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Analysis of long-term snow series at selected stations in Norway

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Abstract

In this study long-term snow trends and variability at 41 Norwegian stations and in six specific regions were examined. Several snow parameters were chosen for analysis: mean and maximum snow depth, duration of snow season, number of days with snow on the ground, number of days with skiing conditions and the maximum daily increase in snow depth. The stations were grouped in regions according to a simple correlation analysis made on time-series of maximum snow depth. Based on the trends and their significance levels we found that there has been a general deacrease in snow depth and the length of the snow season at the majority of the stations. This negative trend is more pronounced in the last few decades, reflecting the recent warming. The strongest trends are seen in the end of the snow season, and the number of days with snow, and the results are more consistent in the southernmost regions.

Keywords

Snow, Norway, Snow season

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1 Introduction

Snow on ground is an important weather element, both on a global scale (albedo, heat balance, atmospheric circulation) and on regional and local scales (flooding by snow-melt, mass balance of glaciers, hydropower production, vegetation season, road maintenance, loads on buildings and constructions, skiing recreation, etc.). Snow cover may force atmospheric circulation and climate in different ways: for example, through the snow-albedo-temperature feedback mechanism, by causing anomalous temperature gradients (inversions), by insulating heat exchanges between the surface and the underlying atmosphere; and by consuming latent heat when melting.

Temporal variations in snow conditions are influenced by changes in temperature and precipitation. The annual mean temperature in different parts of Norway has during the period 1875-2004 increased by 0.5 to 1.5ºC and the annual precipitation has increased by between 3 and 21% during the latest 100 years (Hanssen-Bauer, 2005, Førland et al., 2007). According to Iversen et al (2005), the annual temperature is projected to increase by 2.5 to 3.5ºC up to year 2100, and the annual precipitation by 5 to 20%.

By use of downscaled results from a Regional Climate Model, Vikhamar-Schuler et al (2006) made projections of future changes in snow conditions in Norway. They found that both the mean annual maximum snow water equivalent and the duration of the snow season are projected to decrease almost everywhere in Norway. Generally, the decrease gets smaller with increasing altitude and distance from the coast. The start of the snow accumulation season is projected approximately 3-4 weeks later than in the present climate. The snow melt season starts earlier, leading to an earlier end of the snow season (approximately 1-7 weeks earlier).

In the present report, long-term ($\sim$ 100 years) snow series from the archives of the Norwegian Meteorological Institute have been quality-controlled and scrutinized, and the resulting long series have been analysed both for single locations as well as for specific regions. Several snow parameters have been studied;- including mean and maximum snow depth, duration of snow season, number of days with snow on the ground, number of days with skiing conditions and the maximum daily increase in snow depth.

The present analyses gives a basic for e.g. descriptions of regional differences in snow conditions in Norway, long-term trends during the past 100 years as well as a demonstration of the large inter-annual variability in the various snow parameters.

2 Dataset and analysis

This section gives an overview of the meteorological dataset used in the analysis in this report. Furthermore, it contains a description of how the time-series of the snow parameters were derived.

2.1 Meteorological stations

In the analysis we look at the observations of snow depth and snow cover. Snow depth is measured as the total depth of both the old and new snow on the ground. Snow cover is the areal extent of snow-covered ground. At met.no precipitation stations the snow cover observation is a subjective measure (see Table 1.)

Snow cover code	Description
0	No snow
1	Minor parts of the ground covered with snow
2	Equal areas with and without snow
3	Major parts of the ground covered with snow
4	Ground fully covered

Table 1: *Snow cover codes observed at the met.no precipitation stations.*

Through time, snow depth and/or snow cover have been observed at more than 1400 meteorological stations in Norway (see Figure 1). Among these, there are about 470 stations that are measureing snow today. In this report we have studied data from the meteorological stations with the longest time-series (see the map in Figure 2 and Table 2). This constitutes 41 stations which are shown on the map, and 34 of these stations have times-series of more than 100 years with data. The remaining 7 stations have between 76 (Tromsø) and 97 years with data. There are a few gaps in the time-series, specifically for stations in the northern regions during the period of the second world war (1940-1945). From the maps and Table 2 we see that none of the stations are located above 900 m a.s.l. This means that long term snow measurements from high-mountain stations are very few or even lacking. A frequency distribution of the elevation location of the stations with long time series are shown in Figure 3a. A large part of the stations are located below 100 m a.s.l, and this pattern is even more noticable for the stations with snow measurements today (Figure 3b). The geographical distribution of the stations also shows that there are far more stations in Southern Norway than in Northern Norway.

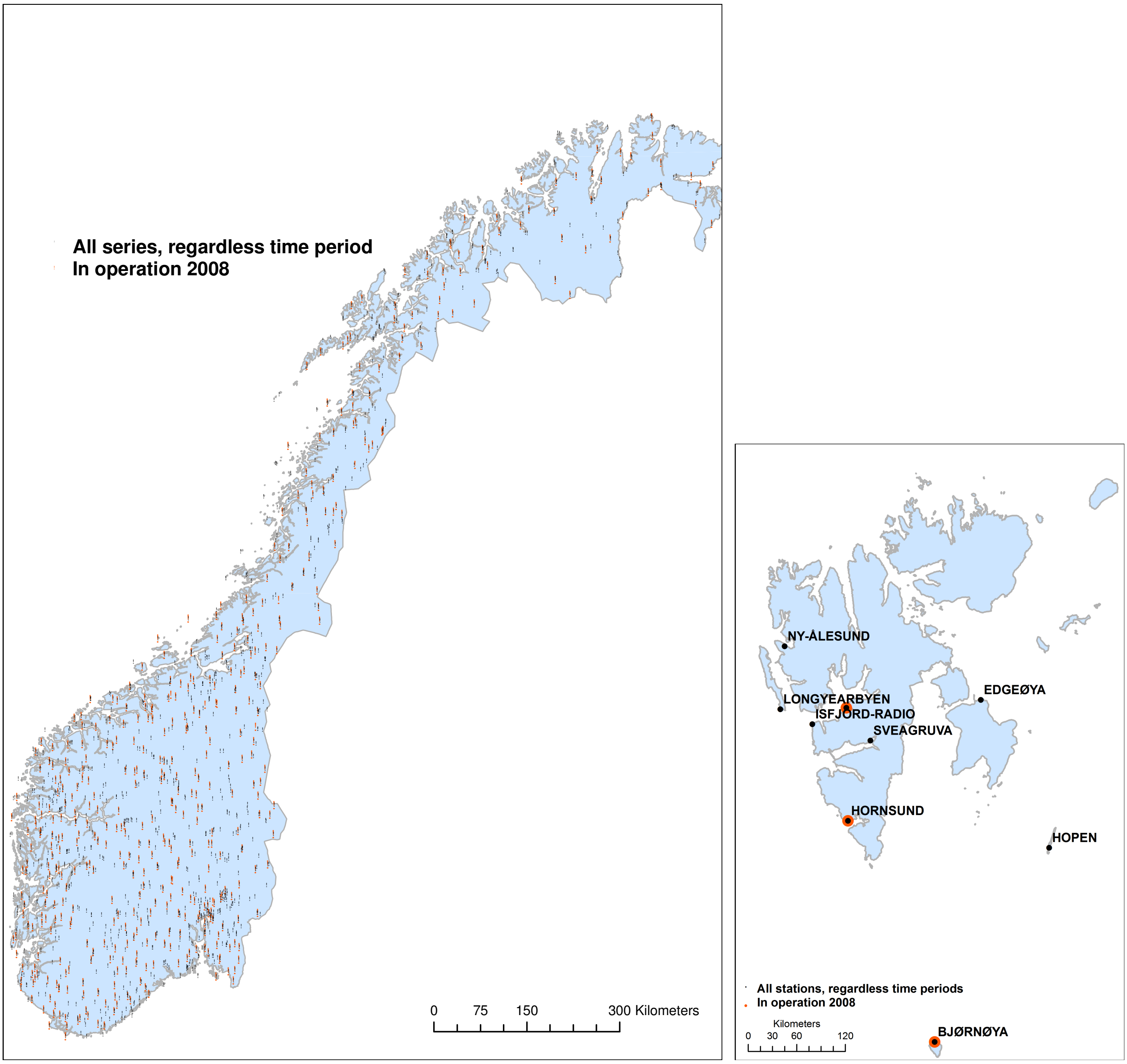

Figure 1: *Map of all stations with snow measurements of any time period in a) mainland Norway and b) Svalbard and Bjørnøya. Orange colour indicate that the station is still in operation pr. 2008.*

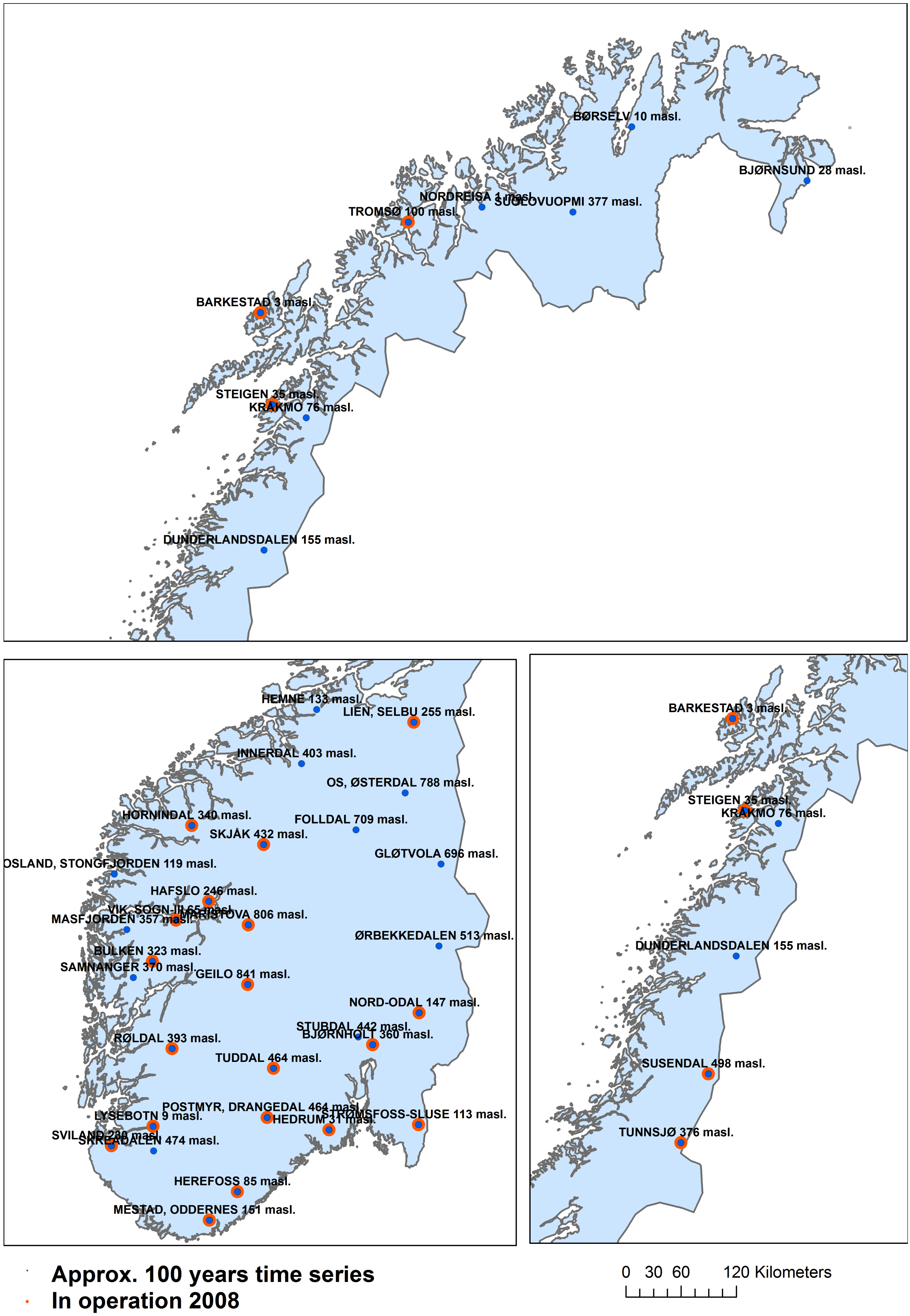

Figure 2: *Map of stations with time series of more than 100 years of snow measurements (snow cover and snow depth). Orange colour indicate that the station is still in operation.(Suolovuopmi is still in operation today, but the location of the station is moved.*

Station number (met.no)	Station name	Elevation m a.s.l.	Time series (Period)
600	GLØTVOLA	696	1895-1998 (104 yrs)
1650	STRØMSFOSS-SLUSE	113	1883-2007 (125 yrs)
5350	NORD-ODAL	147	1895-2004 (110 yrs)
6550	ØRBEKKEDALEN	513	1896-2007 (112 yrs)
9100	FOLLDAL	709	1895-2006 (112 yrs)
10100	OS I ØSTERDAL	788	1900-2006 (107 yrs)
15660	SKJÅK	432	1896-2007 (112 yrs)
18500	BJØRNHOLT	360	1896-2003 (108 yrs)
20120	STUBDAL	442	1897-1986 (90 yrs)
25640	GEILO	841	1895-2007 (113 yrs)
27800	HEDRUM	31	1895-2007 (113 yrs)
31900	TUDDAL	464	1895-2003 (104 yrs)
34900	POSTMYR I DRANGEDAL	464	1895-2007 (113 yrs)
38450	HEREFOSS	85	1895-2007 (113 yrs)
39220	MESTAD I ODDERNES	151	1900-2004 (105 yrs)
42890	SKREÅDALEN	474	1895-2007 (113 yrs)
44800	SVILAND	230	1895-2007 (113 yrs)
45350	LYSEBOTN	9	1895-2007 (113 yrs)
46450	RØLDAL	393	1902-2003 (102 yrs)
50350	SAMNANGER	370	1901-2002 (102 yrs)
51470	BULKEN	323	1895-2007 (113 yrs)
52700	MASFJORDEN	357	1900-1982 (83 yrs)
53070	VIK I SOGN III	65	1895-2007 (113 yrs)
54600	MARISTOVA	806	1896-2003 (108 yrs)
55550	HAFSLO	246	1896-2003 (108 yrs)
57110	OSLAND VED STONGFJORDEN	119	1907-2004 (98 yrs)
58960	HORNINDAL	340	1896-2007 (112 yrs)
64700	INNERDAL	403	1898-2003 (106 yrs)
65220	HEMNE	133	1895-1998 (104 yrs)
68330	LIEN I SELBU	255	1895-2003 (109 yrs)
73800	TUNNSJØ	376	1907-2007 (101 yrs)
77850	SUSENDAL	498	1895-2007 (113 yrs)
79740	DUNDERLANDSDALEN	155	1895-2005 (101 yrs)
83300	STEIGEN	35	1915-2004 (90 yrs)
83500	KRÅKMO	76	1895-2006 (112 yrs)
86850	BARKESTAD	3	1896-2007 (112 yrs)
90450	TROMSØ	100	1945-2007 (63 yrs)
91750	NORDREISA	1	1896-1992 (97 yrs)
93300	SUOLOVUOPMI	377	1908-2003 (96 yrs)
95600	BØRSELV	10	1896-1982 (87 yrs)
99450	BJØRNSUND	28	1895-2004 (110 yrs)

Table 2: *Meteorological stations in Norway with the longest time series of snow depth and/or snow cover measurements.*

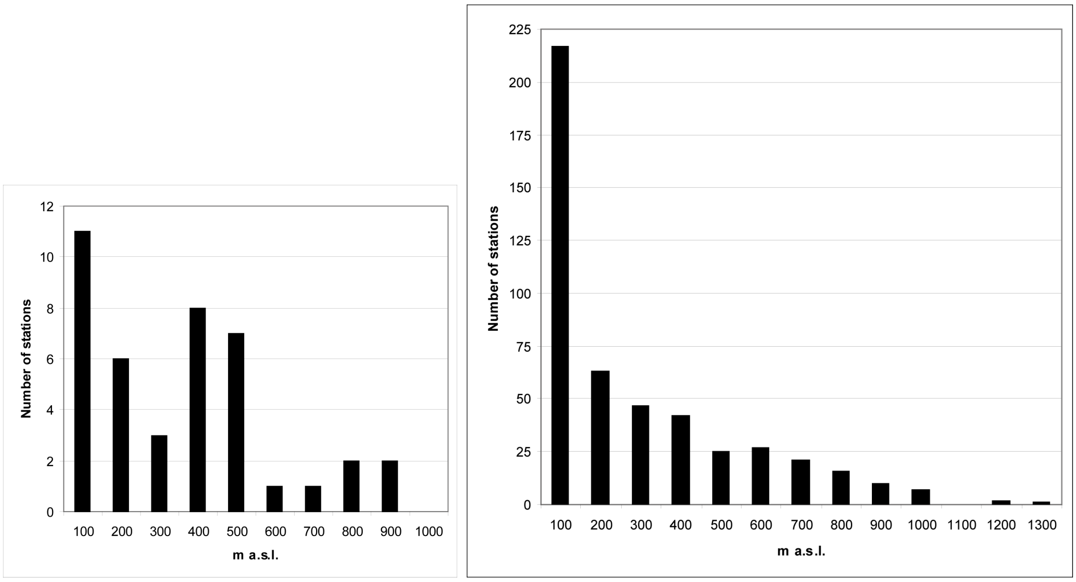

Figure 3: *Frequency distribution of the elevation of the meteorological stations observing snow: a) The 100 years long times series; and b) todays station network.*

2.2 Time-series analysis

In this Section it is described how the different snow parameters were computed from the long-term time series of snow data. For one of the snow parameters (number of snow days), a Mann-Kendall trend test is carried out as well as filtering techniques and linear trend analysis. The aim is to study trends over the last 100 years as well as 30 years periods. Results from the analysis are presented in Chapter 3.

2.2.1 Maximum snow depth

Maximum snow depth (cm) was computed for every winter season from *daily* snow measurements. A winter season is defined to follow the hydrological year (from 1 September to 31 August). An example of a time-series of maximum snow depth is shown in Figure 4.

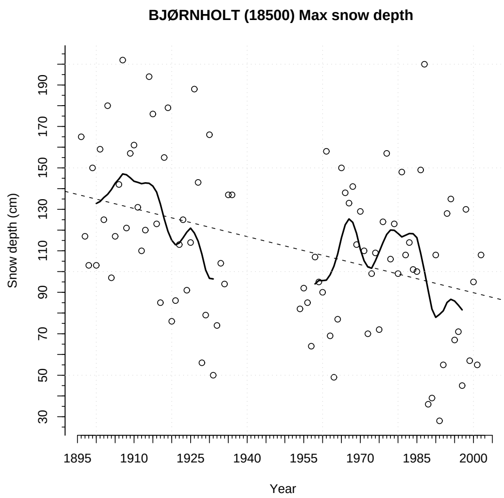

Figure 4: *Maximum snow depth from Bjørnholt (360 m a.s.l.) close to Oslo. Dashed line is a linear trend line while the continuous line is a 10 year gaussfilter. (There are no observations between 1937 and 1953).*

2.2.2 Mean snow depth

Mean snow depth (cm) was computed for every year from *monthly* snow measurements. Examples of time-series of mean snow depth and deviation from the normal period are shown in Figure 5.

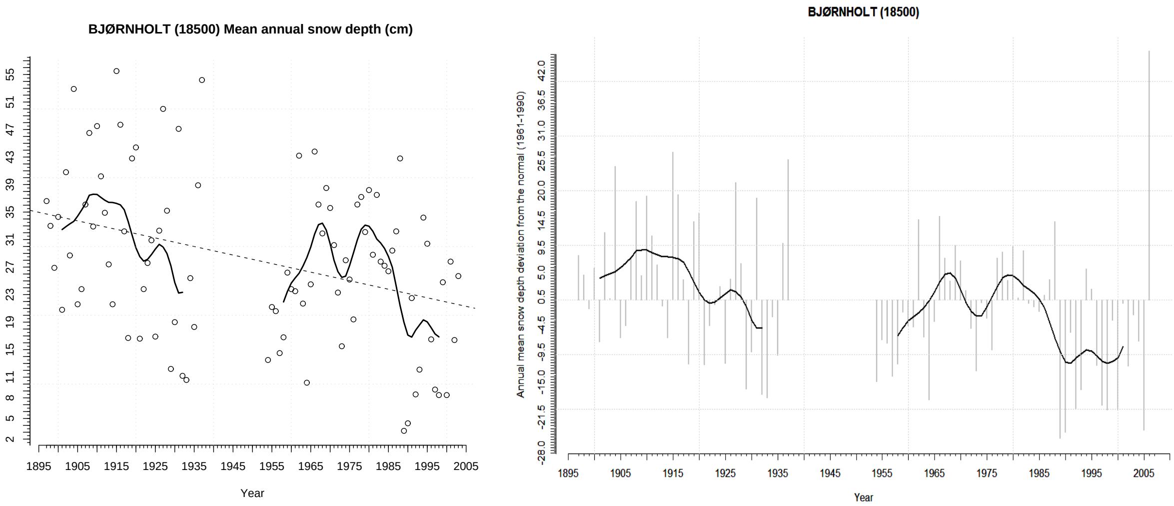

Figure 5: *a) Mean snow depth from Bjørnholt (360 m a.s.l.) close to Oslo. Both a linear trend line and a 10 year gaussfilter are included. b) Snow depth deviation in cm from the normal period 1961-1990. A 5 year gaussfilter is included.*

2.2.3 Snow season duration

To compute the duration of the snow season we first had to define the start and end of the season. Snow season start is in this report defined as the first day in autumn with 10 consecutive days with snow cover code equal to 4 (see Table 1). The end of the snow season was defined as the first day in spring after the last period of 5 consecutive days with snow cover code equal or greater than 2. Furthermore, the snow season duration was computed as the number of days between the first and the last day. These days constitute the period of the winter with permanent snow cover, and thereby excludes short periods with snow fall followed by melt episodes. Examples of time-series of the first day, the last day and the snow season duration are shown in Figure 6abc.

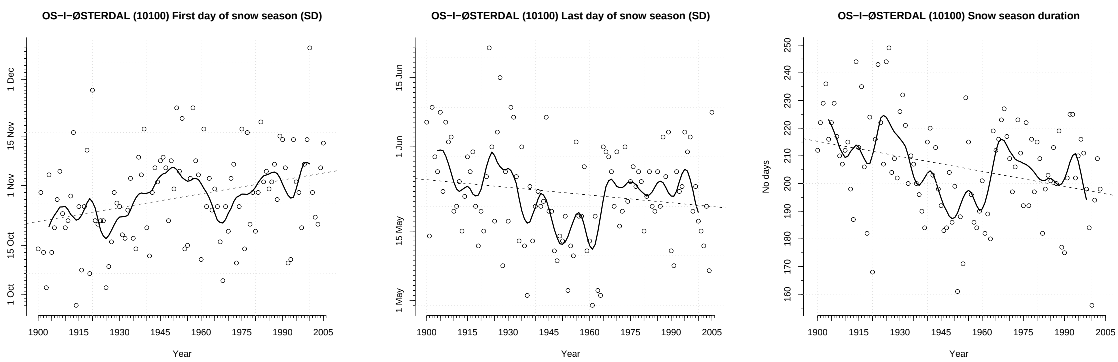

Figure 6: *a) First day and b) last day of the snow season from Os i Østerdal. c) Snow season duration. Both a linear trend line and a 10 year gaussfilter are included. Dates are computed from the observed snow cover code (SD).*

2.2.4 Number of days with snow

The total number of days with snow on the ground was computed by counting all days during a winter season with more than 0 cm snow depth or snow cover code >= 2 (see Table 1). The snow cover code definition is stricter than the snow depth definition. This snow parameter is aimed to include both periods with permanent snow cover as well as short periods with snow fall which later melts (typically during the beginning and end of the snow season period). Figure 7 shows an example from Os i Østerdalen.

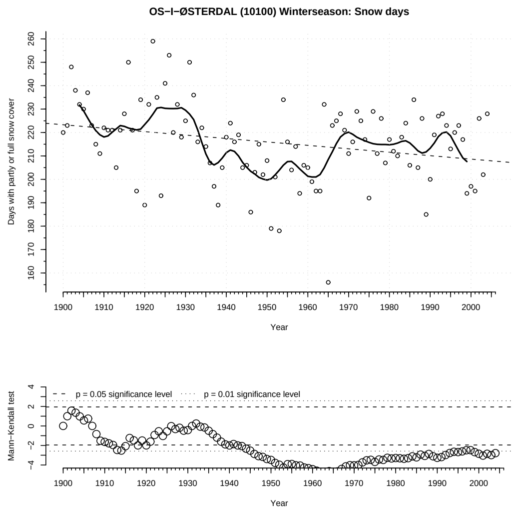

Figure 7: *Number of days with partly or full snow cover from Os i Østerdal (snow cover code >=2). The line is a 10 year gaussfilter. The lowermost graph shows a Mann-Kendall trend test.*

2.2.5 Number of skiing days

A definition of skiing conditions have previously been defined as a day with more than 25 cm snow depth (?). In this report we have used the same definition. Examples of a time series of the number of skiing days are shown in Figure 8.

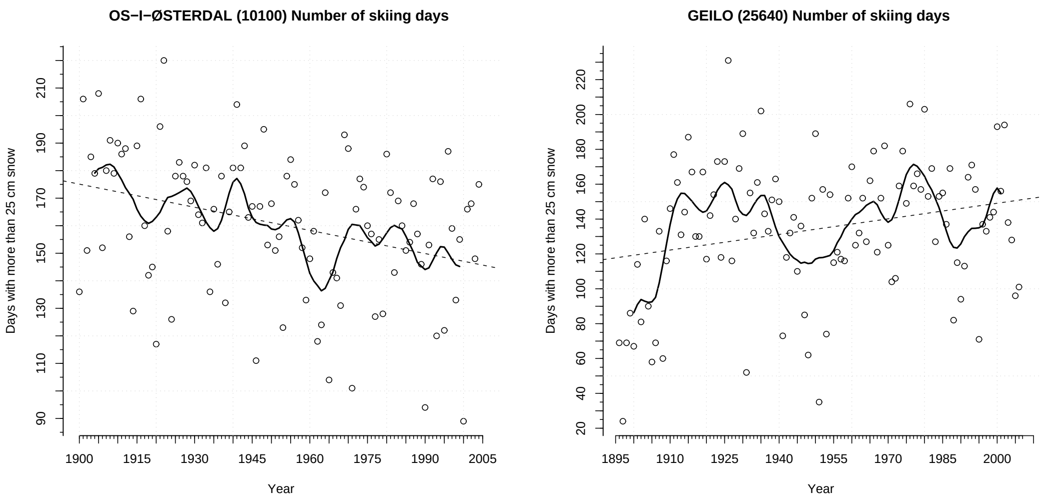

Figure 8: *Number of skiing days at a) Os i Østerdalen; and b) Geilo. Both a linear trend line and a 10 year gaussfilter are shown on the graphs.*

2.2.6 Maximum increase in daily snow depth

The last parameter which was derived in our analysis was maximum daily increase in snow depth. This parameter was computed as the maximum difference in observed snow depth between two consecutive days for every winter season, and is important in matters if transportation, snow loads on roofs, possibility of avalanches etc. Examples of graphs are shown in Figure 9.

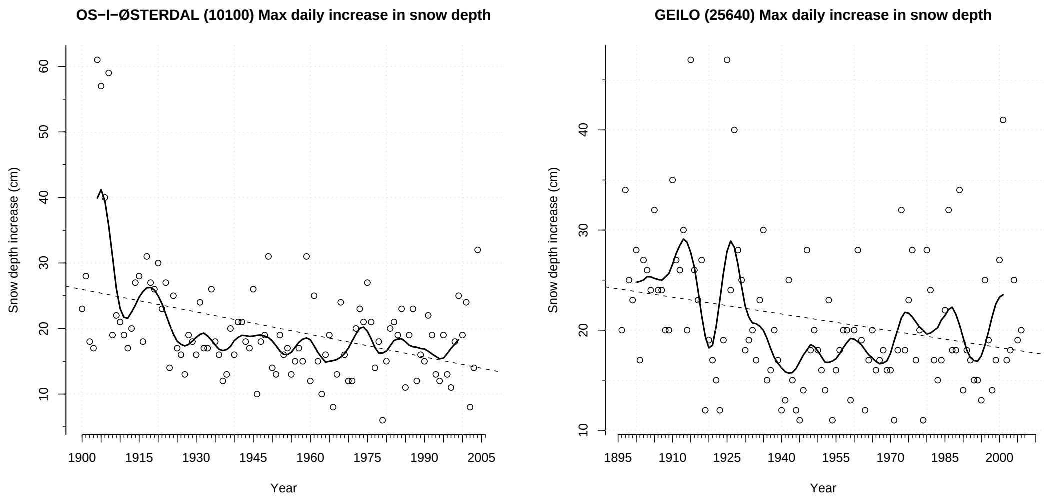

Figure 9: *Maximum daily increase in snow depth at a) Os i Østerdalen; and b) Geilo. Both a linear trend line and a 10 year gaussfilter are shown on the graphs.*

3 Results and discussion

To obtain more robust trends in the snow parameters, we have attempted to group the different meteorological stations into regions with similar snow conditions (see Section 3.1). To explain the different trends in the time-series of the snow parameters, time series of precipitation and temperature were computed and compared with the snow series. The results are presented in sections 3.1.1 - 3.1.7 for the different regions.

3.1 Snow regions

A simple correlation analysis was carried out to help group the stations into regions with similar snow conditions. The resulting groups are shown in Figure 10. The correlation analysis was made based on the time-series of maximum snow depth. Stations with moderate to high correlation (r^2>0.6) were grouped together. However, many stations had even lower correlation coefficients, and they were grouped to common regions in a second judgement. Extracts of the correlation analysis are shown in the Tables 3- 8. The three regions with the highest correlation between stations were: 1) the southern region (Table 3), 2) the eastern region, inland (Table 4) and 3) the western region (Table 5). The lowest correlation between stations were found in the central and all the northern regions. This is related to a lower number of meteorological stations due to complex topography, and therefore, longer distances between the stations in central and northern regions. Thus, the climatic conditions are too different and correlations between stations are low.

