Trend of extreme precipitation in Sweden and Norway during 1961-2004

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EXECUTIVE SUMMARY

The question whether climate is about to become more extreme has motivated numerous studies in different parts of the world both based on model simulation as well as on observations. A frequently used approach is to derive a set of climate indices based on daily temperature and precipitation data in order to quantify various statistics related to the mean climate, as well as moderate and severe extremes. These indices can then be used to study various aspects of their spatial distribution and temporal variability such as trends.

The overall aim of this report is to study the spatial patterns and long term trends of precipitation indices in Sweden and Norway on the annual and seasonal basis for the years 1961 to 2004. These indices are based on daily data from 471 stations. Among these indices are simple measures characterizing basic precipitation statistics like the frequency of rain days and the mean precipitation amount of rainy days, as well as various measures for moderate to severe extremes like percentile-based thresholds, maximum precipitation over a certain number of days, maximum number of consecutive wet days and number of very wet days (≥40 mm). Earlier studies applying these or slightly different indices did include stations from Nordic countries, however, none of them dealt more specifically with the conditions in Scandinavia.

The spatial distribution of these indices shows considerably variability across Sweden and Norway, both for annual indices and in different seasons. Especially the Norwegian West Coast emerges as a region with the highest mean amounts and shows often the highest extremes as well. Over Sweden, spatial variability is less pronounced and rainfall means and extremes are generally more moderate. Over the course of a year, the annual spatial pattern is somewhat modulated with rising extreme in inland regions and decreased extremes in coastal areas close to the West Coast. Analyzing the trends of the various indices for the period 1961-2004 shows that magnitude and sign of the trends vary depending on index, region and season. A clear majority of stations show increasing trends, though the fraction having statistically significant trends is small. In Norway, positive trends are most common during winter, while at Swedish stations, positive trends are most frequent in spring and summer. Autumn has the highest number of stations in both countries with negative trends. The findings are generally in line with results from other studies concluding that regions at middle and higher latitudes are becoming wetter and extremes are becoming more frequent and more intense.

1 Introduction

Even though studying temporal variations of rare weather and climate events is an interesting scientific undertaking by itself, the awareness that global climate change not only leads to changes in the mean climate but may also cause more frequent and more severe weather extremes have triggered an intensive research to answer the question of whether or not the climate is becoming more extreme. This is by no means a surprising development in the light of today's vulnerability against events like heavy rainfalls, drought, hot spells, or storms etc. Any increase in frequency or extent of such events is therefore expected to have profound consequences for economics and societies even in the future.

While an increasing number of climate model studies indicate that rising contents of greenhouse gases in the atmosphere will probably lead to more severe weather conditions in the future, it is of great importance to increase our understanding regarding the occurrence of climate extremes in the recent and more remote past. During the last five to ten years, a large number of studies have therefore been carried out focusing on various aspects of climate extremes (mainly temperature and precipitation) in different regions of the world (e.g. Trenberth, 1999; Easterling et al., 2000; Beniston and Stephenson, 2004). Depending on research tasks, different measures were used to quantify extremes, which not always allow direct comparison of results. A general conclusion of many of these studies is, however, that changes in extreme temperature and precipitation have occurred world-wide during the past century along with the ongoing climate change in terms of the mean temperature. Yet, it is still hard to draw a firm conclusion from these studies, whether these changes are due to natural variability or caused by anthropogenic activity (IPCC, 2001). To mention some examples, Groisman et al. 1999 studied the probability distribution of daily precipitation in eight countries located on different continents and concluded that increased mean precipitation is associated with an increase in heavy rainfalls. In their near-global analysis, Frich et al. 2002 found regions with both negative and positive changes in wet extremes, with parts of Europe having more robust positive changes. On a more regional scale, Moberg and Jones (2005) investigated trends in daily temperature and precipitation extremes across Europe over the past century and found that both mean precipitation and wet extremes have increased mainly during winter. Also Klein Tank and Können (2003) found an increase in the annual number of moderate and very wet days between 1946 and 1999. According to Haylock and Goodess (2004), inter-annual variability and trends in extreme winter rainfall are to a large extent linked to variations in the North Atlantic Oscillation (NAO). Numerous studies have also been carried out at the national level. Fowler and Kilsby (2003) studied multi-day rainfall events in the UK since 1961 and found significant but regionally varying changes in the 5- and 10-day events which they consider as having important implications for the design and planning of flood control measures. Other examples from central Europe include Schmidli and Frei (2005) who found significant increasing trends in winter and autumn rainfall in Switzerland or Hundecha and Bardossy (2005) who found increasing precipitation extremes across western Germany since 1958.

Although earlier studies on precipitation extremes in Europe already included data from Nordic countries (e.g., Moberg and Jones 2005; Klein Tank and Können (2003), Frich et al. 2002), the number of Scandinavian stations was generally rather limited, which did not allow spatial variability of rainfall extremes be studied in more detail. This report therefore seeks to contribute with a more comprehensive survey of rainfall extremes in the Scandinavian region focusing on the recent past.

Within the project "Extreme rainfall events in Sweden and their importance for local planning" supported by Swedish Rescue Services Agency, one important task is to study various statistical properties of precipitation in Sweden during the period 1961-2004 with emphasis on the past change in extreme rainfall events. Another task of the project, to be undertaken at a later stage of the project, is to estimate the future risk for rainfall extremes taking climate change into account.

While the project itself focus only on the conditions in Sweden, from a climatological point of view, it is far more interesting to include even Norway in such an analysis and to consider both countries as one geographical unit. This approach is motivated by the fact that both countries are often affected by the same weather systems as high and low pressure systems approaching Scandinavia from the West commonly cross either both countries or parts of them when moving eastwards. Regarding the physiographical settings, the dominant and common feature is the mountain range of the Scandes, having pronounced influence on the climatic conditions in both countries. Norway, however, posses the much more rugged topography compared to Sweden giving rise to distinct differences in climate conditions on regional and local scale. Furthermore, with the North Atlantic as the closest neighbor to the West, Norway's weather and climate are strongly influenced by maritime conditions whose impact gradually decreases towards Sweden. Since Norway is often located upstream of Sweden in terms synoptic systems and has a more profound topographical influence than Sweden, regional climate there may be more sensitive to any change. Thus, including Norway in the analysis would allow us to better understand the climate in Sweden.

The overall aim of this report is therefore, in line with the first task of the project, to study precipitation extremes in Sweden and Norway during the past 44 years. More specifically, the aim is to study the spatial and temporal variability of precipitation extremes based on daily precipitation observations from a large number of stations. For this purpose, a large number of maps are presented illustrating the regional characteristics of rainfall extremes across Sweden and Norway, both for different seasons as well as on annual scale. Regarding the temporal variability, the focus has been on studying temporal trends since 1961 in the extreme statistics. The approach used here describes rainfall extremes by a number of indices measuring rainfall intensity and frequency. This method is nowadays a well established research tool to reveal extreme climate variability as has been used within the European projects STARDEX (STAtistical and Regional dynamical Downscaling of Extremes for European regions) and EMULATE (European and North Atlantic daily to MULTIdecadal climate variability). The report is organized as follows: section 2 describes the data used, section 3 presents the methods adopted and section 4 gives the results. The final section summarizes the results and provides the conclusions. To make the spatial structures of the indices for Sweden more obvious, we display maps of the indices for Sweden separately in the appendix.

2 Precipitation observations used

This study is based on daily precipitation data from 365 stations in Sweden provided by SMHI and 229 stations in Norway provided by DNMI. There are totally 594 stations covering the period 1961-2004. However, due to a rather high fraction of missing days at some of the stations the number of useful stations is somewhat reduced depending on the amount of missing data that can be tolerated. Using a threshold of 10% and 5% missing data, the effective number of stations reduces to 471 and 411 respectively. Figure 1 shows the location of stations with < 10% of missing values. Station density varies across the region and is in general lower in the northern half but is especially low in the northernmost part of Norway.

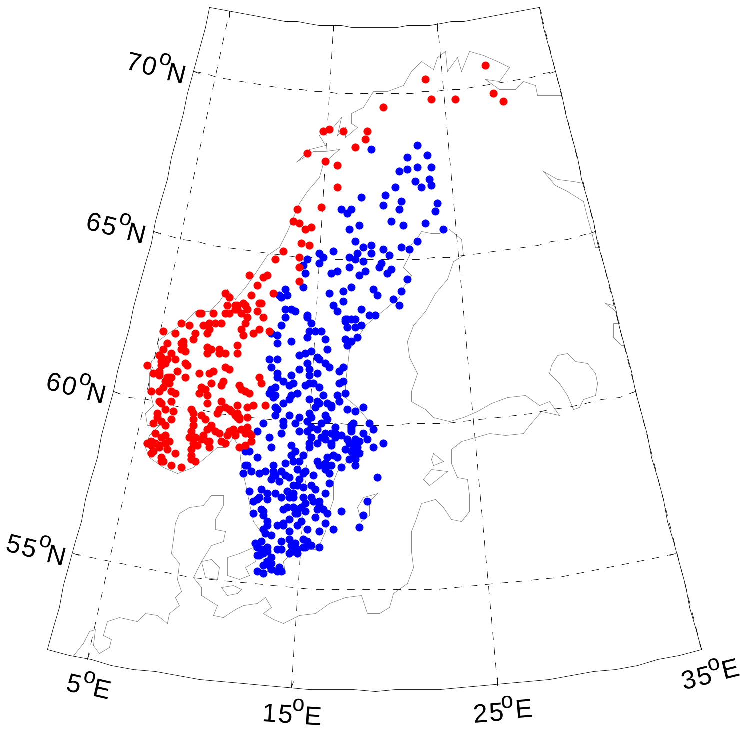


Figure 1: Location of precipitation stations in Sweden (blue) and Norway (red) having <10 % missing data in the period 1961-2004.

3 Method

3.1 Climate indices

To enable objective quantification and characterization of climate variability and change, The Expert Team on Climate Change Detection Monitoring and Indices (ETCCDMI) has compiled a catalogue of so called climate change indices (Karl et al. 1999, Nicholls and Murray 1999). These indices are calculated from daily observations of temperature and precipitation and describe various statistical properties. They serve as a practical and standardized tool to monitor changes in the statistical properties of the key elements temperature and precipitation and have already found wide application within the climate research community.

During the past decade, climate extremes have increasingly gained research attention as any change in the frequency or severity of extremes may have strong impacts on nature and society, especially if the number and extend of extremes is rising. In the light of global warming and its anticipated effect of enhancing the occurrence of extremes, monitoring and analyzing these rare events are of critical importance. Climate change indices containing information about rarely occurring temperature and precipitation events are thus necessary for these purposes. In addition, there are indices accounting for the more common temperature and rainfall conditions providing the general climatological background and helping to place the extremes into a broader context.

Some indices are used more frequently than others depending on research task and even new indices may be defined. One research project that extensively applied these climate change indices is the European project STARDEX (e.g. Haylock and Goodess, 2004), using in all 57 indices of which 33 are dedicated to characterize precipitation intensity and occurrence. A subset of 6 indices was chosen as the most important ones which make up the "core indices". Table 1a shows the complete list of rainfall indices used by STARDEX with the core indices given in bold letters. Some of the indices are based on fixed thresholds that are the same at all locations, like *pn10mm*, the number of days with precipitation >10mm while others are based on thresholds that vary from station to station. The latter indices are relative measures and are typically based on percentiles of the data series.

3.2 Precipitation indices calculated

In this study, 5 of the 6 STARDEX core indices were calculated, together with some additional indices. It has been argued, that the 95-percentile used by STARDEX indicates rather moderate than severe events. Whether to use higher percentiles than 95 is partly a question of sample size: the 95-percentile is a value that is exceeded by 5% of the observations in the data series; correspondingly the 99-th percentile is exceeded by only 1% of the values in a particular sample. If sample size is small, the estimation of percentiles at the far end of the precipitation distribution becomes statistically uncertain and may result in doubtful results. Nevertheless, in this study, the 99-th percentile was added as an index, together with the greatest 1-day rainfall amount. Furthermore, the number of days with rainfall >=40 mm was calculated as this threshold is suggested by SMHI to classify an event as extreme. Various practical applications make use of these added measures. In addition, the number of wet days is calculated representing a simple measure for how often precipitation occurs (see Table 1b). Finally, instead of calculating the index describing the maximum duration of dry spells as one of the STARDEX core indices, the maximum duration of continuous wet spells was calculated. This is because the focus in this report is on the occurrence of rain.

Why are these indices chosen and what do they represent? Starting with *pint*, the simple daily intensity represents a measure for the mean rainfall amount at a given location. Likewise *Nrain*, the number of days with precipitation >0.1 mm is a simply measure of how often precipitation occurs. *Nrain* and *pint* can thus be considered as indicators for the mean climate conditions. Index *pxcwd* (*pxcwdd*) counts the maximum number of consecutive wet (dry) days. Index *pxcwd* may serve as a potential indicator for floods if high rainfall amounts occur over extended periods, while index *pxcdd* is an indicator for absence of rain, which may cause droughts. The remaining indices serve as extreme indicators: *pq90* and *pq99*, the 90^{th} and 99^{th} percentiles are relative measures and indicate moderate and severe extremes. It should be noted here that they indicate extremes in relation to the probability distribution of precipitation at a given site. With other words, rainfall amounts corresponding to *pq90* and *pq99* are not necessarily harmful even though they are considered as "extremes". Indices *px1d* and *px5d* represent the greatest rainfall amount during one and five days respectively. They are measures of short-term rainfall intensity as well as for accumulated amounts and may have practical implications as flood indicators. Since SMHI uses 40 mm/day as a fixed threshold for extreme events, *pn40mm* was added to count the number of days when 40 mm per day are exceeded. Finally, *pnl90* and *pfl90*, the number of days with events exceeding the 1961-1990

90th percentile together with the fraction of annual total precipitation due to events exceeding *pnl90* are measures of very extreme events.

The indices in Table 1a and b are calculated for all Norwegian and Swedish stations on the annual and seasonal basis using data between 1961 and 2004. In this way, time series with annual and three-monthly time resolution are obtained providing a base for analyzing the temporal variability of rainfall statistics like trends.

Table 1a: Complete list of precipitation indices used within the STARDEX-project. The indices in bold letters are the indices calculated within this study, the ones marked with * are the STARDEX-core indices.

INDEX NAME	DESCRIPTION
pav	Mean climatological precipitation (mm/day)
pq20	20th percentile of rainday amounts (mm/day)
pq40	40th percentile of rainday amounts (mm/day)
pq50	50 50th percentile of rainday amounts (mm/day)
pq60	60 60th percentile of rainday amounts (mm/day)
pq80	80 80th percentile of rainday amounts (mm/day)
pq90 *	**pq90 90th percentile of rainday amounts (mm/day)**
prec95p	95th percentile of rainday amounts (mm/day)
pf20	Fraction of total precipitation > annual 20th percentile (%)
pf40	Fraction of total precipitation > annual 40th percentile (%)
pf50	Fraction of total precipitation > annual 50th percentile (%)
pf60	Fraction of total precipitation > annual 60th percentile (%)
pf80	Fraction of total precipitation > annual 80th percentile (%)
pf90	Fraction of total precipitation > annual 90th percentile (%)
pf95	Fraction of total precipitation > annual 95th percentile (%)
pn10	No. of days precip ≥10mm (days)
pxcdd *	**Max no. consecutive dry days (days)**
pxcwd	**Max no. consecutive wet days**
persist_ww	Mean wet-day persistence (days)
persist_dd	Mean dry-day persistence (days)
persist_corr	Correlation for spell lengths (days)
wet_spell_mean	mean wet spell lengths (days)
wet_spell_perc	median wet spell lengths (days)
wet_spell_sd	standard deviation wet spell lengths (days)
dry_spell_mean	mean dry spell lengths (days)
dry_spell_perc	median dry spell lengths (days)
dry_spell_sd	standard deviation dry spell lengths (days)
px3d	Greatest 3-day total rainfall (mm)
px5d *	**Greatest 5-day total rainfall (mm)**
px10d	Greatest 10-day total rainfall (mm)
pint *	**Simple Daily Intensity (rain per rainday, mm/day)**
pfl90 *	**Fraction (%) of total rainfall from events > long-term 90th percentile(1961-1990)**
pnl90 *	**No. of events > long-term 90th percentile (1961-1990)**

Table 1b: Additional indices calculated at the Swedish and Norwegian stations.

INDEX NAME	DESCRIPTION
nrain	**No of rain days (precip>0.1 mm)**
pq99	**99th percentile of rainday amounts (mm/day)**
px1d	**Greatest 1-day total rainfall (mm)**
Pn40mm	**No. of days precip ≥ 40mm (days)**

3.3 Trend analysis of selected indices

To study temporal changes during the past 44 years, linear trends were calculated at each station for *pint, nrain, pq90, pq99, px1d, px5d, pxcwd, pxcdd, pnl90* and *pfl90*. This was done using the ordinary least square (OLS) method (e.g., von Storch and Zwiers, 1999). Trends were calculated for the series with annual indices, but in order to investigate whether differences in the trends exist depending on seasons, trends were also calculated for all the series containing seasonal indices. Estimating the magnitude of a trend is, however, not sufficient in a trend analysis, a necessary second step is to test whether the found trend is significant, i.e., statistically different from a zero trend. If a trend is weak it may be too small to be distinguishable from the internal variability of the data, which makes it difficult to draw firm conclusions whether the trend is 'real' or not. Therefore, computing trends were completed in a second step by applying the rank-based, non-parametric Mann-Kendall test (e.g. Yue et al., 2002). This test is frequently used in climate research and does not require that the data follow a certain distribution. All the estimated trends were first tested at the 5% level. If the significance is approved, a second test was made to determine whether the trend is also significant at the 1% level.

4 Results

4.1 Spatial distribution of indices

In the following section the core indices listed in Table 1a are presented together with the additional indices in Table 1b. As the focus here is on the spatial distribution of these indices, the results are given as maps showing the climatological mean over all years from 1961 to 2004 of a given index. Figures were produced for annual data as well as for those of the four seasons.

Figure 2 shows *pint*, the averaged amount only during rainy days on annual scale while the seasonal patterns *pint* are given in Figure 3.

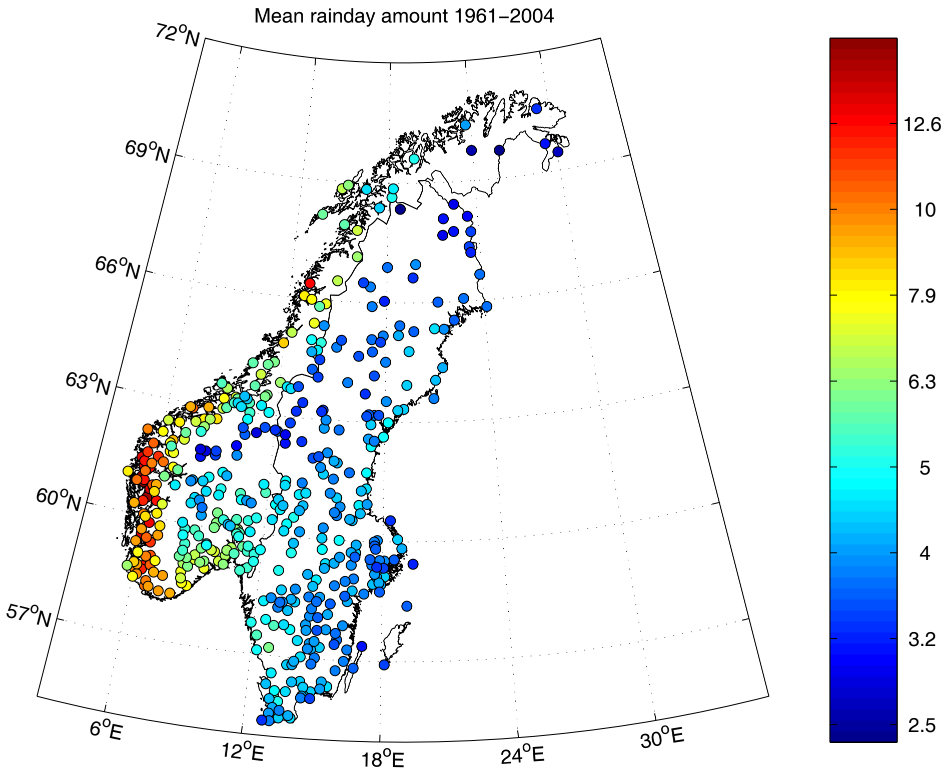


Figure 2: Mean precipitation amount during rainy (> 0.1 mm) days *pint* (mm/day) at all stations with <10% missing values.

Rainfall is strongest along or close to the Norwegian West Coast, followed by the Norwegian South Coast and parts of the Swedish West Coast while precipitation is significantly smaller in other parts of Norway as well most of Sweden. On the annual scale *pint* varies between 2.5 mm and 15.7 mm, for Swedish stations only the *pint* ranges between 2.5 and 6.8 mm. In general, the pattern of annual rainfall distribution is very similar in the different seasons. Along the Norwegian West Coast, *pint* peaks in autumn and winter, whereas the remaining regions receive most precipitation in spring and summer. This feature indicates that different processes generating precipitation across Scandinavia are active and that their importance varies with region. Rainfall maximum during spring and summer in the inland regions are probably explained by stronger convective activity in inland regions during the warm seasons. As a result, the spatial gradient in rainfall amounts across Scandinavia is weaker in spring and summer.

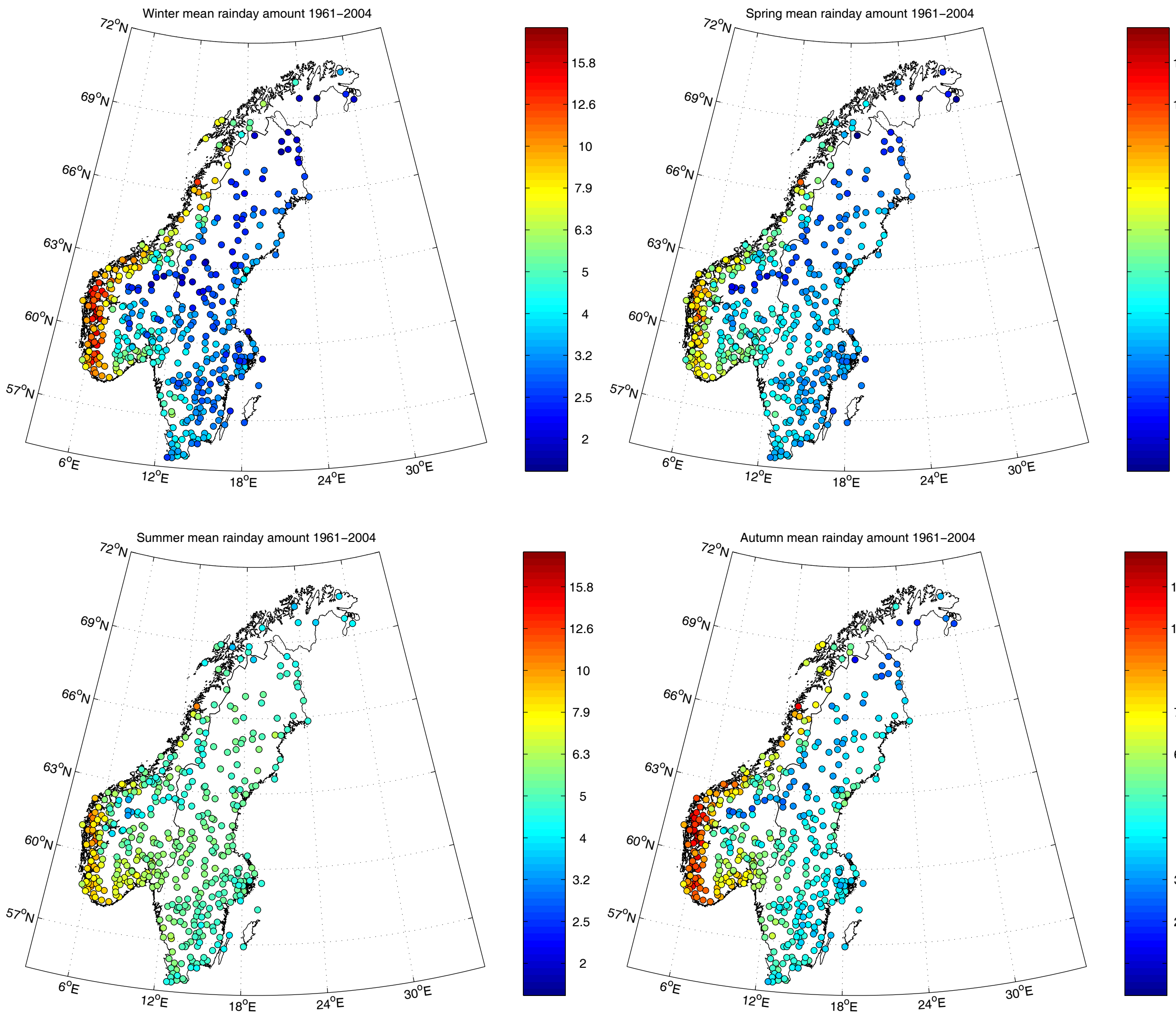


Figure 3: Mean daily precipitation amount during rainy days (> 0.1 mm) *pint* (mm/day) at all stations with <10% missing values in winter, spring, summer and autumn.

Index *Nrain*, the number of days with precipitation >0.1 mm does not belong to the original set of precipitation indices in Table 1a, but has been included here as a simple measure of how often precipitation occurs at different locations. Figure 4 show annual distribution of *Nrain,* Figure 5 gives the seasonal distributions.

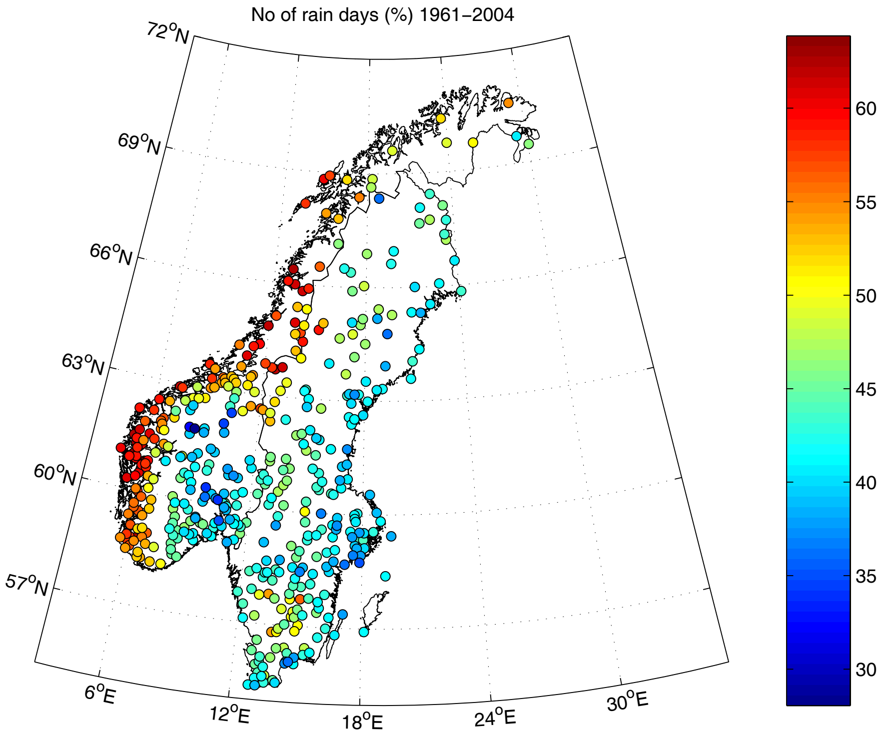


Figure 4: Mean annual fraction of rain days *Nrain* (%) at all stations with <10% missing values.

