Norwegian Centre for Climate Services

Rain, sleet and snow in Norway 1971-2000: Observations vs. climate model simulations

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Photo: Inger Hanssen-Bauer

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Abstract

This report summarizes the analyses of precipitation as rain, sleet, and snow in Norway in the reference period 1971-2000 performed in the RCN project ClimTour. Results from re-gridded and bias-adjusted output from ten Euro-CORDEX models were compared to results from the observation-based dataset *seNorge2018*. Both the Euro-CORDEX-based dataset and *seNorge2018* include daily values for temperature and precipitation for the Norwegian mainland in a 1x1 km grid. The precipitation phases rain, sleet and snow were defined by thresholds for the daily mean temperature (rain if T ≥ 1°C; sleet if 1°C > T > -1°C; snow if T ≤ -1°C). Precipitation amounts and number of days with precipitation were analysed.

Differences between the model-based results and the observationally based results were found both in total precipitation, in the precipitation trends within the period 1971-2000 and in the relative amounts of rain, sleet and snow. While the differences in total precipitation mainly are due to differences between two observationally based datasets, the differences in trends are mainly due to differences between decadal scale variability in the models and reality, and the differences between the relative amounts of precipitation in the various phases are mainly due to the bias adjustment method.

Keywords

Snow, sleet and rain, Norway, model evaluation

Disciplinary signature

Responsible signature

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1 Background and organisation of the report

In Norway, global warming leads not only to increasing temperatures, but especially in winter, also to increased precipitation (Hanssen-Bauer et al. 2017). The consequences of global warming on snow conditions at different Norwegian localities is thus not obvious: Though snow amounts are already decreasing in coastal areas and at low altitudes, long term trends show an increase at high altitudes (Skaugen et al. 2012).

Snow conditions are crucial for skiing-based tourism. In the RCN-supported project ClimTour (*Impacts of climate change on Norwegian nature based tourism*), several practitioners within the tourist industry have requested data on future snow conditions at different altitudes within their regions. In spite of an increase in easily available climate change information on websites (e.g. IPCC WGI Interactive Atlas), spatial resolution and systematic errors are still factors limiting usefulness of these products for practitioners. As part of the ClimTour project, Mayer et al. (2023) applied post-processed results from regional climate models to develop projections for future snow conditions at different altitudes in a case study focused on the Lofoten area in Nordland county. We have now developed similar datasets for the entire Norwegian mainland, and in the present report, we compare the model based dataset for the reference period 1971-2000 to an observation based dataset. We compare total precipitation as well as precipitation in the different phases, and we study the number of days as well as average precipitation per day.

Study area, datasets and methods are described in Chapter 2. Results from the observation based dataset are presented in Chapter 3, while the results as given by an ensemble of climate models are presented in Chapter 4. Discussion of the reasons for differences between the results in Chapter 3 and 4 are presented in Chapter 5, and the main results and conclusions from the study are summarised in Chapter 6.

2 Study area, data and methods

2.1 Study area and data

The analyses of the distribution between rain, sleet and snow are performed for the Norwegian mainland.

Climate in the period 1971-2000 according to observations

To describe the «present climate» in this report, we analysed the observation based dataset *seNorge_2018 version 21.09* (Lusanna, 2021). This comprises observed daily mean temperature and precipitation from all official meteorological stations in mainland Norway interpolated to a high-resolution terrain-following grid with 1 km spacing. We will refer to the dataset as *seNorge2018.* Though new standard normals have now been developed for the period 1991-2020 (Tveito 2021), we use the period 1971-2000 to represent «present climate». This is because 1971-2000 is the reference period for the climate model simulations.

Simulated climate in the period 1971-2000

The global climate projections from Earth System Models (ESMs) used in the 5th Assessment Report from the IPCC (2013) were produced with spatial resolution around 100 km. In the Euro-CORDEX initiative (Jacob et al., 2014) selected global models were downscaled with Regional Climate Models (RCMs). The resolution in the RCMs varies from about 50 km to about 12.5km. The data set is publicly available at several Earth System Grid Federation nodes, e.g.: https://esg-dn1.nsc.liu.se/search/esgf-liu. For the present study, we used a sub-sample of ten ESM-RCM model combinations with 12.5 km resolution (Table 2.1).

The spatial resolution of these data is still too coarse to give a fair representation of the Norwegian topography. Further, there are biases in the modelled temperatures and precipitation (in most cases cold and wet biases), which again affect the snow conditions. Wong et al. (2016) thus post-processed the model results by regridding them to the same1 km grid that is used in the *seNorge* datasets, and then adjusted for the biases, using the observation based dataset *seNorge_1.1* (Mohr 2008) for the period 1971-2000 as "ground truth". The resulting data set is openly available at https://nedlasting.nve.no/klimadata/kss for two greenhouse gas emission scenarios based on the representative concentration pathways RCP4.5 and RCP8.5, comprising a 130-year long period from 1971 until 2100. Nilsen et al. (2021) showed that – compared to the raw Euro-CORDEX dataset – this dataset significantly reduces errors. In accordance with the naming in Nilsen et al. (2021), we call this data set "COR-BA" (bias-adjusted RCM data for Norway from the Euro-CORDEX initiative) hereafter. In the present analyses, we applied data for the period 1971-2000.

***Table 2.1:** Model combinations retrieved from the high-resolution Euro-CORDEX data set. The bias-adjusted data set for Norway is available on https://nedlasting.nve.no/klimadata/kss.*

global climate model and realisation	**regional climate model**	**institution who performed the simulation**
CNRM-CERFACS-CM5_r1i1p1	CCLM4-8-17	Climate Limited-area Modelling Community (CLM-Community)
CNRM-CERFACS-CM5_r1i1p1	RCA4	Swedish Meteorological and Hydrological Institute (SMHI), Rossby Centre
ICHEC-EC-EARTH_r12i1p1	CCLM4-8-17	CLM-Community
ICHEC-EC-EARTH_r3i1p1	HIRHAM5	Danish Meteorological Institute (DMI)
ICHEC-EC-EARTH_r1i1p1	RACMO22E	Royal Netherlands Meteorological Institute (KNMI)
ICHEC-EC-EARTH_r12i1p1	RCA4	SMHI
MOHC-HadGEM2-ES_r1i1p1	RCA4	SMHI
IPSL-CM5A-MR_r1i1p1	RCA4	SMHI
MPI-ESM-LR_r1i1p1	CCLM4-8-17	CLM-Community
MPI-ESM-LR_r1i1p1	RCA4	SMHI

It should be noted that there are some systematic differences between *seNorge_1.1,* which was used for bias adjustment, and *seNorge2018* which is applied here to describe the present climate. Both datasets include adjustments to compensate for the fact that the distribution of precipitation measurements is not representative of the topography in Norway, and for undercatch due to wind. Few stations are situated in mountain areas, though such areas cover a considerable part of the country. Nevertheless, the elevation adjustment in the first *seNorge* version was later judged to be too high, so it was reduced from 10 to 7% per 100 m in *seNorge2018* (Tveito, 2021). In addition, the compensation for catch loss due to wind was improved. Possible consequences of this for the present analyses are further discussed in Chapter 5.

2.3 Methods

The datasets above include gridded daily average temperature and daily precipitation sum, but no information on whether the precipitation is liquid, frozen, or a mixture of these. As several factors affect the relationship between ground temperature and precipitation form, there is no global one-to-one dependence between these variables. Jennings et al. (2018) found that the average air temperature at which the probability for rain and snow is the same is +1.0°C, but with considerable spatial variation from -0.4°C to +2.4°C at 95% of almost 12000 stations in the Northern Hemisphere. The lower values were found at maritime stations. As the maritime influence is considerable in most parts of Norway, we assume a temperature threshold near 0°C to be realistic for our study. Therefore, we apply a simple temperature-based climate indicator separating precipitation falling as snow (mean daily $T \leq -1°C$), sleet ($-1°C < T < 1°C$) or rain ($T \geq 1°C$). The temperature thresholds were applied for every grid point, and for every day. Calculations were performed on an annual basis as well as for winter (DJF) and spring (MAM).

To detect changes in the different forms of precipitation, the non-parametric Mann–Kendall trend test (Wilks, 2019) (p. 178) was applied to quantify the significance of trends at a 5% level ($p < 0.05$). Sen's slope was used to estimate the slopes of the trends (Sen, 1968). Trends in amounts as well as number of days with precipitation of different forms were assessed for the whole of Norway. The trend in amounts were also tested in every grid point. The resulting p-values were then analysed using the method in Benjamini and Hochberg (1995) to control the false discovery rate.

3 Observation based precipitation

3.1 Precipitation amounts

According to the present analyses of the *seNorge2018* dataset, the average annual precipitation for Norway during the period 1971-2000 sums up to 700 mm rain, 147 mm sleet and 445 mm snow (Table 3.1). This adds up to about 1290 mm totally. Thus, about 54% fell as rain, 11% as sleet, and almost 35% as snow in this period. The fractions of snow and sleet were higher in winter and spring. The snow fractions were about 55% and 43%, respectively, and the sleet fraction about 16%.

Table 3.1: *Average amount (mm) and trend magnitude (mm per decade) of seasonal and annual rain, sleet and snow in Norway during the period 1971-2020 based on seNorge2018. Last column gives the maximum and minimum grid point values for single years in the period.*

		Average Value (mm)	Trend Magnitude (mm per decade)	Range (mm)
Rain	Annual	700	+24.3	6.4 - 5993.5
	Winter	130	+17.1	0.1 - 2685.6
	Spring	97	+11.9	0.1 - 1667.4
Sleet	Annual	147	+6.2	0.1 - 2084.9
	Winter	69	+6.3	0.1 -1424.8
	Spring	40	+3.5	0.1 - 859.7
Snow	Annual	445	+13.2	0.1 - 5861.9
	Winter	246	+11.6	0.1 - 3393.7
	Spring	104	+11.5	0.1 - 1864.2

The 1971-2000 mean annual rainfall for different grid points ranges from 62 mm to 4191 mm. Rain accounted for the vast majority of precipitation over lowlands in southern Norway, including coastal areas up to approximately 70 °N (Figure 3.1a). The single grid point 30-year average sleet-values are ranging from 1 mm to 1190 mm. The highest values are found in a zone close to the coast of western Norway (Figure 3.1b), but sleet was not the dominating precipitation phase anywhere in the period 1971-2020. Annual values for snowfall (water equivalent) range from 4 mm to 4246 mm. The larger values were mainly concentrated in mountain areas (Figure 3.1c). Snow was the dominating precipitation phase in the mountains and most northern regions.