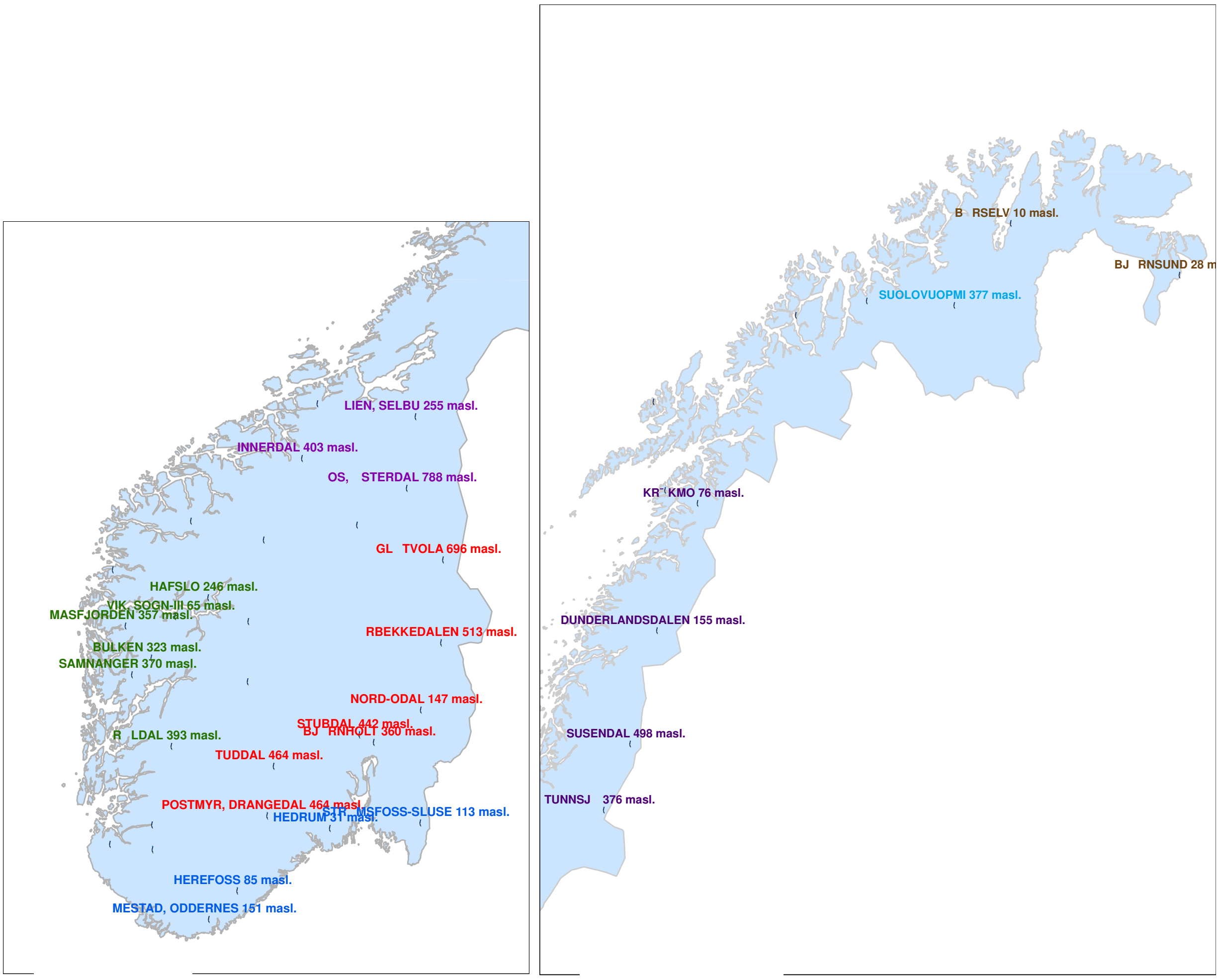

Figure 10: *Meteorological stations with the same color are grouped into separate snow region. The grouping is performed based on stations which have moderate to highly correlated time series of maximum snow depth (Tables 3 - 8). Stations having very low correlation with most of the stations are not grouped (blue dots on the map). In total there were seven regions defined.*

	Strømsfoss sluse	**Hedrum**	**Herefoss**	**Mestad i Oddernes**
Strømsfoss sluse	1	0.80	0.70	0.69
Hedrum	0.80	1	0.77	0.74
Herefoss	0.70	0.77	1	0.89
Mestad i Oddernes	0.69	0.74	0.89	1

Table 3: *Southern region, inland: Extracts of the correlation analysis.*

	Gløtvola	Ørbekkedalen	Nord Odal	Stubdal	Bjørnholt	Tuddal	Postmyr i Drangedal
Gløtvola	1	0.79	0.52	0.57	0.68	0.47	0.52
Ørbekkedalen	0.79	1	0.66	0.67	0.81	0.60	0.61
Nord Odal	0.52	0.66	1	0.71	0.72	0.54	0.64
Stubdal	0.57	0.67	0.71	1	0.90	0.66	0.85
Bjørnholt	0.68	0.81	0.72	0.90	1	0.70	0.86
Tuddal	0.47	0.60	0.54	0.66	0.70	1	0.77
Postmyr i Drangedal	0.52	0.61	0.64	0.85	0.86	0.77	1

Table 4: *Eastern region, inland: Extracts of the correlation analysis.*

	Hafslo	Vik i Sogn	Masfjorden	Bulken	Samnanger	Røldal
Hafslo	1	0.57	0.58	0.67	0.63	0.70
Vik i Sogn	0.57	1	0.30	0.60	0.36	0.55
Masfjorden	0.58	0.30	1	0.71	0.78	0.63
Bulken	0.67	0.60	0.71	1	0.74	0.78
Samnanger	0.63	0.36	0.78	0.74	1	0.74
Røldal	0.70	0.55	0.63	0.78	0.74	1

Table 5: *Western region, intermediate elevations: Extracts of the correlation analysis.*

	Lien i Selbu	Innerdal	Os i Østerdal
Lien i Selbu	1	0.55	0.51
Innerdal	0.55	1	0.46
Os i Østerdal	0.51	0.46	1

Table 6: *Central region, inland: Extracts of the correlation analysis. Generally, a low correlation in this region.*

	Kråkmo	Dunderlandsdalen	Susendal	Tunnsjø
Kråkmo	1	0.57	0.47	0.31
Dunderlandsdalen	0.57	1	0.70	0.57
Susendal	0.47	0.70	1	0.59
Tunnsjø	0.31	0.57	0.59	1

Table 7: *Northern region, inland: Extracts of the correlation analysis.*

	Bjørnsund	Børselv
Bjørnsund	1	0.47
Børselv	0.47	1

Table 8: *Northern region, eastcoast: Extracts of the correlation analysis. A low correlation in this region.*

3.1.1 Southern region

The southern region covers meteorological stations with long time-series of snow data along Sørlandet and Østfold county. In total, four stations were included in this region. All stations were well correlated (Table 3). In the Figures 11- 15, graphs of five different snow parameters are shown for these stations.

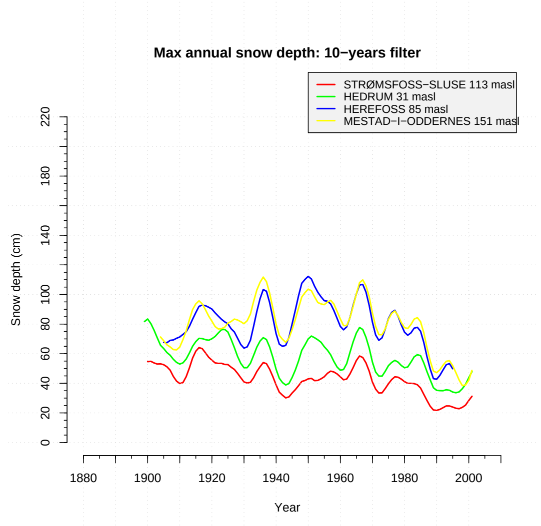

Figure 11: *Southern region: a) Maximum annual snow depth.*

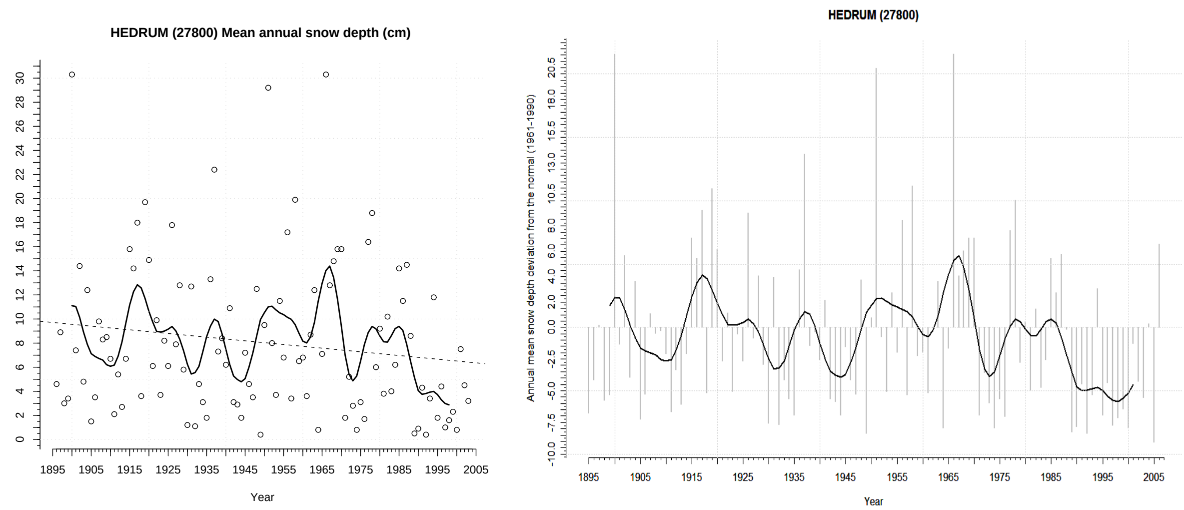

Figure 12: *a) Southern region: Mean snow depth from Hedrum. Both a linear trend line and a 10 year gaussfilter are included. b) Snow depth deviation in cm from the normal period 1961-1990, including a 10 year gaussfilter.*

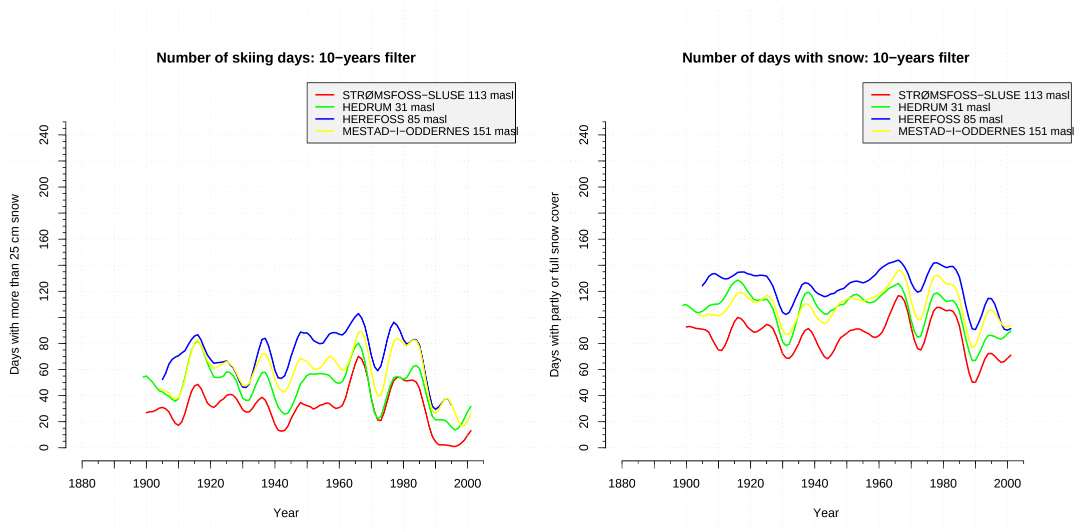

Figure 13: *Southern region: a) Number of skiing days, b) Number of days with snow on the ground. The graph is a 10 year gaussfilter.*

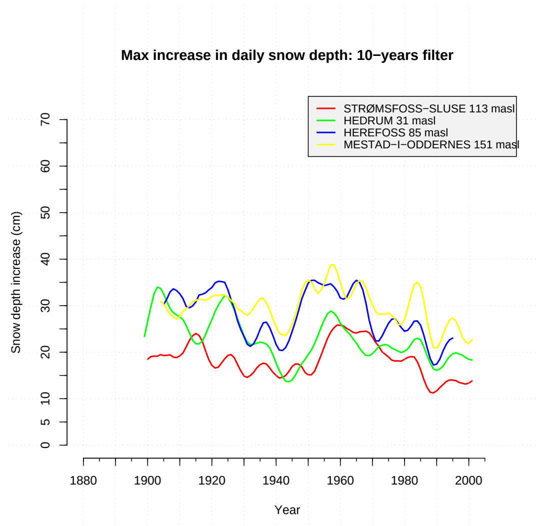

Figure 14: *Southern region: a) Maximum daily increase in snow depth. The graph is a 10 year gaussfilter.*

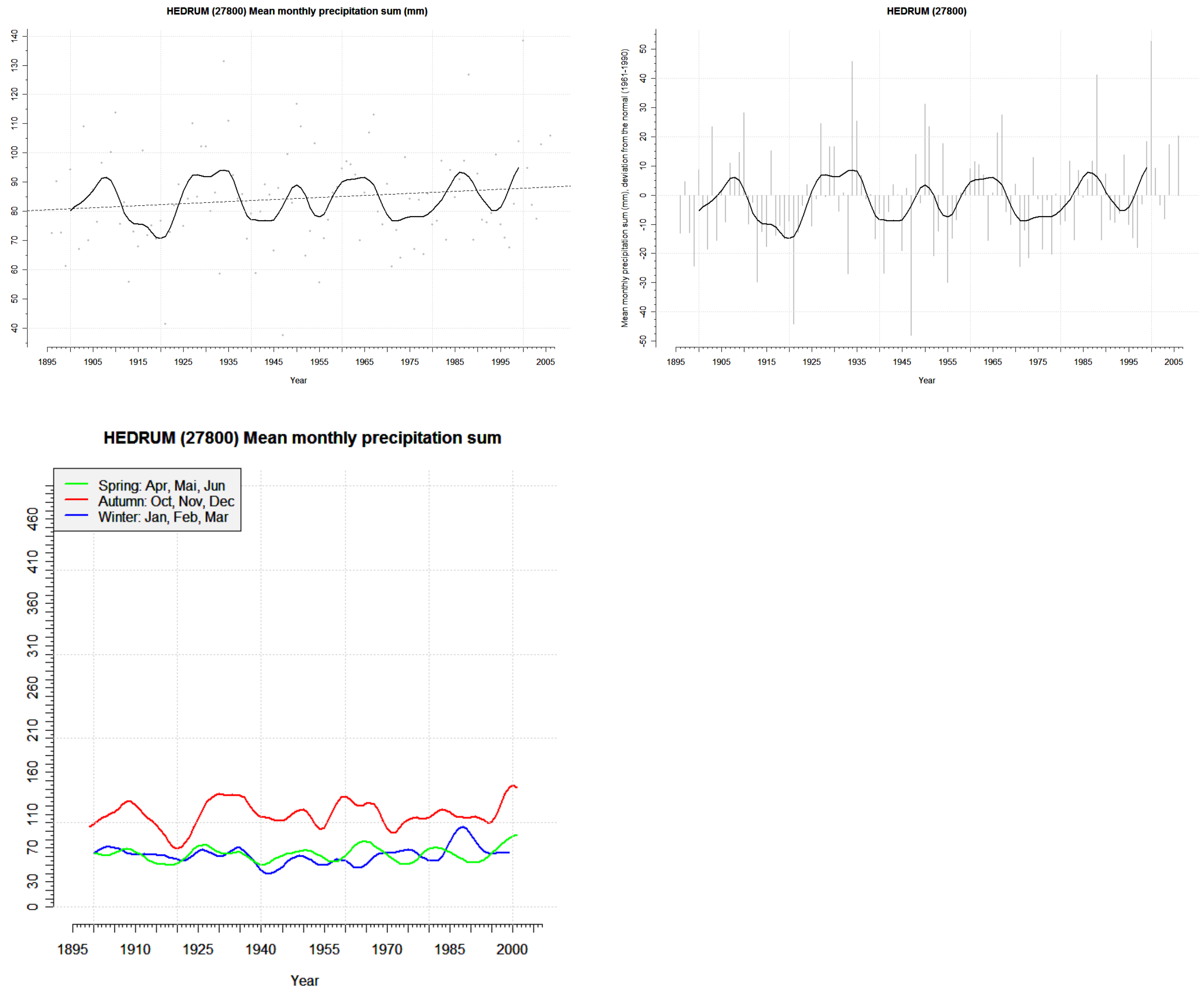

Figure 15: *Southern region: a) Mean monthly precipitation sum from Hedrum, computed for twelve months in a year. A linear trend line is included; b) Precipitation deviation from the normal period 1961-1990; and c) Seasonal mean monthly precipitation sum. All graphs include a 10 year gaussfilter.*

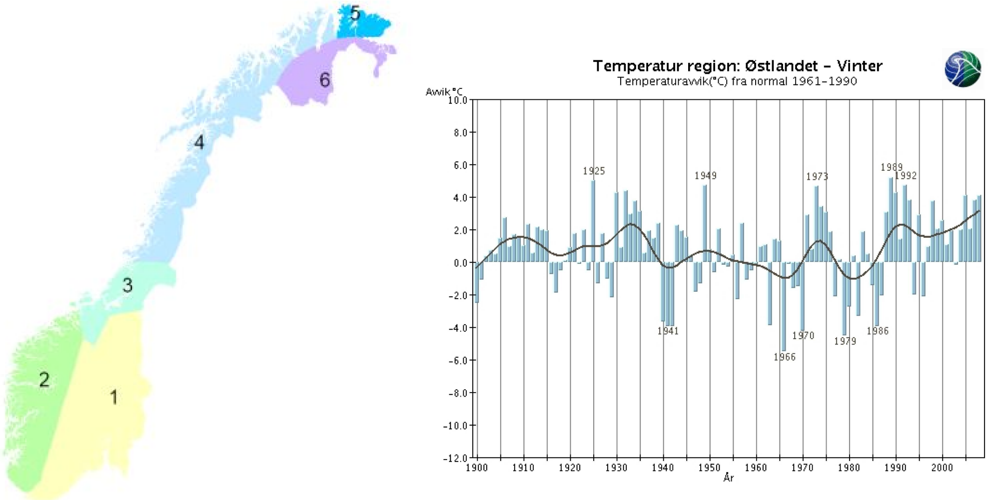

Figure 16: *a) The map shows six climatological regions for temperatures from 1900 till today. Both the southern and eastern regions (described in this report) are included in the temperature region number 1. b) Winter temperatures from 1900 till today (deviation from normal 1961-1990) for temperature region number 1.*

3.1.2 Eastern region, inland

The eastern region covers meteorological stations with long time-series of snow data in the inland regions of Southern Norway. In total, seven stations were included in this region. All stations were relatively well correlated (Table 4). In the Figures 17- 21, graphs of five different snow parameters are shown for these stations.

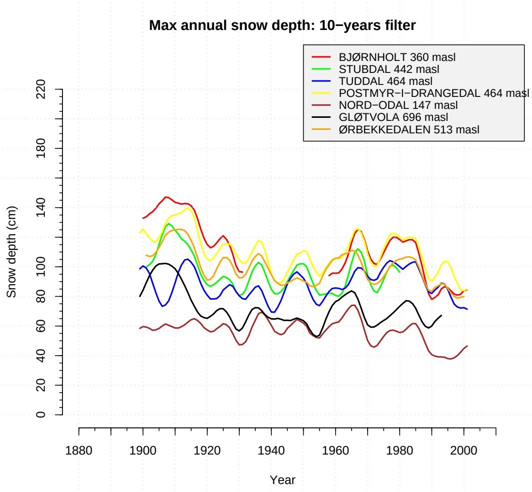

Figure 17: *Eastern region, inland: a) Maximum annual snow depth.*

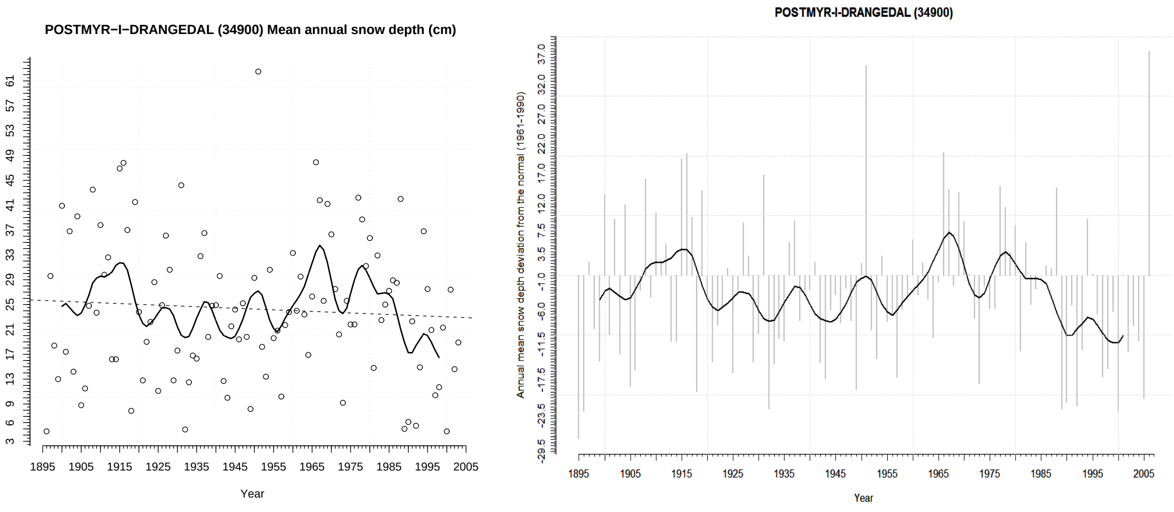

Figure 18: *a) Eastern region, inland: Mean snow depth from Postmyr i Drangedal. Both a linear trend line and a 10 year gaussfilter are included. b) Snow depth deviation in cm from the normal period 1961-1990, including a 10 year gaussfilter.*

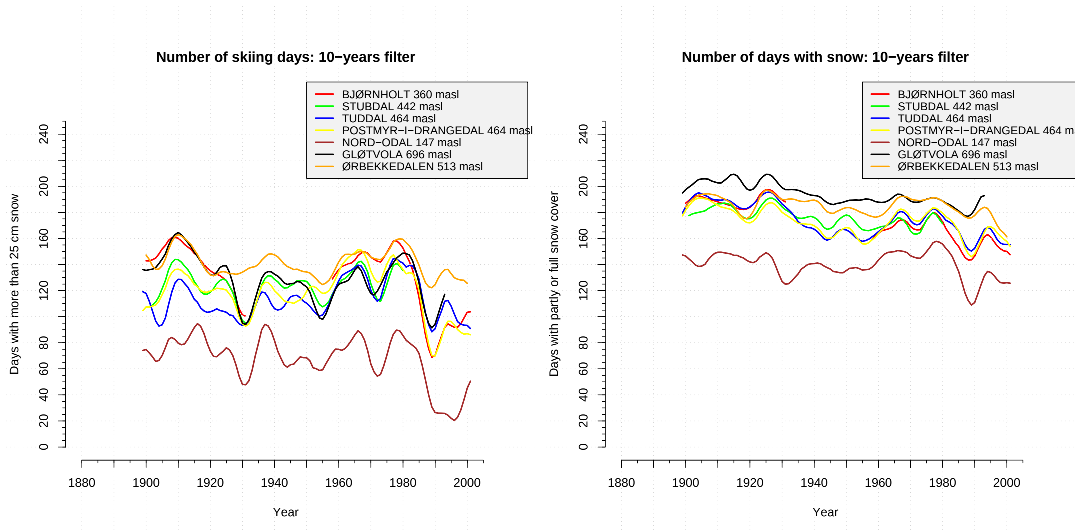

Figure 19: *Eastern region, inland: a) Number of skiing days, b) Number of days with snow on the ground. The graph is a 10 year gaussfilter.*

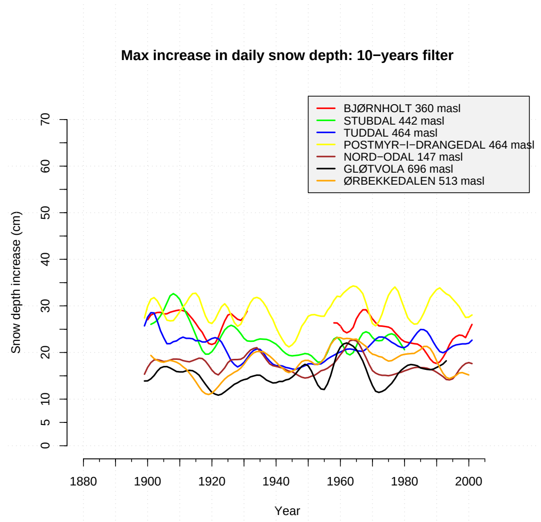

Figure 20: *Eastern region, inland: a) Maximum daily increase in snow depth. The graph is a 10 year gaussfilter.*

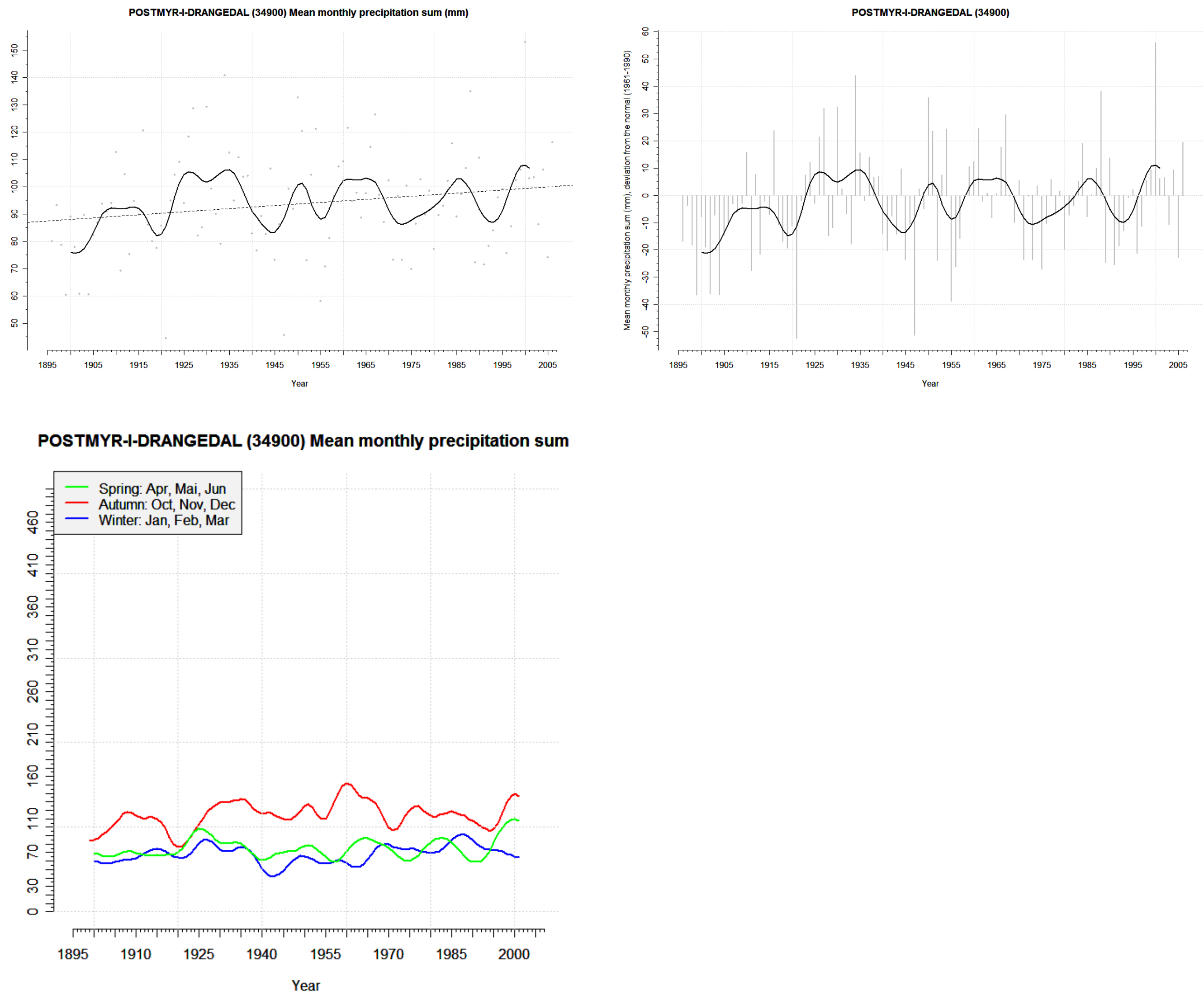

Figure 21: *Eastern region, inland: a) Mean precipitation from Postmyr i Drangedal. A linear trend line is included; b) Precipitation deviation from the normal period 1961-1990; and c) Seasonal mean monthly precipitation sum. All graphs include a 10 year gaussfilter.*

3.1.3 Western region, intermediate elevations

The Western region covers meteorological stations with long time-series of snow data at intermediate elevations along the west-coast of Southern Norway. In total, six stations were included in this region. Most of the stations were relatively well correlated (Table 5). In the Figures 22- 26, graphs of five different snow parameters are shown for these stations.

