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Climate indicators for Norwegian travel behaviour; - in present and future climate

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Abstract

Analyses are presented for climate indicators important for every-day travel behaviour. The chosen climate indicators are number of: 1).Hot days, 2). Very hot days, 3). Wet days, 4). Windy days and 5). Days with snow on the ground. Focus areas are the cities Oslo and Stavanger. Results for present-day climate (1971-2000) are based on the MET Norway climate data archives, while projections for future climate (2040-2070) are based on downscaled and tailored data elaborated from regional climate models (EUROCORDEX). The projections for future climate development are calculated for two scenarios for greenhouse gas emission: “Moderate emissions” (RCP4.5) and “High emissions” (RCP8.). To indicate uncertainty, the results for future climate are presented as Mean, Low and High projections.

Keywords
Travel behaviour, climate indicators, projections, Stavanger, Oslo

Disiplinary signature

Responsible signature

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1 Introduction

The ambition of the ClimaMob project is to assess likely impacts of climate change on everyday travel behaviour and implications of these changes for mitigation and adaptation strategies. Transport mode choice varies according to prevalent weather conditions. Climate change projections indicate higher temperature, increase in total precipitation and more frequent and more intense events of heavy rainfall (IPCC, 2013; ; Hanssen-Bauer et al., 2015, 2017). These changes will affect future travel behaviour. However, little research has been conducted to explore how climate change could affect future mobility patterns. In addition, little is known about the social impacts of these changes and the mitigation and adaptation strategies that need to be implemented to avoid non-sustainable mode-choice and mobility patterns up to 2050. ClimaMob project addresses these problems. The main objectives of ClimaMob are: (i) to understand how climate change and resulting direct weather impacts will affect everyday mobility patterns up to 2050, and (ii) to assess implications of these changes for adaptation and mitigation strategies in urban areas.

In the White Paper (St.Meld. St. 26, 2012-2013; National Transport Plan), the Norwegian government states that the projected growth in person transport in larger urban areas should be carried by increased use of public transport, cycling and walking. This calls for a transformation of people's' travel behaviour (Hickman and Banister 2013). Present and future climate is likely to have a major impact on everyday travel behaviour, and this needs to be considered in strategic planning and the development of viable implementation paths. ClimaMob is thus motivated by the need for increased knowledge of how climate change will affect everyday mobility patterns, and in particular mode choice, up to 2050. The scientific evidence on the relation between climate change and human activities has become stronger over time. Thus the latest IPCC-report (IPCC, 2013) states that the evidence for human influence has grown since IPCC (2007), and that it is “extremely likely” (i.e. probability 95–100%) that human influence has been the dominant cause of the observed warming since the mid-20th century. Knowledge of the likely development of “everyday travel behaviour” and how to design effective strategies to reduce person transport related greenhouse gas emissions is crucial in a climate perspective. However, climate change and related direct weather impacts have more far reaching consequences for the sector which also need to be considered, above all how people arrange activities, transport modes and destinations in relation to prevalent and anticipated weather conditions.

Existing knowledge on the relationship between weather conditions and daily mobility has primarily concentrated on the effects of precipitation, temperature or seasonal variations on travel behaviour. In Canada and northern USA, car traffic reductions are reported with snowfall (Datla and Sharma, 2010; Knapp and Smithson, 2000), with rain in Scotland and Australia (Hassan and Barker, 1999; Keay and Simmonds, 2005). Other studies, mainly European, show a positive relationship between precipitation and use of motorized modes, primarily car, and often at the expense of cycling and walking (Böcker et al., 2013b, Aaheim and Hauge, 2007 Bergström and Magnussen, 2003). In general, precipitation has larger effects on leisure trips than on mandatory trips such as commuting to work or grocery shopping (Böcker et al., 2013b). Several studies on the effect of temperature on travel behaviour report a significant reduction of trips by cycling in winter (Fyhri and Hjorthol, 2006; Müller et al., 2006; Bergström and Magnussen, 2003). Other studies look at temperature effects directly, but it seems that temperature has less clear impact on mode choice than precipitation (Böcker et al., 2013). The impact of wind has received less attention, but some studies find that wind negatively affects cycling (Heinen et al., 2011; Aaheim and Hauge, 2005).

The majority of existing research is based on data from countries with different climate conditions than Norway, and none has developed a comprehensive framework of the relationship between weather conditions and travel behaviour and mobility. This research area has only recently emerged imperative in the context of climate change mitigation and adaptation. Based on analyses of survey data, climate change projections, and scenario techniques, ClimaMob will assess measures and policy instruments to adjust/correct the trajectory of travel behavior.

As a part of ClimaMob, Tabin & Rasheed (2017) have studied the relation between travel counts and weather conditions. For this purpose, during one year traffic counts of cars and bikes along various traffic routes in Oslo have been collected. In the analysis, these traffic counts have been associated with weather data from Oslo-Blindern. The analysis was done by using machine learning algorithms. The results demonstrated, not surprisingly; that bike traffic count is more influenced by weather related variables than car traffic. Bike counts seem to be varying strongly with humidity (precipitation) and temperature, while car counts do not show any strong variation with weather.

Norway has experienced substantial climate changes during the latest decades, and projections indicate further changes in the future. The mean annual air temperature in Norway has increased by ca. 1 °C the latest 100 years, and is projected to increase by 2.7 to 4.5°C up to year 2100 (Hanssen-Bauer et al., 2015, 2017). The largest increase is expected in the winter season. Annual precipitation has increased by 18% since year 1900, and is estimated to increase by 8 to 18% up to the end of the century. The projections also indicate more days with heavy rainfall, and increased intensity during heavy rainfall events.During the year, the variation of bike counts is influenced by the typical weather associated with the month, while the monthly car counts are influenced by the vacation periods in the months.

ClimaMob has focused on climate indicators important for present and future weather conditions influencing everyday travel behavior, and particularly on establishing projections of these climate indicators up to 2050. Based on input from WP1 and WP2, the following climate indicators with potential relevance for travel behaviour have been identified:

1. Number of hot days (days with maximum temperature > 25 °C)
2. Number of very hot days (days with maximum temperature > 30 °C)
3. Number of wet days (days with precipitation amount > 5 mm).
4. Number of days with high wind speed
5. Number of days with snow on the ground (more than half the ground covered by snow)

This report deals with analyzing present day status and historic trends for the identified climate indicators; downscaling and tailoring the climate indicators for future climate development in the selected cities (Oslo and Stavanger) and comparative analyses of changes from present to future climate conditions in the selected cities.

2 Data

Description of present day weather conditions and historic climate development are based on the climate data archives of MET Norway. Projections for future climate are based on the global climate model simulations for IPCC's Fifth Assessment Report (IPCC, 2013). The global models have a rather coarse resolution in time and space. To give more realistic projections on regional and local scale, the results in this report are based on downscaled regional climate model simulations from the EURO-CORDEX initiative.

2.1 Observations

Historical climate data for Oslo are based on observations from the weather stations Oslo-Blindern (MET station no. 18700) and Gardermoen (airport outside Oslo, st.no. 04780). For Stavanger, observations from Sola airport (MET st.no. 44560) are used. These three weather stations have been operational for a long time and the observations have a high quality.
For data on snow and wind the stations Særheim (MET st.no 44300), Stavanger-Våland (MET st.no 44640) and Tryvannshøgda (MET st.no 18950) have also been studied.
Figure 2.1 shows the positions of the different weather stations.

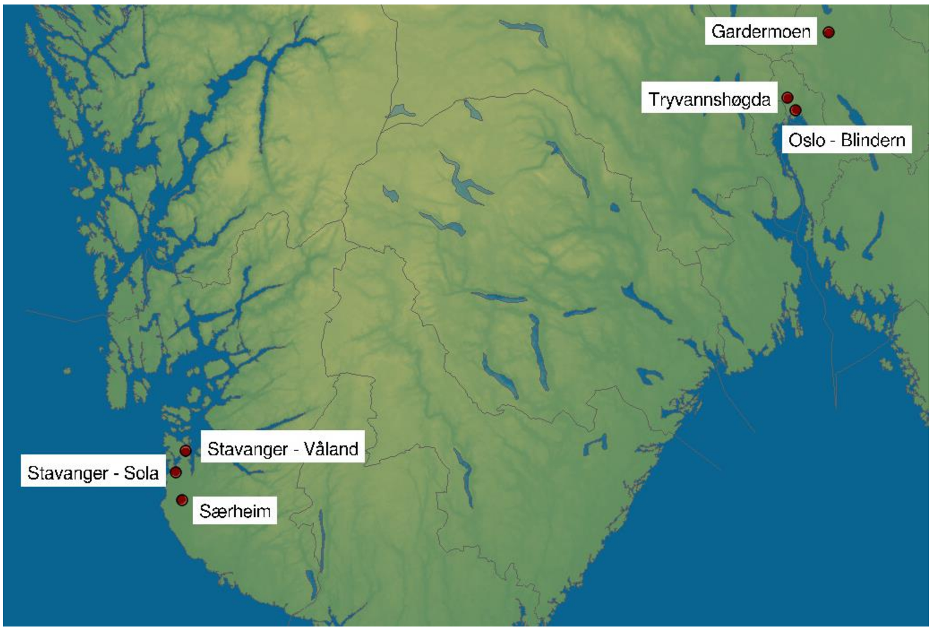


Figure 2.1 Map over the weather stations.

2.2 EURO-CORDEX projections

CORDEX (Coordinated Regional Climate Downscaling Experiment) is an international cooperation where the goal is to make regional climate model data available for climate studies. All CORDEX-models cover a minimum of the period 1970-2100, and there are projects for all continents.

Within Euro-CORDEX (http://www.euro-cordex.net/), global simulations are downscaled for Europe using regional climate models with spatial resolution of 12x12 km^2 and 50x50 km^2. Because of Norway's rugged topography, only the 12x12 km^2 resolution is used for detailed climate projections for Norway (Hanssen-Bauer et al., 2017). In Norway, daily values for temperature and precipitation for two different emission scenarios (RCP4.5 and RCP8.5) for ten climate projections have been post-processed and bias-adjusted from 12x12 km^2 resolution to a grid of 1x1 km^2. More details are presented by Hanssen-Bauer et al (2015) and at www.klimaservicesenter.no. For this report, data for temperature and precipitation have been prepared from NVE (The Norwegian Water Resources and Energy Directorate).

2.2.1 Emission scenarios

To describe future climate development, global climate models are run for different emission scenarios. In IPCC (2013), emission scenarios for greenhouse gases and aerosols are described by so-called "Representative Concentration Pathways, RCPs", The EURO-CORDEX downscaling just comprised two simulation for the lowest (and unfortunately probably too optimistic) emission scenario RCP2.6, and thus it was not possible to estimate representativeness nor uncertainty for this emission scenario. For each of the two emission scenarios; RCP4.5 and RCP8.5, ten regional climate model simulations were available, and thus most projections for Norway are based on these emission scenarios (Hanssen-Bauer et al., 2015, 2017). In a white paper on climate adaptation for Norway, the government states that "to be prepared" the high alternative for national climate projections should be used when consequences are evaluated. Thus for climate adaptation in Norwegian counties ("klimaprofiler", www.klimaservicesenter.no), emission scenario RCP8.5 is highlighted.

RCP4.5: Moderate emission
Stable/some increasing emission to 2040, then decreasing emission
In RCP4.5 the concentrations of greenhouse gases in the atmosphere will increase towards 2060, but will stabilize in the end of the century. This scenario depends on substantial reduction in emission of greenhouse gases. The emissions can increase slightly during the next few decades, but must decrease from 2040. From 2080 the emissions must stabilize at a level of 40% of the emissions in 2012. This scenario can be possible in an energy-effective world with ambitious climate politics in most countries. On global scale, for this scenario an increase in temperature of 2.5 ^{o}C is estimated for the end of this century, relative to 1850-1900.

RCP8.5: High emission
Continuous increase in emission of greenhouse gases
This scenario has high emission, it is often called 'business as usual'. This is because the increase in emission of greenhouse gases follows the same development as we have seen the latest decades. In this scenario the CO_2 emissions will triple within 2100, in addition to a rapid increase in emission of methane. On global scale the temperature is estimated to increase with more than 4 ^{o}C at the end of this century, relative to 1850-1900. In this scenario the concentration of greenhouse gases in the atmosphere, and the global mean temperature, will continue to increase after year 2100.

2.3 Uncertainties

Projections of future climate development are hampered by several sources of uncertainties. Hanssen-Bauer et al (2015) has listed three main categories of uncertainties:

- Uncertainties related to future human emission of greenhouse gases
- Uncertainties linked to natural climate variations (e.g. volcanoes and solar radiation)
- Uncertainties in climate models (incomplete understanding of the climate system and limited computing capacity for numerical calculations)

There is also uncertainty in the downscaling and post processing of the data from the global model runs to a much finer grid.

It is therefore important to remember that with ten climate model simulations and two emission scenarios we have predictions of a possible future, but we have to take the uncertainties into account.

Even for a given emission scenario (RCP), we cannot with certainty calculate how the climate will develop, partly because we do not know the climate system's sensitivity. IPCC (2013) uses the spread in ensembles of model calculations under the same RCP as a measure of uncertainty. As mentioned above, there are several sources of uncertainty in model calculations, and we have no guarantee that the spread in model calculations is representative of the real uncertainty. We consider, however, that the spread within ensembles of model calculations carried out for the same RCP is the best measure of uncertainty we currently are able to provide.

