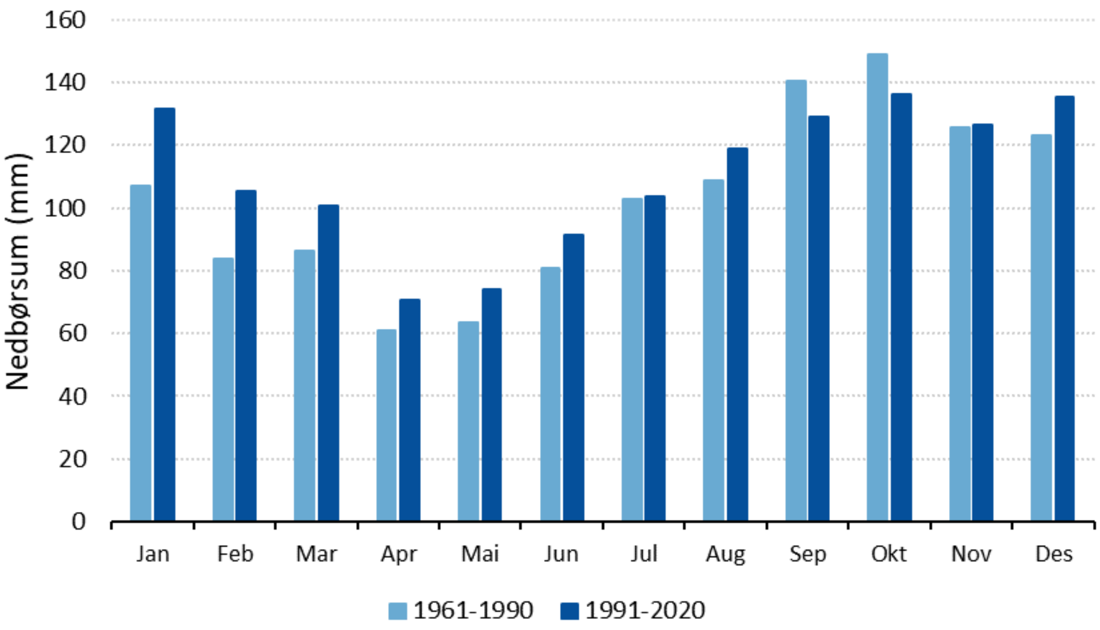
No. 1/2024
ISSN 2387-4201
Climate

METreport

Precipitation variability in Norway 1961-2020

Julia Lutz, Inger Hanssen-Bauer, Ole Einar Tveito and Andreas Dobler



Figur: *Monthly precipitation normals (mm) for the two latest standard normal periods.*

Title Precipitation variability in Norway 1961-2020	**Date** 17.01.2024
Sections Division for model and climate analysis and Division for climate services	**Report no.** No. 1/2024
Author(s) Julia Lutz, Inger Hanssen-Bauer, Ole Einar Tveito and Andreas Dobler	**Classification** ● Free ○ Restricted
Client(s) MET Norway and the Norwegian Centre for Climate Services	**Client's reference**

Abstract

Precipitation in Norway increased by about 20% from 1900 to 2022. This report investigates the changes in precipitation patterns in Norway, focusing on the comparison between the standard normal periods 1961-1990 and 1991-2020 as defined by the World Meteorological Organization. Norway experienced a 7% increase in average annual precipitation from 1961-1990 to 1991-2020, reaching a spatial average of 1324 mm, with notable regional variations. The precipitation rise is primarily influenced by an increase in both the number of days with precipitation and the average precipitation on these days. Particularly noteworthy is the significant increase in heavy daily precipitation, surpassing the overall rise in precipitation on wet days.

Keywords

Precipitation; Precipitation indices; Precipitation variability

Disciplinary signature

Responsible signature

Contents

1 Introduction

The climate exhibits variations both temporally and spatially. The World Meteorological Organization (WMO) has established the concept of "standard normal periods" (available at https://community.wmo.int/wmo-climatological-normals) to serve as a basis for the analysis of climate trends over time and facilitate comparisons of climate conditions across different locations. Traditionally, such climate standard normals were calculated every 30 years, with the most recent two periods covering 1961-1990 and 1991-2020[1]. This report is dedicated to documenting the changes in some precipitation indices in Norway between these two periods. Additionally, it covers the trends in total precipitation from 1900 to the present, accompanied by a discussion of the underlying mechanisms driving these changes.

The structure of this report can be summarised in the following way:

- Chapter 2 provides a comprehensive overview of the datasets and definitions related to various precipitation indices.
- Chapter 3 presents the findings from the analyses of these indices.
- Chapter 4 sums up the key conclusions derived from the study.

2 Data and definitions

2.1 Data

For the present analyses, we employed two different observationally based gridded datasets with a spatial resolution of 1 km^2:

1. **KlimGrid (Tveito, 2021 and 2023)**: This dataset is used for the examination of total annual, seasonal, and monthly precipitation. KlimGrid is a homogenised dataset starting in the year 1900, providing monthly time resolution. Thus, this dataset is particularly well-suited for calculating long-term trends but is not applicable for deriving climate indices depending on daily values.
2. **seNorge2018, version 20.05 (Lussana et al., 2019; Lussana, 2020)**: For the analyses of indices dependent on daily values, we rely on this dataset. It is available from 1957 onwards and provides data on a daily resolution.

It is important to note that there exist systematic differences between these two datasets. However, the relative changes (in %) from the period 1961-1990 to 1991-2020 should be preserved on a large scale.

[1] At the Seventeenth World Meteorological Congress (WMO, 2015), the definition of a climatological standard normal has changed. It now refers to the most-recent 30-year period finishing in a year ending with 0 (e.g. 1971-2000, 1981-2010, 1991-2020, etc.), rather than non-overlapping periods. However, the period 1961-1990 has been retained as a "standard reference period" for long-term climate change assessments.

2.2 Definitions

The climate indices covered by the present report are listed in Table 2.1. Most of them follow standards set by WMO or in European networks. However, what is considered to be "normal variation" of monthly, seasonal or annual precipitation varies between countries. In some countries, precipitation within +/- one standard deviation from the mean value, based on the current standard normal period, is considered normal. In other countries, various percentiles are used. In Norway, we use the 25th and 75th percentiles. Thus, without climate change, on average half the month/seasons/years would be considered as "normal", while 25% would be "dry" and 25% would be "wet".