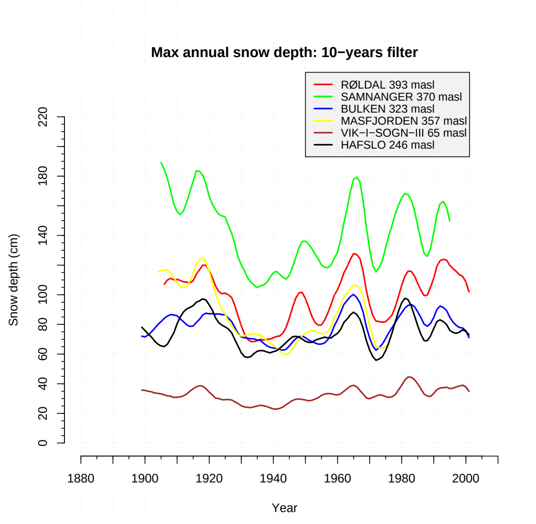

Figure 22: *Western region: a) Maximum annual snow depth.*

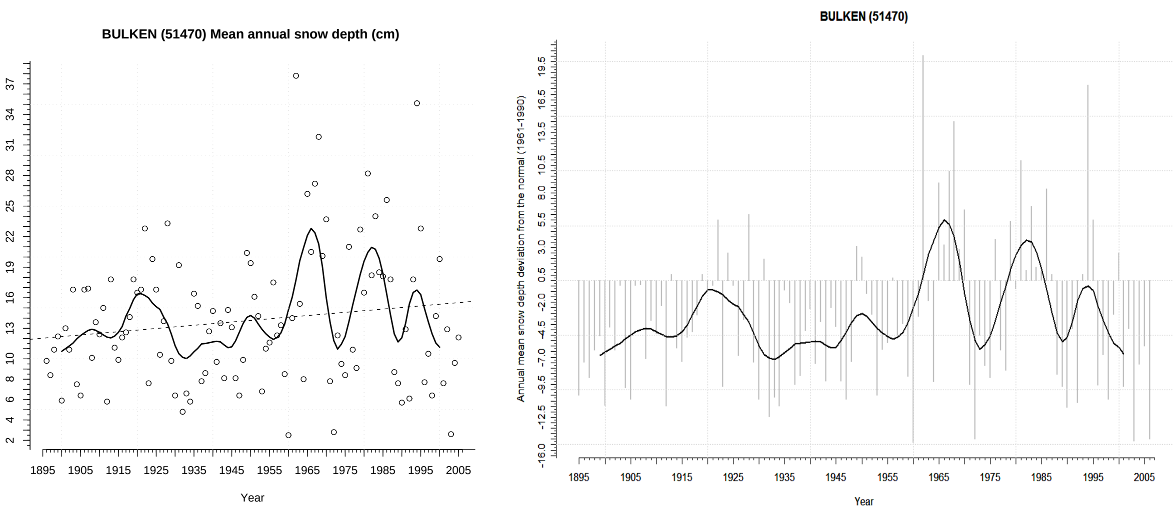

Figure 23: *a) Western region: Mean snow depth from Bulken. Both a linear trend line and a 10 year gaussfilter are included. b) Snow depth deviation in cm from the normal period 1961-1990, including a 10 year gaussfilter.*

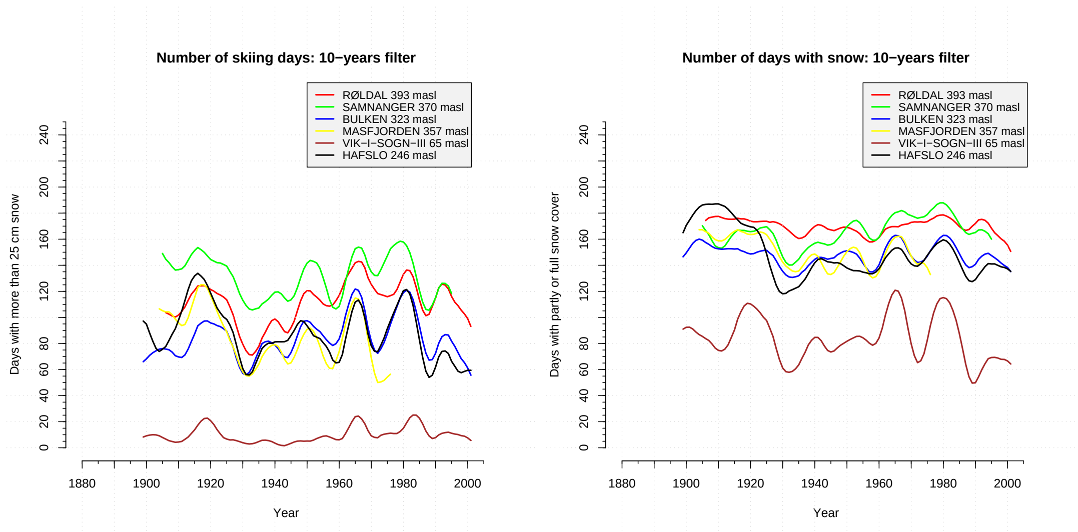

Figure 24: *Western region: a) Number of skiing days, b) Number of days with snow on the ground. The graph is a 10 year gaussfilter.*

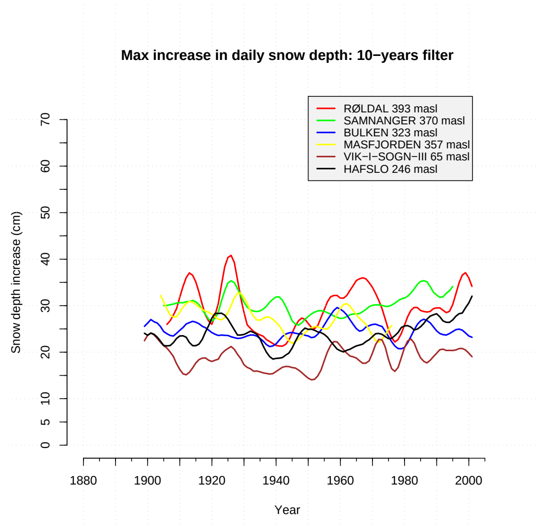

Figure 25: *Western region: a) Maximum daily increase in snow depth. The graph is a 10 year gaussfilter.*

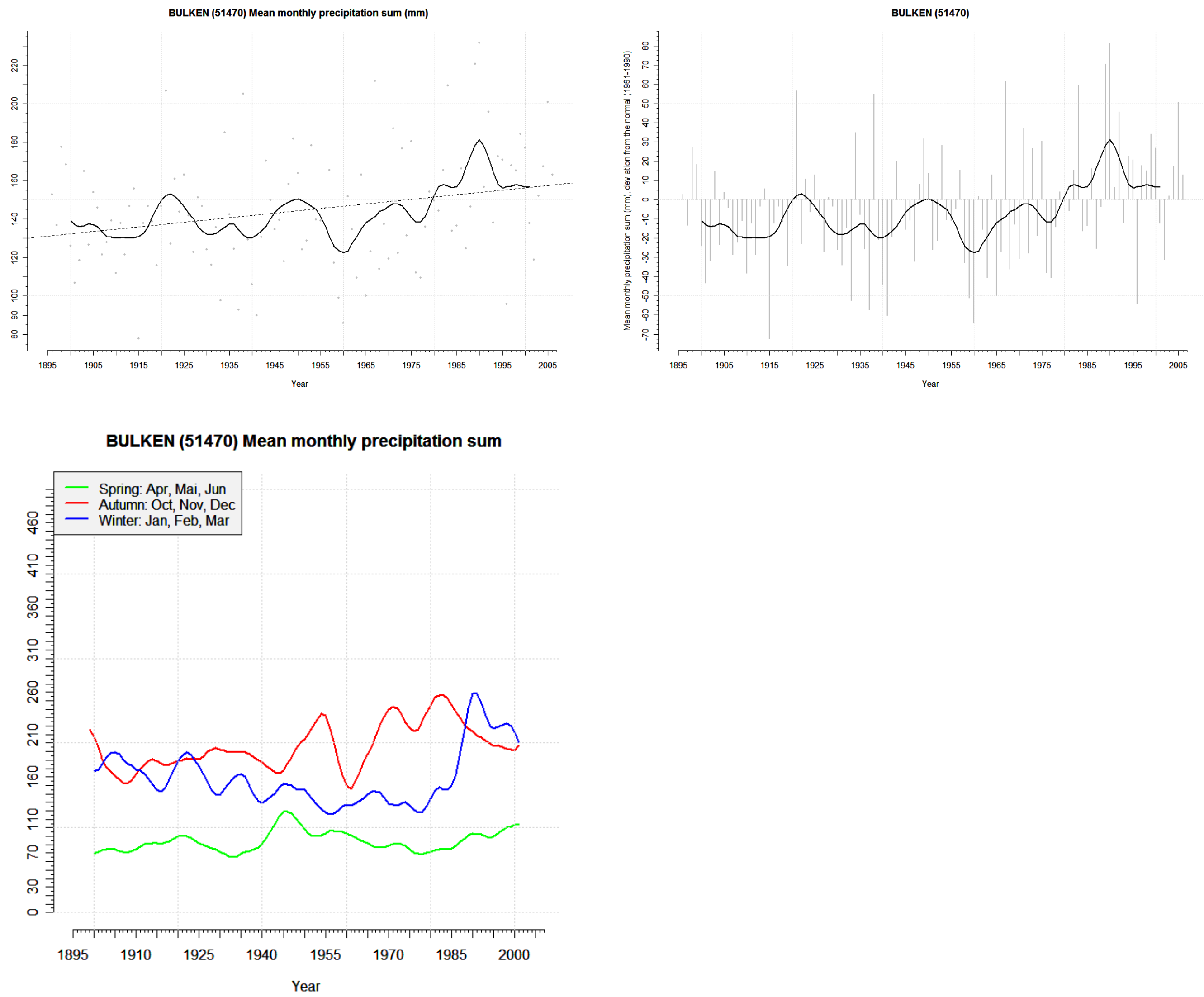

Figure 26: *Western region: a)Mean precipitation from Bulken. A linear trend line is included; b) Precipitation deviation from the normal period 1961-1990; and c) Seasonal mean monthly precipitation sum. All graphs include a 10 year gaussfilter.*

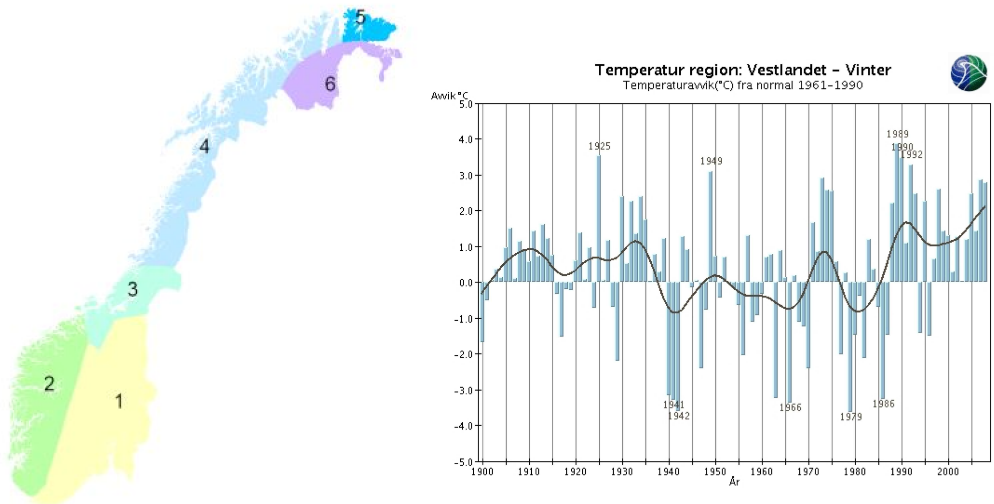

Figure 27: *a) The map shows six climatological regions for temperatures from 1900 till today. The western region (described in this report) is included in the temperature region number 2. b) Winter temperatures from 1900 till today (deviation from normal 1961-1990) for temperature region number 2.*

3.1.4 Central region, inland

The Central region covers meteorological stations with long time-series of snow data in inland areas. In total, only three stations were included in this region, and these are poorly correlated (Table 6). In the Figures 28- 31, graphs of five different snow parameters are shown for these three stations.

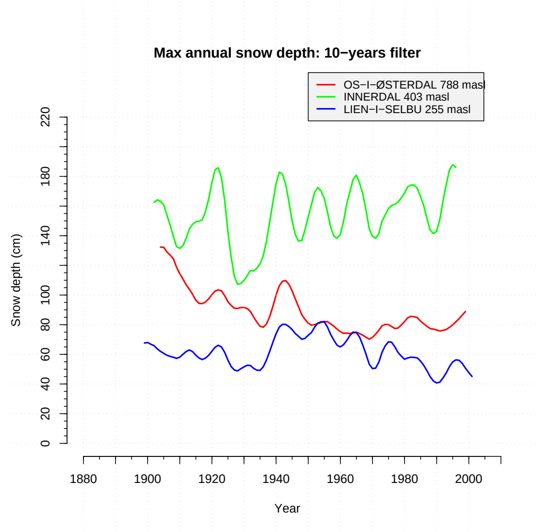

Figure 28: *Central region: a) Maximum annual snow depth.*

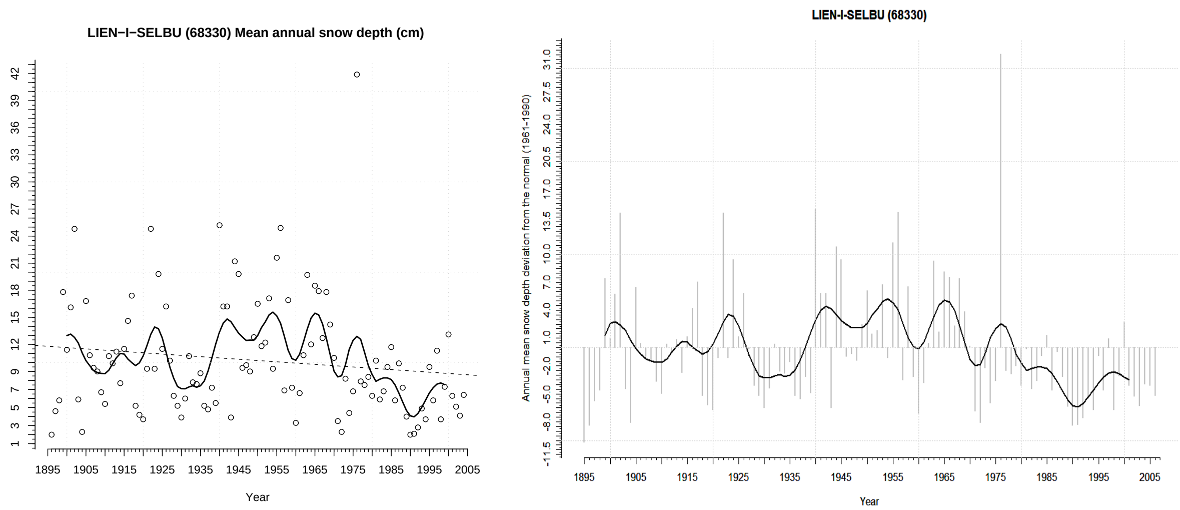

Figure 29: *a) Central region: Mean snow depth from Lien i Selbu. Both a linear trend line and a 10 year gaussfilter are included. b) Snow depth deviation in cm from the normal period 1961-1990, including a 10 year gaussfilter.*

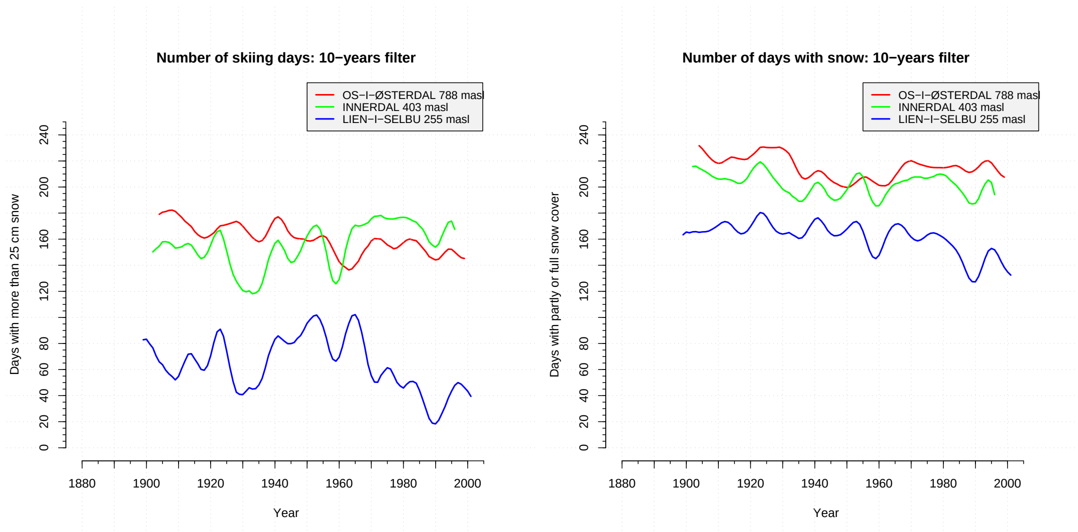

Figure 30: *Central region: a) Number of skiing days, b) Number of days with snow on the ground. The graph is a 10 year gaussfilter.*

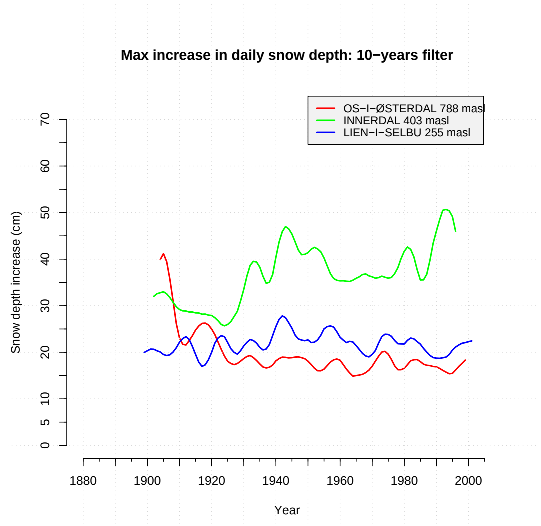

Figure 31: *Central region: a) Maximum daily increase in snow depth. The graph is a 10 year gaussfilter.*

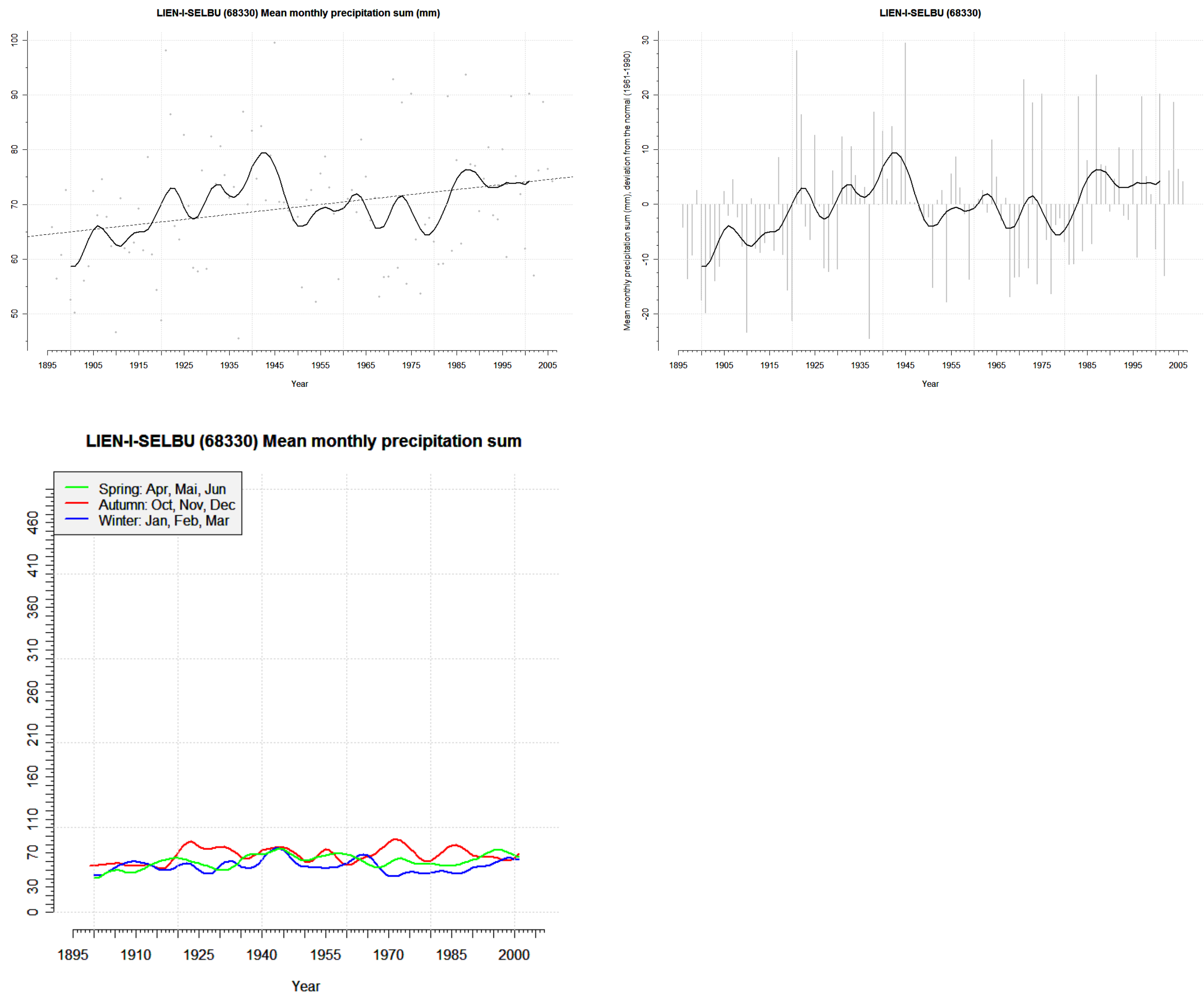

Figure 32: *Central region: a) Mean precipitation from Lien i Selbu. A linear trend line is included; b) Precipitation deviation from the normal period 1961-1990; and c) Seasonal mean monthly precipitation sum. All graphs include a 10 year gaussfilter.*

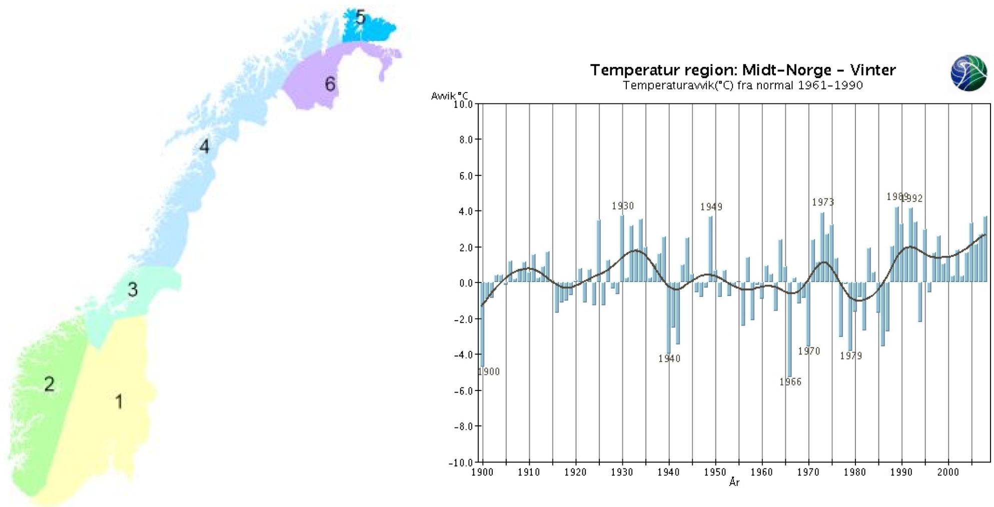

Figure 33: *a) The map shows six climatological regions for temperatures from 1900 till today. The central region (described in this report) is included in the temperature region number 3. b) Winter temperatures from 1900 till today (deviation from normal 1961-1990) for temperature region number 3.*

3.1.5 Northern region, inland

The Northern region, inland covers meteorological stations with long time-series of snow data in inland areas of Nord Trøndelag and Nordland. In total, four stations were included in this region. In Table 7 we see that the stations have varying correlation ranging from $r^2 = 0.31$ (Tunnsjø and Kråkmo) to $r^2 = 0.70$ (Dunderlandsdalen and Susendal). In the Figures 34- 37, graphs of five different snow parameters are shown for these four stations.

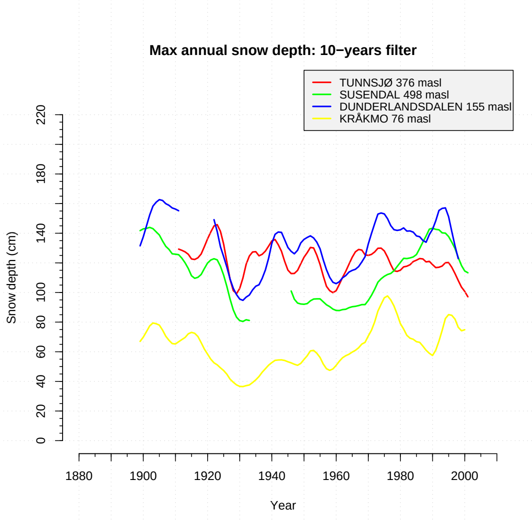

Figure 34: *Northern region, inland: a) Maximum annual snow depth.*

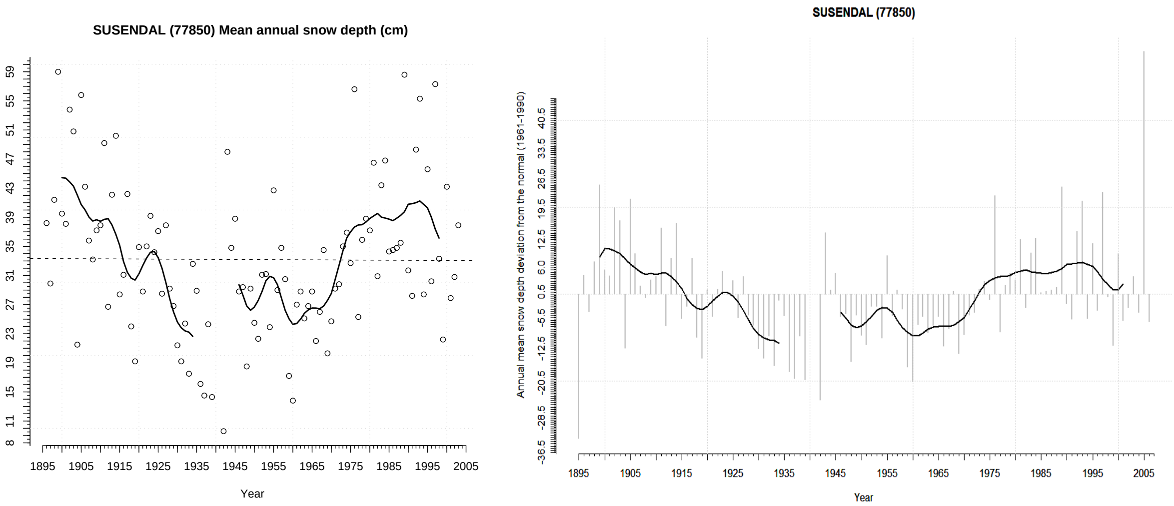

Figure 35: *a) Northern region, inland: Mean snow depth from Susendal. Both a linear trend line and a 10 year gaussfilter are included. b) Snow depth deviation in cm from the normal period 1961-1990, including a 10 year gaussfilter.*

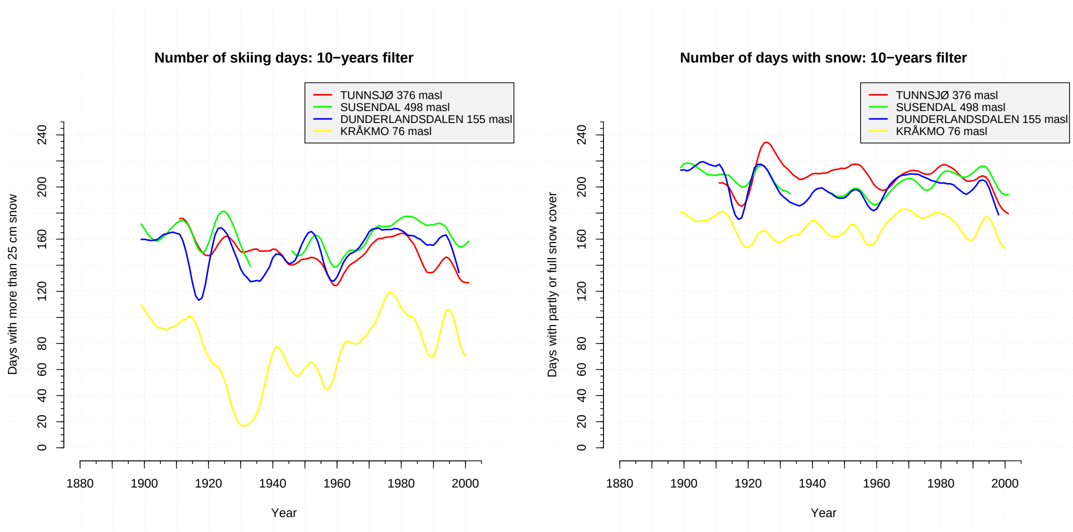

Figure 36: *Northern region, inland: a) Number of skiing days, b) Number of days with snow on the ground. The graph is a 10 year gaussfilter.*

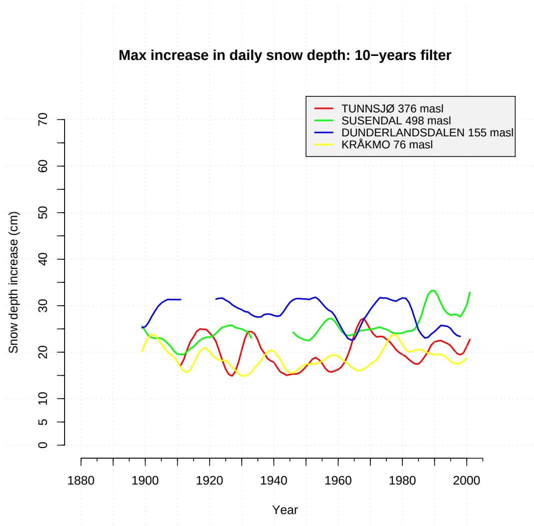

Figure 37: *Northern region, inland: a) Maximum daily increase in snow depth. The graph is a 10 year gaussfilter.*

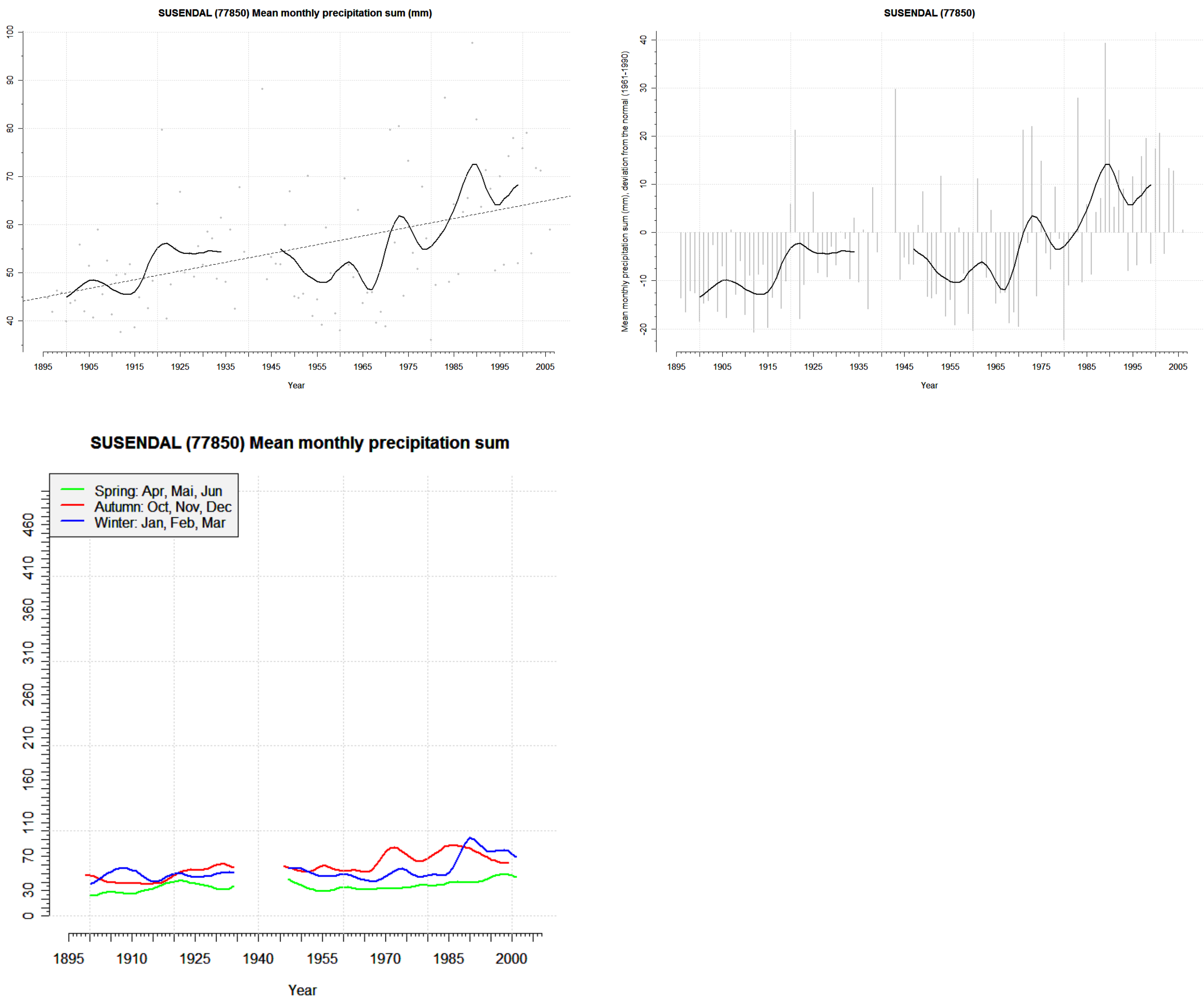

Figure 38: *Northern region, inland: a) Mean precipitation from Susendal. A linear trend line is included; b) Precipitation deviation from the normal period 1961-1990; and c) Seasonal mean monthly precipitation sum. All graphs include a 10 year gaussfilter.*

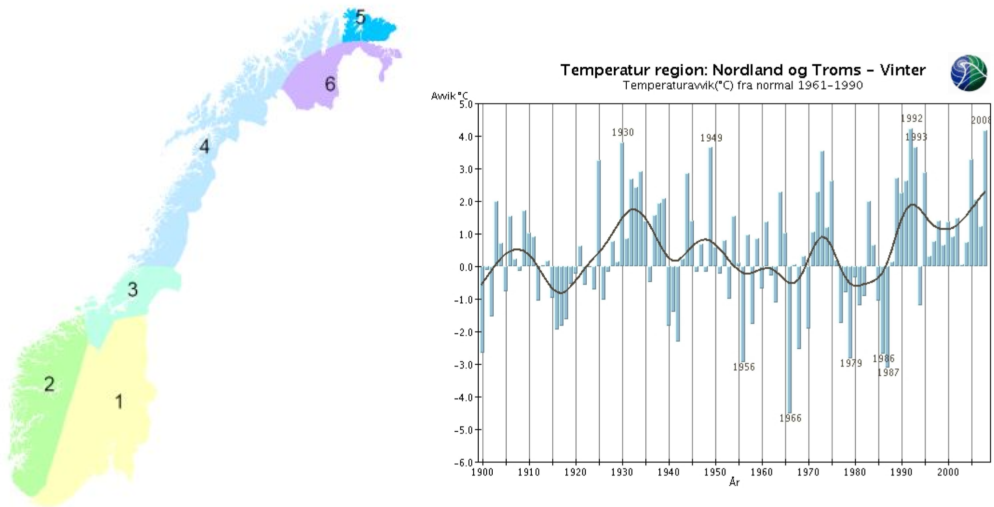

Figure 39: *a) The map shows six climatological regions for temperatures from 1900 till today. The Northern region, inland (described in this report) is included in the temperature region number 4. b) Winter temperatures from 1900 till today (deviation from normal 1961-1990) for temperature region number 4.*

3.1.6 Northern region, eastcoast

The Northern region, eastcoast covers meteorological stations with long time-series of snow data along the coastal areas of Finnmark. Only two stations were included in this region due to few stations in this area having long time-series. The two stations, Bjørnsund and Børselv, are located quite far from each other and have low correlation (Table 8). In the Figures 40- 43, graphs of five different snow parameters are shown for these four stations.