On the annual basis, the fraction of rain days varies from slightly less than 30% to slightly more than 60% (35% to 62% at Swedish stations). Comparing Figure 4 with Figure 2, obvious similarities can be found. As a general trend, regions with high *pint* also experience more rainy days, however, there are also exceptions. For instance, in Figure 4, the central parts of Southern Sweden as well as the inland regions of Middle and Northern Sweden appear with slightly enhanced frequency of rainy days, but a corresponding pattern in the annual distribution of *pint* cannot be found. The general pattern of *Nrain* with the highest numbers of rainy days at the Norwegian West Coast remains over the course of a year. Seasonal patterns of *Nrain* are similar to the corresponding patterns of *pint*.

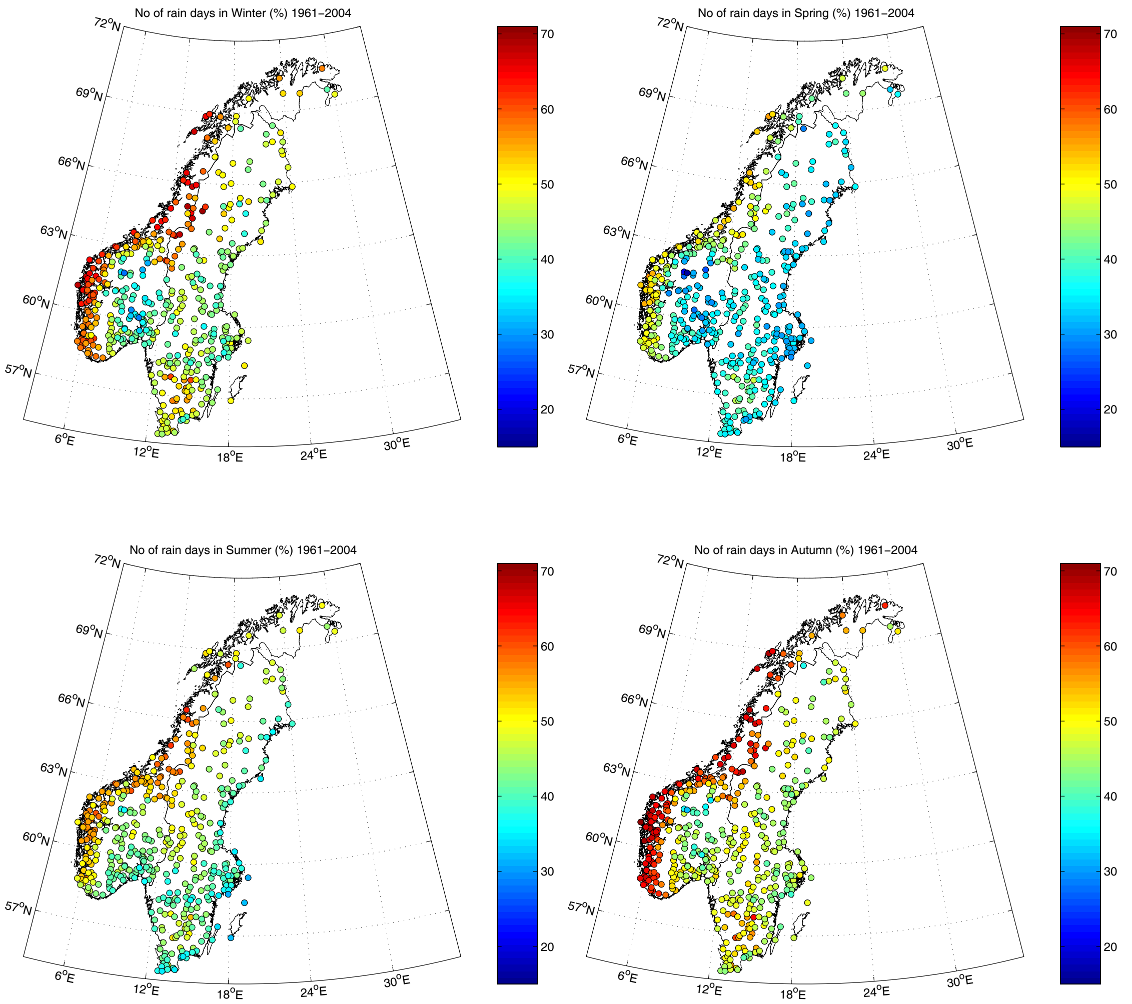


Figure 5: Mean seasonal fraction of rain days *Nrain* (%) at all stations with <10% missing values in winter (upper left), spring (upper right), summer (lower left) and autumn (lower right).

Figures 6 and 7 show the annual and seasonal distributions of *pq90*. The annual and seasonal patterns of *pq90* are quite similar to the corresponding patterns of *pint* with the highest values occurring along the Norwegian West Coast and significant lower thresholds in the other regions. Regarding the Swedish stations, *pq90* varies between 6 and 16 mm. The seasonal patterns of *pq90* do not deviate considerably from the annual *pq90* pattern and their development over the course of a year is similar to the seasonal variations in *pint*. Consequently, highest *pq90* can be expected during summer at Swedish stations, while *pq90* peaks in autumn and winter at the maritime stations along the Norwegian West Coast.

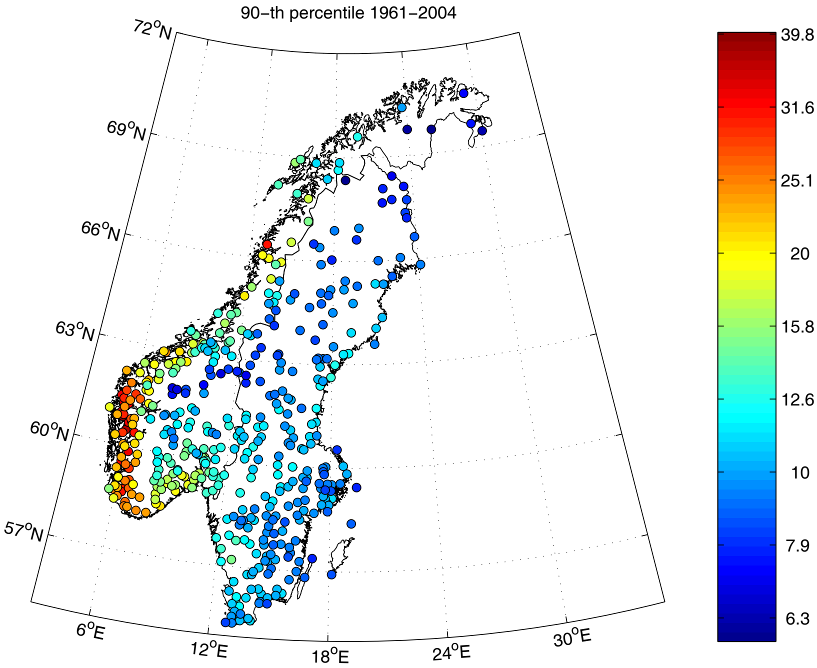


Figure 6: Annual mean 90-th percentile *prec90p* (mm) at all stations with <10% missing values.

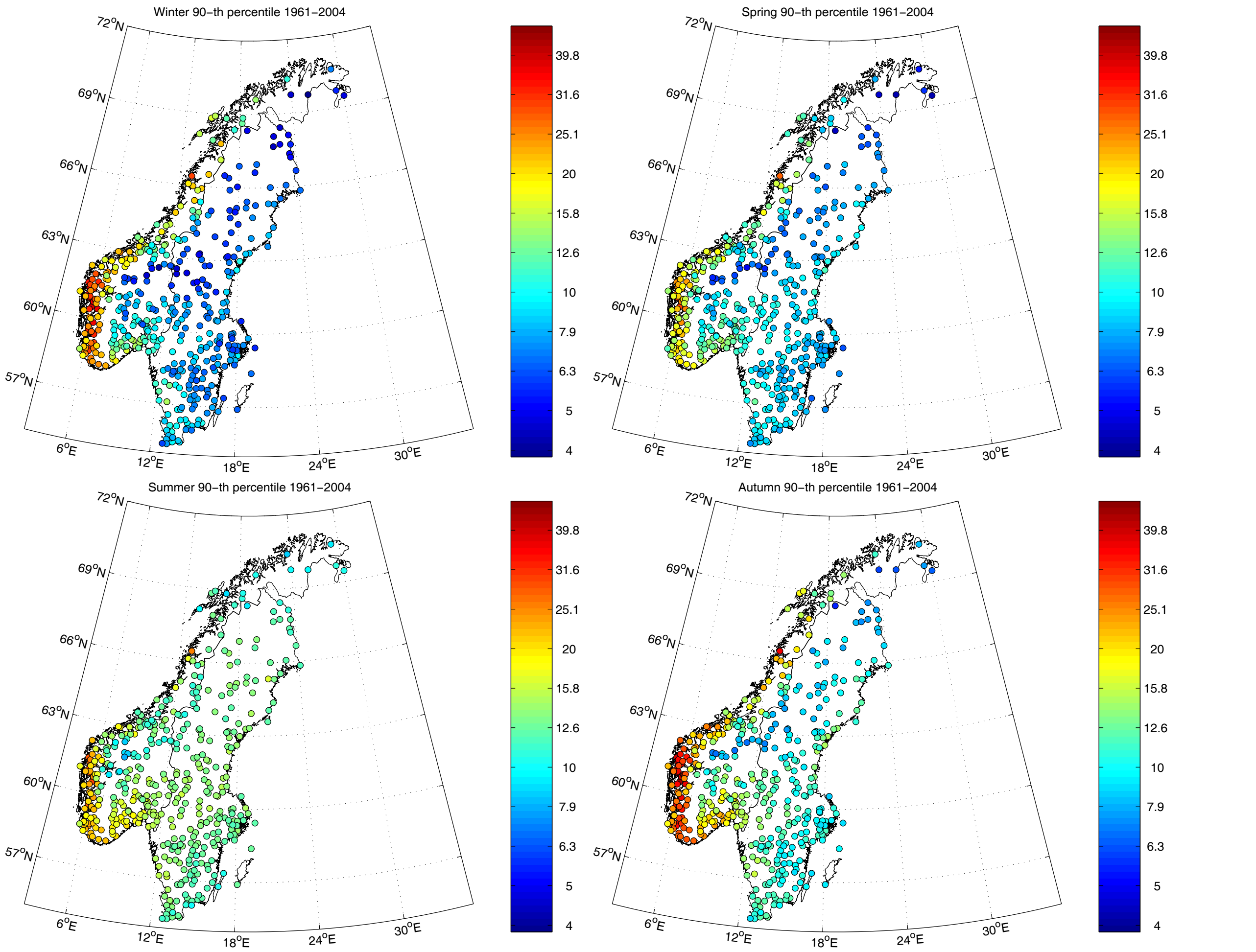


Figure 7: Mean 90-th percentile *pq90* (mm) at all stations with <10% missing values in winter (upper left), spring (upper right), summer (lower left) and autumn (lower right)

The following two figures display the annual (Figure 8) and seasonal (Figure 9) patterns of *pq99*. Annual *pq99* shows in general the same pattern as the annual *pq90*, however, the range in *pq99* including all stations (17-87 mm) is considerably larger than the corresponding range for *pq90* (6-40 mm). For Swedish stations, annual *pq99* varies between 19 and 37.5 mm. Not surprisingly, the seasonal patterns of *pq99* are very similar to the seasonal patterns of *pq90*. At Swedish stations, the strongest *pq99* again occurs in summer when it ranges between 22 and 40 mm and are weakest in spring when *pq99* lies between 9.5 and 25 mm. In autumn and winter, *pq99* is highest along the Swedish West Coast and at some selected stations along the Baltic Coast.

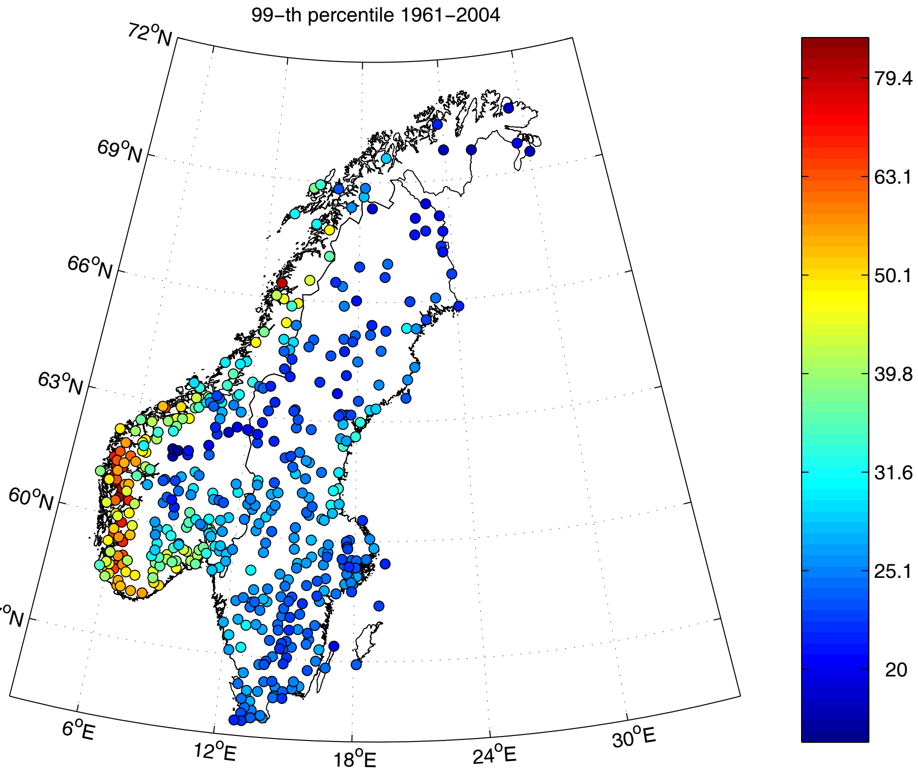


Figure 8: Annual mean 99-th percentile *prec99p* (mm) at all stations with <10% missing values.

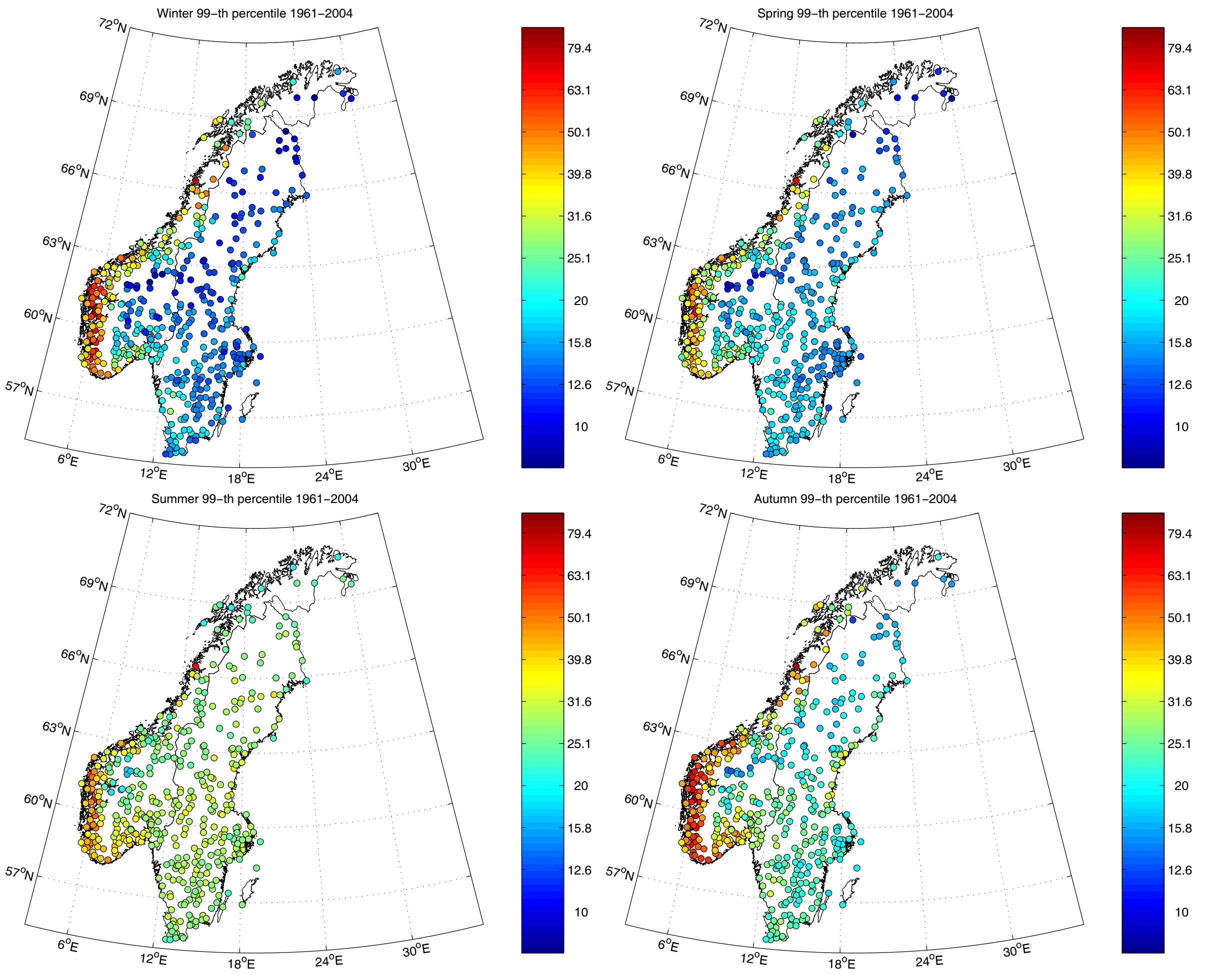


Figure 9: Mean 99-th percentile *prec99p* (mm) at all stations with <10% missing values in winter (upper left), spring (upper right), summer (lower left) and autumn (lower right).

Figure 10 and 11 show annual and seasonal maps of the mean maximum amount during one day, *px1d*. The geographical distribution of *px1d* on the annual basis shows the same general features as the annual maps of *pint*, *pq90* and *pq99*, i.e., *px1d* is highest along the southern part of the Norwegian West Coast followed by stations at the Norwegian South Coast. Index *px1d* ranges from 19 to 113 mm taking all stations into account, for Swedish stations only the corresponding interval is 25 to 47 mm. In addition, the seasonal patterns of *px1d* resemble generally the seasonal patterns of *pint*, *pq90* and *pq99*. In the *px1d* distributions, however, the feature with enhanced extremes at stations along the Swedish West Coast and some selected stations along the Baltic Sea Coast (e.g. in autumn to spring) is clearer than in the corresponding patterns of *pq90* and *pq99*.

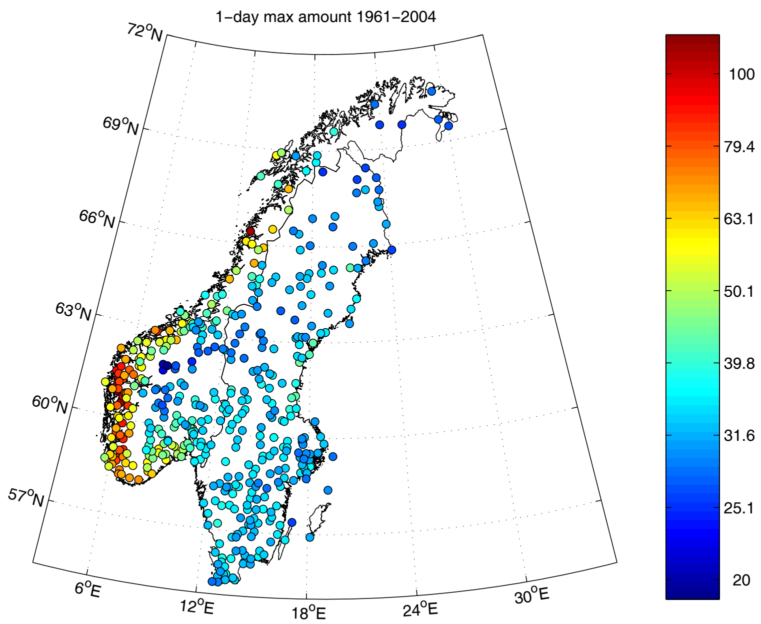


Figure 10: Mean annual maximum 1-day amount *px1d* (mm) at all stations with <10% missing values.

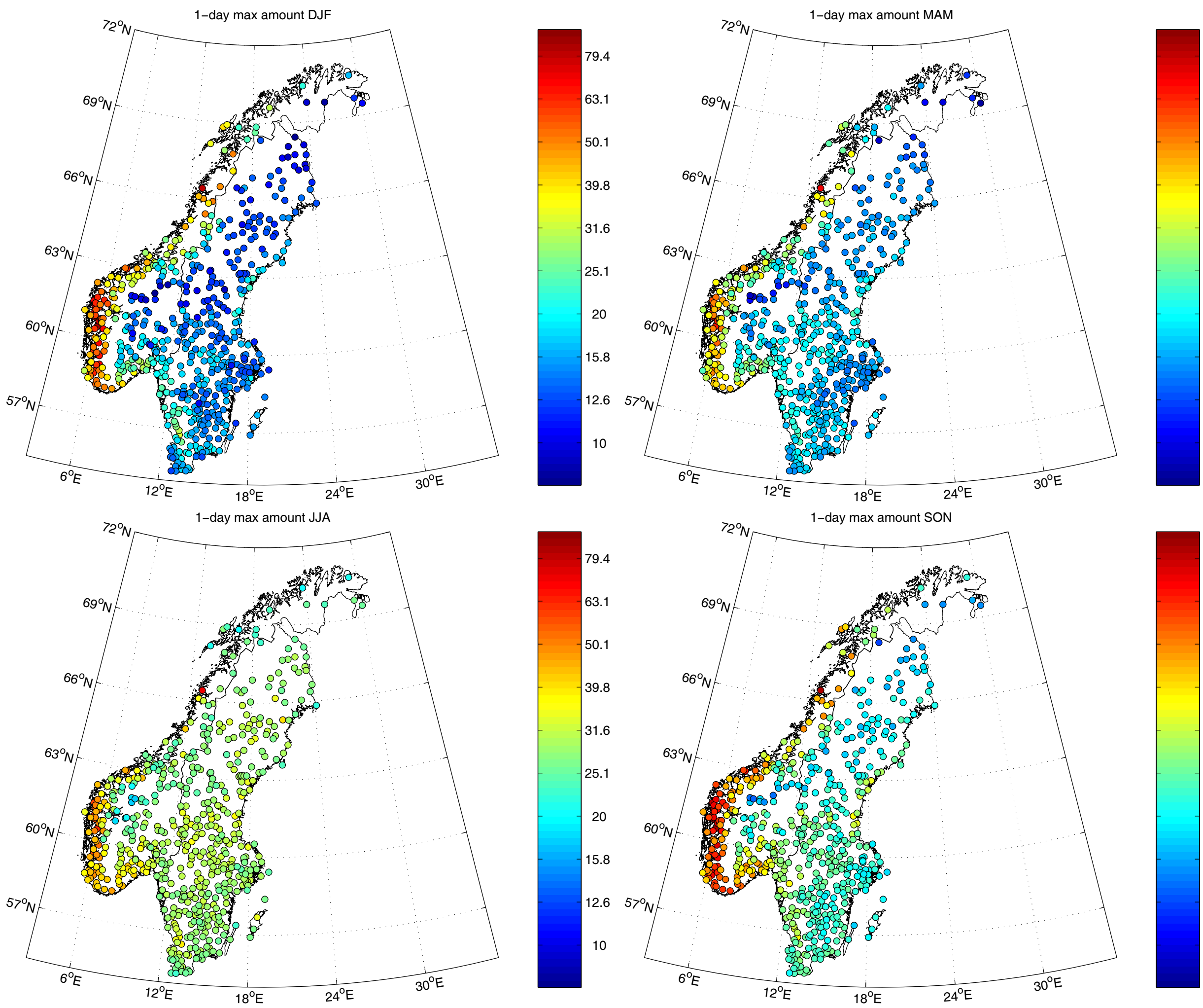


Figure 11: Mean seasonal maximum 1-day amount *px1d* (mm) at all stations with <10% missing values in winter, spring, summer and autumn.

In Figures 12 and 13, the annual and seasonal patterns of the mean maximum amount over five days, *px5d*, are given. Annual and the seasonal patterns of *px5d* are very similar to those spatial of *px1d* at corresponding time scales. The range in *px5d* across Scandinavia is rather big with 33 mm at the driest and 260 mm at the wettest locations. For Swedish stations, *px5d* ranges from 39 to 82 mm.

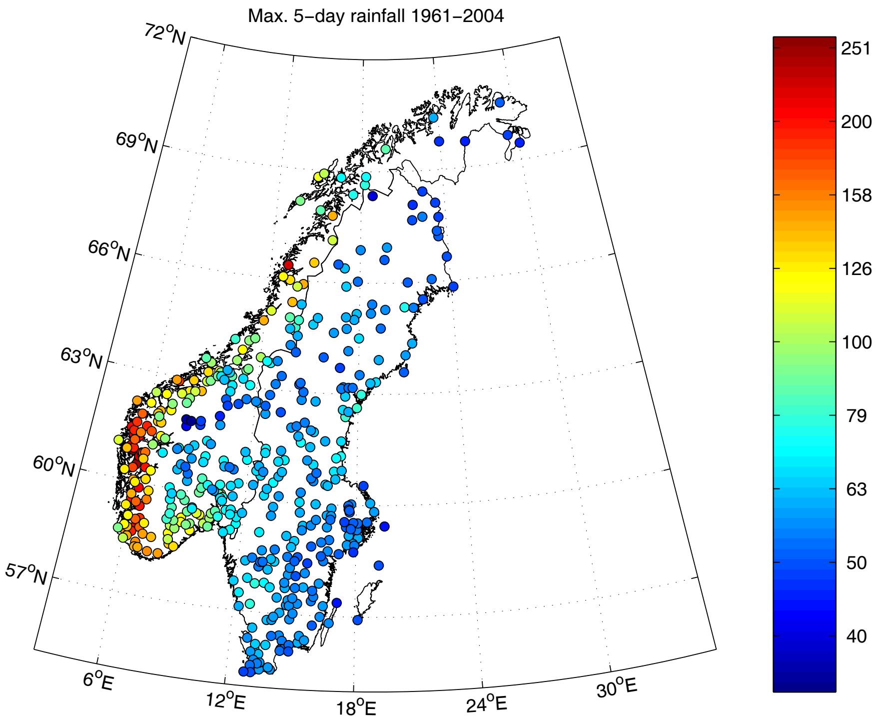


Figure 12: Mean annual maximum 5-day amount *px5d* (mm) at all stations with <10% missing values.