Table 2.1 *Definition of the precipitation indices discussed in this report.*

Precipitation index	Unity	Definition	Comment
Precipitation sum	mm	Annual, seasonal or monthly accumulated precipitation	WMO standard
Normal variation of precipitation	mm	25th to 75th percentiles of precipitation sum	Definition varies internationally
Wet days	number of days	Days with precipitation ≥ 1 mm	WMO standard
Simple daily intensity index	mm per day	Precipitation sum of wet days divided by number of wet days	WMO standard
Heavy daily precipitation	mm	99.7th percentile for daily precipitation	Definition varies internationally
Very heavy precipitation days	number of days	Days with precipitation ≥ 20 mm	European definition

Additionally, the definition of "heavy daily precipitation" varies between countries. This is a measure related to the local daily precipitation statistics, so it is usually defined as a percentile. However, different percentiles are applied in the national definitions, and it also varies if the percentiles are calculated based on all days, or only on precipitation days. Here, we use the 99.7th percentile based on all days following the suggestions of Schär et al. (2016). This implies that in a constant climate, there would be on average one day per year with heavy daily precipitation at any location.

3 Indices 1991-2020 vs. 1961-1990

3.1 Precipitation sum: Monthly, seasonal and annual

Based on KlimGrid, the average annual precipitation in Norway during the period 1991-2020 was 1324 mm (Tveito, 2021). Large geographical differences in precipitation amounts exist across regions. The mean estimated annual precipitation ranged from 212 mm in Saltdal, Nordland county, to as high as 6130 mm at Ålfotbreen, Vestland county (Figure 3.1.1, left panel). Typically, the most precipitation-rich areas are located in western Norway, where low-pressure systems predominantly approach from the west-southwest. The heaviest precipitation events in western and southwestern Norway are frequently linked to *atmospheric rivers*, which are narrow bands of moisture-laden air propelled by wind from southern areas to our (northern) latitudes (Gimento et al., 2014).

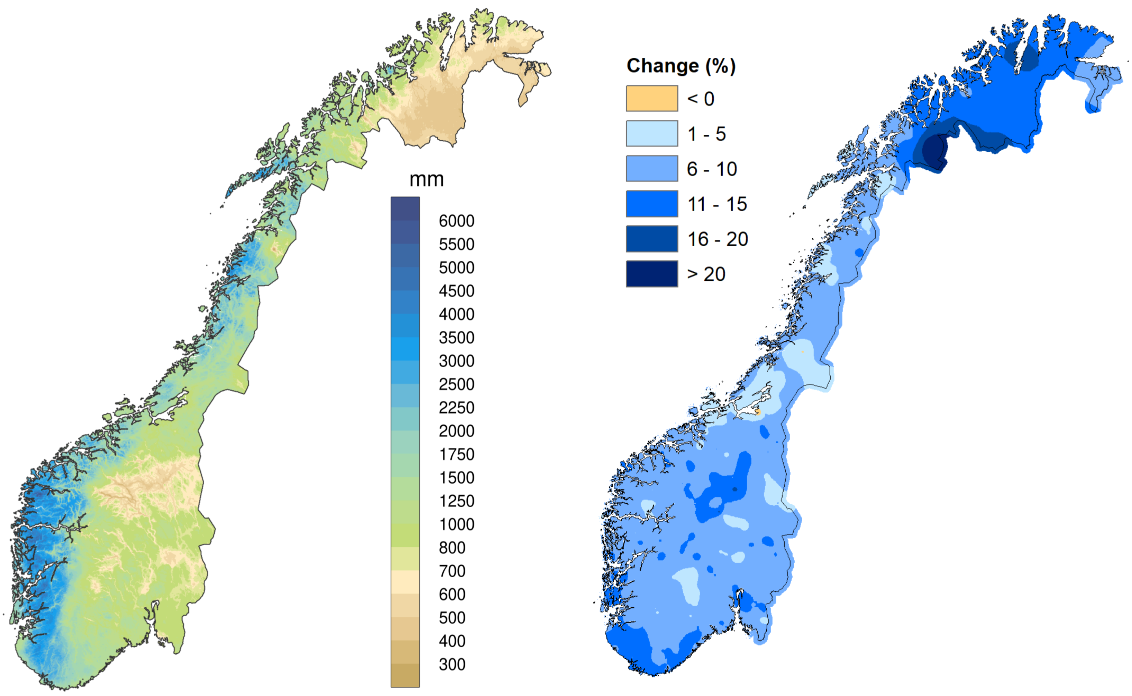


Figure 3.1.1 *Average annual precipitation (mm) for 1991-2020 (left panel) and relative change from the 1961-1990 average (%) (right panel) based on the KlimGrid dataset.*

In relative comparison to the 1961-1990 normal of precipitation, the 1991-2020 precipitation normal was 7 % higher. Precipitation levels have shown a general increase across the country; however, there are notable geographical variations concerning the relative increase, as illustrated in Figure 3.1.1 (right panel). The most substantial increases occur in northern Norway, particularly south of Tromsø, where percentages exceed 20 %. Additionally, the Finnmark plateau exhibits remarkable values, with an increase of up to 15 % and even higher. The southern part of Norway also experiences an increase of up to 15 %, whereas in central Norway, the mean precipitation only increases by 1-5 %.

When compared to earlier standard normals in the 20th century, the increase in precipitation from the previous to the present normal period follows a discernible pattern of successively rising precipitation (see Figure 3.1.2). The linear trend indicates that, from 1901 to 2022, Norway has witnessed a total increase of about 20 % in average annual precipitation relative to the 1991-2020 baseline. Notably, this trend has shown steeper inclines over the past 40 to 50 years. This coincides with the period in which changes in anthropogenic climate forcings have been dominating on the global scale (IPCC, 2021). On the regional scale, the picture is more complex due to the potential dominance of the internal variability within the climate system over the global signal, especially over shorter time frames (Deser et al., 2012). Nevertheless, Konstali and Sorteberg (2022) stated that while dynamical mechanisms have played a significant role in explaining precipitation variability in Norway since 1901, the recent increase is primarily attributed to rising temperature and relative humidity, making it more directly associated with anthropogenic warming. Thus, we would expect that the changes in average precipitation in Norway from 1961-1990 to 1991-2020 are mainly in accordance with climate projections. Compared to the ensembles of projections presented by Hanssen-Bauer et al. (2015), the observed increase in annual precipitation falls within the ensemble range, albeit towards the upper limit.