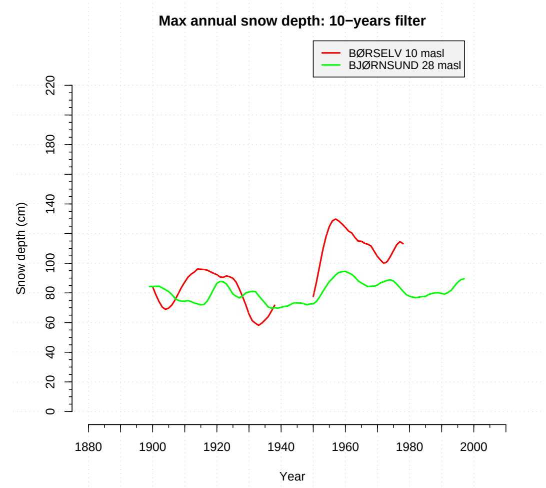

Figure 40: *Northern region, eastcoast a) Maximum annual snow depth.*

Figure 41: *a) Northern region, eastcoast: Mean snow depth from Bjørnsund. Both a linear trend line and a 10 year gaussfilter are included. b) Snow depth deviation in cm from the normal period 1961-1990, including a 10 year gaussfilter.*

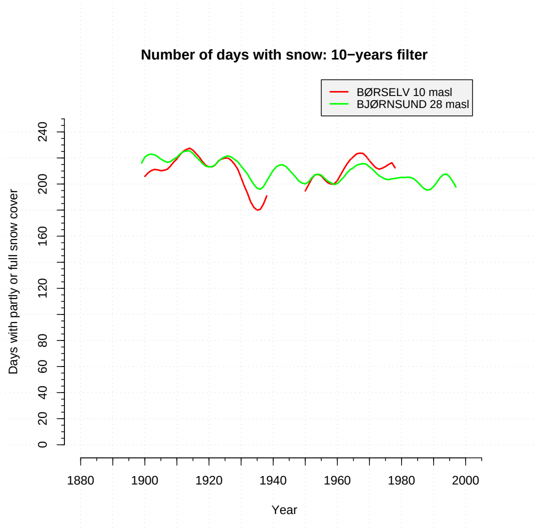

Figure 42: *Northern region, eastcoast: a) Number of skiing days, b) Number of days with snow on the ground. The graph is a 10 year gaussfilter.*

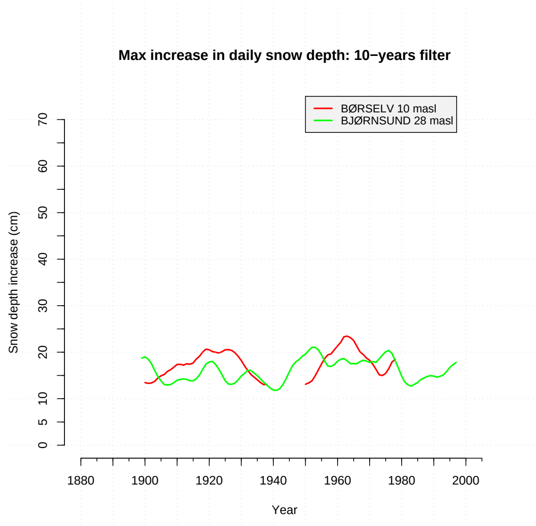

Figure 43: *Northern region, eastcoast: a) Maximum daily increase in snow depth. The graph is a 10 year gaussfilter.*

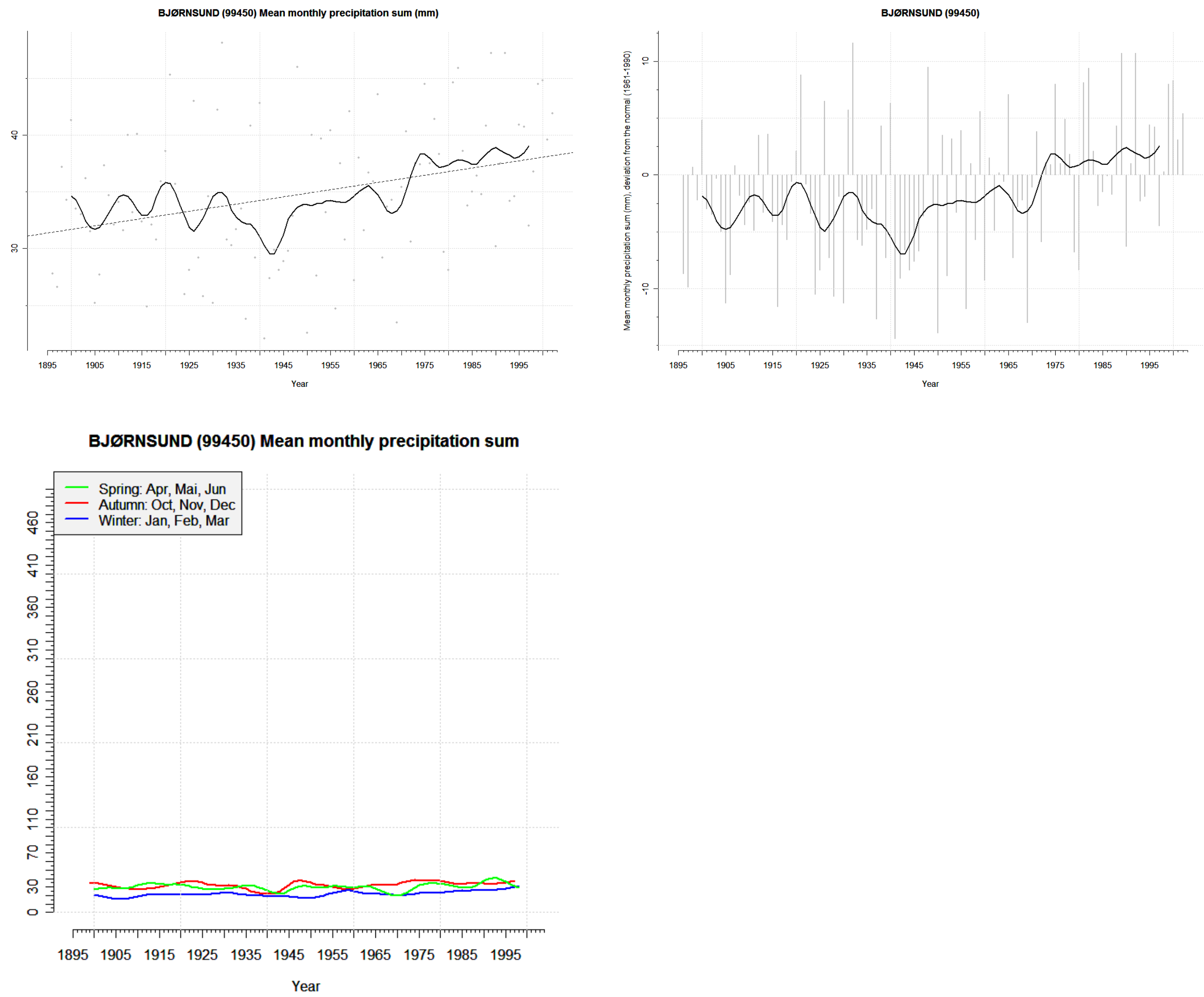

Figure 44: *Northern region, eastcoast: a) Mean precipitation from Bjørnsund. A linear trend line is included; b) Precipitation deviation from the normal period 1961-1990; and c) Seasonal mean monthly precipitation sum. All graphs include a 10 year gaussfilter.*

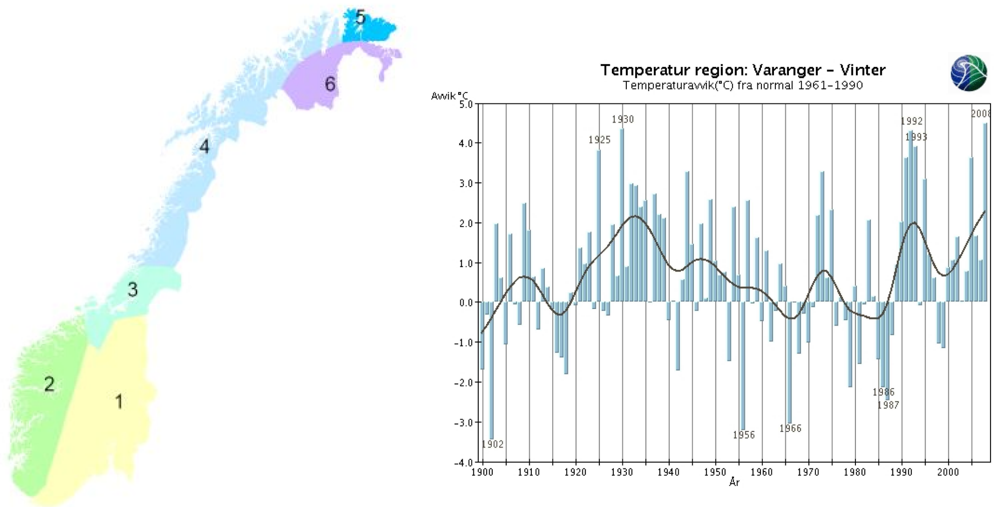

Figure 45: *a) The map shows six climatological regions for temperatures from 1900 till today. The Northern region, eastcoast (described in this report) is included in the temperature regions 4 and 6. b) Winter temperatures from 1900 till today (deviation from normal 1961-1990) for temperature region number 5.*

3.1.7 Northern region, Finnmarksvidda

There is only one station at Finnmarksvidda with a 100 year time-series of snow data: Suolovuopmi. In the Figures 46- 49, graphs of five different snow parameters are shown for this station.

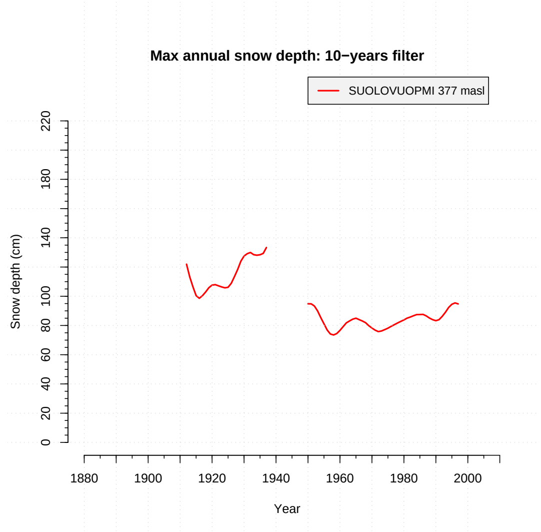

Figure 46: *Northern region, Finnmarksvidda a) Maximum annual snow depth.*

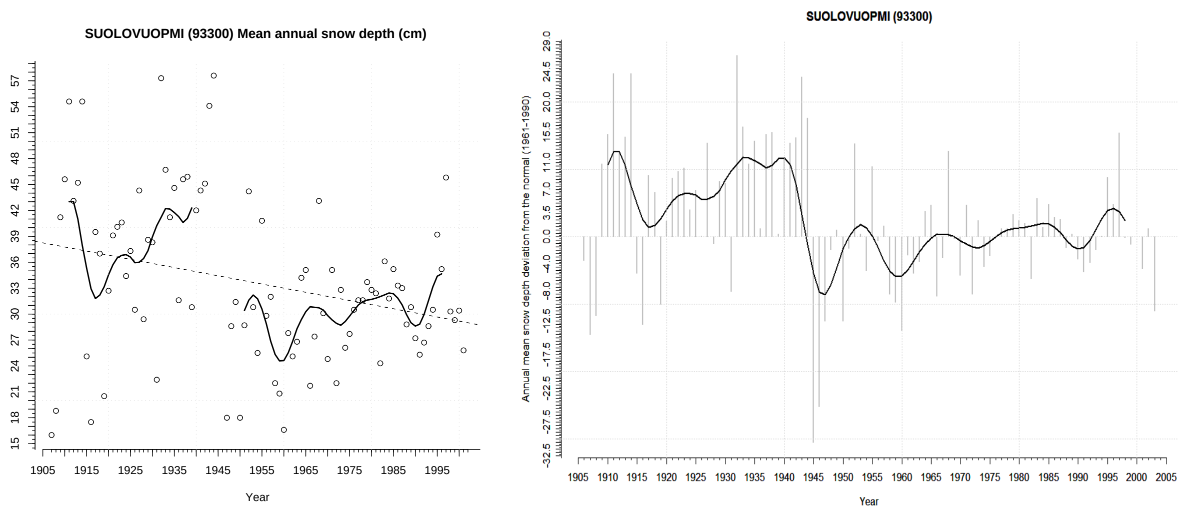

Figure 47: *a) Northern region, Finnmarksvidda: Mean snow depth from Suolovuopmi. Both a linear trend line and a 10 year gaussfilter are included. b) Snow depth deviation in cm from the normal period 1961-1990, including a 10 year gaussfilter.*

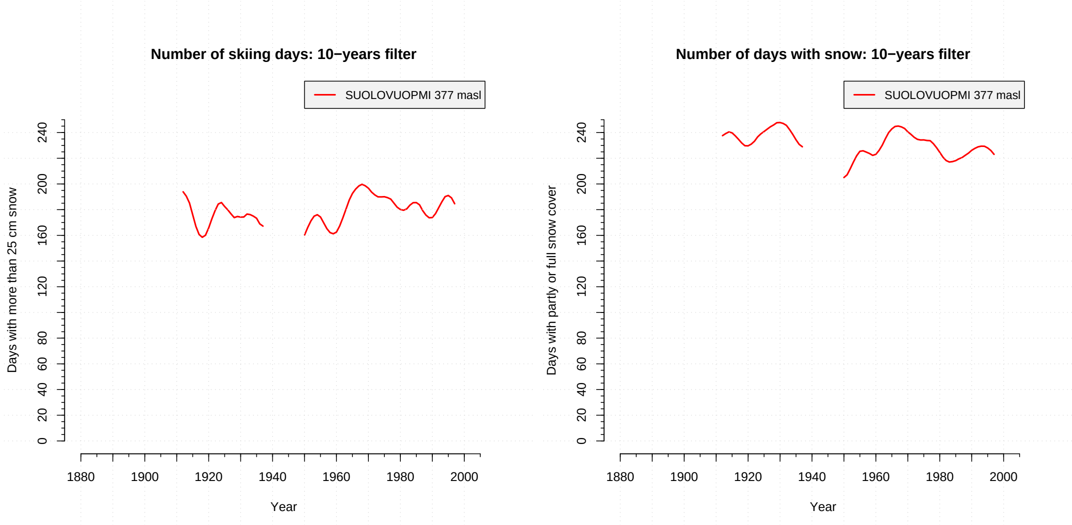

Figure 48: *Northern region, Finnmarksvidda: a) Number of skiing days, b) Number of days with snow on the ground. The graph is a 10 year gaussfilter.*

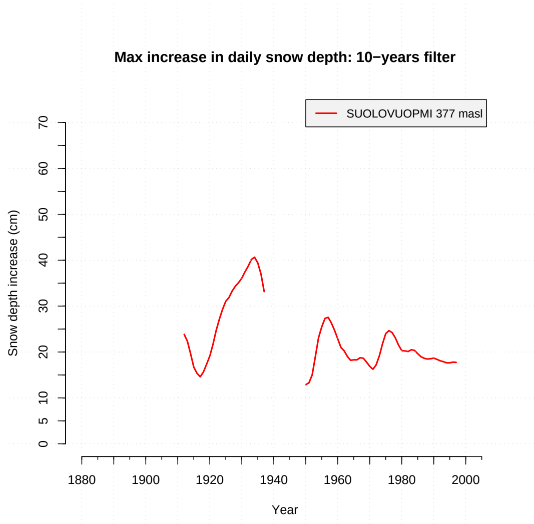

Figure 49: *Northern region, Finnmarksvidda: a) Maximum daily increase in snow depth. The graph is a 10 year gaussfilter.*

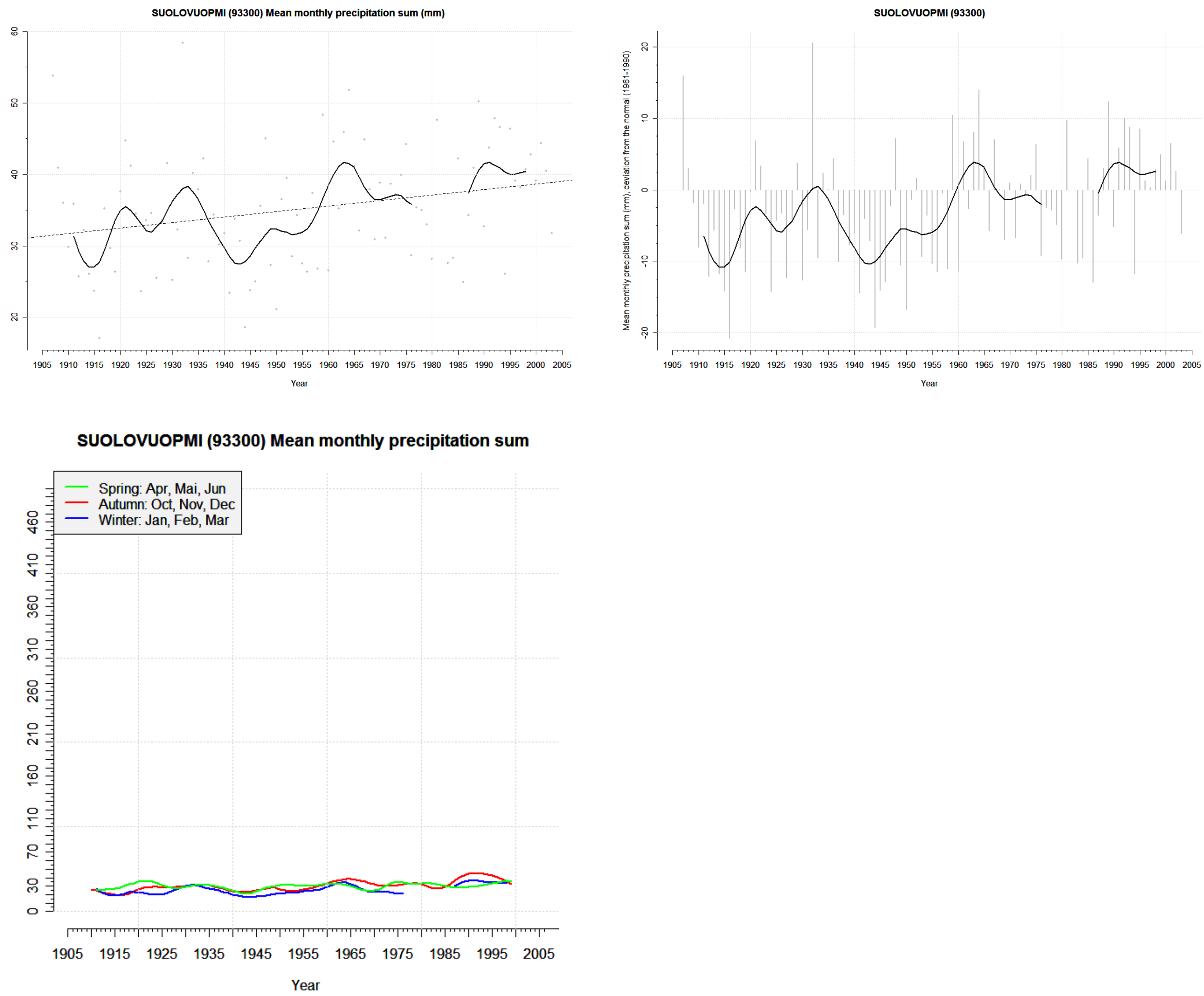

Figure 50: *Northern region, Finnmarksvidda: a) Mean precipitation from Suolovuopmi. A linear trend line is included; b) Precipitation deviation from the normal period 1961-1990; and c) Seasonal mean monthly precipitation sum. All graphs include a 10 year gaussfilter.*

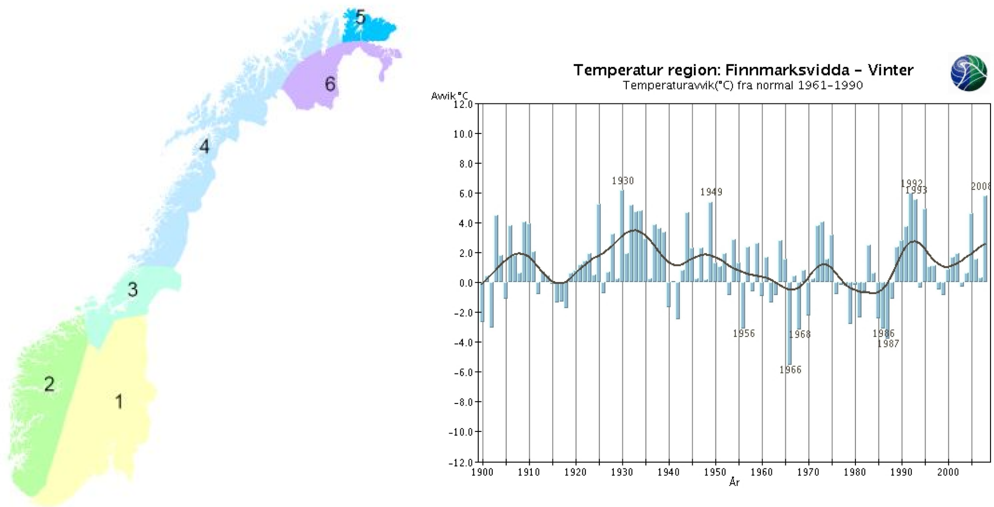

Figure 51: *a) The map shows six climatological regions for temperatures from 1900 till today. The Northern region, Finnmarksvidda (described in this report) is included in the temperature region number 6. b) Winter temperatures from 1900 till today (deviation from normal 1961-1990) for temperature region number 6.*

3.2 Trend analysis

Tables 9 - 10 show the slopes of snow parameters at all 41 stations, and whether or not the slope is found to be statistically significant. Note that for all parameters, except start of snow season, a negative trend indicates less snow. For the sake of simplicity, we will use the word decrease for all trends indicating less snow at the end of the time series. It is obvious that the length of the snow season and the number of snow days have decreased at most stations studied. Trends for other snow parameters are not as evident, suggesting that the intensity of snow events have not changed much. The end of snow season shows the greatest differences, and we find that 35 out of 41 stations reveil a negative trend in the end of snow season (20 of which are statistically significant).

We took a closer look on the number of snow days, with the purpose of finding possible connections between trend and station location. There are too few stations to determine any clear connection, however, there are indications of temperature being the main factor. The stations along the southern coast, where we would expect to see the strongest negative trends, are located in pretty high elevations, where winter temperatures stay below zero even with the observed warming over the last decades. At the highest elevated stations (25640 Geilo, and 54600 Maristova), we see no significant trend in the number of snow days, probably for this same reason. The lowest elevated stations are located in the north, where we find the lowest temperatures throughout the year. Station 57110 Osland ved Stongfjorden is the only station with a strong positive trend (significant at the 0.01 alpha level). The other snow parameters also show strong positive trends at this station. An evaluation of annual mean temperature and precipitation in this area reveal an increase in both. The temperature increase, however, is obviously not large enough to tip winter temperatures above zero, and so it is the increase in precipitation which is related to the positive trends seen in the snow parameters.

The Mann-Kendall trend test performed on the number of snow days demonstrate positive trends in the beginning and negative trends in the end of the 20'th century at the majority of the stations studied. The negative trend in the past few decades is consistent with recent observed increase in tempereature associated with global warming. Stations showing strong negative trends in the entire last half of the century include 600 Gløtvola, 10100 Os i Østerdal, 18500 Bjørnholt, 31900 Tuddal, 52700 Masfjorden, 55550 Hafslo, and 79740 Dunderlandsdalen. Station 57110 Osland ved Stongfjorden is again the greatest exception, showing a very significant positive trend after 1966. Stations 15660 Skjåk and 50350 Samnanger also demonstrate significant positive trends after 1980. A few stations reveal periods of significant negative trends in the middle of the century (periods are indicated in parenthesis). These stations include 42890 Skreådalen (1945-1970), 45350 Lysebotn (1920-1965), 77850 Susendal (1945-1985), and 86850 Barkestad (1920-1975).

We find that the snow season is shorter and the number of snowdays has decreased in all regions, except Northen region, eastcoast, where the two stations show oposite trends. However, only the negative trend seen at station 99450 Bjørnsund is significant. Results for mean and max annual snow depth and maximum daily increase in snow depth are ambiguous. In the three southernmost regions (southern, eastern, and western) we find consistent decrease in all snow parameters. This is especially true for the eastern region, where all seven stations show negative trends in both number of snow days and snow season duration. At 6 (4) of these stations the trends are significant for the number of snow days (snow season duration). We have to keep in mind, however, that stations in the southern regions were relatively well correlated compared to the central and northern regions, which might have some impact on the average trends.

In Table 11 we present the greatest value of the snow parameters within the years studied at each station. Station 79740 Dunderlandsdalen shows by far the greatest maximum snow depth with 370 cm, occuring between March 12th and 15th in 1920. The longest snow season duration (256 days) is also found at this station, as well as at station 93300 Suolovuopmi. The largest daily increase in snow depth is found at station 46450 Røldal with 92 cm, closely followed by station 64700 Innerdal with 90 cm. The last mentioned station also holds the greatest value in mean annual snow depth with 91.4 cm. The largest number of snow days is seen at station 73800 Tunnsjø with 276 days.