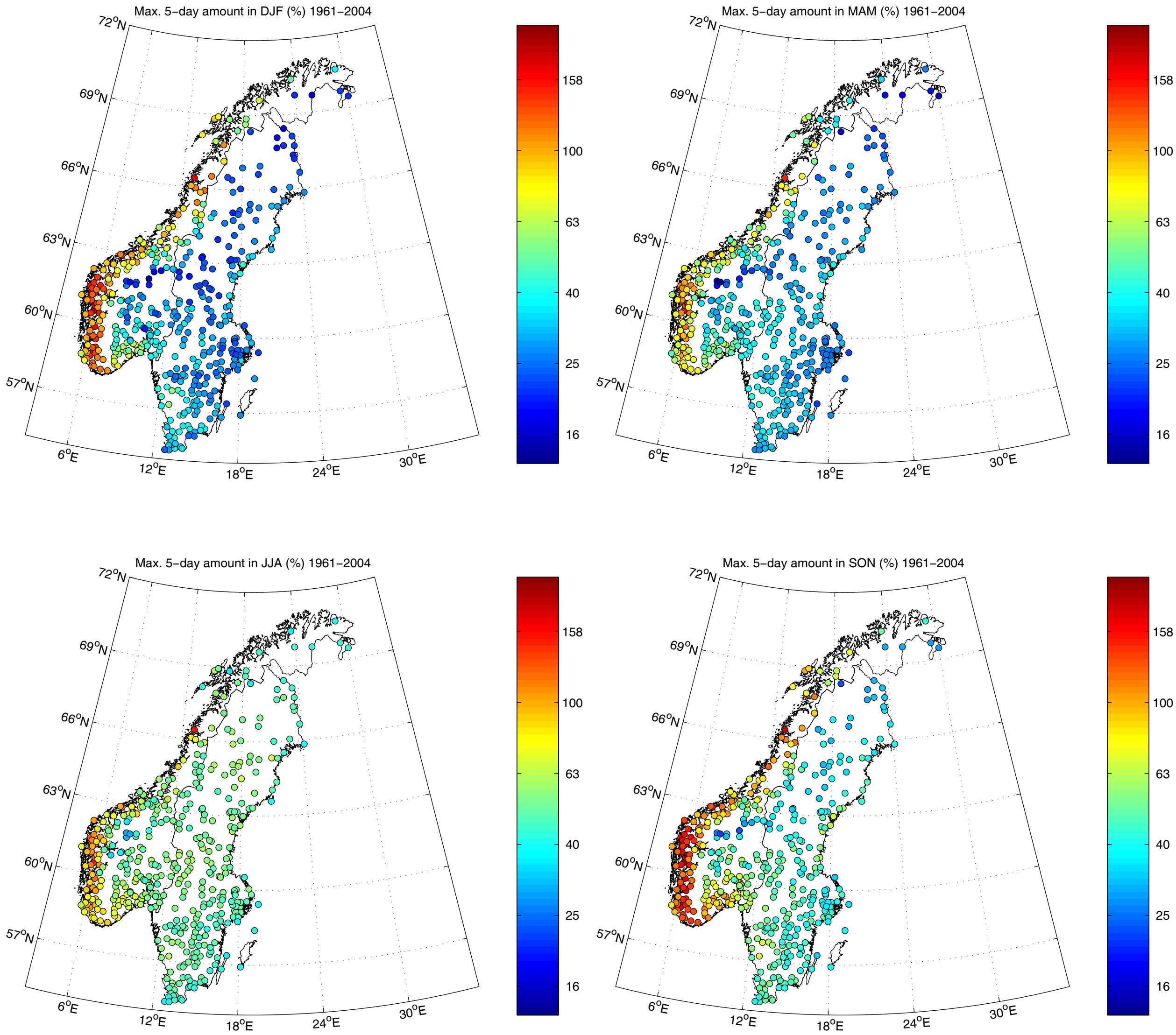


Figure 13: Mean seasonal maximum 5-day amount *px5d* (mm) at all stations with <10% missing values in winter, spring, summer and autumn.

Figures 14 and 15 show annual and seasonal maps of the index *pnl90*, the number of days exceeding the long-term 90th percentile. The long-term 90th percentile is calculated for the period 1961-1990 and differs from *pq90* insofar as it is based on all rainy days in this 30 year period (in contrast, *pq90* is calculated individually for each year). Index *pnl90* is highest along the Norwegian West Coast but is also relatively high in the middle part of Southern Sweden. The spatial distribution of *pnl90* varies with season: the autumn and winter patterns are similar to the annual pattern. In spring, *pnl90* is much lower than those in other seasons and does not vary much with location. A different picture appears in summer when *pnl90* is generally larger at all stations and highest at locations away from the coast line. The summer pattern is almost reversed to the winter pattern which implies that inland locations experience their relative rainfall extremes during the summer, while coastal stations, especially along the Norwegian West Coast have their relative extremes mainly in autumn and winter ("relative extremes" means here amounts belonging to the upper tail of the precipitation distribution of a given station).

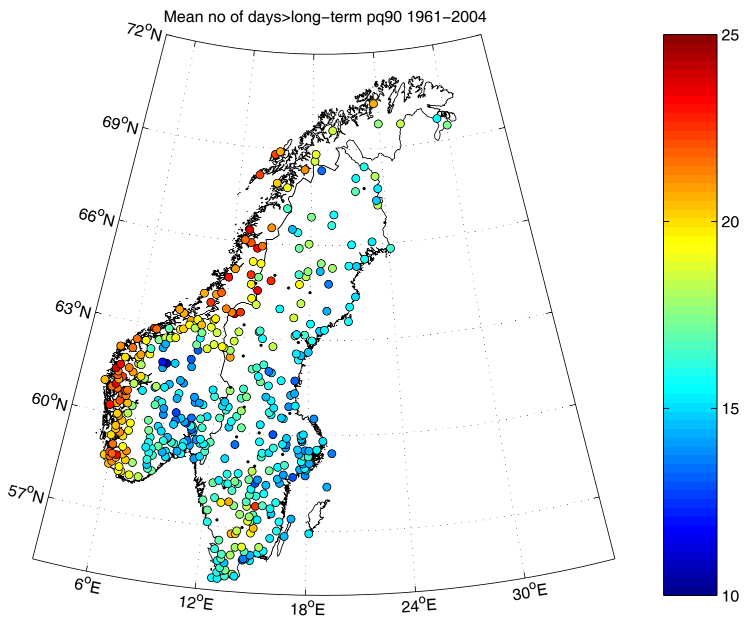


Figure 14: Mean annual number of days exceeding the long-term 90th percentile, *pnl90* at all stations with <10% missing values. The small black dots indicate stations at which *pnl90* is zero.

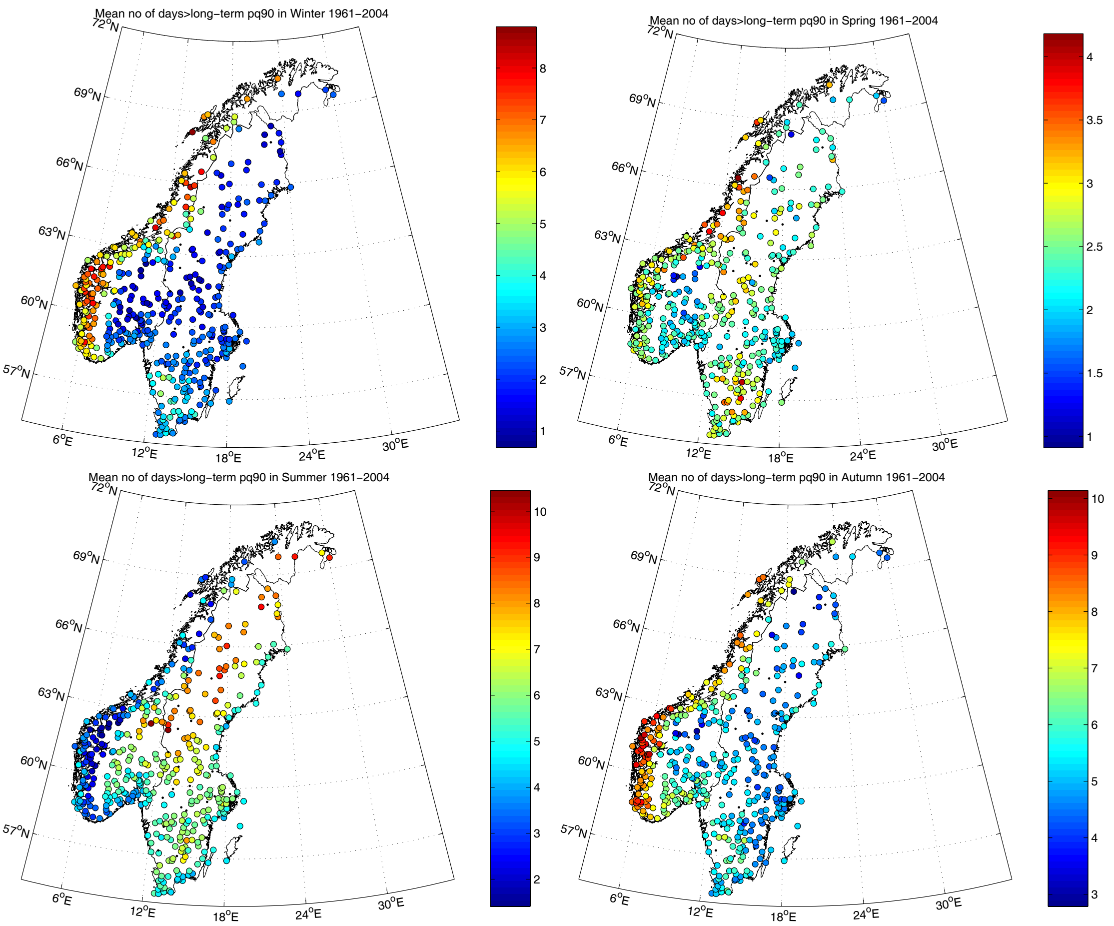


Figure 15: Mean annual number of days exceeding the long-term 90th percentile, *pnl90* at all stations with <10% missing values in winter, spring, summer and autumn. The small black dots indicate stations at which *pnl90* is zero.

Figure 16 shows the mean annual fraction of precipitation >*pnl90*, *plf90*, while Figure 17 gives *plf90* in different seasons. The annual *pfl90* varies between 30 and 45% with increasing *pfl90* towards the east. It indicates that a considerably proportion of the total annual rainfall is made up by events belonging to the uppermost tail of the precipitation probability distribution. The fact that such a large portion of the total annual sums are related to the 10% strongest events does not necessarily mean that these events are extremes in terms of causing any damage. Depending on season, *pfl10* varies between 10 and 60%. The summer pattern mostly resembles the annual spatial distribution indicating that a large part of total summer rainfall especially at non-coastal stations is attributed to the 10% strongest events. In winter, however, this pattern is reversed, which implies that a relatively large part of the winter precipitation at coastal stations, especially along the Norwegian West Coast is attributed to upper tail events.

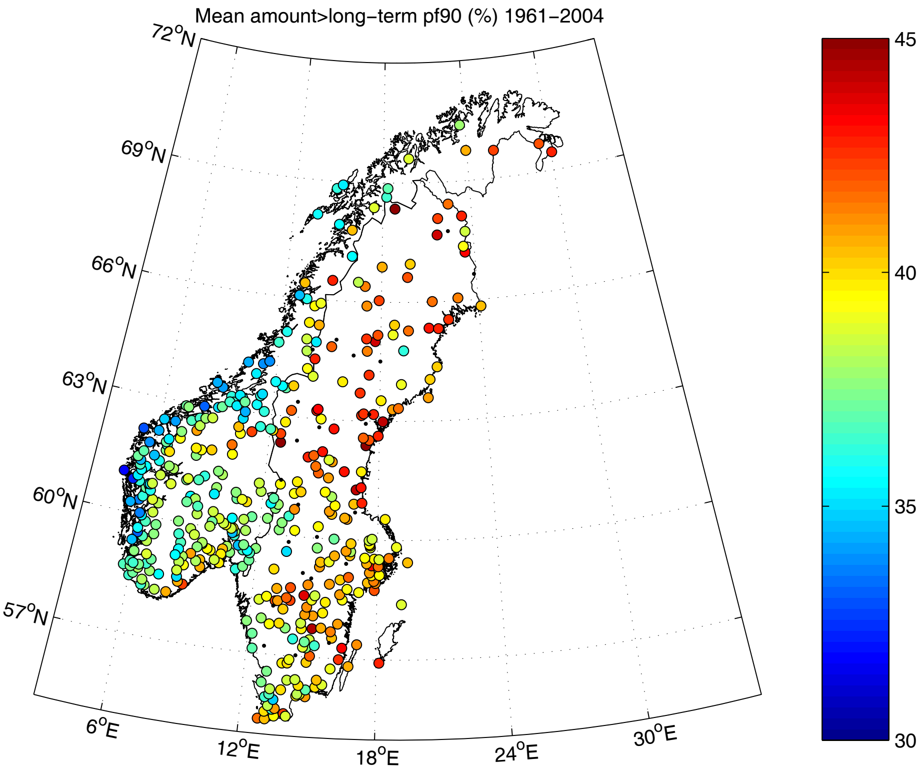


Figure 16: Mean annual fraction of precipitation > *pnl90, pfl90*, at all stations with <10% missing values. The small black dots indicate stations at which *pfl90* is zero.

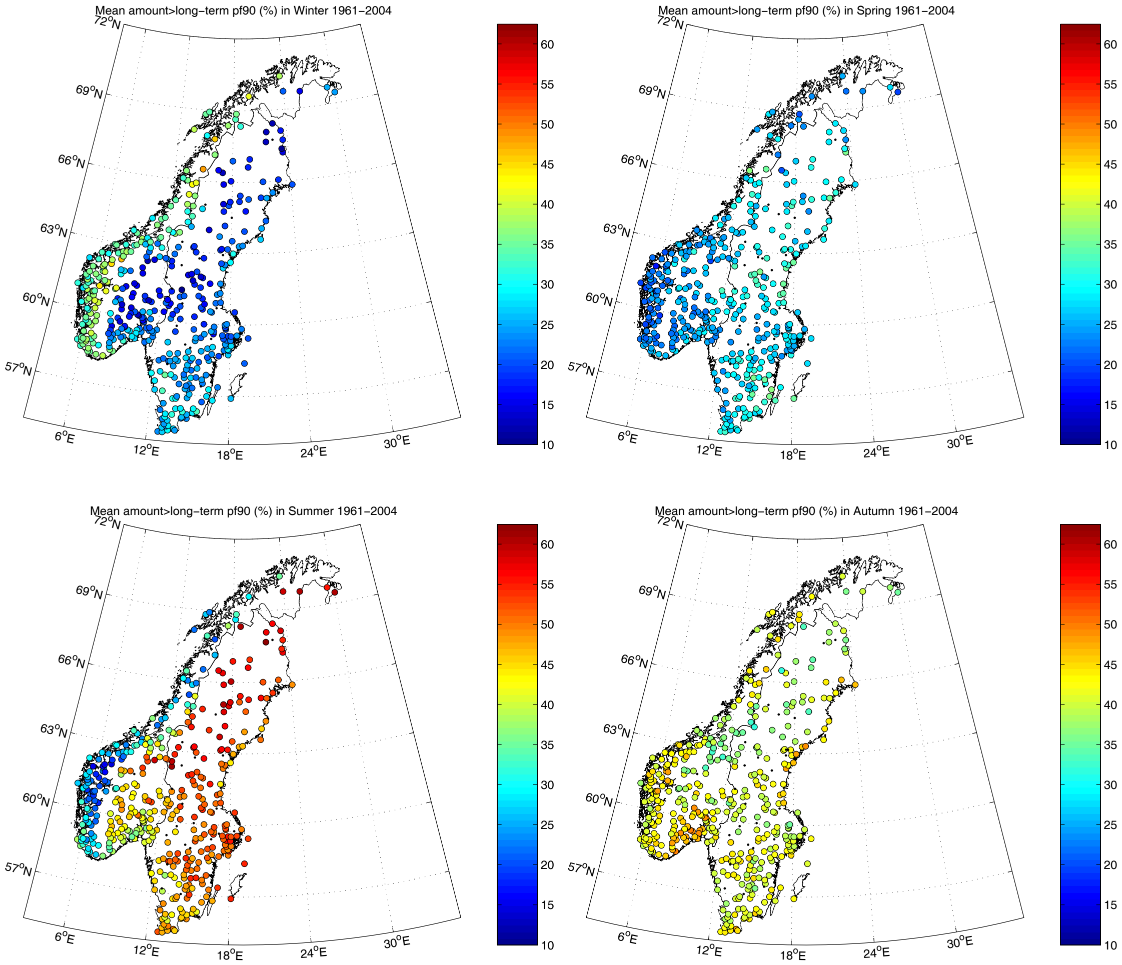


Figure 17: Mean seasonal fraction of precipitation >*pnl90, pfl90*, at all stations with <10% missing values in winter, spring, summer and autumn. The small black dots indicate stations at which *pfl90* is zero.

According to SMHI, days during which rainfall exceeds 40 mm are classified as extremes. Since this measure is used in Sweden for various practical applications, it is also included here as an extreme index. Figure 18 shows the mean annual number of days when precipitation exceeds 40 mm; Figure 19 shows the index for different seasons. As can be seen from the figures, days with precipitation >40 mm are very rare. For Swedish stations these events occur less than one time per year on average. In Norway only coastal stations experience relatively large number of such days; some stations have as many as >15 days per year on average. These events are most likely to occur in autumn and winter.

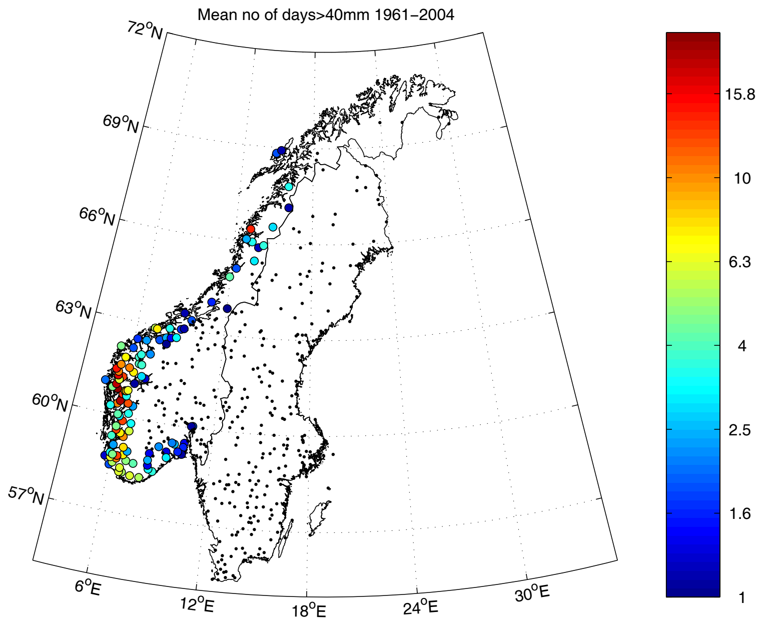


Figure 18: Mean annual number of days with precipitation > 40mm, *pn40m*, at all stations with <10% missing values. The small black dots indicate stations at which *pn40m* <1.

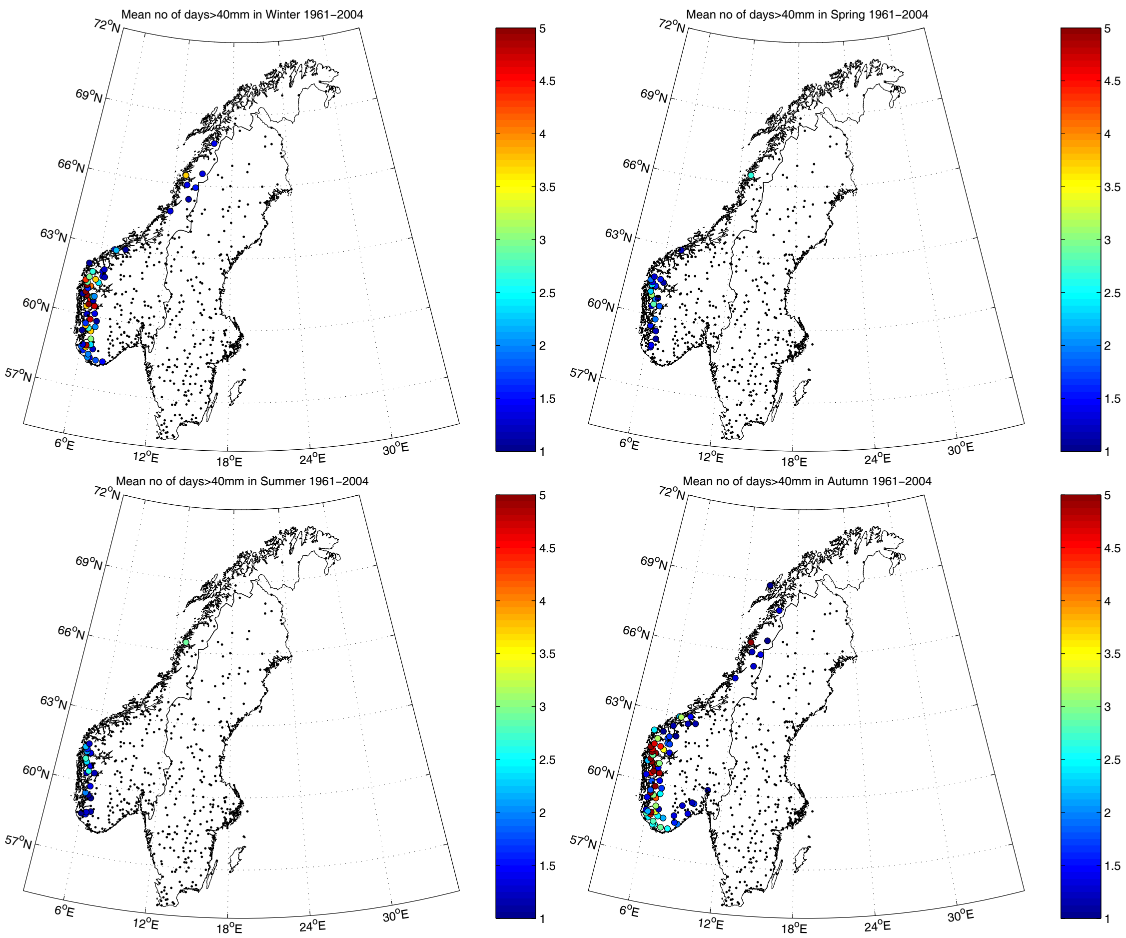


Figure 19: Mean seasonal number of days with precipitation >40 mm, *pn40mm*, at all stations with <10% missing values in winter, spring, summer and autumn. The small black dots indicate stations at which *pn40mm* <1.

Figures 21 and 22 present the annual and seasonal means of the maximum number of consecutive wet days, *pxcwd,* which is a measure for the longest continuous period with rain. On the annual basis, *pxcwd* ranges between 8 to 15 days at the majority of the stations and almost all stations in Sweden. Not surprisingly, Norwegian coastal areas experience the most extended wet spells with average maximum durations between 15 and 28 days. The autumn and winter pattern are rather similar to the annual pattern, while the longest wet spells are generally shorter in spring and summer, when the spatial differences in *pxcwd* across Scandinavia are smaller as well.

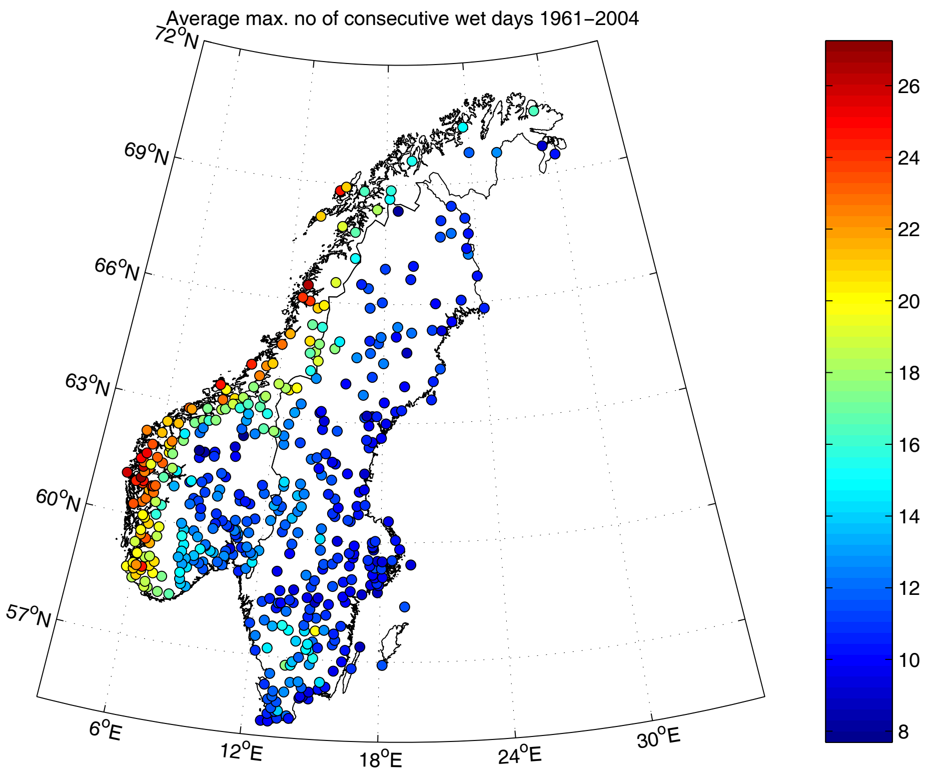


Figure 20: Mean annual maximum number of consecutive wet days, *pxcwd*, at all stations with <10% missing values.

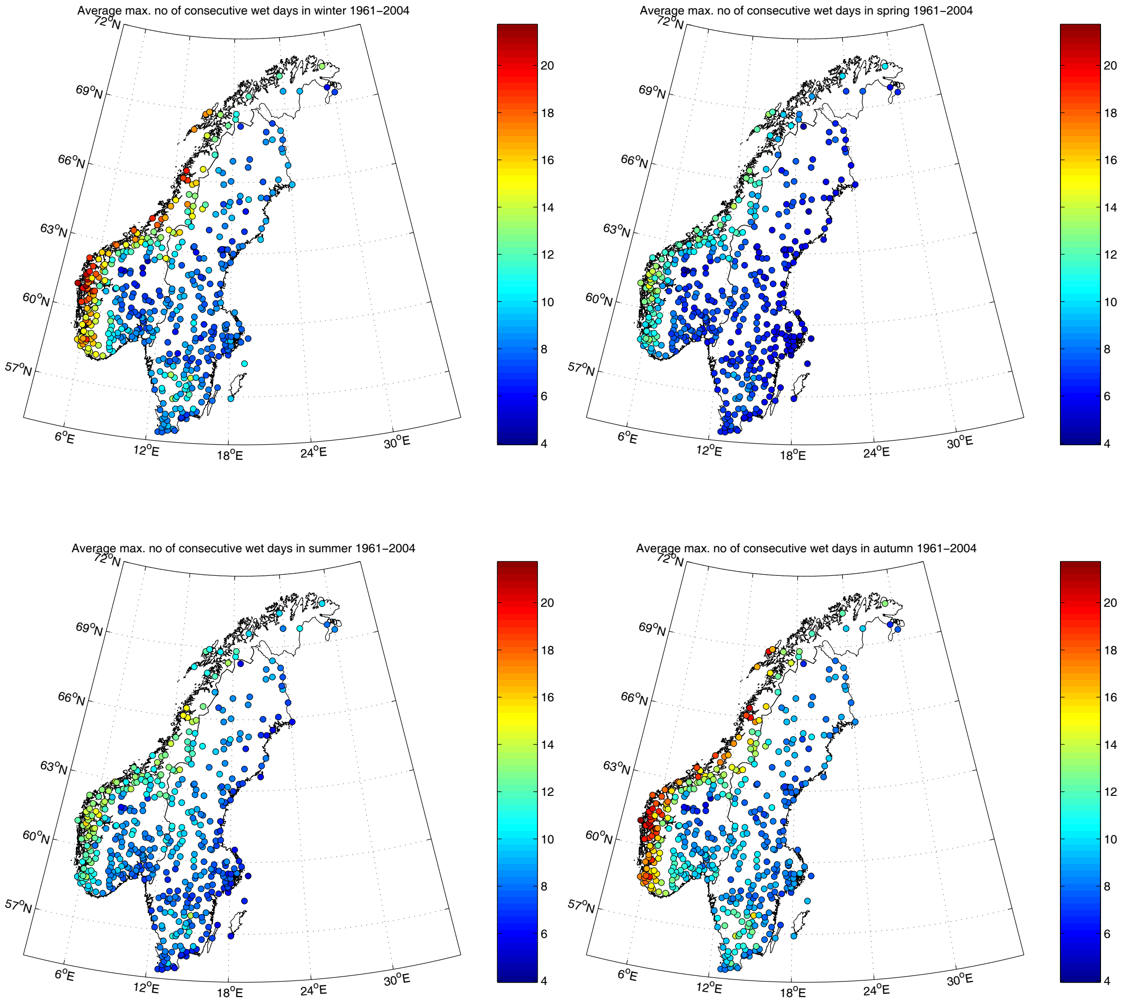


Figure 21: Mean seasonal maximum number of consecutive wet days, *pxcwd*, at all stations with <10% missing values in winter (upper left), spring (upper right), summer (lower left) and autumn (lower right).