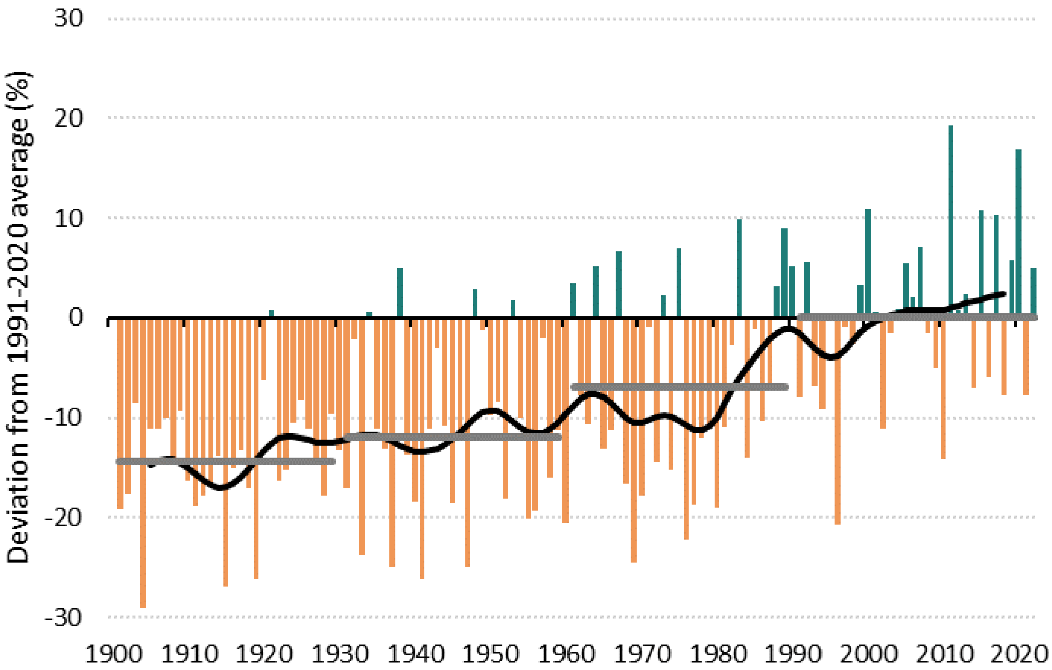


Figure 3.1.2: *Mean annual precipitation in Norway 1901-2020 given as anomalies (%) from the standard normal period 1991-2020. Annual values are vertical bars (negative: orange; positive: green), while the black curve shows the low-pass filtered evolution, and the grey horizontal lines show the standard normals.*

However, the climate projections (Hanssen-Bauer et al., 2015) indicate increased precipitation in all seasons, while actual observations show a rise from 1961-1990 to 1991-2020 in all months except September and October (see Figure 3.1.3). The observed precipitation increase in winter and spring has so far exceeded the projected increase, whereas autumn has witnessed a reduction in precipitation – a deviation from the anticipated rise. These disparities raise the question of whether such differences can be explained by variations in atmospheric circulation patterns.

In Norway, the North Atlantic Oscillation (NAO) index (Hurrell, 1995 and 2003) is a simple measure of atmospheric circulation conditions, especially during the winter months. When this index has high values, the prevailing westerlies are strong, and mild and humid air enters the country from the west-southwest. When the index is low, winters become colder and drier. Here we have made a simple analysis based on a comparison of monthly series of average precipitation totals for Norway and the NAO index in the period 1961-2020 published by NOAA[2].

[2] https://www.ncei.noaa.gov/access/monitoring/nao/

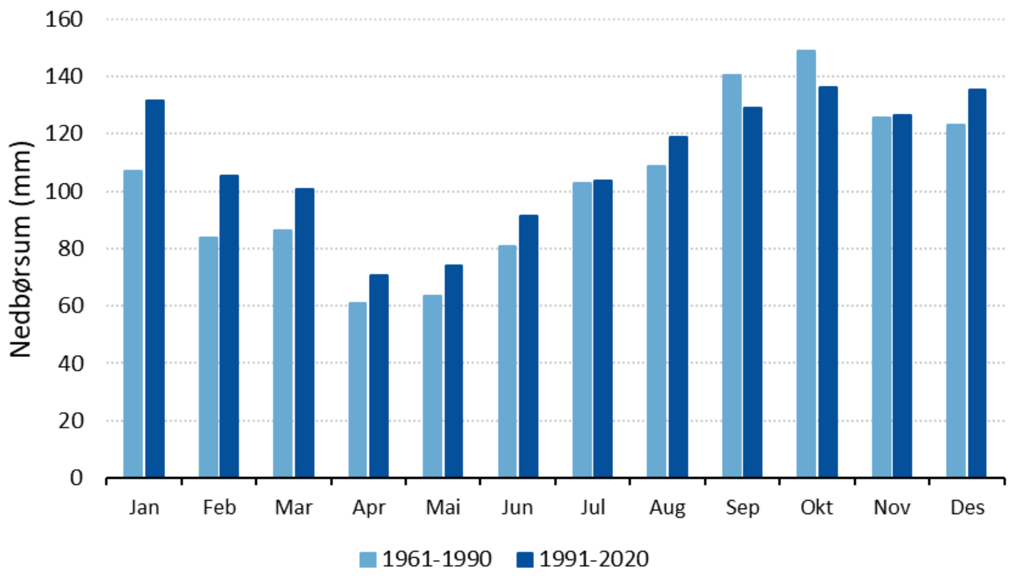


Figure 3.1.3 *Monthly precipitation normals (mm) for the two latest standard normal periods.*