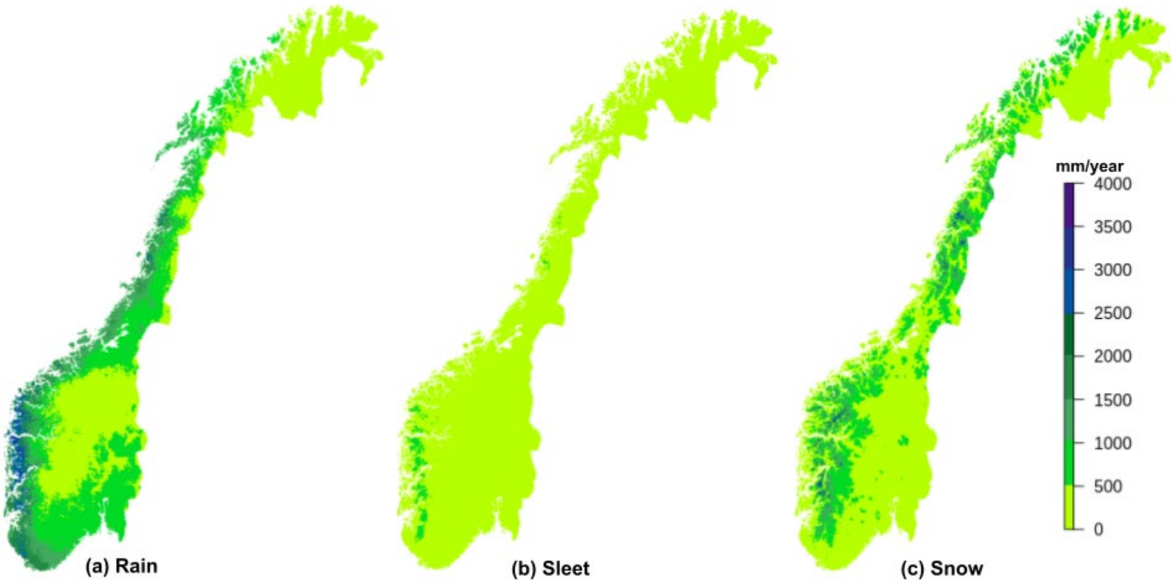

Figure 3.1. *Average annual precipitation sums as (a) rain, (b) sleet and (c) snow during 1971-2000 based on seNorge2018*

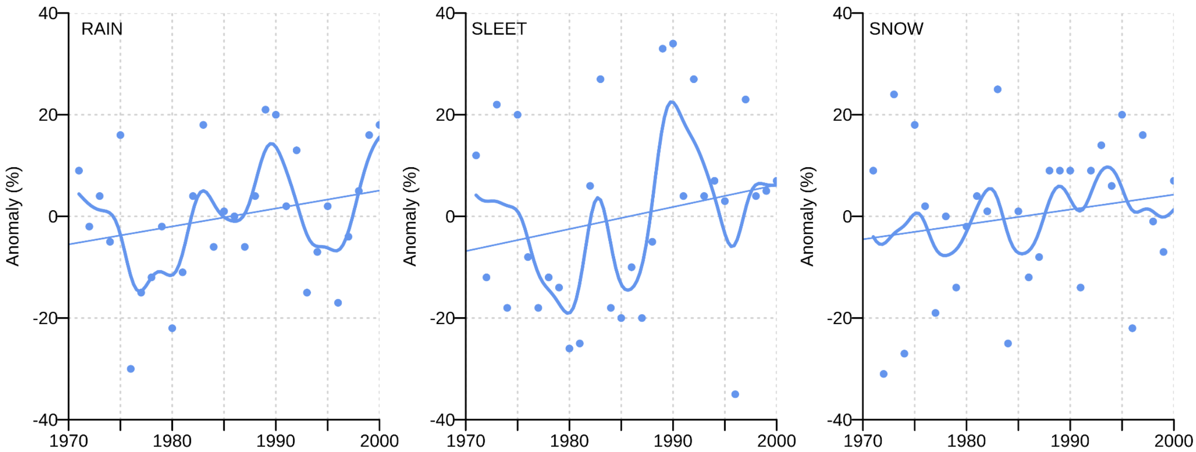

Figure 3.2 *Anomalies (in % of 1971-2000 average) in annual precipitation of different phases in Norway based on seNorge2018. (3 year Gaussian filter and trendline added.)*

Table 3.2: *Mann-Kendall non-parametric trend test for annual and seasonal precipitation amounts*

	Rain		**Sleet**		**Snow**	
	Test statistics (τ)	**P-value**	**Test statistics (τ)**	**P-value**	**Test statistics (τ)**	**P-value**
Annual	0.073	0.570	0.061	0.638	0.052	0.685
Winter	0.144	0.262	0.157	0.221	0.183	0.153
Spring	**0.228**	**0.080**	0.182	0.164	0.163	0.212

Mean annual precipitation for Norway increased from 1971 to 2000 by 24.3 mm/decade for rain, 6.2 mm/decade for sleet, and 13.2 mm/decade for snow. Measured in percent of total precipitation in the respective phases, the increase was 3.5, 4.2 and 3.0 % per decade (Figure 3.2). However, none of the national trends in annual values are even close to being statistically significant at the 5% level according to the Mann-Kendall nonparametric test (Table 3.2).

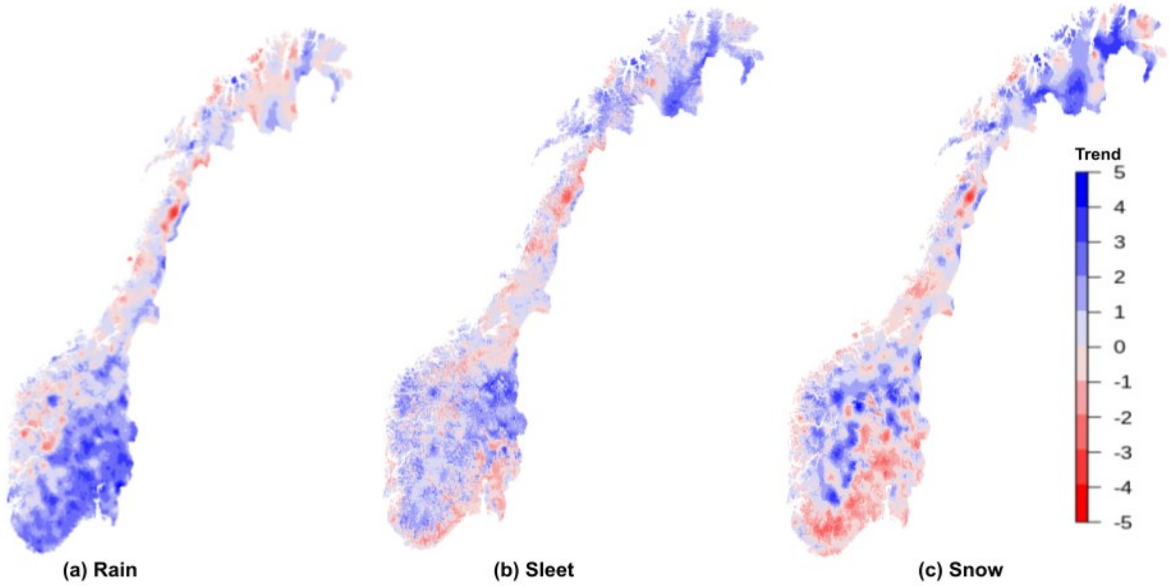

Figure 3.3. *Trends in the different forms of precipitation over Norway during 1971–2000. Positive p-values (blue) are for positive trends (increasing precipitation) and negative p-values (red) for negative trends (decreasing precipitation). Areas with significant trends are given in Figure 3.4.*

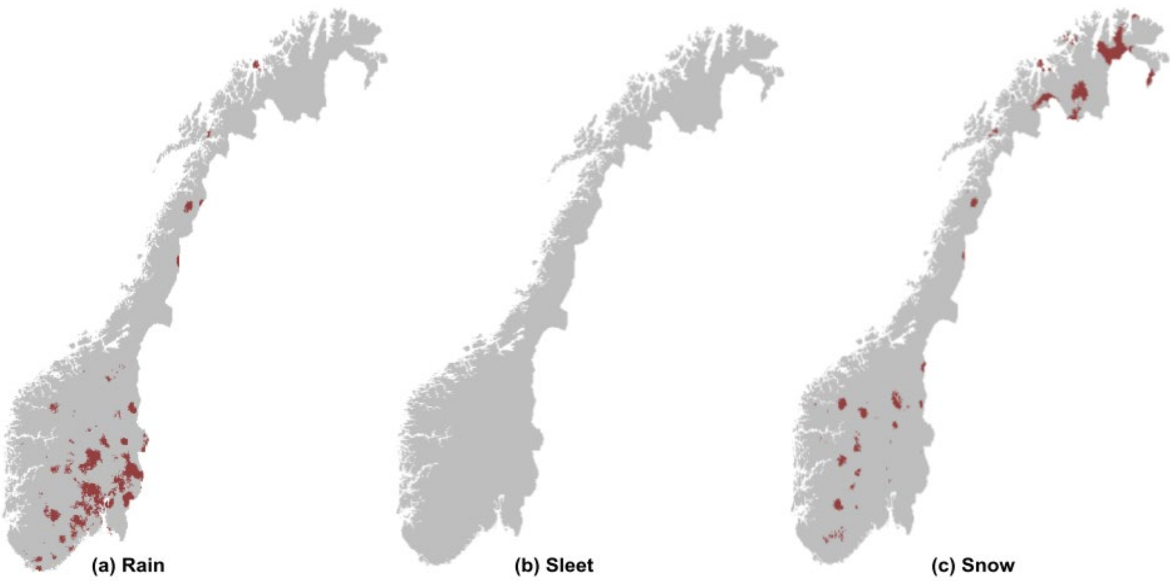

Figure 3.4. *Red colour shows grid points where trends are significant at the 5% level (p < 0.05)*

Trends vary considerably between regions (Figure 3.3). Annual rainfall (Figure 3.3a) shows a general increase in southern and south-eastern Norway, but a decrease in some west-northwestern areas. The trends are statistically significant only in some limited areas (Figure 3.4a), and with few exceptions, areas with significant trends show increased rainfall.

Trends in annual snowfall show a general increase at high altitudes, and also in most of northern Norway, while there has been a decrease at low altitudes and in coastal areas in southern and south-eastern Norway (Figure 3.3c), quite in accordance with the conclusions from Dyrrdal et al. (2011). The trends are statistically significant only in parts of the area (Figure 3.4c), and again, a majority of the significant trends show an increase. For sleet (Figure 3.3b), the geographical pattern is more similar to the pattern for snow than to the pattern for rain, but no trends are statistically significant (Figure 3.4b).

