Norwegian Centre for Climate Services

Background information for "Klima i Norge 2100"

- on freezing/thawing, minimum/maximum temperature, short-term rainfall, wind and permafrost

NCCS report no. 1/2016

Authors

Eirik J. Førland (ed), Inger Hanssen-Bauer, Jan Erik Haugen, Hans Olav Hygen, Hilde Haakenstad, Ketil Isaksen og Anita Verpe Dyrrdal

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Abstract

This report is presenting supplementary studies performed at the Norwegian Meteorological Institute (MET Norway) to document updates and background information for Chapter 3 (Climate in Norway during period with instrumental measurements) and chapter 5 (Future climate change) in the NCCS Report 2/2015 "Klima i Norge 2100" (Hanssen-Bauer et al., 2015). The topics include freezing/thawing events, minimum/ maximum temperatures, short-term rainfall, wind and permafrost.

Keywords

Climate in Norway, projections, freezing/thawing, minimum/maximum temperature, short-term rainfall, wind, permafrost.

Eirik J. Førland — Disciplinary signature

Inger Hanssen Bauer — Responsible signature

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1. Introduction

In fall 2015 the Norwegian Centre for Climate Services (NCCS) published the report «Klima i Norge 2100 (KiN2100)» (Hanssen-Bauer et al., 2015). This report was prepared in a collaboration between several Norwegian climate research groups and institutes, and the report presents an assessment of present knowledge on historical climate development, today's climate and projections for future climate in Norway.

KiN2100 was mostly based on published articles, but during the process of writing, several studies had to be updated and a few knowledge-gaps had to be filled. Additionally; - as KiN2100 is written in Norwegian; it was a wish to make some background material available also for scientists outside Norway. Thus the present report is written in English.

This report is presenting supplementary studies performed at the Norwegian Meteorological Institute (MET Norway) to document updates and background information for Chapter 3 (Climate in Norway during period with instrumental measurements) and chapter 5 (Future climate change) in KiN2100. The topics include freezing/thawing events, minimum/ maximum temperatures, short-term rainfall, wind and permafrost.

2. Freezing / thawing events

Authors: Hans Olav Hygen and Eirik J. Førland

2.1 Introduction

For studies of freezing / thawing events, number of days where temperature is crossing 0 °C is requested by several Norwegian user groups. The optimal indicator for days with "zero-crossing" is days where the minimum temperature is below 0 °C, and maximum temperature above 0 °C. However, presently the available projections for Norway do not include bias-adjusted values for daily minimum and maximum temperature. On the other hand, bias-adjusted values for daily mean temperature are available on a 1 x 1 km grid covering both past (1957-present) and projected future climate (e.g. 2071-2100). Consequently, in previous Norwegian climate impact projects, daily mean in an interval around 0 °C, was used as indicator for zero crossings.

In the project InfraRisk (NGI, 2013), daily mean temperature in the interval -1.5 to +1.0 °C was used as an indicator for daily freeze/thaw-events. To evaluate whether mean temperature around zero would be a valuable indicator for the frequency of freeze/thaw

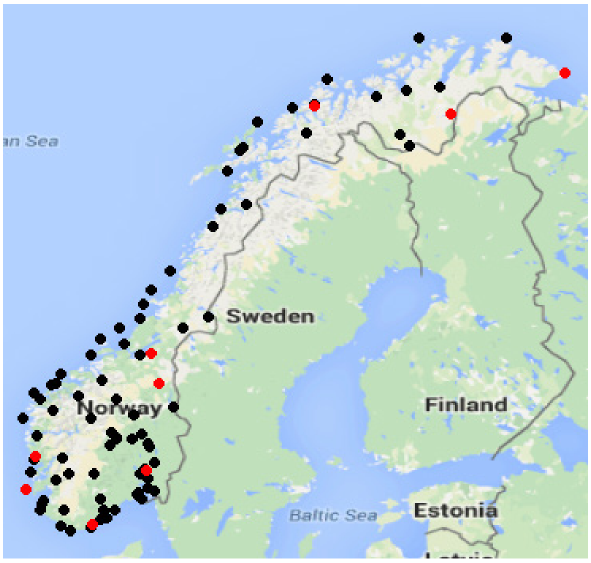


Figure 2.1 *Map of the 84 stations used for the analysis in figure 2.4. The red dots marks 9 stations used in more detailed studies shown in figure 2.2, 2.3, 2.5, 2.6 and table 2.1*

events for the "Klima i Norge 2100" report (Hanssen-Bauer et al., 2015), a selection of daily temperature series from MET Norway's weather stations were used in the present pilot study. For these stations, series of daily mean temperature as well as daily minimum and maximum temperature were available (www.eklima.met.no). Two selections of series were used: a). 84 stations covering the period 1971-2000, and b). 8 series with almost complete records during 1957-present. Both selections of stations represent different geographic and climatic zones in Norway, cf. Figure 2.1.

2.2 Warm, cold and zero-crossing days

In figures 2.2 and 2.3, days with mean temperatures in the interval -10 °C to +10 °C are classified as either "warm days" (Minimum temperature above 0 °C, red in the figures), "cold days" (Maximum temperature below 0 °C blue in the figures) or "days with zero-crossing" (Minimum below 0 °C and maximum temperature above 0 °C, green in the figures). The figures indicate a different signature for maritime stations like Bergen and Tromsø, versus more continental stations like Røros and Karasjok. The coastal stations have fewer cases of "cold days" and "days with zero-crossing" than the inland stations. For "days with zero-crossing", there is a substantially larger span in mean daily temperature for continental versus coastal stations. For both Røros and Karasjok, "zero-crossing" may occur for days with mean temperature in the range -9,5°C to + 10,0 °C, while for Bergen and Tromsø the mean temperature is mainly in the range -4,0 °C to + 5,0 °C.

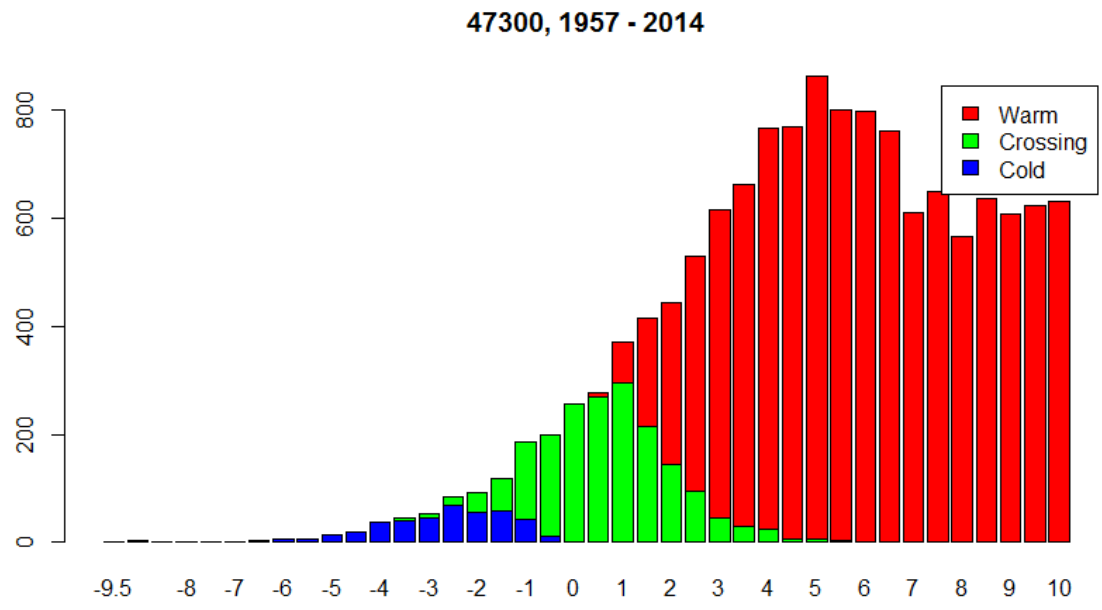


***Figure 2.2** Distribution of «warm» (red), «cold» (blue) and «freeze/thaw» (green) days (y-axis, number of days) as a function of daily mean temperature (x-axis, °C) for weather station 47300 Utsira.*

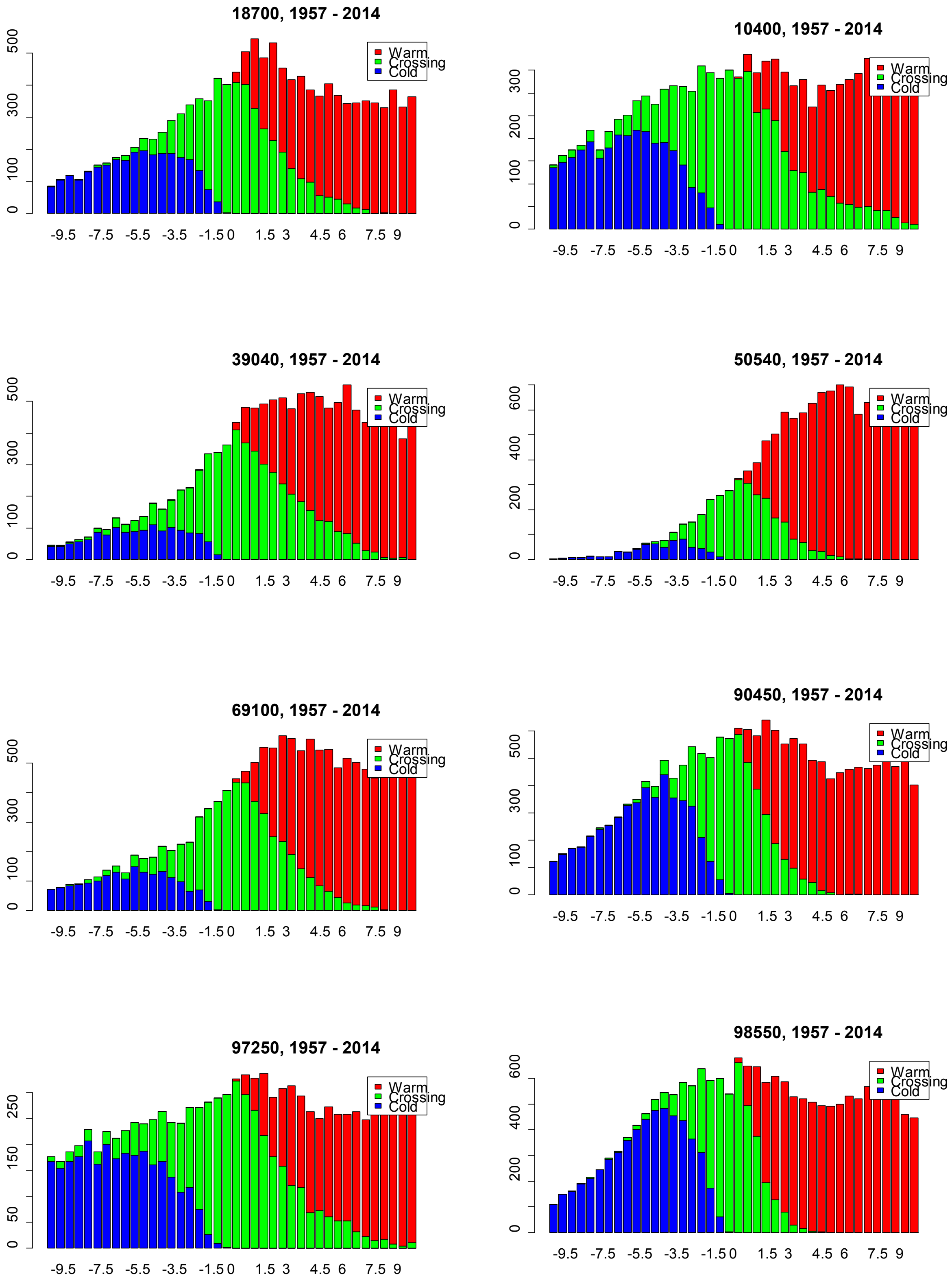


Figure 2.3 *Distribution of «warm» (red), «cold» (blue) and «freeze/thaw» (green) days (y-axis, number of days) as a function of daily mean temperature (x-axis, °C) for the weather stations: 10400 Røros, 18700 Oslo-Blindern, 39040 Kjevik, 50540 Bergen – Florida, 69100 Værnes, 90450 Tromsø, 97250 Karasjok, 98550 Vardø*

2.3 Zero-crossing vs. daily mean temperature

For 84 stations (see location in figure 2.1) the relationship between zero crossings and mean temperatures near zero is studied for the period 1971-2000 (figure 2.4). The relationship is studied for different intervals of mean daily temperature near zero: -1 to 1 °C; -2 to 2 °C; -3 to 3 °C and -1.5 to 1 °C (the last interval was used in the InfraRisk-report (NGI, 2013)). Figure 2.4 indicates a large spread in the relationship between number of days with zero-crossing and number of days with mean temperature close to 0 °C.

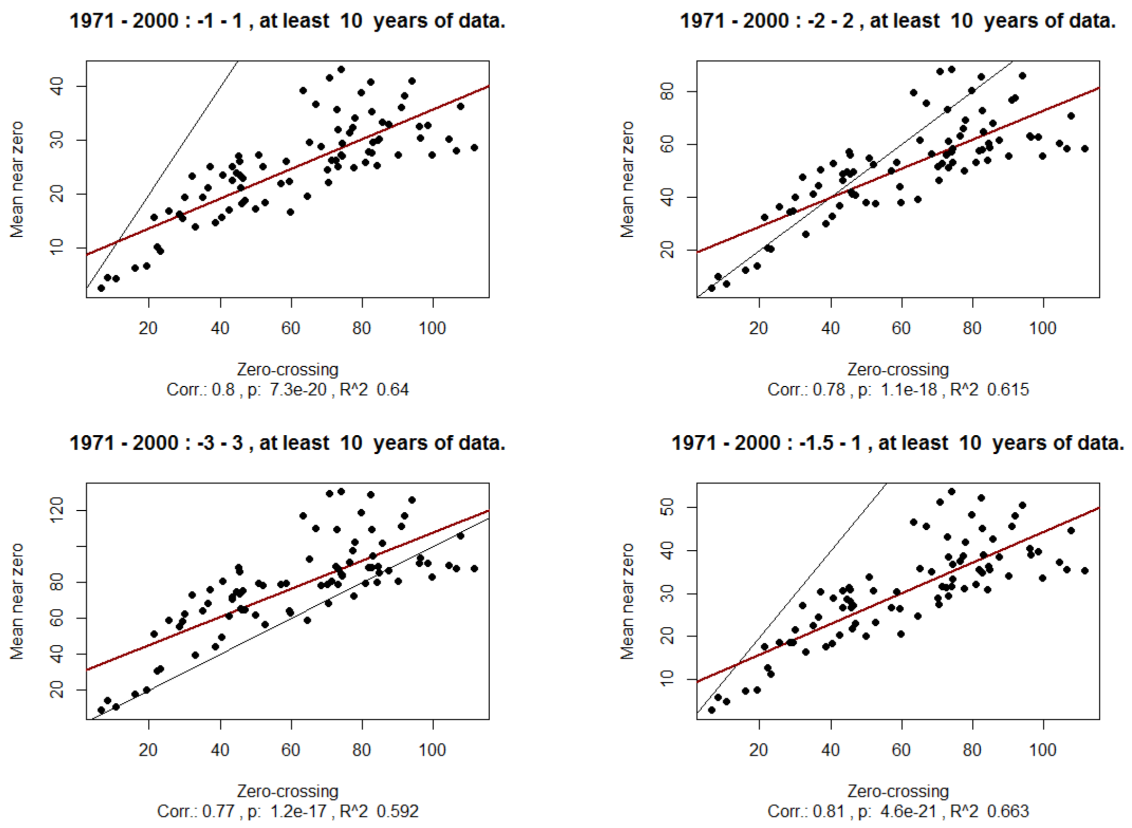


Figure 2.4 *Relationship between number of days with zero-crossing versus number of days with mean daily temperature in specific intervals for 84 weather stations during the period 1971 – 2000. The numbers show number of cases per year. The solid black line represents a one to one relationship between the two datasets, and the red line represents the linear regression. Beneath each figure is the correlation coefficient, p-value and* R^2.