Table 3.1.1 *Relationship between changes in monthly precipitation sums and monthly NAO indices in the period from 1961 to 2020. "R (NAO-RR)" represents the correlation coefficient between the NAO index and the monthly precipitation sums. "DIFF-NAO" is the difference in the mean NAO index between the periods 1991-2020 and 1961-1990. "DIFF-RR" is the difference in precipitation sums, respectively.*

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
R (NAO-RR)	0,5	0,5	0,6	0,3	0,1	0,1	-0,1	0,0	0,4	0,3	0,4	0,6
DIFF-NAO	0,7	0,7	0,3	0,4	-0,3	-0,6	-0,6	-0,2	-0,2	-0,6	0,4	0,4

The correlation between monthly precipitation for Norway and the mean NAO index for the same month in this period is highest from December to March, but also has some explanatory potential in April and in the autumn (Table 3.1.1, top line). The difference between the average NAO index in the last two standard normal periods (Table 3.1.1, bottom line) is positive in winter, and greatest in early spring. This means that the average NAO index in the winter months and most of the spring has on average been higher in the current standard normal period than in the preceding period. This can explain why average winter precipitation in Norway has increased even more than global warming would imply from the period 1961-1990 to 1991-2020. On the other hand, the table shows that the NAO index in the period May to October was lower in the current standard normal period than in the previous. From May to August, the NAO index is uncorrelated to average precipitation, but the low values in September and October indicate that the variations in atmospheric

Figure 3.1.4 *Precipitation regions (RR) 1 - 11.*

circulation may have contributed to less precipitation in autumn, thereby masking the direct impact of global warming and increased humidity.

Though annual precipitation has increased everywhere, the relative changes vary throughout the country (Figure 3.1.1, right panel). Eleven "precipitation regions" (Figure 3.1.4) have been defined based on areas where time series of precipitation are highly correlated (Hanssen-Bauer et al., 2022). In these regions the increase in annual precipitation from 1961-1990 to 1991-2020 varies from 5% to 11%, and the regional differences are even larger for seasonal precipitation (Table 3.1.2). The main picture is that - with a few exceptions - precipitation has increased in winter, spring, and summer, but decreased in autumn. The winter increase was largest in the southernmost regions, while the increase in spring was larger in north-western areas. The reduced autumn precipitation was most prominent in western regions.

Table 3.1.2 *Change in precipitation (% of 1991-2020 average) from the period 1961-1990 to 1991-2020 in different Norwegian precipitation regions (Figure 3.1.4).*

Precipitation region	RR1	RR2	RR3	RR4	RR5	RR6	RR7	RR8	RR9	RR10	RR11	Norge
Annual	8	6	9	11	7	6	7	5	7	11	6	7
Winter	23	14	25	25	20	13	12	11	13	21	0	17
Spring	2	6	6	12	17	13	14	13	23	21	16	14
Summer	6	11	7	7	4	11	10	8	0	9	14	7
Autumn	2	-3	-2	-3	-10	-10	-7	-10	-4	0	-4	-6

The regional variations in the increase in precipitation from 1961-1990 to 1991-2020 have led to a change in terms of which precipitation region has the highest annual precipitation on average. In the period 1961-1990 it was RR5 “Vestland”, while in the period 1991-2020 it was RR4 “Sørvestlandet” (see Figure 3.1.5).

Likewise, variations in the changes in precipitation in different seasons have led to changes in several regions in terms of which season is “most rainy” (Figure 3.1.6). In the period 1961-1990, autumn was the season with the most precipitation in nine of the eleven regions, as well as on average for Norway. Though autumn (barely) held the ground as the number one rainy season on average for Norway in the period 1991-2020, winter took over from autumn in five regions, while summer took over in two regions.

3.2 “Normal variability” of precipitation

For a number of practitioners, information on the typical variability in precipitation is just as relevant as the average conditions. Figures 3.1.5 and 3.1.6 provide not only the average but also the 25th and 75th percentiles of annual and seasonal precipitation sums for the different precipitation regions. Thus, the resulting span (vertical lines) covers 15 of the 30 annual or seasonal values over the respective 30-year periods.

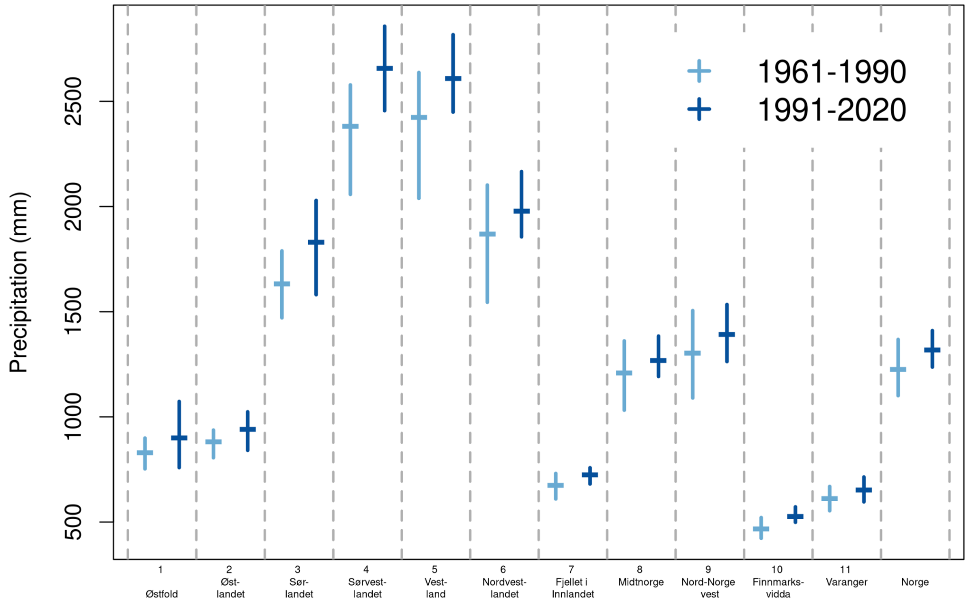


Figure 3.1.5 *Mean annual precipitation sum and yearly variability for Norway and Norwegian precipitation regions (cf. Fig. 3.1.4) for the periods 1961-1990 and 1991-2020.*