Finally, Figure 22 and 23 give the annual and seasonal means of the maximum number of consecutive dry days, *pxcdd*, which indicates the longest period without any rainy days. For Swedish and Norwegian condition, this index range on annual scale between 10 to 22 days. Stations along the Norwegian west coast tend to have smaller *pxcdd* compared to the remaining regions, where *pxcdd* varies more from station to station. There is, however, a general trend with shorter dry periods when moving from south to north. At seasonal scale, spring is characterized by more extended dry periods (at many stations *pxcdd* ranges between 10 to 16 days), while *pxcdd* is generally smaller in autumn and winter (Figure 23). The Norwegian west coast remains in all seasons as the region where *pxcdd* is shortest. Summer shows a well defined spatial pattern with decreasing *pxcdd* from south-east to north-west.

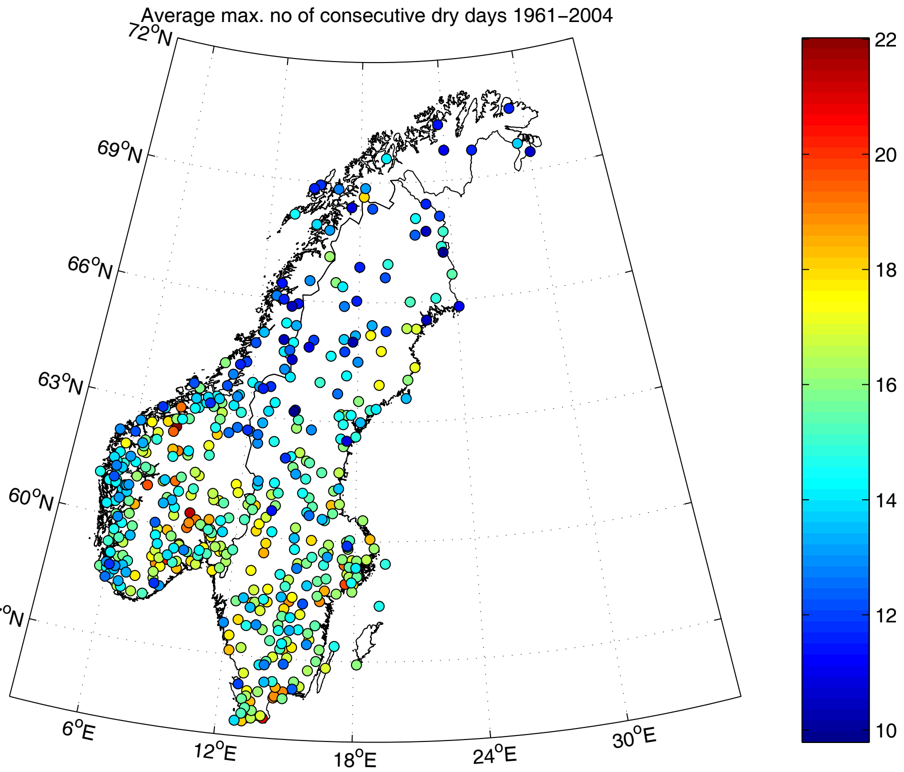


Figure 22: Mean annual maximum number of consecutive dry days, *pxcdd*, at all stations with <10% missing values.

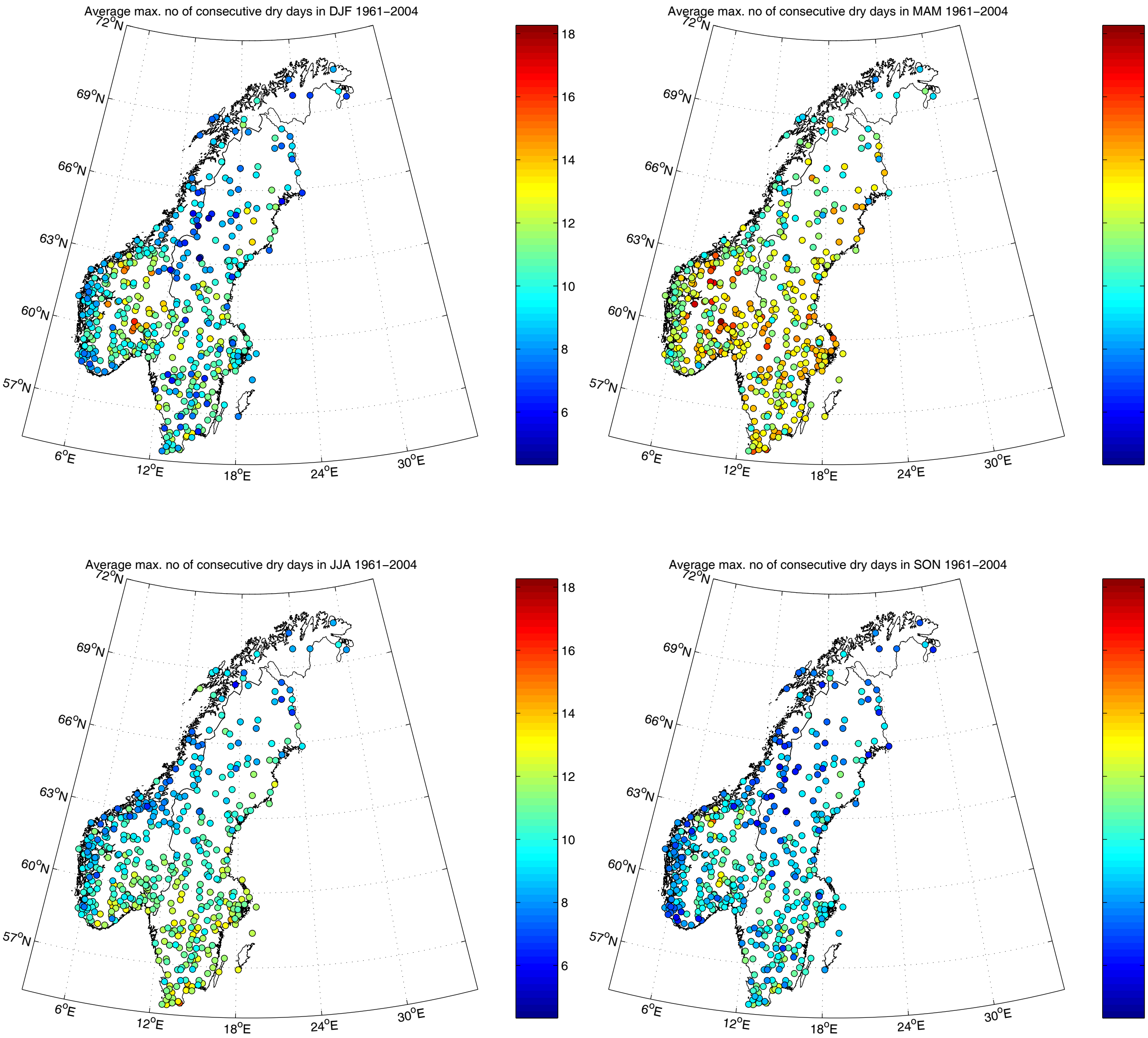


Figure 23: Mean seasonal maximum number of consecutive dry days, *pxcdd*, at all stations with <10% missing values in winter (upper left), spring (upper right), summer (lower left) and autumn (lower right).

4.2 Temporal trends of indices

This section presents the linear trends of the various precipitation indices during 1961-2004. Trends were calculated for the annual index series as well as for the seasonal ones. All trends were tested on their statistical significance using the Mann-Kendall test whose results are given as well.

4.2.1 Annual trend

To get an overview about the spatial distribution of the magnitude and sign of the annual trends, maps for each index were plotted showing the estimated trend at all stations without information on the significances of the trends (Figures 25 to 33). Trends for the amount based indices (*pint, pq90, pq99, px1d,* and *px5d*) are normalized and expressed as the percentage change per 10 years relative to the 1961-2004 average of each station. Furthermore, Table 2 summarizes the results of the analysis of the annual trends and of the significance test.

The magnitude and sign of the trends vary depending on index and station. While the maps of the indices itself often showed distinguishable and coherent spatial patterns, this is to a much lesser extent the case for the spatial distribution of the temporal trends. With other words, magnitude and sign of a trend may vary even over short distances. Some general patterns can be anyhow distinguished. As can be seen from Figures 25 to 33 and from Table 2, a majority of all the stations have increasing trends independent of precipitation index. The only exception is index *pxcdd* which has decreasing trend at the majority of stations. Many stations along the Norwegian West Coast and the western part of Southern Sweden have positive trends in the mean precipitation intensity (Figure 25) and similar patterns can to some extend be found in the maps for the moderate extremes (Figure 27) and the more strong extremes (Figure 28). However, many stations in the eastern part of Southern Sweden and along the Norwegian West Coast have negative trends in *pq99*. The one-day maximum amount (Figure 31) has a “hot spot” in Southern Sweden with many neighboring stations having strong positive trends. Also the trends in the 5 day maximum amounts (Figure 32) are mainly positive, but the south-eastern part of Southern Norway and the eastern part of Southern Sweden are characterized by negative trends. Index *pnl90* has the highest fraction of stations with positive trends. Negative trends in *pnl90* occur only in the south-eastern part of Southern Norway, at some stations along the Baltic Sea and in southernmost Sweden (Figure 30). Also the fraction of precipitation related to events above the long-term 90th percentile has increased at the majority of all the stations, but negative trends can still be found in the mountainous regions in Southern Norway and at scattered coastal and inland locations in both countries (Figure 29). The spatial distribution of trends in the maximum length of consecutive wet days in Sweden is rather complex (Figure 33), but coherent regions with the positive trends can be found in the south-western part of Southern Norway, while the north-eastern part of Southern Norway is dominated by negative trends. Negative trends at many locations dominate the map of trends in *pxcdd* (Figure 34), but southern-most Sweden is characterized by a cluster of stations with positive trends.

Table 2: Fraction of stations (%) having either positive (column 2) or negative trends (column 5). ** indicate fraction of stations with significant trend at 0.05% level, while *** indicates a significance level of 0.01.

	positive	positive**	positive***	negative	negative**	negative***
nrain	71.1	9.4	7.1	28.9	2.5	0.4
pint	72.1	8.7	10.2	27.9	2.3	2.1
pq90	77.1	11.2	6.4	22.9	1.0	2.9
pq99	71.1	7.7	2.5	28.9	0.4	0.0
px1d	69.4	5.4	2.5	30.6	0.2	0.0
px5d	75.7	7.0	3.7	24.3	0.4	0.0
pnl90	88.0	12.9	7.2	12.0	0.0	0.2
pfl90	80.6	9.5	4.1	19.4	0.0	0.0
pxcwd	70.3	6.0	4.2	29.7	1.7	0.2
pxcdd	33.3	2.1	1.2	66.7	7.1	3.9

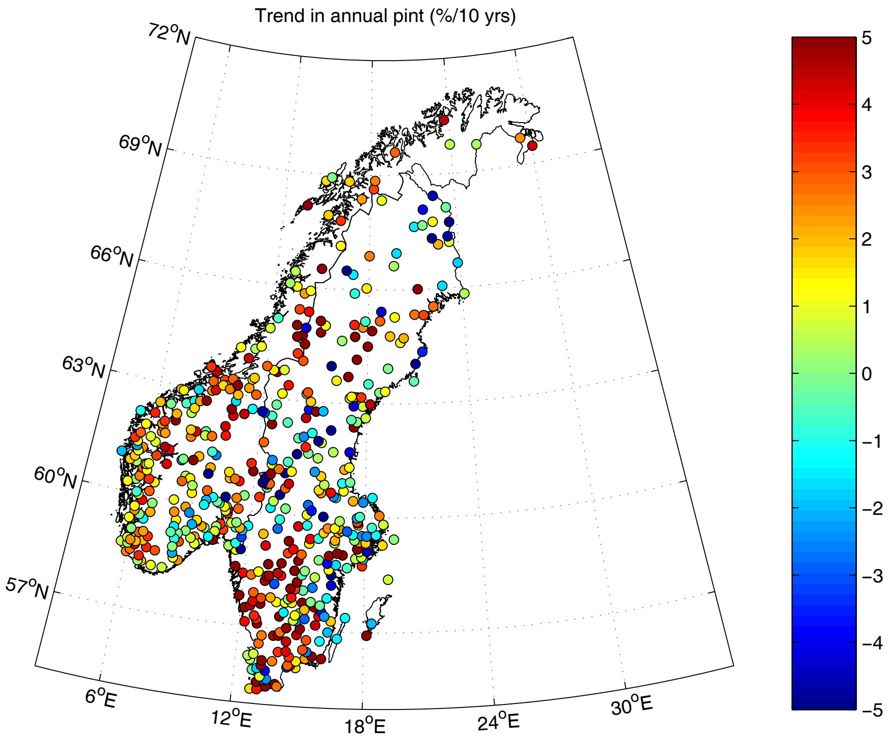


Figure 24: Trend in the mean precipitation intensity, 1961-2004. The colors indicate the magnitude of the trend expressed as a change in percent/10 years.

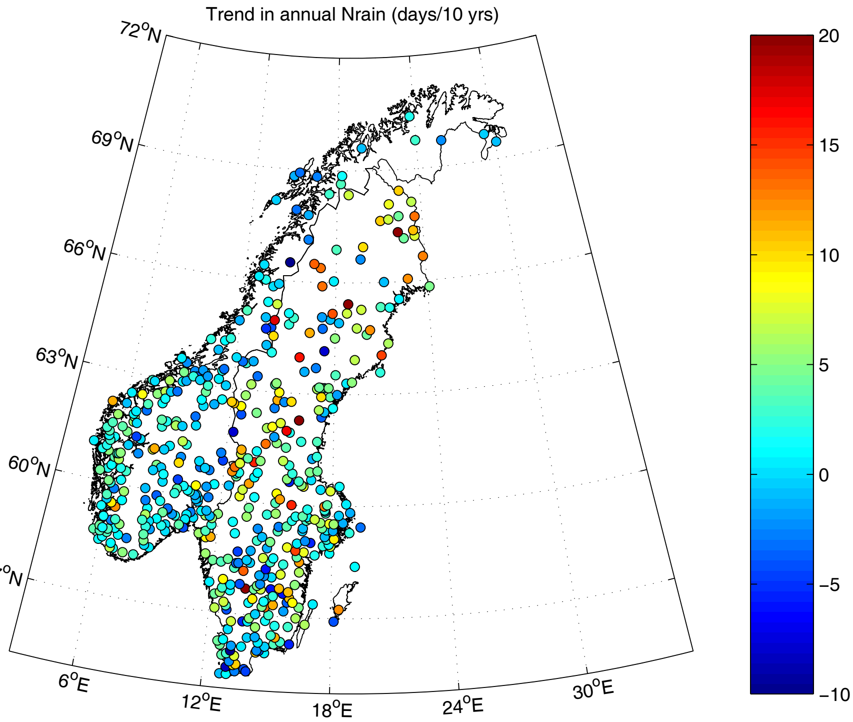


Figure 25: Trend in the number of rain days, 1961-2004. The colors indicate the change in the number of rain days expressed as days/10 years.

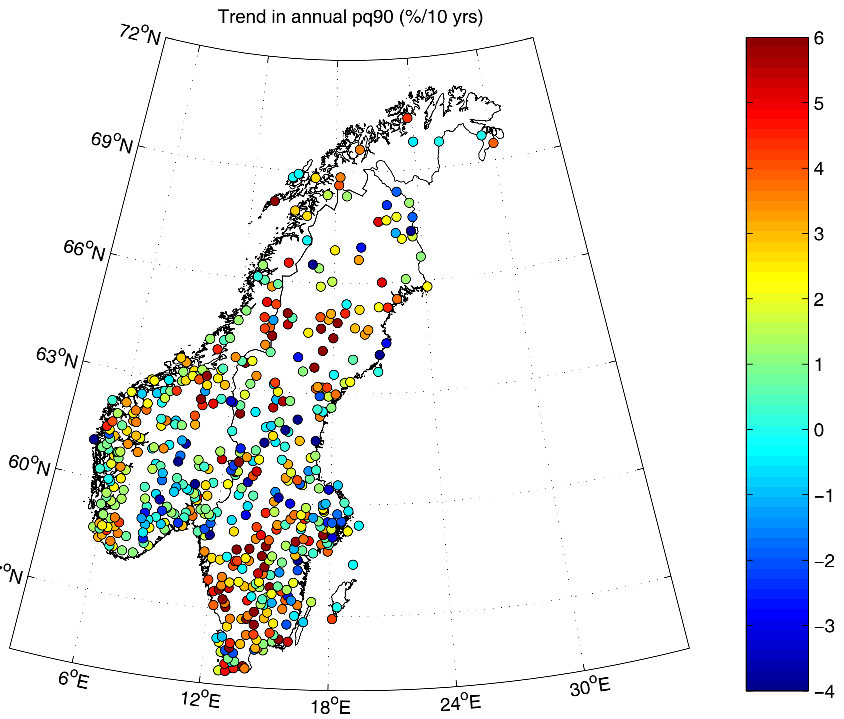


Figure 26: Trend in the moderate precipitation extreme *pq90*, 1961-2004. The colors indicate the magnitude of the trend expressed as a change in percent/10 years.

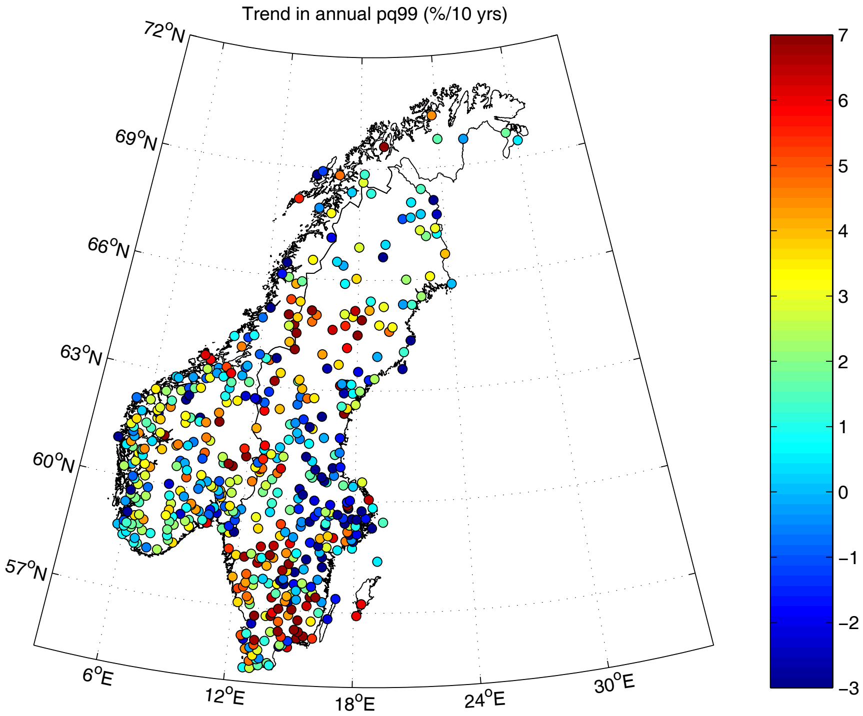


Figure 27: Trend in the precipitation extreme *pq99*, 1961-2004. The colors indicate the magnitude of the trend expressed as a change in percent/10 years.

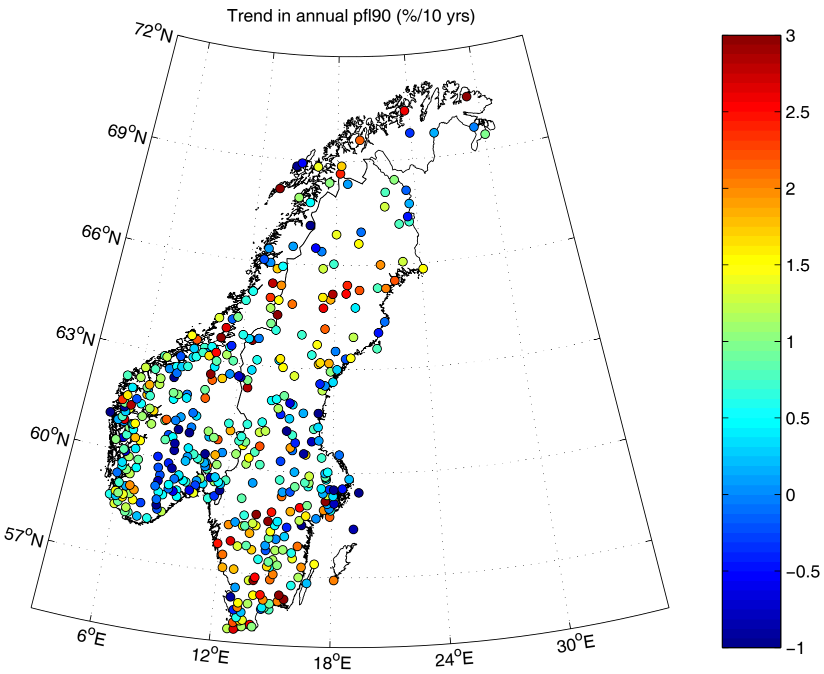


Figure 28: Trend in the fraction of precipitation related to events>long-term 90th percentile, *pfl90*, 1961-2004. The colors indicate the magnitude of the trend expressed as a change/10 years.

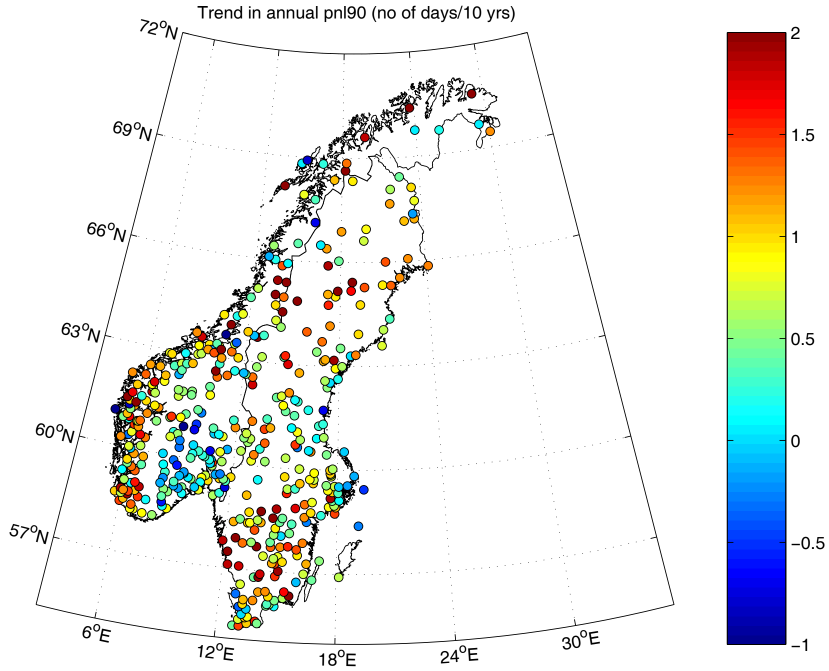


Figure 29: Trend in the number of days with events>long-term 90th percentile, *pnl90*, 1961-2004. The colors indicate the magnitude of the trend expressed as a change in number of days/10 years.

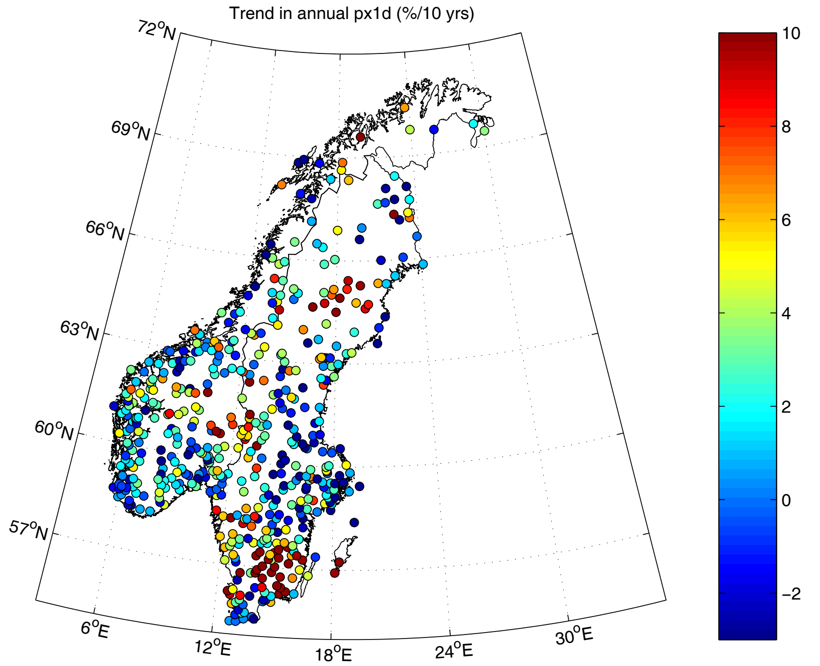


Figure 30: Trend in the one-day maximum amount, *px1d*, 1961-2004. The colors indicate the magnitude of the trend expressed as a change percent/10 years.