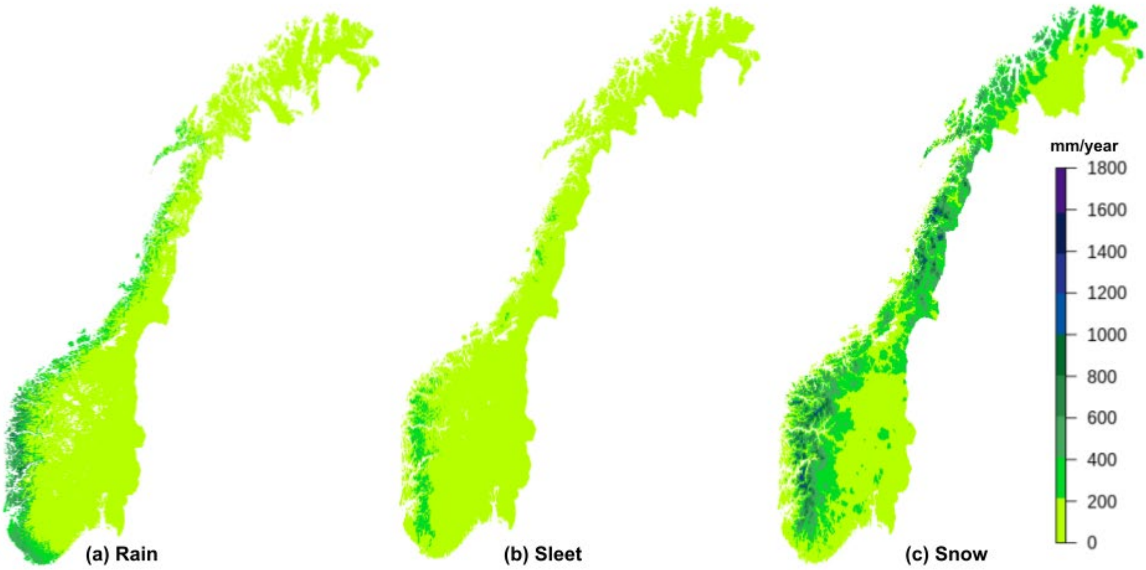

Figure 3.5. *Average winter precipitation sums as (a) rain, (b) sleet and (c) snow during 1971-2000 based on seNorge2018.*

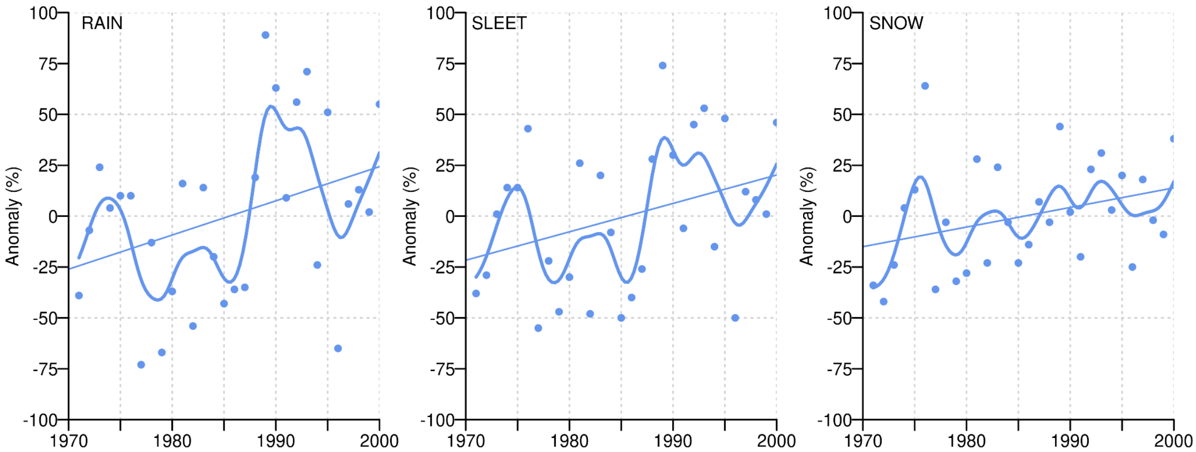

Figure 3.6. *Anomalies (in % of 1971-2000 average) in winter precipitation in different phases in Norway based upon seNorge2018. (3 year Gaussian filter and trendline added.)*

In winter, the largest amounts of rain in the period 1971-2000 were observed along the coast of western and south-western Norway (Figure 3.5a). The largest amounts of snow were observed in mountain areas in western Norway and Nordland county (Figure 3.5c). The geographical pattern for sleet was rather similar to the pattern for rain, although the maximum zone was shifted slightly in from the coast (Figure 3.5c). Rain was the dominant precipitation phase along most of the coast of southern Norway, while snow dominated in northern Norway and generally in the mountains and inland regions.

The linear trends in winter precipitation are all positive (Figure 3.6). The relative increase is larger than for annual precipitation, but still not statistically significant at the 5% level (Table 3.2).

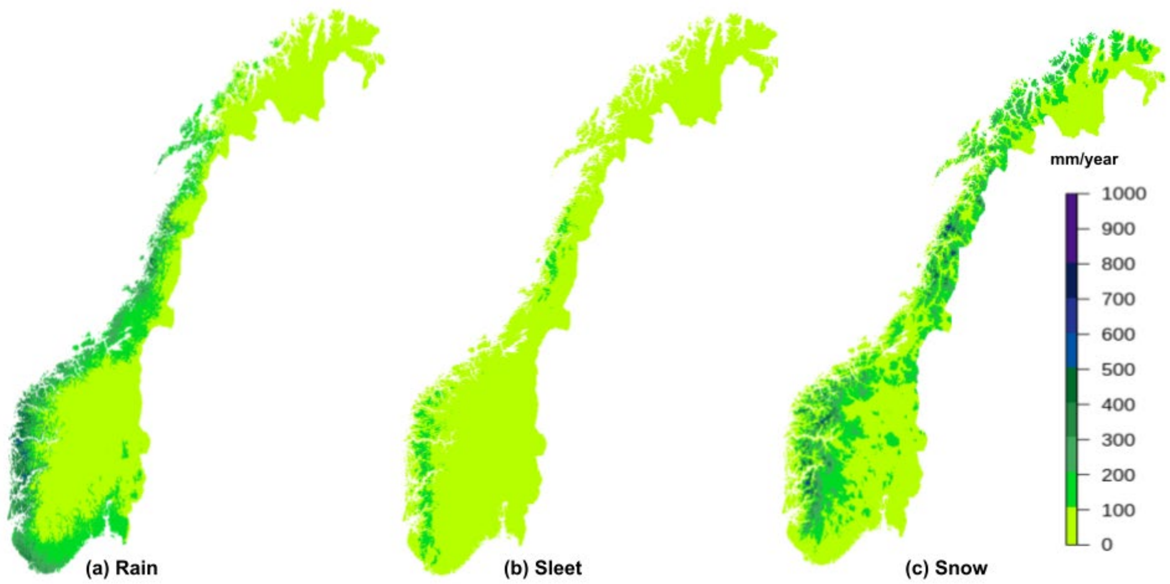

Figure 3.7. *Average spring precipitation sums as (a) rain, (b) sleet and (c) snow during 1971-2000, based on seNorge2018.*

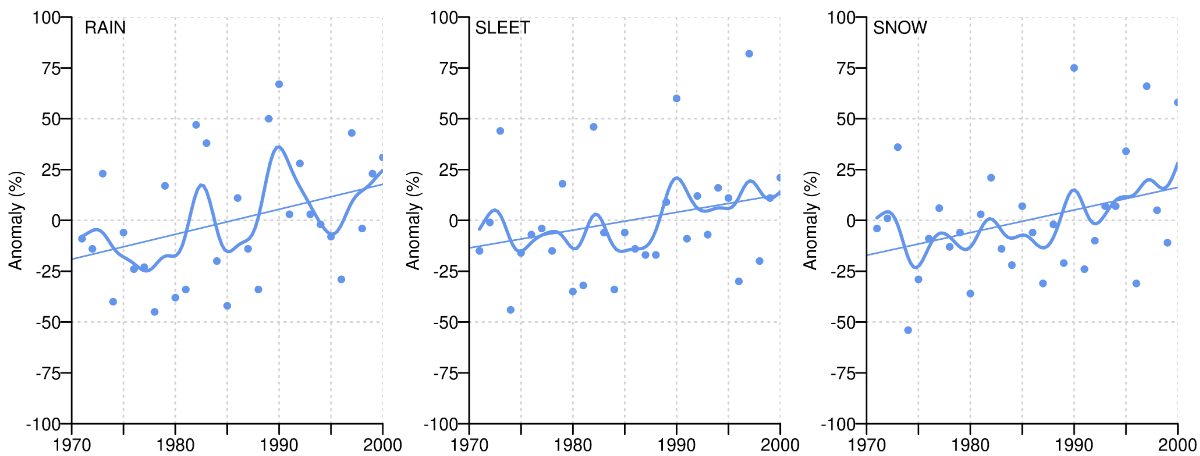

Figure 3.8. *Anomalies (in % of 1971-2000 average) in spring precipitation of different phases in Norway based on seNorge2018. (3 year Gaussian filter and trendline added.)*

The geographical distribution of rain, sleet and snow in spring (Figure 3.7) is qualitatively similar to the corresponding pattern for winter (Figure 3.5). However, rain is the dominant precipitation phase over a larger area, including inland low altitude regions in southern Norway.

All trends are positive in spring (Figure 3.8), and although none of the trends are significant at the 5% level, the trend for rain is significant at the 10% level (Table 3.2). Especially for snow, the added trends in spring and winter sum up to more than the annual trend, indicating reduced snowfall during summer and autumn combined.

3.2 Number of days

On the average for Norway there were 101 rainy days, 19 days with sleet and 72 snowy days per year during the period 1971-2000, according to the present analyses (Table 3.3). Thus, about 53% of the precipitation days were rainy days, while about 10% were characterised as sleet-days, and slightly less than 37% were snowy days. The fact that the distribution in percent is rather similar between frequency and amount indicates that the average daily amount of precipitation in a rain-, sleet- and snow-day are not very different. The average amount of snow per day is still slightly lower than for the other phases, which is to be expected, as cold air has a smaller potential for carrying precipitable water than warmer air. On average, about 1 of 4 rainy days, 3 of 4 days with sleet and 4 of 5 days with snow occurred in winter or spring.

Table 3.3: *Average value and trend magnitude (per decade) of the seasonal and annual number of days with rain, sleet and snow in Norway during the period 1971-2020 based on seNorge2018. Last column gives the maximum and minimum grid point values for single years in the period.*

		Average days	Trend Magnitude (days per decade)	Range (days)
Rain	Annual	101	+3.6	0 - 284
	Winter	10	+1.2	0 - 83
	Spring	17	+1.6	0 - 74
Sleet	Annual	19	+0.7	0 - 64
	Winter	7	+0.6	0 - 36
	Spring	7	+0.4	0 - 28
Snow	Annual	72	-0.4	0 - 219
	Winter	38	+0.5	0 - 88
	Spring	20	+0.6	0 - 72

The 1971-2000 average number of rainy days for different grid points ranged between 0 and 238, while sleet days ranged between 0 and 49, and snow days between 0 and 195 days. The spatial patterns for the number of days with precipitation in different phases (Figure 3.9) closely follow the patterns for total precipitation (Figure 3.1). The highest numbers of rainy days are found along the western coast, while the highest numbers of snowy days are found in the mountains and in some northern areas. Rainy days accounted for the vast majority of precipitation over lowlands in southern Norway, including coastal areas up to approximately 70 °N. Snowy days dominate in the mountains and most northern regions. The average number of sleet days is less than 30 almost everywhere. The exception is a few areas in western and south-western Norway.