The relationship between the two freeze-thaw indicators was studied in more details for eight stations with long temperature series (Figure 2.5). The eight stations are representing coastal and inland in both South- and North-Norway, cf. figure 2.1.

Table 2.1 *Correlation coefficients between number of days with zero crossings and number of days with mean temperature in different intervals for eight weather stations.* ***Bold*** *indicates for each station the interval with highest correlation coefficient. The font colours used is matching the colour code used in figure 2.5 – 2.7*

Mean temperature range	-1 to +1 °C	-2 to +2 °C	-3 to +3 °C	-1,5 to +1 °C
18700 Oslo - Blindern	0,71	**0,77**	0,76	0,74
10400 Røros	0,54	0,64	**0,77**	0,57
39040 Kjevik	0,42	0,53	**0,58**	0,40
47300 Utsira	0,93	**0,96**	0,95	**0,96**
50540 Bergen – Florida	0,87	0,91	**0,92**	0,88
69100 Værnes	0,67	**0,75**	0,74	0,69
90450 Tromsø	0,78	**0,86**	0,81	0,81
97250 Karasjok	0,37	0,53	**0,63**	0,44
98550 Vardø	0,67	0,78	**0,82**	0,76
Mean	0,66	0,75	0,78	0,69
Median	0,67	0,77	0,77	0,74

Figure 2.5 supports the tendency from figure 2.2 and 2.3 to higher covariation between the two freeze/thaw-indicators for coastal than for inland stations. The correlation coefficients for indicators based on different intervals of daily mean temperatures versus zero crossings (minimum*maximum temperature <0 °C) are outlined in Table 2.1. The table underlines that maritime stations (like Bergen, Tromsø, Vardø, and especially Utsira) show a good correlation between zero crossings and mean temperatures near zero, while more continental stations (Røros, Karasjok) show a significantly weaker relationship. For example, Bergen-Florida has a correlation coefficient of 0,92 for mean temperatures between -3 and 3 °C, while the best correlation for Karasjok is 0,63.

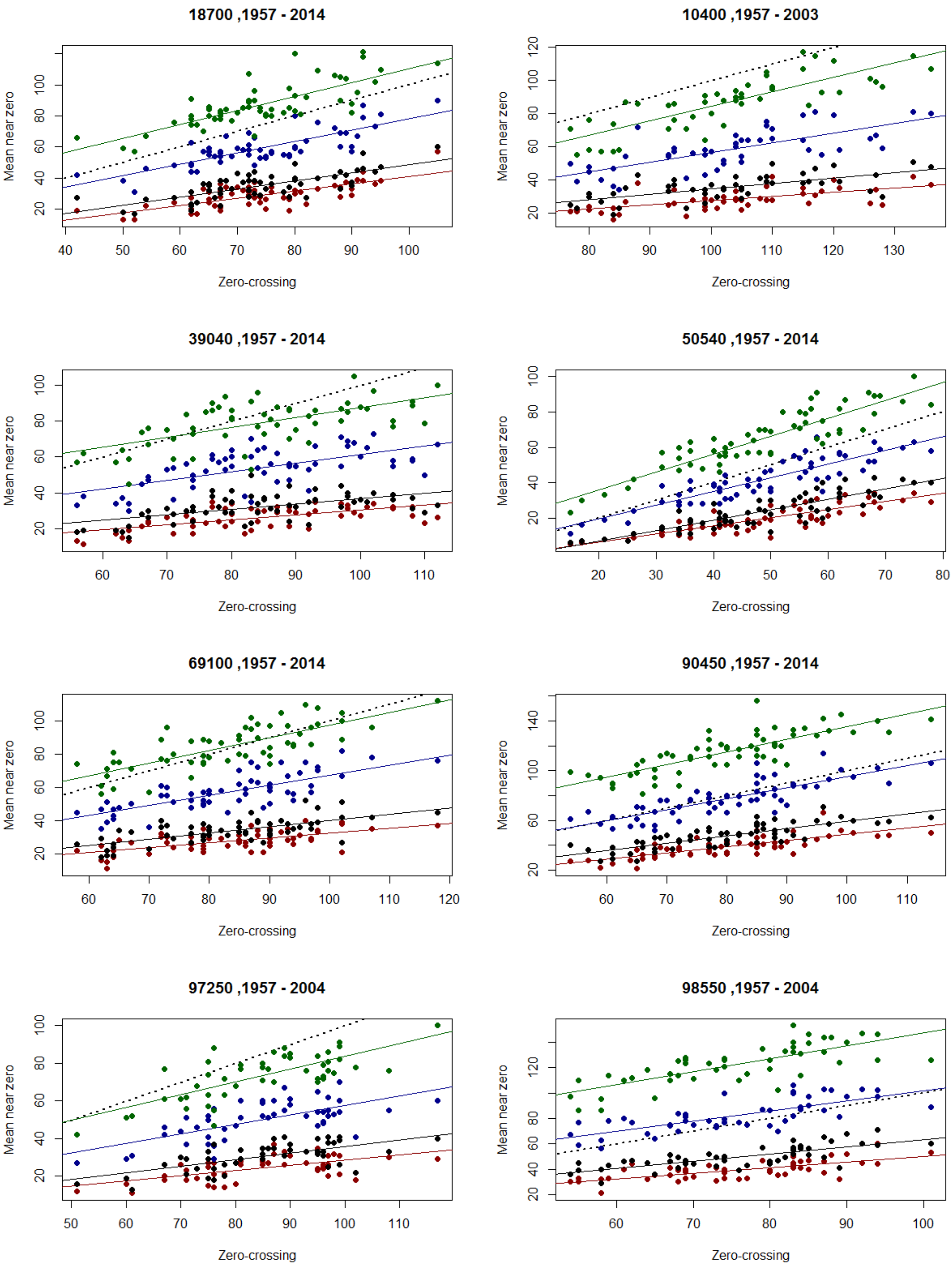


Figure 2.5 *Number of days with zero-crossing versus number of days with daily mean temperature in different intervals: Red: -1 to + 1 °C, Blue: -2 to +2 °C, Green: -3 to +3 °C, Black: -1,5 to +1,0 °C. Single years are marked by dots, lines are the respective regression lines. Slashed line is 1-1 relationship. Stations: 10400 Røros, 18700 Oslo-Blindern, 39040 Kjevik, 50540 Bergen-Florida, 69100 Værnes, 90450 Tromsø, 97250 Karasjok, 98550 Vardø.*

2.4 Recent trends in near-zero temperatures

Figure 2.6 and 2.7 demonstrate a large inter-annual variability in the various freeze/thaw indicators during 1957-2014. For the most realistic freeze/thaw indicator; - i.e. min*max <0 °C, (dotted red-blue curve in the figures), the figures for all stations show a span of more than 50 days between years with highest and lowest number of days. For Utsira the span is between ca. 5 and 60 days, while for Røros it is between ca. 60 and 130 days per year. The figures underline the fact that the covariation between various indicators vary both in time and between different stations.

For all stations, no significant trends were found in the time development during 1957-2014 for the various freeze/thaw indicators. This means that although there has been a substantial warming during the recent decades, there has been no increase or decrease in freeze/thaw events.

At the outer western coastal stations, the winter temperatures are close to zero, and just a small further temperature increase may lead to fewer days with minimum temperatures below 0 °C, cf. figure 2.2. As a winter warming of 3-4 °C is projected for Western Norway up to year 2100 (Hanssen-Bauer et al., 2015), and chapter 3 documents larger historical increase in minimum than for mean temperatures; the number of days with freezing/thawing will most probably be strongly reduced along the western coast during this century.

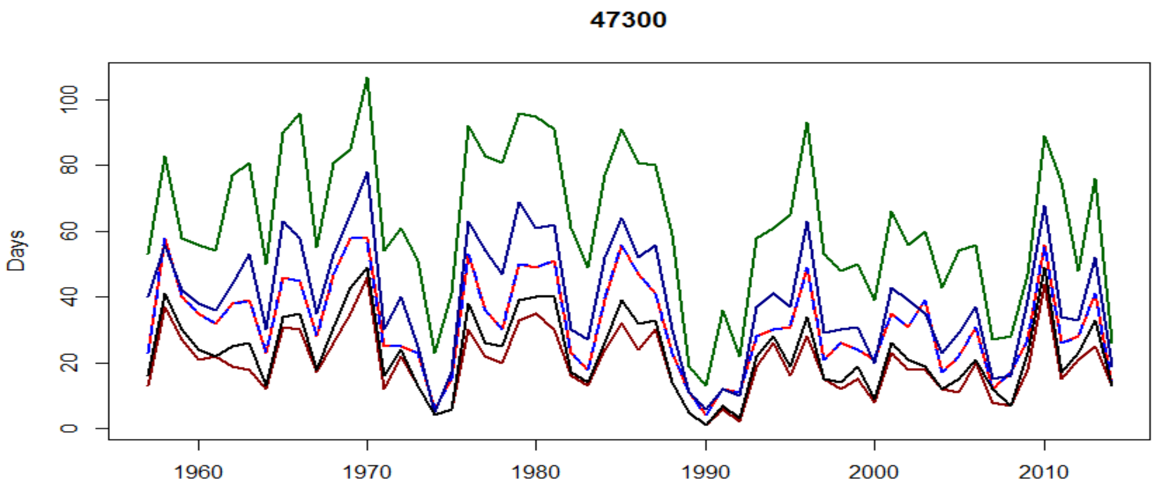


Figure 2.6 *Time series (1957-2014) of number of days with zero-crossing (dotted red-blue graph) and mean temperatures in the intervals: Brown: -1 to + 1 °C, Blue: -2 to +2 °C, Green: -3 to +3 °C, Black: -1,5 to +1,0 °C for weather station 47300 Utsira Fyr.*

Figure 2.7 *Time series (1957-2014) of number of days with zero-crossing (dotted red-blue graph) and mean temperatures in the intervals: Brown: -1 to + 1 °C, Blue: -2 to +2 °C, Green: -3 to +3 °C, Black: -1,5 to +1,0 °C. Stations: 10400 Røros, 18700 Oslo-Blindern, 39040 Kjevik, 50540 Bergen-Florida, 69100 Værnes, 90450 Tromsø, 97250 Karasjok, 98550 Vardø*

2.5 Conclusions

This brief analysis demonstrate that nationwide there is no clear-cut interval of daily mean temperatures around zero that gives a satisfactory measure of days where the temperature is crossing 0 °C. For rough estimates, the widest range of mean temperatures (-3 to +3 °C) seems to give highest correlation. However, for some locations (e.g. Kjevik and Karasjok) even this indicator explains less than 40 % of the variability in number of days with zero crossings. The data used in this study indicates that further exploration in this might result in a useful indicator, at least for the coastal areas, but the development in the field of climate models and downscaling will probably soon make this indicator obsolete.

The obvious indicator for days with zero crossing is of course when minimum temperature < 0 °C and maximum temperature > 0 °C. However, we do not presently have access to high-quality bias-adjusted projections of minimum and maximum temperatures. Instead of using some dubious indicator based on mean daily temperature, we decided **not** to include information on freeze / thaw days in the present version of “Klima i Norge 2100” (Hanssen-Bauer et al., 2015). It is evident that a realistic indicator of changes in days with zero-crossings is important for many user groups, and projections will be established when we have access to improved bias-adjusted measures for local minimum and maximum temperatures.

The present study does not indicate any trends in freeze/thaw events during the period 1957-2014.

3. Daily maximum and minimum temperatures

Authors: Inger Hanssen-Bauer and Eirik J. Førland

3.1 Background

Hanssen-Bauer et al. (2015) demonstrated an increase since 1971 in frequency of days with mean temperature exceeding 20 °C. It is not just in Norway the number of hot days has increased in recent decades. IPCC (2013) states that the number of warm days and nights has increased in most regions globally, while the number of cold days and nights has decreased. It was also stated that these changes often have a close relationship with an increase in minimum temperature. To view the historical climate trends in Norway in such a perspective, trends in minimum, mean and maximum temperature have been examined for selected Norwegian stations.

Very few Norwegian stations have centennial long homogeneous temperature records, and in addition the stations were not equipped with maximum thermometers for the first decades in the 20th century. Most analyzes in this study are therefore based on the period 1955-2014. Table 3.1 gives an overview of the stations included in the analysis. The stations were grouped both according to north / south location and in relation to coast / inland (Figure 3.1). Three of these stations (Færder, Utsira and Vardø) have series of average and minimum temperature also for the period 1900-2014, and these are analyzed also for the long period.

Table 3.1 Stations included in the analysis and their affiliation to two groupings (see text)

Station name	St.number	County	Grouping-1	Grouping-2
Gardermoen	4780	Akershus	South	Inland
Færder	27500	Vestfold	South	Outer coast
Sauda	46610	Rogaland	South	Fjord
Utsira	47300	Rogaland	South	Outer coast
Værnes	69100	Nord-Trøndelag	Central	Fjord
Ørland	71550	Sør-Trøndelag	Central	Fjord
Snåsa	70850	Nord-Trøndelag	Central	Inland
Bodø	82290	Nordland	Central	Outer coast
Bardufoss	89350	Troms	North	Inland
Tromsø	90450	Troms	North	Fjord
Sihccajavre	93900	Finnmark	North	Inland
Vardø	98550	Finnmark	North	Outer coast

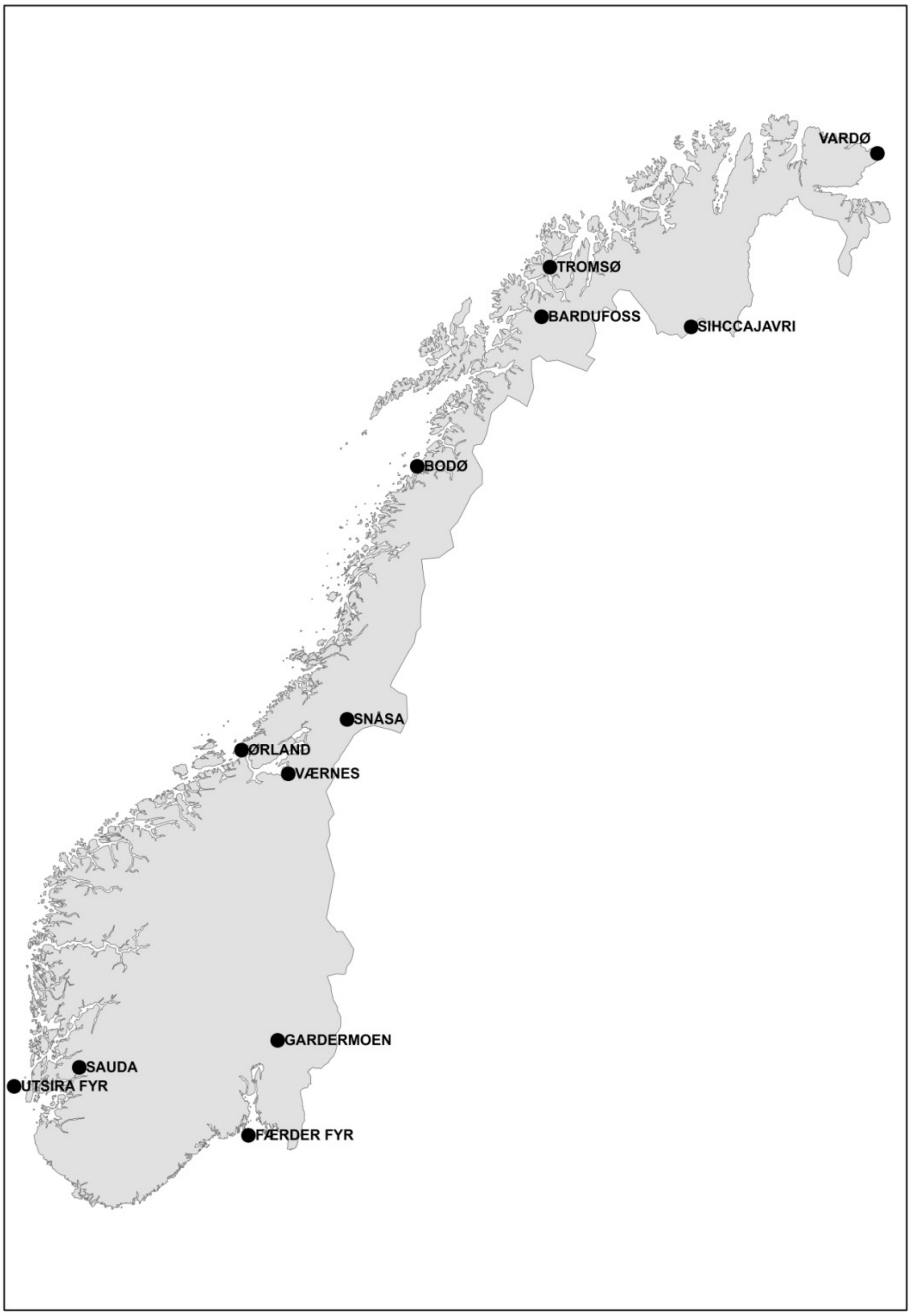


Figure 3.1 *Weather stations used in analysis of maximum and minimum temperatures*

3.2 Trends for single stations

The trends in minimum- and average temperatures in the three centennial-long series are shown in Table 3.2. The average temperatures typically tend to have increased by around 0.1 °C per decade (0.07 to 0.16) during the period 1900-2014. The average daily minimum temperature increased more than the average temperature in all seasons at all stations (difference: 0.01 to 0.07 °C per decade). Except from the winter at Færder and the autumn at Vardø, the seasonal trends in absolute minimum temperature are even higher than for the average daily minimum.