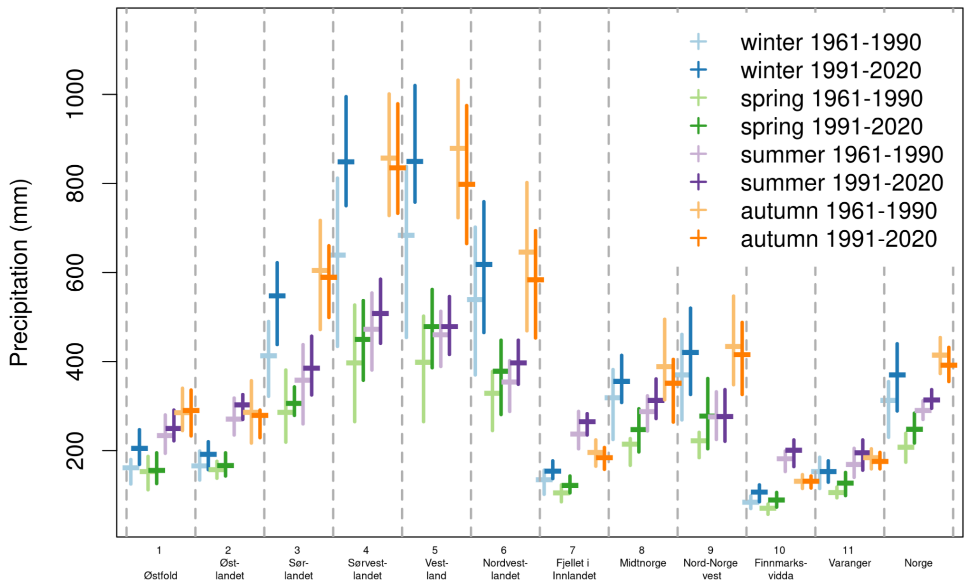


Figure 3.1.6 *Mean seasonal precipitation sum and yearly variability for Norway and Norwegian precipitation regions (cf. Fig. 3.1.4) for the periods 1961-1990 and 1991-2020.*

With the exception of the south-eastern regions 1 to 3, this span has decreased for annual precipitation across all regions, and on average for Norway (see Figure 3.1.5). Seasonally, the picture is more complex, as shown in Figure 3.1.6. In winter, the interval expanded for the southernmost and northernmost regions but decreased in western and central regions, as well as on average for Norway. In spring, only the south-westerly exposed regions 1, 3, 4 and 5 witnessed a reduction, while the span increased in the rest of the country. Summer exhibited a reduction in southern regions and an increase in northern regions. In autumn, the span decreased in most regions.

3.3 Wet days and simple daily intensity index

Figure 3.3.1 presents the number of wet days in Norway for the period 1991-2020, including a comparison with the period 1961-1990. Across most regions of Norway, the change falls within the range of 0 to 10 days. On average, there have been 4.2 more wet days across Norway than the 1961-1991 average of 140 days. However, two areas in western Norway substantially differ from the rest: a patch northeast of the Sognefjord witnesses a strong decrease in wet days, while a patch

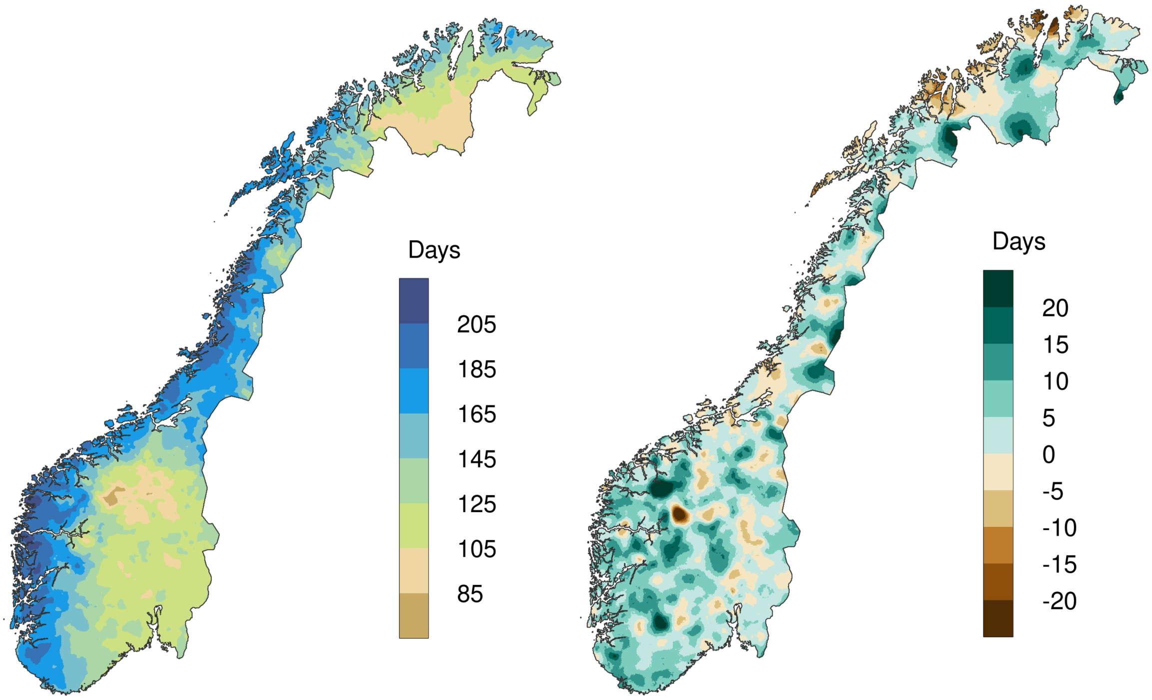


Figure 3.3.1*: a) Average number of wet days per year in the period 1991-2020; b) Difference between 1991-2020 and 1961-1990 for number of wet days per year.*

east of the Innvikfjorden experiences a strong increase. Note that such patches can also be a result of changes in the station network, i.e. stations that have been added or removed during the periods of interest.