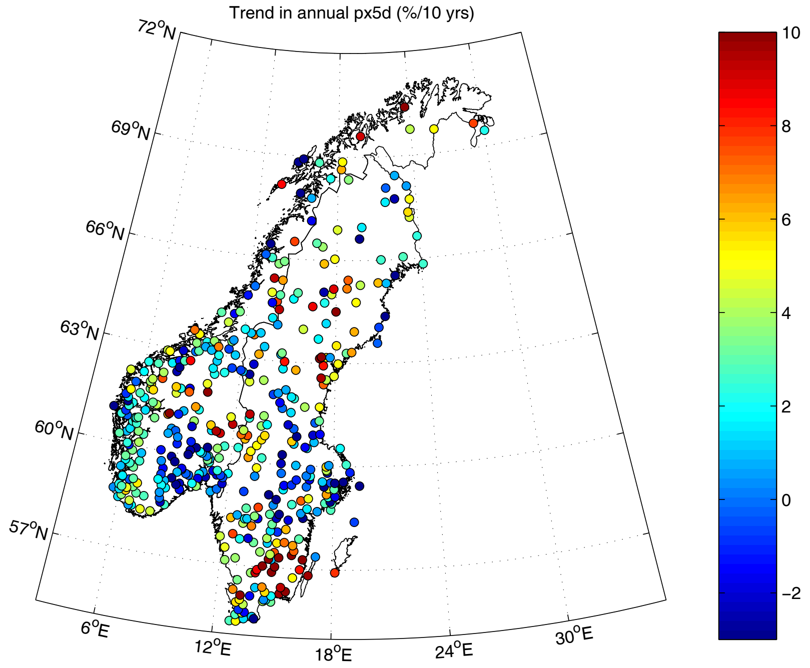


Figure 31: Trend in the five-day maximum amount, *px5d*, 1961-2004. The colors indicate the magnitude of the trend expressed as a change percent/10 years.

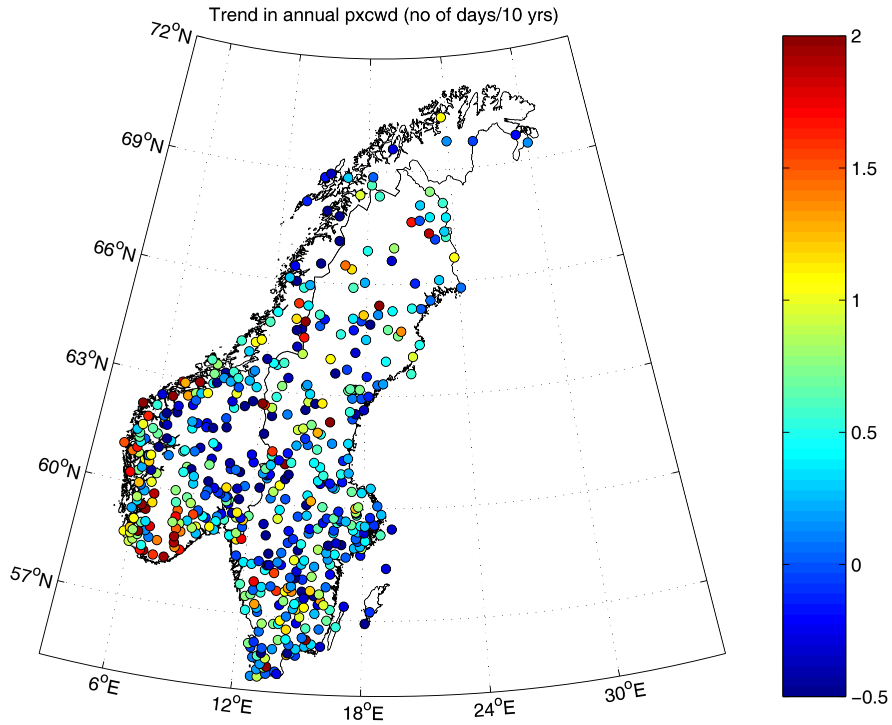


Figure 32: Trend in the maximum number of consecutive wet days, *pxcwd*, 1961-2004. The colors indicate the magnitude of the trend expressed as a change in number of days/10 years.

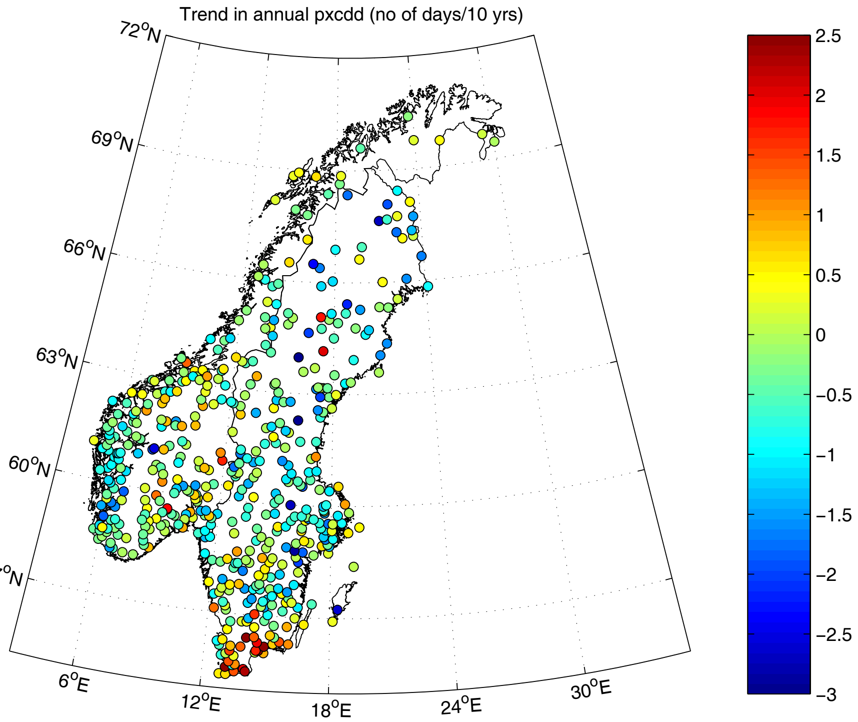
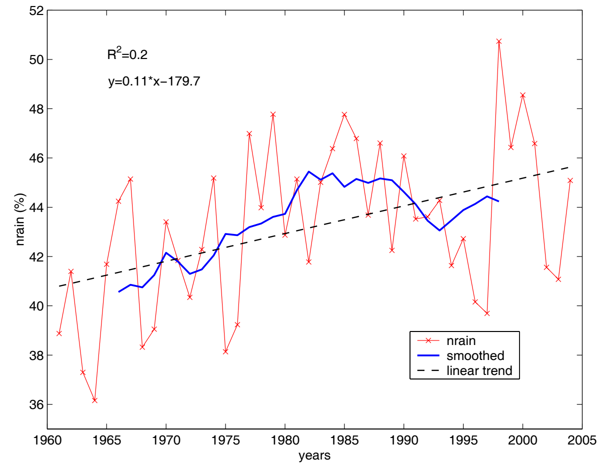
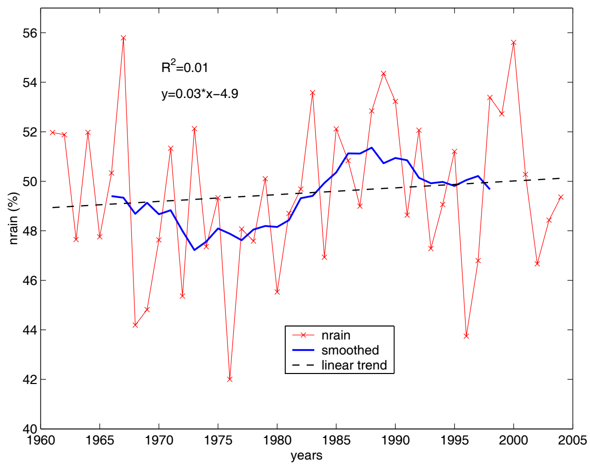


Figure 33: Trend in the maximum number of consecutive dry days, *pxcdd*, 1961-2004. The colors indicate the magnitude of the trend expressed as a change in number of days/10 years.

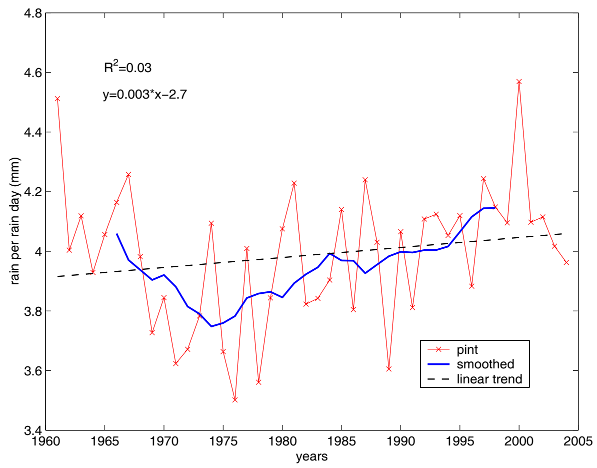
The previous figures and Table 2 indicate that climate in Sweden and Norway has become wetter during the past 44 years even if magnitude and sign in the trends varies depending on index and station. From the information provided so far, it is difficult to get a collected picture about the temporal evolution in the precipitation statistics and the magnitudes of the trends. Therefore, mean index series were created for each index by averaging over all stations with <10% missing data. This was done separately for Swedish and Norwegian stations (i.e., a certain index was averaged over all Swedish and all Norwegians stations separately). Figure 34 shows the averaged series for all indices in Sweden in the left column, for Norway in the right column. All the indices in both countries have trends pointing towards increased precipitation both with respect to occurrence and amount, but the strength of the trend for a certain index slightly differs between Sweden and Norway. Furthermore, it is obvious that the indices vary from year to year and on inter-decadal time scales.


R2=0.2
y=0.11*x−179.7
nrain (%)
years
nrain
smoothed
linear trend

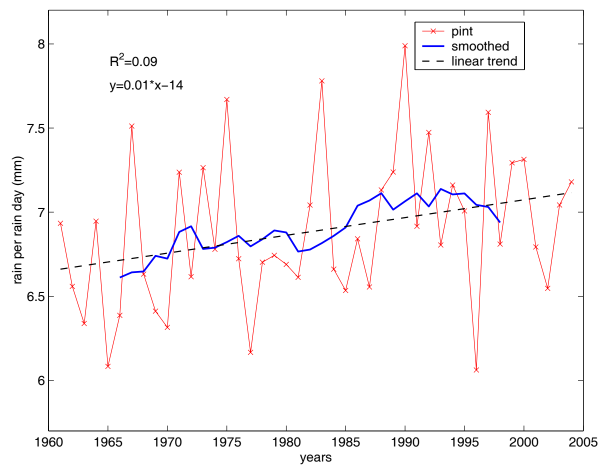
a)


R2=0.01
y=0.03*x−4.9
nrain (%)
years
nrain
smoothed
linear trend

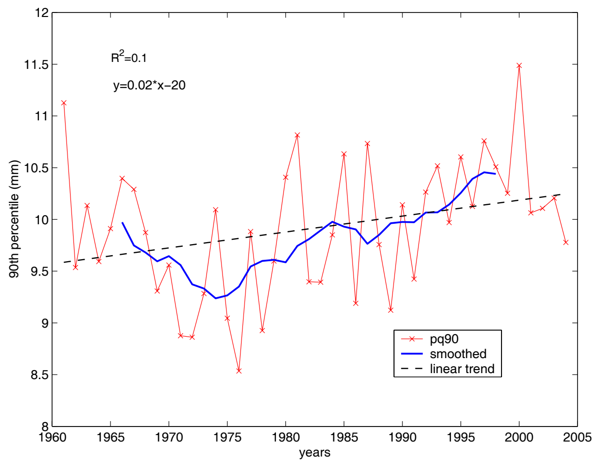
b)


R2=0.03
y=0.003*x−2.7
rain per rain day (mm)
years
pint
smoothed
linear trend

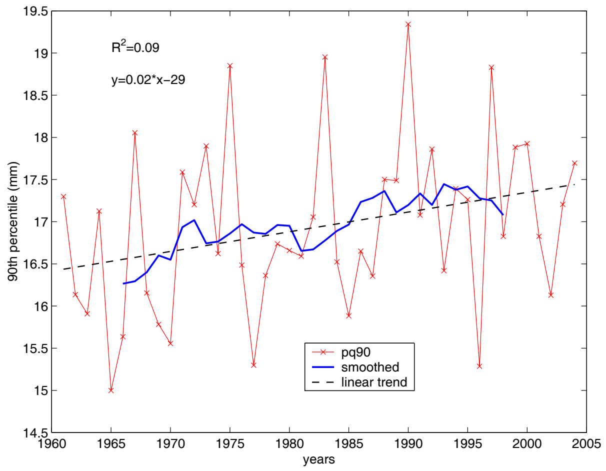
c)


R2=0.09
y=0.01*x−14
rain per rain day (mm)
years
pint
smoothed
linear trend

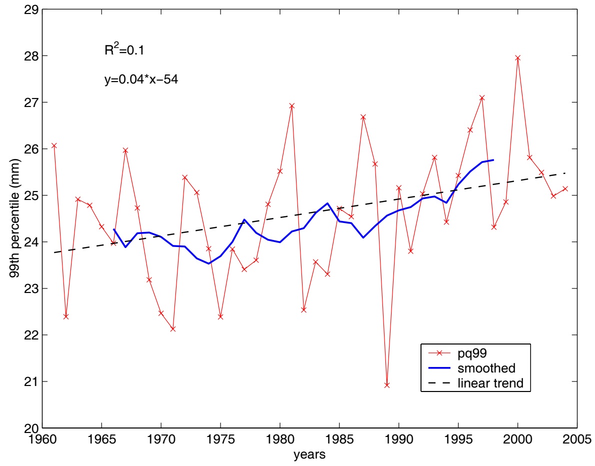
d)


R2=0.1
y=0.02*x−20
90th percentile (mm)
years
pq90
smoothed
linear trend

e)

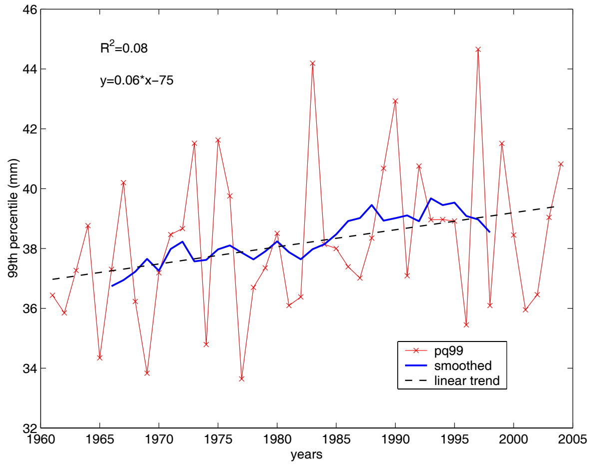

R2=0.09
y=0.02*x−29
90th percentile (mm)
years
pq90
smoothed
linear trend

f)



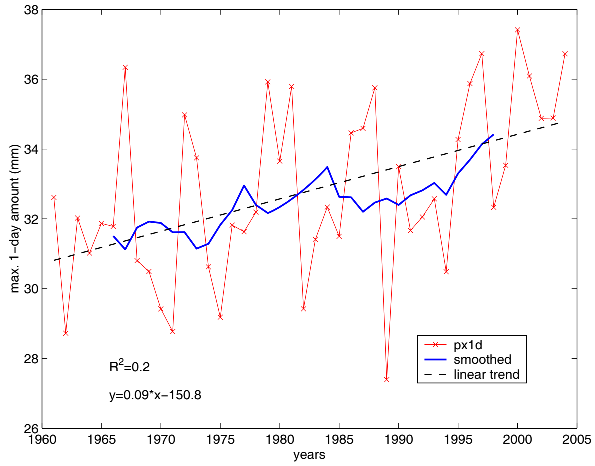
R^2=0.1
y=0.04*x−54
pq99
smoothed
linear trend
99th percentile (mm)
years

g)



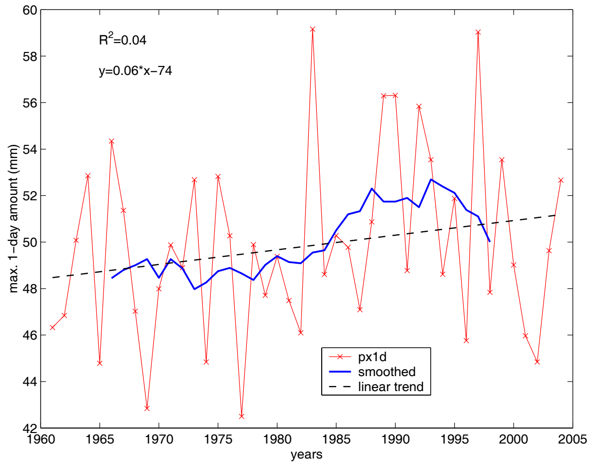
R^2=0.08
y=0.06*x−75
pq99
smoothed
linear trend
99th percentile (mm)
years

h)



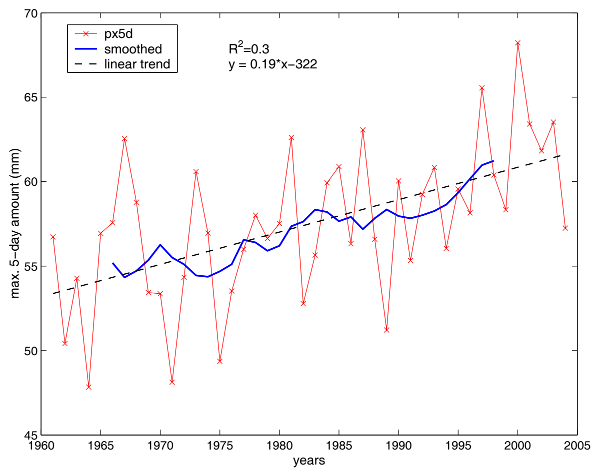
px1d
smoothed
linear trend
R^2=0.2
y=0.09*x−150.8
max. 1−day amount (mm)
years

i)



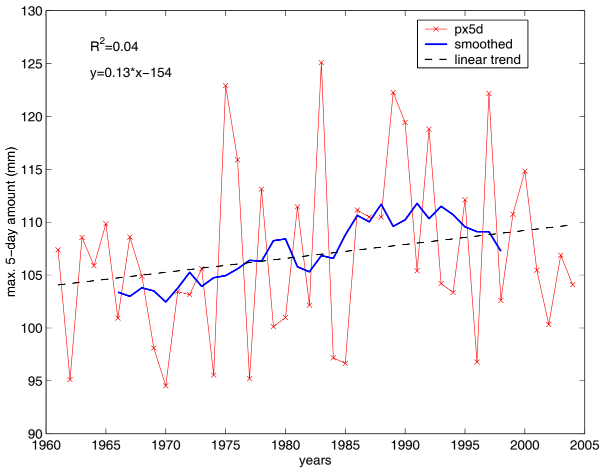
R^2=0.04
y=0.06*x−74
px1d
smoothed
linear trend
max. 1−day amount (mm)
years

j)



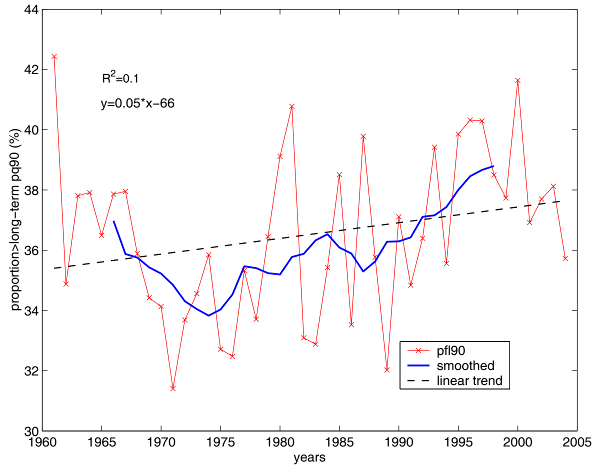
px5d
smoothed
linear trend
R^2=0.3
y = 0.19*x−322
max. 5−day amount (mm)
years

k)

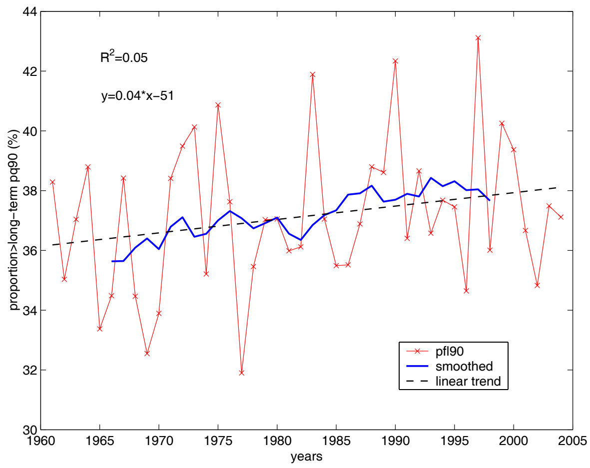


R^2=0.04
y=0.13*x−154
px5d
smoothed
linear trend
max. 5−day amount (mm)
years

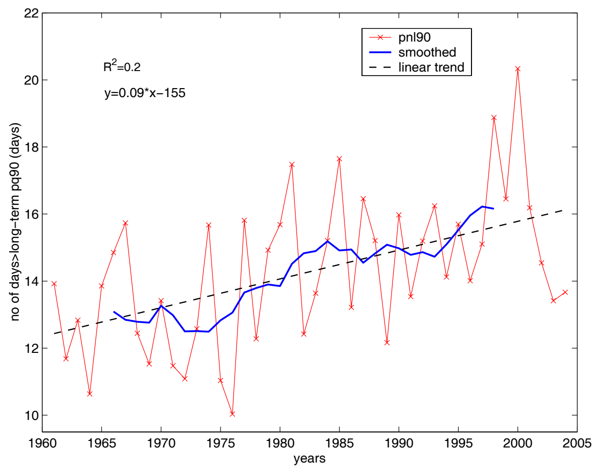
l)


R2=0.1
y=0.05*x−66
proportion>long−term pq90 (%)
years
pfl90
smoothed
linear trend

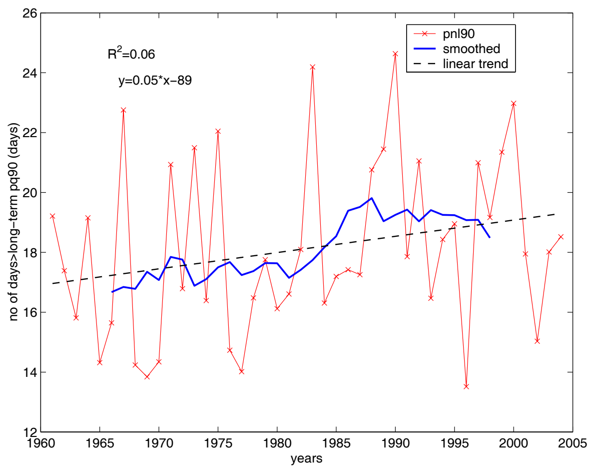
m)


R2=0.05
y=0.04*x−51
proportion>long−term pq90 (%)
years
pfl90
smoothed
linear trend

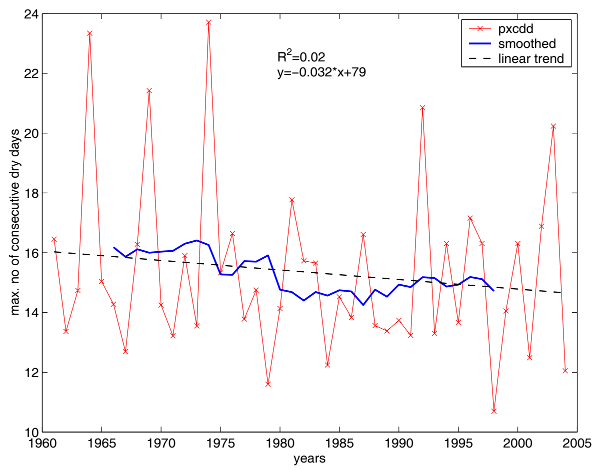
n)


R2=0.2
y=0.09*x−155
no of days>long−term pq90 (days)
years
pnl90
smoothed
linear trend

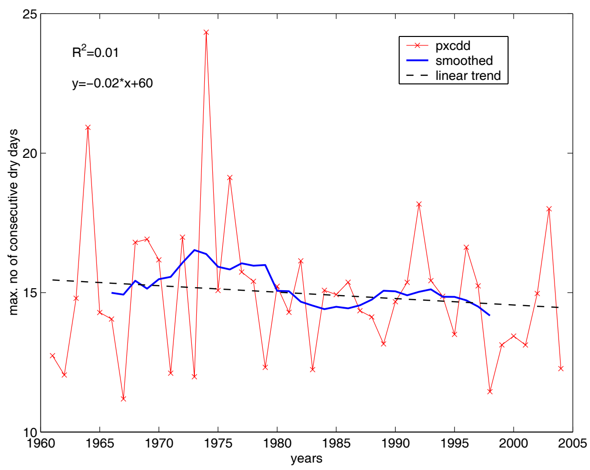
o)


R2=0.06
y=0.05*x−89
no of days>long−term pq90 (days)
years
pnl90
smoothed
linear trend

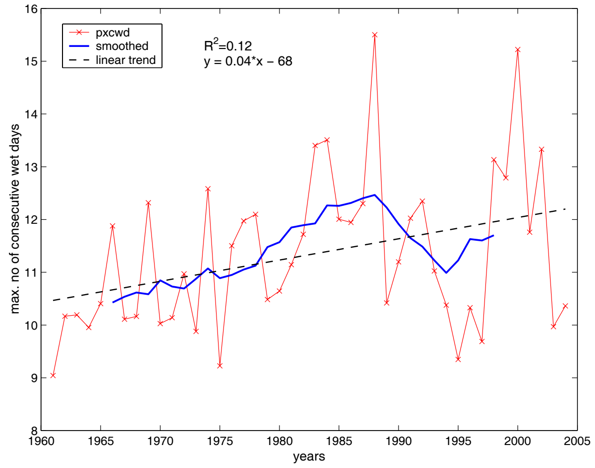
p)


R2=0.02
y=−0.032*x+79
max. no of consecutive dry days
years
pxcdd
smoothed
linear trend

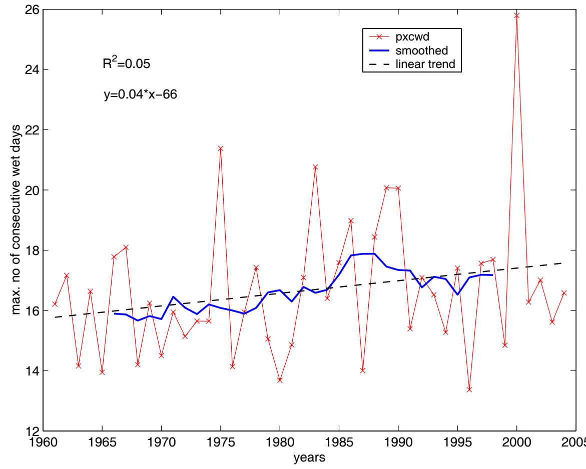
q)


R2=0.01
y=−0.02*x+60
max. no of consecutive dry days
years
pxcdd
smoothed
linear trend

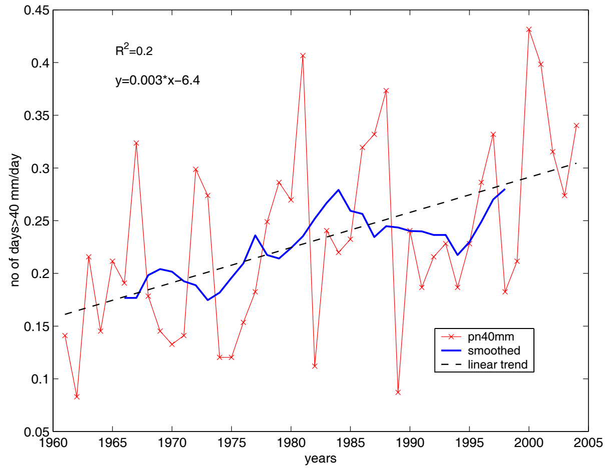
r)



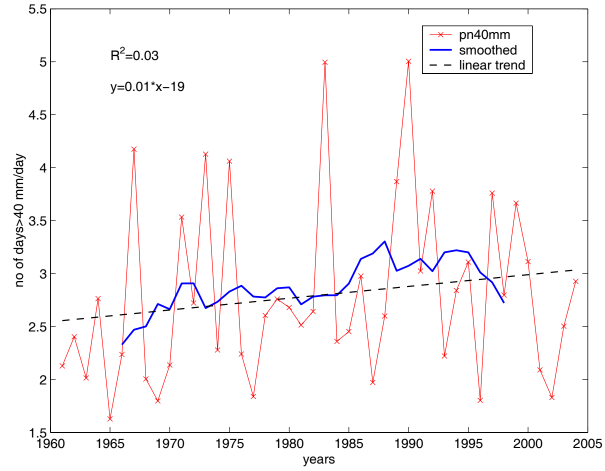
s)



t)



u)



v)

Figure 34: Mean index averaged over all stations with <10% missing data for Sweden (panels a), c) e), g), i), k), m), o), q), s), u)) and Norway (panels b), d), f), h), j), l), n), p), r), t) v)). The smoothed curve represents the 10-year running mean of the averaged index series.