Table 3.2 Average trends (°C per decade) in absolute and average annual/seasonal minimum - and in average temperatures during the period 1900-2014 for single stations

Station	Season	Absolute minimum	Average daily minimum	Average
Færder	**Annual**	**0.05**	**0.17**	**0.11**
	Winter	0.05	0.12	0.07
	Spring	0.25	0.21	0.14
	Summer	0.20	0.15	0.09
	Autumn	0.22	0.18	0.11
Utsira	**Annual**	**0.16**	**0.10**	**0.08**
	Winter	0.19	0.08	0.07
	Spring	0.15	0.10	0.08
	Summer	0.14	0.11	0.09
	Autumn	0.11	0.11	0.09
Vardø	**Annual**	**0.17**	**0.15**	**0.11**
	Winter	0.18	0.12	0.10
	Spring	0.22	0.20	0.16
	Summer	0.20	0.14	0.11
	Autumn	0.09	0.13	0.11

With very few exceptions, the trends are larger when studying the period 1955-2014. For this period, during all seasons, the 12 stations in Table 3.1 show an increase in average temperature between 0.11 and 0.63 °C per decade (Table 3.3). As for the longer period, a majority of the stations revealed greater increase of mean minimum temperature than of mean temperature, and even greater increase of the lowest seasonal minimum. For the winter season a majority of the stations also showed a smaller increase for average daily maximum than for mean temperature, and even smaller increase for the seasonal highest maximum. For the spring, summer and autumn seasons, there were large variations between the stations concerning the relationship between trends in mean and maximum temperatures.

Table 3.3 *Average trends (°C per decade) in minimum, maximum and mean temperatures during 1955-2014 for single stations*

Station	Season	Abs. Minimum	Average Min.	Average	Average Max.	Abs. Maximum
Gardermoen	**Annual**	**1.02**	**0.49**	**0.40**	**0.31**	**0.12**
	Winter	1.12	0.77	0.63	0.48	0.31
	Spring	0.79	0.48	0.45	0.41	0.50
	Summer	0.51	0.35	0.21	0.13	0.06
	Autumn	0.83	0.30	0.24	0.17	0.13
Færder	**Annual**	**0.30**	**0.31**	**0.26**	**0.21**	**0.08**
	Winter	0.33	0.40	0.33	0.27	0.09
	Spring	0.51	0.41	0.37	0.32	0.28
	Summer	0.17	0.22	0.18	0.13	0.08
	Autumn	0.38	0.15	0.11	0.07	0.02
Sauda	**Annual**	**1.01**	**0.38**	**0.25**	**0.20**	**0.08**
	Winter	1.08	0.57	0.42	0.35	0.16
	Spring	0.59	0.38	0.26	0.25	0.33
	Summer	0.19	0.31	0.14	0.07	0.07
	Autumn	0.56	0.25	0.17	0.15	0.08
Utsira	**Annual**	**0.12**	**0.16**	**0.11**	**0.23**	**0.09**
	Winter	0.41	0.25	0.24	0.20	0.05
	Spring	0.31	0.27	0.26	0.26	0.47
	Summer	0.31	0.28	0.27	0.30	0.31
	Autumn	0.16	0.12	0.11	0.09	0.23
Værnes	**Annual**	**0.41**	**0.32**	**0.29**	**0.27**	**-0.04**
	Winter	0.41	0.45	0.38	0.30	0.08
	Spring	0.16	0.35	0.30	0.28	0.30
	Summer	0.28	0.28	0.27	0.27	-0.08
	Autumn	0.42	0.14	0.16	0.19	0.34
Ørland	**Annual**	**0.42**	**0.17**	**0.22**	**0.30**	**0.10**
	Winter	0.46	0.31	0.28	0.28	0.10
	Spring	0.04	0.17	0.23	0.32	0.56
	Summer	0.07	0.17	0.23	0.34	0.07
	Autumn	0.26	0.05	0.14	0.21	0.42
Snåsa	**Annual**	**0.73**	**0.29**	**0.28**	**0.27**	**0.01**
	Winter	0.70	0.55	0.46	0.36	0.14
	Spring	0.32	0.30	0.25	0.23	0.44
	Summer	0.13	0.21	0.25	0.31	-0.01
	Autumn	0.89	0.11	0.13	0.17	0.33
Bodø	**Annual**	**0.37**	**0.28**	**0.27**	**0.27**	**-0.08**
	Winter	0.44	0.42	0.39	0.37	0.09
	Spring	0.27	0.25	0.23	0.24	0.26
	Summer	0.28	0.23	0.23	0.27	-0.06
	Autumn	0.52	0.21	0.20	0.18	0.16
Bardufoss	**Annual**	**0.53**	**0.35**	**0.27**	**0.23**	**-0.25**
	Winter	0.78	0.50	0.42	0.37	0.03
	Spring	0.22	0.35	0.28	0.24	0.40
	Summer	0.44	0.30	0.19	0.14	-0.25
	Autumn	0.41	0.24	0.20	0.17	0.26
Tromsø	**Annual**	**0.17**	**0.21**	**0.21**	**0.32**	**-0.03**
	Winter	0.22	0.32	0.33	0.35	0.21
	Spring	0.17	0.24	0.22	0.39	0.68
	Summer	0.23	0.13	0.14	0.28	-0.02
	Autumn	0.31	0.14	0.16	0.25	0.36
Sihccajavre	**Annual**	**0.14**	**0.35**	**0.29**	**0.30**	**-0.06**
	Winter	0.33	0.49	0.43	0.47	0.17
	Spring	0.30	0.35	0.37	0.45	0.46
	Summer	0.14	0.21	0.15	0.15	-0.09
	Autumn	0.37	0.19	0.19	0.24	0.27
Vardø	**Annual**	**0.36**	**0.32**	**0.30**	**0.30**	**0.20**
	Winter	0.38	0.35	0.33	0.29	0.25
	Spring	0.49	0.37	0.35	0.36	0.72
	Summer	0.39	0.23	0.20	0.22	0.21
	Autumn	0.41	0.29	0.28	0.30	0.45

3.3 Regional trend characteristics

Grouping of the stations according to maritime influence (grouping 2 in Table 3.1) clearly shows that the temperature trends during winter in general have been larger in the inland than along the coast (Table 3.4). However, there are no clear differences between the groups concerning differences between trends in minimum -, average – and maximum temperatures. During winter, all groups show larger trends for lowest minimum temperature and smallest trends for highest maximum temperature. During the other seasons the pattern varies.

Table 3.4 *Average trends (°C per decade) in minimum, maximum and mean temperatures during 1955-2014 for stations in group Coast, Fiord and Inland*

Grouping-2	Season	Lowest minimum	Mean daily-min	Mean	Mean daily-max	Highest maximum
COAST	Winter	0.29	0.27	0.24	0.25	0.07
	Spring	0.39	0.36	0.32	0.28	0.12
	Summer	0.40	0.33	0.30	0.30	0.43
	Autumn	0.29	0.24	0.22	0.23	0.14
FIORD	Winter	0.54	0.41	0.35	0.32	0.14
	Spring	0.24	0.29	0.25	0.31	0.47
	Summer	0.19	0.22	0.20	0.24	0.01
	Autumn	0.39	0.15	0.16	0.20	0.30
INLAND	Winter	0.73	0.58	0.49	0.42	0.16
	Spring	0.41	0.37	0.34	0.33	0.45
	Summer	0.31	0.27	0.20	0.18	-0.07
	Spring	0.63	0.21	0.19	0.19	0.25

Table 3.5 *Average trends (°C per decade) in minimum, maximum and mean temperatures during 1955-2014 for stations in group South, Central and North*

Grouping-1	Season	Lowest minimum	Mean daily-min	Mean	Mean daily-max	Highest maximum
SOUTH	Winter	0.74	0.50	0.41	0.33	0.15
	Spring	0.55	0.39	0.34	0.31	0.40
	Summer	0.30	0.29	0.20	0.16	0.13
	Autumn	0.46	0.20	0.15	0.11	0.11
CENTRAL	Winter	0.50	0.43	0.38	0.34	0.10
	Spring	0.30	0.27	0.25	0.27	0.39
	Summer	0.19	0.22	0.25	0.30	-0.02
	Autumn	0.52	0.13	0.16	0.19	0.31
NORTH	Winter	0.45	0.41	0.37	0.37	0.16
	Spring	0.29	0.32	0.31	0.35	0.64
	Summer	0.30	0.20	0.17	0.21	-0.04
	Spring	0.38	0.22	0.21	0.24	0.34

However, grouping into north-south location (grouping 1 of table 3.1), revealed certain regional characteristics (Table 3.5). For the winter season all groups indicated largest increase for the lowest minimum temperature, and second largest for the mean daily minimum temperature. With a few exceptions, the largest increase was found for the lowest minimum temperature also for the other seasons.

For the central and northern groups there is also in all seasons a tendency to larger trends for mean maximum temperature than for the mean temperature. For spring and autumn there is a tendency in these groups that the season's highest maximum temperature increases even more than the mean maximum temperature. On the other hand, for the summer season the trend is close to zero for the highest maximum temperature in these regions.

3.4 Conclusions

For Norwegian stations there is over the latest 60 years a general tendency for higher increase in minimum temperature than in mean temperature. These results are consistent with global trends (IPCC, 2013). For the groupings 1 and 2, the increase is even larger for the lowest seasonal minimum temperature than for the mean minimum temperature. This increase in minimum temperatures has significantly contributed to the increase in daily mean temperature and consequently also to the increase of number of days with temperatures above certain limits.

4. Wind

Authors: Eirik J. Førland, Hilde Haakenstad and Jan Erik Haugen

4.1 Introduction

Wind conditions in Norway are difficult to analyze; - both concerning long-term variations as well as local differences. This is partly because the observations of wind are strongly influenced by local effects; and partly that measuring sites, observation practices and instrumentation has changed a lot over time. For example, in the past fifty years observations are shifted from visual (Beaufort scale) to instrumental at several measuring stations with long wind series. Consequently; - to describe temporal and spatial wind conditions, modeled wind calculated from numerical atmospheric models are often used instead of direct wind measurements. In areas with large topographic differences, models with very high resolution are needed for a realistic description of local wind directions and speeds. Frequently the local topography is not adequately described in the models, and local wind direction and wind speed may differ significantly from the modeled wind.

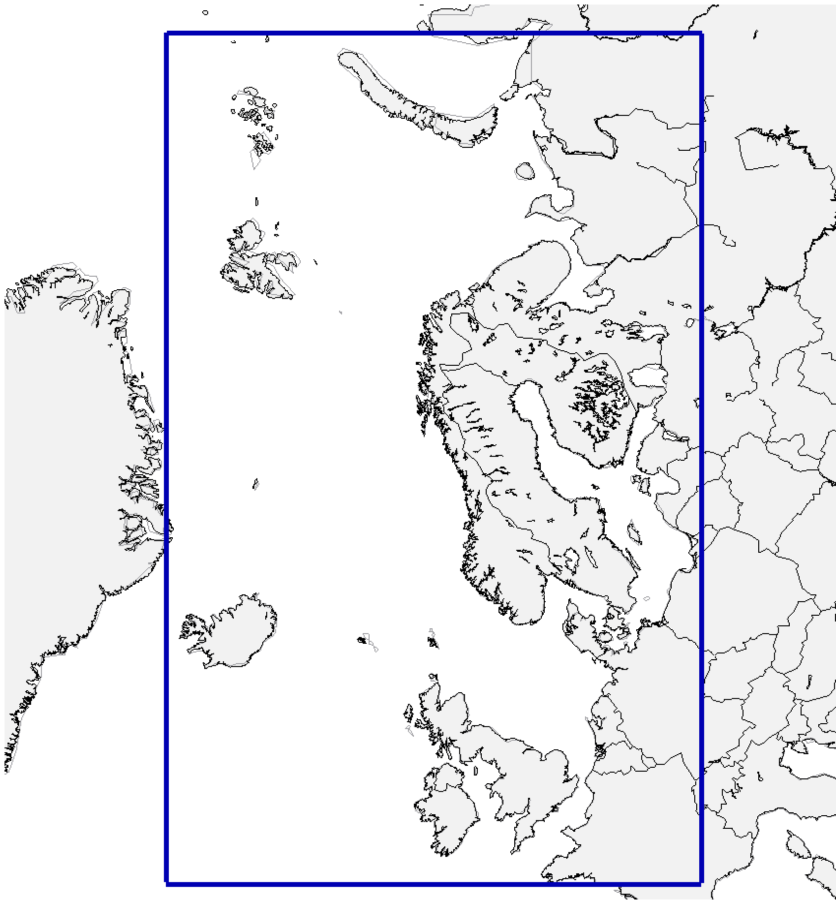
Friction from the terrain usually reduces the wind speed, but locally terrain effects may reinforce the wind speed. Such wind amplification can occur over mountains and ridges in the terrain, and in narrowings of valleys and fjords. The wind in fjords and valleys are often turbulent; with large variations over short distances in both wind speed and direction.

In the following analysis of wind, we focus on the development of wind conditions at locations where we can compare the model data and observational data.

4.2 Model calculations of wind

NORA10 is an archive of model calculations carried out with particular attention on generating a good wind and wave archive for Norwegian waters. Validation against observations shows that the data set also provides good wind data for the Norwegian mainland (Reistad et al., 2011). The NORA10 archive covers the period from September 1957 until 2015 and is being updated regularly. For the period 1957-2002, the model calculations are performed by downscaling the global re-analysis ERA40 (Uppala et al, 2005). A re-analysis is a recalculation of the state of the atmosphere. By re-running the numerical weather models more real-time observations will be available, and thus more accurate calculation of the state of the atmosphere will be achieved. If these recalculations are performed for a long time period; it is possible to establish a set of data that can be used for analysis of climatology, trends and extremes for various climate elements.

After the ERA40 period (i.e. after August 2002), the NORA10 results are based on downscaling of the ECMWF - IFS global operational analysis (European Centre for Medium - Range Weather Forecasts - Integrated Forecasting System). Because of the low horizontal resolution in re-analysis, it is necessary to downscale the global data to higher spatial resolution so that meso-scale phenomena can be dissolved in the simulations. Model calculations are performed with the numerical weather prediction model HIRLAM, on a rotating spherical grid with 248x400 grid points and 0.1º spatial resolution (Figure 4.1).



Figur 4.1 *NORA10 model domain.*

The model has 40 hybrid levels from the ground to the top of the atmosphere (the vertical coordinate gradually changes from following the topography close to the ground to following the pressure levels at high altitudes). The model calculations are carried out in a long sequence of short overlapping projections for every 6 hours. In the start of each cycle a digital filter initialization is performed for the atmospheric condition. The ERA40 / ECMWF data is forced into the model in such a way that the fine-scale structures in the model are retained to the next prognosis, while the atmospheric large-scale pattern is governed by the ERA40 / ECMWF - analyzes.