The report “Climate in Norway 2100”, Hanssen-Bauer et al (2015, 2017) used ensembles to estimate future climate change. For meteorological and hydrological variables, they presented the results from ensembles for a given RCP as median value (MED), 10-percentile (LOW) and 90 percentile (HIGH). The median implicates that there are as many projections with greater climate change values larger than the median as projections with lower values. Low and high projections (10- and 90-percentiles) are defined such that 10 percent of the simulations have lower (10-percentile) or greater value (90th percentile). Accordingly, 80 percent of the climate simulations have values between the high and low projections. In this report the High and Low is the highest value and the lowest value of the model runs, they are used as estimate of the model uncertainties.

3 Methods

The climate at a specific location is usually described by mean values and variations around these (Hanssen-Bauer et al., 2015). A common concept in climatology is "standard normals," which refers to the average values over specified 30-year periods (www.wmo.int). In today's digitized world it is customary to calculate normals also for other 30-year periods. In this report we are comparing two 31-years periods to identify changes. A period representing present day climate (reference period 1970-2000) is compared to a period representing projected climate in the middle of the century (scenario period 2040-2070). In the following chapters, the period 1970-2000 is often called “2000”, and the period 2040-2070 is called “2050”. To estimate changes from present-day to future climate, the period 2050 is compared with 2000 for two emission scenarios (RCP4.5 and 8.5, cf. ch. 2.1.1).

For some of the identified climate indicators, maps are produced for the whole of Norway. For the areas in focus (Oslo and Stavanger), tailored data for the ClimaMob indicators (ch. 1) are established and analysed. The methods used for subtracting results for the different indicators are described below. For establishing projections for number of hot days and very hot days, different methods have been evaluated.

4 Hot days and very hot days

The discussions in ClimaMob WP1 and WP2 indicated that the everyday travel behavior during summer might be influenced by high daytime temperatures. Accordingly two temperature indicators were identified to describe present and future “hot weather” in Norway:

1. Number of hot days (days with maximum temperature > 25 °C)
2. Number of very hot days (days with maximum temperature > 30 °C)

For present-day climate, maximum temperature is recorded at all MET’s weather stations. For the selected stations Oslo-Blindern, Gardermoen and Stavanger (Sola), long historical climate series are available. Unfortunately, for future climate, the available downscaled projections do not include local values of maximum temperature. However, projections of daily mean temperature are downscaled down to 1x1 km spatial resolution and are thus available for grid points close to the three selected sites. To get a measure of high maximum temperatures, the project had to develop relationships between mean daily temperature and daily maximum temperature. Figure 4.1 demonstrates that the highest number of “warm days” (mean temperature exceeding 20 °C) during present climate is found in Southeastern Norway.

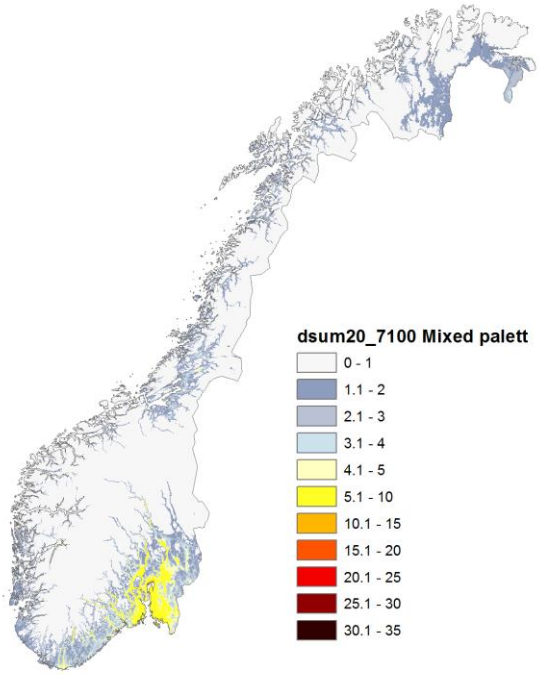


Figure 4.1 Average number of days with mean temperature exceeding 20 °C during 1971-2000 (From Hanssen-Bauer et al., 2017)

4.1 Mean and maximum temperatures in Oslo and Stavanger

4.1.1 Present conditions for mean and maximum temperatures

Mean temperatures for each month based on observations at Oslo-Blindern, Oslo Airport (Gardermoen) and Stavanger Airport (Sola), are given in Table 4.1. Here we see that the stations near Oslo have lower mean temperature during winter than Stavanger, but higher temperature during summer. At Oslo (Gardermoen), the mean temperature is above 0 °C from April to October; at Oslo-Blindern from March to November, and at Stavanger (Sola) all the year. This is because Stavanger is near the coast and has a milder and more moist climate. The coastal areas are affected by the warmer ocean during winter.

Table 4.1 Observed monthly mean temperature during 1970-2000

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Oslo-Blindern	-3.3	-3.2	0.4	4.8	11.0	14.9	16.8	15.7	11.0	6.3	1.2	-2.1	6.1
Oslo (Garderm.)	-6.0	-6.1	-1.6	3.1	9.8	13.8	15.7	14.3	9.3	4.6	-1.0	-4.7	4.3
Stavanger (Sola)	1.6	1.2	3.0	5.7	10.1	12.7	14.5	14.7	11.7	8.7	4.9	2.7	7.6

Mean monthly maximum temperature is higher in Oslo (Blindern) than Stavanger from May to September, Table 4.2. The mean maximum temperature in Oslo is higher than 20 °C for June, July and August, while in Stavanger no months have mean values exceeding this threshold.

Table 4.2 Observed monthly average maximum temperature during 1970-2000

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Oslo-Blindern	-0.9	-0.1	3.9	9.3	16.4	20.0	21.9	20.6	15.1	9.1	3.4	0.3
Oslo (Garderm.)	-2.8	-2.0	2.7	8.1	15.7	19.4	21.3	19.9	14.3	8.1	1.9	-1.4
Stavanger (Sola)	3.8	3.9	6.0	9.5	14.3	16.6	18.2	18.3	15.0	11.4	7.2	5.0

Table 4.3 shows that maximum temperatures exceeding (or close to) the hot day definition of 25 °C have occurred in Oslo and Stavanger in all months from April to September. Very hot days, with maximum temperatures exceeding 30 °C are experienced in the Oslo region both in June, July and August; and in Stavanger in July and August.

Table 4.3 Observed highest maximum temperature during 1970-2000

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Oslo-Blindern	12.5	13.7	17.0	**25.4**	**27.7**	**32.2**	**31.3**	**34.2**	**26.4**	19.5	14.4	12.5
Oslo (Garderm.)	10.8	12.4	16.4	**24.3**	**26.8**	**32.3**	**31.5**	**32.6**	**25.7**	20.1	13.6	11.6
Stavanger(Sola)	12.4	10.6	16.7	**25.2**	**26.5**	**28.4**	**30.9**	**33.5**	**24.8**	20.6	14.5	11.4

4.1.2 Projected changes in mean temperature

Figure 4.2 shows projected changes in mean temperature for July from 2000 to 2050 for the high emission scenario (RCP8.5). Similar maps for changes in mean temperature for January, April and October are presented in Appendix 11.1. The largest increase (darker red in the map) in summer temperatures is found in the northernmost part of Norway. (The seemingly isolated high warming in a few local spots in SE-Norway is fictitious).

For the moderate emission scenario (RCP4.5) the projected changes in mean temperatures for grid points in the Oslo and Stavanger areas (Table 4.4) indicates a warming June, July and August of ca. 1.5 °C. For the high emission scenario (RCP8.5, Table 4.5) the projected summer warming in Stavanger is ca. 1.7 and in Oslo ca. 2.0 °C. Estimates of uncertainties (low and high projections; section 2.2) are presented in Appendix 11.1.

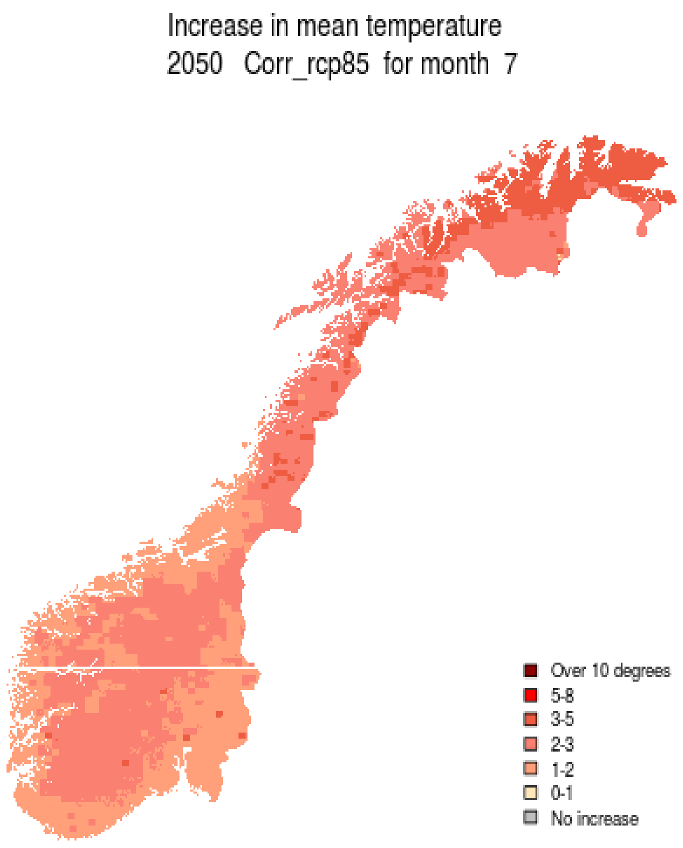


Figure 4.2 Changes in mean July-temperature (°C) from 2000 to 2050 for RCP8.5.

Table 4.4 Projected changes (°C) in monthly and annual mean temperatures from 2000 to 2050 under emission scenario RCP4.5

Location	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Year
Stavanger-Sola	1.3	1.7	1.6	1.4	1.4	1.3	1.3	1.4	1.4	1.5	1.8	1.7	1.5
Oslo-Blindern	2.1	2.4	2.4	2.2	2.0	1.4	1.5	1.6	1.7	1.7	2.1	2.3	1.9
Gardermoen	2.1	2.4	2.3	2.2	2.0	1.4	1.5	1.6	1.7	1.8	2.2	2.3	2.0

Table 4.5 Projected changes (°C) in monthly and annual mean temperatures from 2000 to 2050 under emission scenario RCP8.5

Location	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Year
Stavanger-Sola	1.8	2.3	2.3	1.9	1.6	1.8	1.5	1.8	2.1	2.4	2.0	2.1	2.0

Oslo-Blindern	2.9	3.4	3.3	3.0	2.4	2.1	1.9	2.6	2.4	2.7	2.5	2.9	2.6
Gardermoen	2.9	3.3	3.1	3.0	2.4	2.1	2.0	2.2	2.4	2.8	2.7	2.9	2.6

4.2 Relations between mean daily temperature and maximum temperature

Daily maximum temperature is needed to calculate number of “hot days” (days with maximum temperature > 25 °C) and “very hot days” (days with maximum temperature > 30 °C). As mentioned above, maximum temperature is recorded at METs weather stations in Norway, but is not available in the downscaled (1x1 km) datasets for future climate. Accordingly, measures for future occurrence of “hot days” and “very hot days” had to be based on downscaled values of daily mean temperature instead of maximum temperatures. Two different strategies were used to deduce number of hot days / very hot days from series of daily mean temperatures; see ch. 4.2.1 and 4.2.2.

4.2.1 Threshold values for mean temperature during hot days and very hot days

Comprehensive analyses (see Appendix 11.1) were performed to identify thresholds of mean daily temperature best suited to describe number of days with maximum temperature exceeding 25 and 30 °C.

Figure 4.3: Optimal threshold (°C) for daily mean temperature to describe number of hot days (maximum temperature >=25 °C) for selected weather stations in Southern Norway.

Figure 4.3 indicates that for Southern Norway there are regional differences in distribution of threshold values for optimal daily mean temperature as indicator for maximum temperature exceeding 25 °C. In inland mountainous areas the threshold value is found to be 17-18 °C, in other inland regions 18-19 °C; in coastal areas 19-20 °C, and at the coast line 20-22 °C. The reason for this geographical pattern is that the daily temperature amplitude at the coastal stations is reduced because of the neighbourhood to the sea. Thus the difference between daily maximum and daily mean temperature usually is rather low. At the inland stations, the minimum temperatures at warm days (for clear days with low wind speeds), are rather low because of negative radiation budget and thus strong cooling during the night. Accordingly, the amplitude maximum-minimum temperatures are usually high, causing larger difference between daily maximum and daily mean temperatures.

For very hot days, the threshold value for mean temperature is mainly in the interval 21 to 25 °C. Also for this indicator the general features are lowest values in inland areas and highest values are found along the coast and fjords (see Figure 11.4 in Appendix 11.1).