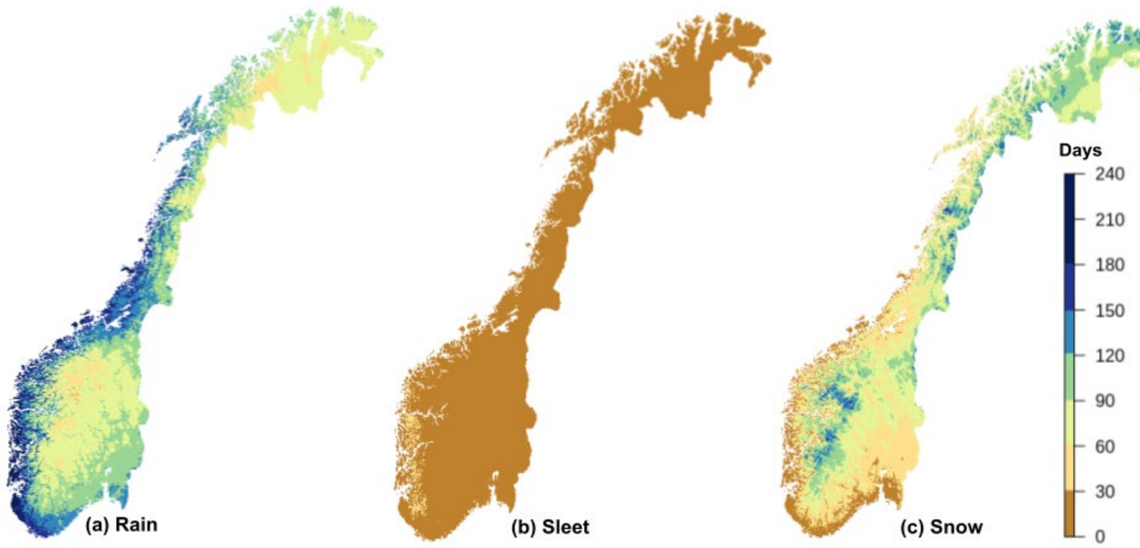

Figure 3.9. *Average number of days per year with (a) rain, (b) sleet and (c) snow during 1971-2000, based on seNorge2018.*

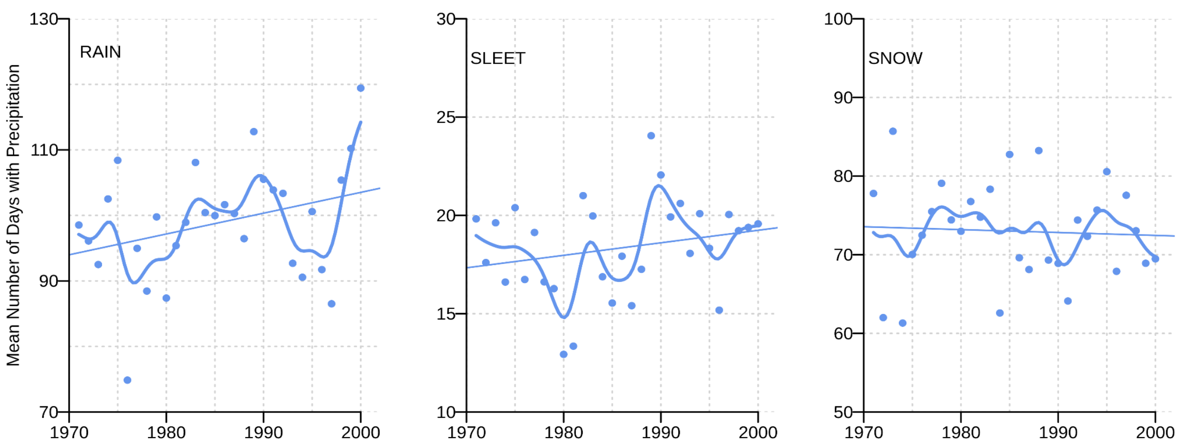

Figure 3.10. *Number of days per year with precipitation in different phases in Norway for the period 1971-2000 based on seNorge2018. (3 year Gaussian filter and trendline added.)*

The time series of mean annual precipitation days (Figure 3.10) exhibit a positive trend in the number of rainy days from 1971 to 2000 (an increase of 3.6 days per decade). There is also a tendency for an increased number of sleet days and a reduced number of snowy days. For snow, the increase in amount and reduction in the number of days implies that the average precipitation per day with snowfall has increased. However, the absolute changes are very small. None of the trends are statistically significant at the 5% level (Table 3.4). The trends are still qualitatively in agreement with a previous study

(Dyrrdal, 2009) where linear trend analysis of observational time series showed a general decrease in the number of snow days in Norway.

Table 3.4: *Mann-Kendall nonparametric trend test for number of days with precipitation*

	Rain		Sleet		Snow	
	Test statistics (τ)	P-value	Test statistics (τ)	P-value	Test statistics (τ)	P-value
Annual	0.117	0.355	0.0363	0.783	-0.14	0.263
Winter	0.172	0.187	0.209	0.108	0.053	0.695
Spring	0.232	0.074	0.177	0.175	0.099	0.454

In winter, the geographical pattern for the number of days with rain and sleet are rather similar, with very low values in mountain areas and in northern regions, and somewhat higher values along the coast and in some low-land areas in southern Norway (Figure 3.11 a and b). For snow, the picture is quite the opposite, with high values in the mountains and in the north, and lowest values along the coast in southern Norway (Figure 3.11 c). Rainy days are dominating over snowy days only along the outer coastline in western and south-western regions.

The linear trends are all positive (Figure 3.12), indicating increased number of days with precipitation in all phases. The increase is - relatively speaking - larger than for annual precipitation, but still not statistically significant at the 5% level (Table 3.4).

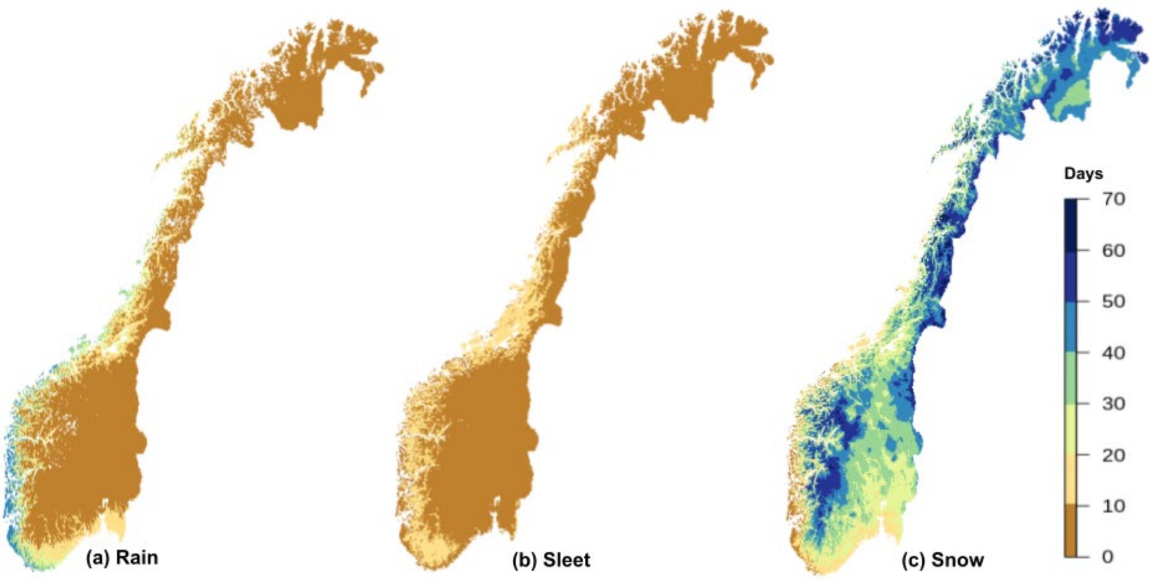

Figure 3.11. *Average number of days per winter (DJF) with (a) rain, (b) sleet and (c) snow during 1971-2000 based on seNorge2018.*

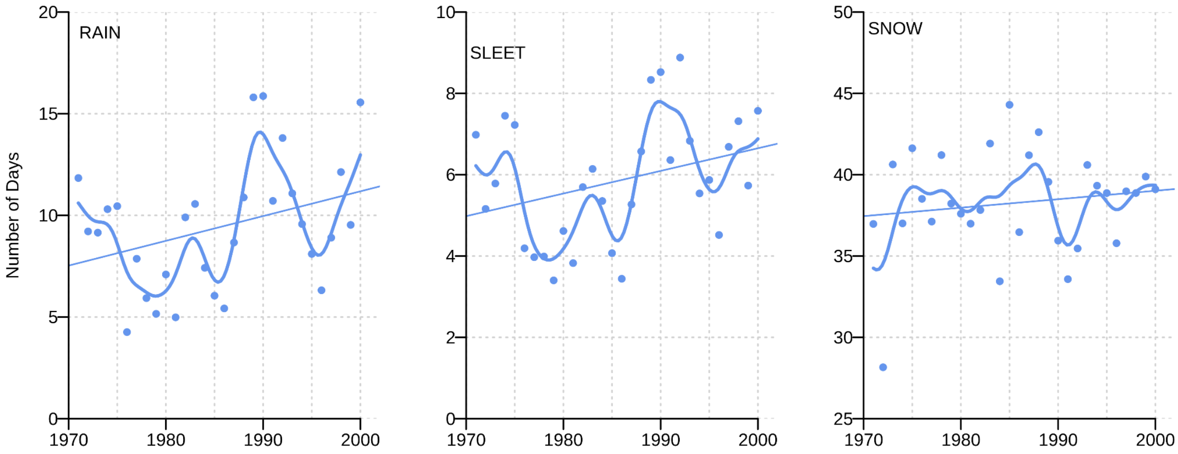

Figure 3.12. *Number of days per winter (DJF) with precipitation in different phases in Norway for the period 1971-2000, based on seNorge2018. (3 year Gaussian filter and trendline added.)*

In spring (Figure 3.13), the geographical pattern for the number of days with precipitation of different phases qualitatively shows the same geographical patterns as they do in winter. However, quantitatively there are considerable differences, and rainy days are dominating over snowy days along the coast as far north as Lofoten, and in southern Norway, also at low altitudes inland.

As for winter, the linear trends are all positive (Figure 3.14), and again the increase is - relatively speaking - larger than for annual precipitation. Still, none of the trends are significant at the 5% level, however, the trend in rainy days in spring is significant at the 10% level (Table 3.4).