4.2.2 Seasonal trend

The results of the estimated seasonal trends are summarized in Figure 35. It shows the magnitude of the trends at each location (blue dots: Swedish stations, red dots: Norwegian stations) for the various indices and for each season. A corresponding plot for the annual trends is added to enable comparison between seasonal and annual trends. In addition, Table 3 gives the fraction of stations having positive (Table 3a) and negative trends (Table 3b). Statistics regarding the sign of the trend is given for all stations together (column 3 in Table 3a, b), as well as separately for Swedish and Norwegian stations (column 4 and 5 in Table 3a, b) together with the proportion of stations having statistically significant trends (column 6 to 11 Table 3a, b). From Figure 35 and Table 3a it is obvious that the various indices have positive trends at the majority of all the stations (often >70%) in winter, spring and summer. The only exception is index *pxcdd*, having negative trends at the greater part of all stations. Generally, winter is the season having the highest fraction of stations with statistically significant positive trends, either at the 0.05 or 0.01 levels (Table 3a, column 6 to 11). The fraction of stations with negative trends is highest in autumn independent of index, both when taking all the stations together but also when looking at Norway and Sweden separately (the only exception is *pxcwd* in Sweden). Figure 35 shows that the strength of the negative trends in autumn is larger than those in other seasons, but statistically significant decreasing trends are, nevertheless, rare (Table 3b, columns 6-11). All trends indicate increasingly wetter conditions in all seasons, although the magnitude of the change varies with season.

Comparing the strength of the trends in the both countries, trends at Swedish stations have smaller ranges in almost all indices in winter and spring but differences are smaller in summer and autumn. The bigger range in the Norwegian station is especially obvious for *px5d* having much stronger positive trends at some selected stations and this is to a lesser extent also valid for *pq99* and *px1d*. Only *nrain* has a bigger range in its trends at Swedish stations. Regarding the seasonal variation in the number of stations with positive trends, the fraction of stations experiencing increasing trends in any of the indices is always highest in winter in Norway (Table 3a column 5). In Sweden, however, the proportion of stations with positive trends is highest either in spring (*pq90, pq99, px1d, px5d, pfl90*) or summer (*nrain, pint, pnl90, pxcwd*). These findings clearly demonstrate the importance of regional differences in the precipitation statistics across Scandinavia.

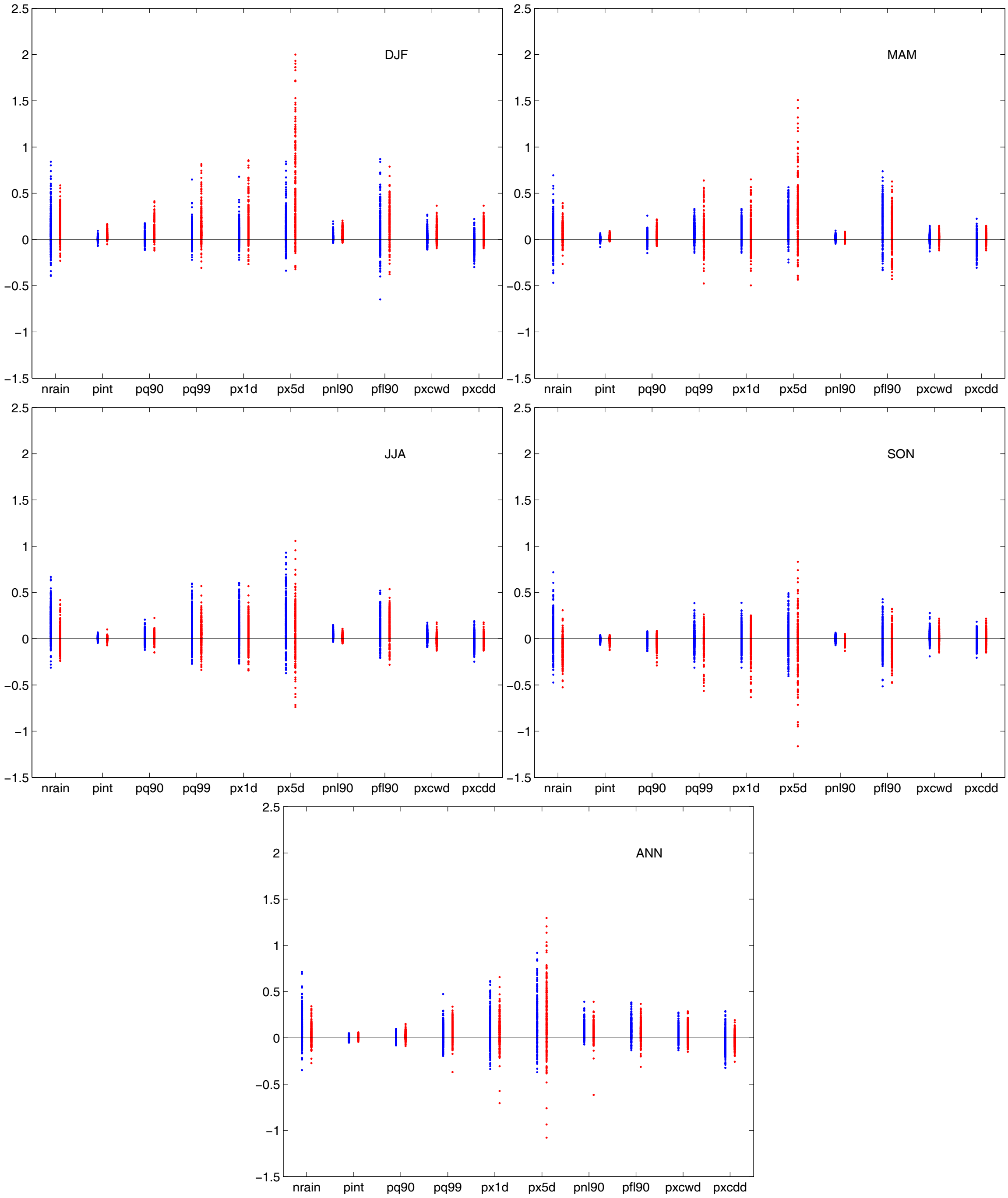


Figure 35: Magnitude of seasonal and annual trends at Swedish stations (blue dots) and Norwegian stations (red dots). The units of the trends are in % for *nrain* and *pfl90*, in mm/day for *pint, pq90, pq99, px1d,* and in days for *px5d*, *pnl90, pxcwd* and *pxcdd*. All trend magnitudes represent changes per year.

Table 3a: Fraction of stations (%) with positive trends in different seasons. Column 3: all stations; column 4: Swedish stations; column 5: Norwegian stations; column 6: all stations with significant trends (0.05%), column 7: Swedish stations with significant trends (0.05%), column 8: Norwegian stations with significant trends (0.05%), column 9-11: same as column 6-8 but for trends significant at 0.01 level.

Index	season	pos all	pos S	pos N	pos* all	pos* S	pos* N	pos** all	pos** S	pos** N
nrain	**DJF**	77.3	72.5	83.6	11.3	8.1	15.5	5.2	6.0	4.1
nrain	**MAM**	68.4	61.5	78.3	5.9	7.4	3.7	2.9	3.6	1.8
nrain	**JJA**	74.0	87.1	55.3	11.4	17.2	3.2	4.8	7.4	0.9
nrain	**SON**	43.9	61.7	18.4	4.4	7.4	0.0	4.4	7.1	0.5
pint	**DJF**	78.5	67.1	93.1	15.1	11.8	19.4	10.3	8.9	12.0
pint	**MAM**	75.6	70.0	83.7	7.1	6.4	8.2	3.6	5.4	1.0
pint	**JJA**	70.0	73.1	65.4	8.2	8.4	7.8	4.6	4.9	4.1
pint	**SON**	33.7	34.1	33.2	0.9	1.3	0.5	0.4	0.6	0.0
pq90	**DJF**	79.9	71.8	90.3	15.5	14.6	16.6	7.8	6.1	10.1
pq90	**MAM**	78.2	78.5	77.9	7.3	8.1	6.3	2.8	3.4	1.9
pq90	**JJA**	68.3	66.7	70.5	6.3	8.1	3.7	1.9	1.9	1.8
pq90	**SON**	37.9	42.4	31.3	0.8	1.0	0.5	0.0	0.0	0.0
pq99	**DJF**	77.7	70.4	87.1	10.7	9.3	12.4	3.6	4.3	2.8
pq99	**MAM**	80.4	86.2	72.1	8.9	11.8	4.8	2.6	3.4	1.4
pq99	**JJA**	72.4	76.1	67.3	5.3	5.8	4.6	1.9	2.3	1.4
pq99	**SON**	47.9	50.8	43.8	1.3	2.3	0.0	0.2	0.3	0.0
px1d	**DJF**	77.9	70.7	87.1	12.1	10.4	14.3	3.0	3.9	1.8
px1d	**MAM**	80.6	86.2	72.6	9.1	12.1	4.8	2.6	3.4	1.4
px1d	**JJA**	72.1	76.1	66.4	5.5	6.5	4.1	1.7	1.9	1.4
px1d	**SON**	47.0	51.4	40.6	1.3	2.3	0.0	0.2	0.3	0.0
px5d	**DJF**	85.7	83.3	88.4	13.2	9.2	17.6	7.9	4.2	12.0
px5d	**MAM**	87.1	92.1	81.5	9.6	14.1	4.6	4.8	8.3	0.9
px5d	**JJA**	71.9	80.8	62.0	7.5	10.0	4.6	1.8	2.9	0.5
px5d	**SON**	49.2	52.3	45.8	2.4	2.9	1.9	0.0	0.0	0.0
pnl90	**DJF**	83.8	78.7	89.2	13.6	10.4	17.0	6.9	5.4	8.5
pnl90	**MAM**	84.9	86.4	83.3	4.9	7.7	1.9	1.6	1.8	1.4
pnl90	**JJA**	81.6	93.6	69.0	10.5	16.0	4.8	3.0	4.1	1.9
pnl90	**SON**	39.0	55.2	21.9	0.0	0.0	0.0	0.0	0.0	0.0
pfl90	**DJF**	77.8	69.7	86.3	12.0	9.0	15.1	3.5	3.6	3.3
pfl90	**MAM**	78.2	84.6	71.4	9.0	12.7	5.2	2.8	4.5	1.0
pfl90	**JJA**	80.0	79.0	81.0	6.1	7.8	4.3	1.2	1.4	1.0
pfl90	**SON**	38.7	44.8	32.4	0.7	0.9	0.5	0.5	0.9	0.0
pxcwd	**DJF**	72.1	67.3	78.1	7.5	3.3	12.8	4.3	5.5	2.7
pxcwd	**MAM**	67.4	60.8	76.3	7.2	5.7	9.1	2.5	2.4	2.7
pxcwd	**JJA**	58.8	71.3	41.6	6.5	8.9	3.2	1.7	3.0	0.0
pxcwd	**SON**	69.9	76.7	60.7	5.0	7.0	2.3	3.1	5.0	0.5
pxcdd	**DJF**	36.9	37.50	36.1	2.0	1.84	2.3	0.4	0.00	0.9
pxcdd	**MAM**	27.6	29.73	24.7	1.2	1.01	1.4	0.6	1.01	0.0
pxcdd	**JJA**	41.0	39.60	42.9	1.1	0.33	2.3	1.1	0.66	1.8
pxcdd	**SON**	58.2	57.00	59.8	6.4	5.33	7.8	1.7	2.00	1.4

Table 3b: Same as Table 3a but for negative trends.

		neg all	neg S	neg N	neg * all	neg* S	neg * N	neg ** all	neg ** S	neg ** N
nrain	**DJF**	22.7	27.5	16.4	1.0	1.4	0.5	0.0	0.0	0.0
nrain	**MAM**	31.6	38.5	21.7	1.9	2.9	0.5	1.0	1.6	0.0
nrain	**JJA**	26.0	12.9	44.7	0.4	0.3	0.5	0.0	0.0	0.0
nrain	**SON**	56.1	38.3	81.6	6.6	4.8	9.2	1.9	1.9	1.8
pint	**DJF**	21.5	32.9	6.9	1.0	1.8	0.0	0.6	0.7	0.5
pint	**MAM**	24.4	30.0	16.3	1.0	1.0	1.0	0.6	1.0	0.0
pint	**JJA**	30.0	26.9	34.6	1.3	0.6	2.3	0.4	0.3	0.5
pint	**SON**	66.3	65.9	66.8	4.4	5.5	2.8	1.7	2.9	0.0
pq90	**DJF**	20.1	28.2	9.7	0.4	0.4	0.5	0.2	0.4	0.0
pq90	**MAM**	21.8	21.5	22.1	0.4	0.7	0.0	0.0	0.0	0.0
pq90	**JJA**	31.7	33.3	29.5	0.6	0.0	1.4	0.0	0.0	0.0
pq90	**SON**	62.1	57.6	68.7	2.7	2.6	2.8	0.8	1.0	0.5
pq99	**DJF**	22.3	29.6	12.9	0.0	0.0	0.0	0.2	0.4	0.0
pq99	**MAM**	19.6	13.8	27.9	0.4	0.0	1.0	0.6	0.0	1.4
pq99	**JJA**	27.6	23.9	32.7	0.2	0.0	0.5	0.0	0.0	0.0
pq99	**SON**	52.1	49.2	56.2	2.1	2.6	1.4	0.0	0.0	0.0
px1d	**DJF**	22.1	29.3	12.9	0.0	0.0	0.0	0.2	0.4	0.0
px1d	**MAM**	19.4	13.8	27.4	0.6	0.0	1.4	0.2	0.0	0.5
px1d	**JJA**	27.9	23.9	33.6	0.2	0.0	0.5	0.0	0.0	0.0
px1d	**SON**	53.0	48.6	59.4	1.9	2.3	1.4	0.0	0.0	0.0
px5d	**DJF**	14.3	16.7	11.6	0.0	0.0	0.0	0.0	0.0	0.0
px5d	**MAM**	12.9	7.9	18.5	0.0	0.0	0.0	0.0	0.0	0.0
px5d	**JJA**	28.1	19.2	38.0	0.4	0.4	0.5	0.0	0.0	0.0
px5d	**SON**	50.8	47.7	54.2	1.5	1.2	1.9	0.2	0.4	0.0
pnl90	**DJF**	16.2	21.3	10.8	0.0	0.0	0.0	0.0	0.0	0.0
pnl90	**MAM**	15.1	13.6	16.7	0.0	0.0	0.0	0.0	0.0	0.0
pnl90	**JJA**	18.4	6.4	31.0	0.0	0.0	0.0	0.0	0.0	0.0
pnl90	**SON**	61.0	44.8	78.1	1.2	0.5	1.9	0.7	0.5	1.0
pfl90	**DJF**	22.2	30.3	13.7	0.5	0.9	0.0	0.2	0.0	0.5
pfl90	**MAM**	21.8	15.4	28.6	0.5	0.0	1.0	0.0	0.0	0.0
pfl90	**JJA**	20.0	21.0	19.0	0.0	0.0	0.0	0.0	0.0	0.0
pfl90	**SON**	61.3	55.2	67.6	2.6	1.8	3.3	0.2	0.0	0.5
pxcwd	**DJF**	27.9	32.7	21.9	1.6	2.6	0.5	0.2	0.4	0.0
pxcwd	**MAM**	32.6	39.2	23.7	1.0	1.7	0.0	0.0	0.0	0.0
pxcwd	**JJA**	41.2	28.7	58.4	2.7	1.3	4.6	0.2	0.3	0.0
pxcwd	**SON**	30.1	23.3	39.3	1.0	0.3	1.8	0.4	0.7	0.0
pxcdd	**DJF**	63.1	62.50	63.9	6.1	6.25	5.9	3.3	4.78	1.4
pxcdd	**MAM**	72.4	70.27	75.3	7.0	6.08	8.2	2.9	3.04	2.7
pxcdd	**JJA**	59.0	60.40	57.1	5.0	4.95	5.0	1.9	2.97	0.5
pxcdd	**SON**	41.8	43.00	40.2	1.7	2.00	1.4	1.7	2.00	1.4

5 Summary, discussion and conclusions

The focus of this report is on the spatial patterns of various precipitation indices on the annual and seasonal basis, especially on the long term trends of the extreme precipitation over the past 44 years in Norway and Sweden. Due to the large number of stations used, spatial structures of the indices could be revealed.

The maps of the various precipitation indices clearly showed regional differences in rainfall statistics across Norway and Sweden. Owing to the country's pronounced topography and its proximity to the North Atlantic, the spatial variability in precipitation indices in Norway is much stronger compared to the conditions in Sweden. Especially the Norwegian West Coast frequently emerges as "record breaker" as most of the indices reach their highest values here. Humid air masses approaching Scandinavia from westerly directions reach at the first place the Norwegian West Coast where the strong topography of this region contributes to orographic lifting and ample precipitation generation. Even at the Swedish West Coast some indices appear with increased values mainly in winter and spring (e.g., *pint*, *px1d*, *px5d*), though to a much lesser extent. Studying different seasons, it is interesting to note how spatial patterns of the indices change over the course of the year. During winter, spatial differences in the indices are in general strongest, but they gradually weaken towards summer. Especially *pint, nrain, pq90, pq99, px1d,* and *px5d* show this feature. Depending on region, the relative importance of the processes that generate precipitation varies. Enhanced rainfall during spring and summer in the inland regions can be explained by stronger convective activity in inland regions during the warm seasons, while the West Coast areas experience stronger maritime influence caused by westerlies with enhanced rainfall amounts in autumn and winter. Hellström (2005) made an attempt to identify key factors and processes that trigger heavy rainfall events in Sweden. She compared atmospheric conditions for days with heavy rainfall ≥ 40 mm with non-extreme rainfall days. The study shows that around 70% of all extremes occur on days classified as cyclonic, which are characterized by higher vertical velocities and higher moisture content. The large-scale pressure distribution during these days has a more pronounced ridge over western Russia compared to the non-extreme events.

Analysing the trends in the various indices over the past 44 years shows that positive as well negative trends exist. There are considerably more stations with trends pointing towards wetter climate conditions in the annual as well as in the seasonal series except for autumn. The fraction of stations with significant trends is, however, considerably smaller especially for the negative trends. A difference in the magnitude and sign of trends depending on season is a common feature as examples from other studies. Moberg and Jones (2005) found that the increasing trends in average and moderate extreme precipitation across Europe during the past century are most evident in winter. The trends at their fewer Scandinavia stations did not show a homogenous pattern, i.e., both negative and positive trends were found. Also Hundecha and Bardossy (2005) found seasonal differences in the trends in heavy precipitation in Western Germany with increasing trends in winter, spring and autumn and trends towards lesser extremes in summer since 1958. Furthermore, Schmidli and Frei (2005) show that heavy precipitation in Switzerland experienced statistically significant positive trends in autumn and winter while trends in spring and summer generally lack significance.

From a global warming point of view, physical reasoning leads to the well known hypothesis that increased temperatures may generally enhance the hydrological cycle as more water vapor can be kept in the warmer atmosphere. One consequence of such a modification could be increased rainfall intensities and stronger extremes (e.g. Trenberth 1999). Whether this is a plausible explanation why the majority of the Scandinavian stations show positive trends in all precipitation indices, or whether other processes like changes in the atmospheric circulation regimes may have caused the increasing trends remains to be seen. However, the results from this study, together with findings from other works carried out in various regions around the world, contribute to a slowly forming picture of coherently increasing trends at middle to high latitudes in the cold season during the past 44 years. One way to shed more light into the possible causes of the variability in the daily precipitation indices would be to study the relation with variability in large-scale circulation over Scandinavia. In addition, it would be interesting to study the influence of physiographical factors such as altitude or distance to coast on the spatial patterns of extreme precipitation.

To sum up, the most important conclusions from this study are:

- Annual and seasonal maps of the precipitation indices reveal complex spatial variations in precipitation characteristics across Sweden and Norway
- Different indices often display similar spatial patterns which indicate that they are not independently from each other. Further, there seems to be a strong connection between precipitation amount and extremes. As an example, the Norwegian west coast (especially the southern part) appears as an outstanding region having the highest mean rainfall amounts, the highest extremes and the largest number of rain days.
- The threshold of 40 mm/year suggested by SMHI as an extreme indicator is very rarely exceeded at Swedish stations (on average less than once a year). Along the Norwegian west coast, however, this threshold is exceeded on average >15 days/year.
- At west coast locations (especially in Norway) rainfall amounts and extremes are highest during autumn and winter, while the remaining regions have their highest amounts/extremes in spring and summer. This clearly indicates differences in the relative importance of precipitation generating processes across Scandinavia .
- The spatial structures of the annual and seasonal trends are complex, having greatly varying magnitude and sign within short distance.
- A clear majority of all stations have increasing annual trends independent of index, but the fraction with statistically significant trends is small.
- Regarding trends over the course of the year, winter, spring and summer are the seasons when the majority of the stations show trends toward wetter conditions in all indices, while the fraction of stations with trends pointing toward dryer conditions is highest in autumn.
- In Norway, the fraction of stations with positive trends is highest in winter independent of index, but in Sweden, spring and summer are the seasons with the largest number of stations having positive trends.

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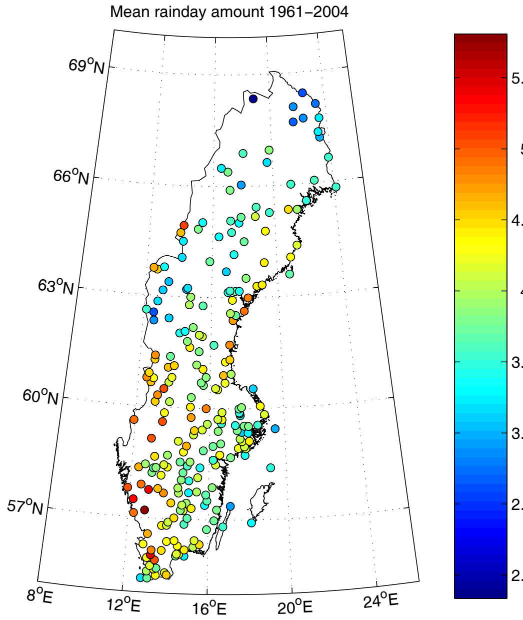
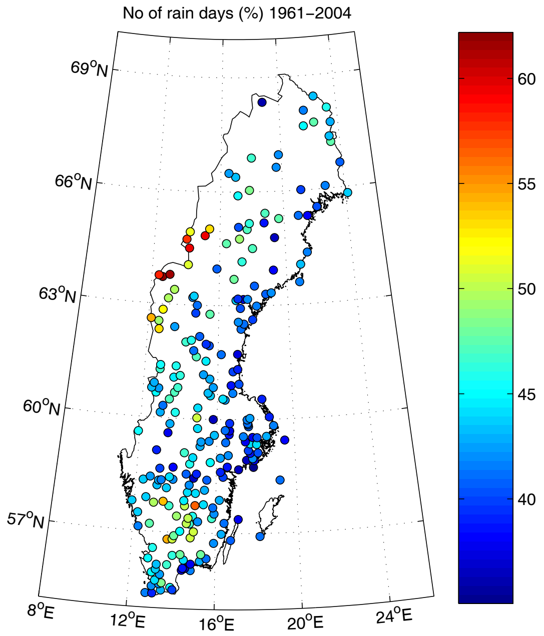
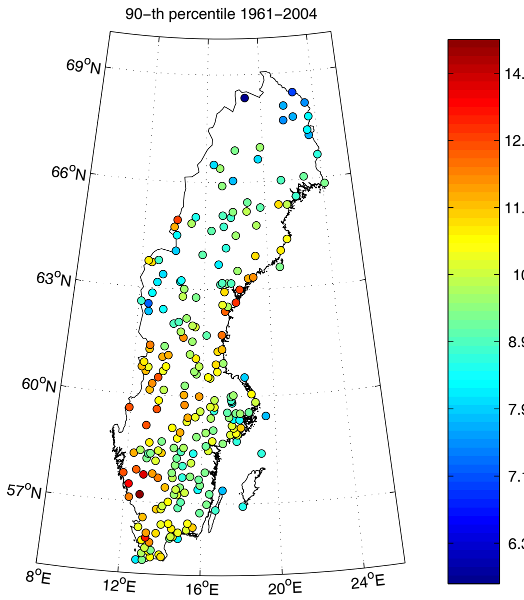
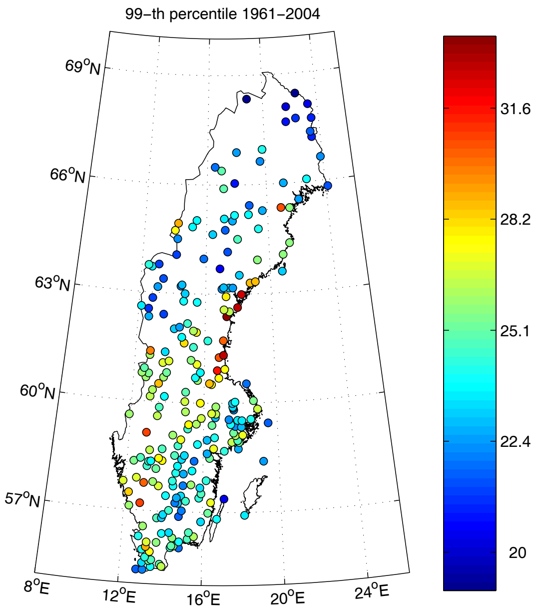
APPENDIX