4.2.2 Correlation between hot days and mean daily temperature

For Oslo (Blindern and Gardermoen) the optimal daily mean temperature threshold value for hot days was found to be 19.0 °C and for Stavanger 19.5 °C, cf. section 4.2.1. Figure 4.4-4.6 demonstrate that there is a strong relationship between annual number of hot days (TAX>25 °C) and number of days with mean temperature (TAM) exceeding 19.0 resp. 19.5 °C. The relationship between number of hot days (N_{TAX}) and number of days with mean temperature (N_{TAM}) exceeding the defined thresholds may be described by regression lines:

Eq. 4.1:
Oslo-Blindern (TAM >= 19.0 °C): Regression line: $N_{TAX}=0.83*N_{TAM} + 1.8$ ($R^2 = 0.86$)

Eq. 4.2:
Oslo (Garderm.) (TAM≥= 19.0°C): Regression line: $N_{TAX}=1.023*N_{TAM} + 1.4$ ($R^2=0.90$)

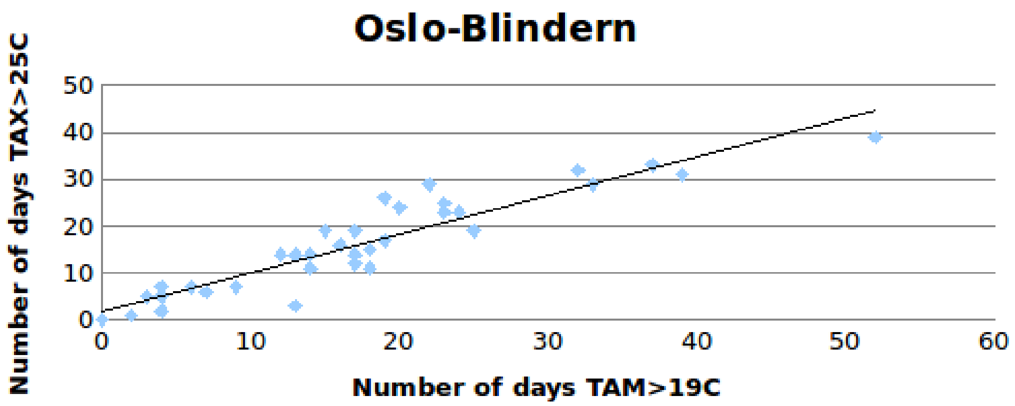
Eq. 4.3:
Stavanger (Sola) (TAM >= 19.5°C): Regression line: $N_{TAX}=0.80*N_{TAM} + 0.4$ ($R^2 = 0.82$)

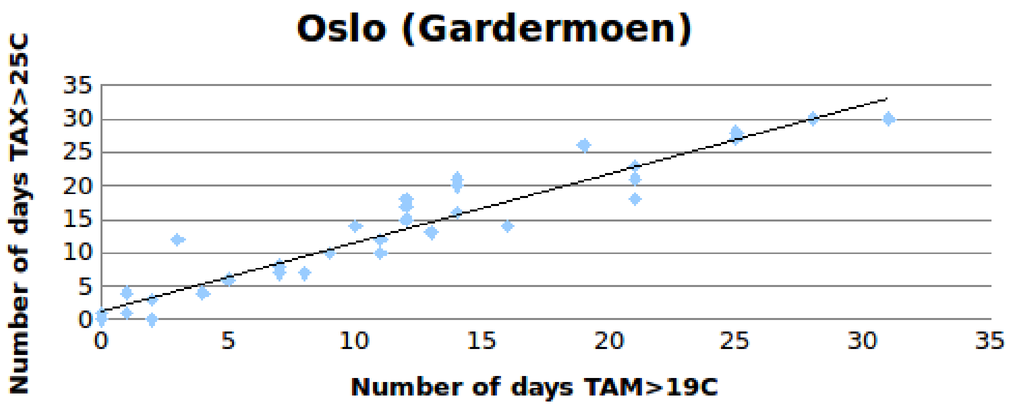
For Oslo (Gardermoen) the variance (R**2) is 0.90 indicating that 90 % of the variability in annual number of hot days may be explained by mean daily temperature. Also for Oslo-Blindern and Stavanger (Sola) these regressions may explain more than 80 % of the variability in annual number of “hot days”.

By assuming that these regressions also are valid in a future climate; eq. 4.1 – 4.3 may be used to deduce projections of number of hot days (N_{TAX}). As mentioned above, the available downscaled projections do not include local estimates of daily maximum temperature i.e. for

Oslo or Stavanger. However, the 1x1 km projections of daily mean temperature (TAM) may be used to estimate number of days (N_{TAM}) with TAM exceeding the thresholds of 19.0 or 19.5C. By inserting projections of N_{TAM} in eq. 4.1 - 4.3, these regressions may be used to get estimates of future number of "hot days" (N_{TAX}). The results are presented in Table 4.8 and 4.9.

Under present climate, the number of "very hot days" is rather low in all parts of Norway. Based on the application of the detection methodology, it was decided to use the same threshold value (TAM>=22.5 °C) for both Stavanger and Oslo to get measures of days with maximum temperature exceeding 30 °C.





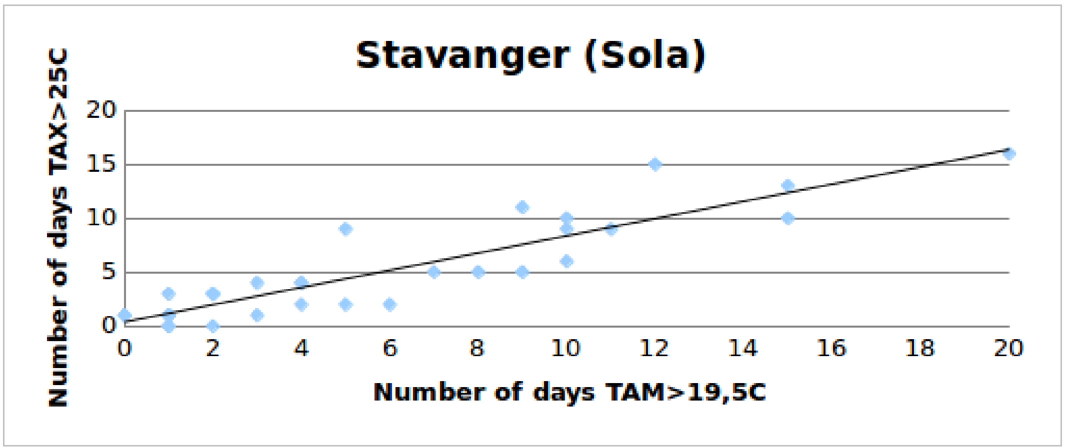


Figure 4.4 Co-variation during 1981-2015 between number of hot days (TAX>25 °C) and days with mean temperature (TAM) exceeding threshold temperatures (19.0 °C for the Oslo stations, 19.5 °C for Stavanger (Sola)

4.3 Number of hot days and very hot days

4.3.1 Present conditions for hot and very hot days

During the reference period 1971-2000, Oslo-Blindern had in average 16 hot days per year, while the similar number in Stavanger (Sola) was just 4 days per year (Table 4.6). At both locations most hot days occurred during May to August, but with a few cases also in April and September. In Oslo, July had the highest frequency, and in Stavanger July and August.

Table 4.6 Mean annual number of hot days (maximum temperature ≥25 °C) during 1970-2000

Location	Apr	May	June	July	Aug	Sep	Total
Oslo –Blindern	0.1	0.9	4.6	6.4	3.9	0	16.0
Oslo (Gardermoen)	0	0.5	3.8	5.7	3.4	0.1	13.5
Stavanger (Sola)	0.1	0.3	0.8	1.4	1.5	0.0	4.2

Number of very hot days is very low in Norway, Table 4.7. In the Oslo region, in average just one day per year qualify as a very hot day; - in Stavanger such days occur in average just every third year. August has the highest occurrence of very hot days; and the main season is June-August.

Table 4.7 Mean annual number of very hot days (max. temperature ≥30 °C) during 1970-2000

Location	May	June	July	Aug	Sep	Total
Oslo –Blindern	0	0.3	0.4	0.5	0	1.1
Oslo (Gardermoen)	0	0.2	0.2	0.4	0	0.8
Stavanger (Sola)	0	0	0.1	0.2	0	0.3

Tables 4.6 and 4.7 present 30 year averages, but it is important to note the large variations from year to year. At Oslo-Blindern, the summer of 1997 brought nearly 40 hot days (black line in Figure 4.5), while some years had less than 5 hot days. In Stavanger, a few years had more than 10 hot days, while in some years there were no hot days. Figures 4.5 and 4.6 illustrate the rather high covariation between number of hot days and days with mean temperature over different thresholds.

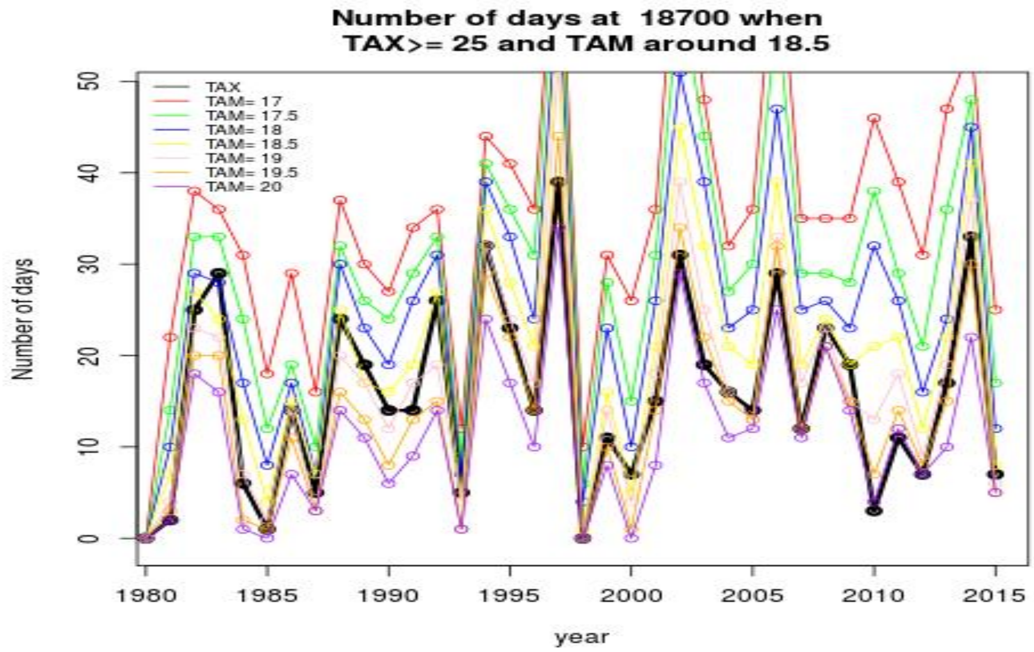


Figure 4.5. Oslo-Blindern 1980-2015. Observed number of hot days (TAX ≥ 25 °C) and number of days with mean temperature (TAM) exceeding different thresholds in the interval 17 to 20 °C.

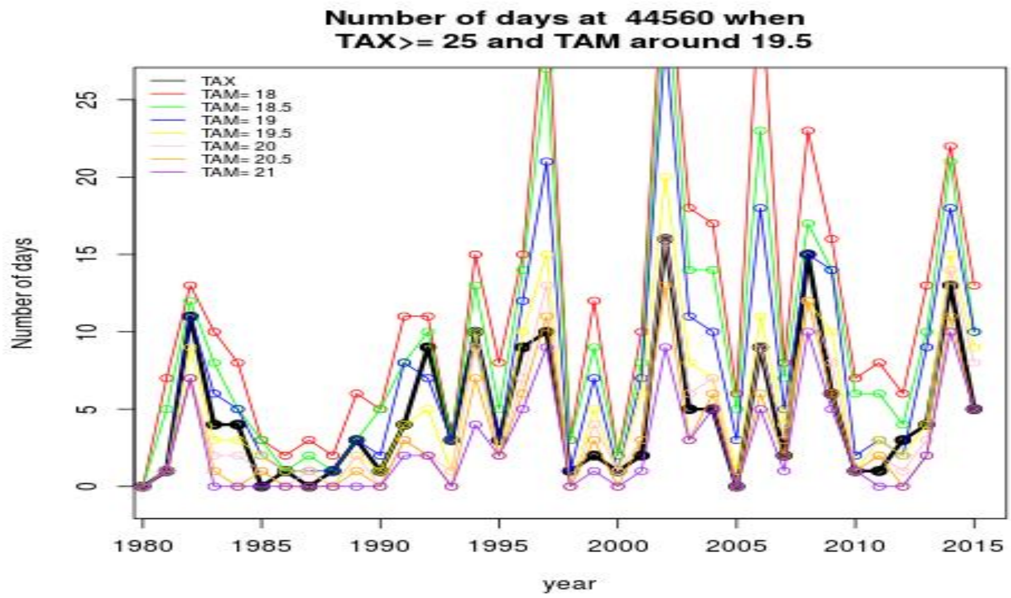


Figure 4.6: Stavanger (Sola) 1980-2015. Observed number of hot days (TAX ≥ 25 °C) and number of days with mean temperature (TAM) exceeding different thresholds in the interval 18 to 21 °C.

4.3.2 Projections of hot days and very hot days up to 2050

Figure 4.7 shows the increase in hot days from 2000 to 2050 for high emissions, RCP8.5, for the months May, June, July and August. The figures show a distinct geographical distribution, where the areas near the coast and valleys in southern Norway, and particularly southeastern Norway, are likely to have a substantial increase in number of hot days.