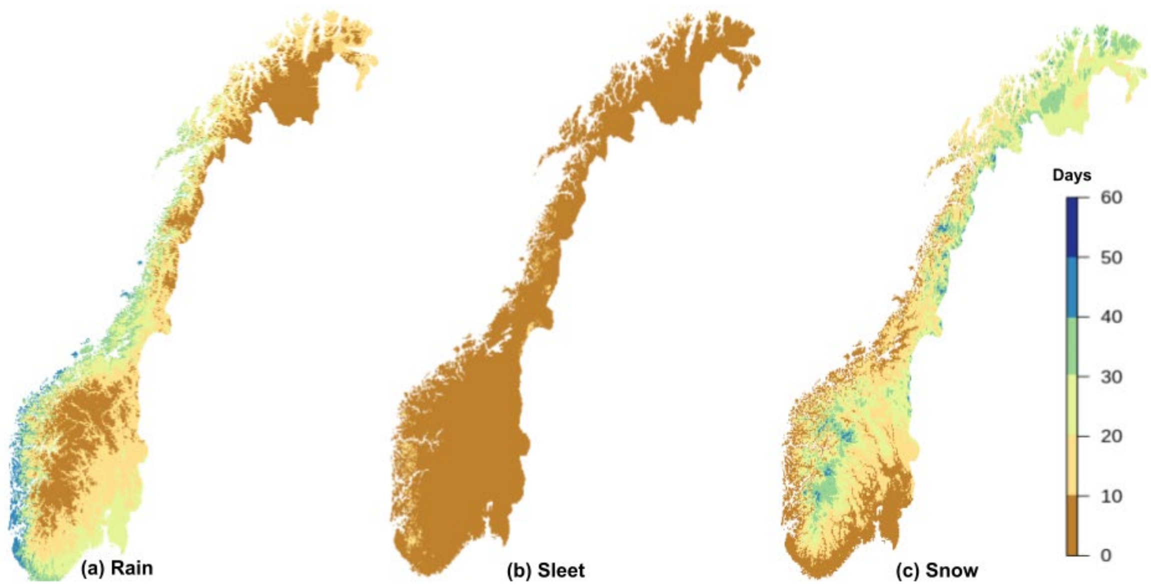

Figure 3.13. *Average number of days per spring (MAM) with (a) rain, (b) sleet and (c) snow during 1971-2000, based on seNorge2018.*

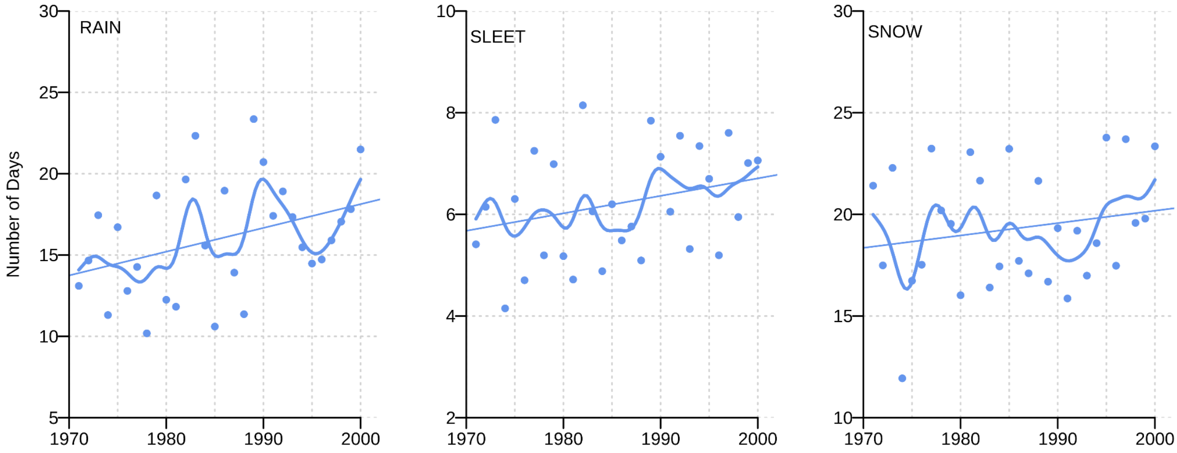

Figure 3.14. *Number of days per spring (MAM) with precipitation in different phases in Norway for the period 1971-2000, based on seNorge2018. (3 year Gaussian filter and trendline added.)*

4 Results from climate models

The bias adjusted COR-BA dataset, including ten of the Euro-CORDEX simulations (Table 1), was applied to calculate the model-based precipitation climatology for the reference period 1971-2000. As the ten models were all bias adjusted using the same reference dataset (*seNorge_1.1)*, the climatology for this period is rather similar for all models, as illustrated below for annual mean precipitation as rain (Figure 4.1). The maps in this Chapter are thus to a large degree based on the averages of these ten models.

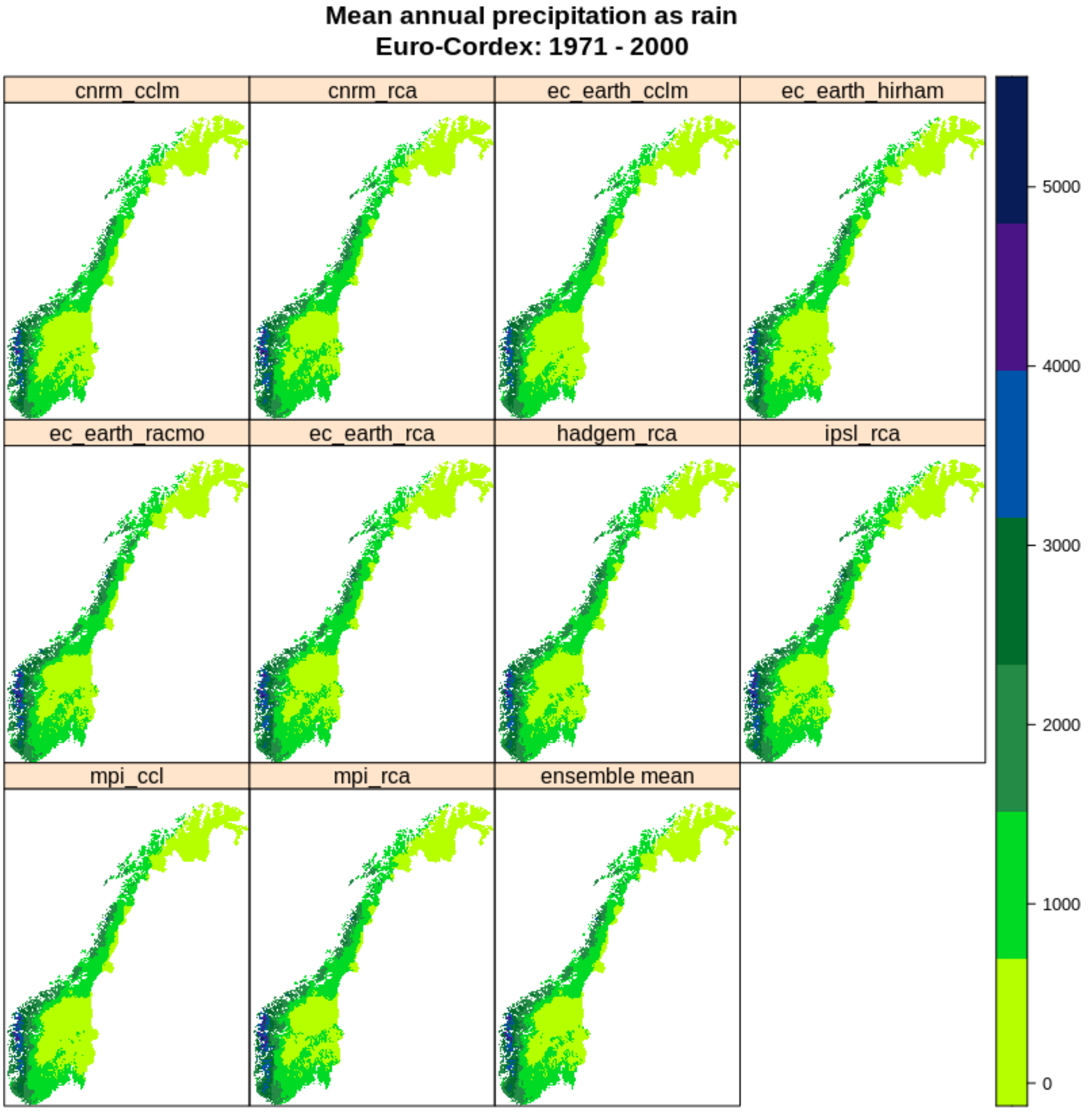

Figure 4.1. *Mean annual precipitation as rain in Norway for the period 1971-2000, according to the 10 models in the COR-BA dataset and the ensemble mean.*

4.1 Precipitation amounts

According to analyses based upon the COR-BA dataset, the average annual precipitation for Norway during the period 1971-2000 sums up to 1026 mm rain, 198 mm sleet and 370 mm snow (Table 4.1). This adds up to almost 1600 mm totally, which is quite in line with the result based directly on the *seNorge_1.1* dataset (Hanssen-Bauer et al. 2017, page 20), but 24% more than the results based on *seNorge2018* presented in Section 3.1 (Table 3.1). The difference in total precipitation between the two *seNorge*-datasets can thus be explained by the differences between the two datasets in adjustment factors for catch deficiency and altitude. This, together with possible reasons for other differences between the results in Chapter 3 and the results presented in this chapter, is further discussed in Chapter 5.

Table 4.1: *Average value (mm) and trend magnitude (mm per decade) of the seasonal and annual amount of rain, sleet and snow in Norway during the period 1971-2020 based on the ensemble-mean of 10 bias-adjusted simulations from the COR-BA dataset. Last column gives the maximum and minimum grid point values for single years in the period.*

		Average amount (mm)	Trend (mm per decade)	Range (mm)
Rain	Annual	1026	+33.2	160.1 - 6270.6
	Winter	174	+4.5	0.1 - 2257.5
	Spring	149	+11	0.1 - 1230.3
Sleet	Annual	198	-0.1	11.1- 1919.9
	Winter	86	-1.3	0.1 - 1100.9
	Spring	52	+0.2	0.4 - 647.1
Snow	Annual	370	-13.2	1.8 - 3666.4
	Winter	203	-11.3	0.3 - 1839.1
	Spring	92	-2.1	0.1 - 1213.3

Based on the COR-BA dataset, about 64% of the total precipitation fell as rain, 12% as sleet, and slightly less than 23% as snow (Table 4.1). Thus, compared to the observation based dataset in Section 3.1, rain accounts for a considerably larger part of the total precipitation and snow for a considerably smaller part.

The geographical distributions of annual precipitation in the different phases (Figure 4.2) show that rain is at maximum in western Norway, and also is the dominating phase of precipitation in most of Norway almost up to 70 °N, with the exception of some mountain areas where snow is dominating. North of about 70 °N, the average annual sum of rain and snow are more similar. Compared to the observation based dataset in Section 3.1, rain is the dominating precipitation phase over larger areas.

Trend analyses of the COR-BA simulations from 1971 to 2000 show that while the annual precipitation as rain increased by 33.2 mm per decade, the changes in sleet were very small, and the annual snow amounts were reduced by 13.2 mm per decade (Table 4.1 and Figure 4.3). Compared to the observation based dataset in Section 3.1 (Table 3.1), the simulated increase in rain is larger, but the differences in trends for sleet and especially for snowfall more than compensate for this. The total simulated precipitation trend is thus smaller than observed for the period 1971-2000.