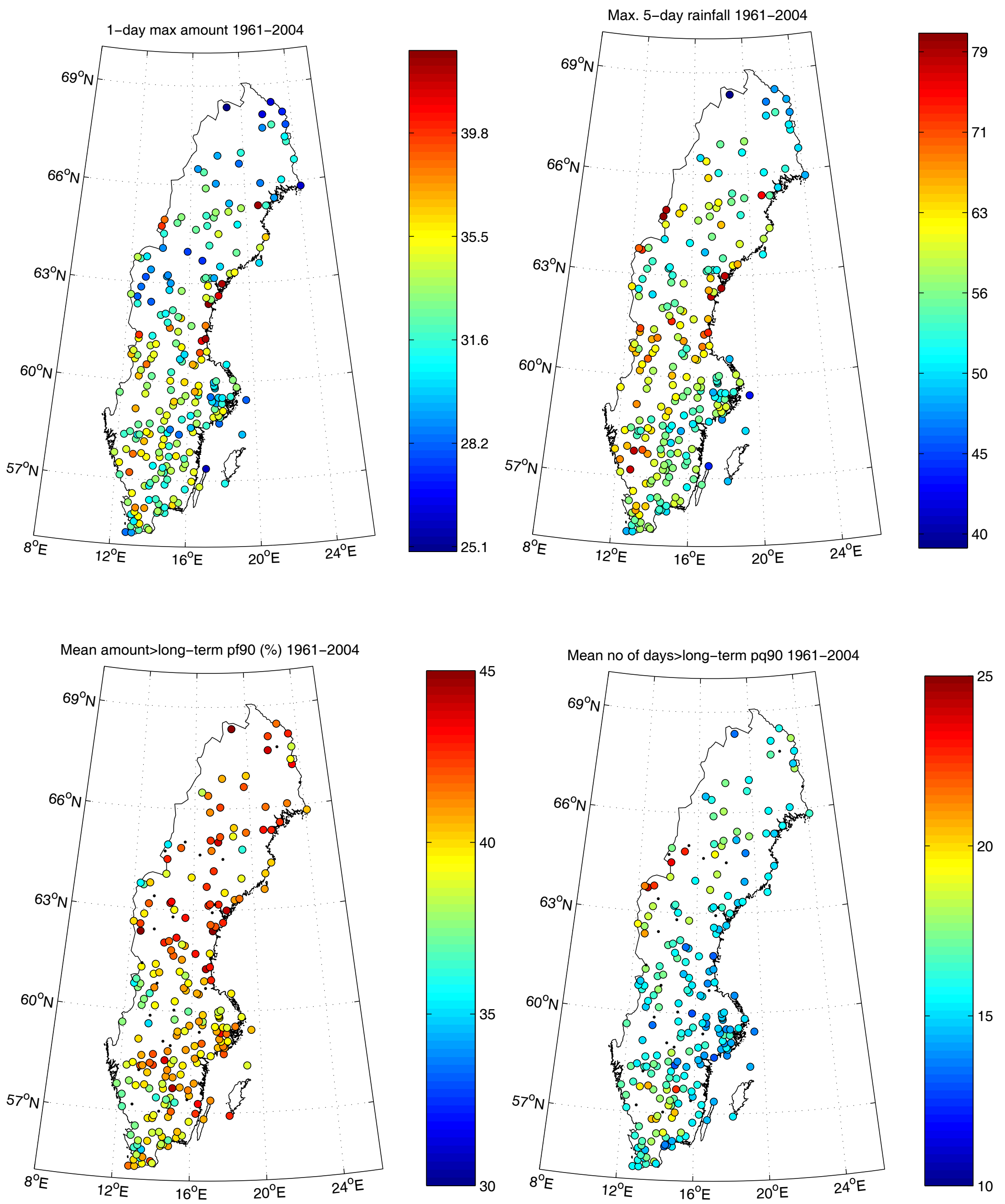
Annual maps of spatial distribution of precipitation indices at Swedish stations

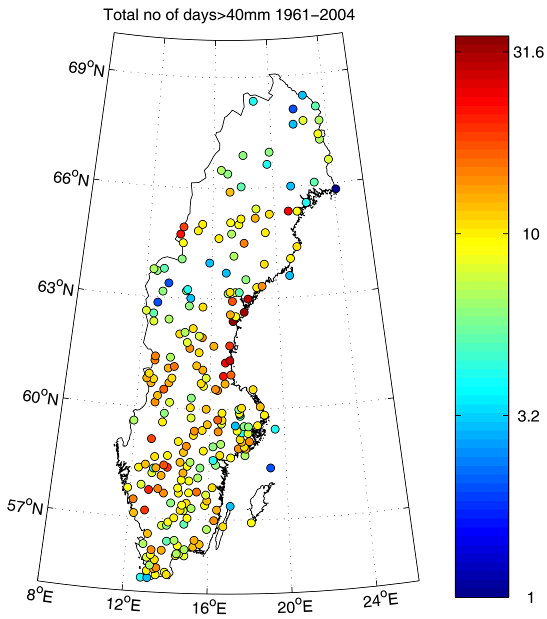


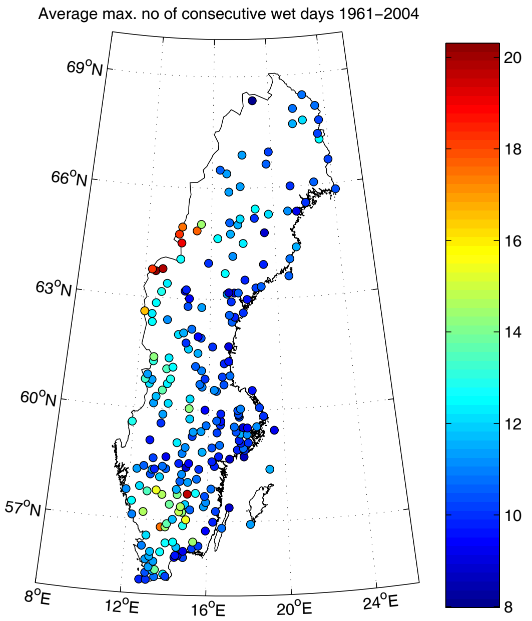


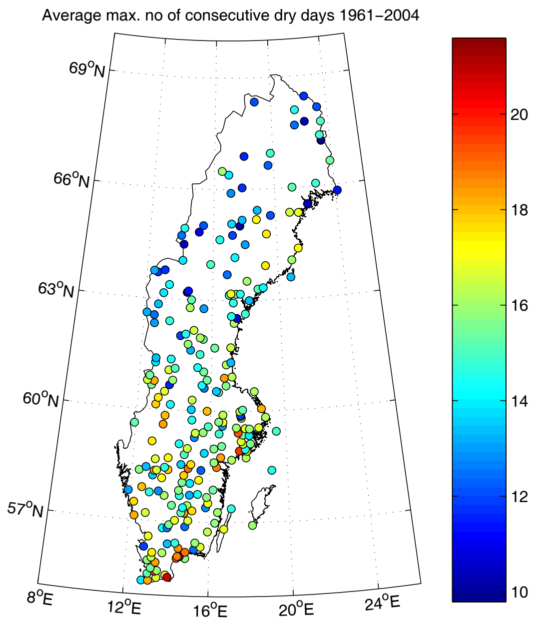




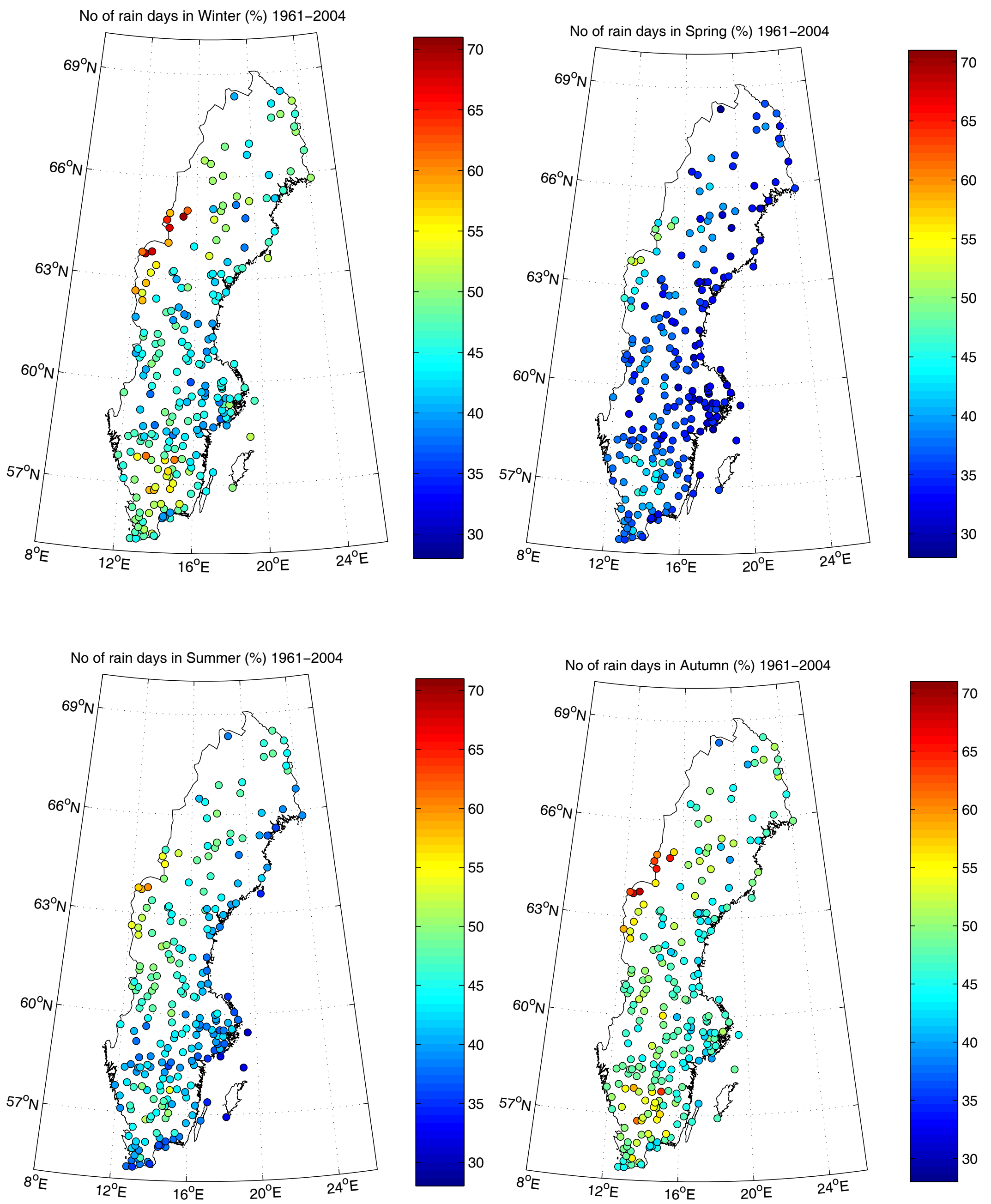

1-day max amount 1961–2004
Max. 5-day rainfall 1961–2004
Mean amount>long-term pf90 (%) 1961–2004
Mean no of days>long-term pq90 1961–2004
69°N
66°N
63°N
60°N
57°N
8°E
12°E
16°E
20°E
24°E
25.1
28.2
31.6
35.5
39.8
40
45
50
56
63
71
79
30
35
40
45
10
15
20
25

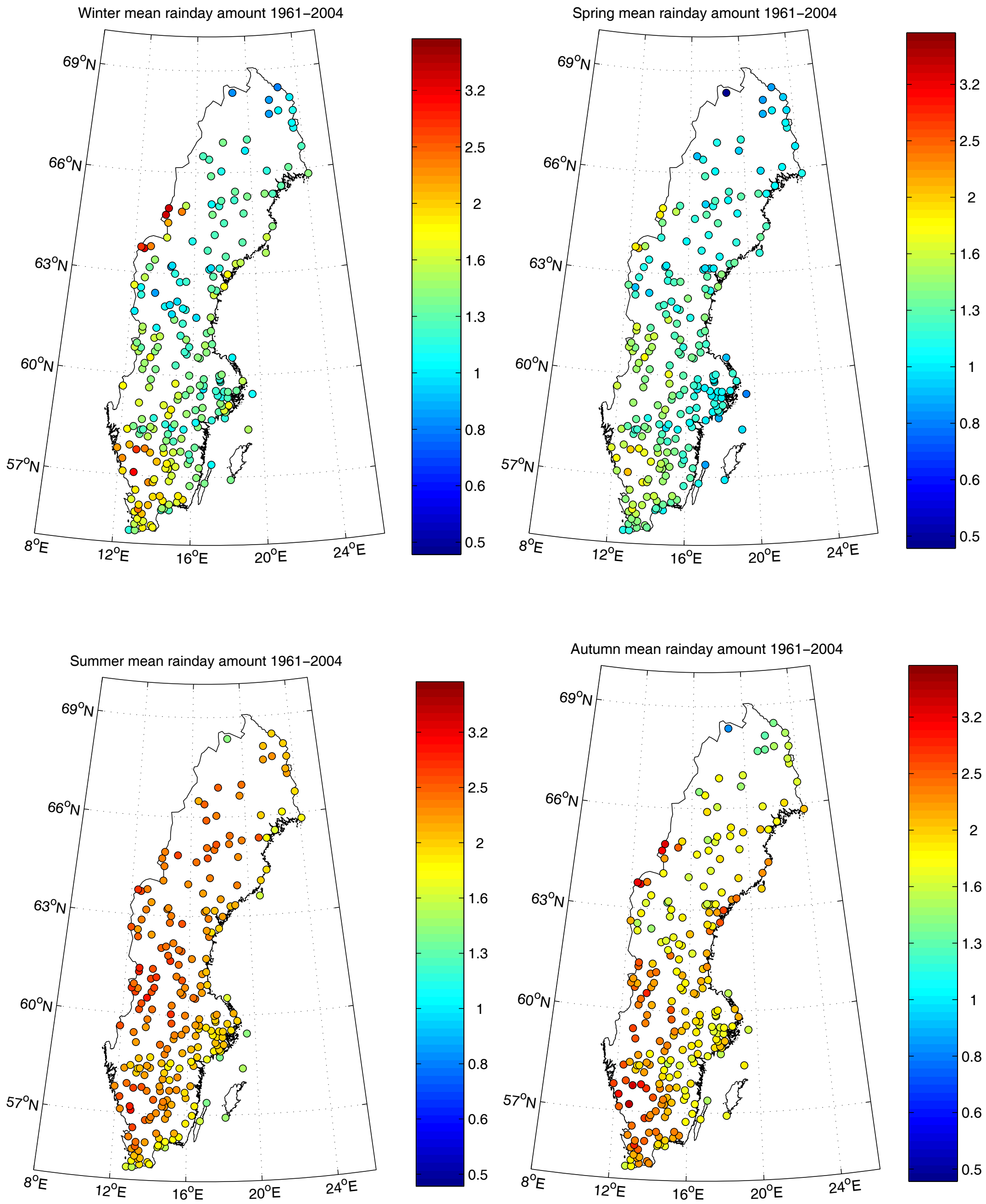

Total no of days>40mm 1961–2004
69°N
66°N
63°N
60°N
57°N
8°E
12°E
16°E
20°E
24°E
31.6
10
3.2
1


Average max. no of consecutive wet days 1961–2004
69°N
66°N
63°N
60°N
57°N
8°E
12°E
16°E
20°E
24°E
20
18
16
14
12
10
8

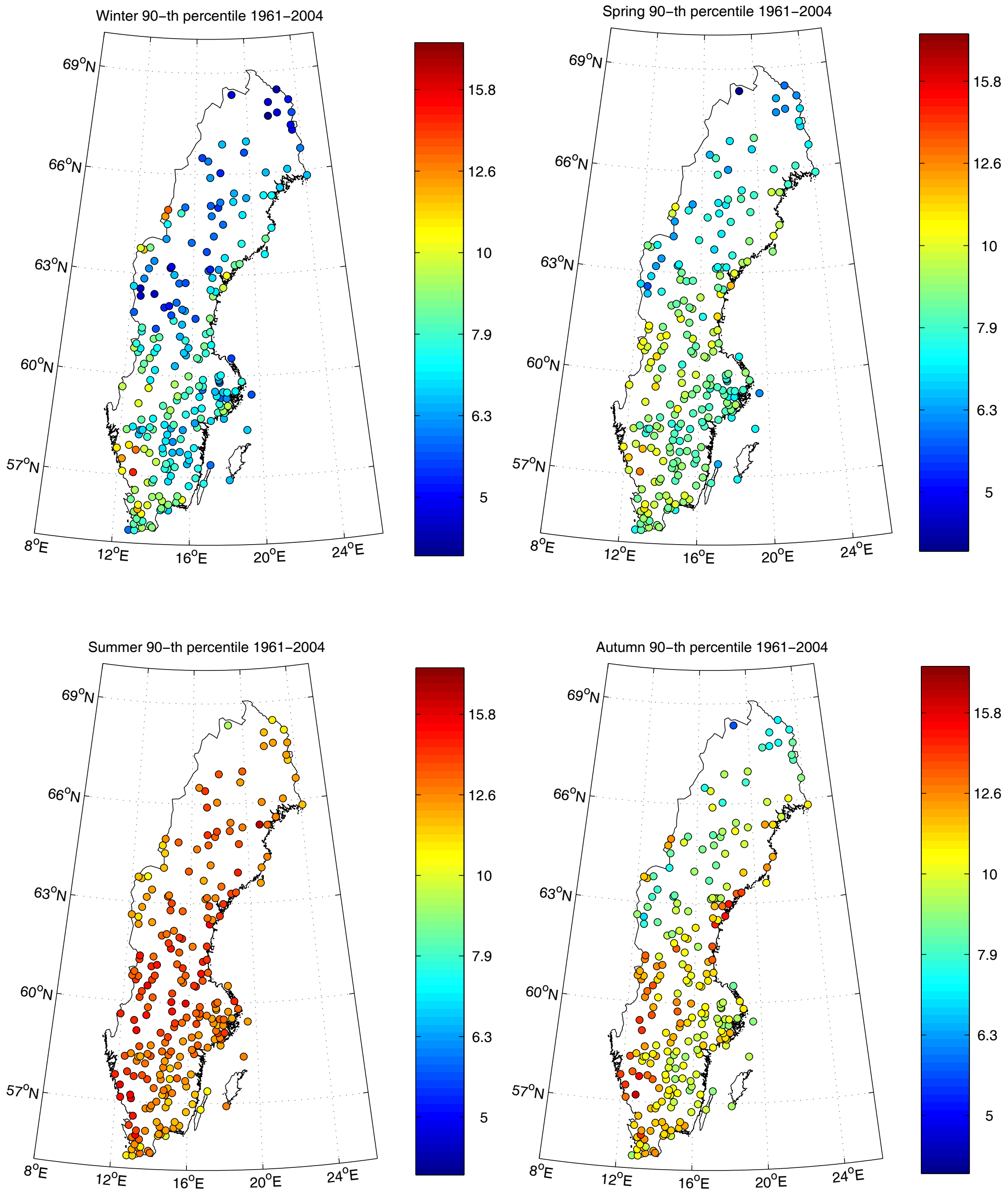

Average max. no of consecutive dry days 1961–2004
69°N
66°N
63°N
60°N
57°N
8°E
12°E
16°E
20°E
24°E
20
18
16
14
12
10

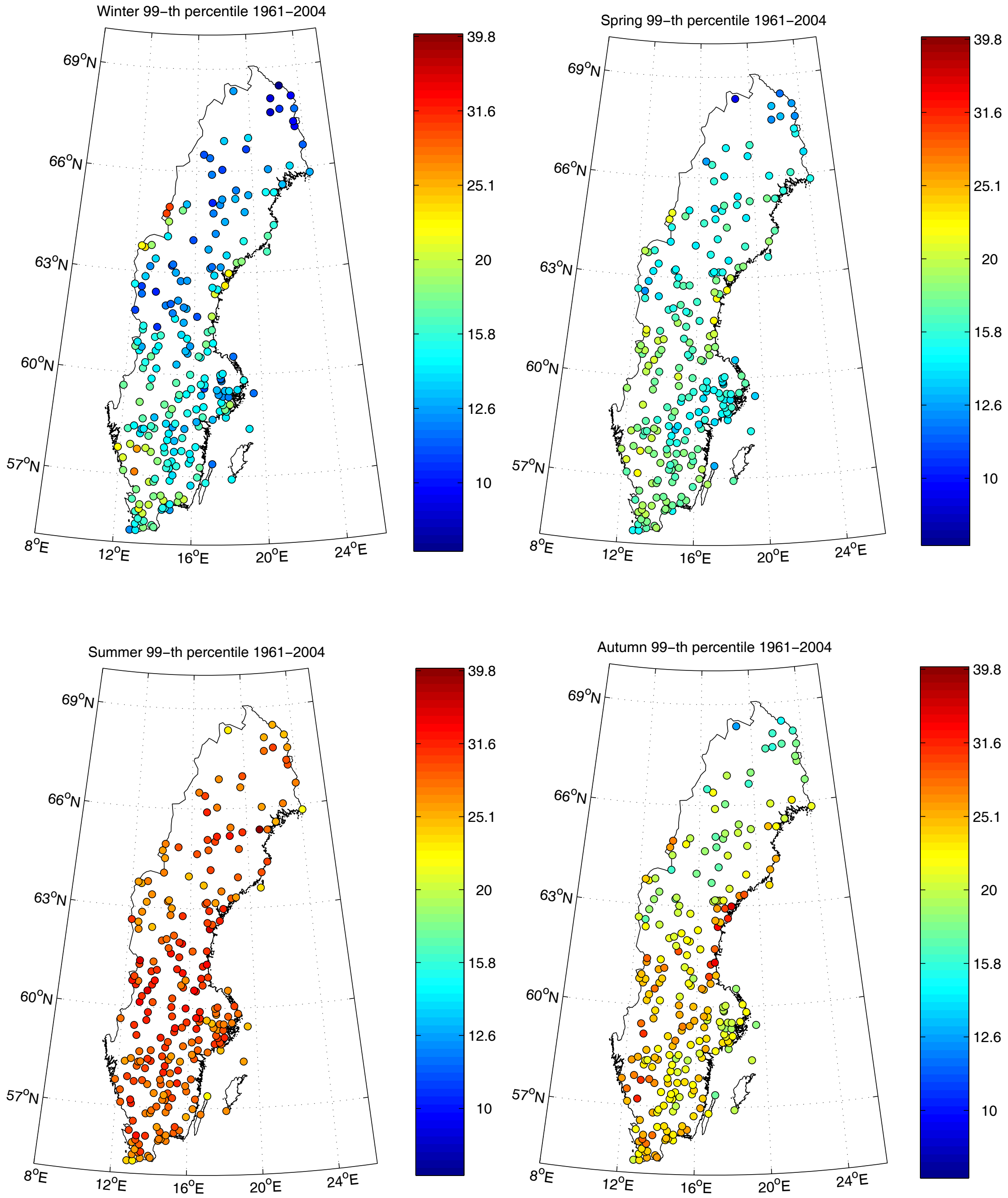
Seasonal maps of spatial distribution of precipitation indices at Swedish stations