Station no (met.no)	Max snow depth	Skiing days	Snow days	Daily increase
600	-0.2120 ***	-0.2425 *	-0.2011 ***	0.0270
1650	-0.2182 ***	-0.0717	-0.1089	-0.0280
5350	-0.1170	-0.2723 **	-0.1177	-0.0108
6550	-0.2442 ***	-0.1270	-0.1380 ***	0.0138
9100	0.1406 ***	0.2552 *	-0.2129 ***	0.0435 ***
10100	-0.3985 ***	-0.2800 ***	-0.1467 ***	-0.1145 ***
15660	0.0448	0.0969	0.1056 *	-0.0318
18500	-0.4514 ***	-0.3501 ***	-0.3824 ***	-0.0565 **
20120	-0.1845	0.1083	-0.1643 **	-0.0757 ***
25640	-0.0424	0.2984 ***	-0.0785	-0.0559 ***
27800	-0.2201 **	-0.1807	-0.2015 *	-0.0747 ***
31900	0.0092	0.0775	-0.2882 ***	-0.0029
34900	-0.2457 **	-0.1324	-0.2233 ***	0.0354
38450	-0.1896	-0.1502	-0.1801 *	-0.0800 **
39220	-0.2174	-0.1089	-0.0062	-0.0508
42890	0.0877	-0.0192	-0.0936	0.0237
44800	0.0324	0.0223	0.0042	0.0142
45350	-0.0058	0.0123	-0.0919	0.0089
46450	0.1352	0.1680	-0.0588	0.0225
50350	-0.2336	-0.1826	0.1023	0.0297
51470	-0.0032	0.0613	-0.0656	-0.0013
52700	-0.4794 ***	-0.4540 **	-0.2286 **	-0.0749 **
53070	0.0272	0.0291	-0.1305	0.0083
54600	-0.1353	0.1032	0.0720	-0.0619
55550	0.0032	-0.2301 *	-0.3356 ***	0.0429 *
57110	0.2549 ***	0.1786 ***	0.3407 ***	0.0876 ***
58960	-0.4648 ***	-0.1294	-0.0522	-0.0268
64700	0.2504	0.2719 **	-0.1318 *	0.1510 ***
65220	0.3525 ***	0.4227 ***	0.0634	0.0640 ***
68330	-0.0842	-0.2512 *	-0.2585 ***	0.0086
73800	-0.2074	-0.2433 **	-0.1187	0.0273
77850	-0.0321	-0.0008	-0.0608	0.0498 **
79740	-0.0737	-0.0290	-0.2267 ***	-0.0381
83300	0.0100	0.1185	0.1238	0.0746 **
83500	0.1592 *	0.0733	-0.0546	0.0060
86850	-0.1532	-0.0504	-0.0749	-0.0141
90450	0.4437	0.4890 *	-0.1887	-0.1058
91750	0.0050	-0.0694	-0.1542 *	0.0915 ***
93300	-0.4863 ***	0.0808	-0.1624 **	-0.0876
95600	0.4146 ***	0.0910	0.0068	0.0294
99450	0.0587	0.0385	-0.1961 ***	0.0156

Table 9: *Slopes for maximum annual snow depth, number of skiing days, number of snow days, and maximum increase in daily snow depth. Alpha levels: *** = 0.01, ** = 0.05, * = 0.1*

Station no (met.no)	**Mean annual snow depth**	**Start of snow season**	**End of snow season**	**Snow season duration**
600	-0.0503 **	0.1519 ***	-0.0890 ***	-0.2484 ***
1650	-0.0180	-0.0400	-0.0272	-0.1824
5350	-0.0294	-0.0200	-0.1275 ***	-0.1131
6550	-0.0590 **	0.0517	-0.1197 ***	-0.1689 ***
9100	0.0310 ***	0.3596 ***	-0.0791 **	-0.4531 ***
10100	-0.1622 ***	0.1260 ***	-0.0621 *	-0.1807 ***
15660	0.0197 *	0.0820	0.0968 **	0.0110
18500	-0.1243 ***	0.2450 ***	-0.2009 ***	-0.5163 ***
20120	-0.0246	-0.0448	-0.1220 ***	-0.0685
25640	0.0541	0.0406	-0.0651 **	-0.1162 **
27800	-0.0305	0.1991 **	-0.1355 **	-0.4439 ***
31900	0.0316	0.1485 ***	-0.1470 ***	-0.3036 ***
34900	-0.0251	0.0131	-0.1460 ***	-0.1192
38450	-0.0170	0.1870 **	-0.0485	-0.3351 **
39220	-0.0069	-0.0720	-0.0245	0.0760
42890	0.0383	0.0587	-0.0379 *	-0.0851
44800	0.0070 **	-0.0210	-0.0513	0.2022
45350	0.0018	-0.1805	-0.0835	0.0806
46450	0.0384	0.0670	0.0046	-0.0616
50350	-0.0321	-0.2041 **	-0.0018	0.2075 *
51470	0.0317	0.0945	-0.0573	-0.1565 **
52700	-0.1206 ***	0.0218	-0.1416 *	-0.1787
53070	0.0148 **	0.0782	-0.0292	-0.2493 *
54600	-0.0028	-0.0501	-0.0778 **	-0.0320
55550	-0.0233	-0.0197	-0.2316 ***	-0.2435 **
57110	0.0214 ***	-0.0566	0.2239 ***	0.5072 ***
58960	-0.0984 **	0.0888	-0.0181	-0.1069
64700	0.0948 *	0.0053	-0.1429 ***	-0.1384
65220	0.1157 ***	-0.0865	0.0276	0.0917
68330	-0.0286	0.2911 ***	-0.0614	-0.3703 ***
73800	-0.0758 *	0.1431 **	-0.0425	-0.1856 **
77850	-0.0026	0.0849 *	-0.0518	-0.1197 *
79740	-0.0101	0.2351 ***	-0.1381 ***	-0.3563 ***
83300	0.0187	0.0299	0.0037	-0.0080
83500	0.0189	-0.0160	-0.0292	-0.0259
86850	-0.0103	-0.0172	-0.0884	0.1909
90450	0.2634 ***	-0.1285	0.1988 **	-0.0628
91750	-0.0244	0.2290 **	-0.1009 **	-0.3463 ***
93300	-0.0953 ***	0.0447	-0.0866 **	-0.1346 *
95600	0.1106 ***	-0.0662	-0.0042	0.0623
99450	0.0237	0.0620	-0.1306 ***	-0.1988 ***

Table 10: *Slopes for mean annual snow depth and the snow season computed from observations of snow cover. Alpha levels: *** = 0.01, ** = 0.05, * = 0.1*

Station no (met.no)	Max snow depth [cm]	Skiing days [# of days]	Snow days [# of days]	Daily increase [cm]	Mean snow depth [cm]	Snow season duration [# of days]
600	137	195	237	36	44.8	243
1650	102	146	155	37	21.0	161
5350	132	154	180	35	31.4	189
6550	190	192	231	36	51.4	228
9100	86	165	230	25	25.1	228
10100	225	220	259	61	81.5	249
15660	79	171	183	74	19.8	180
18500	202	187	239	49	55.5	242
20120	199	187	228	45	50.5	219
25640	300	231	256	47	70.2	253
27800	180	153	171	55	30.3	181
31900	175	207	226	60	44.0	240
34900	211	205	228	78	62.5	231
38450	196	171	176	75	47.6	177
39220	204	167	180	77	49.9	180
42890	263	181	204	64	75.8	228
44800	52	41	115	44	5.2	143
45350	45	32	105	33	4.3	126
46450	210	187	196	92	58.1	218
50350	283	193	210	50	77.3	221
51470	162	164	189	50	37.8	191
52700	181	170	196	51	39.6	204
53070	99	90	167	46	10.7	167
54600	270	204	230	80	77.8	228
55550	155	179	201	56	37.6	203
57110	89	69	154	40	8.8	157
58960	290	187	229	76	70.2	225
64700	270	216	259	90	91.4	253
65220	165	173	205	63	37.3	219
68330	146	160	201	61	41.9	215
73800	200	217	276	50	68.9	255
77850	210	214	240	55	59.0	242
79740	370	209	257	58	85.7	256
83300	92	93	177	53	12.5	195
83500	183	199	211	41	46.8	231
86850	180	183	206	60	49.2	211
90450	240	213	236	63	73.7	231
91750	219	244	256	58	65.4	252
93300	181	231	260	80	57.6	256
95600	156	215	262	52	51.8	242
99450	122	217	250	39	39.4	250

Table 11: *Greatest value of snow parameters at each station*

4 Summary and conclusions

In this study we examined six different snow parameters at 41 Norwegian meteorological stations with long time series. The parameters showing the strongest trends were the end of snow season and the number of snow days. These trends are mostly negative, particularly for the last few decades, resulting in a shorter snow season. An earlier end of snow season, particularly, means that melting occurs earlier than before, which is of great importance in e.g. flood tracking. The results are consistent with the findings of Vikhamar-Schuler et al (2006), showing a rather large projected change in the end of the snow season some places, suggesting that the trends found in this study will continue.

Due to the lack of highly elevated stations, mountain areas, where other conditions might govern, are not well covered in this analysis. In a warmer climate it is likely that more moisture leads to heavier and more frequent snowfall, but at the same time more melting will occur. This might explain why we see a shorter snow season at most stations, but don't see the same negative trends in maximum values and mean snow depth. The southernmost regions reveal more consistent decrease in all snow parameters, and the stations showing the strongest negative trends are also located here. In the eastern region specifically, all seven stations show negative trends in the number of snow days and snow season duration, most of them statistically significant.

Station 79740 Dunderlandsdalen reveal the greatest value in both maximum snow depth and snow season duration. The maximum snow depth occured in 1920 and was observed to be 370 cm, which is considerably larger than the average at the station and the greatest values at the other stations. Station 46450 Røldal shows the greatest daily increase in snow depth and mean annual snow depth with 92 cm and 91.4 cm, respectively.

5 Acknowledgements

Thanks to Eirik Førland at met.no for editorial reading and suggestions.
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6 References

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APPENDIX

The appendix contains figures of six snow parameters for every station listed in Table 2. The six snow parameters are:

1. Maximum snow depth
2. Mean snow depth
3. Number of skiing days
4. Number of days with snow on the ground
5. Snow season duration
6. Maximum daily increase in snow depth

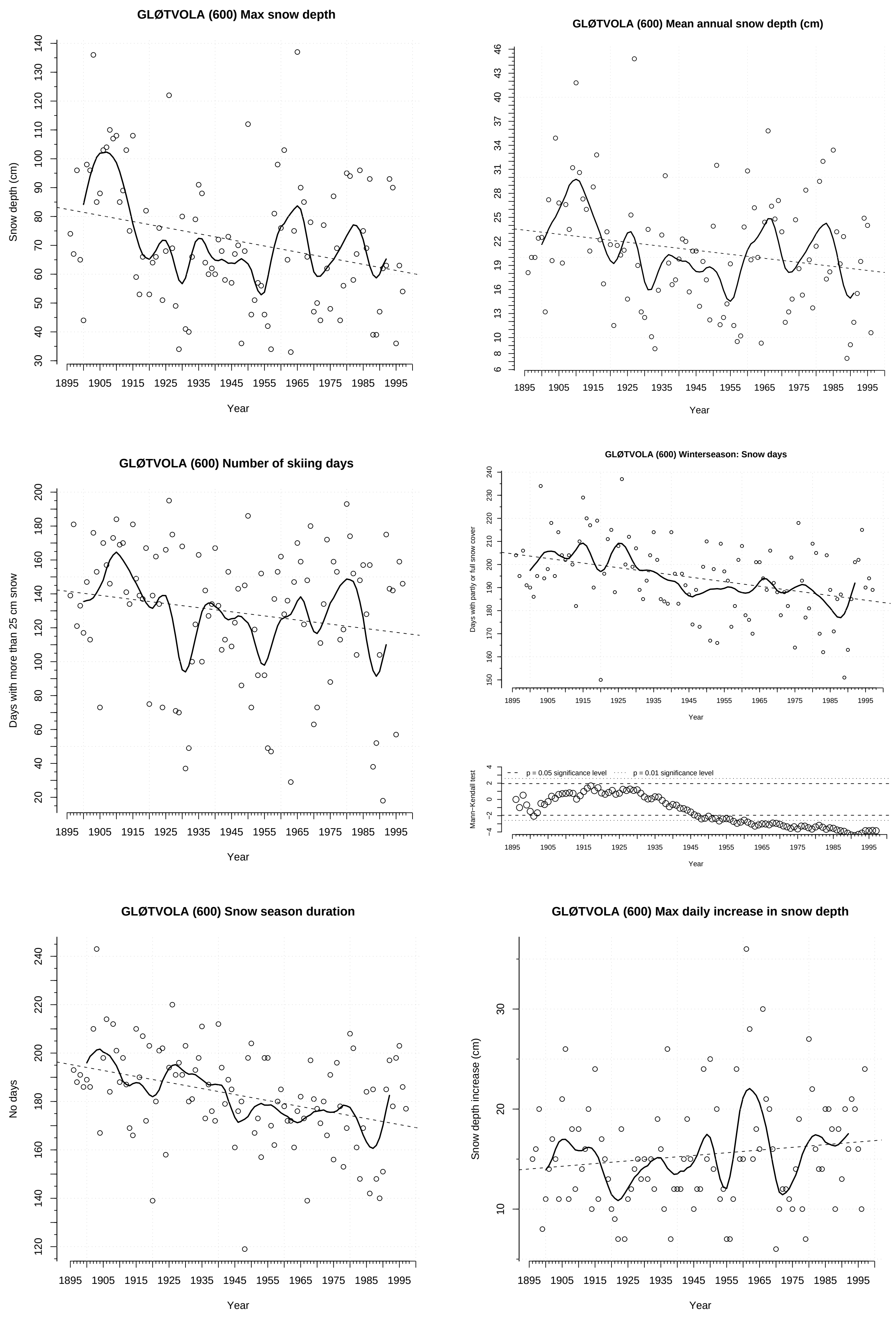


Figure 52: *Gløtvola meteorological station.*

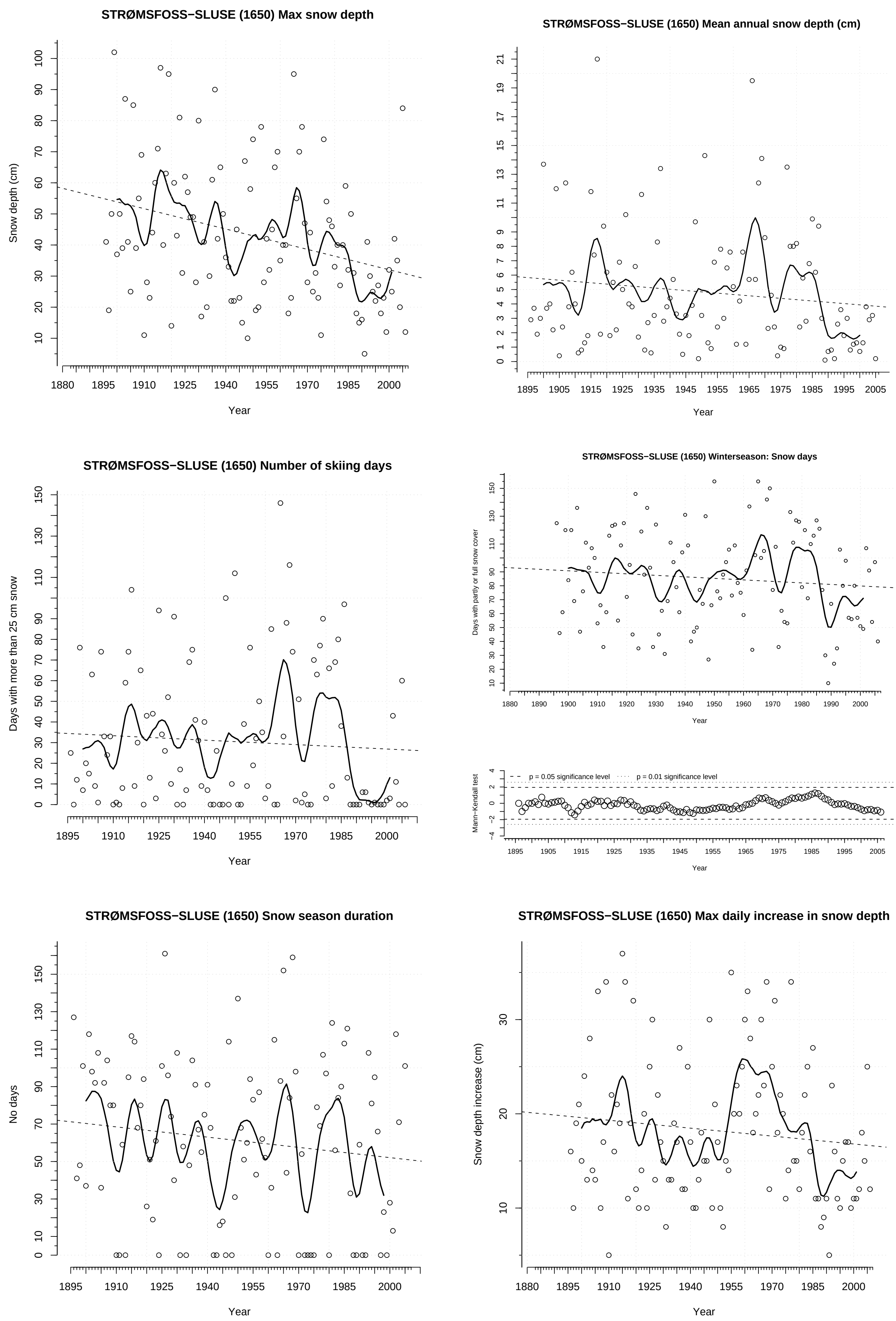


Figure 53: *Strømsfoss sluse meteorological station.*

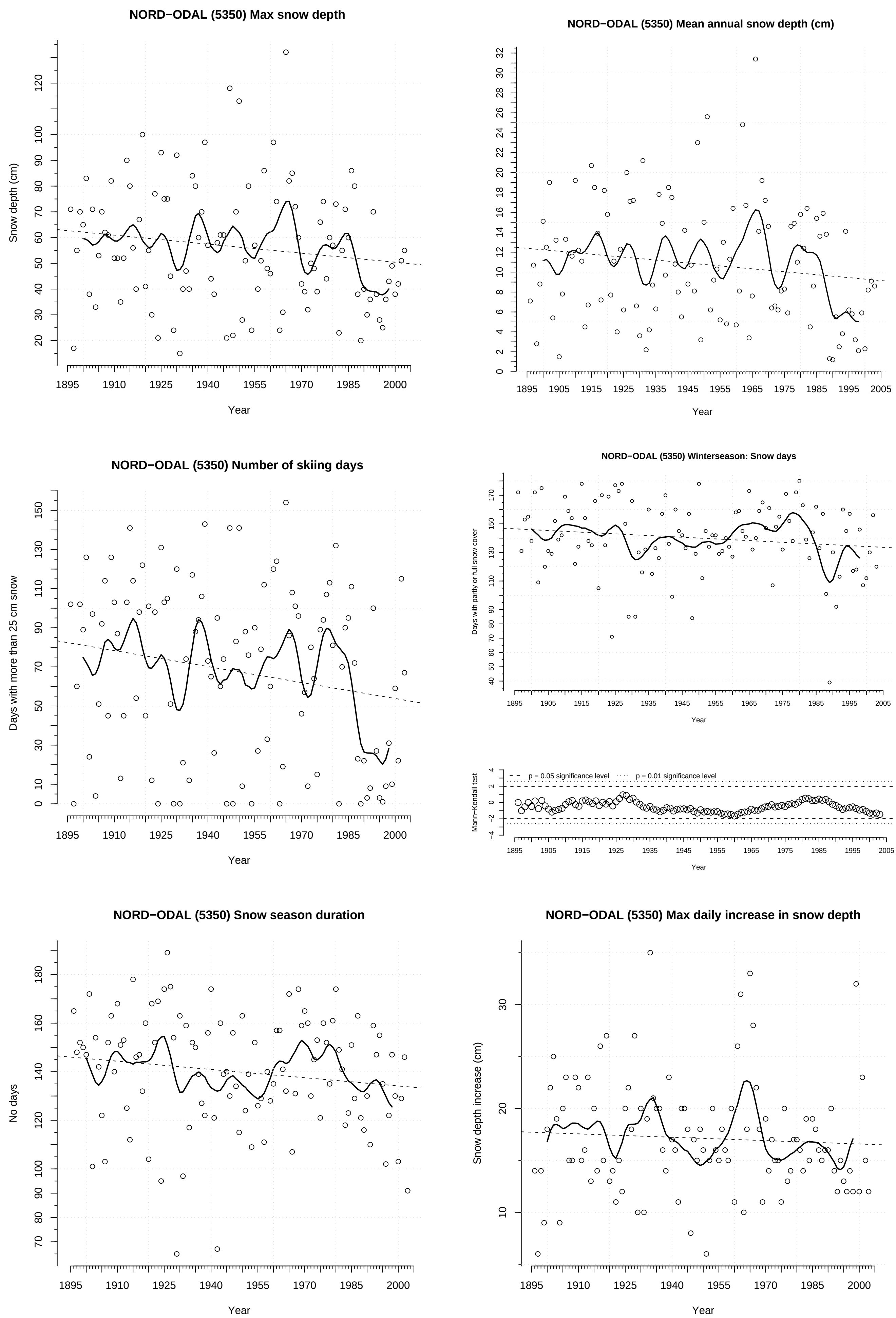


Figure 54: *Nord Odal meteorological station.*

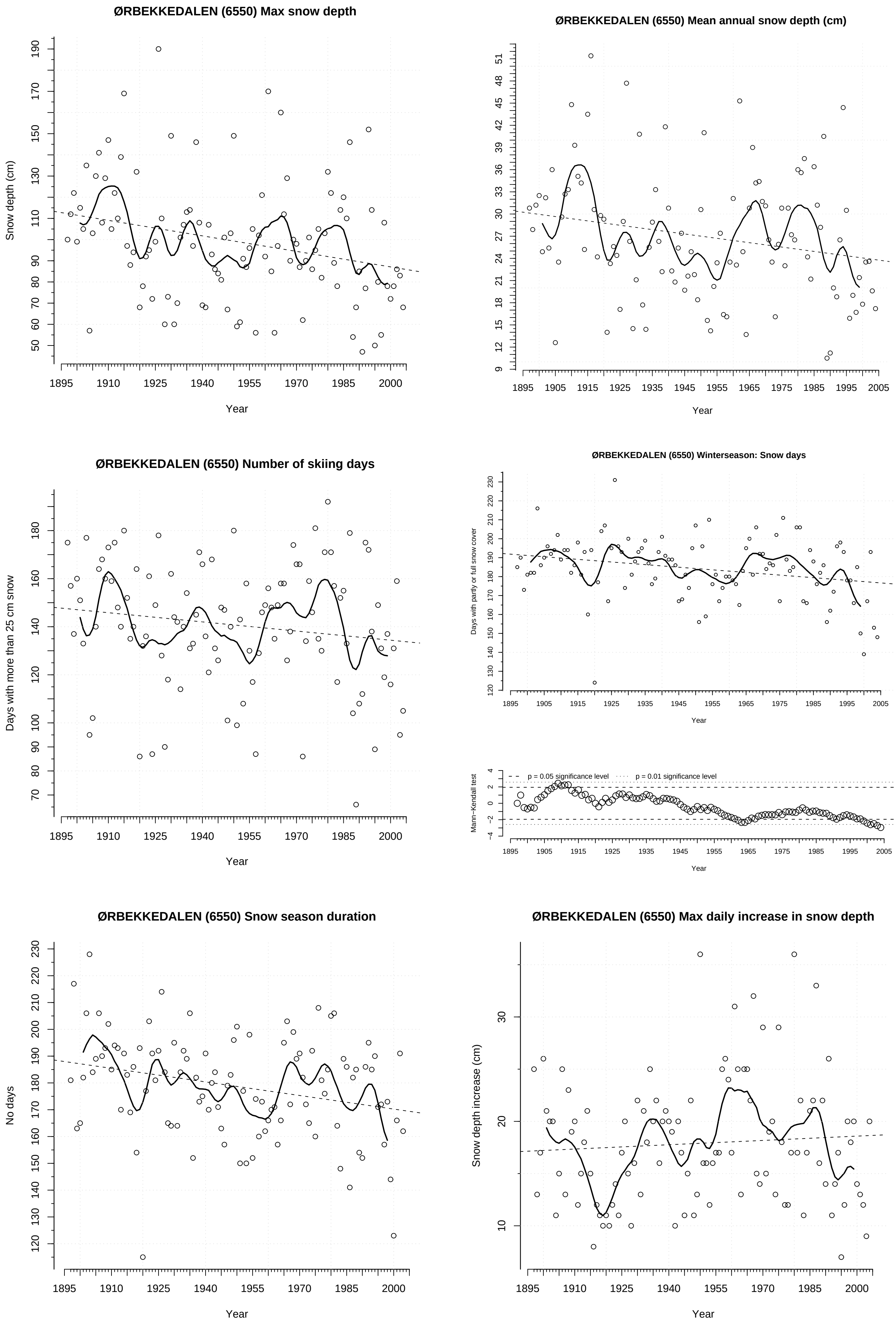


Figure 55: *Ørbekkedalen meteorological station.*

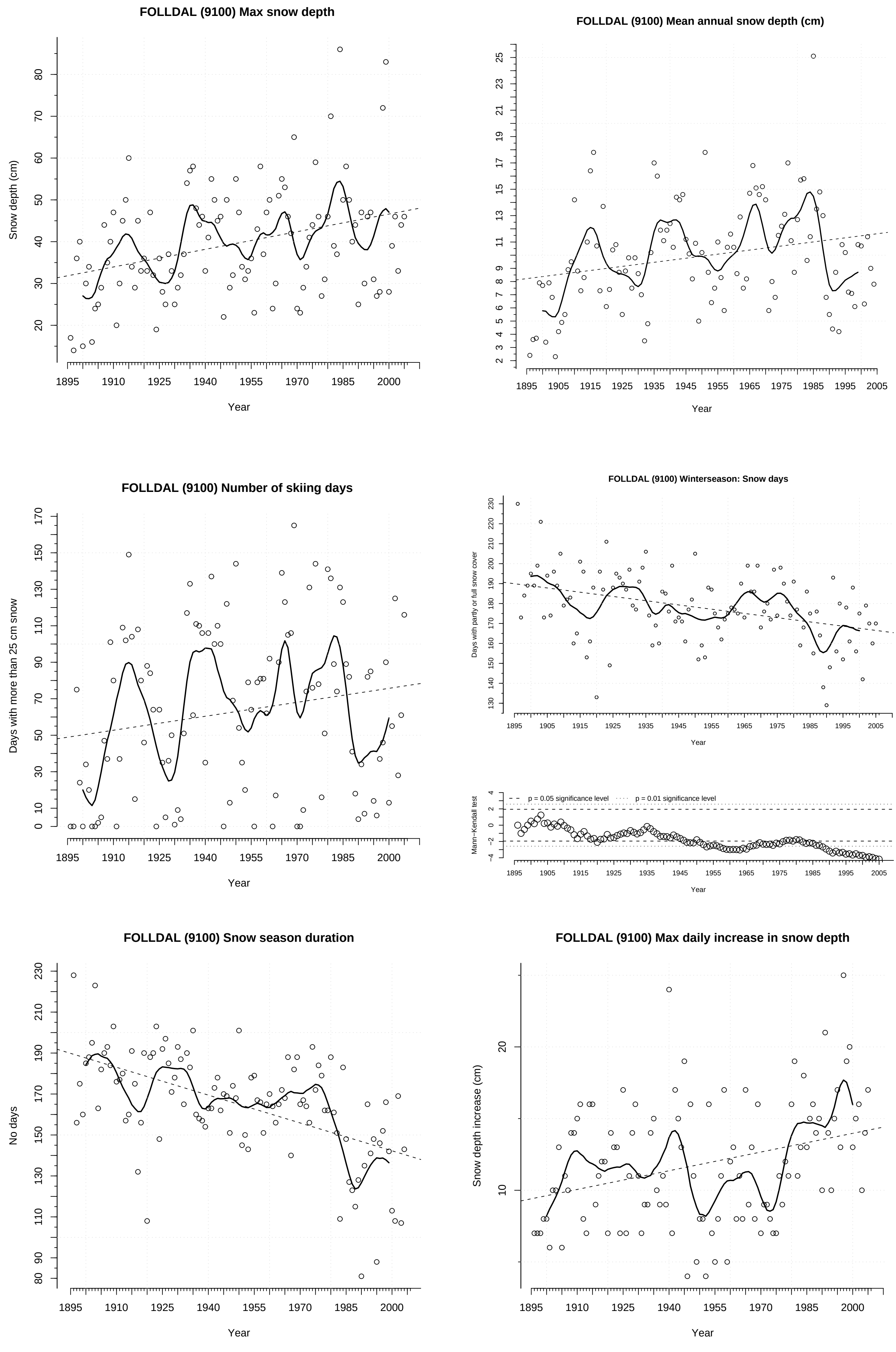
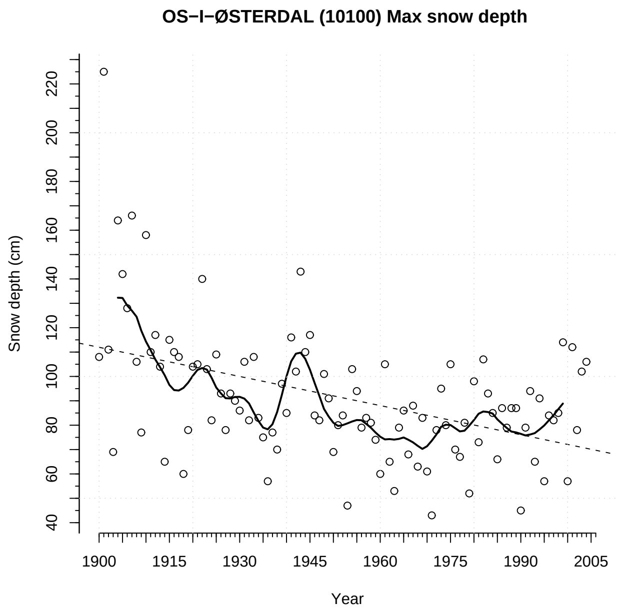
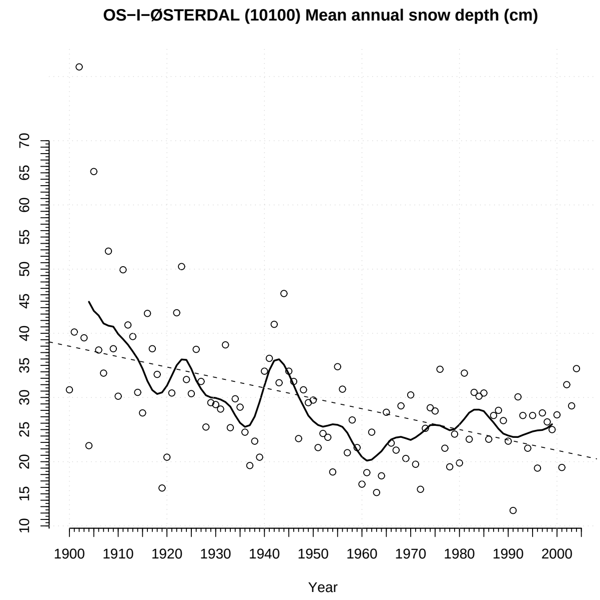
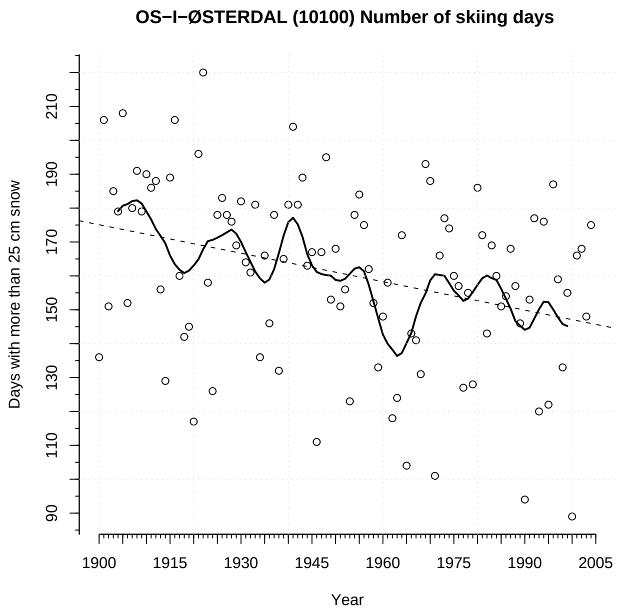
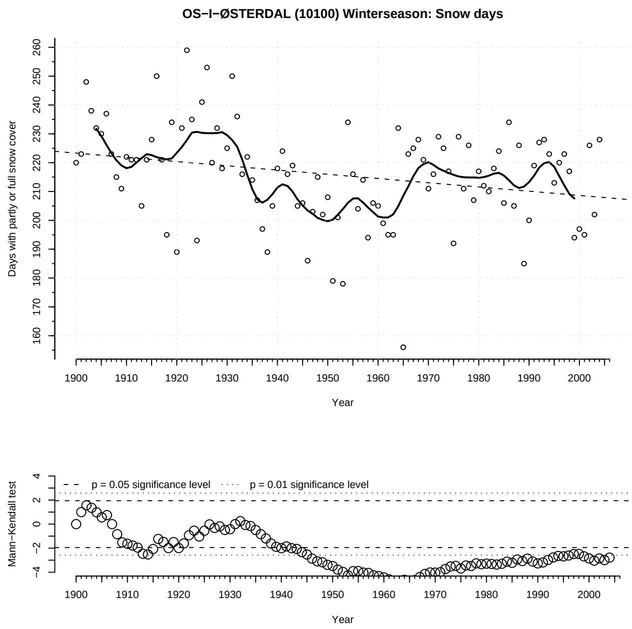