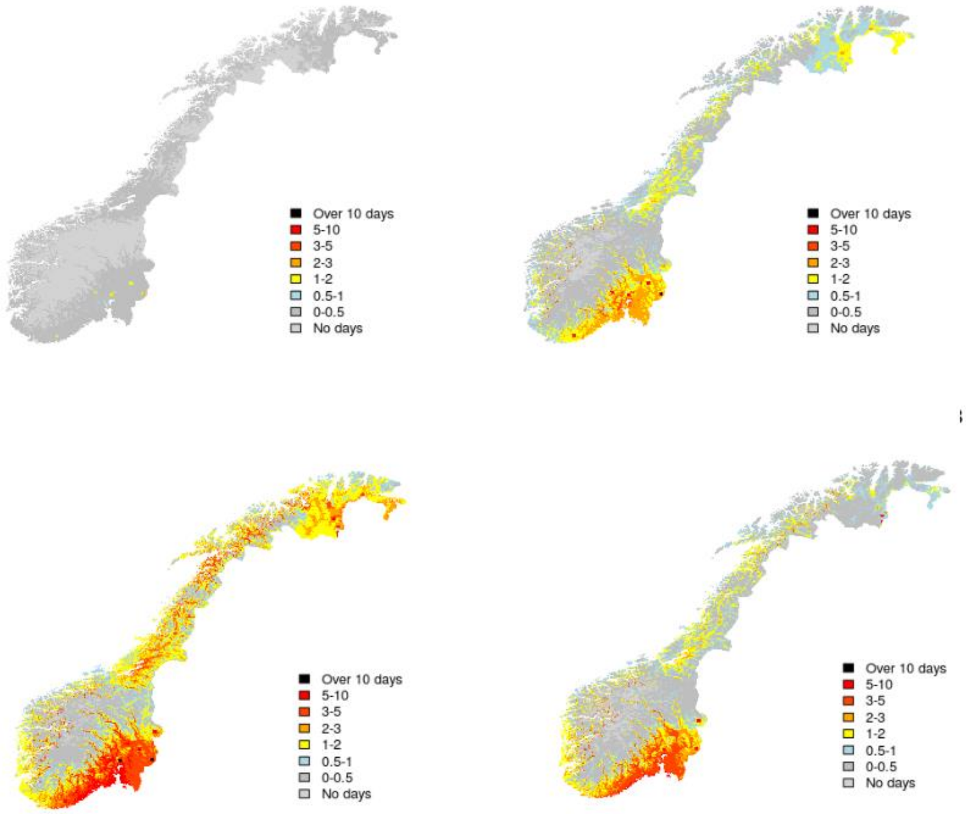


Figure 4.7 Increase in number of "hot days" from 2000 to 2050 for emission scenario RCP8.5. Upper left: May; Upper right: June; Bottom left: July and Bottom right: August.

One of the erroneous "hot spots" (cf. section 4.1.2) in the 1x1 km projection in Figure 4.7 is influencing the projections for the Oslo-Blindern location. Thus we have below used data for the location Gardermoen as indicator for future number of hot days in the Oslo-region. Complete tables, including values for Low and High projections for the two Oslo locations as well as for Stavanger are presented in Appendix 11.1

As outlined in section 4.2, number of days with mean temperature TAM>=19.0 °C was found to be a good indicator of number of days with maximum temperature exceeding 25 °C ("hot days") in Oslo. For Stavanger the optimal threshold value was TAM >= 19.5 °C. One approach for estimating number of hot days in the future is thus to assume that the increase in number of hot days (NTAX) is identical to the increase in number of days with mean temperature exceeding the threshold values (NTAM). Projected increase in number of hot days by assuming that NTAX=NTAM is shown for the months May-September and for annual values in Table 4.8.

Another approach is to apply the regressions developed in section 4.2.2. For e.g. RCP4.5 for Gardermoen during 1970-2000, the number of days with mean temperature exceeding 19.0 °C (NTAM) was 10.0 days (table 4.9 first column). Inserting NTAM=10.0 in eq. 4.2 gives an estimate of 11.6 for NTAX (second column in Table 4.9), while the observed value is 13.5 (third column in Table.4.9). Up to 2050 NTAM increases by 8.1 days (Table 4.9) to a total of 10.0 + 8.1 =18.1 days.

Inserting NTAM=18.1 in eq.4.2 gives an estimate for NTAX of 19.9 days, i.e. an increase of 19.9-11.6 = 8.3 days (right column in Table 4.8). As the observed value of NTAX is 13.5 days; the estimate for NTAX in 2050 is thus 13.5 + 8.3 = 21.8 days. Similar calculations were performed also for RCP8.5 and for Stavanger area.

The two rightmost columns in Table 4.8 shows the increase up to 2050 in annual number of hot days based on these two methods. Both methods show similar results. For Stavanger area the annual increase in number of hot days for RCP4.5 is 2-3 days and for RCP8.5 3-4 days: For Oslo area the similar number are 8 days (RCP4.5) and 12 days (RCP8.5).

Table 4.8 Increase from 2000 to 2050 in number of hot days (NTAX) based on number of days with TAM exceeding threshold values (NTAM) and regression equations 4.2 and 4.3 (REGR).

			NTAX=NTAM						REGR
Location	Emission	Threshold	May	June	July	Aug	Sep	Annual	Annual
Oslo (Garderm.)	RCP4.5	19.0 C	0.3	1.6	3.9	2.1	0.2	8.1	8.3
Oslo (Garderm.)	RCP8.5	19.0 C	0.4	2.6	5.1	3.5	0.4	11.9	12.2
Stavanger (Sola)	RCP4.5	19.5 C	0.1	0.5	1.4	1.0	0.1	3.0	2.4
Stavanger (Sola)	RCP8.5	19.5 C	0.1	0.7	1.3	1.5	0.2	3.8	3.0

Thus, for Oslo (Gardermoen area) the number of hot days is projected to increase from the present 13.5 days per year to ca. 22 days/year for the low emission scenario (RCP4.5), and to ca. 26 days/year for RCP8.5 (Table 4.9). For Stavanger area there will still be rather low frequencies of “hot days”: ca. 7 days/year for RCP4.5 and 8 days/year for RCP8.5.

Table 4.9 Number of hot days (NTAX) in present climate (observed 1971-2000) and projected for 2050 based on number of days with mean temperature exceeding threshold values (NTAM) and regression equations 4.2 and 4.3 (REGR)

	1970-2000			2050			
				RCP4.5		RCP8.5	
Element	NTAM	NTAX	NTAX	NTAX	NTAX	NTAX	NTAX
Method	(OBS)	(REGR)	(OBS)	(NTAM)	(REGR)	(NTAM)	(REGR)
Oslo(Garderm.)	10.0	11.6	13.5	21.6	21.8	25.4	25.7
Stavanger(Sola)	3.6	3.3	4.2	7.2	6.6	8.0	7.2

For very hot days, the increase from 2000 to 2050 is rather modest (see Appendix Table 11.5.). For the highest emission scenario (RCP8.5), the increase in number of very hot days in Stavanger (Sola) is in average 0.5 days per year and for Oslo (Gardermoen) 2 days per year. Thus, by comparing with table 4.3.2, the conclusion is that also in 2050 there will be very few very hot days per year both in Stavanger (in average 1 per year) and in Oslo (in average 3 per year).

5 Wet days

There are substantial differences in precipitation conditions between Oslo and Stavanger, concerning total rainfall, extreme values as well as number of wet days. Stavanger, on the southwestern part of Southern Norway, is strongly affected by the lows coming from west with moist air. While Oslo, in the southeast of Norway, can get more precipitation with winds from southeast and with heavy convective precipitation during summer. There is a seasonal difference in the precipitation amount at the two different locations.

5.1 Total precipitation and extreme values

At the two Oslo stations the normal of the total annual precipitation is around 800 mm (Table 5.1), while Stavanger has around 1200 mm per year. In Stavanger the wettest months (ca. 140 mm/month) are September – November. At the Oslo stations, all months from July to November have monthly amounts around 80 to 90 mm/month. In late spring (April – June) there are just small differences in total rainfall amounts between Oslo and Stavanger.

Table 5.1 Mean precipitation (mm) in Oslo and Stavanger during 1970-2000.

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Oslo-Blindern	50	36	52	43	44	68	78	87	85	83	79	53	757
Oslo (Garderm)	58	45	58	48	54	75	76	82	87	92	90	62	826
Stavanger (Sola)	103	83	82	54	60	69	85	113	140	149	138	122	1199

Maps showing projected changes in mean precipitation for Norway for emission scenario RCP4.5 for the months January, April, July and October are presented in Appendix 11.2. The maps demonstrate e.g. that during July a substantial increase in rainfall is projected for the northern part of the country, while a decrease is projected for the southernmost part.

Detailed projections for changes in monthly and annual precipitation in Oslo and Stavanger are presented in Appendix 11.2. The projections are presented both as absolute values (in millimetres, Table 11.6) and as percentages (Table 11.7) for both RCP4.5 and RCP8.5.

For the Stavanger-area, the highest increase is found for winter and spring, while the lowest increase is in the autumn. In RCP8.5 the increase in autumn is 0-5%, while during spring there is an increase up to 16% in mean precipitation. Also for the Oslo-area the highest increase is found for winter and spring, while in late summer and autumn there is small increase or even a decrease. During winter and spring the scenario with high emission shows an increase of 15-20% in mean precipitation.

Days with heavy rainfall will increase both in intensity and frequency (Hanssen-Bauer et al., 2015). For the Oslo area, the intensity for 1-day rainfall will increase by ca. 10 % for the high emission scenario (RCP8.5), while the similar value for the Stavanger area is ca. 6 %. Førland et al (2015) found indications that for heavy rainfall the increase is higher for more extreme events (long return periods) and for shorter durations (a few hours).

5.2 Number of days with precipitation

The ClimaMob-surveys (e.g. Tabib & Rasheed, 2017) revealed that humidity (precipitation) is important for travel behavior, cf. ch. 1). During discussions within the project it was decided to apply a threshold of 5 mm precipitation per day as definition of a “wet day”.

Table 5.2 Observed number of wet days (≥ 5 mm) during 1970-2000

Location	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Year
Oslo Blindern	3.7	2.4	4.0	2.9	3.2	4.7	4.8	5.6	5.3	5.7	5.5	4.0	51.9
Oslo (Garderm)	4.0	3.1	4.6	3.4	3.8	5.2	5.1	5.2	5.4	5.9	6.5	4.7	56.9
Stavanger (Sola)	8.1	6.0	6.0	3.9	3.9	4.8	5.9	7.2	9.5	9.7	10.1	8.6	83.6

Table 5.2 shows that in present day climate (1970-2000) Stavanger has in average 84 wet days a year, while Oslo-Blindern has 52 days. This means that in Stavanger the travelers have “wet conditions” in 25 % of the days each year, and in Oslo 15 % of the days. In Stavanger the wet day frequency is lowest (ca. 4 days per month) in April and May, i.e. for the months with lowest total rainfall (Table 5.1). Highest frequency is observed in September to November; - the months with highest total rainfall. Also in Oslo the lowest frequency is found in the month with lowest total precipitation (February). In this month there is just 2 to 3 “wet days”. During the period from June to November there are 5-6 days per month with rainfall ≥5 mm.

Downscaled projections (section 2.1) are used to illustrate future changes in number of wet days, both for the entire Norway (figure 5.1) and for the three selected locations (Table 5.3). For Oslo and Stavanger, detailed surveys of projected changes in wet days are presented in Table 11.9 in Appendix 11.2. These tables outline monthly and annual changes from 2000 to 2050 for high, median and low projections under emission scenarios RCP4.5 and RCP8.5. A summary of table 10.2.4 is presented in table 5.3. Both for Stavanger and Oslo, projections based on emission scenarios RCP4.5 as well as RCP8.5 indicate an increase of 2 to 3 wet days per year from 2000 to 2050. Compared to the present level (Table 5.2) of wet days, these changes are minor. The largest increase is projected for the period December to May, and for the Oslo-area this may implicate more days with heavy snowfall during the winter period.