4.3 Wind climatology and recent trends

Table 4.1 shows that values for wind speed exceeded in 1 % of the time mainly are 1-2 m/s (in average 1,8 m/s) lower in the NORA10-model calculations than measured at the weather stations. The fact that the difference between observed and modeled wind varies relatively little from station to station suggests that the observed spatial variations are modeled quite well. Figure 4.2 shows that in exposed areas along the coast and in the mountains the modeled 1% wind speed is stronger than 15 m/s (equivalent to gale), while large parts of the southeastern lowland have values lower than 6 m/s (moderate breeze). However, the most severe wind damage to infrastructure is caused by strong wind gusts. When strong wind passes ridges, strong local gusts may occur also in low-lying areas in fjords and valleys.

Studies of long-term variations of strong winds depend on what kind of data they are based. A study of long-term variability of modeled winds over northwest Europe (British Isles, North Sea and Norwegian Sea) concluded that there was no clear trend in the frequency of storms in our seas and coastal areas since 1880 (Feser et al., 2014). An analysis of the frequency of strong winds measured during the period 1957-2014 at a selection of Norwegian weather stations concluded that while the number of incidents with mean wind speed over the 90 percentile is increasing, there are negative or no trends for the 90th percentile of wind gusts (Tveito, 2014).

Historical development in modelled high wind speeds for Norway are mapped in figure 4.3. The map is produced by analyzing changes in the annual 99-percentile of modelled wind from the NORA10-dataset during 1961-2010 (NGI, 2013). The results (figure 4.3) indicate an increase of up to 6-8 percent for eastern and western parts of South-Norway. On the other hand there are areas in the Norwegian mainland with minor increase or even a small decrease, as in parts of the northernmost (Finnmark) and southernmost (Sørlandet) districts, as well as in some mountainous areas in southern Norway.

Figures 4.4 a-h illustrates the development during the period 1958-2014 of wind speeds that are exceeded in 1% of the time ("99-percentile") at the weather stations Gardermoen, Færder, Oksøy, Utsira, Svinøy, Halten, Tromsø and Vardø. The figures demonstrate large inter-annual variations in values based on observations as well as on model calculations. As mentioned above, the model-based values are generally lower than those observed, but the figure shows that there is a covariation in the inter-annual variability. According to table 4.1, the correlation coefficients between observation and model-based annual wind speeds are ranging from 0.42 (Vardø) to 0.78 (Tromsø).

For wind speeds exceeded in 1 % of the time, table 4.1 in general indicates weak (< 10 %) positive trends for observed as well as modelled values for all stations. The observed trends are influenced by changes in instruments/measuring methods and measuring sites, while the model based trends are affected by changes in data input to the model (Aarnes et al., 2015)

Analyses are also performed for maximum values of wind speeds averaged over 1, 3, 6, 12 and 24 hours (NGI, 2013). Values for 1 hour indicate a linear trend of ca. 8 percent for the period 1961-2010. Positive trends are also found for the other durations; - with lowest trends for 12 hours periods. The highest wind speeds primarily occur during the winter season, and partly also during autumn. Just a few cases of high wind speeds occur during the spring season.

Table 4.1 *Mean values, trends and covariation in 99-percentile of observed and modeled (NORA10) wind speed 10 m above surface during the period 1958-2014. * (Tromsø 1964-2014)*

Weather station	Mean wind speed (m/s) for 99 percentile		Corr.Coeff.	Trend (%)	
	Observed	NORA10		Observed	NORA10
Gardermoen	9	7	0,58	2	9
Færder Fyr	17	16	0,61	3	7
Oksøy Fyr	16	15	0,62	-1	2
Utsira Fyr	20	18	0,48	17	5
Svinøy Fyr	22	19	0,68	8	5
Halten Fyr	21	19	0,62	x	2
Tromsø Langnes	13	11	0,78	9*	2
Vardø Radio	16	15	0,42	3	1
Average	16,8	15,0			

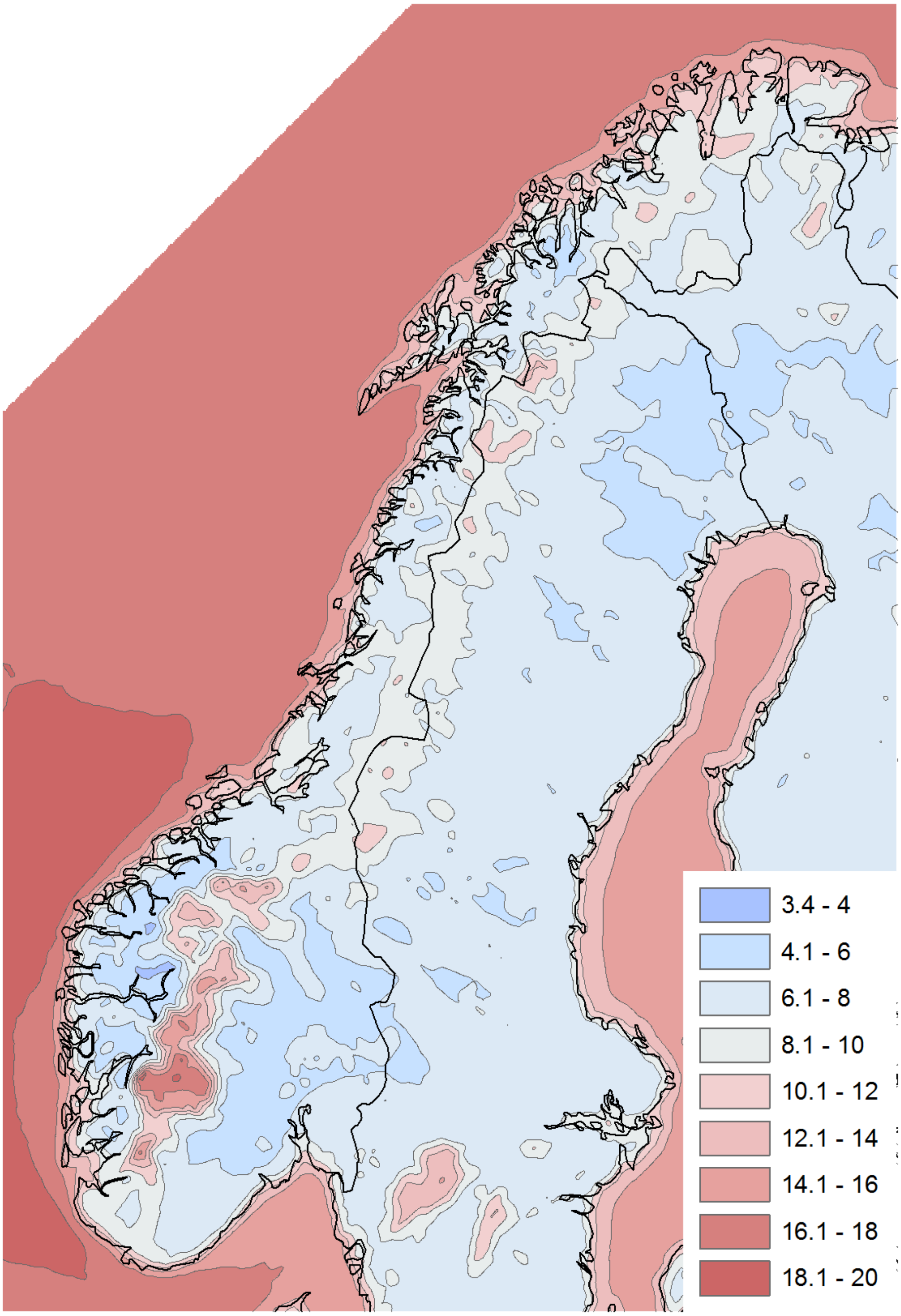
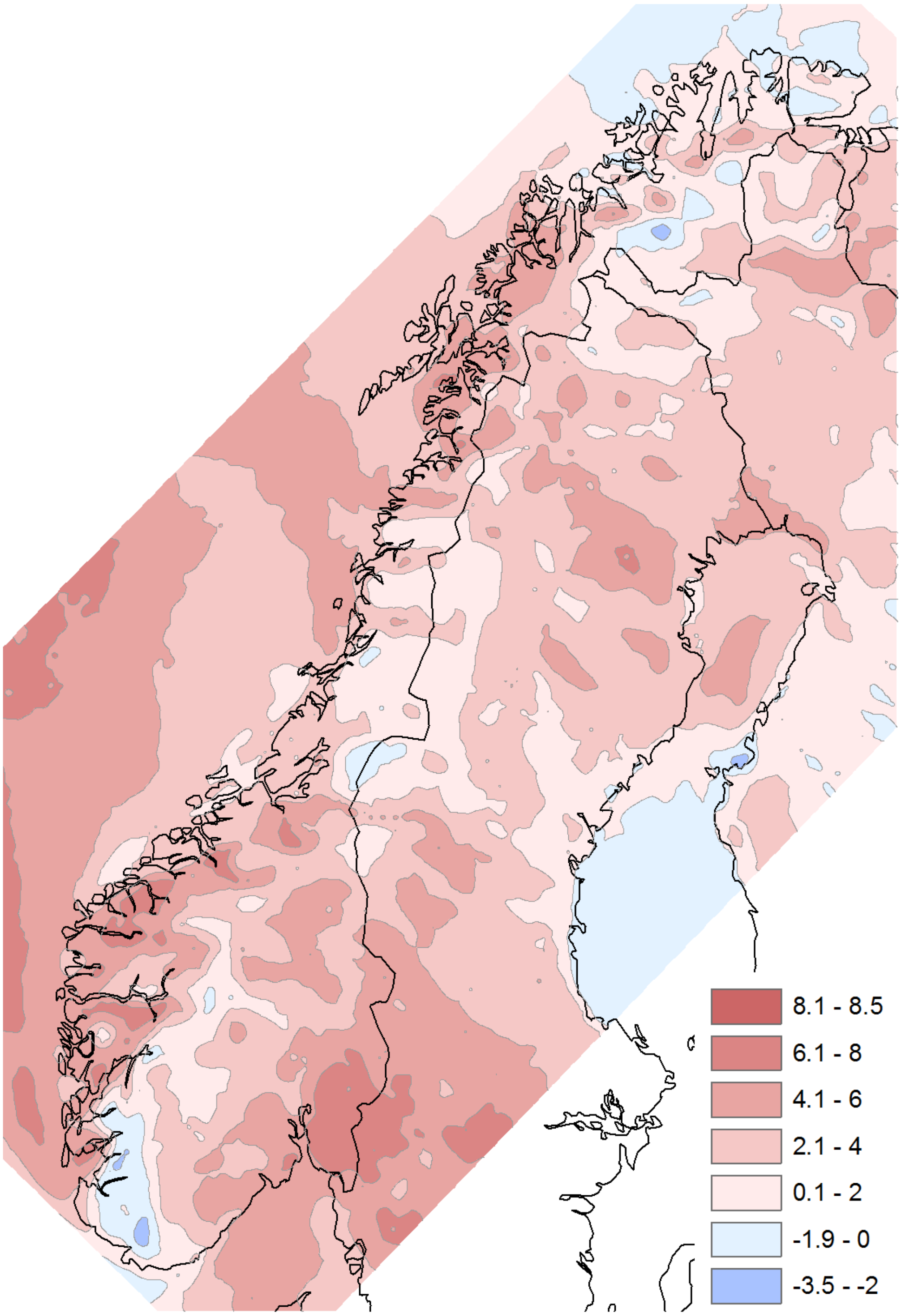
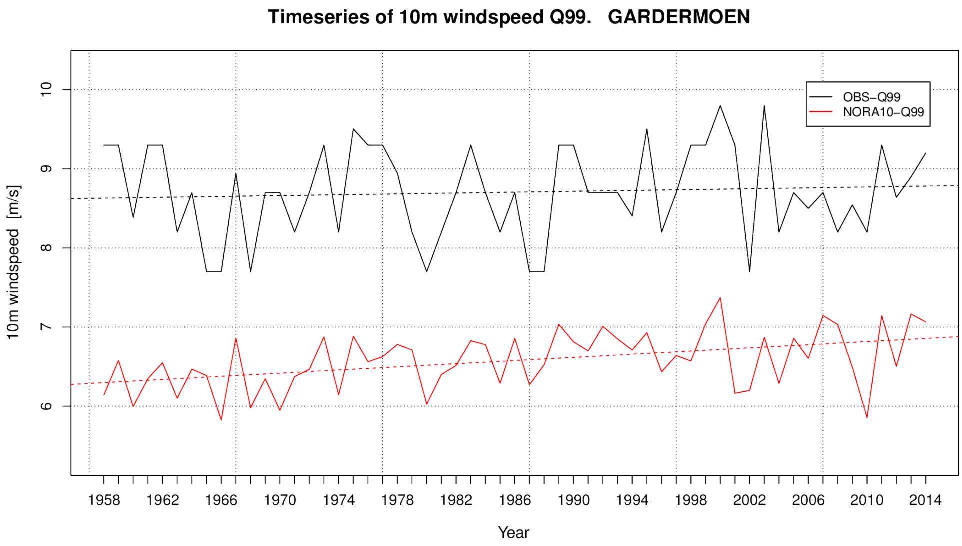
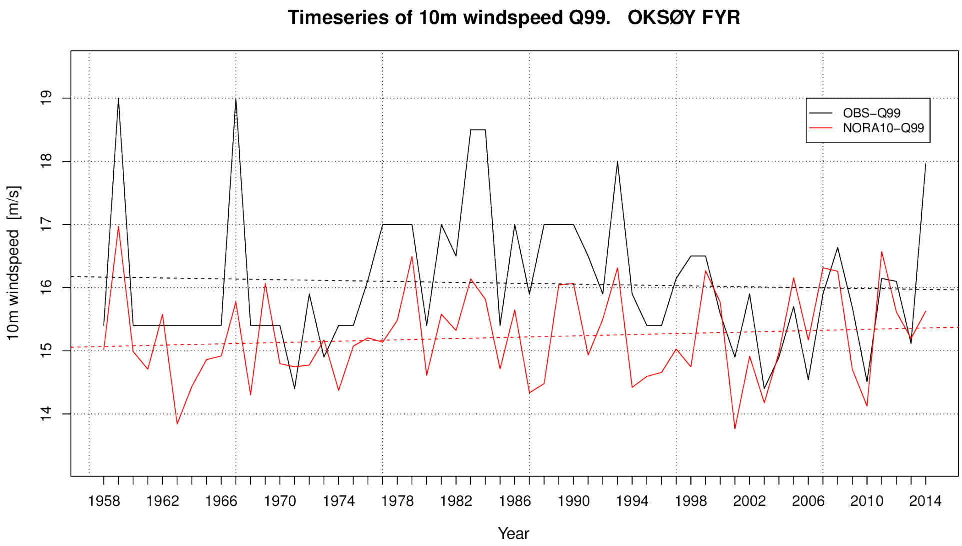


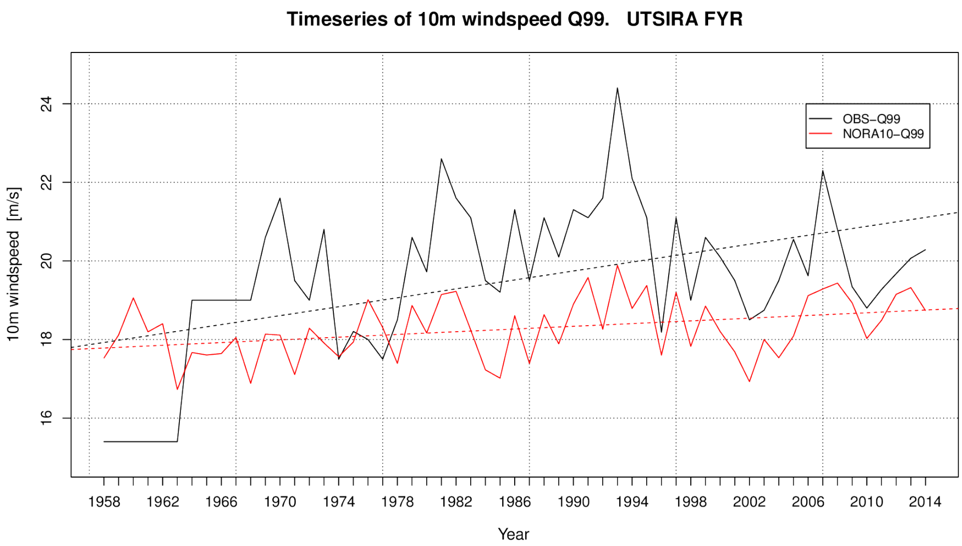
Figure 4.2 *Annual modelled (NORA10) 99-percentile wind speed (m/s) for the period 1971-2000.*