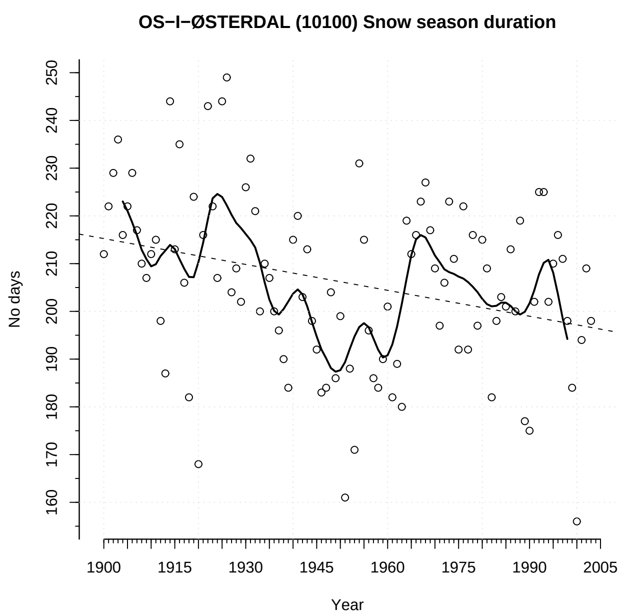
Figure 56: *Folldal meteorological station.*