Table 5.3 Projected changes in number of wet-days from 2000 to 2050 for emission scenarios RCP4.5 and RCP8.5

	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Year

RCP4.5													
Stavanger (Sola)	-0.1	0.3	0.2	0.3	0.7	0.6	-0.2	0	0.2	-0.2	0.3	0.6	2.7
Oslo-Blindern	0.5	-0.1	0.7	0.3	1	04	-0.2	-0.2	-0.5	0.3	0.1	0.4	2.5
Gardermoen	0.5	0.1	0.6	0.2	0.8	0.1	-0.2	-0.1	-0.5	02	0	0.4	1.9
RCP8.5													
Stavanger(Sola)	0	0.5	0.5	0.8	0.7	0.2	0.2	-0.3	-0.2	0	-0.4	0.3	2.2
Oslo-Blindern	0.6	0.5	0.7	0.6	0.8	0.3	-0.2	-0.6	-0.2	0.2	-0.3	0.6	3.2
Gardermoen	0.7	0.7	0.7	0.6	0.6	0.1	-0.2	-0.5	0	0	-0.3	0.4	2.7

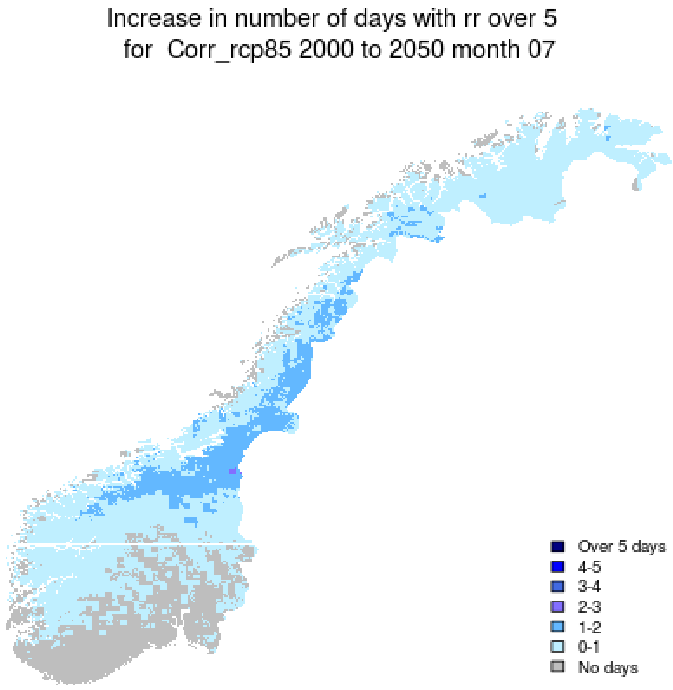
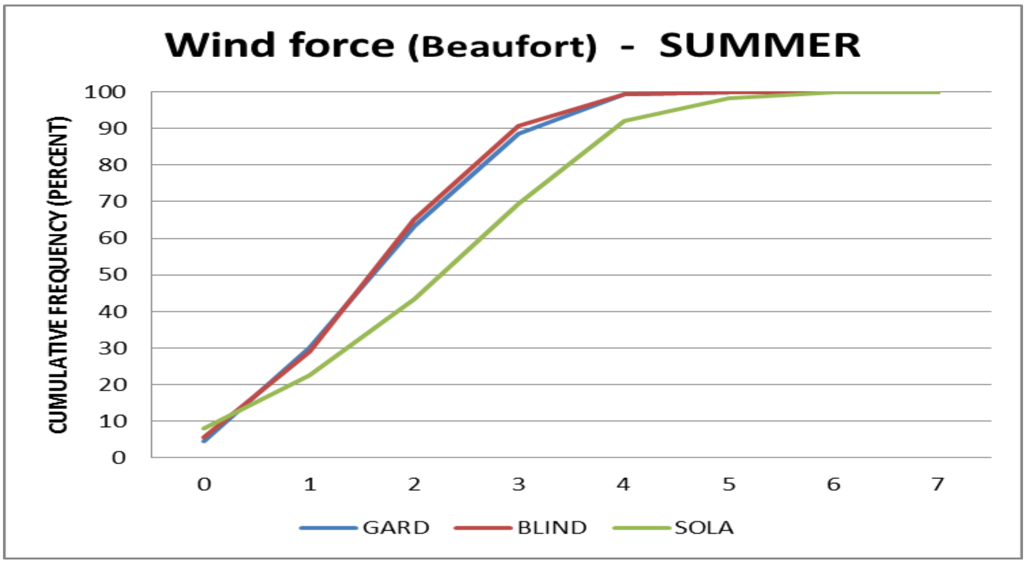


Figure 5.1 Change in number of days with precipitation ≥ 5 mm from 2000 to 2050 for July for emission scenario RCP8.5

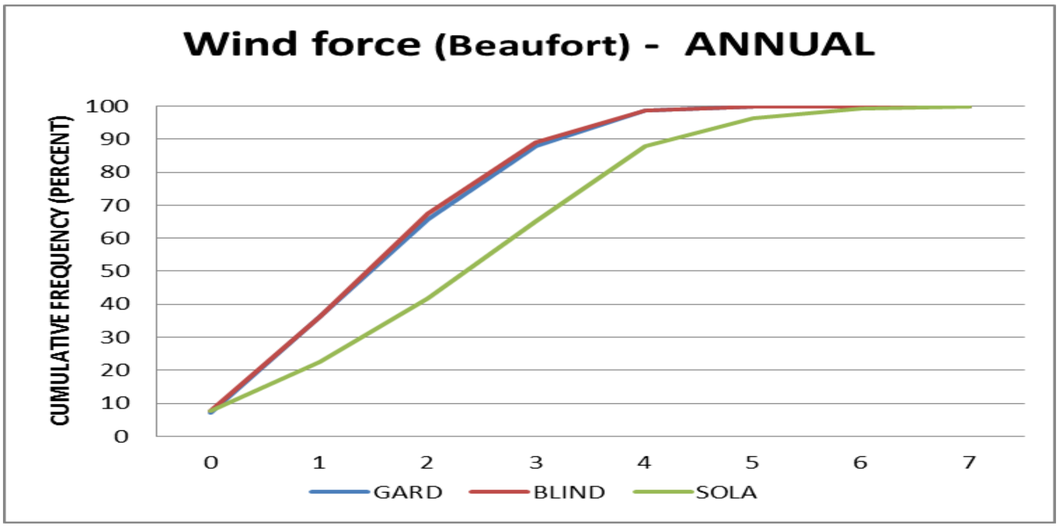
Figure 5.1 indicate moderate changes in the frequency of wet days in most parts of the country for July. For some other months the maps are found in Appendix 11.2. They show that for April there is a tendency to increased frequency in most of the country, and particularly in southwestern regions. In July and October the largest increase is found in inland areas in parts of Central and Northern Norway.

6 Wind

Figure 6.1 and Tables 6.1 and 6.2 demonstrate that the Stavanger area experiences tougher wind conditions than the more sheltered Oslo area.



a).



b).

Figure 6.1 Cumulative distribution of wind forces in Stavanger (Sola) and Oslo area (Oslo-Blindern and Gardermoen) for a). Summer (May-September and b). Annual. For explanation of Beaufort wind scale, see upper part of Table 6.1. The figure is based on observations at 01, 07, 13 and 19 NMT during 1970-2000.

Table 6.1 Percentage of time when wind force is exceeding various thresholds in Stavanger (Sola) and Oslo-area (Oslo-Blindern and Gardermoen). The table is based on observations at 01, 07, 13 and 19 NMT during 1970-2000.

Scale	0	1	2	3	4	5	6
Beaufort name	Calm	Light air	Light breeze	Gentle breeze	Moderate breeze	Fresh breeze	Strong breeze
m/s	> 0.2	> 1.5	> 3.3	> 5.4	> 7.9	> 10.7	> 13.8
ANNUAL							
GARD	93.0	63.6	34.2	12.0	1.4	0.2	0
BLIND	92.3	63.8	32.6	10.8	1.4	0.2	0
SOLA	92.2	77.3	58.3	34.9	12.1	3.6	0.7
SUMMER							
GARD	95.7	69.9	36.6	11.3	0.7	0	0
BLIND	94.5	71.0	34.9	9.3	0.7	0	0
SOLA	92.1	77.6	56.8	30.5	7.9	1.7	0.0

At Stavanger (Sola), the wind speed is exceeding 5 m/s (12 km/h) (equal or larger than "Gentle breeze") in more than 30 % of the time, both on annual basis and also during the summer period (May-September). In the Oslo area, this wind speed is exceeded in just around 10 % of the time. Wind speed larger than 8 m/s (20 km/h) (≥ "Moderate breeze") is exceeded in 8 % of the time in Stavanger during May-September, but in less than 1 % of the time in the Oslo-area.

Climate models indicate small or no changes in wind conditions up to the end of this century, but the uncertainties in the wind projections are large. The results in Figure 6.1 and Table 6.1 may thus be used as indicators also for future wind conditions in the Stavanger and Oslo areas.

Table 6.2 Observed mean wind speed (m/s) for days with or without daytime (07-19 NMT) precipitation for the summer months May-Sept. in Oslo (Blindern) and the Stavanger region (Særheim and Sola). Wind speed is mean value for the observations at 06, 12 and 18 UTC.

Location	Period	No precip.	Precip. >=0.1 mm	Precip. >=1.0 mm
Oslo-Blindern	2006-2016	2.9	2.9	3.0
Særheim	2010-2016	3.7	4.2	4.2
Stavanger (Sola)	2005-2010	4.5	5.1	5.2

Table 6.2 shows that in the Stavanger area, the weather conditions for rainy days may be even more unpleasant because rainy days also are windy days. Both at Særheim (25 km south of Stavanger) and Sola, the mean speed is more 0.5 m/s higher for summer days (May-September) with rainfall, than during dry weather. At Oslo-Blindern there is no difference in mean wind speed between dry days and rainy days.

7 Days with snow on the ground

Observations demonstrate that there is large differences in days with snow for Oslo area and Stavanger. In present climate (1970-2000) the snow season in the Stavanger area (Sola and Stavanger-Våland) is in average just around 35 days/year (Table 7.1). The snow season in the Oslo-area is substantially longer than at the southwestern coast of Norway. Thus Oslo-Blindern during 1970-2000 had ca. 115 days per year where the ground is covered by snow. In the hilly areas around Oslo ("Nordmarka") the snow season is substantially longer; e.g. 180 days/year at Tryvannshøgda (514 m a.l.).

Projections for future development of snow cover are based on data presented by Hanssen-Bauer et al., 2015. Projections based on the moderate emission scenario (RCP4.5) indicate an annual reduction of 30 - 35 snow days in the Oslo area and 20 - 30 days in the Stavanger area. This implicates that in the Stavanger area there will be just around 10 days per year with snow cover on the ground in 2050 (Table 7.1). In lower parts of the Oslo area there will be snow on the ground in ca. 80 days per year, while areas above 500 m a.s.l. will be snow covered for 150 days. If the global greenhouse gas emissions follow the "business as usual" scenario (RCP8.5), snow covered ground will be very rare in the Stavanger area in 2050, while number of snow days in lower parts of Oslo will be just half the present level.

Table 7.1 Observed and projected number of days per year with snow covered ground. Projections are presented for both moderate emissions (RCP4.5) and high emissions (RCP8.5)

Locations	Observed (1970-2000)	Projections for 2050	
		RCP4.5	RCP8.5
Oslo – Blindern (94 m a.s.l.)	114	~ 80	~ 60
Oslo – Tryvannshøgda (514 m a.s.l.)	180	~ 150	~ 125
Stavanger (Sola) (7 m a.s.l.)	37	~ 10	~ 0
Stavanger-Våland (72 m a.s.l.)	33	~ 10	~ 0

8 Summary

The ClimaMob project aims at assessing the likely impacts of climate change on everyday travel behaviour, and will also study implications of these changes for mitigation and adaptation strategies. To understand how climate change and resulting weather impacts will affect mobility patterns up to the mid of this century, ClimaMob surveys have identified five climate indicators important for present and future weather conditions. The indicators are: Number of 1).Hot days, 2). Very hot days, 3). Wet days, 4). Windy days and 5). Days with snow on the ground. ClimateMob analyses (Tabib & Rasheed, 2017) demonstrated that temperature and particularly "humidity" (precipitation) influenced bike traffic in Oslo.

The five selected climate indicators have been elaborated for two Norwegian city areas experiencing different climate conditions: Stavanger and Oslo. Present climate is represented by the period 1970-2000 (named "2000" in this report) and future climate by the scenario period 2040-2070 (named "2050"). Projections are made under two emissions scenarios: RCP4.5 ("Moderate emissions") and RCP8.5 ("High emissions"). If nothing else is stated, the projections below are based on the high emission scenarios. Detailed results for emission scenarios RCP4.5 and RCP8.5, as well as Mean, Low (lowest value) and High (highest value) are presented in Appendix.

The present day weather conditions are based on the historical climate data archives at MET Norway, while projections for future climate development are based on downscaled results from regional climate models produced in the EURO-CORDEX initiative.

- ✓ Hot days are defined as days with maximum temperature higher than 25 °C. In present climate, the Oslo area has an average of 15 hot days per year, and Stavanger 4 d/year. The projections indicate that in "2050", Oslo will have 12 more hot days/year than in present climate; Stavanger 3-4 more hot days.

- ✓ Very hot days are defined as days with maximum temperature higher than 30 °C. In present climate, Oslo has in average 1.0 very hot days per year; Stavanger 0.3 days/yr. This means that in Stavanger very hot days occur in average just every third year. The projections indicate a rather modest increase: +0.5 "very hot days"/year for Stavanger and +2 days/year for the Oslo area. Consequently, "very hot days" will occur rather seldom also in "2050"; - in average 3 d/year in Oslo and 1 d/year in Stavanger.

- ✓ Number of wet days is defined as days with more than 5 mm precipitation. In present climate, the Oslo area has in average ca. 55 wet days per year, and Stavanger ca. 85 days/year. The projections indicate rather small changes up to “2050”; - i.e. an increase of less than 5 wet days per year both in Oslo and Stavanger.

- ✓ Stavanger is more exposed for high wind speeds than Oslo. Wind speed in Stavanger is exceeding 5 m/s (12 km/h, “Gentle breeze”) for more than 30% of the time both during summer and also on an annual basis. In Oslo this wind force is exceed just in 10 % of the time in present climate. Climate models indicate small or no changes in wind conditions up to the end of this century, but the uncertainty is large.

- ✓ In Stavanger, rainy days tend to be windier than dry days. In Oslo there is no difference in mean wind speed for wet and dry days during the summer season.