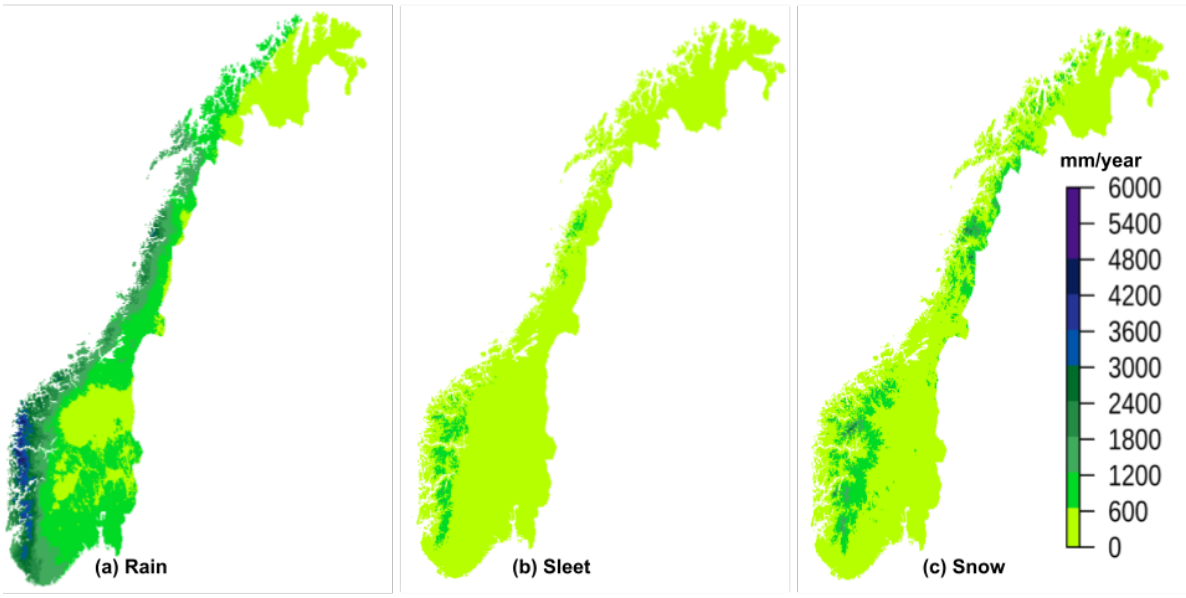

Figure 4.2. *Average annual precipitation sums as (a) rain, (b) sleet and (c) snow during 1971-2000, according to the COR-BA dataset.*

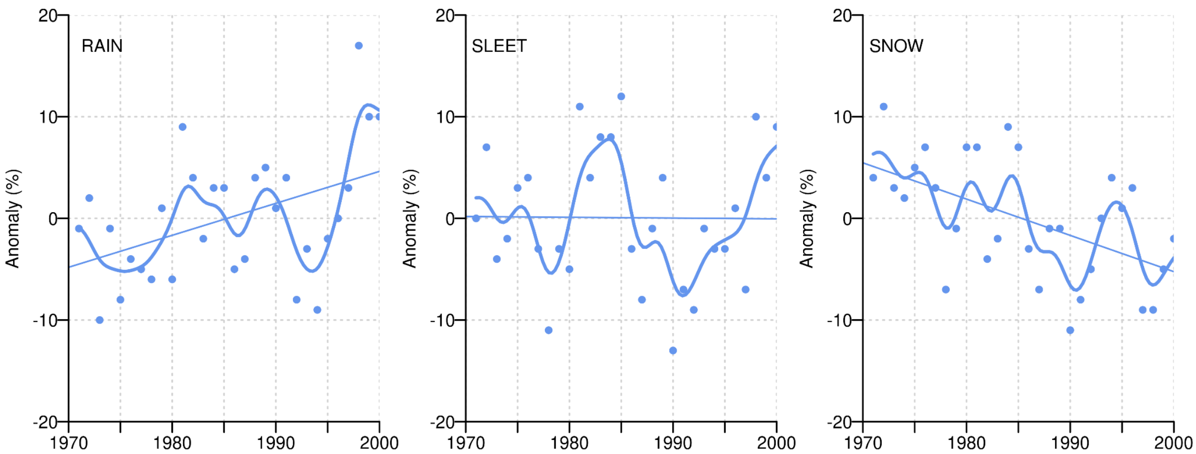

Figure 4.3. *Anomalies (in % of 1971-2000 average) in annual precipitation in different phases in Norway based on the COR-BA-dataset. (3 year Gaussian filter and trendline added.)*

4.2 Number of days

According to the COR-BA dataset, the average number of precipitation days in Norway in the period 1971-2020 were 126, 26 and 80 days for rain, sleet and snow, respectively (Table 4.2). These numbers are all higher than the observation based numbers in Section 3.1 (Table 3.3). Still, the relative distribution of the precipitation days with rain, sleet and snow (56.2%, 10.6% and 33.2% respectively) was more in line with the *seNorge2018*-based observations than the total amounts of rain, sleet and snow in mm.

Table 4.2: *Average value and trend magnitude (per decade) of the seasonal and annual number of days with rain, sleet and snow in Norway during the period 1971-2020 based on the ensemble-mean of 10 bias-adjusted simulations from the COR-BA dataset. Last column gives the maximum and minimum grid point values for single years in the period.*

		Average (days)	Trend (days per decade)	Range (days)
Rain	Annual	136	+2.2	20 - 313
	Winter	12	+0.6	0 - 73
	Spring	24	+1.1	0 - 74
Sleet	Annual	26	+0.0	4 - 61
	Winter	9	+0.2	0 - 28
	Spring	8	-0.01	1 - 26
Snow	Annual	80	-1.7	1 - 214
	Winter	42	-1	1 - 85
	Spring	22	-0.5	0 - 66

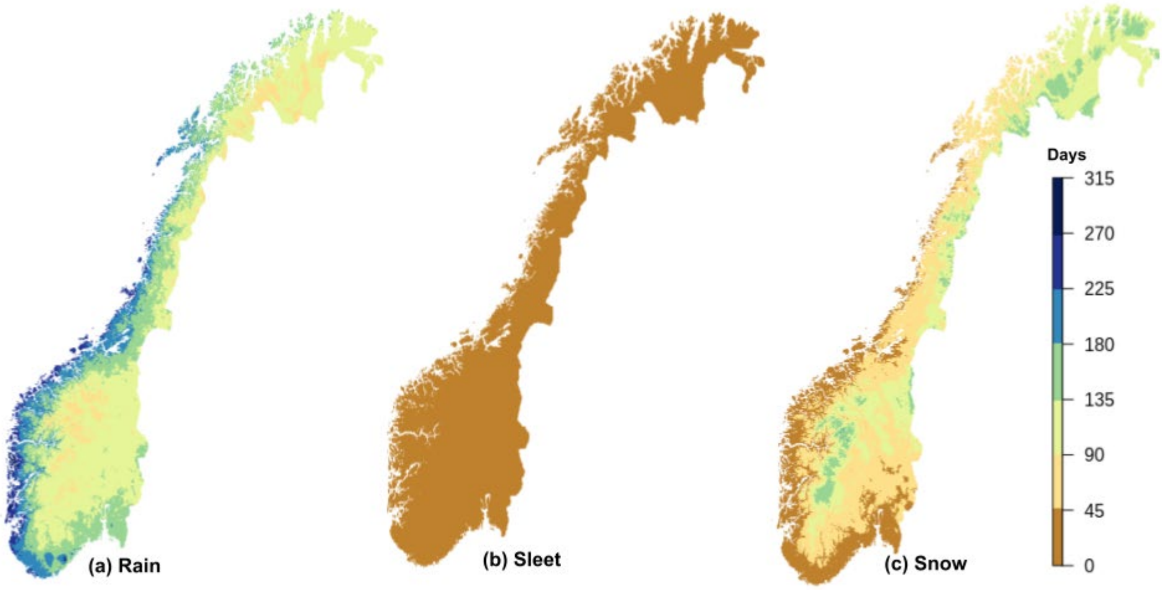

Figure 4.4. *Average number of days per year with (a) rain, (b) sleet and (c) snow during 1971-2000 according to the COR-BA dataset.*

The geographical distribution of number of days with precipitation of different phases as given by the COR-BA dataset (Figure 4.4) shows qualitatively the same patterns as the distribution based upon *seNorge2018* (Figure 3.9), though the absolute numbers are somewhat larger in the COR-BA dataset.

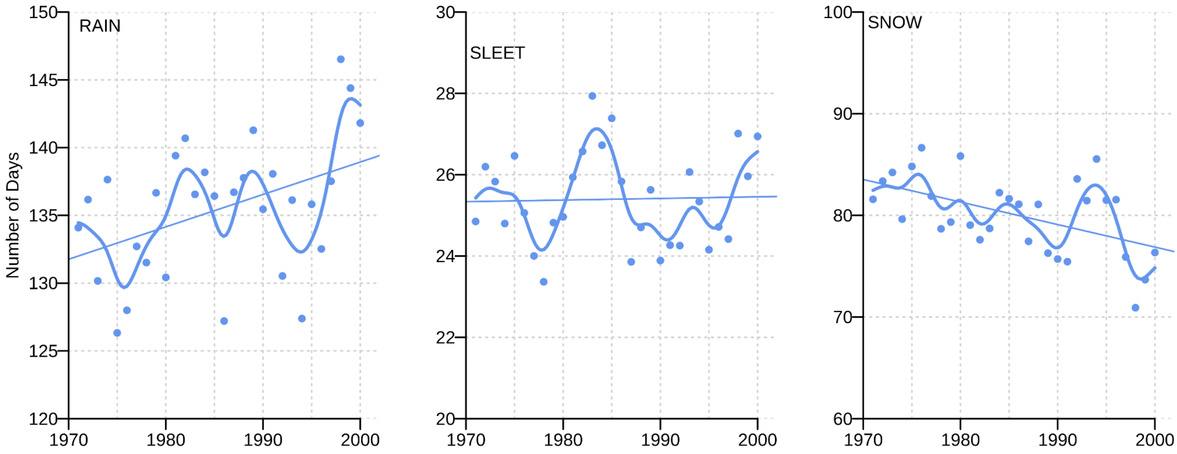

Figure 4.5. *Number of days per year with precipitation in different phases in Norway for the period 1971-2000, according to the COR-BA dataset. (3 year Gaussian filter and trendline added.)*

The trends in number of days with precipitation of different phases as given by the COR-BA dataset (Figure 4.5) are in a qualitative agreement with the trends based on *seNorge2018* (Figure 3.10) as they indicate an increase in the number of rainy days and a reduction in the number of snow days during the period 1971-2000. However, the increase in rainy days is smaller, and the reduction of snow days larger in the COR-BA dataset.

5 Discussion

5.1 Sources for differences

We here discuss the differences between the observation based results presented in Chapter 3 and the corresponding model based results in Chapter 4 with respect to the three sources for such differences described below.