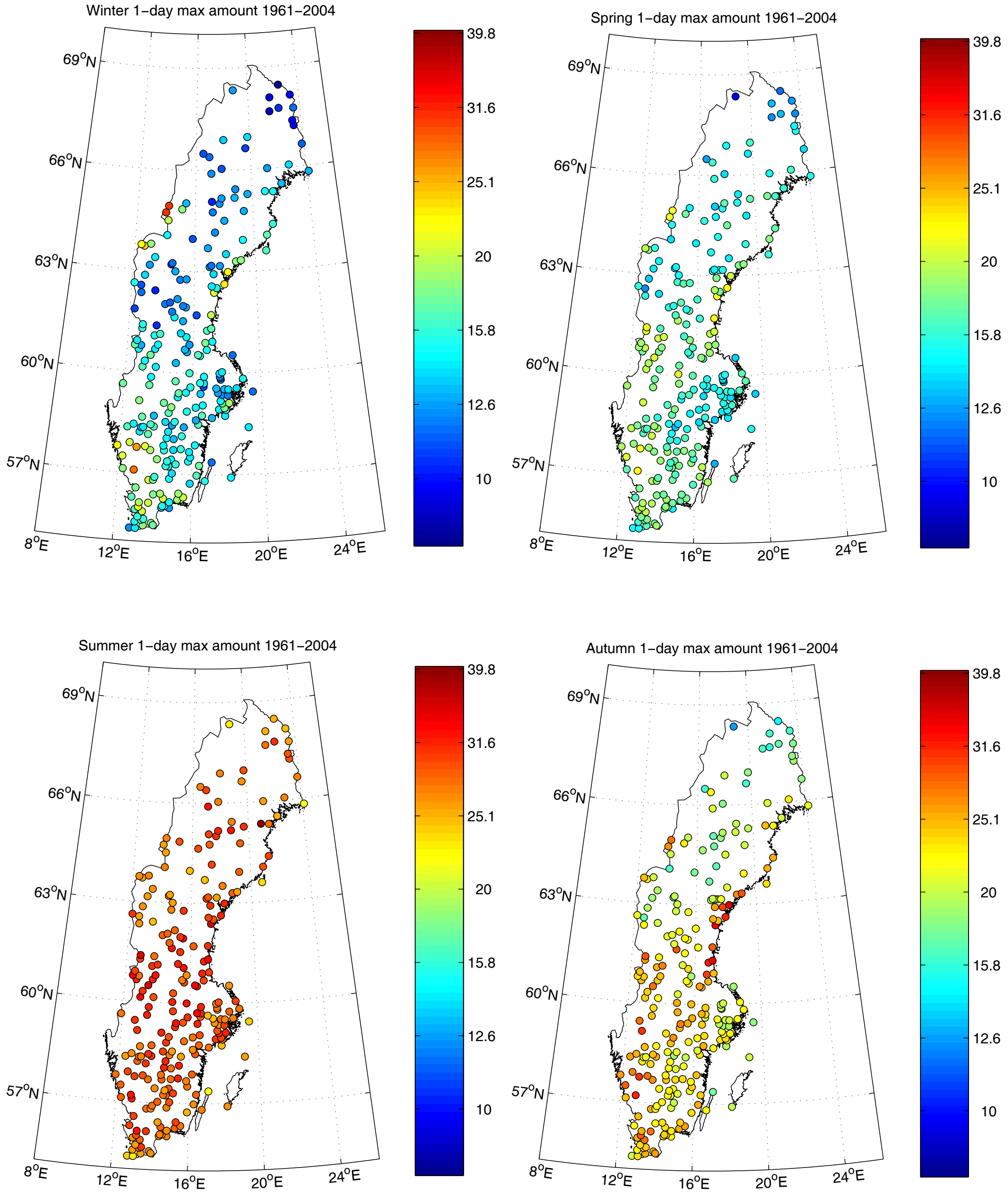


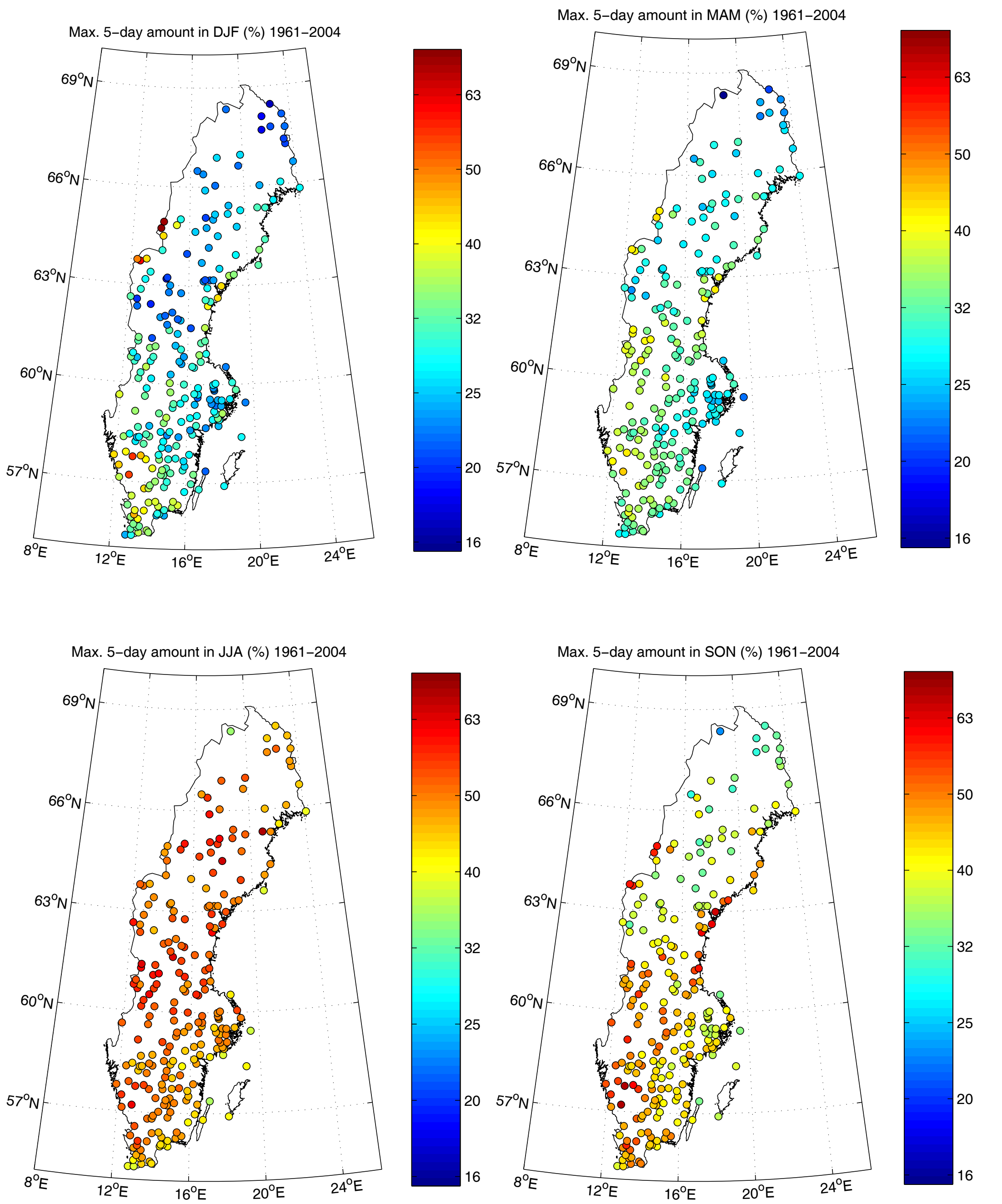


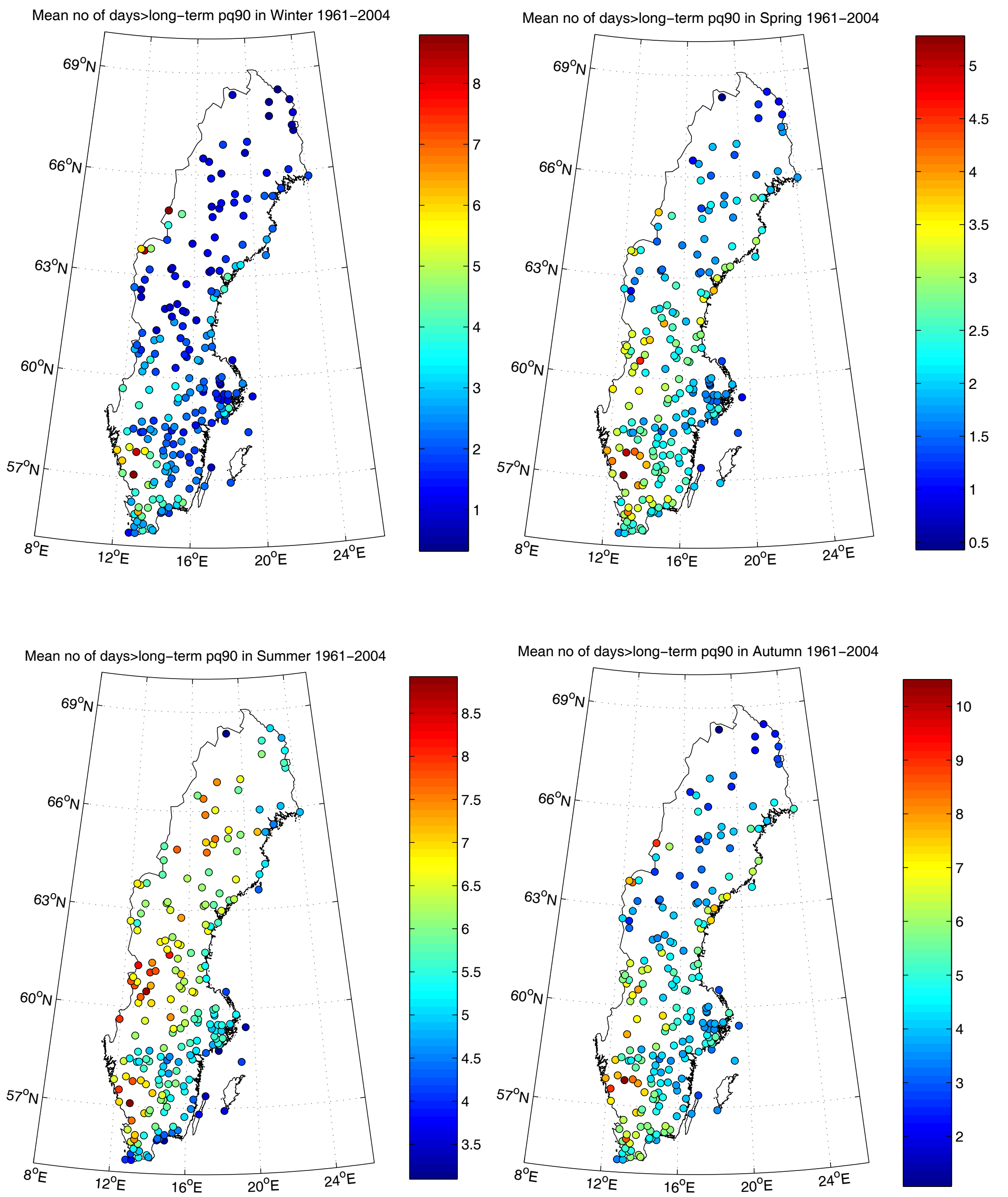
Winter mean rainday amount 1961−2004
Spring mean rainday amount 1961−2004
Summer mean rainday amount 1961−2004
Autumn mean rainday amount 1961−2004
69°N
66°N
63°N
60°N
57°N
8°E
12°E
16°E
20°E
24°E
3.2
2.5
2
1.6
1.3
1
0.8
0.6
0.5


Winter 90−th percentile 1961−2004
Spring 90−th percentile 1961−2004
Summer 90−th percentile 1961−2004
Autumn 90−th percentile 1961−2004
69°N
66°N
63°N
60°N
57°N
8°E
12°E
16°E
20°E
24°E
15.8
12.6
10
7.9
6.3
5

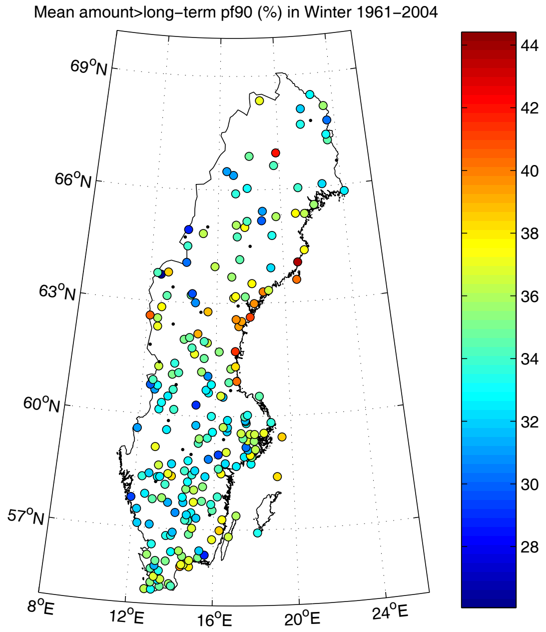

Winter 99−th percentile 1961−2004
Spring 99−th percentile 1961−2004
Summer 99−th percentile 1961−2004
Autumn 99−th percentile 1961−2004
69°N
66°N
63°N
60°N
57°N
8°E
12°E
16°E
20°E
24°E
39.8
31.6
25.1
20
15.8
12.6
10

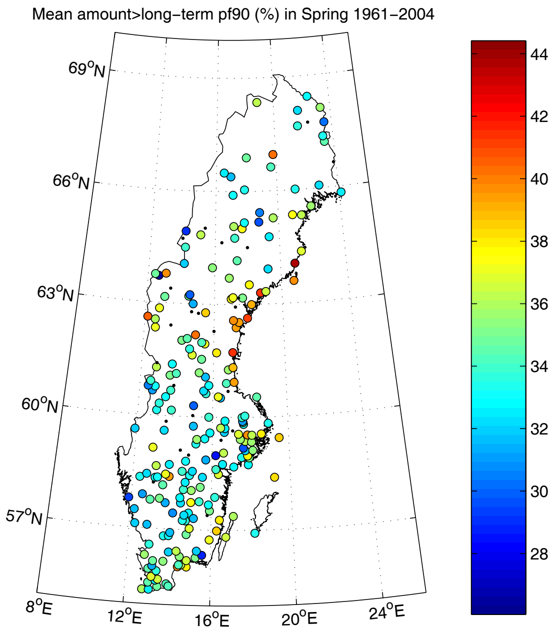

Winter 1−day max amount 1961−2004
Spring 1−day max amount 1961−2004
Summer 1−day max amount 1961−2004
Autumn 1−day max amount 1961−2004
69°N
66°N
63°N
60°N
57°N
8°E
12°E
16°E
20°E
24°E
39.8
31.6
25.1
20
15.8
12.6
10

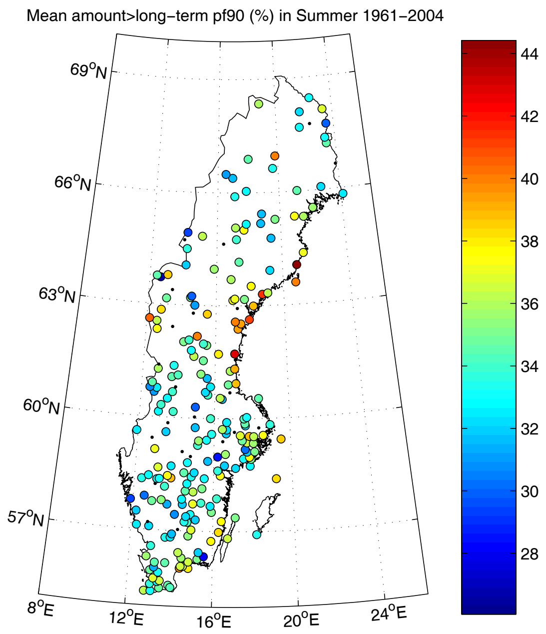

Max. 5-day amount in DJF (%) 1961–2004
Max. 5-day amount in MAM (%) 1961–2004
Max. 5-day amount in JJA (%) 1961–2004
Max. 5-day amount in SON (%) 1961–2004
69^oN
66^oN
63^oN
60^oN
57^oN
8^oE
12^oE
16^oE
20^oE
24^oE
63
50
40
32
25
20
16

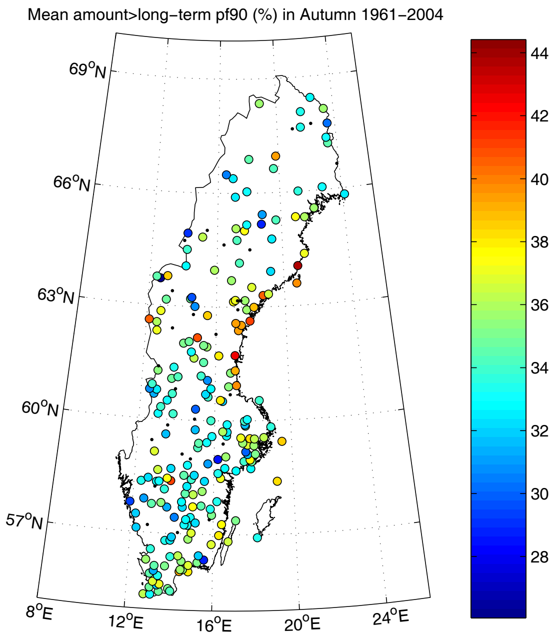


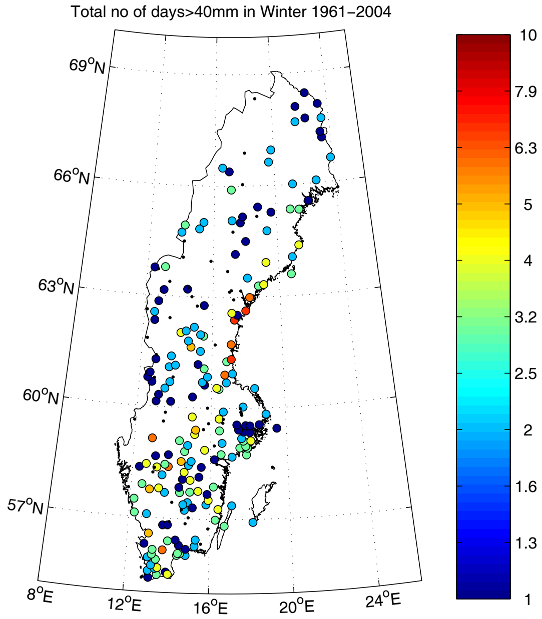
Mean no of days>long-term pq90 in Winter 1961–2004
Mean no of days>long-term pq90 in Spring 1961–2004
Mean no of days>long-term pq90 in Summer 1961–2004
Mean no of days>long-term pq90 in Autumn 1961–2004
69°N
66°N
63°N
60°N
57°N
8°E
12°E
16°E
20°E
24°E

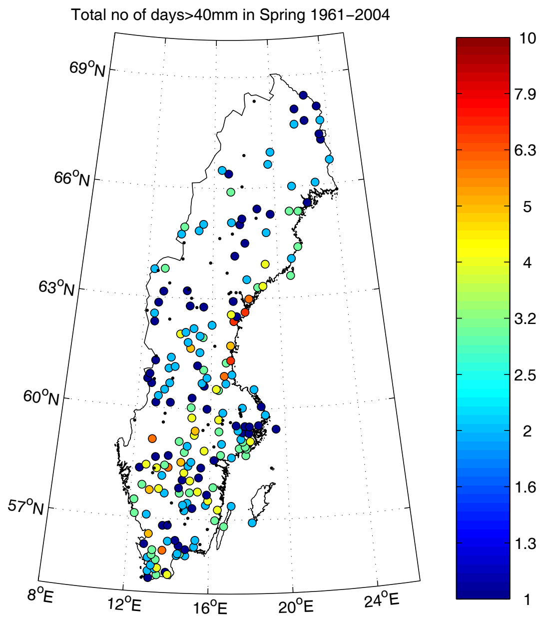

Mean amount>long−term pf90 (%) in Winter 1961−2004
69°N
66°N
63°N
60°N
57°N
8°E
12°E
16°E
20°E
24°E
44
42
40
38
36
34
32
30
28

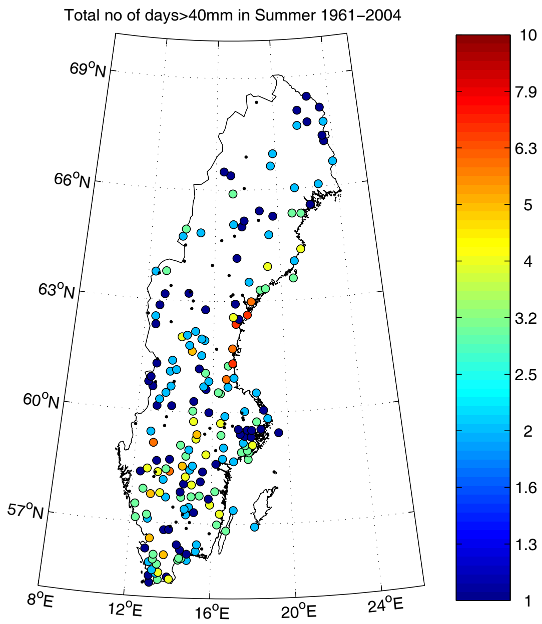

Mean amount>long−term pf90 (%) in Spring 1961−2004
69°N
66°N
63°N
60°N
57°N
8°E
12°E
16°E
20°E
24°E
44
42
40
38
36
34
32
30
28

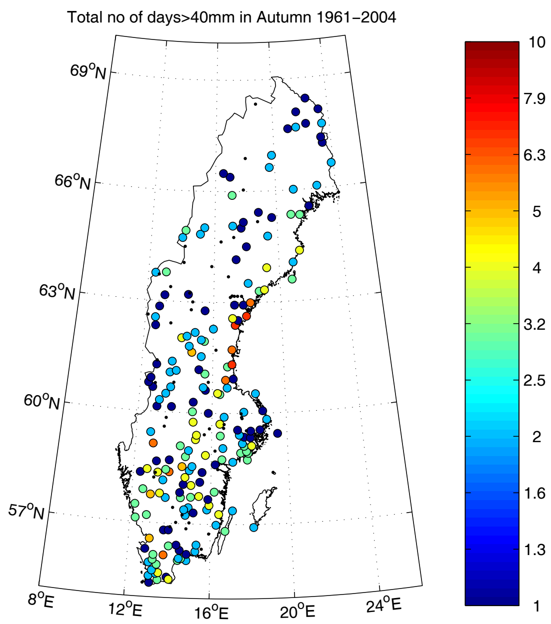

Mean amount>long−term pf90 (%) in Summer 1961−2004
69°N
66°N
63°N
60°N
57°N
8°E
12°E
16°E
20°E
24°E
44
42
40
38
36
34
32
30
28


Mean amount>long−term pf90 (%) in Autumn 1961−2004
69°N
66°N
63°N
60°N
57°N
8°E
12°E
16°E
20°E
24°E
44
42
40
38
36
34
32
30
28

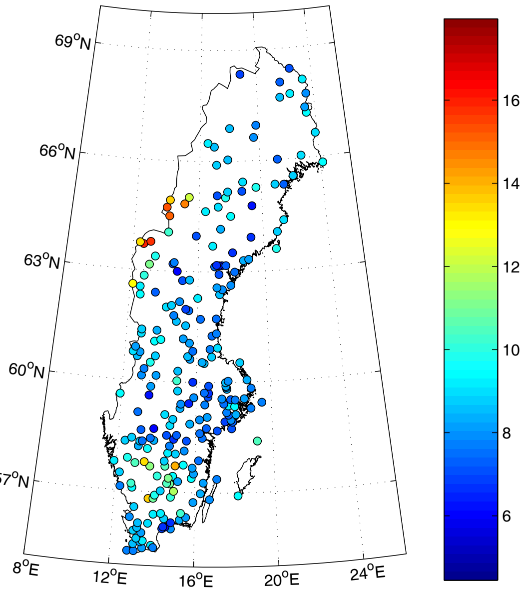

Total no of days>40mm in Winter 1961−2004
69°N
66°N
63°N
60°N
57°N
8°E
12°E
16°E
20°E
24°E
10
7.9
6.3
5
4
3.2
2.5
2
1.6
1.3
1


Total no of days>40mm in Spring 1961−2004
69°N
66°N
63°N
60°N
57°N
8°E
12°E
16°E
20°E
24°E
10
7.9
6.3
5
4
3.2
2.5
2
1.6
1.3
1

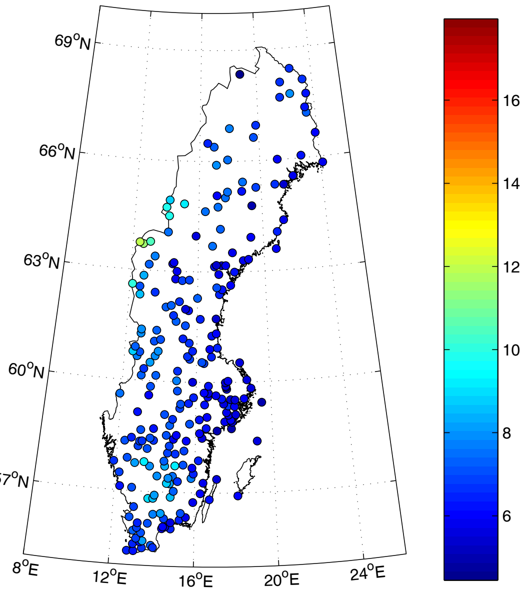

Total no of days>40mm in Summer 1961−2004
69°N
66°N
63°N
60°N
57°N
8°E
12°E
16°E
20°E
24°E
10
7.9
6.3
5
4
3.2
2.5
2
1.6
1.3
1


Total no of days>40mm in Autumn 1961−2004
69°N
66°N
63°N
60°N
57°N
8°E
12°E
16°E
20°E
24°E
10
7.9
6.3
5
4
3.2
2.5
2
1.6
1.3
1

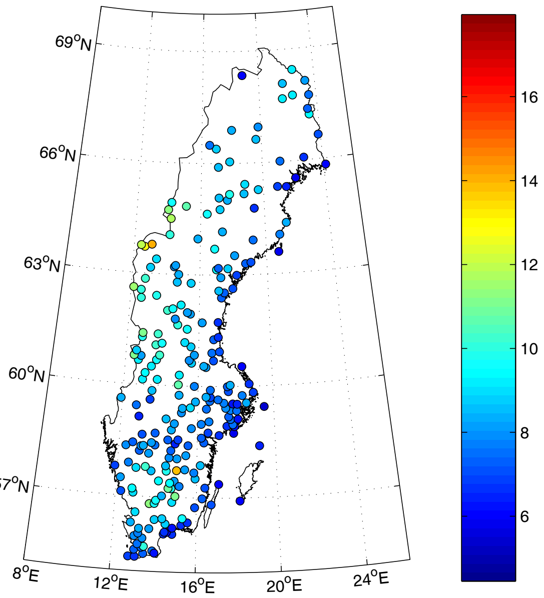
Average max. no of consecutive wet days in winter 1961−2004



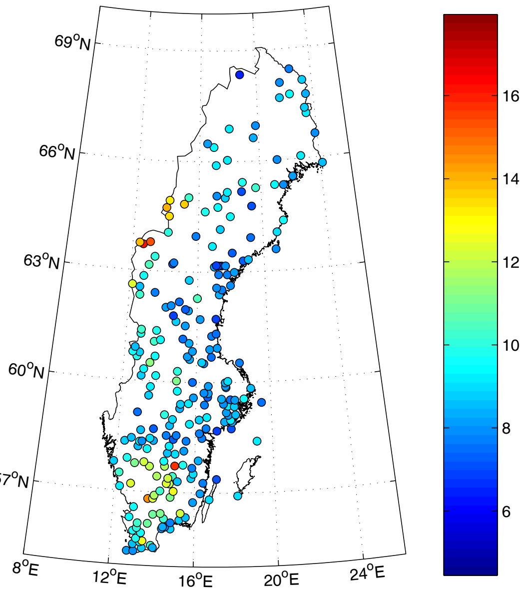
Average max. no of consecutive wet days in spring 1961−2004

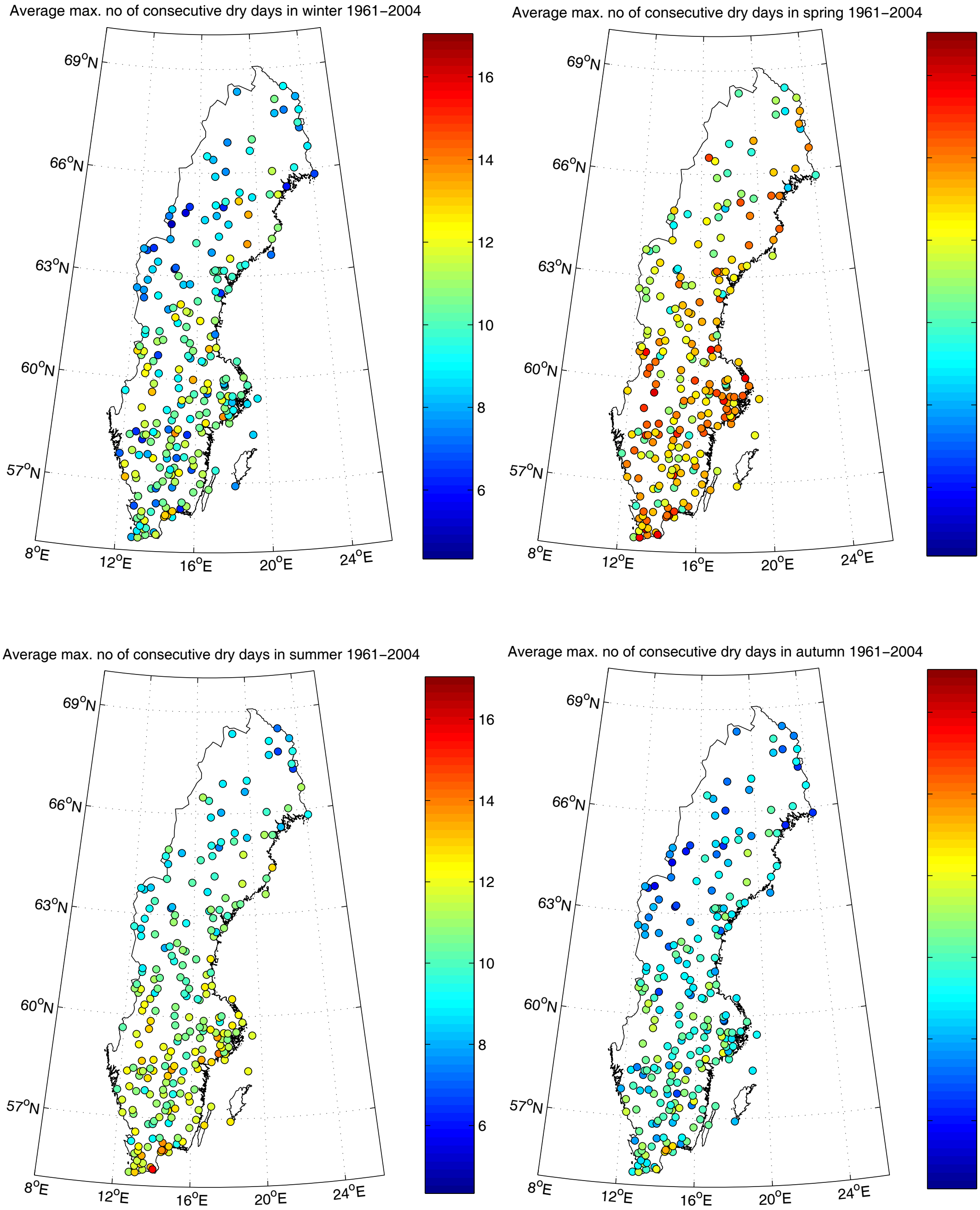


Average max. no of consecutive wet days in summer 1961−2004



Average max. no of consecutive wet days in autumn 1961−2004




Average max. no of consecutive dry days in winter 1961−2004
Average max. no of consecutive dry days in spring 1961−2004
Average max. no of consecutive dry days in summer 1961−2004
Average max. no of consecutive dry days in autumn 1961−2004
69°N
66°N
63°N
60°N
57°N
8°E
12°E
16°E
20°E
24°E
6
8
10
12
14
16