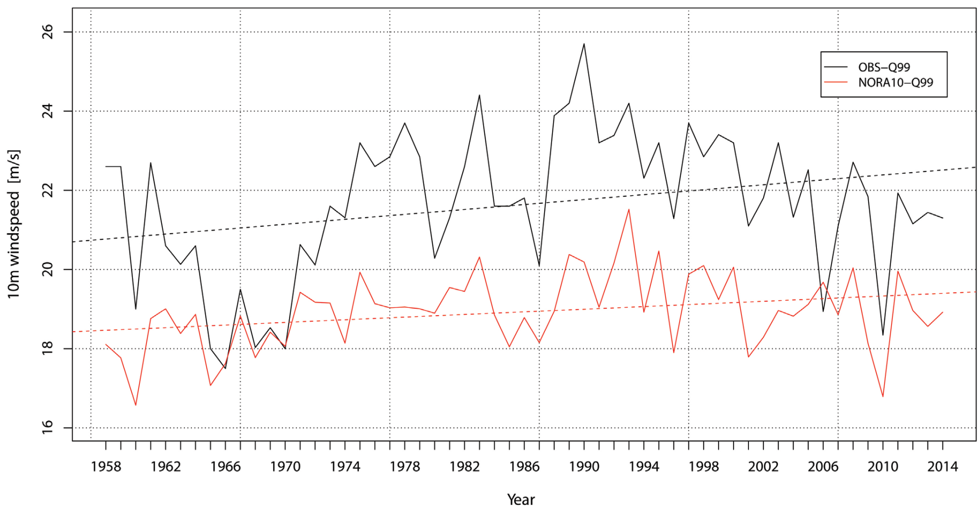
Figur 4.3 *Linear trends (%) in modelled 99-percentiles high wind speeds during the period 1961-2010. The map is based on annual 99 %-values from the NORA10 dataset.*


Timeseries of 10m windspeed Q99. GARDERMOEN
10m windspeed [m/s]
Year
OBS−Q99
NORA10−Q99

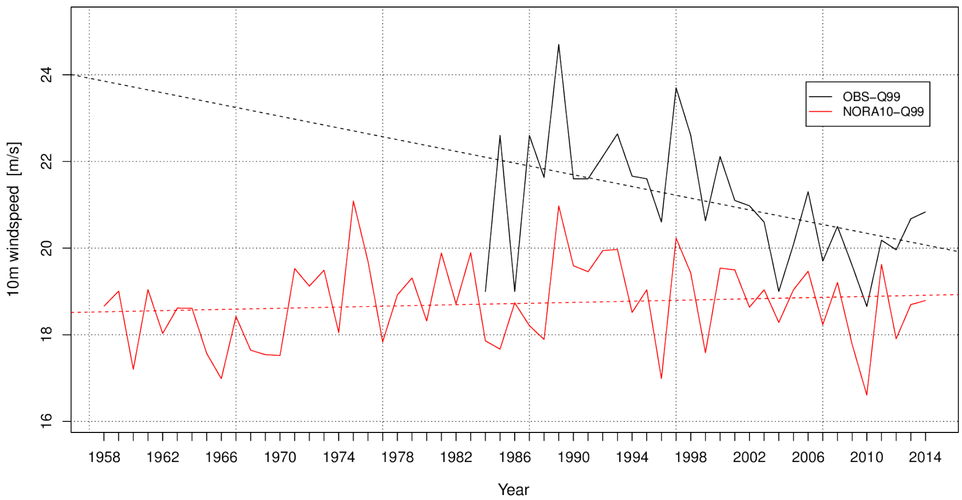

Timeseries of 10m windspeed Q99. OKSØY FYR
10m windspeed [m/s]
Year
OBS−Q99
NORA10−Q99


Timeseries of 10m windspeed Q99. UTSIRA FYR
10m windspeed [m/s]
Year
OBS−Q99
NORA10−Q99

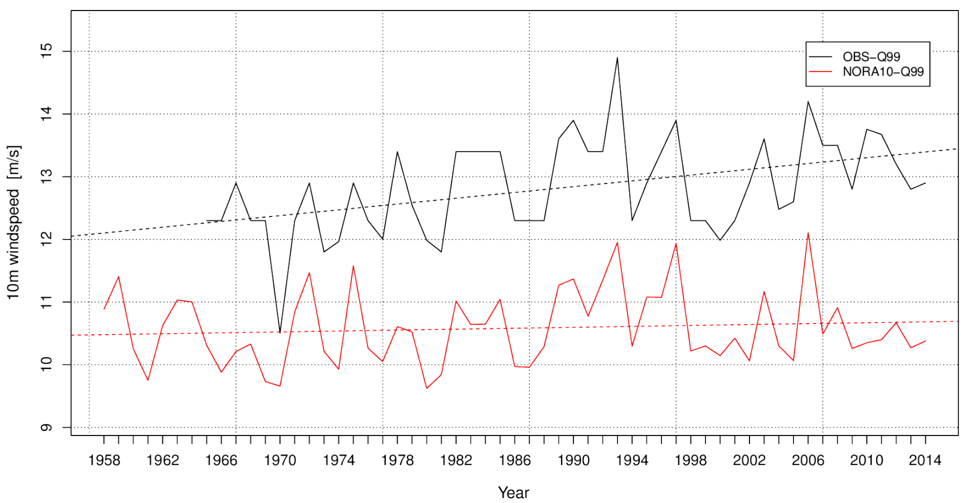
Timeseries of 10m windspeed Q99. SVINØY FYR



Timeseries of 10m windspeed Q99. HALTEN FYR



Timeseries of 10m windspeed Q99. TROMSØ – LANGNES



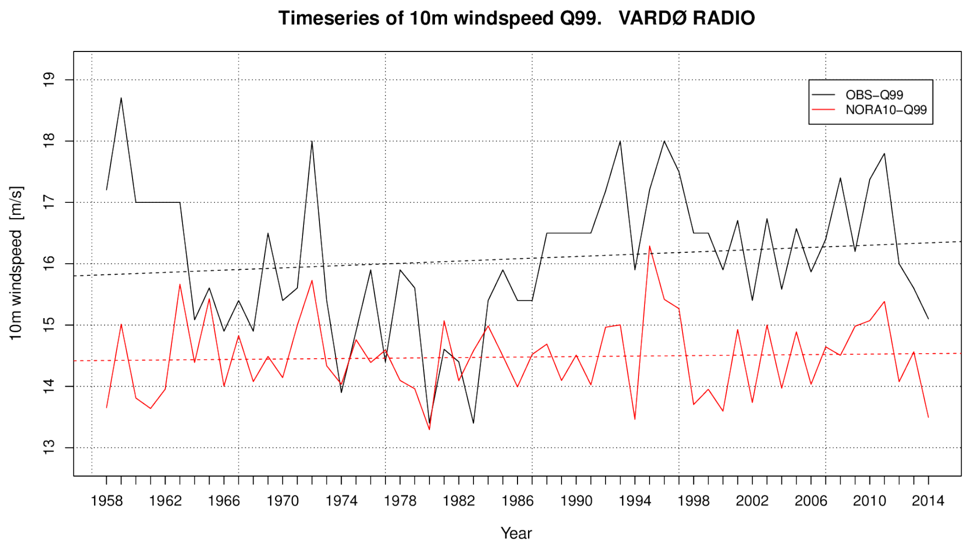


Figure 4.4 *Time series of the 99 percentile wind speed (m/s) values 10 m above surface from observations (OBS) and model calculations (NORA10) at eight weather stations. Dotted lines indicate linear trend.*

4.4 Wind projections

The wind projections are based on ten EURO-CORDEX (www.euro-cordex.net*)* RCM-simulations for emission scenarios RCP4.5 and RCP8. Despite improved information in the regional climate projections compared with the global projections; they contain systematic errors, both from the regional climate model itself, as well as from the driving global climate model. There is therefore a need for statistical calibration of projections before they are used in effect studies. In the wind analyses, this "calibration" is performed by use of a bias-correction method called quantile-mapping (see Sorteberg et al., 2014)

On an annual basis the projections show a very modest decrease in median value for wind speed which is exceeded in 1 % of the time both for RCP4.5 and RCP8.5 (Table 4.2). The tendency to decreasing values is strongest (but still very modest) in spring and summer. In winter, there is a tendency to a small increase for both median and high projections. For the winter season, the entire wind distribution is shifted towards higher values, while the opposite is true in spring and summer. For the absolute maximum values (open circles in figure 4.5), there is an increase for all seasons. For winter and summer, the increase is larger than 20 % for some projections.

In winter the projections indicate a slight increase (0-2 %) in the median value of the 99-percentile for wind speed across large parts of Norway (figure 4.6a), while during summer (figure 4.6c) there is a slight decrease over eastern parts of the country. The reduction in wind speed during summer is consistent with results from wind analyzes performed in the ECLISE-project (Haakenstad & Haugen, 2014) based on regional climate projections from CMIP3 models (IPCC, 2007).

Table 4.2 *Change (%) in 99-precentile for wind from 1971-2000 to 2071-2100 for emission scenarios RCP4.5 and RCP8.5 for median, low and high projections. Region: Norwegian mainland*

	RCP 4.5			RCP 8.5		
Season	**Med**	**Low**	**High**	**Med**	**Low**	**High**
Annual	-0,8	-2,6	0,9	-0,9	-3,6	0,9
Winter (DJF)	1,2	-0,1	2,6	1,2	-0,5	2,5
Spring (MAM)	-1,5	-2,6	-0,6	-2,0	-3,9	-0,8
Summer (JJA)	-1,9	-4,0	-0,3	-2,7	-5,5	-1,2
Autumn (SON)	-0,3	-2,1	0,8	0,1	-2,4	1,1

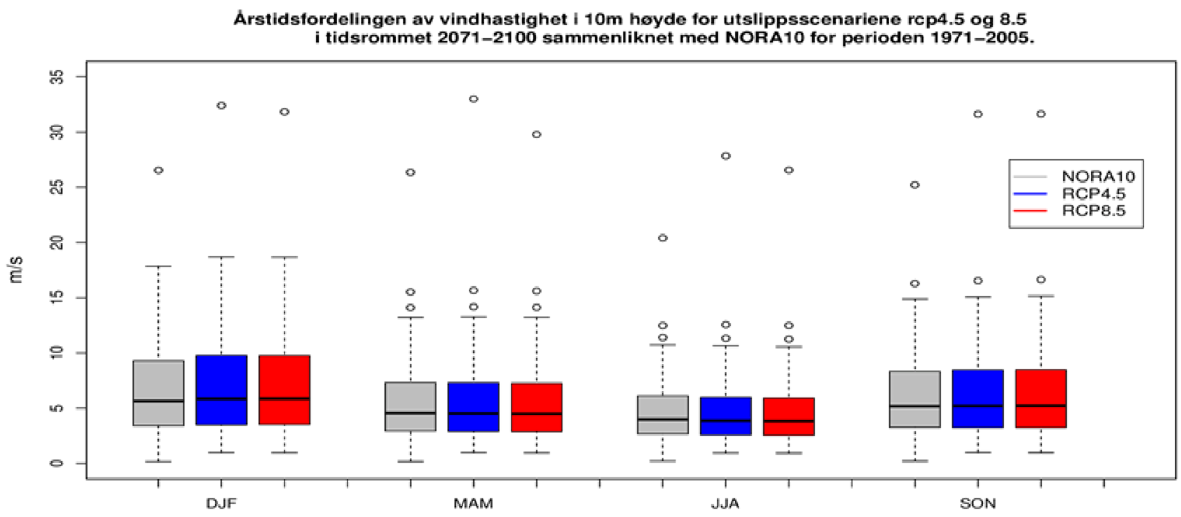


Figure 4.5. *Seasonal distribution of wind speeds (m/s at 10 m a.s.l.) for simulations based on NORA10 (1971-2005) and for emission scenarios RCP4.5 and RCP8.5 (2071-2100)*

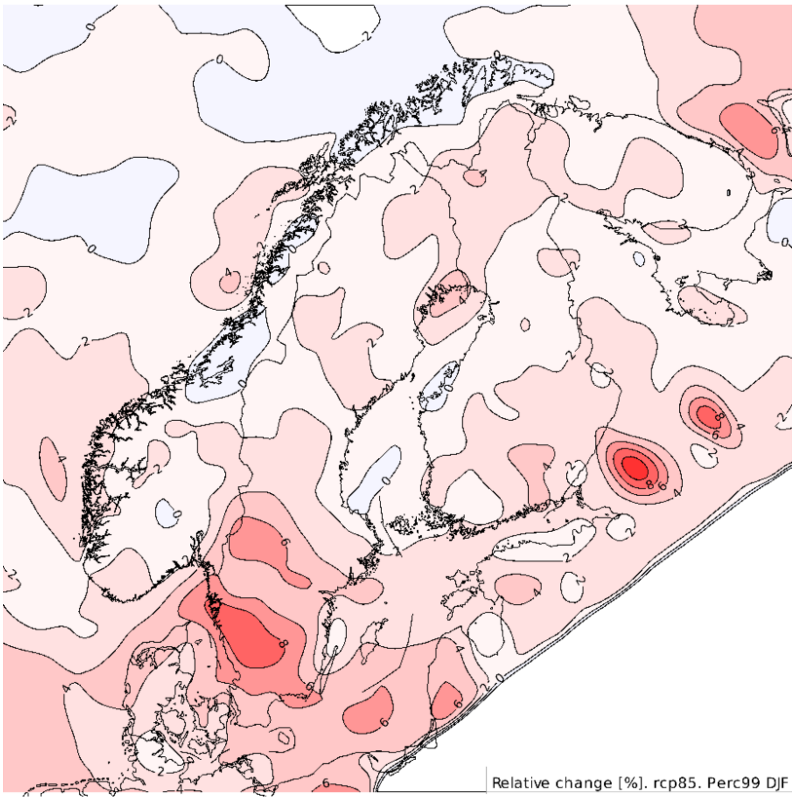


Figure 4.6a *Relative change (%) in the 99 percentile of wind speed from 1971-2000 to 2071-2100 for emission scenario RCP8.5 for* ***Winter (DJF)***

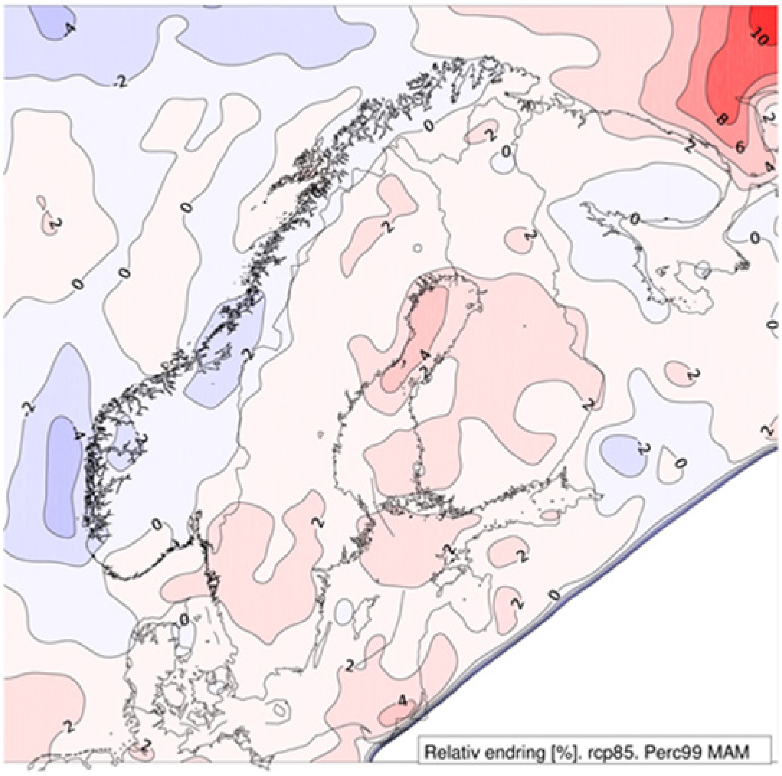


Figure 4.6b *Relative change (%) in the 99 percentile of wind speed from 1971-2000 to 2071-2100 for emission scenario RCP8.5 for* ***Spring (MAM)***

