in growing season for grass of 1 to 4 weeks from 1961-1990 to 2021-2050 in the selected municipalities. The calculated increase in growing degree days varies from below 100 to above 200, and inland areas tend to get the larger projected increase in growing degree days. Note that a more “average” temperature projection probably would give a somewhat larger increase in both growing season and growing degree days in the five southernmost municipalities, as the growing season would probably start earlier with a more “middle-of-the road” temperature scenario.

Local projections for frequencies of days when the temperature crosses 0 ^{o}C have not been produced. However, taking into considerations the presented temperature projections, this frequency will probably decrease in autumn and spring at most of the climate stations used in the present analyses. In spring, it the frequency may increase temporarily in Porsanger and Tana. In winter, the frequency of days when the temperature crosses 0 ^{o}C will probably increase at most stations. An exception is the southernmost coastal areas, where it may decrease.

Annual precipitation is projected to increase in northern Norway during the 21st century, and for the seven municipalities, the projected increase is in general of the same magnitude as the increase which has been measured during the 20th century. For the winter season, the precipitation increase experienced during the later decades has actually been stronger than the projected trends. This may indicate that the climate models tend to underestimate the antropogenic effect on precipitation in the area. On the other hand, the increase in precipitation during the later years may be more or less attributed to natural variability, and thus not totally result from antropogenic forcing.

An example projection was used to calculate possible changes in snow season in the seven municipalities from 1961-1990 to 2021-2050. The results show a 3 to 7 weeks reduced snow season towards the mid-century most places, but a smaller reduction in some mountain areas, and an even longer reduction in a few northern coastal localities. If the winter precipitation in the example projection is too low, the reductions may be overestimated. However, if the winter and especially spring temperatures are too low, the reduction may be underestimated.

It should be emphasized that there is a considerable uncertainty concerning local future climate projections, and that the example projections mentioned above only shows one of several possible future developments.

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