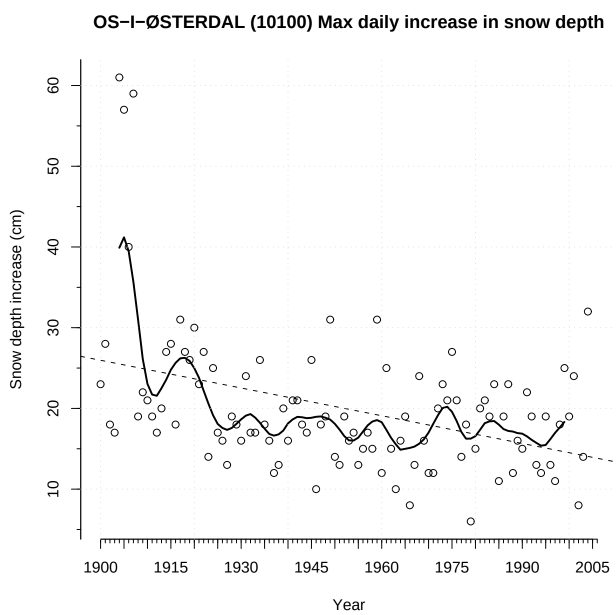


Figure 57: *Os i Østerdal meteorological station.*

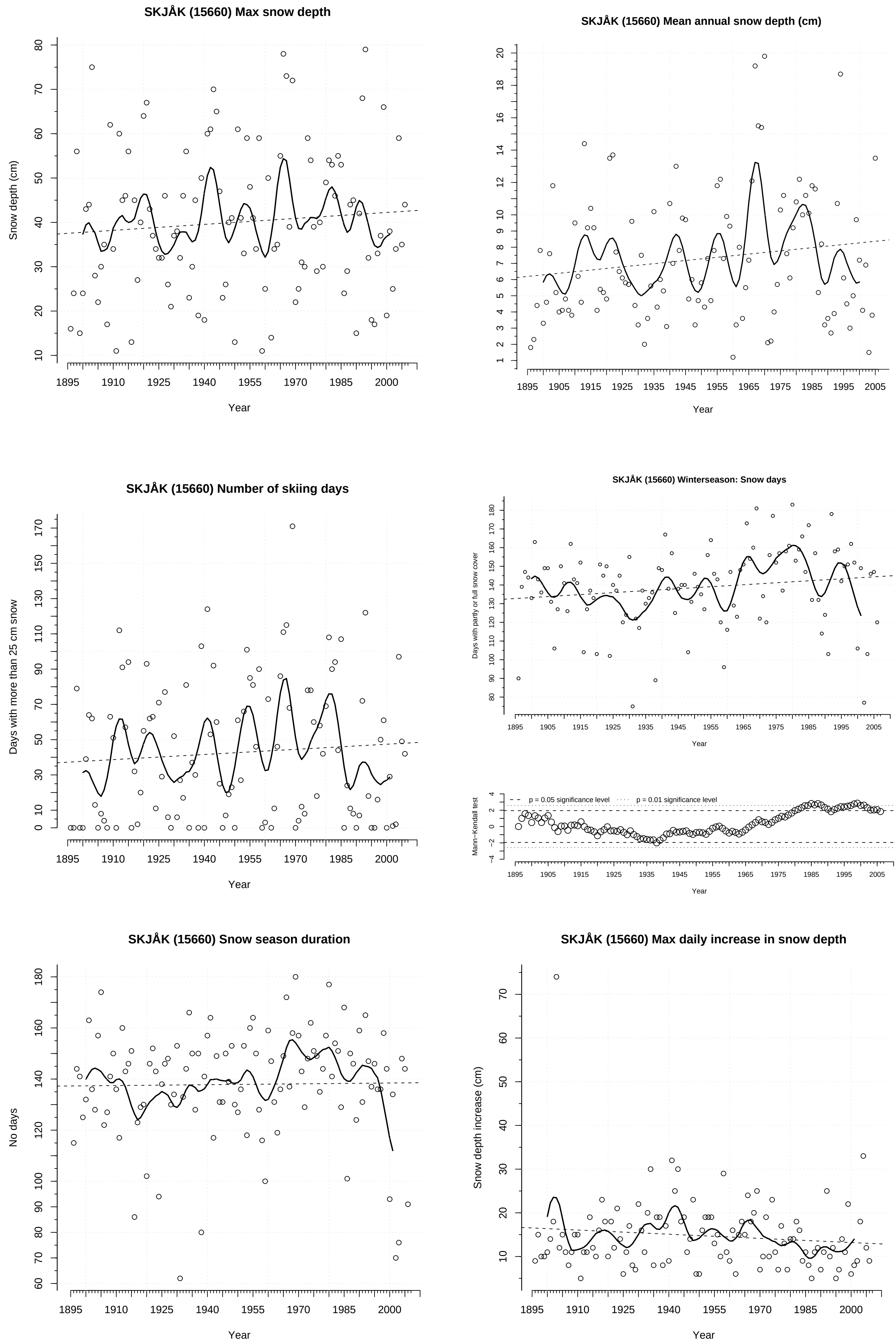


Figure 58: *Skjåk meteorological station.*

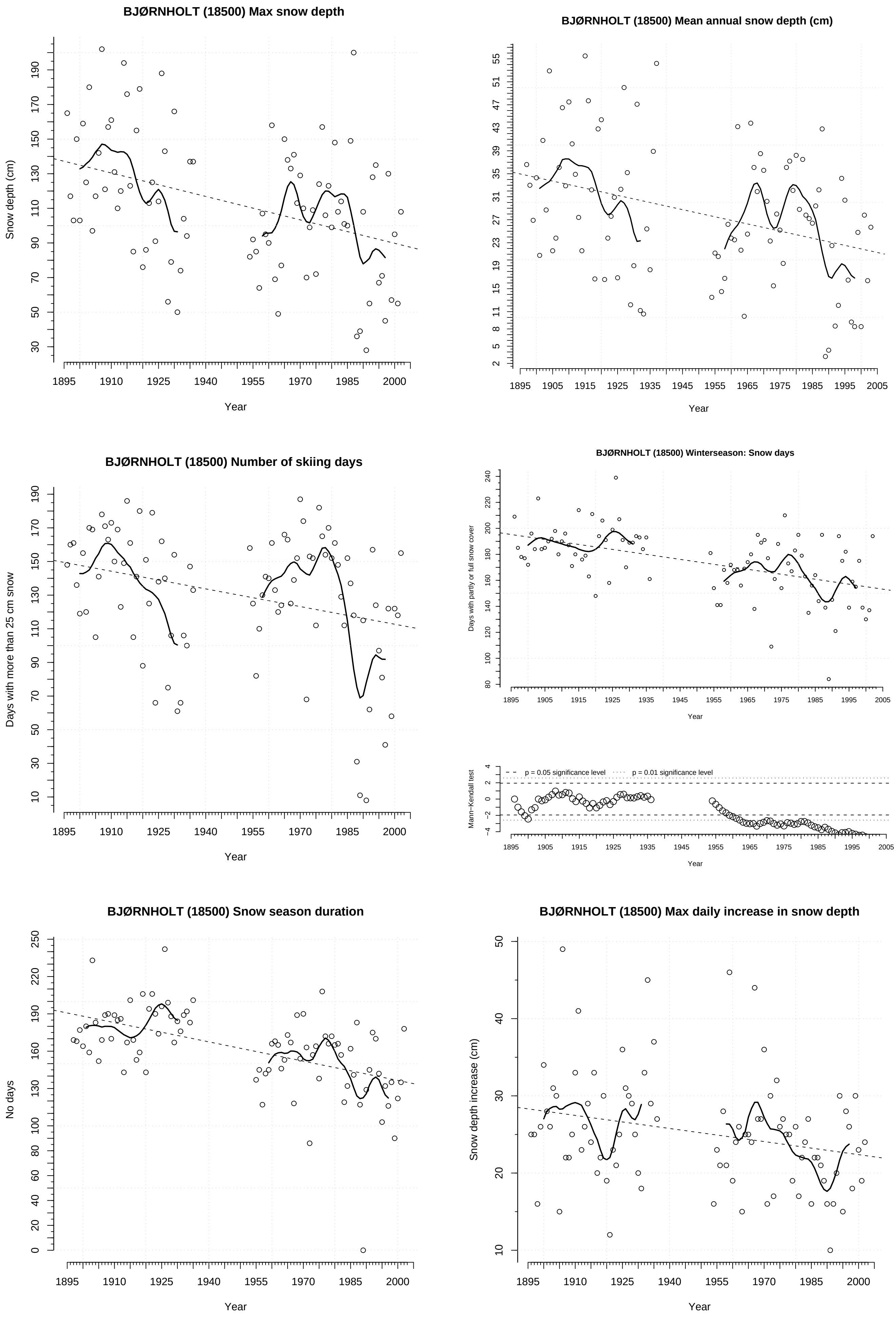


Figure 59: *Bjørnholt meteorological station.*

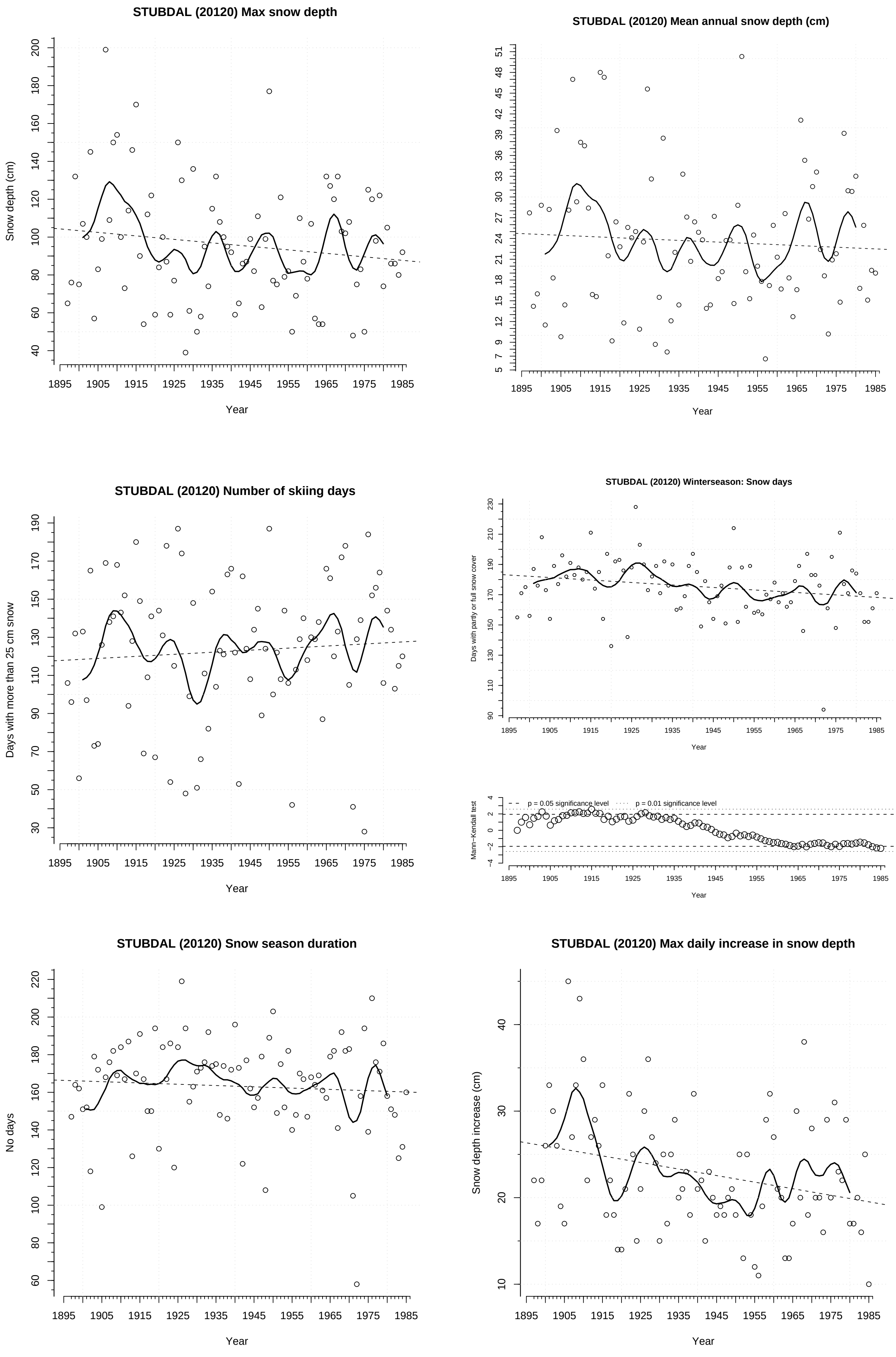


Figure 60: *Stubdal meteorological station.*

Figure 61: *Geilo meteorological station.*

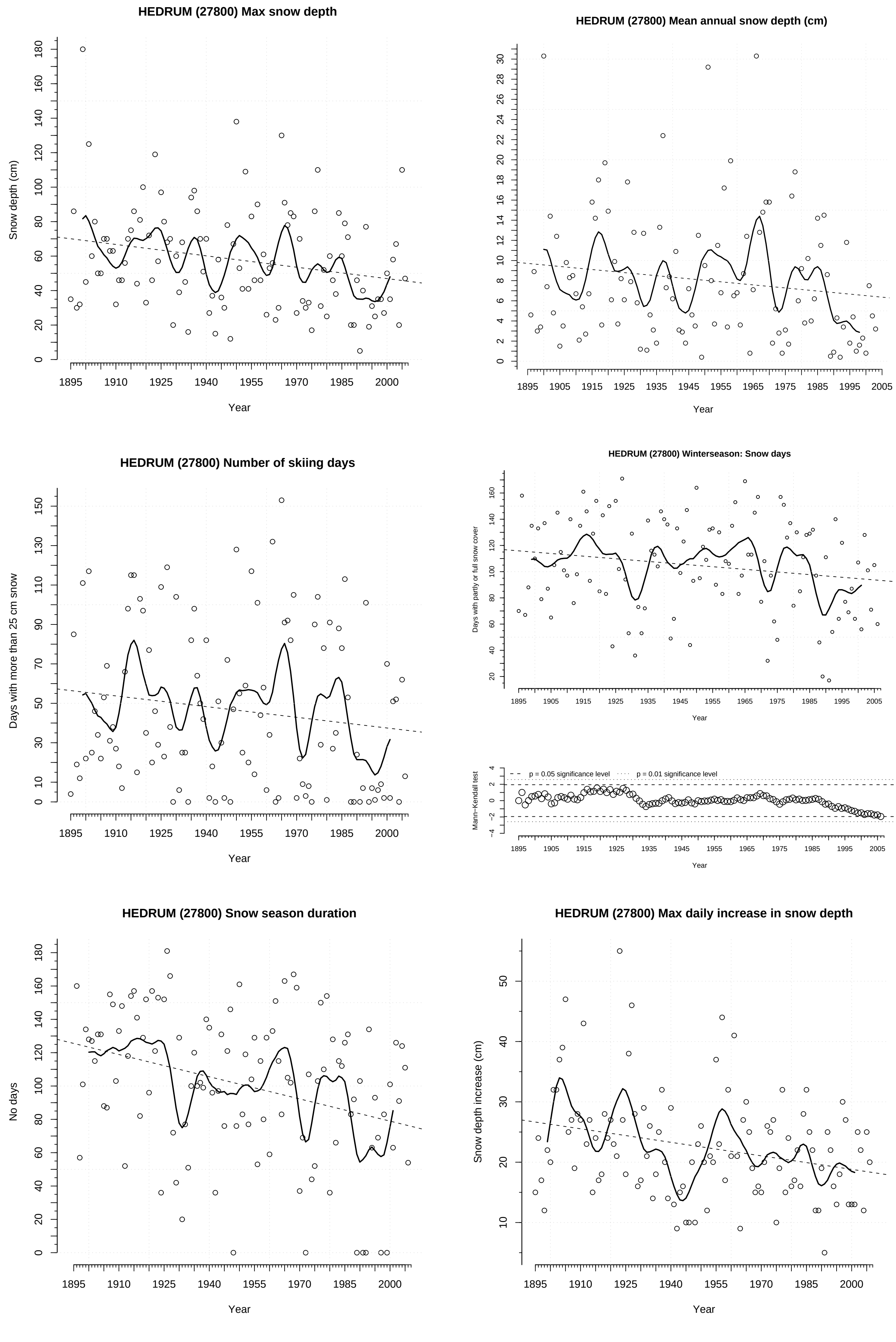


Figure 62: *Hedrum meteorological station.*

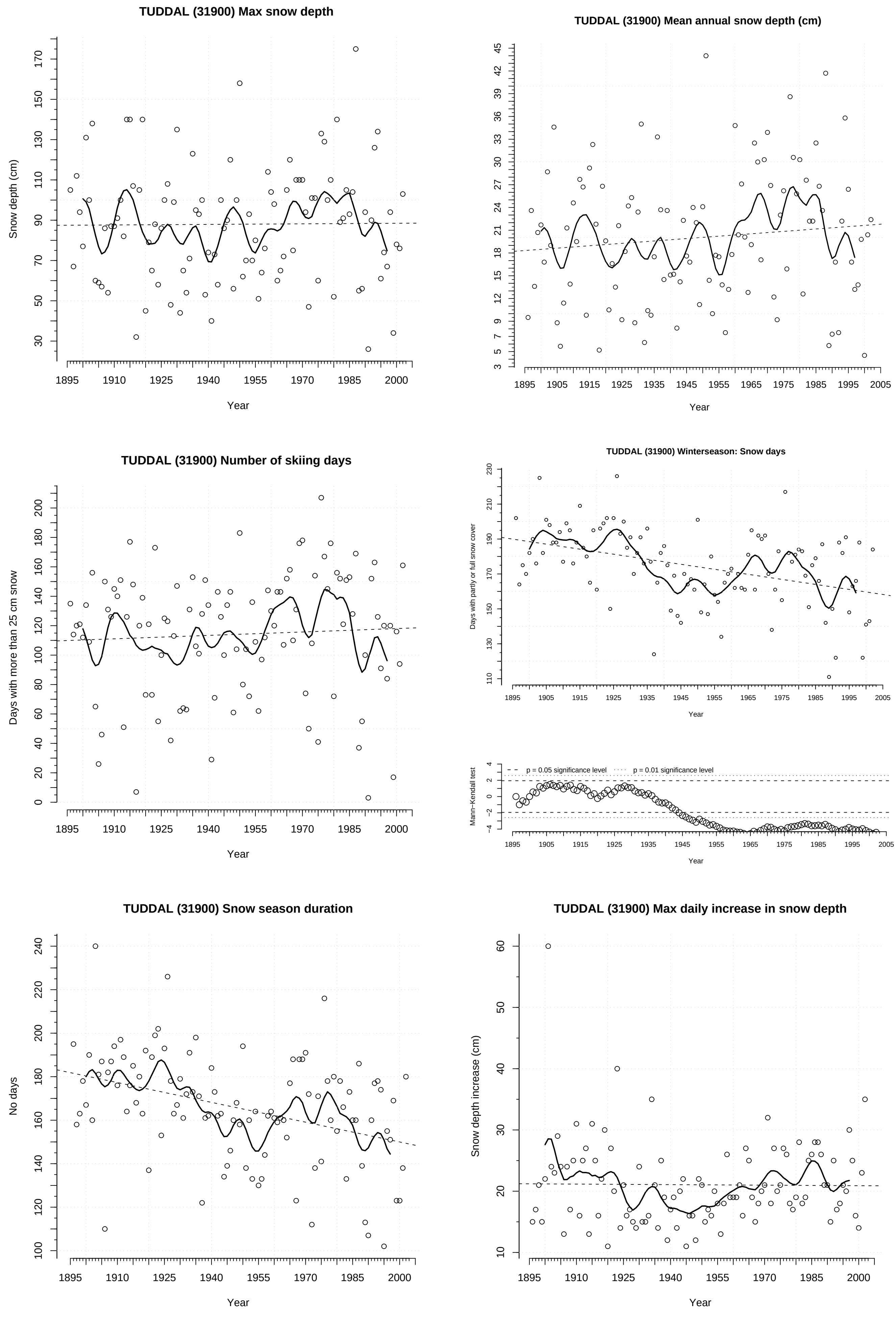


Figure 63: *Tuddal meteorological station.*

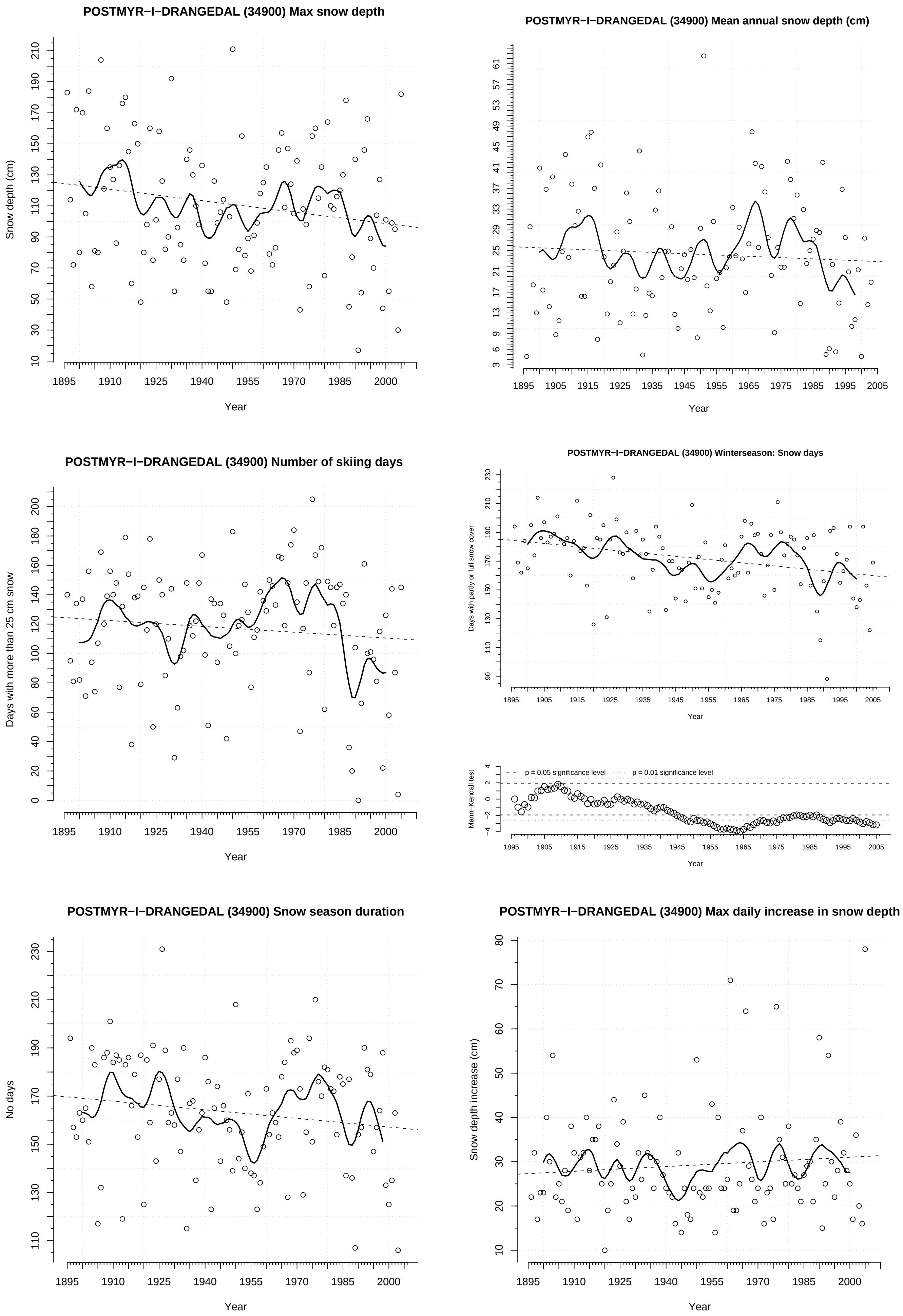


Figure 64: *Postmyr i Drangedal meteorological station.*

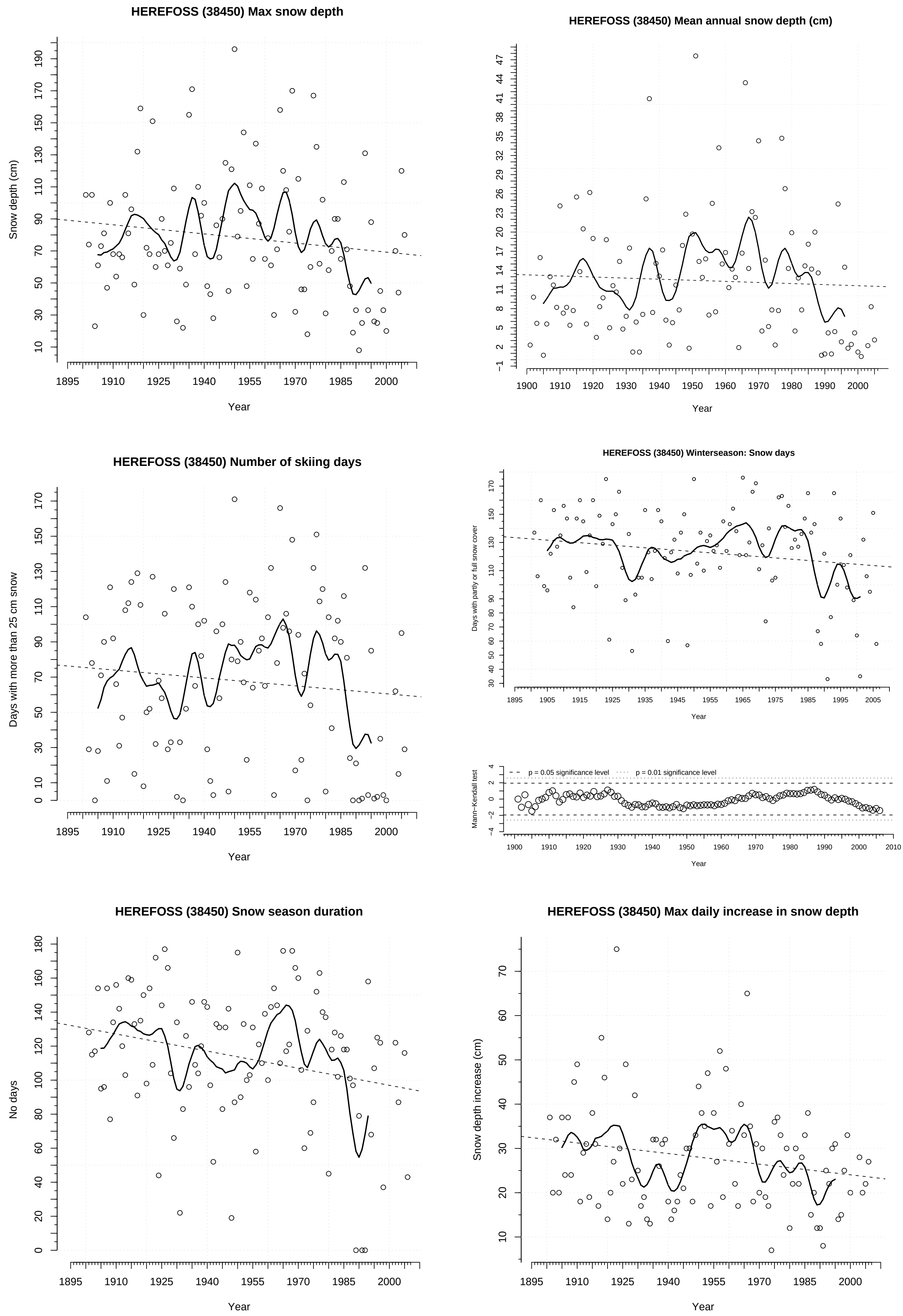


Figure 65: *Herefoss meteorological station.*

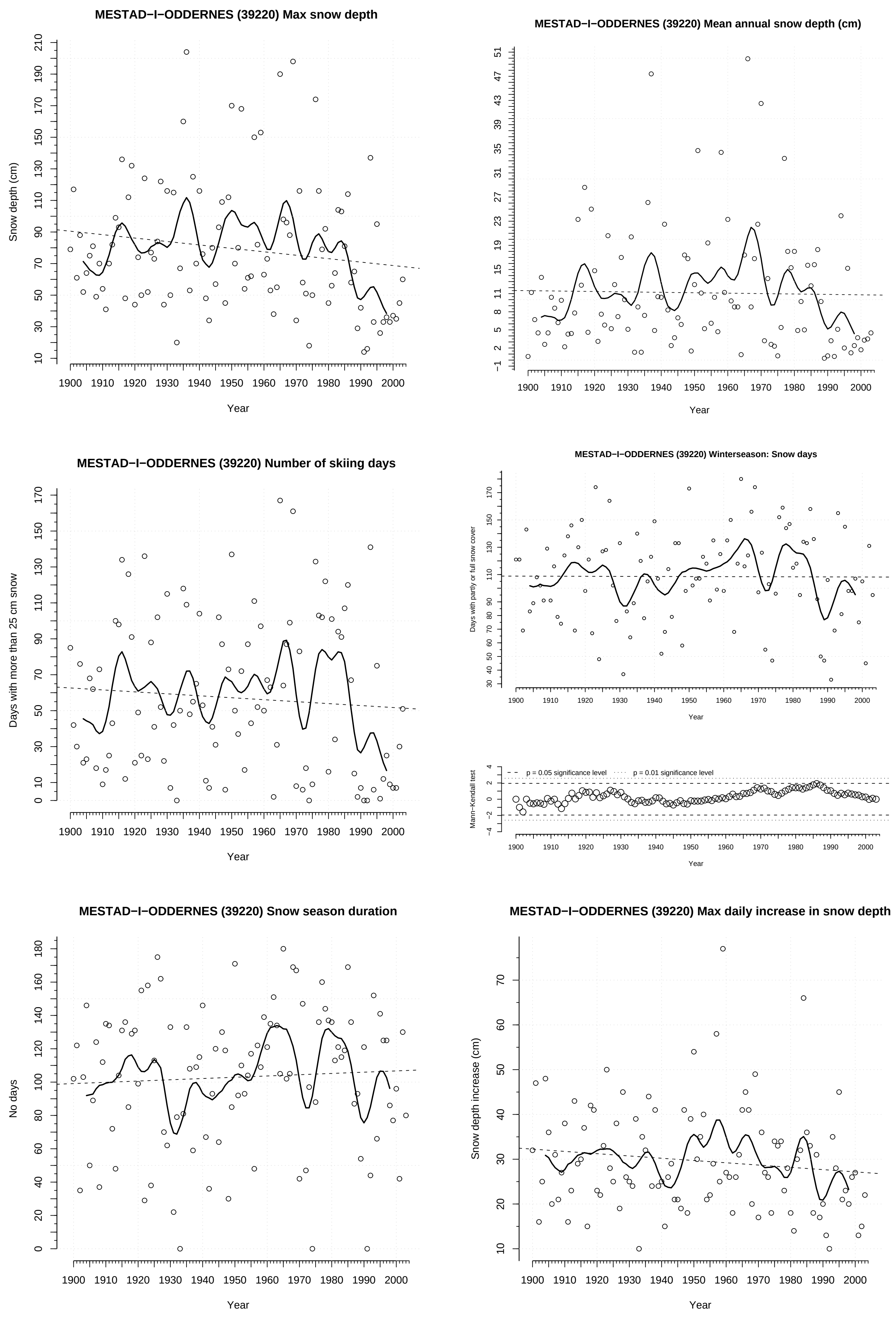


Figure 66: *Mestad i Oddernes meteorological station.*

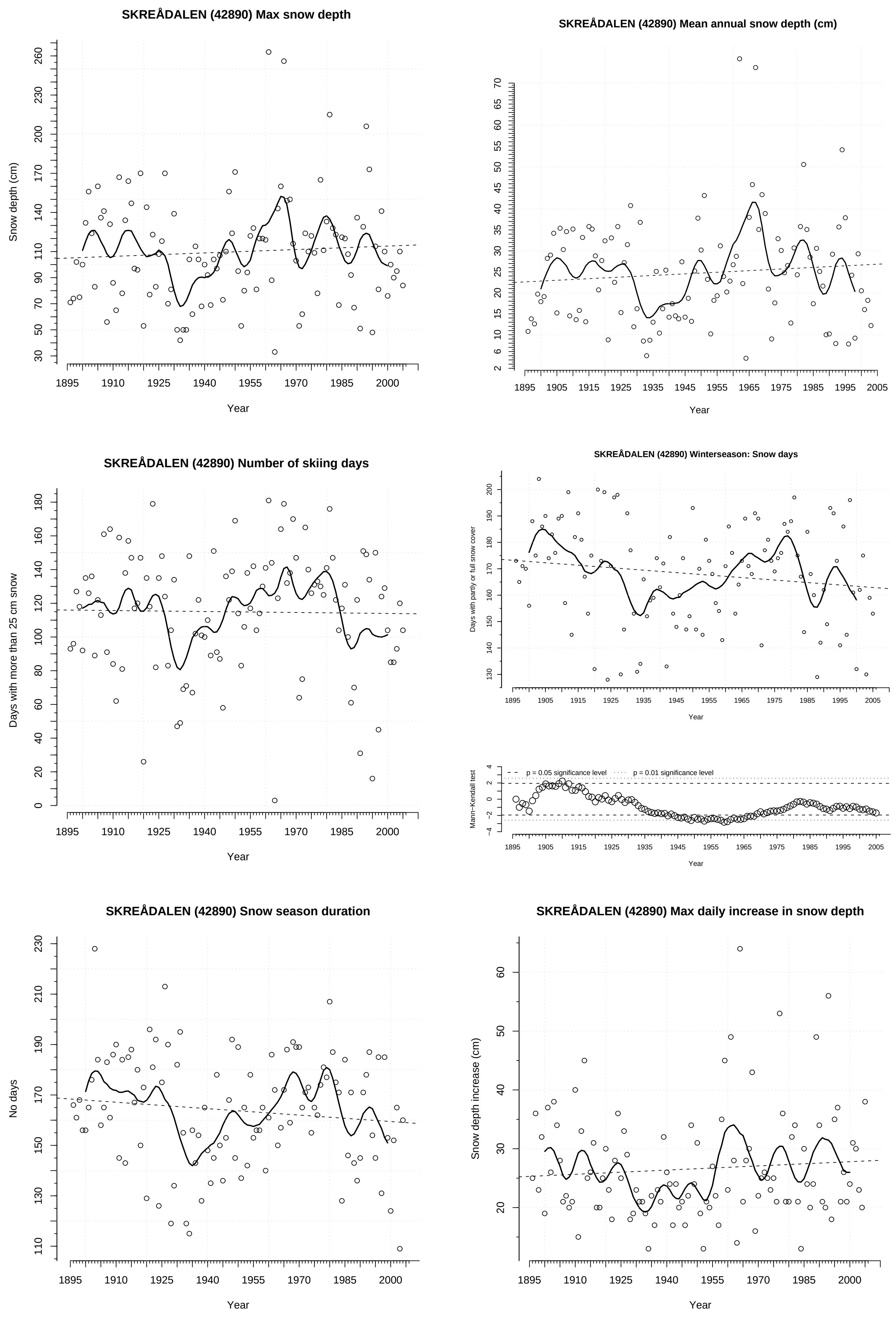


Figure 67: *Skreådalen meteorological station.*

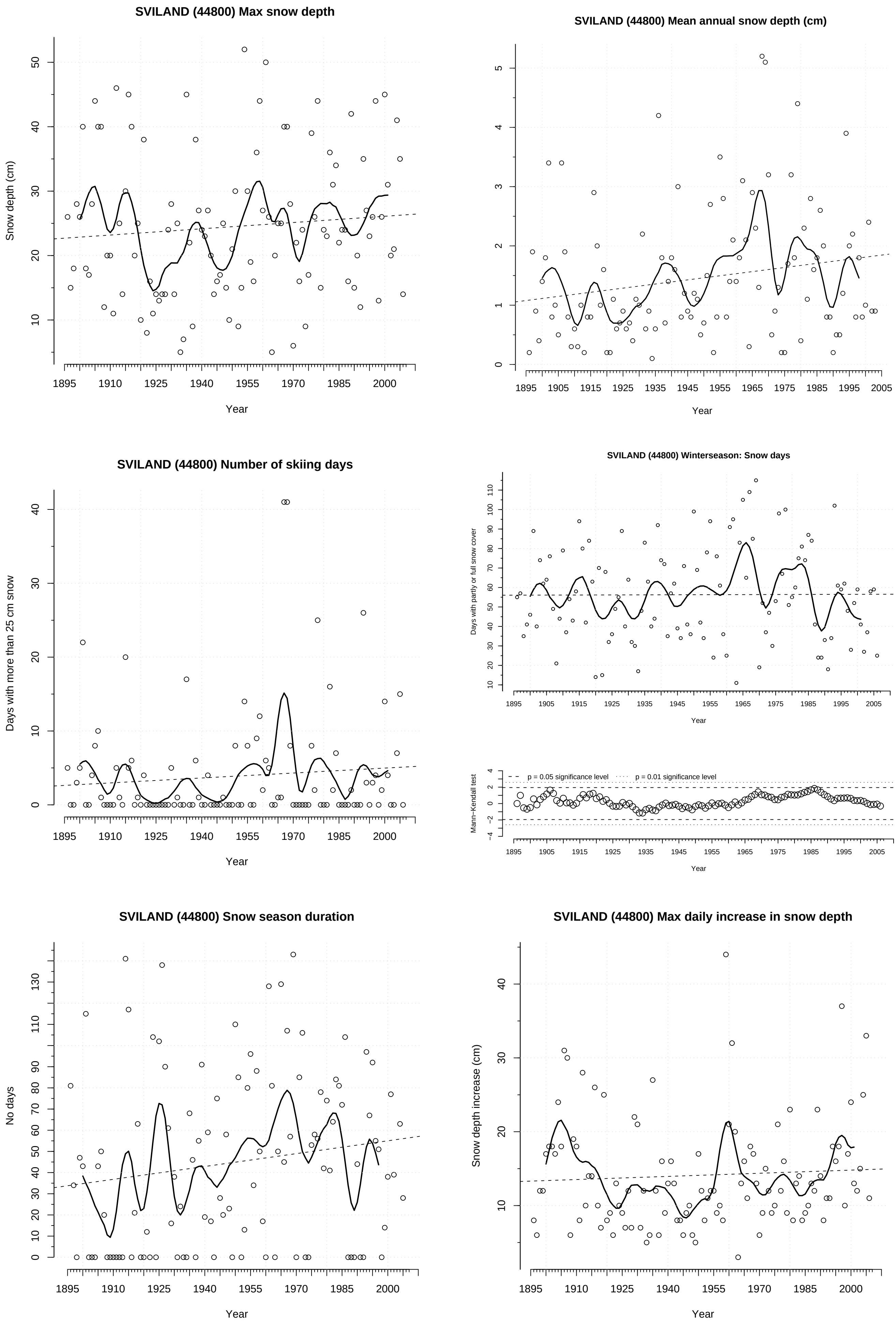


Figure 68: *Sviland meteorological station.*

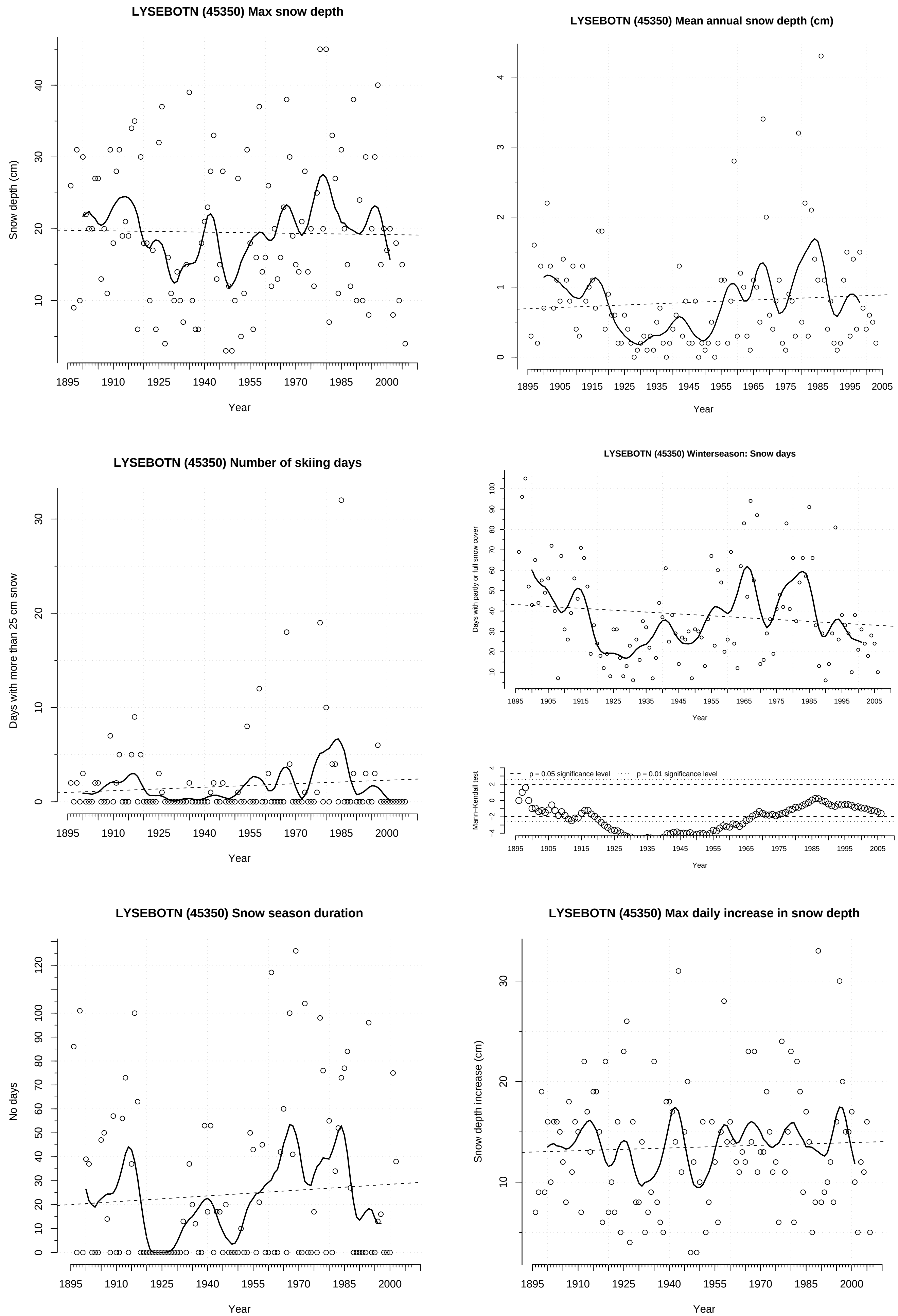


Figure 69: *Lysebotn meteorological station.*

Figure 70: *Røldal meteorological station.*