Figure 3.3.2 shows the simple daily intensity index for the period 1991-2020 along with the changes from 1961-1990 to 1991-2020. The majority of Norway exhibits a weak increase in the intensity index, ranging from 0 to 1 mm per day. Relative to the 1961-1990 average of 8.4 mm per day for Norway, there has been an average increase of 0.3 mm per day. Notably, there are some areas with more pronounced increases, particularly over the Lofoten islands, where the intensity index has increased by over 4 mm per day.

We conclude that the observed increase in total precipitation from the period 1961-1990 to 1991-2020 is due to both an increase in the number of wet days and in the simple daily intensity index. The relative increase in precipitation intensity index (4.3%) was, however, slightly larger than the relative increase in the number of wet days (3.3%).

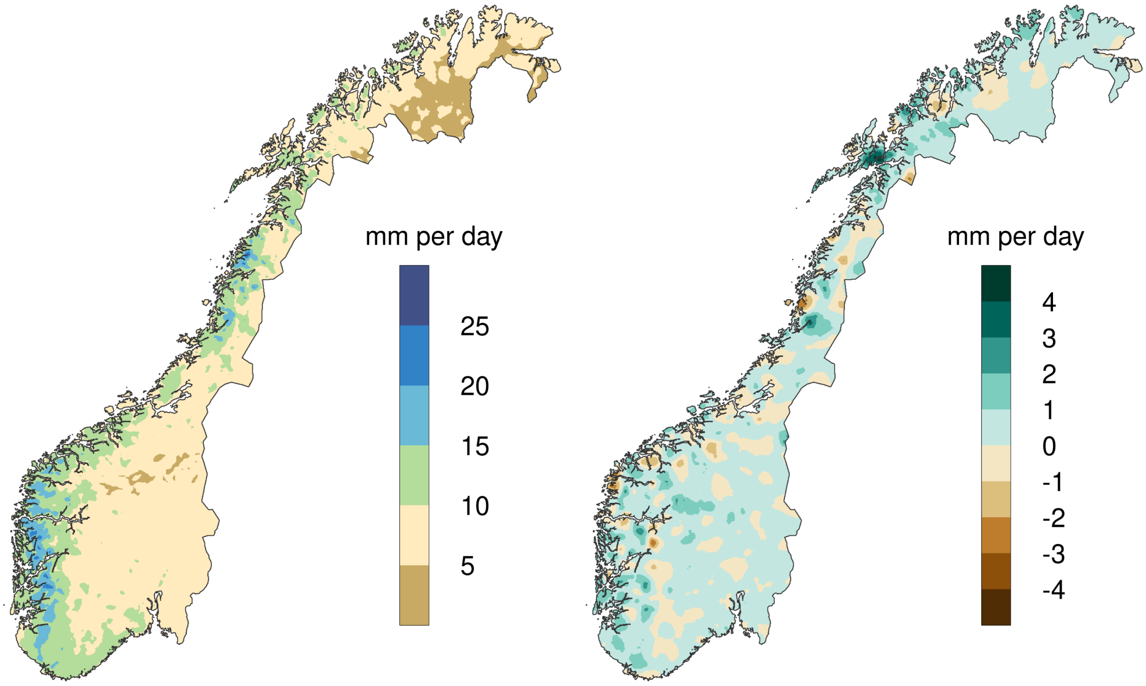


Figure 3.3.2*: a) Simple daily intensity index (mm/day) in the period 1991-2020; b) Difference between 1991-2020 and 1961-1990 in simple daily intensity index.*

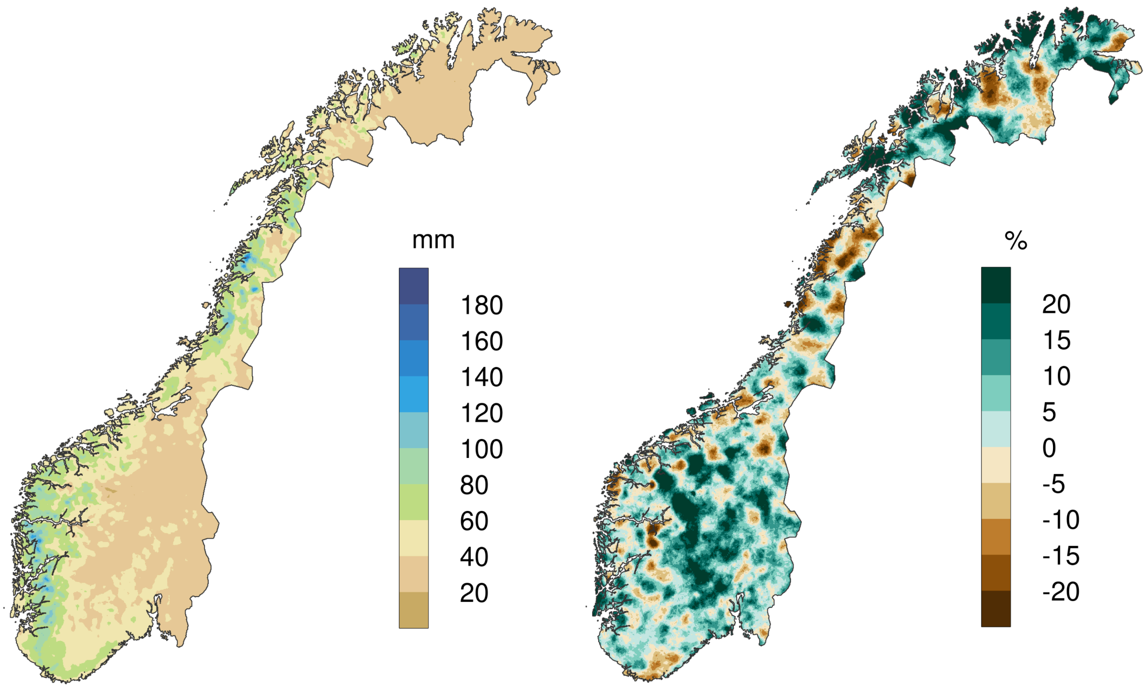


Figure 3.4.1*: a) Threshold value for heavy daily precipitation (mm/day) in the period 1991-2020; b) Relative difference between 1991-2020 and 1961-1990 in %.*

3.4 Heavy daily precipitation (99.7 percentile)

The 99.7th percentile of precipitation for the period 1991-2020 is illustrated in Figure 3.4.1, along with its relative difference compared to 1961-1990. The relative change spans mainly from 0 to 15 %, with an average increase of 5.6 %. However, some areas show substantially higher changes, with the 99.7th percentile of precipitation experiencing up to 70 % increase. This underscores that the intensity of heavy daily precipitation has increased across most parts of Norway from the previous standard normal period 1961-1990 to the current standard normal period 1991-2020.