- ✓ Snow on ground is observed for 114 days/year at Oslo-Blindern in present climate, and 37 days per year in Stavanger. The projections indicate substantial reductions in length of snow season: In lower parts of the Oslo area the number of days with snow on the ground will be almost half of the present level, while in Stavanger days with snow on the ground will be very rare.

9 Acknowledgement

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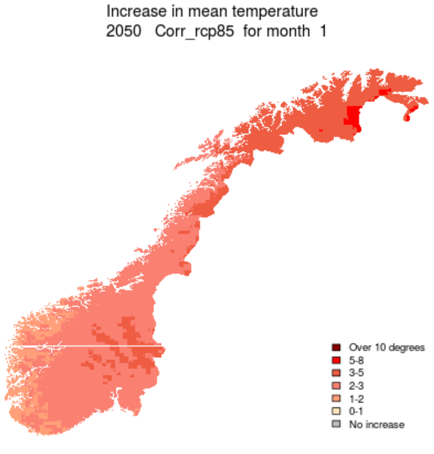
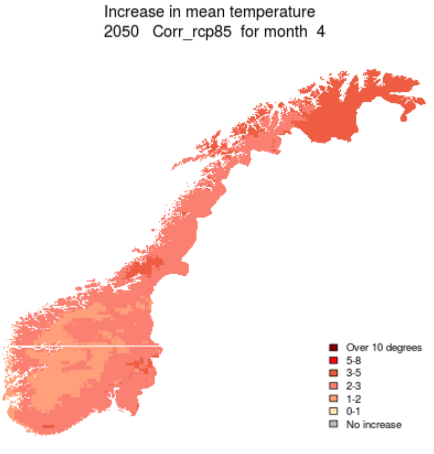
11 Appendix

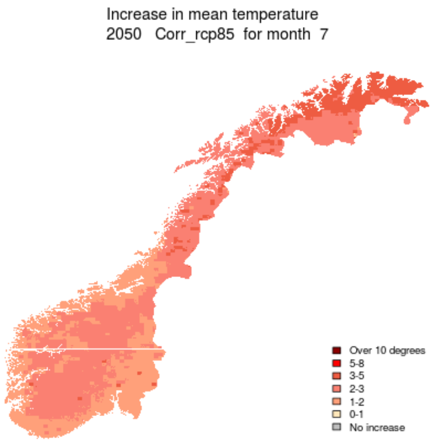
This appendix gives more detailed information on climate prediction for temperature and precipitation in tables and maps. There are also more information on the method for calculating the relation between mean temperature and maximum temperature for the data on hot days and very hot days. Appendix 11.1 shows information on temperature, first prediction on mean temperature, then hot and very hot days, including the method used. Appendix 11.2 shows information on predictions for precipitation, both mean precipitation in percent and absolute value, and number of wet days.

11.1 Temperature

11.1.1 Projected changes in mean temperature







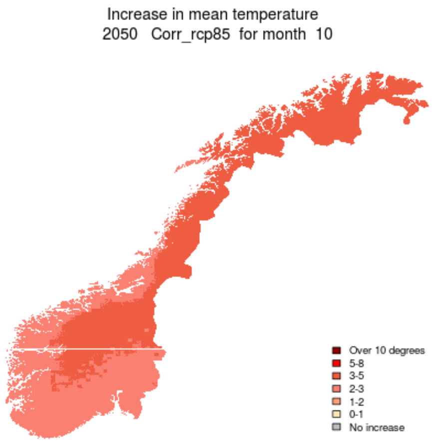


Figure 11.1: Changes in mean temperature from "2000" to "2050" for January (upper left), April (upper right), July (bottom left) and October (bottom right) with high emission scenario (RCP 8.5).

Table 11.1 shows increase in mean temperature for Sola, Oslo-Blindern and Gardermoen for each month from 2000 to 2050. The mean for both moderate emission (RCP4.5) and high emission (RCP8.5) are the mean of all the ten models. The high and the low value is the model with the highest increase and the lowest increase.
For both Stavanger and Oslo the highest increase is in the winter half of the year. The change in Stavanger is about 1-2 °C in mean temperature, and 2-3 °C near Oslo.

Table 11.1 Increase (°C) in mean temperature from "2000" to "2050"
a). Stavanger (Sola)

Emission	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
RCP4.5 mean	1.3	1.7	1.6	1.4	1.4	1.3	1.3	1.4	1.4	1.5	1.8	1.7	1.5
RCP4.5 high	2.4	2.8	2.3	2,0	2.0	1.8	1.9	2.2	2.4	2.5	2.5	2.8	2.1
RCP4.5 low	0.1	0.0	0.5	0.6	0.9	0.7	0.6	0.6	0.7	0.8	1.3	1.1	0.8
RCP8.5 mean	1.8	2.3	2.3	1,9	1.6	1.8	1.5	1.8	2.1	2.4	2.0	2.1	2.0
RCP8.5 high	3.1	3.1	2.9	2.5	2.2	2.6	2.4	2.4	2.9	3.9	2.5	3.3	2.5
RCP8.5 low	1.1	1.3	1.5	1.3	1.1	1.3	0.7	1.1	1.5	1.6	1.3	1.5	1.4

b). Oslo-Blindern

Emission	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
RCP4.5 mean	2.1	2.4	2.4	2.2	2.0	1.4	1.5	1.6	1.7	1.7	2.1	2.3	1.9
RCP4.5 high	3.8	4.4	4.8	3.8	2.9	2.6	2.4	2.6	2.8	2.6	2.6	3.5	3.1
RCP4.5 low	0.7	0.2	0.7	0.8	0.8	0.5	0.5	0.8	0.8	0.9	1.2	1.1	1.0
RCP8.5 mean	2.9	3.4	3.3	3.0	2.4	2.1	1.9	2.6	2.4	2.7	2.5	2.9	2.6
RCP8.5 high	4.5	5.0	4.9	3.9	3.1	3.1	2.9	3.0	3.3	4.3	3.4	4.3	3.5

RCP8.5 low	1.5	1.2	1.6	1.7	1.6	1.4	1.2	1.5	1.7	1.7	1.8	2.0	1.9

c). Oslo (Gardermoen)

Emission	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
RCP4.5 mean	2.1	2.4	2.3	2.2	2.0	1.4	1.5	1.6	1.7	1.8	2.2	2.3	2.0
RCP4.5 high	3.5	3.9	4.6	3.9	3.0	2.6	2.4	2.7	2.9	2.7	2.7	3.4	3.0
RCP4.5 low	0.6	0.0	0.6	1.0	0.8	0.6	0.5	0.8	0.8	1.1	1.2	1.1	1.0
RCP8.5 mean	2.9	3.3	3.1	3.0	2.4	2.1	2.0	2.2	2.4	2.8	2.7	2.9	2.6
RCP8.5 high	4.8	5.0	4.7	4.0	3.3	3.0	3.0	3.0	3.4	4.5	3.8	4.4	3.6
RCP8.5 low	1.3	1.0	1.6	2.0	1.6	1.4	1.2	1.6	1.7	1.6	1.9	2.0	1.9

11.1.2 Hot days and very hot days

Definitions of hot and very hot day were given from WP1 and WP2:
Hot day: Highest daily temperature (maximum temperature, TAX) >= 25 °C
Very hot day → highest daily temperature (maximum temperature, TAX) >= 30 °C

The data available from the downscaled climate models are just mean daily air temperature (TAM) for each day, so we had to find a correlation for the increase in TAM and the increase in TAX. There are different approaches to finding the threshold for TAM at hot days with TAX over 25 °C and very hot days with TAX over 30 °C. After trying different approaches we ended up with detection theory for a threshold for making maps for the whole country and linear regression for finding threshold for the areas in focus. Below the detection theory is described.

11.1.3 Detection theory – hits versus false hits and false misses

Hypothesis is that when TAX (maximum temperature) higher than 25 degrees, TAM (mean temperature) is higher than 20 degrees. Here we want to have highest number of hits, but also the lowest number of misses and false hits (see table below).
We looked at observations for almost all stations in Norway and tried out different values of TAM and found the threshold for each place.

	Hit	Miss
True	TAX >= 25 TAM >= 20	TAX < 20 TAM < 25
False	TAX < 25 TAM >= 20	TAX >= 25 TAM < 20

An example is shown in Figure 11.2 for Oslo – Blindern where we find the mean temperature nearest to where the highest temperature exceeds 25 degrees.

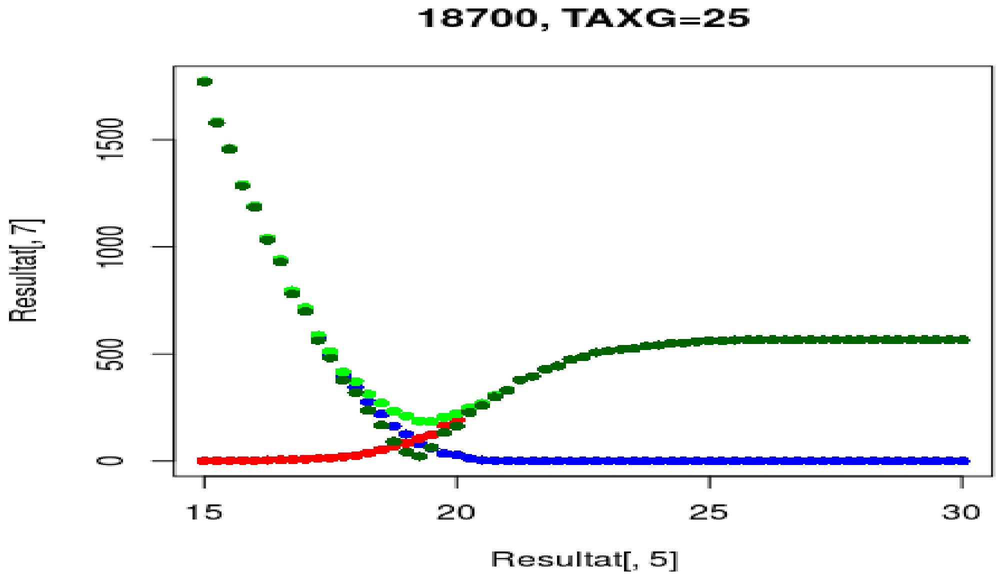


Figure 11.2 Example of Hit-and-miss diagram for station 18700 Oslo-Blindern Blue line: Number of false hits plotted with temperature TAM when hot days. Red line: Number of false misses plotted with temperature TAM when hot days. Green line: Number of false hits and false misses together plotted with TAM on hot days. Dark Green line: Number of false misses minus number of false hits plotted with TAM on hot days

The threshold values found using this method are plotted for southern Norway for both hot days and very hot days. Figure 11.3 for hot days and 11.4 for very hot days. The threshold for different stations on the maps demonstrates differences from coastal stations to inland stations. At the coastal stations, the difference between maximum and minimum temperature is lower than for inland stations.

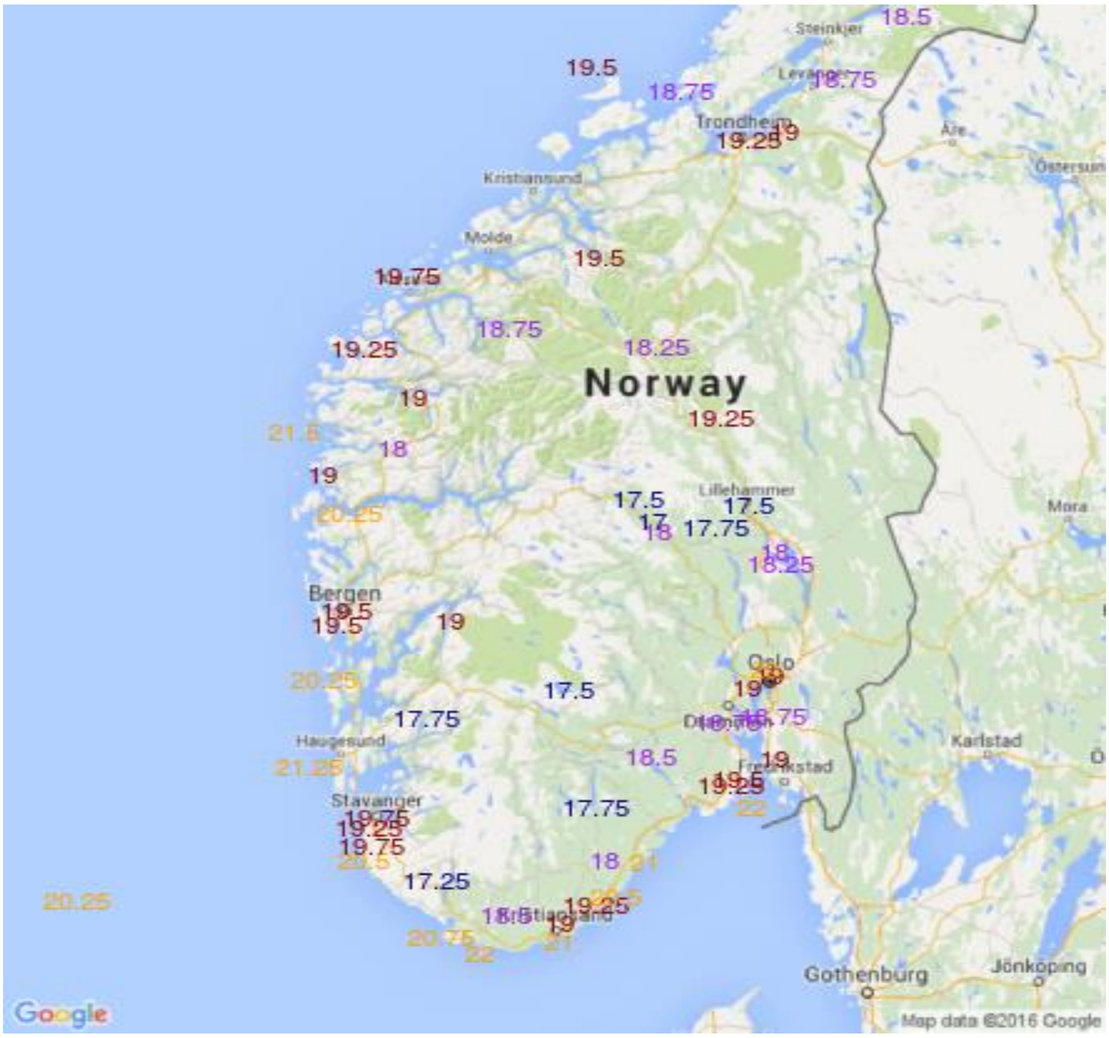


Figure 11.3: Southern Norway. Threshold for mean temperature at hot day; TAX>=25 °C