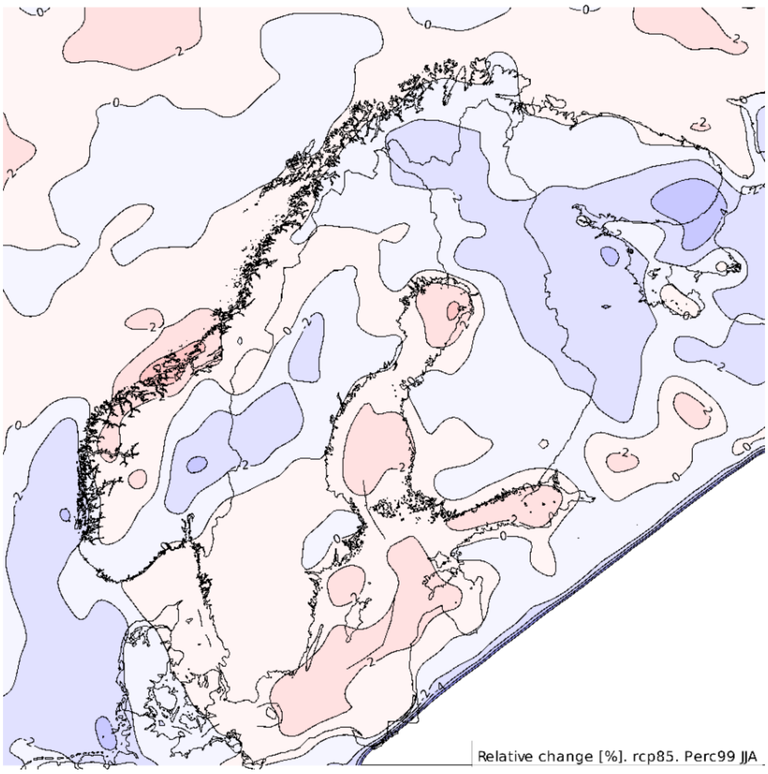


Figure 4.6c *Relative change (%) in the 99 percentile of wind speed from 1971-2000 to 2071-2100 for emission scenario RCP8.5 for* ***Summer (JJA).***

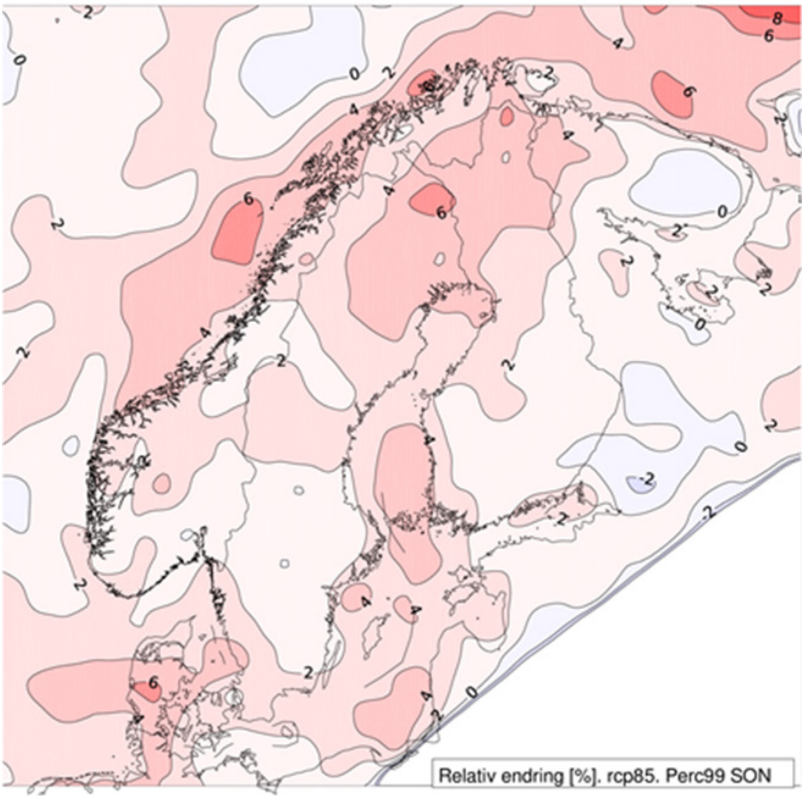


Figure 4.6d *Relative change (%) in the 99 percentile of wind speed from 1971-2000 to 2071-2100 for emission scenario RCP8.5* ***Autumn (SON)***

5. Permafrost

Author: Ketil Isaksen

5.1 Present state and recent trends

Areas underlain by permafrost, or permanently frozen ground, constitute of soil or rock and included ice and organic material that remains at or below 0°C for at least two consecutive years. About a quarter of the exposed land surface of the Northern Hemisphere is occupied by permafrost (Zhang et al. 2003). In Norway permafrost is widespread in the higher mountains and is found locally in some peat bogs. Measurements show that the permafrost in Norway is "warm", typically between -3 and 0 °C (Christiansen et al. 2010; Isaksen et al. 2011b; Farbrot et al. 2011; Farbrot et al. 2013). The layer of the ground that is subject to annual thawing and freezing (*the active layer*) in areas underlain by permafrost in Norway may be up to 10 m in bedrock (Farbrot et al. 2013).

The lower altitudinal limit of mountain permafrost is clearly lower in the eastern parts of southern Norway (transition zone at 900-1100 m a.s.l., Heggem et al. 2005; Juliussen and Humlum, 2007) than in the central and western parts (transition zone at 1300-1550 m a.s.l., Isaksen et al. 2002; Sollid et al. 2003; Ødegård et al. 1992). Both snow conditions and surface material favour a lower permafrost limit in the eastern parts of southern Norway (Farbrot et al. 2011). Snow distribution within the altitudinal transition zone of the mountain permafrost is a primary controlling factor for permafrost occurrence (Gisnås et al. 2014; Heggem et al. 2005; Isaksen et al. 2002, 2011b; Sollid et al. 2003). In northern Norway there are three different environmental types of permafrost (Farbrot et al. 2013): 1. Continental permafrost in the inner part of Finnmark and Troms, widespread in peat bogs and on bare windswept hills. 2. Maritime permafrost above 800-900 m a.s.l. in coastal mountain regions, which is mostly governed by elevation and snow distribution, 3. Low Arctic permafrost on Varangerhalvøya, having elevated plains with widespread but warm permafrost. In steep bedrock slopes in Norway there are to date few quantitative studies of the lower limit and thermal state of permafrost. However, first results show that the permafrost is present in steep north-facing rock walls at lower altitudes than reported above (Frauenfelder et al. 2014; Hipp et al. 2014; Isaksen et al. 2011a).

Permafrost is like the other cryospheric components sensitive to climate change. Frozen ground affects the stability of steep slopes and rock faces (see eg. Arenson et al. 2007) and the danger of slope instabilities may increase if the permafrost warm or thaws (see eg. Fischer et al. 2006, Haeberli et al. 2010). Peatlands and organic material intermixed with mineral soils in permafrost regions contain large amounts of organic carbon. Thawing permafrost and the resulting microbial decomposition of the previously frozen organic carbon is one of the most significant potential feedbacks from terrestrial ecosystems to the atmosphere in a changing climate (Schuur et al, 2008). It is also great geotechnical challenges related to buildings and construction work in permafrost (see eg. Bommer et al. 2010; Canadian Standards Association 2014).

Both warming and thawing of permafrost in Norway have been measured in some areas in recent years (Isaksen et al. 2007 and 2011b; Farbrot et al. 2013). The longest time series in Norway goes back to 1999 at Juvvasshøe (1894 m a.s.l.) in southern Norway. On Tarfalaryggen (1550 m a.s.l.) in northern Sweden, near the Norwegian border, the series goes back to 2000 (Sollid et al. 2000). In the upper 10 to 20 meters of the permafrost the ground temperatures are affected by the annual and the seasonal variations in air temperature (Figure 5.1). At greater depths, however, a couple of cold or mild winters will not have any significant impact on the temperature and the series therefore provides a direct measure of the long-term temperature trend.

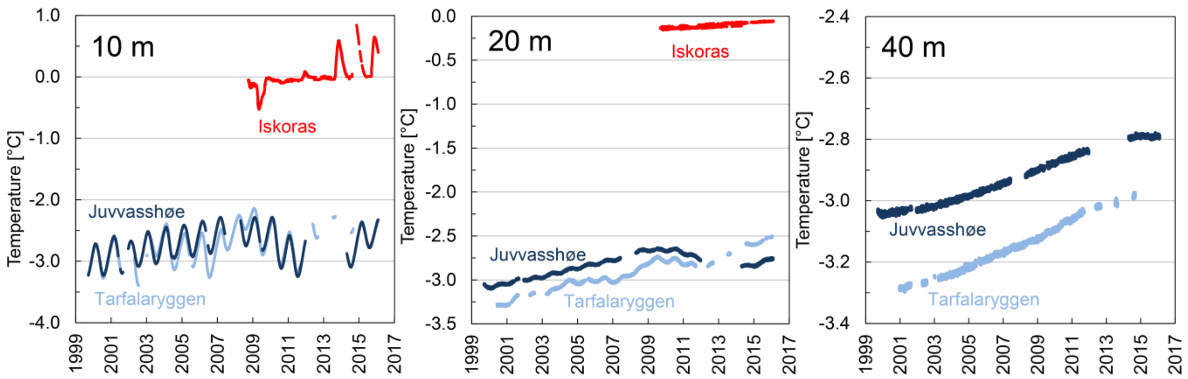


***Figure 5.1**. Observed soil temperature for three selected depths in permafrost from the official permafrost stations at Juvvasshøe in Oppland, Tarfalaryggen in Swedish Lapland and Iškoras in Finnmark. Source for data from Tarfalaryggen: Tarfala Research Station, The Bolin Centre Database.*

Soil temperature measurements made since 2008 on Iškoras (591 m a.s.l.) in Finnmark northern Norway shows clear signs of thawing permafrost (Figure 5.1). Through winter 2013-14 ground temperatures were for the first time well above 0 °C on 10m. Updated soil temperature observations from the colder permafrost at Juvvasshøe and Tarfalaryggen show a clear warming from 25 meters and deeper into the ground. Since the soil temperatures are observed over several years, it is possible to calculate temperature trends at different depths (Figure 5.2). At 40 m depth the temperature at Juvvasshøe and Tarfalaryggen increased by respectively 0.20 and 0.25 °C / decade since measurements began. A clear increase in temperature can now be measured down to at least 80 m depth (Figure 5.2). This provides direct evidence of a surface warming going on for decades. Values from 30 to 50 m depth is used to calculate the temperature changes on the surface of the permafrost, and gives an average value representative for the past 20 to 30 years. A study by Isaksen et al. (2007) showed that the temperature in the upper layers of permafrost in Juvvasshøe and Tarfalaryggen rose on average 0.4-0.5 °C per decade. Updated estimates show that this rate is still the same at Juvvasshøe but has increased to about 0.6 °C per decade for Tarfalaryggen.

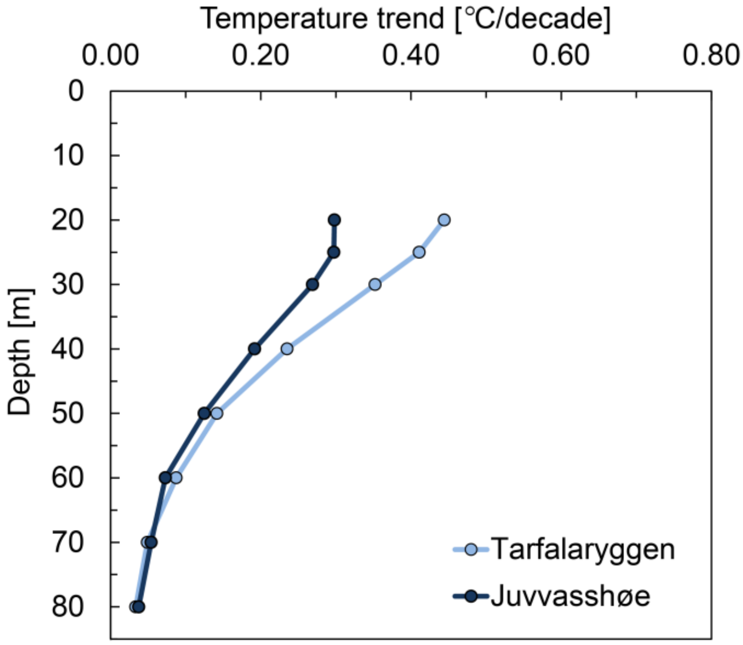


***Figure 5.2** Observed changes in temperature (linear trend in °C/ per decade) in the permafrost on Tarfalaryggen and Juvvasshøe for the period 2000 to 2014 (updated after Isaksen et al. (2007)).*

On Juvvasshøe data from continued monitoring of the thawing depth in the upper active layer show that the greatest thaw depth came in 2014 (Figure 5.3). Results from permafrostmodels indicate a significant increase of the depth of the active layer after the Little Ice Age, particularly after 1990 (Hipp et al. 2012)

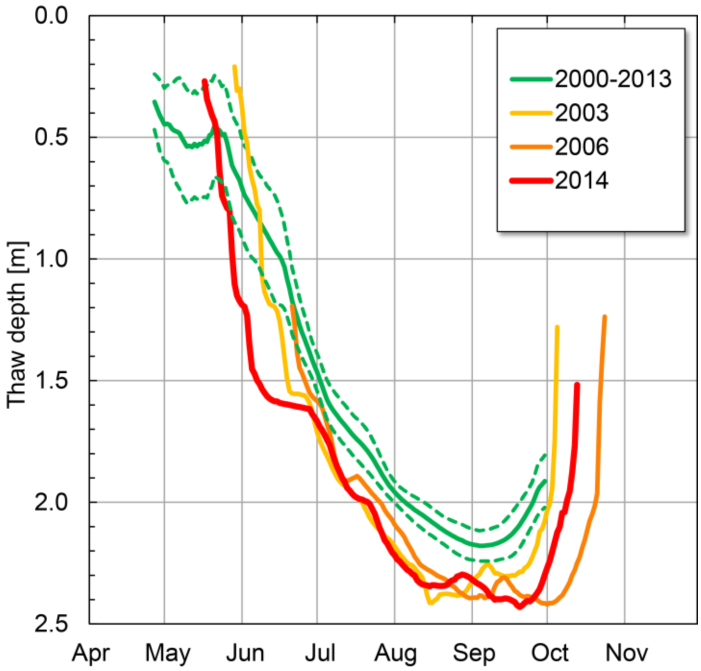


Figure 5.3 *Daily calculated thaw depth values for the three record years 2003, 2006 and 2014 on Juvvasshøe, southern Norway. The 2000 to 2013 average is in green. The dotted line around the average line shows the one standard deviation range of the data.*

A ten-year record (1999–2009) of annual mean ground surface temperatures (MGSTs) and mean ground temperatures (MGTs) was analysed for 16 monitoring sites in Jotunheimen and on Dovrefjell, southern Norway by Isaksen et al. (2011b). Warming has occurred at sites with cold permafrost, marginal permafrost and deep seasonal frost. Ongoing permafrost degradation is suggested both by direct temperature monitoring and indirect geophysical surveys. An increase in MGT at 6.6–9.0 m depth was observed for most sites, ranging from ~0.015 to ~ 0.095°C/year. The greatest rate of temperature increase was for sites having MGTs slightly above 0°C. The lowest rate of increase was for marginal permafrost sites that are affected by latent heat exchange close to 0°C. Increased snow depths and an increase in winter air temperatures appear to be the most important factors controlling warming observed over the ten-year period (Isaksen et al. 2011b).