3.5 Number of days with 20 mm precipitation or more

Figure 3.5.1 presents the number of days with at least 20 mm precipitation for the period 1991-2020, together with the changes from 1961-1990 to 1991-2020. Across most of Norway, there is a clear positive trend in the frequency of days with very heavy precipitation, varying from 0 to 4 days, with an average of 1.7 days. Note that southwestern Norway and the Lofoten Islands experience a more pronounced increase with 6 to 10 days, the maximum in some areas reaching even 20 days.

The probability of daily precipitation amounts surpassing a certain threshold, as well as precipitation percentiles, can also be estimated directly from the number of wet days and the simple daily intensity index (Benestad et al., 2019). The formula for this estimation is

$$Pr(X > x) = f_w \cdot e^{-x/\mu},$$

where X is the daily precipitation amount, x the threshold (e.g. 20 mm), f_w the fraction of wet days and μ the simple daily intensity. Values of the annual number of days with 20 mm precipitation or more using the formula are similar to the empirical values shown here. For the 99.7 percentile, the two methods yield slightly different results, although the general patterns are similar (not shown). This discrepancy arises because the equation is not expected to perform optimally for the extreme tail of the daily precipitation distribution (Benestad et al., 2019). Despite this, the universality of the formula fastens the process of computing the number of days above multiple thresholds and different percentiles, as it relies solely on the wet day frequency and intensity. It can also offer insights into the contribution to changes from either the wet day frequency or the intensity.

3.6 Maximum consecutive five-day precipitation sum

In Figure 3.6.1, the mean annual maximum for consecutive 5-day precipitation sums over Norway for the period 1991-2020 is illustrated, accompanied by a relative comparison to the standard normal period 1961-1990. Across most regions of Norway, the change fluctuates between 0 and 15 %, with an average increase of 5.6 %. However, some areas, like the Lofoten Islands, show a substantially higher increase of up to 65 %.

4 Summary and conclusions

This report discusses precipitation patterns in Norway, comparing data from the two recent standard normal periods 1961-1990 and 1991-2020. Norway experienced an average annual precipitation of 1324 mm during 1991-2020, with considerable variations across its different regions.

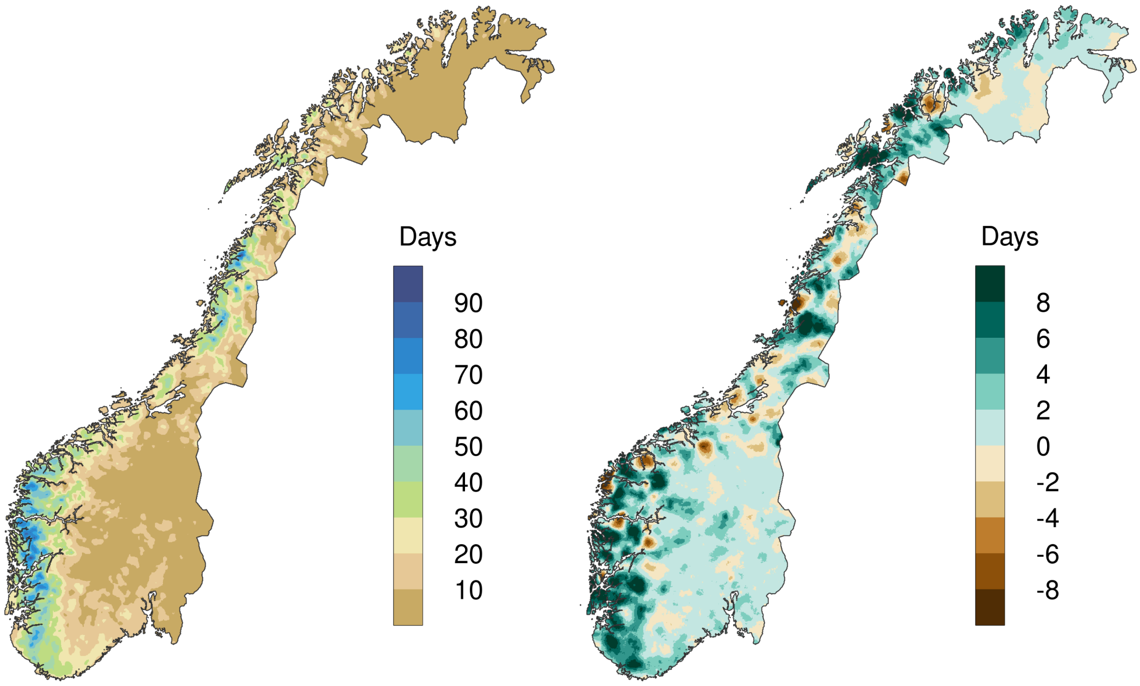


***Figure 3.5.1**: a) Mean annual number of days with 20 mm precipitation or more in the period 1991-2020; b) Difference between 1991-2020 and 1961-1990 in number of days with precipitation ≥ 20 mm.*