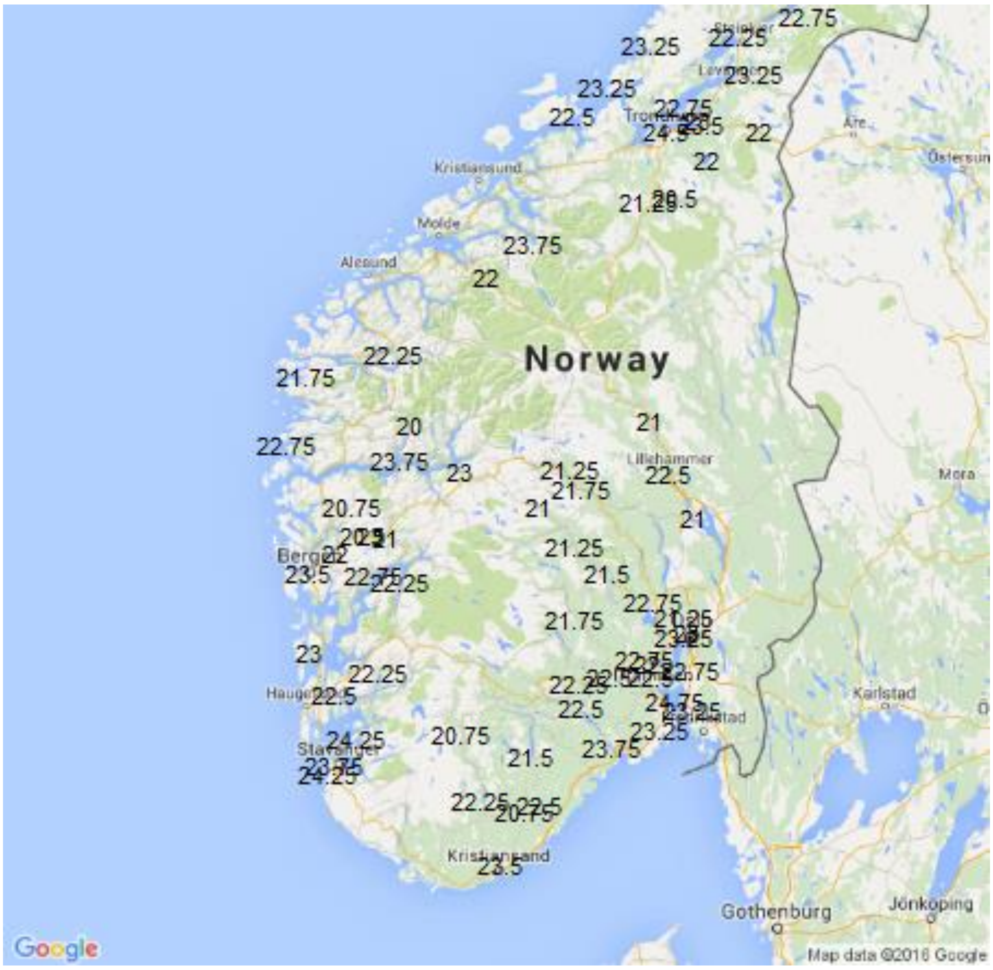


Figure 11.4: Southern Norway. Threshold for mean temperature at very hot day; TAX>=30 °C

Hot days

During October to April there are very few observations of hot days. For the months May to September an estimate of a mean threshold value for the whole of Norway is: ➔ TAM = 18.97 °C ~ 19.0°C

Very hot days

The number of days with temperature higher than 30 °C is very low in Norway. Based on this limited dataset, an estimate of the mean threshold value for the whole of Norway is:➔ TAM = 22.5 °C

11.1.4 Observations of hot days and very hot days

For the areas Oslo and Stavanger we found the threshold to be 19.0 degrees and 19.5 degrees for hot days. And for very hot days the number of observations was very few, so we assumed the same threshold for Oslo and Stavanger, mean temperature at 22.5 degrees. Below is observation of hot days and number of days with mean temperature regarding threshold.

a) Hot days

Table 11.2 Hot days.

Mean annual number of hot days during 1970-2000 with maximum temperature (TAX) ≥25.0 °C

Location	Apr	May	June	July	Aug	Sep	Total
Oslo -Blindern	0.1	0.9	4.6	6.4	3.9	0	16.0
Oslo - Gardermoen	0	0.5	3.8	5.7	3.4	0.1	13.5
Stavanger - Sola	0.1	0.3	0.8	1.4	1.5	0	4.2

Mean annual number of days during 1970-2000 with daily mean temperature (TAM) ≥19.0°C

Location	Apr	May	June	July	Aug	Sep	Total
Oslo -Blindern	0	0.6	4.4	6.8	4.2	0.1	16.1
Oslo - Gardermoen	0	0.2	2.6	4.7	2.5	0	10.0

Mean annual number of days during 1970-2000 with daily mean temperature (TAM) ≥19.5°C

Location	Apr	May	June	July	Aug	Sep	Total
Stavanger - Sola	0	0.1	0.5	1.2	1.6	0.1	3.6

b) Very hot days

Table 11.3

Mean annual number of very hot days during 1970-2000 with maximum temperature(TAX) ≥30°C

Location	June	July	Aug	Total
Oslo -Blindern	0.3	0.4	0.5	1.1
Oslo (Gardermoen)	0.2	0.2	0.4	0.8
Stavanger (Sola)	0	0.1	0.2	0.3

Mean annual number of days with mean temperature (TAM) ≥22.5°C during 1970-2000

Location	June	July	Aug	Total
Oslo -Blindern	0.4	0.5	0.8	1.8
Oslo - Gardermoen	0.2	0.2	0.4	0.8
Stavanger - Sola	0	0.1	0.5	0.6

11.1.5 Projections of hot days and very hot days

Table 11.4 Hot days

Stavanger (Sola): Change in number of days with TAM>=19.5

Emission	May	June	July	Aug	Sep	All year
RCP45 Mean	**0.1**	**0.5**	**1.4**	**1.0**	**0.1**	**3.0**
RCP45 High	0.4	1.3	3.4	2.2	0.4	5.3
RCP45 Low	-0.1	0.2	-0.1	0.3	-0.2	1.2

RCP85 Mean	**0.1**	**0.7**	**1.3**	**1.5**	**0.2**	**3.8**
RCP85 High	0.6	1.9	2.8	2.8	1.0	7.7
RCP85 Low	0	0.2	0.1	0.2	0	1.3

Stavanger (Sola): Number of hot days in 2050 using regression line y=1,09x+0,005

Emission	May	June	July	Aug	Sep	All year
RCP45 Mean	**0.2**	**1.1**	**2.8**	**2.8**	**0.2**	**7.2**
RCP45 High	0.5	2.0	5.0	4.1	0.5	9.7
RCP45 Low	0	0.8	1.2	2.1	-0.1	5.2
RCP85 Mean	**0.2**	**1.3**	**2.8**	**3.3**	**0.4**	**8.1**
RCP85 High	0.7	2.6	4.4	4.8	1.2	12.3
RCP85 Low	0.1	0.8	1.4	2.0	0.2	5.3

Oslo (Gardermoen): Change in number of days with TAM>=19.0

Emission scenario	May	June	July	Aug	Sep	All year
RCP45 Mean	**0.3**	**1.6**	**3.9**	**2.1**	**0.2**	**8.1**
RCP45 High	0.8	4.3	6.3	4.7	0.5	13.8
RCP45 Low	0	-0.2	0.9	0	0	2.5
RCP85 Mean	**0.4**	**2.6**	**5.1**	**3.5**	**0.4**	**11.9**
RCP85 High	1.1	5.3	8.1	5.7	1.3	20.1
RCP85 Low	0	1	2.9	0.7	0	4.6

Oslo (Gardermoen): Number of hot days in 2050 using regression line y=0,876x-0,0007

Emission scenario	May	June	July	Aug	Sep	All year
RCP45 Mean	**0.7**	**4.7**	**8.4**	**4.9**	**0.2**	**18.9**
RCP45 High	1.1	7.1	10.5	7.1	0.5	23.9
RCP45 Low	0.5	3.2	5.5	3.8	0	14.0
RCP85 Mean	**0.8**	**5.6**	**9.4**	**6.1**	**0.4**	**22.2**
RCP85 High	1.4	8.0	12.1	8.0	1.2	29.4
RCP85 Low	0	1.0	2.9	0.7	0	15.9

Oslo-Blindern: Change in number of days with TAM>=19.0

Emission scenario	May	June	July	Aug	Sep	All year
RCP45 Mean	**0.5**	**1.8**	**4.6**	**3.1**	**0.5**	**10.5**
RCP45 High	0.9	4.6	7.7	6.0	1.7	19.3
RCP45 Low	0.1	-0.2	0.5	0.6	-0.3	1.6
RCP85 Mean	**0.7**	**3.4**	**6.2**	**4.7**	**0.8**	**15.8**
RCP85 High	1.6	6.3	9.7	7.1	2.4	26.4
RCP85 Low	0.1	1.3	3.1	1.9	0	7.6

Oslo-Blindern: Number of hot days in 2050 using regression line y=1,06x+0,003

Emission scenario	May	June	July	Aug	Sep	All year
RCP45 Mean	**1.2**	**6.6**	**12.1**	**7.7**	**0.6**	**28.2**

RCP45 High	1.6	9.5	15.4	10.8	1.9	37.5
RCP45 Low	0.8	4.4	7.7	5.1	-0.2	18.8
RCP85 Mean	**1.4**	**8.3**	**13.8**	**9.5**	**1.0**	**33.8**
RCP85 High	2.3	11.3	17.5	12.0	2.6	45.1
RCP85 Low	0.7	6.1	10.5	6.5	0.1	25.1

Table 11.5 Very hot days

Stavanger (Sola) Change in number of very hot days

Emission scenario	May	June	July	Aug	Sep	All year
RCP45 Mean	**0**	**0.1**	**0.2**	**0**	**0**	**0.4**
RCP45 High	0.1	0.2	0.7	0.3	0	1
RCP45 Low	0	0	0	0	0	0
RCP85 Mean	**0**	**0.1**	**0.3**	**0.1**	**0**	**0.5**
RCP85 High	0.2	0.4	0.7	0.4	0.1	1.5
RCP85 Low	0	0	0	0	0	0.1

Oslo (Gardermoen): Change in number of very hot days

Emission scenario	May	June	July	Aug	Sep	All year
RCP45 Mean	**0**	**0.3**	**0.7**	**0.2**	**0**	**1.3**
RCP45 High	0	1.3	1.4	0.4	0	2.9
RCP45 Low	0	0	0.1	0	0	0.4
RCP85 Mean	**0**	**0.4**	**1.1**	**0.5**	**0**	**2.1**
RCP85 High	0.2	1.4	2.3	0.9	0.2	4.1
RCP85 Low	0	-0.2	0.1	0	0	-0.1

Oslo-Blindern: Change in number of very hot days

Emission scenario	May	June	July	Aug	Sep	All year
RCP45 Mean	**0.1**	**0.7**	**1.8**	**0.6**	**0**	**3.2**
RCP45 High	0.2	2.4	3.1	1.4	0.2	5.4
RCP45 Low	0	0.1	0.3	0.2	0	0.9
RCP85 Mean	**0.1**	**1.2**	**2.6**	**1.4**	**0.1**	**5.2**
RCP85 High	0.4	3.2	4.3	2.7	0.3	10.3
RCP85 Low	0	0.1	0.7	0	0	0.8

11.2 Precipitation

11.2.1 Projected changes in mean precipitation

Figure 11.5 shows the change in mean precipitation in percent, and it is clear that there are regional and seasonal differences. The largest changes are found for the northern part of the country. However, when we look at the absolute values the western part of Norway has the greatest increase.