Permafrost modelling show that the land area with permafrost in Troms and Finnmark is reduced from being ca. 27% in normal period 1961-1990 to about 19% in the period 1981-2010 (Figure 5.4, Farbrot et al. 2013). The same model suggests that approximately 10% of Norway's land area was covered by permafrost in 1961 to 1990, and that this decreased to approximately 6 % in 1981-2010 (Gisnås et al. 2013). This model represents the equilibrium state under the applied climate period, and does not represent the transient behavior of ground temperatures; thus, the modelled state of permafrost may for some areas be reached after a considerable time lag (Gisnås et al. 2013). However, it still provides a relatively good representation of permafrost distribution in Norway. More advanced model results for southern Norway also support warming of the permafrost and that it has thawed in some areas, compared to a few decades ago (Westermann et al, 2013).

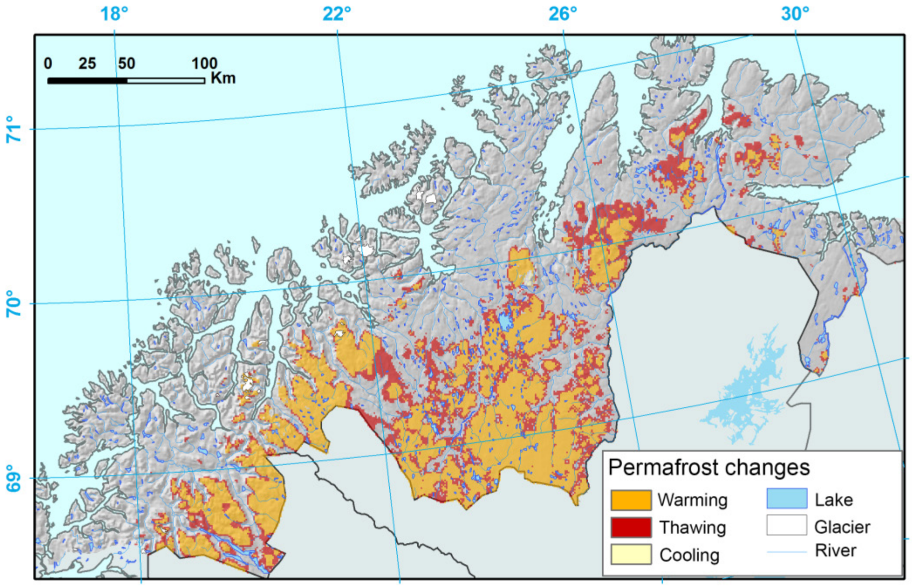


Figure 5.4 *Modelled change in average temperature near the permafrost surface of the permafrost in Troms and Finnmark from 1961-1990 to 1981-2010. Areas with warming (red) and thawing (orange) permafrost are indicated. (Modified from Farbrot et al. (2013), by Bernd Etzelmüller, UiO).*

5.2 Future changes in permafrost

Thawing permafrost has consequences for the stability of steep mountain slopes and rock faces (see eg. Arenson et al, 2007; Fischer et al, 2006, Haeberli et al, 2010). As shown in chapter 5.1, there has been a significant warming and degradation of permafrost in Norway in recent decades. Model simulations of permafrost in southern Norway, on the basis of empirical-statistical downscaled data from SRES A1B and A2 Emissions Scenarios, shows that this trend will enhance (Hipp et al 2012; Gisnås et al. 2013). The projections show that areas with warm permafrost, which currently has an annual temperature between -1 and 0 °C, will thaw completely by 2050 (Hipp et al. 2012). The simulations also suggest the lower altitudinal limit of permafrost will rise by 200-300 meters until the year 2100 in the mountainous regions of southern Norway with thawing of permafrost in most areas located below 1800 m a.s.l. For the period 2071-2100 the model simulations show that the area of permafrost will remain at only 0.2 per cent of the total area of mainland Norway, and mean annual ground temperature will on average increase by 2.3 °C, compared to 1981-2010 (Gisnås et al. 2013).

The warming and thawing rate of the permafrost depends largely on the ground's thermal properties and especially the ice-content. Where permafrost temperatures are close to 0°C, the high latent heat requirements also result in smaller changes in soil temperature as phase change is occurring (Throop et al. 2012; Romanovsky et al. 2010). Very warm permafrost can therefore persist even in a warming climate (e.g. James et al. 2013). To increase the knowledge about permafrost response to future climate change in Norway there is a need for better knowledge about climate changes in the Norwegian mountains. Especially changes in snow cover and its thermal properties, thickness and duration will have a major effect on permafrost future state and distribution in Norway (cf. Westermann et al. 2013).

6. High-intensity rainfall

Authors: Anita V. Dyrrdal and Eirik J. Førland

6.1 Introduction

Intense precipitation over short durations, such as a few hours, is the main cause of rainfall-induced damages in urban areas. A recent overview of climatology, trends, estremes and design values for high-intensity rainfall is presented by Førland et al. (2015). For projections of future development, sub-daily precipitation from climate models are not thoroughly evaluated for Norway. However, ongoing studies aim to establish a better basis for projections of intense short-duration precipitation and rapid flooding (e.g. the NRC project ExPrecFlood). Preliminary results for changes in sub-daily precipitation intensity from this work are presented here.

6.2 Data and Methods

A much applied method for taking account of expected effects of climate change is to multiply todays design values by an expected relative change in precipitation intensity; a climate factor. In other words, a climate factor is the percentwise change in a variable based on climate simulations. As for precipitation intensity, the climate factor (K_f) will be a function of several variables, and can be expressed mathematically as in Paus et al. (2014):

$$K_f(GI, t + \Delta t, T, Z, S) = \frac{I(GI, t + \Delta t, T, Z, S}{I(GI, t, T, Z)}$$

where K_f is the climate factor and I is the design precipitation intensity under given conditions [l/s*ha or mm]. These conditions include return period (GI), precipitation duration (T), the geographical location (Z), reference period (t), duration of simulation period (Δt) and the climate scenario used as basis for the simulations (S).

We have computed climate factors for 3-hourly precipitation and daily precipitation by use of three precipitation indices; 5-year return level (M5), 200-year return level (M200) and 99.5 percentile (q99.5). The climate factors are computed as the change in the index of interest between the two periods 1976-2005 and 2071-2100, as given in six climate simulations from the EURO-CORDEX project (see Table 6.1). EURO-CORDEX (www.euro-cordex.net) is the European branch of the CORDEX initiative, and consists of 29 participating groups. (CORDEX (Giorgi et al., 2009) stands for «COordinated Regional climate Downscaling EXperiment», and is the newest ensemble of dynamically downscaled (regional) climate simulations).

The simulations in EURO-CORDEX exist on two spatial resolutions; 0.11° (~12 km) and 0.44° (~50 km), but we have focused on the finest resolution of ~12 km to compute climate factors for Norway. Two simulations are given by the same RCM, downscaled from two different GCMs. Simulations are produced for the two emission scenarios RCP4.5 and RCP8.5.

Table 6.1 Climate simulations. RCM = Regional climate model, GCM = Global climate model.

Institution	RCM	GCM	Abbreviation
Danish Meteorological Institute (DMI)	HIRHAM 5	ICHEC EC-EARTH	**DMI**
Pierre-Simon Laplace Institute/National Institute for Industrial Environment and Risks (IPSL-INERIS)	WRF 3.3.1	IPSL-CM5	**IPSL**
Royal Netherlands Meteorological Institute (KNMI)	RACMO 2.2	ICHEC EC-EARTH	**KNMI**
Swedish Meteorological and Hydrological Institute (SMHI)	RCA 4	ICHEC-EC-EARTH	**SMHI-I**
SMHI	RCA 4	CNRM-CM5	**SMHI-C**
CLM community (CLMcom)	CCLM 4.8.17	MPI-ESM-LR	**CCLM**

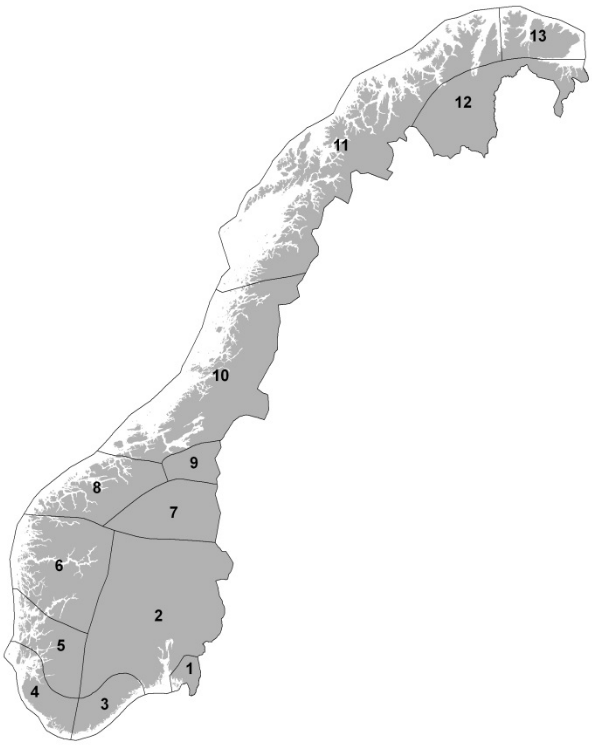
Return levels are computed by fitting annual maximum precipitation series to the GEV distribution, using a Bayesian prior on the shape parameter according to Martins & Stedinger (2001). The prior ensures reasonable values even for long return periods, for which «outliers» in short time series can be problematic. For more information on the models and the GEV method, see Dyrrdal et al. (2014a), Dyrrdal et al. (2014b) and Dyrrdal & Stordal (2016).

6.3 Results

Figure 6.2 - 6.7 and Tables 6.2 - 6.4 show climate factors for 3-hourly precipitation, computed for the 13 precipitation regions (Figure 6.1) used by Hanssen-Bauer et al (2015). The tables also include climate factors for daily precipitation. The mean values for the entire country for both durations are summarized in Table 6.5.

Although most computed climate factors are positive, there is a large spread in the values. Most simulations indicate an expected increase in 3-hourly precipitation of about 15-20%

(RCP4.5) or 20-40% (RCP8.5), depending on the index, and higher climate factors in regions 12-13 (Finnmark in the far north). Some simulations also show higher values for regions 1-2 (Southeast). Climate factors based on q99.5 are lower than those based on return levels and they do not differ significantly between the two durations. Climate factors based on M5 are lower than those based on M200, and both tend to be higher for 3-hourly than for daily precipitation. However, climate factors for daily precipitation generally show a wider range of values. The results indicate that extreme precipitation will increase more than the somewhat lower intensities, which corresponds with studies from other countries (Paus et al., 2015; Westra et al., 2014), and that the increase will be higher for shorter durations.



Region	District
1	Østfold
2	Østlandet
3	Sørlandet
4	Sørvestlandet
5	Sunnhordland/Ryfylke
6	Sogn og Fjordane / Nordhordland
7	Dovre / Nord-Østerdal
8	Møre og Romsdal
9	Inntrøndelag
10	Trøndelag / Helgeland
11	Hålogaland
12	Finnmarksvidda
13	Varanger

Figure 6.1. *Norwegian precipitation regions*

In the main report «Klima i Norge 2100» (Hanssen-Bauer et al., 2015), a few more simulations of daily precipitation from EURO-CORDEX were used to study expected future changes; in total 10 simulations. Of those 10 simulations, 5 are among the 6 models used here (Table 6.1). Only climate factors based on q99.5 were obtained, giving country mean values of 1.12 and 1.19 for RCP4.5 and RCP8.5, respectively. These numbers are almost identical to the ones obtained through the 6 simulations, as seen in Table 6.5 (1.11 and 1.20, respectively).

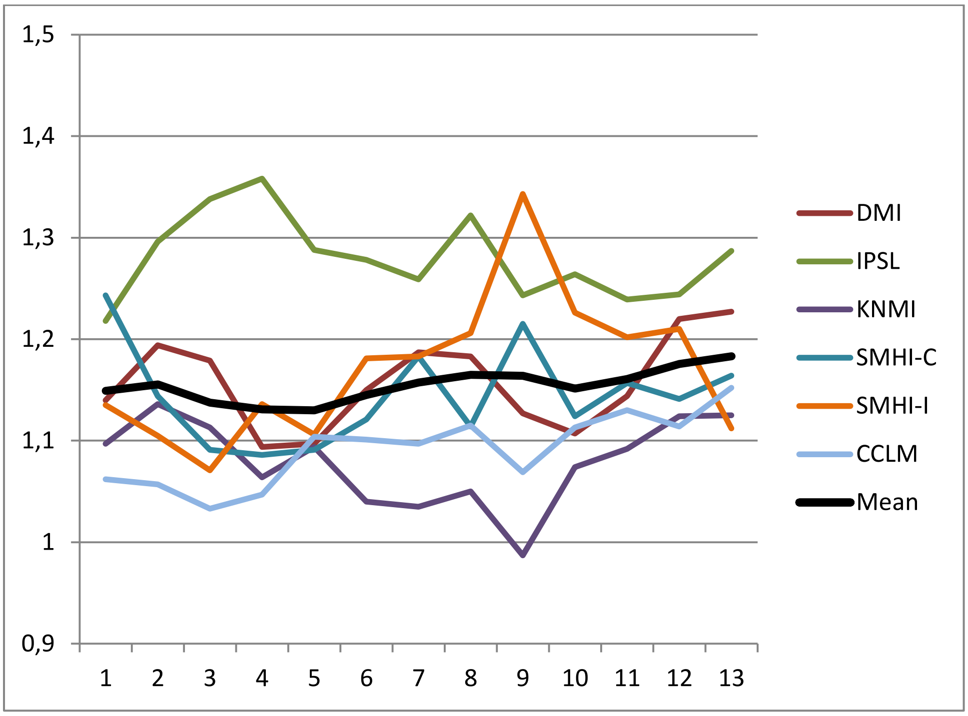


Figure 6.2 *Region-wise and simulation-wise climate factors based on changes in M5 for 3-hourly precipitation. Emission scenario RCP4.5.*

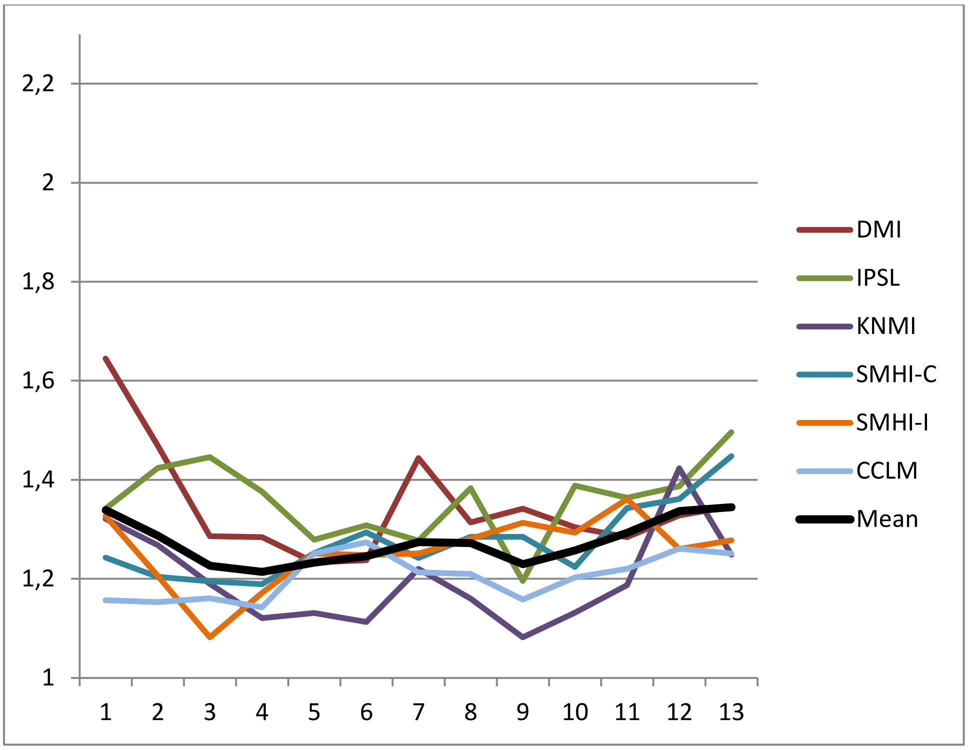


Figure 6.3 *Region-wise and simulation-wise climate factors based on changes in M5 for 3-hourly precipitation. Emission scenario RCP8.5.*