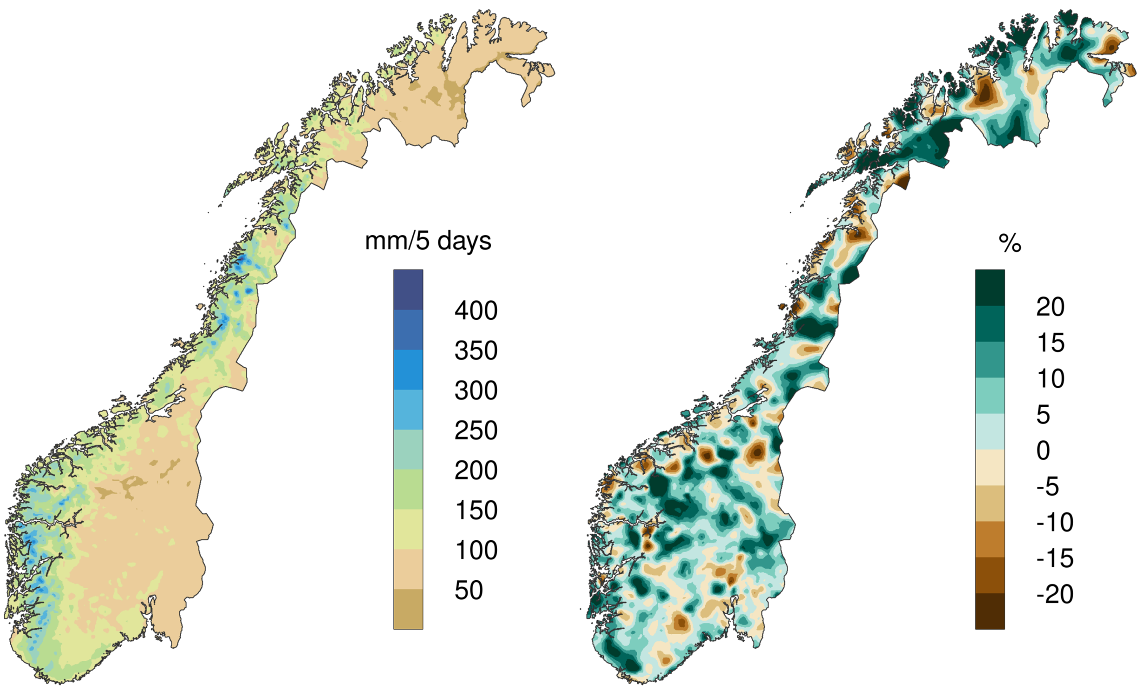


***Figure 3.6.1**: a) Mean annual maximum for consecutive 5-days precipitation sum (mm) in the period 1991-2020; b) Relative difference between 1991-2020 and 1961-2020 in %.*

Precipitation has increased by 7% from the 1961-1990 standard normal. The average annual increase aligns with amounts that could be expected as a consequence of global warming during the same period. The average increase in winter precipitation has, however, surpassed the anticipated levels, while there has been a decrease in autumn precipitation. These deviations from projected linear trends can be linked to variations in atmospheric circulation patterns.

The precipitation increase from 1961-1990 to 1991-2020 is influenced partly by an increase in the number of wet days (+3.3 %) but even more so by an increase in the average precipitation on wet days (+4.3 %). Remarkably, heavy daily precipitation saw a substantial increase (+5.6 %), surpassing the rise in precipitation on wet days. This pattern is also reflected in the maximum precipitation over five consecutive days.

Despite notable geographical variations in all analysed precipitation indices, the overarching trend is clear: precipitation in Norway has increased from the previous (1961-1990) to the present (1991-2020) standard normal period, with a more pronounced rise on days with heavy precipitation.

References

Benestad, R. E., Parding, K. M., Erlandsen, H. B., & Mezghani, A. (2019). A simple equation to study changes in rainfall statistics. *Environmental Research Letters*, 14(8), 084017

Deser, C., Knutti, R., Solomon, S. *et al.* (2012) Communication of the role of natural variability in future North American climate. *Nature Clim Change* 2, 775–779, doi:10.1038/nclimate1562

Gimento, L., Nieto R., Vázquez M. and Lavers D.A. (2014) Atmospheric rivers: a mini-review. Front. Earth Sci. 2:2. doi: 10.3389/feart.2014.00002

Hanssen-Bauer, I., Førland, E. J., Haddeland, I., Hisdal, H., Mayer, S., Nesje, A., Nilsen, J.E.Ø., Sandven, S., Sandø, A.B., Sorteberg, A., and Ådlandsvik, B. (red.) Andreassen, L.M., Beldring, S., Bjune, A., Breili, K., Dahl, C.A., Dyrrdal, A.V., Isaksen, K., Haakenstad, H., Haugen, J.E., Hygen, H.O., Langehaug, H.R., Lauritzen, S.E., Lawrence, D., Melvold, K., Mezghani, A., Ravndal, O.R., Risebrobakken, B., Roald, L., sande, H., Simpson, M.J.R., Skagseth, Ø., Skaugen, T., Skogen, M., Støren, E.N., Tveito, O.E. and Wong, W.K. (2015) *Klima i Norge 2100 Kunnskapsgrunnlag for klimatilpasning* oppdatert i 2015, NCCS report no. 2/2015

Hanssen-Bauer, I., Tveito, O. E., Tajet, H. T. T., Skaland, R. G. (2022) Temperatur- og nedbør-regioner i Norge. Sammenligning av forskjellige regioninndelinger, MET Report 11-2022

Hurrell, J. W. (1995). Decadal Trends in the North Atlantic Oscillation: Regional Temperatures and Precipitation. *Science*. **269** (5224): 676–679, doi:10.1126/science.269.5224.676

Hurrell, J. W. (2003). *The North Atlantic Oscillation: Climatic Significance and Environmental Impact*. American Geophysical Union, ISBN 9780875909943

IPCC (2021) *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*[Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, In press, doi:10.1017/9781009157896

Konstali, K. and Sorteberg, A. (2022) Why has precipitation increased in the last 120 years in Norway? JGR. 122 (15), doi:10.1029/2021JD036234

Lussana, C., Tveito, O. E., Dobler, A., and Tunheim, K. (2019) *seNorge_2018, daily precipitation, and temperature datasets over Norway*, Earth Syst. Sci. Data, 11, 1531–1551, doi:10.5194/essd-11-1531-2019

Lussana, C. (2020) *seNorge observational gridded dataset. seNorge_2018, version 20.05.* MET report no. 07/2020

Schär, C., Ban, N., Fischer, E.M. et al. (2016) Percentile indices for assessing changes in heavy precipitation events. Climatic Change 137, 201–216

Tveito, O. E. (2021): *Norwegian standard climate normals 1991-2020 - the methodological approach* MET report 05-2021

Tveito, O. E. (2023): *The effect of homogenization when constructing long term gridded monthly precipitation and temperature data.* Int. J. Climatol (accepted)