A. Differences between the two *seNorge* versions: These are caused by differences in the adjustment factors in the two versions (see Section 2.1, last paragraph).
B. Differences between the real world and the climate simulations: Systematic differences between the real world and the climate models are taken care of here by bias adjustments of daily temperature and precipitation (which may introduce other problems; see point C below). But even a "perfect" climate model would not be able to give a "perfect" description of regional temperature and precipitation variability from year to year. The climate we experience regionally depends not only on the global energy balance, but also on fluctuations in the ocean and atmospheric circulation, as such fluctuations very much influence the geographical variation of temperature and precipitation. The global climate models manage to recreate such regional fluctuations in a realistic way (Deser et al. 2012), but since they are a result of the chaos effect, it is impossible to say exactly when and where hot, cold, wet or dry periods occur. Over periods of 30 years, this kind of climate variability may largely influence regional trends, and either amplify or counteract trends resulting from changes in the global energy balance.
C. Effects of the bias adjustment of the model results: Bias adjustments are performed in order to adjust for systematic errors in the models, and to tune the model results to the observed climate statistics for a reference period. Thus, the 30-year statistics for temperature and precipitation in bias-adjusted datasets are forced to fit the statistics of the reference dataset. However, the bias adjustment of precipitation and temperature in COR-BA was here performed independently, thus covariance between these variables may be distorted in the process. Meyer et al. (2019) show that univariate bias adjustment in an Alpine catchment lead to too much precipitation falling at temperatures above 0 °C, compared to multivariate bias correction.

5.2 1971-2000 precipitation climatology

The bias adjustment involved in the production of the COR-BA dataset forces the model climatology for total precipitation to match the *seNorge_1.1* climatology quite closely. Thus, the differences in average 1971-2000 annual and seasonal total precipitation, are resulting almost entirely from differences between the two *seNorge* datasets (point A above). This is the case both nationally and for the geographical distribution. The fact that the adjustments for altitude were too high in *seNorge_1.1* can explain why precipitation in the COR-BA dataset is 23.4% higher than in *seNorge2018.* This could be caused by either at average larger precipitation amounts on days with precipitation, and/or a higher number of precipitation days. The present analysis shows that the number of precipitation days is 26% higher in the COR-BA dataset than in *seNorge2018.* Thus, the average amount of precipitation per precipitation day is about the same for *seNorge2018* (6.7 mm) and the COR-BA dataset (6.6 mm). The difference between total precipitation in the two datasets is thus caused by the higher number of precipitation days in the COR-BA dataset, which is again caused by a higher number of precipitation days in *seNorge_1.1* compared to *seNorge2018.*

The COR-BA dataset differs from *seNorge2018* not only for total precipitation, but also concerning the relative distribution of precipitation in rain, sleet and snow. The results in Chapter 3 and 4 show that while the relative numbers for *seNorge2018* are 54% rain, 11% sleet and 35% snow, they are 63%, 12% and 23% for the COR-BA dataset. Thus, relatively speaking, there is considerably more rain and less snow in the COR-BA dataset than in the *seNorge2018* dataset. This difference cannot be explained by the differences in altitude adjustment between the *seNorge* datasets, as the exaggerated adjustments in the older dataset would rather be expected to give a larger percentage of snow, because the snow percentage is larger at high altitudes. As the definition of rain, sleet and snow here is given by daily temperature thresholds, differences might arise not only from different precipitation adjustments, but also from different temperature adjustments in the *seNorge* datasets. These differences are, however, relatively small. All-in-all, the differences between the *seNorge* datasets may account for only minor parts of the differences we find between COR-BA and *seNorge2018* concerning the distribution between the precipitation phases. These differences are thus caused by differences between average modelled and the observed climate (point B) or by the post processing of the model data (point C above). Biases in temperature and precipitation climatology were adjusted but since the adjustment was performed independently for temperature and precipitation it leads to an underestimation of the amounts of snow and an overestimation of the amounts of rain as explained in Meyer at al. (2019). Thus the application of univariate bias adjustment is probably the main reason for the overestimation of rain and underestimation of snow.

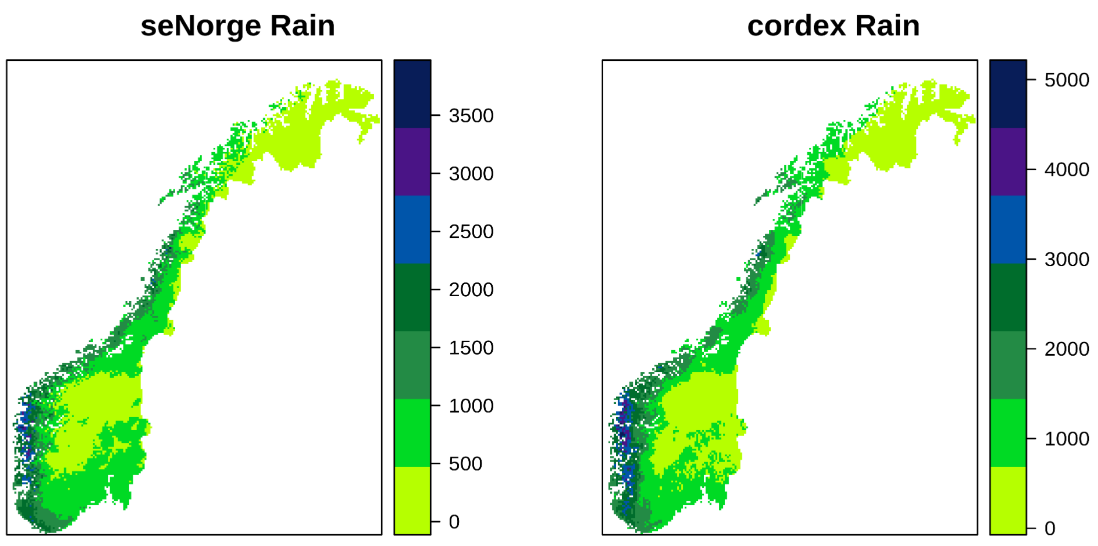

***Figure 5.1** Average annual precipitation sums as rain during 1971-2000 based on seNorge2018 (left panel) and the COR-BA dataset (right panel).*

Even if the relative amounts of rain, sleet and snow in the period 1971-2000 differ substantially between *seNorge_1.1* and the COR-BA dataset, the geographical distributions of precipitation in the various phases are rather similar in the two datasets (see Figure 3.1 and 4.2). The results for rain are also shown in Figure 5.1. Though the scales are different, the spatial patterns are similar.

5.3 1971-2000 precipitation trends

The trends for rain, sleet and snow in Table 3.1 and 4.1, sums up to an increase in total precipitation for Norway of about 20 mm per decade as given by the COR-BA dataset, and more than 40 mm per decade as given by *seNorge2018*. This is confirmed by Figure 5.2.

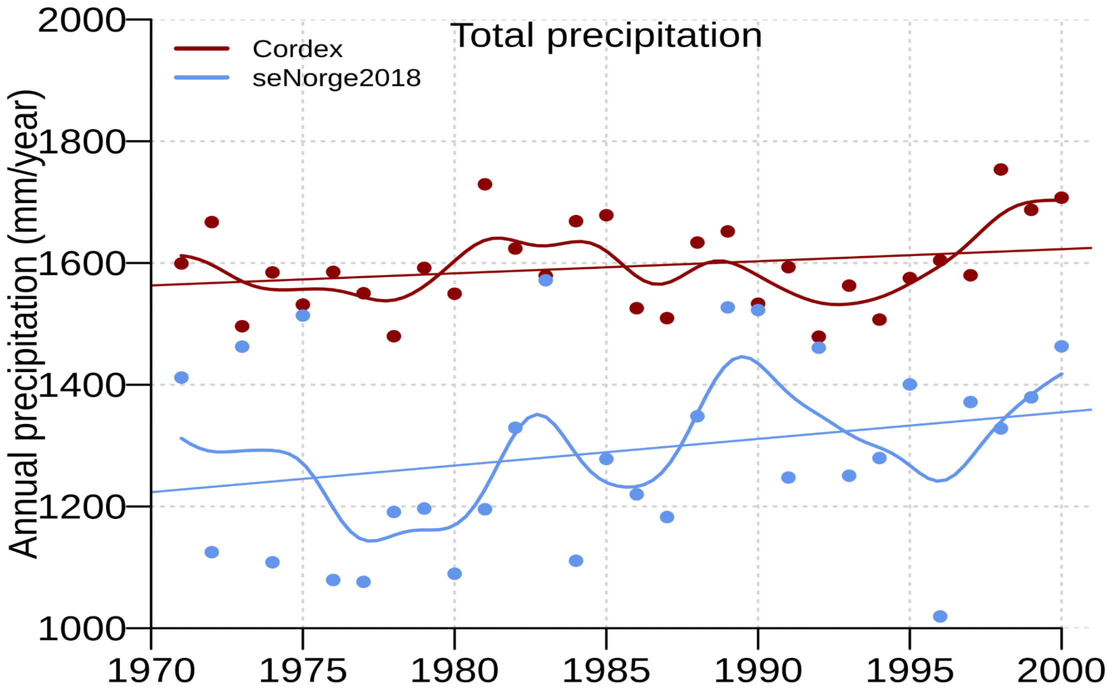

Figure 5.2 *Total annual precipitation for Norway from 1971 to 2000 based on seNorge2018 (blue) and the COR-BA dataset (red). 3 year Gaussian filter and trendline added.*

Figure 5.2 also shows that the difference between the two datasets in individual years varies significantly. While there is almost no difference in 1983, the difference is almost 600 mm in 1996. This variation in difference is far beyond what can be explained by differences between the two *seNorge* datasets, as these are actually based on the same observations and thus are highly correlated. The considerably smaller year-to-year variability in the difference between the *seNorge* datasets is illustrated here by comparing the total precipitation in these datasets directly for 1983 and 1996 (Figure 5.3).

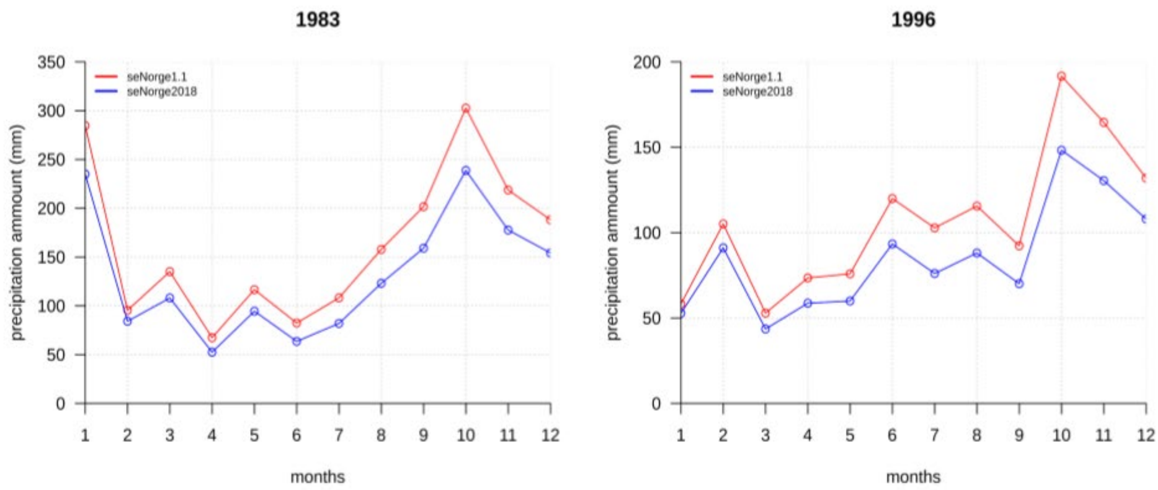

Figure 5.3. *Monthly precipitation for Norway in 1983 and 1996 based on seNorge_1.1 (red) and seNorge 2018 (blue)*

Thus the differences in year-to-year variability, and also the differences between the trends in the two datasets have to be linked mainly to differences between model ensemble mean and reality.