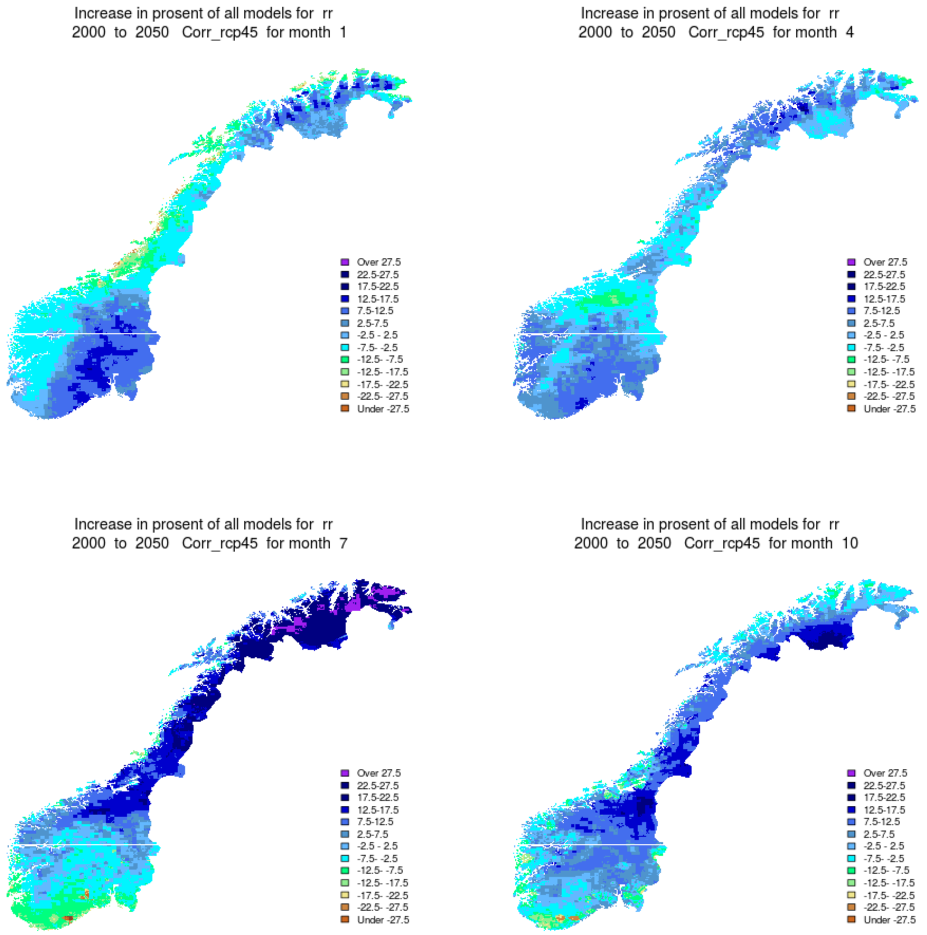


Figure 11.5: Change in mean precipitation in percent from 2000 to 2050 for January (upper left), April (upper right), July (bottom left) and October (bottom right) for emission scenario RCP4.5

For Stavanger and Oslo, the projections show the increase or decrease in mean precipitation in both absolute value and percent towards 2050. Table 11.6 and 11.7 show the changes in mm and percentage for both moderate emission (RCP45) and high emission (RCP85). Here is presented the mean value. The High and The Low value is the model with the highest increase and the lowest increase.

Table 11.6 Projected changes (mm) in monthly and annual mean precipitation Stavanger (Sola)

Emission	Jan	Feb	Mar	Apr	Ma	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
RCP45 Mean	**8**	**5**	**4**	**5**	**8**	**9**	**-4**	**7**	**11**	**7**	**8**	**17**	**84**
RCP45 High	40	26	37	20	25	37	10	29	36	43	28	34	222

RCP45 Low	-18	-32	-19	-7	-12	-8	-26	-16	-16	-37	-3	0	-36
RCP85 Mean	**10**	**11**	**11**	**12**	**8**	**7**	**5**	**6**	**2**	**9**	**1**	**16**	**98**
RCP85 High	36	33	41	22	22	28	26	35	25	50	37	44	211
RCP85 Low	-14	-12	-13	-13	1	-6	-12	-22	-20	-49	-31	-18	16

Oslo-Blindern

Emission	Jan	Feb	Mar	Apr	Ma	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
RCP45 Mean	**5**	**-1**	**6**	**4**	**10**	**7**	**2**	**0**	**-4**	**8**	**1**	**5**	**43**
RCP45 High	15	13	15	14	23	31	23	17	18	30	18	21	167
RCP45 Low	-5	-9	0	-5	-10	-10	-12	-16	-18	-11	-13	-6	5
RCP85 Mean	**8**	**6**	**8**	**8**	**11**	**5**	**5**	**-4**	**3**	**7**	**-1**	**7**	**62**
RCP85 High	25	17	13	16	21	25	23	24	18	25	16	20	173
RCP85 Low	-2	-1	-4	1	-3	-3	-15	-15	-8	-9	-15	-6	20

Oslo (Gardermoen)

Emission	Jan	Feb	Mar	Apr	Ma	Jun	July	Aug	Sep	Oct	Nov	Dec	Year
RCP45 Mean	**7**	**0**	**8**	**5**	**11**	**6**	**1**	**0**	**-4**	**7**	**3**	**7**	**51**
RCP45 High	17	13	19	14	22	30	24	21	21	33	21	24	182
RCP45 Low	-7	-9	2	-6	-11	-9	-17	-18	-18	-13	-12	-6	15
RCP85 Mean	**12**	**8**	**10**	**10**	**12**	**6**	**3**	**-3**	**4**	**5**	**2**	**10**	**78**
RCP85 High	28	18	18	23	21	24	18	20	20	17	20	25	177
RCP85 Low	-1	1	-2	2	-3	-5	-21	-21	-8	-12	-14	-7	24

Table 11.7 Projected changes in percent (%) in monthly and annual mean precipitation Stavanger (Sola)

Emission	Jan	Feb	Mar	Apr	Ma	Jun	July	Aug	Sep	Oct	Nov	Dec	Year
RCP45 Mean	**6**	**4**	**4**	**7**	**11**	**11**	**-4**	**5**	**7**	**4**	**5**	**11**	**6**
RCP45 High	29	23	37	27	33	48	9	20	23	24	17	22	15
RCP45 Low	-13	-29	-19	-9	-17	-11	-23	-11	-10	-21	-2	0	-2
RCP85 Mean	**8**	**10**	**11**	**16**	**11**	**9**	**5**	**4**	**1**	**5**	**0**	**10**	**7**
RCP85 High	26	29	42	30	29	36	22	23	16	28	23	29	14
RCP85 Low	-10	-11	-13	-17	1	-7	-10	-15	-12	-28	-19	-12	1

Oslo-Blindern

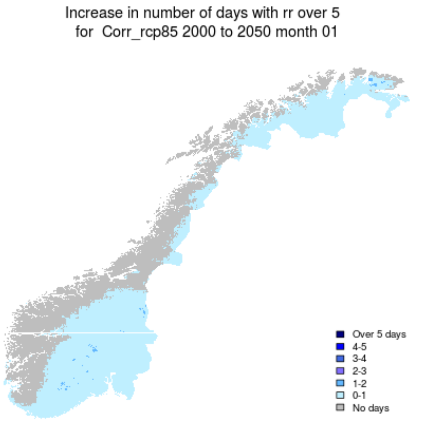
Emission scenario	Jan	Feb	Mar	Apr	Ma	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
RCP45 Mean	**11**	**-2**	**15**	**9**	**18**	**10**	**2**		**-5**	**9**	**1**	**8**	**5**
RCP45 High	30	28	36	28	40	46	27	18	21	34	24	35	21
RCP45 Low	-11	-19	-1	-11	-18	-15	-14	-18	-21	-12	-17	-10	1
RCP85 Mean	**16**	**13**	**19**	**16**	**19**	**8**	**6**	**-4**	**3**	**8**	**-2**	**12**	**8**
RCP85 High	50	37	32	33	37	37	27	27	21	29	22	32	22
RCP85 Low	-4	-3	-9	1	-6	-5	-18	-17	-10	-10	-19	-9	3

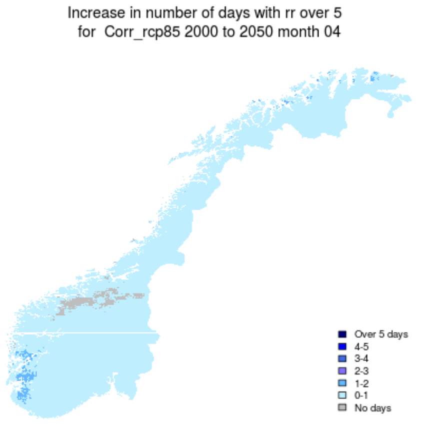
Oslo (Gardermoen)

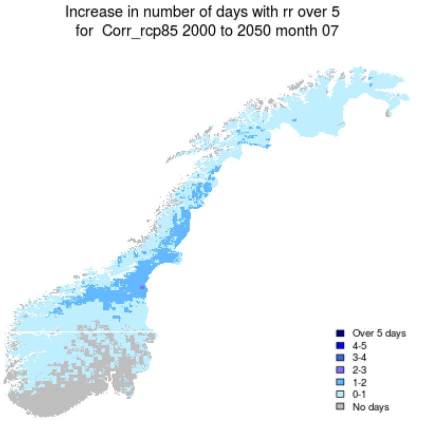
Emission scenario	Jan	Feb	Mar	Apr	Ma	Jun	July	Aug	Sep	Oct	Nov	Dec	Year
RCP45 Mean	**12**	**0**	**17**	**8**	**18**	**8**	**2**	**0**	**-4**	**7**	**3**	**9**	**6**
RCP45 High	29	25	39	25	34	43	28	22	23	32	24	32	21
RCP45 Low	-12	-17	5	-11	-17	-13	-20	-20	-20	-13	-13	-9	2
RCP85 Mean	**21**	**15**	**21**	**19**	**18**	**8**	**3**	**-3**	**4**	**5**	**2**	**13**	**9**
RCP85 High	47	34	37	43	32	34	21	21	22	17	23	33	20
RCP85 Low	-2	3	-4	3	-4	-7	-24	-22	-9	-12	-16	-9	3

11.2.2 Projected of changes in number of wet days

The definitions of a wet day were discussed within the project, and it was decided to apply a threshold of 5 mm precipitation per day.







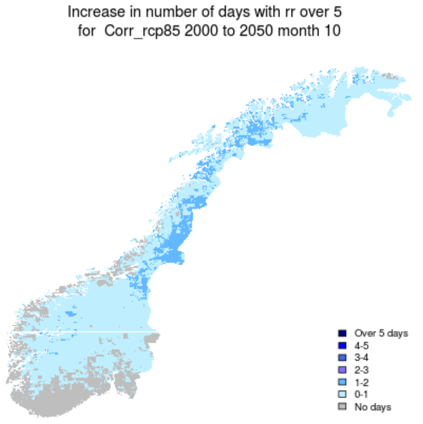


Figure 11.6 Change in number of days with precipitation ≥ 5 mm from 2000 to 2050 for January (upper left), April (upper right), July (bottom left) and October (bottom right) for emission scenario RCP8.5

Table 11.8 Mean annual number of wet days per year during 1970-2000

Location	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Year
Oslo - Blindern	4	2	4	3	3	5	5	6	5	6	5	4	52
Oslo (Garderm.)	4	3	5	3	4	5	5	5	5	6	6	5	57
Stavanger (Sola)	8	6	6	4	4	5	6	7	9	10	10	9	84

Table 11.9 Projected changes in number of wet days per year up to 2050

Stavanger (Sola)

Emission scenario	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Year
RCP45 Mean	**0**	**0**	**0**	**0**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**3**
RCP45 High	3	2	2	1	2	2	1	1	2	2	1	2	12
RCP45 Low	-3	-2	-1	0	-1	-1	-2	-1	-1	-3	-1	-1	-3
RCP85 Mean	**0**	**1**	**1**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**2**
RCP85 High	3	2	2	2	2	2	2	2	2	2	2	2	12
RCP85 Low	-2	-1	-1	-1	-1	-1	-1	-2	-2	-3	-2	-2	-4

Oslo-Blindern

Emission scenario	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Year
RCP45 Mean	**1**	**0**	**1**	**0**	**1**	**0**	**0**	**0**	**-1**	**0**	**0**	**0**	**3**
RCP45 High	2	1	2	1	2	2	1	1	1	2	2	2	11
RCP45 Low	0	-1	0	0	-1	-1	-1	-1	-2	0	-1	-1	0
RCP85 Mean	**1**	**1**	**1**	**1**	**1**	**0**	**0**	**-1**	**0**	**0**	**0**	**1**	**3**
RCP85 High	2	2	2	1	1	1	1	1	2	1	1	2	11
RCP85 Low	0	0	0	0	0	-1	-1	-2	-1	0	-2	0	0

Oslo (Gardermoen)

Emission scenario	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Year
RCP45 Mean	**1**	**0**	**1**	**0**	**1**	**0**	**0**	**0**	**-1**	**0**	**0**	**0**	**2**
RCP45 High	1	1	2	1	2	2	1	1	1	2	1	1	10
RCP45 Low	0	-1	0	0	-1	-1	-1	0	-2	-1	-1	-1	0
RCP85 Mean	**1**	**1**	**1**	**1**	**1**	**0**	**0**	**-1**	**0**	**0**	**0**	**0**	**3**

RCP85 High	2	2	2	2	1	1	1	1	1	1	1	2	10
RCP85 Low	0	0	0	0	0	-1	-1	-1	-1	-1	-1	-1	-1