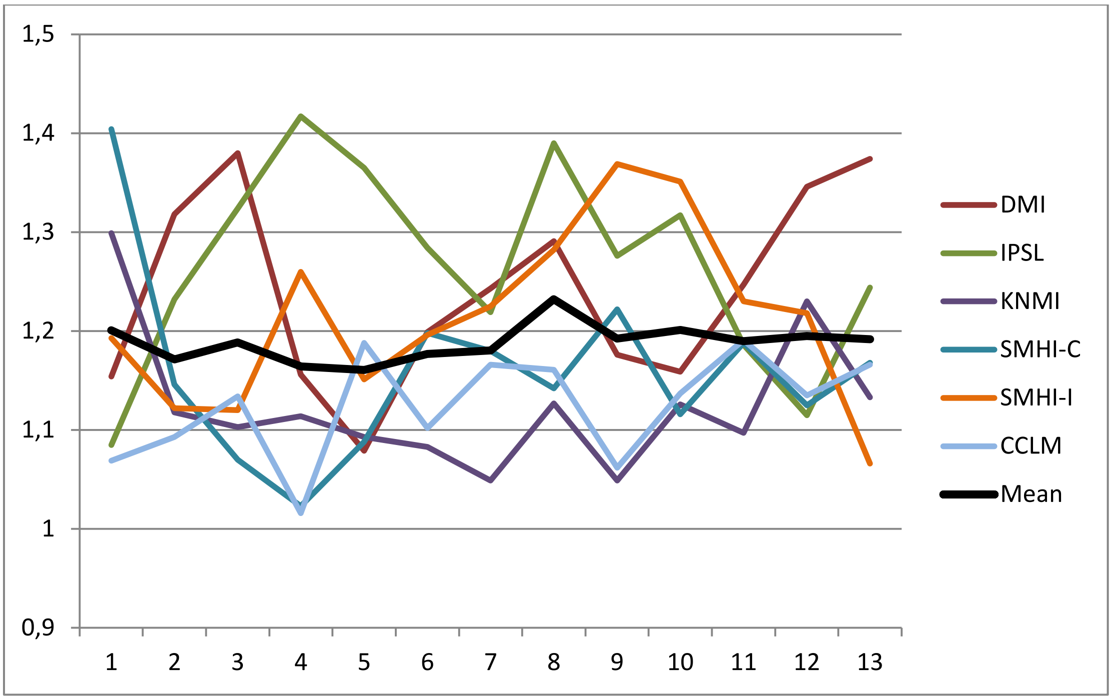


Figure 6.4 *Region-wise and simulation-wise climate factors based on changes in M200 for 3-hourly precipitation. Emission scenario RCP4.5.*

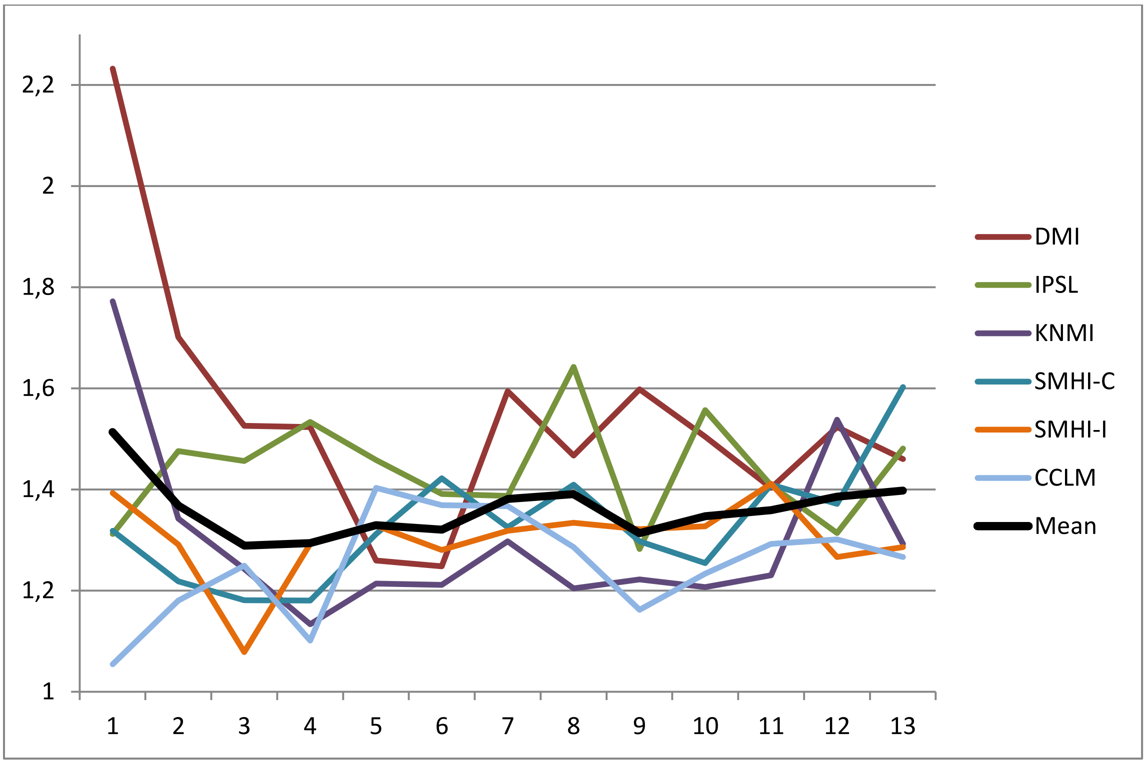
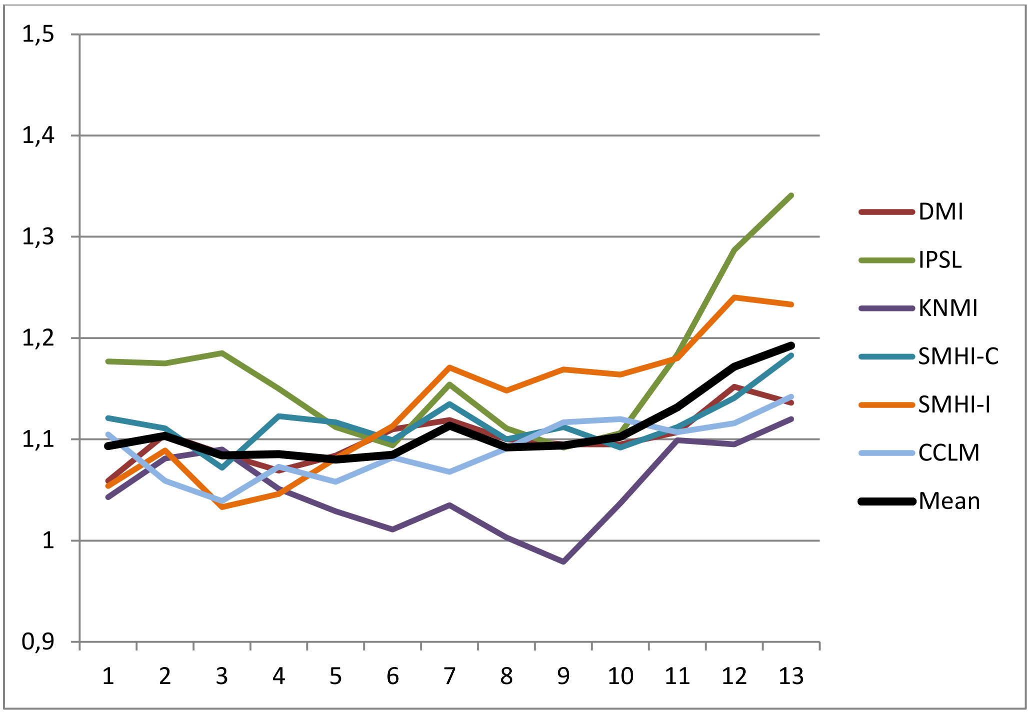
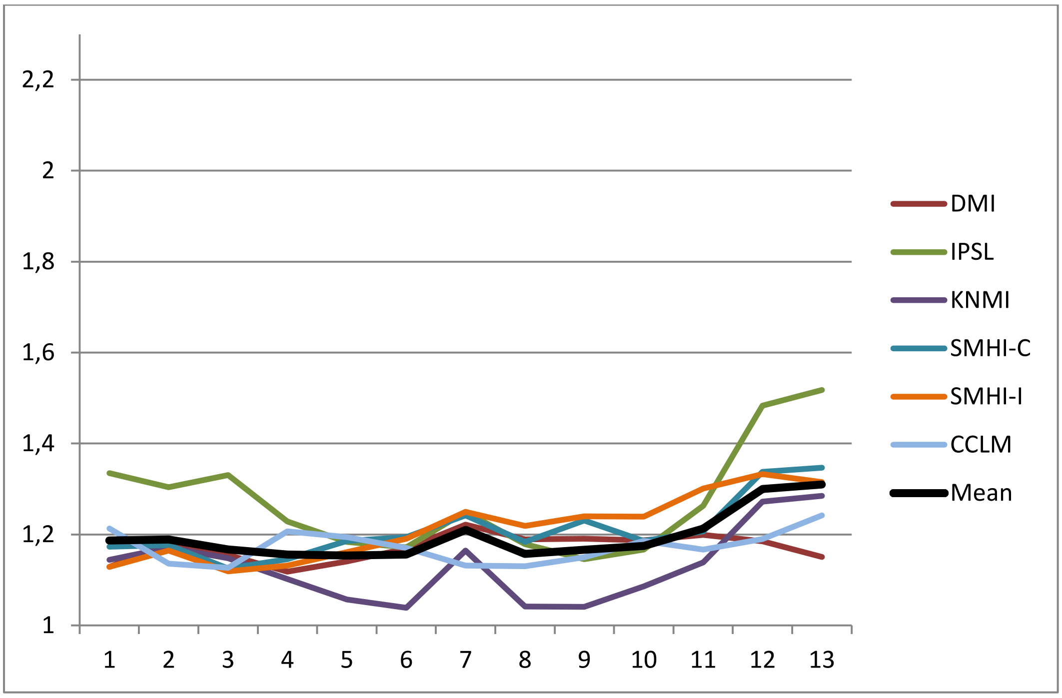


Figure 6.5*. Region-wise and simulation-wise climate factors based on changes in M200 for 3-hourly precipitation. Emission scenario RCP8.5.*



Figur 6.6 *Region-wise and simulation-wise climate factors based on changes in q99.5 for 3-hourly precipitation. Emission scenario RCP4.5.*



Figur 6.7 *Region-wise and simulation-wise climate factors based on changes in q99.5 for 3-hourly precipitation. Emission scenario RCP8.5.*

Table 6.2 *Region-wise climate factors for 3-hourly (black) and daily (orange) precipitation based on simulated changes in q99.5, mean over all simulations and low/high estimate.*

	RCP4.5						RCP8.5					
Region	Mean		Low		High		Mean		Low		High	
1	1.09	1.11	1.04	1.07	1.18	1.21	1.19	1.22	1.13	1.13	1.34	1.37
2	1.10	1.11	1.06	1.04	1.18	1.19	1.19	1.21	1.14	1.15	1.30	1.35
3	1.08	1.08	1.03	1.00	1.19	1.19	1.17	1.17	1.12	1.08	1.33	1.37
4	1.09	1.09	1.05	1.04	1.15	1.20	1.16	1.17	1.10	1.12	1.23	1.29
5	1.08	1.08	1.03	1.03	1.12	1.14	1.15	1.16	1.06	1.07	1.19	1.21
6	1.08	1.08	1.01	1.00	1.11	1.12	1.16	1.16	1.04	1.03	1.19	1.21
7	1.11	1.12	1.04	1.04	1.17	1.17	1.21	1.21	1.13	1.14	1.25	1.28
8	1.09	1.09	1.00	0.98	1.15	1.15	1.16	1.16	1.04	1.05	1.22	1.22
9	1.09	1.09	0.98	0.98	1.17	1.14	1.17	1.17	1.04	1.05	1.24	1.22
10	1.10	1.09	1.04	1.02	1.16	1.14	1.18	1.18	1.09	1.08	1.24	1.22
11	1.13	1.13	1.10	1.10	1.18	1.18	1.21	1.21	1.14	1.15	1.30	1.31
12	1.17	1.18	1.10	1.13	1.29	1.25	1.30	1.30	1.19	1.18	1.48	1.42
13	1.19	1.17	1.12	1.11	1.34	1.27	1.31	1.30	1.15	1.16	1.52	1.48

Table 6.3 *Region-wise climate factors for 3-hourly (black) and daily (orange) precipitation based on simulated changes in M5, mean over all simulations and low/high estimate.*

	RCP4.5						RCP8.5					
Region	Mean		Low		High		Mean		Low		High	
1	1.15	1.08	1.06	0.97	1.24	1.19	1.34	1.24	1.16	1.12	1.65	1.33
2	1.16	1.13	1.06	1.01	1.30	1.24	1.29	1.23	1.15	1.13	1.47	1.36
3	1.14	1.09	1.03	0.97	1.34	1.22	1.23	1.17	1.08	1.11	1.45	1.40
4	1.13	1.10	1.05	1.00	1.36	1.34	1.21	1.19	1.12	1.13	1.38	1.35
5	1.13	1.08	1.09	1.00	1.29	1.19	1.23	1.17	1.13	1.11	1.28	1.26
6	1.15	1.10	1.04	1.01	1.28	1.16	1.25	1.17	1.11	1.03	1.31	1.23
7	1.16	1.13	1.04	1.01	1.26	1.22	1.27	1.23	1.21	1.12	1.44	1.28
8	1.17	1.13	1.05	1.00	1.32	1.21	1.27	1.21	1.16	1.05	1.38	1.30
9	1.16	1.10	0.99	0.91	1.34	1.17	1.23	1.14	1.08	0.99	1.34	1.23
10	1.15	1.11	1.07	1.03	1.26	1.17	1.26	1.18	1.13	1.07	1.39	1.21
11	1.16	1.14	1.09	1.09	1.24	1.18	1.29	1.23	1.19	1.16	1.36	1.28
12	1.18	1.20	1.11	1.13	1.24	1.26	1.34	1.33	1.26	1.16	1.42	1.45
13	1.18	1.21	1.11	1.13	1.29	1.26	1.34	1.33	1.25	1.20	1.50	1.47

Table 6.4 *Region-wise climate factors for 3-hourly (black) and daily (orange) precipitation based on simulated changes in M200, mean over all simulations and low/high estimate.*

	RCP4.5						RCP8.5					
Region	Mean		Low		High		Mean		Low		High	
1	1.20	0.99	1.07	0.85	1.40	1.19	1.51	1.24	1.05	1.02	2.23	1.40
2	1.17	1.10	1.09	0.98	1.32	1.20	1.37	1.27	1.18	1.11	1.70	1.41
3	1.19	1.07	1.07	0.90	1.38	1.33	1.29	1.17	1.08	1.02	1.53	1.47
4	1.16	1.13	1.02	0.97	1.42	1.42	1.29	1.22	1.10	1.11	1.53	1.48
5	1.16	1.06	1.08	0.93	1.37	1.11	1.33	1.20	1.21	1.12	1.46	1.28
6	1.18	1.11	1.08	1.03	1.28	1.18	1.32	1.21	1.21	1.14	1.42	1.29
7	1.18	1.07	1.05	0.92	1.24	1.15	1.38	1.23	1.30	1.06	1.59	1.32
8	1.23	1.18	1.13	1.00	1.39	1.38	1.39	1.29	1.20	1.05	1.64	1.48
9	1.19	1.11	1.05	0.92	1.37	1.25	1.31	1.18	1.16	1.04	1.60	1.37
10	1.20	1.15	1.12	1.10	1.35	1.23	1.35	1.20	1.21	1.08	1.56	1.29
11	1.19	1.15	1.10	1.11	1.25	1.20	1.36	1.27	1.23	1.19	1.41	1.35
12	1.19	1.25	1.12	1.20	1.35	1.43	1.39	1.38	1.27	1.13	1.54	1.51
13	1.19	1.31	1.07	1.26	1.37	1.44	1.40	1.45	1.27	1.19	1.60	1.61

Table 6.5 *Climate factors, mean over the entire country and over all simulations.*

	RCP4.5		RCP8.5	
Index	3-hourly	Daily	3-hourly	Daily
M5	1.16	1.13	1.28	1.22
M200	1.19	1.14	1.38	1.26
q99,5	1.11	1.11	1.20	1.20

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