Variation in precipitation from year to year in Norway is to a large extent connected to the variability in atmospheric circulation: Where, and from which direction do the storm tracks hit the country with their wave cyclones? Hanssen-Bauer and Førland (2000) concluded that most of the variability and trend in precipitation in Norway from 1900 to 1994 could be explained by variability in atmospheric circulation. Konstali and Sorteberg (2021) confirmed that dynamical mechanisms are the dominant cause of the increase in precipitation before 1995, though the increase after 1995 to a larger degree results from a general increase in temperature and relative humidity. While climate models are expected to capture trends caused by increased temperature and humidity reasonably well, they cannot be expected to be in phase with the real world concerning the dynamically linked trends. Differences between the simulated and real circulation (point B above) thus seem to be the main reason for the differences in total precipitation trends in the period 1971-2000. The COR-BA dataset is the mean of ten model simulations, and the more random variability in atmospheric circulation is thus dampened as the variability in different models partly cancel each other (Figure 5.4). This explains why the difference between individual years is smaller in COR-BA than in *seNorge2018* (Figure 5.2). However, some decadal scale variability is still evident in the mean (Figure 5.4), and this variability is not in phase with the observed variability from 1971 to 2000.

While the total precipitation increase in *seNorge2018* results from an increase in all precipitation phases, the COR-BA dataset shows an increase only in rain, while the average amount of snow shows a negative trend. Differences in atmospheric circulation anomalies between the datasets lead to differences in total precipitation as well as in the temperature on days with precipitation (point B above). The temperature on precipitation days is, however, also affected by the bias adjustments (point C), which again may have an influence on the trends in rain, sleet and snow. The main cause of the mismatch between trends in the *seNorge2018* and COR-BA datasets is still most likely the effect of atmospheric circulation on the variability. This is confirmed when comparing the geographical distribution of the rainfall trends from 1971 to 2000 (Figure 5.5). It becomes clear that while the observed increase in rain mainly is due to an increase in areas exposed to weather from south and east (left panel), the COR-BA average indicates an increase in precipitation in areas exposed to precipitation from west and north-west.

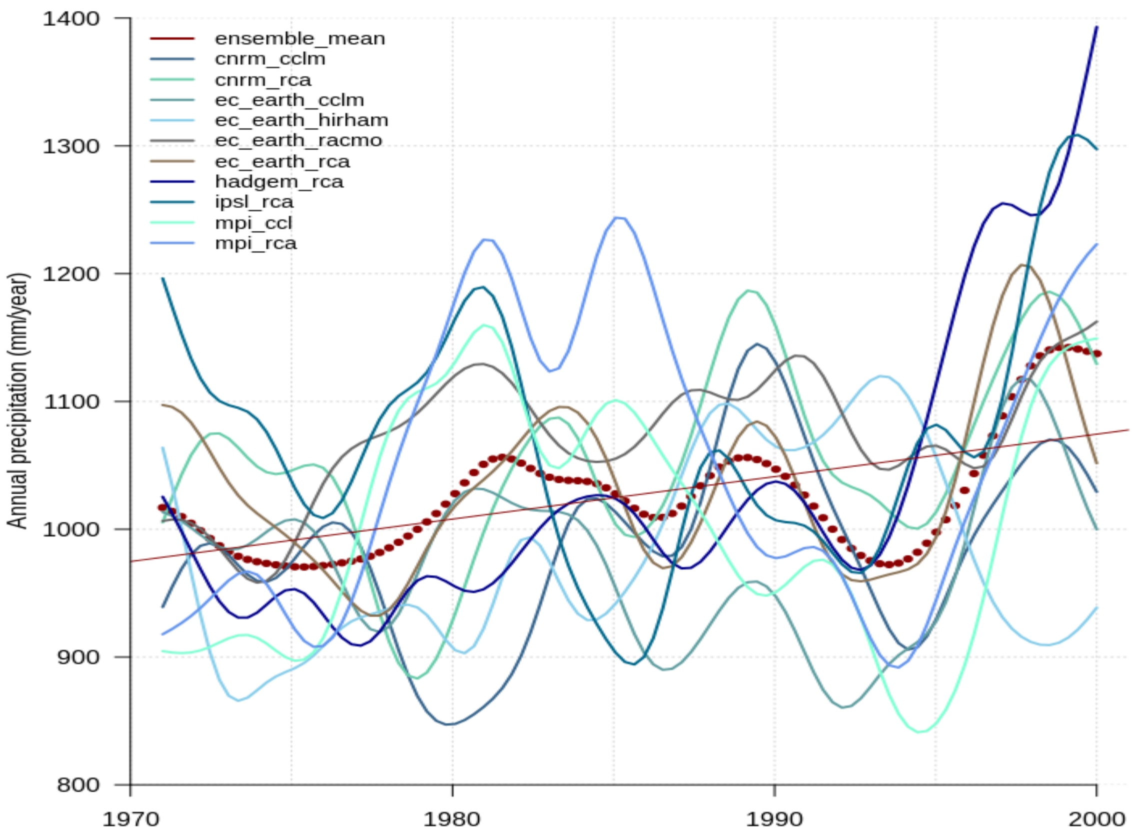

Figure 5.4. *Three year Gaussian filter for annual precipitation for the ten COR_BA simulations and for the mean from 1971 to 2000. Trendline for the mean is added.*

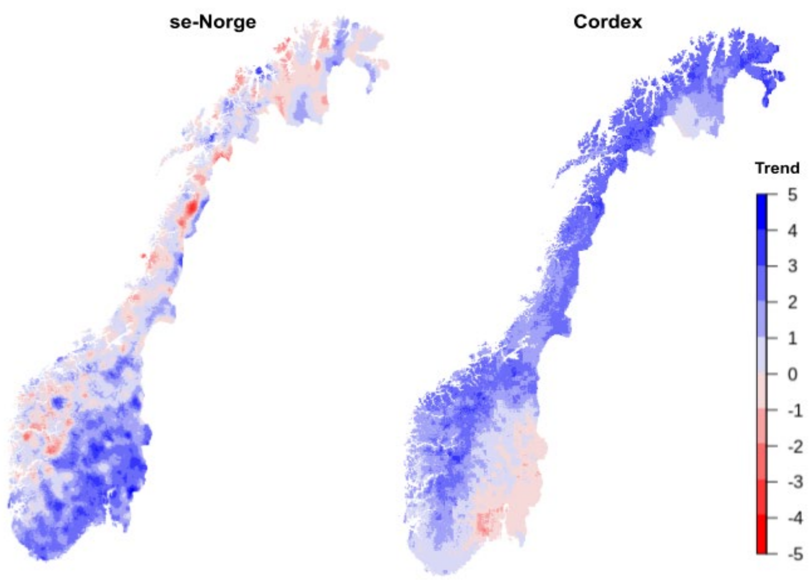

Figure 5.5. *Comparison between seNorge2018 and COR-BA rainfall trends over Norway during 1971–2000.*

We conclude that the mismatching trends in the period 1971-2000 to a large extent is explained by point B above. This is also consistent with the fact that none of the national trends are statistically significant at the 5% level, and thus very well may result from the more random variability in atmospheric circulation, particularly at the local scale.

6. Summary and conclusions

Precipitation as rain, sleet and snow in Norway during the period 1971-2000 was calculated based on daily temperature and precipitation values from two datasets:

- *seNorge_2018 version 20.08,* here referred to as *seNorge2018*. This is a 1x1 km gridded dataset with daily resolution, based on observations from official weather stations.
- Post processed versions of ten Euro-CORDEX model simulations, here referred to as *COR-BA*. Daily temperature and precipitation fields from the Euro-CORDEX simulations were re-gridded to the *seNorge*-grid, and bias adjusted, using a previous version of *seNorge_1.1* (an older version of seNorge) as "ground truth".

The total daily precipitation were in both datasets classified as rain, sleet or snow, applying threshold values for daily mean temperature (*T ≤ -1°C→ snow*; *-1°C < T <1°C→ sleet; T ≥ 1°C→ rain)*.

The following differences were found between *COR-BA* and *seNorge2018*:

- **Total precipitation:** Though the geographical distribution of total precipitation showed the same patterns in the two datasets, total precipitation was considerably higher in *COR-BA* than in *seNorge2018*. The main reason for this is a difference between *seNorge_1.1* and *seNorge2018.* In both datasets an elevation gradient for precipitation is applied in the spatial interpolation. However, the gradient applied in the older dataset was later found to be too high, and was thus reduced. The difference between the *seNorge*-datasets does, however, not vary much from year to year, so the trends in those datasets are not very affected by the difference in elevation gradients.
- **Distribution rain-sleet-snow:** Relatively speaking, there was considerably more rain and less snow in the *COR-BA* dataset than in the *seNorge2018* dataset. The main reason for this is probably the fact that the bias adjustment for temperature and precipitation in the *COR-BA* dataset was performed independently. The bias adjustment ensures that the climatologies for temperature and precipitation in *COR-BA* match the climatology in *seNorge_1.1*. Meyer et al. (2019) showed, however, that univariate bias adjustment may lead to too much rain and too little snow.
- **Linear trends:** The linear trends throughout the period 1971-2000 were different. Though total precipitation and rainfall in both datasets increased, *seNorge2018* showed increased snowfall, while the *COR-BA* dataset showed reduced snowfall from 1971 to 2000. We argue that these differences probably are connected to differences in atmospheric circulation. None of the trends were, however, statistically significant at the 5% level.

The COR-BA dataset is provided as a basis for assessing possible consequences of climate change. A final, but central question is thus: Can we trust modelled future precipitation conditions given by this dataset? Our conclusions are:

- The application of a reference dataset with too much precipitation will lead to overestimated total precipitation also in the future.
- The bias adjustment procedure will imply a continued overestimation of the percentage of rain, while the percentage of snow will be too low.

- Concerning projected trends, the picture is more mixed. Trends over 30-year periods will still be dominated by decadal scale variability, which in models is not synchronised with the real world. However, when considering climate change in Norway, we are usually comparing the climate in independent 30-year periods (e.g. Hanssen-Bauer et al. 2017). Such differences are less affected by decadal scale variability, as each period includes several decades. The qualitative results of such analyses are thus still assumed to be sound.

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