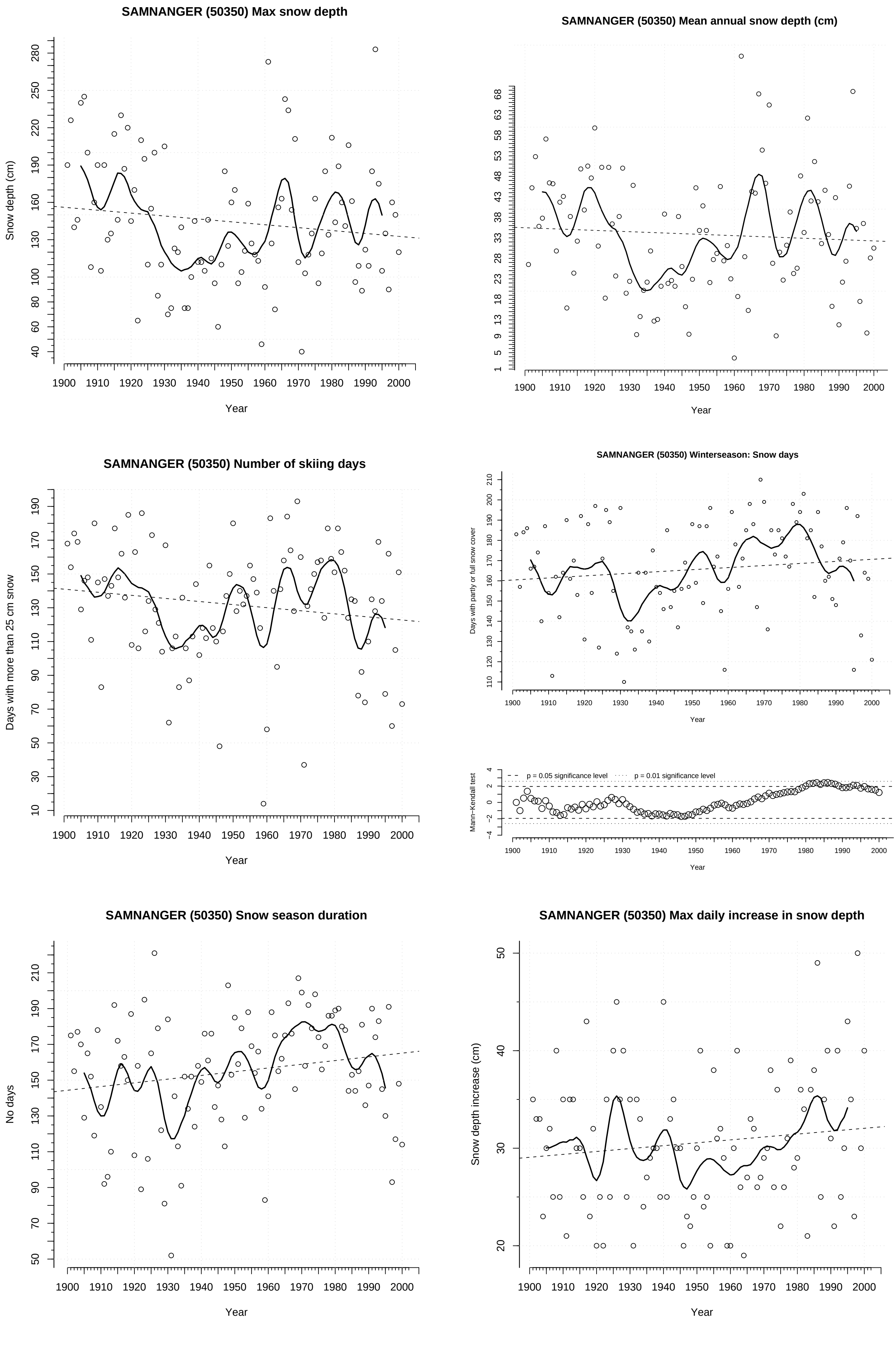


Figure 71: *Samnanger meteorological station.*

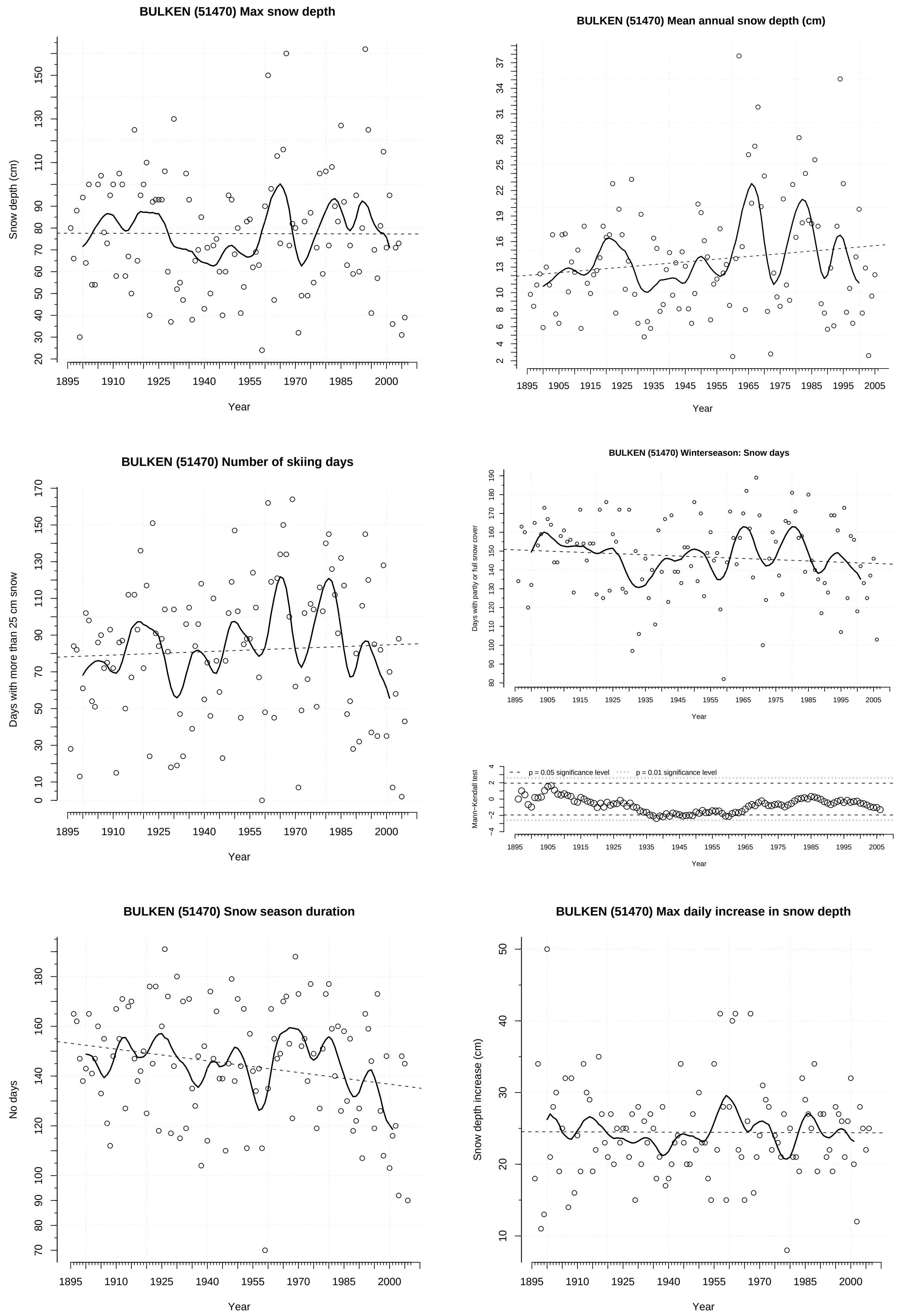


Figure 72: *Bulken meteorological station.*

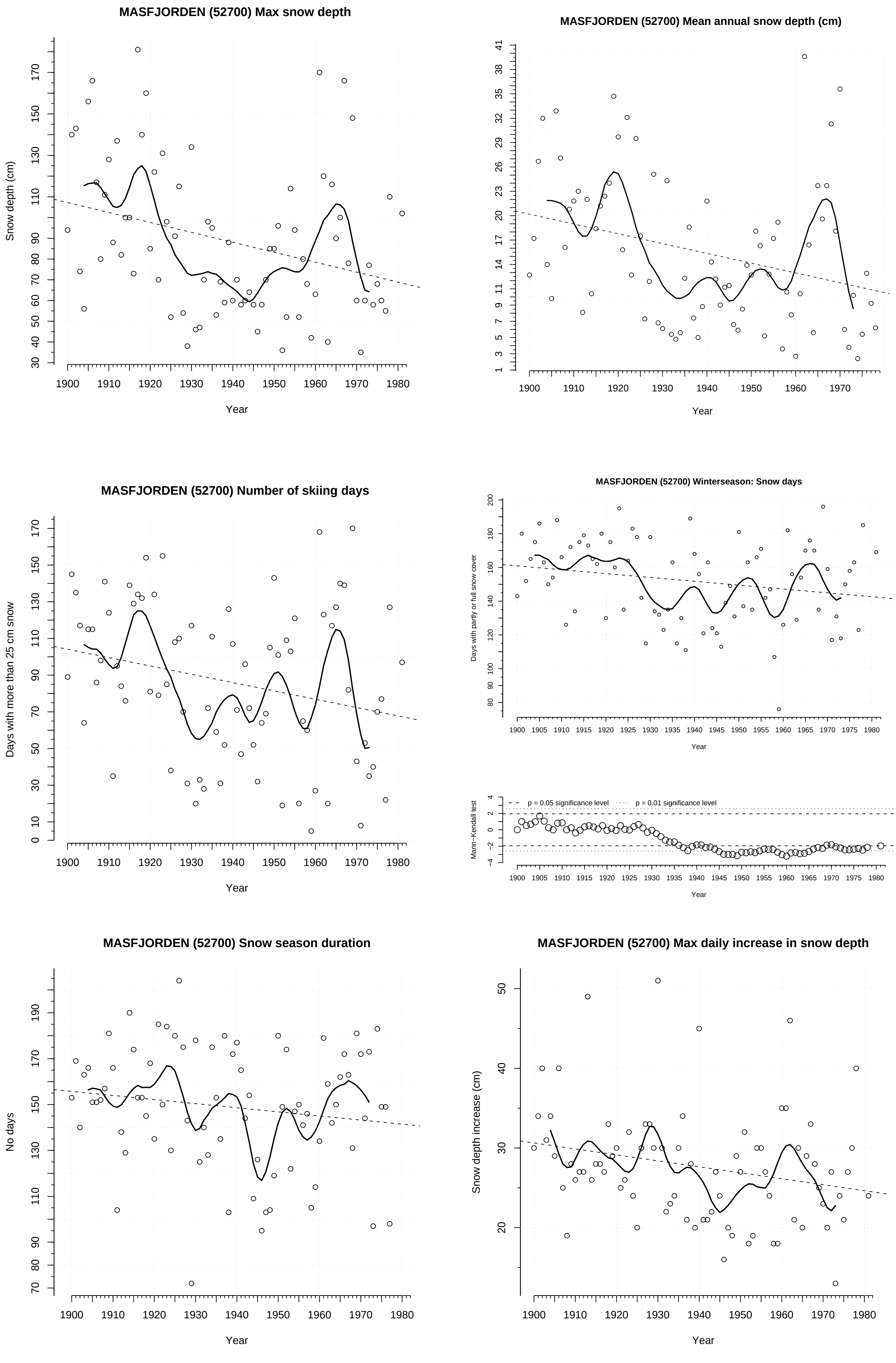


Figure 73: *Masfjorden meteorological station.*

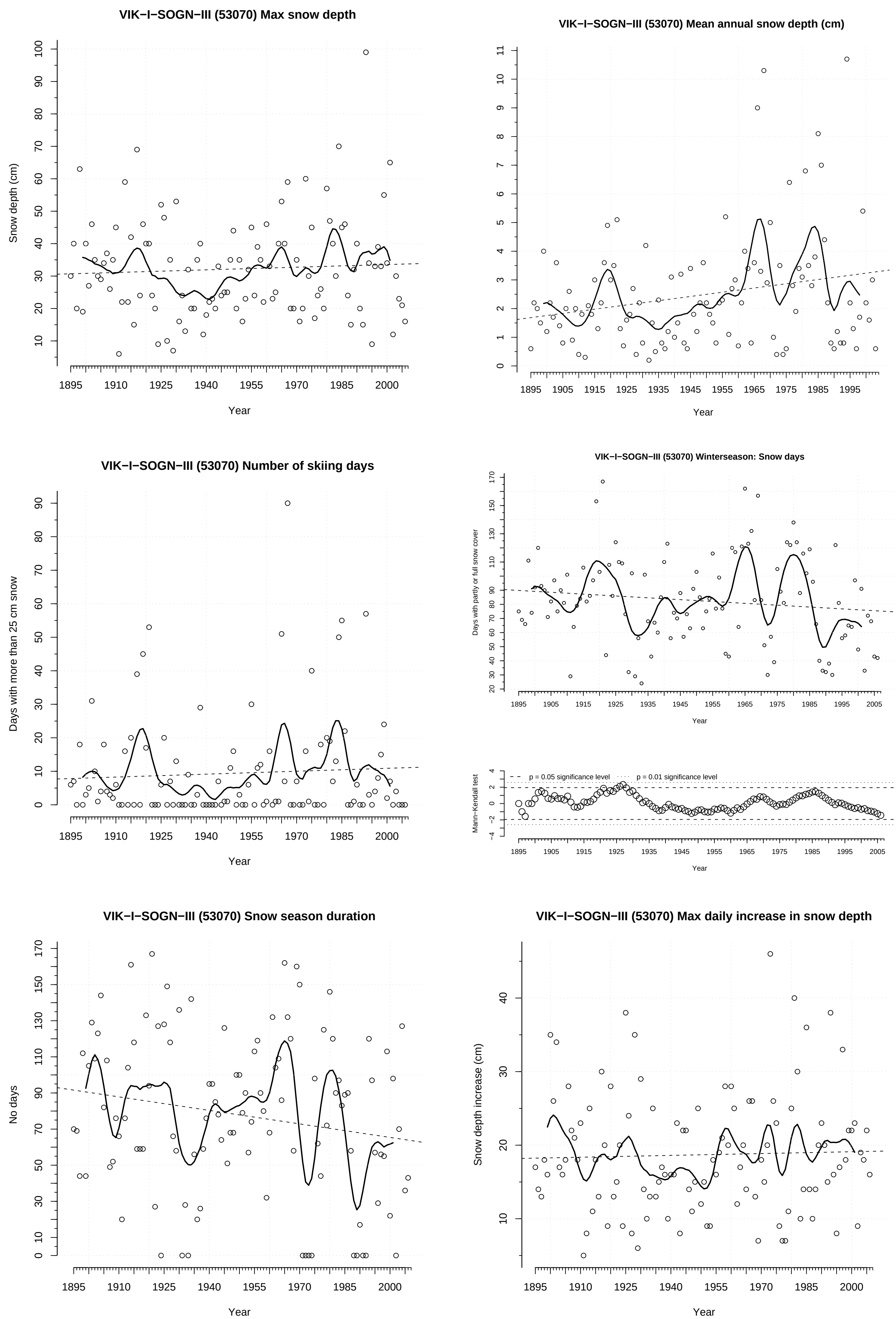


Figure 74: *Vik i Sogn meteorological station.*

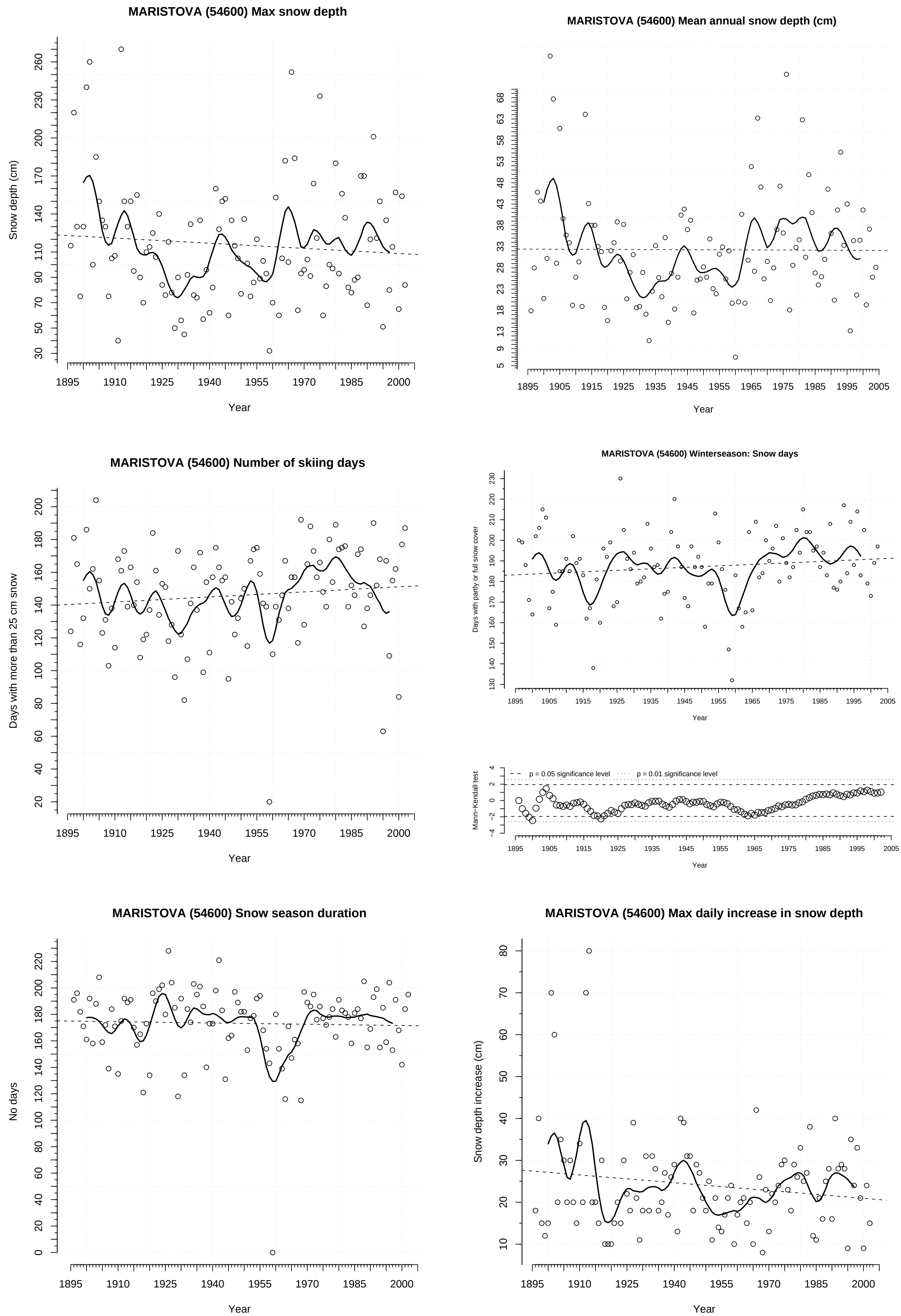


Figure 75: *Maristova meteorological station.*

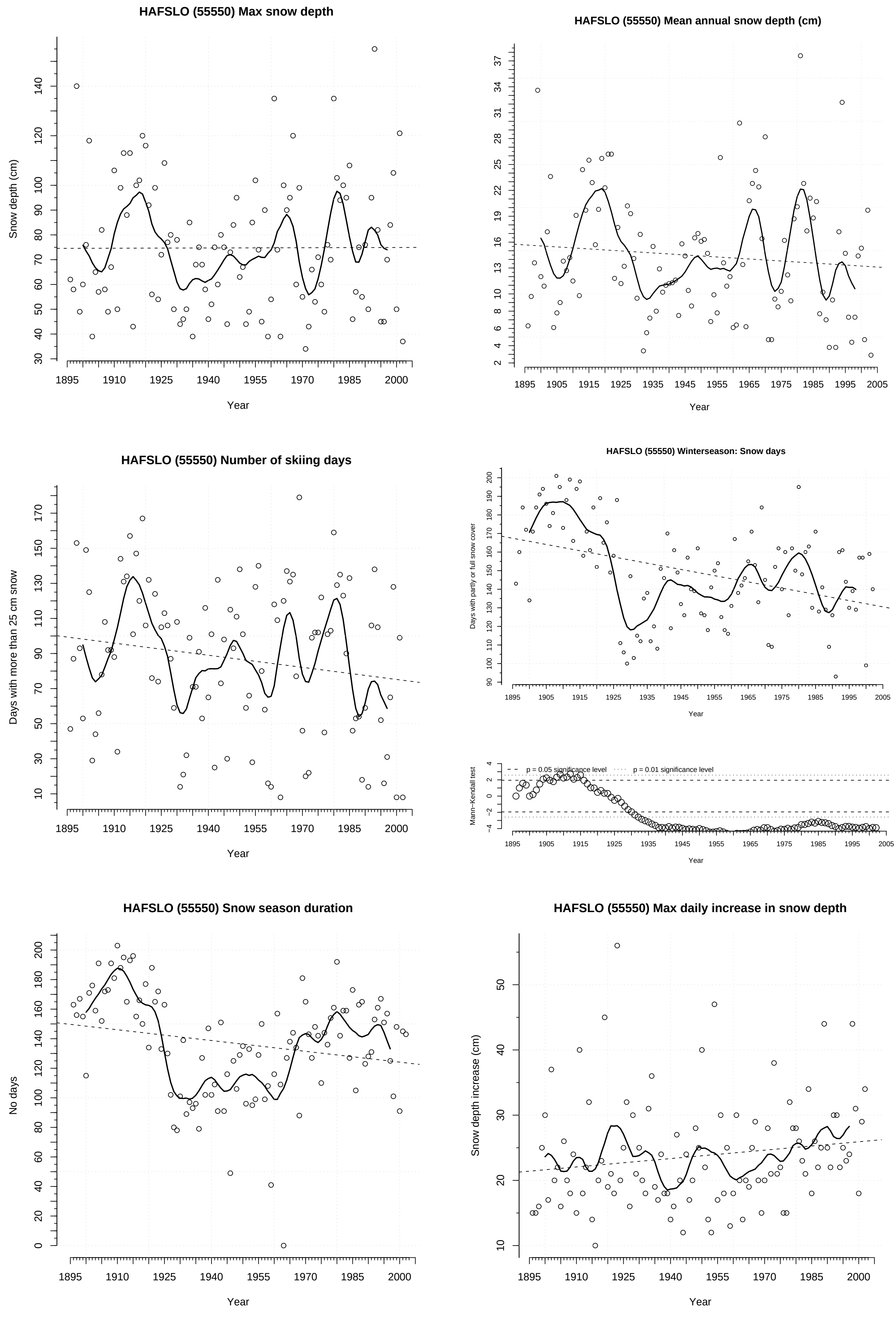


Figure 76: *Hafslo meteorological station.*

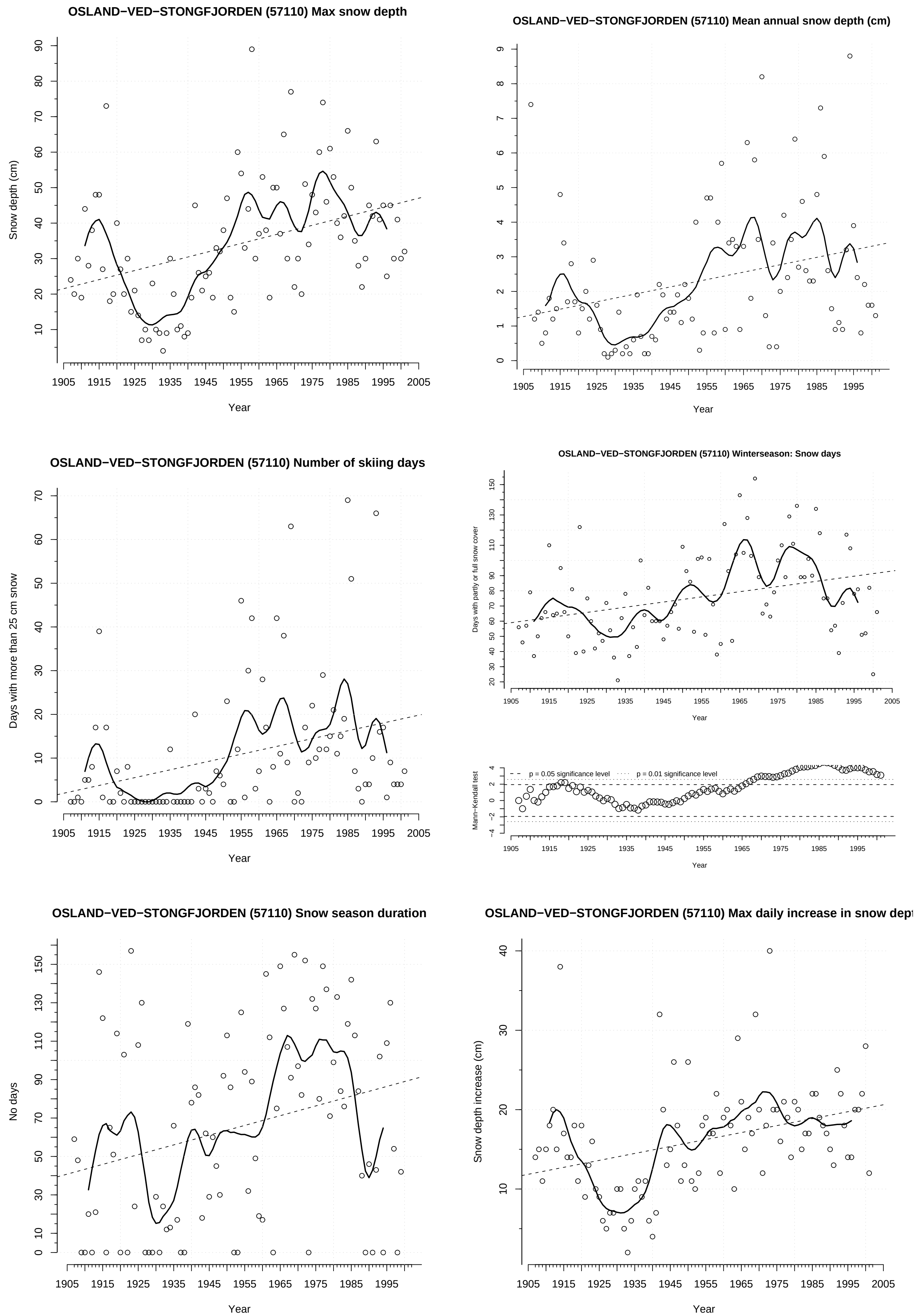


Figure 77: *Osland ved Stongfjorden meteorological station.*

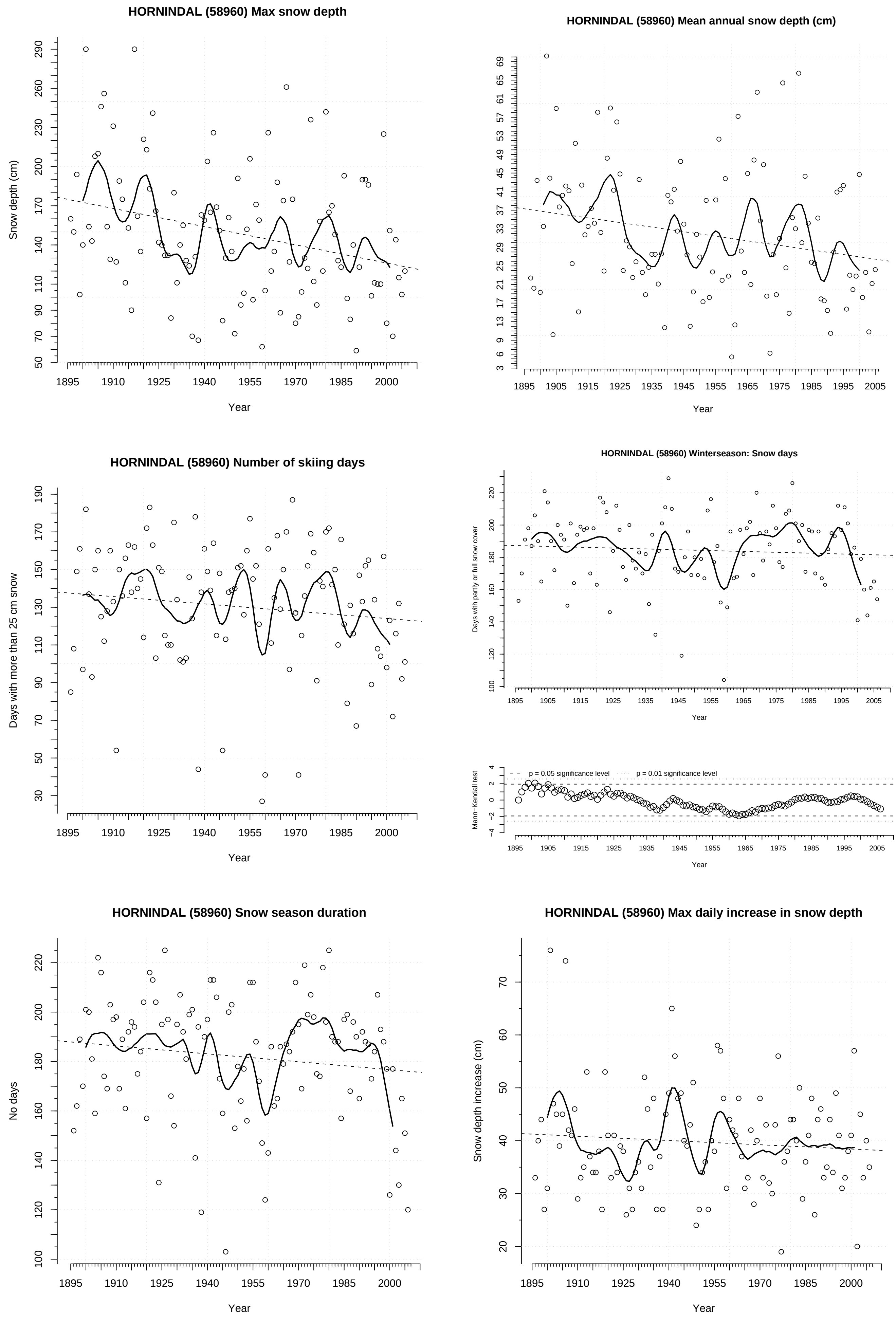


Figure 78: *Hornindal meteorological station.*

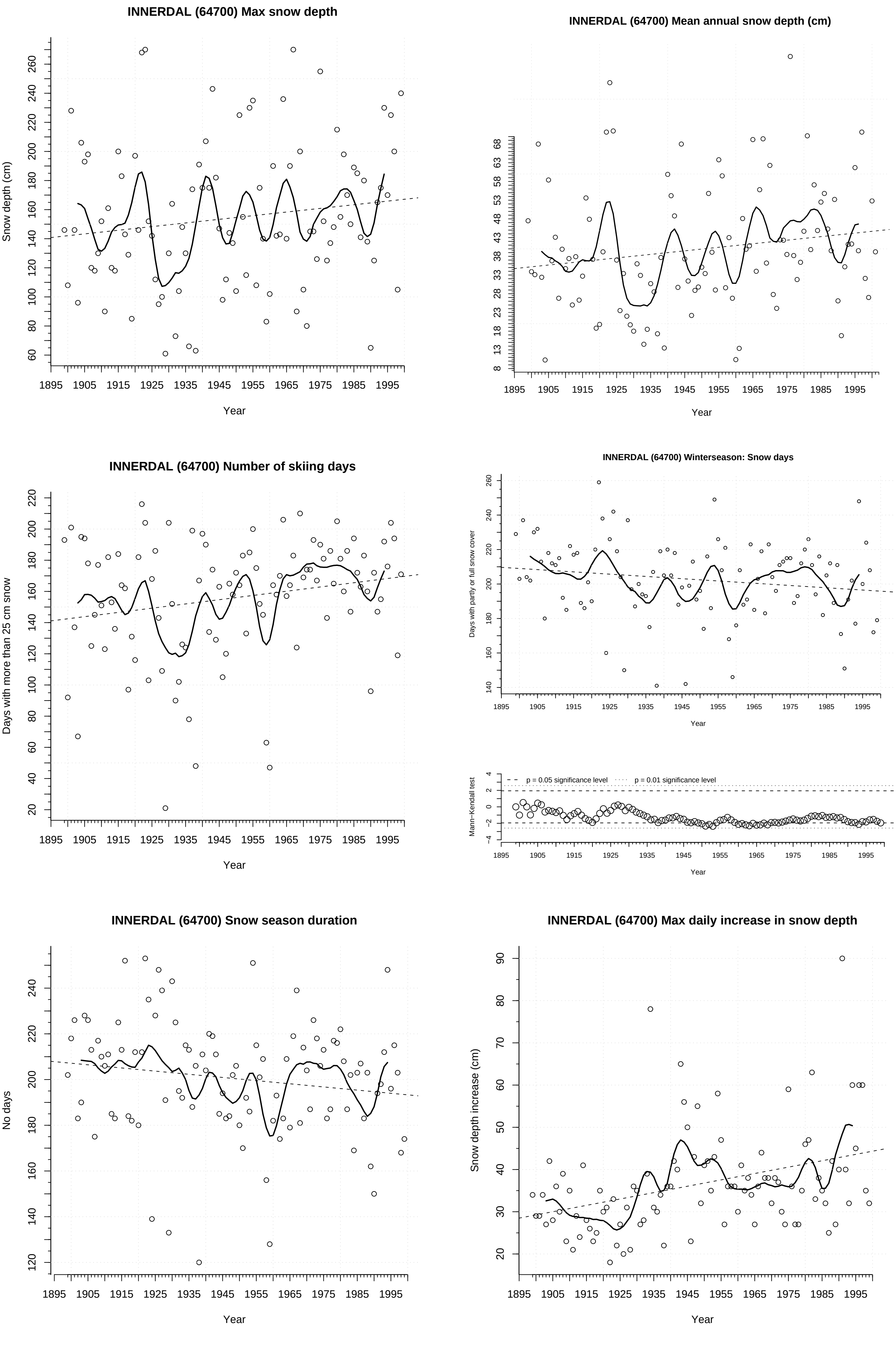


Figure 79: *Innerdal meteorological station.*

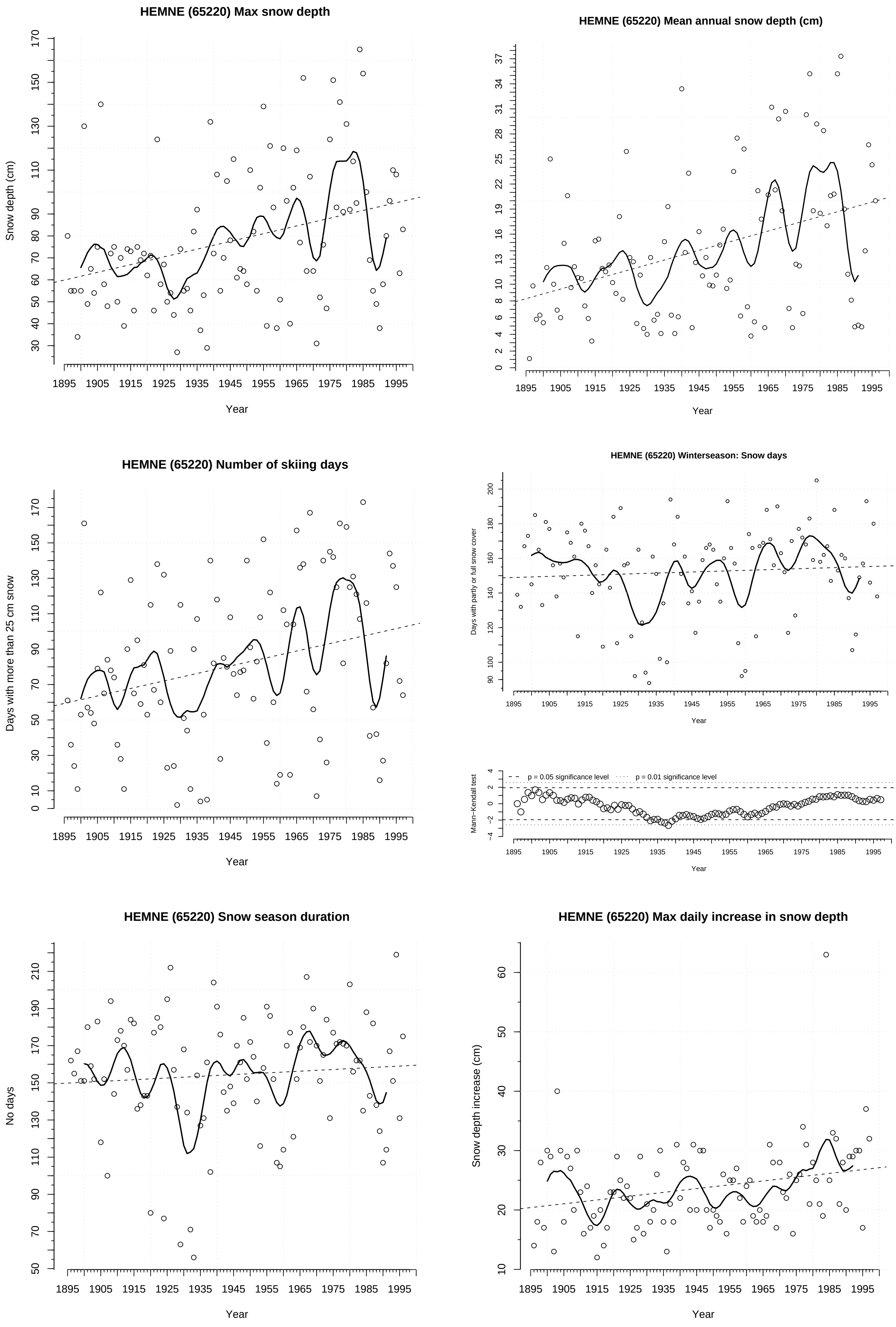


Figure 80: *Hemne meteorological station.*

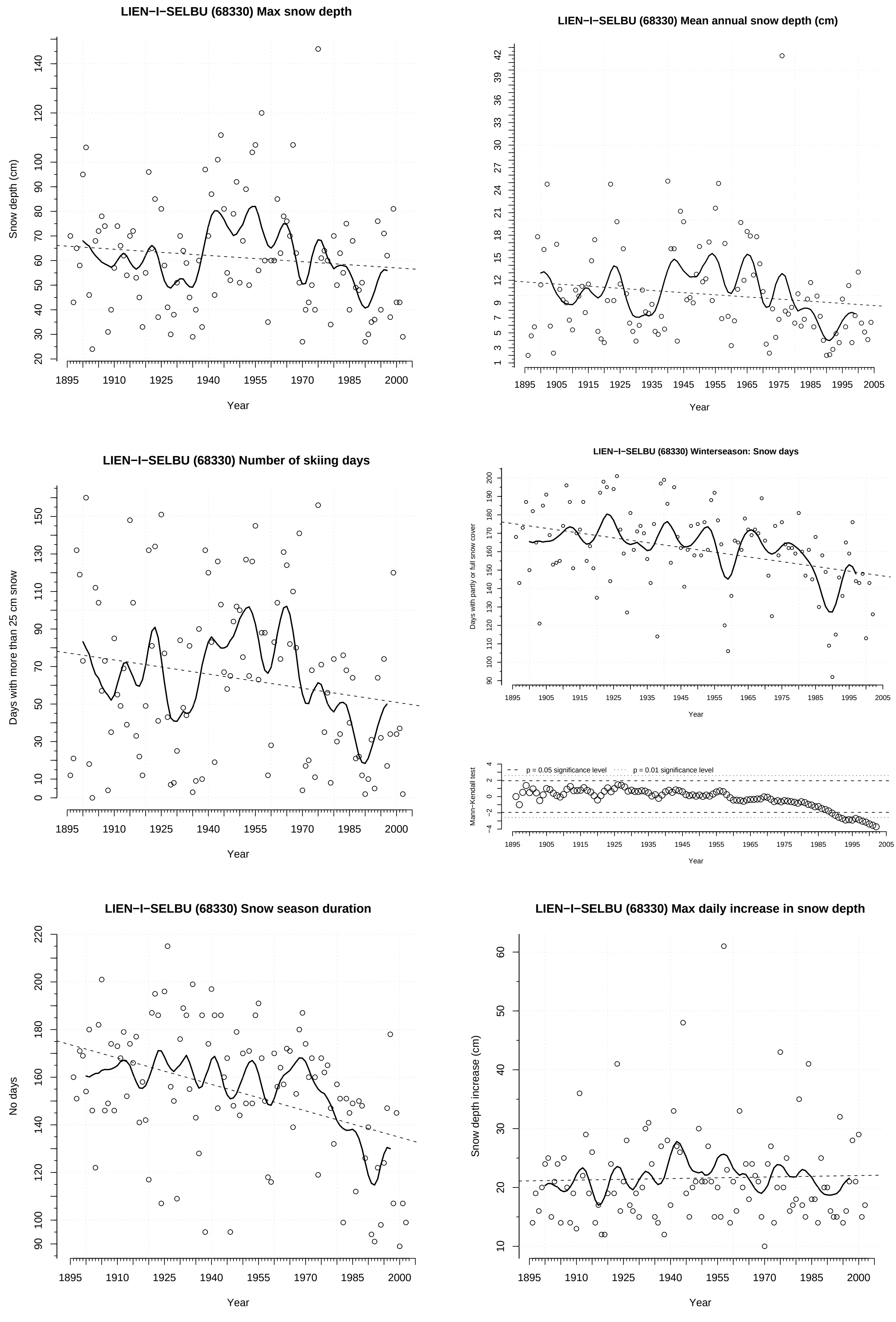


Figure 81: *Lien i Selbu meteorological station.*

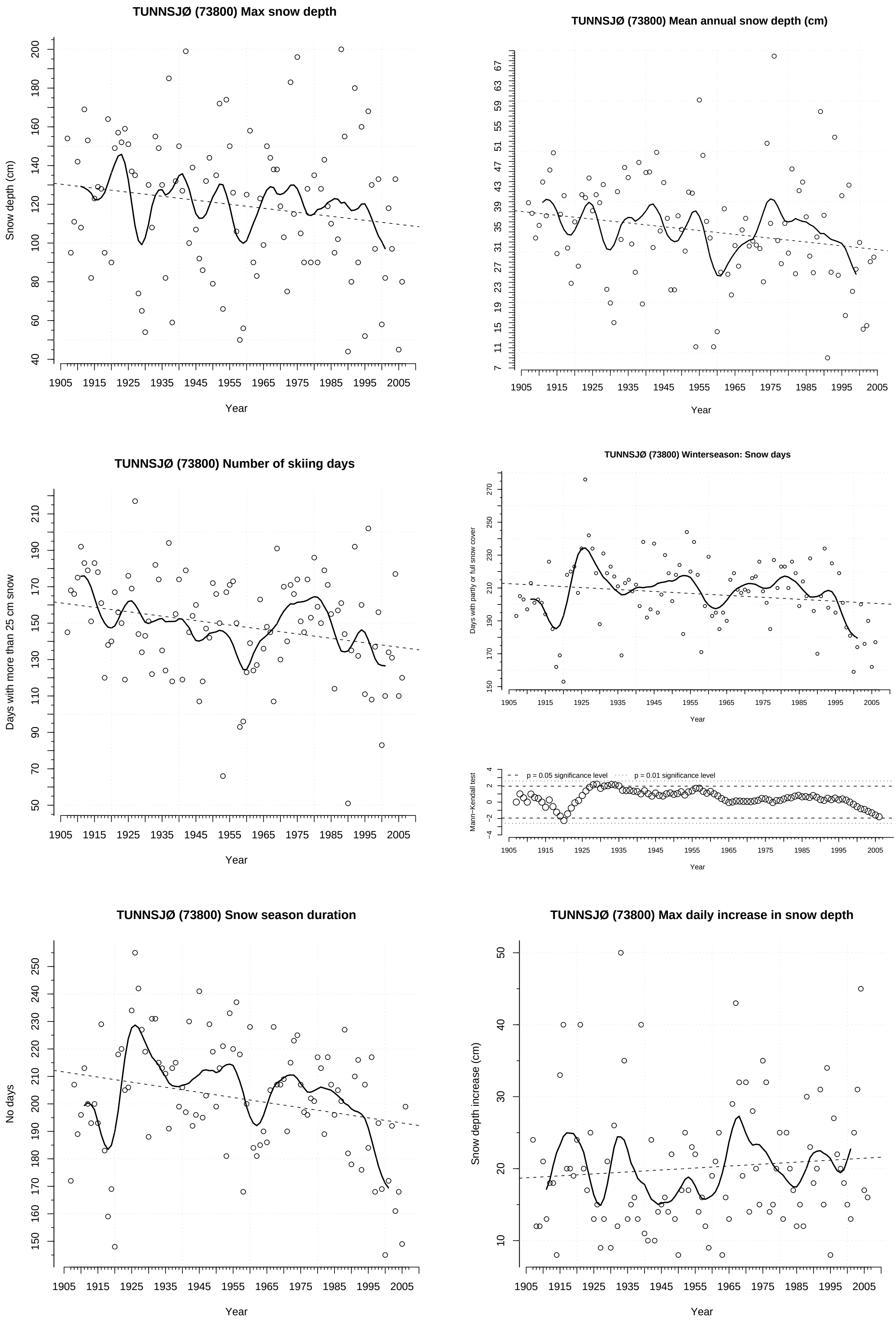


Figure 82: *Tunnsjø meteorological station.*

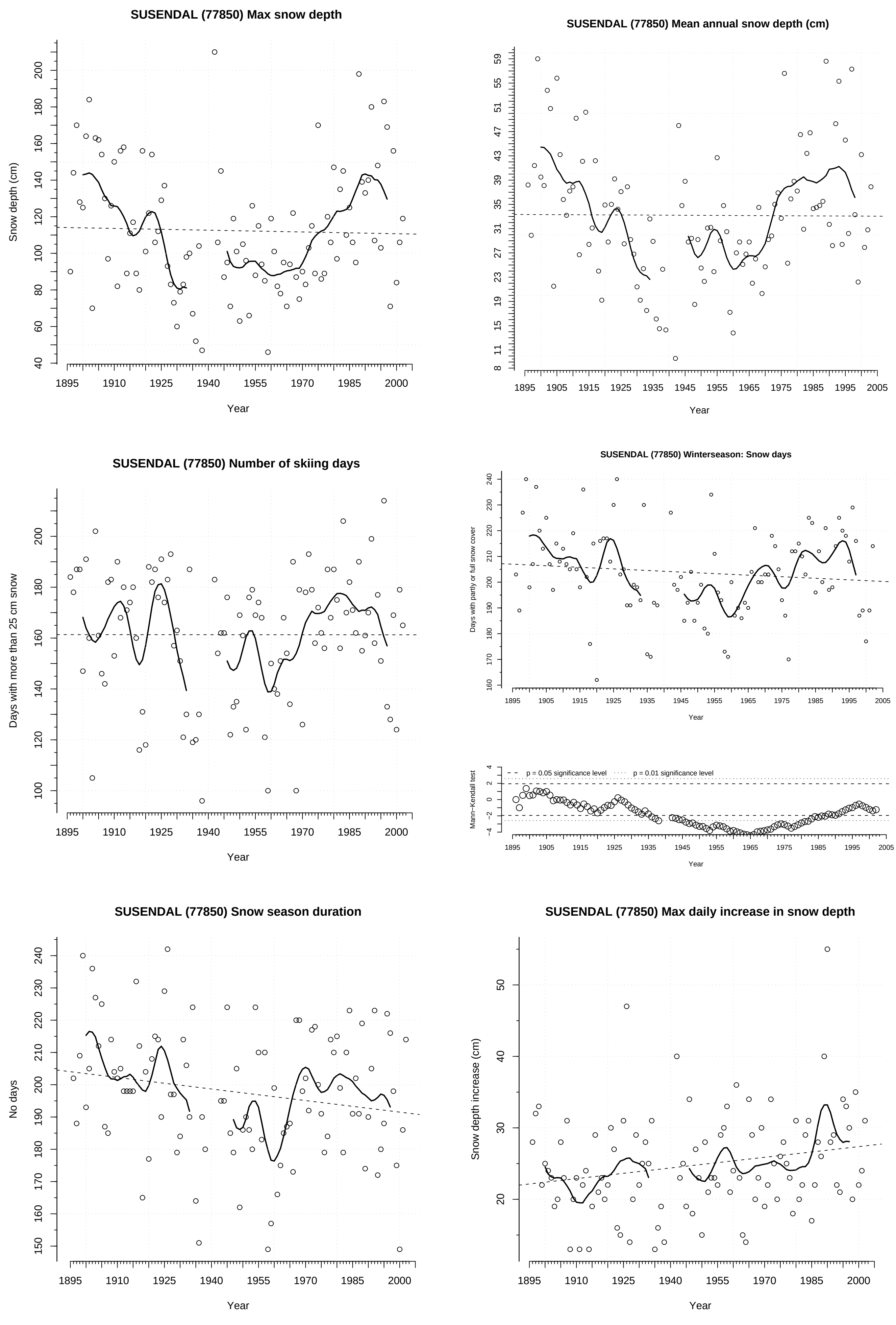


Figure 83: *Susendal meteorological station.*

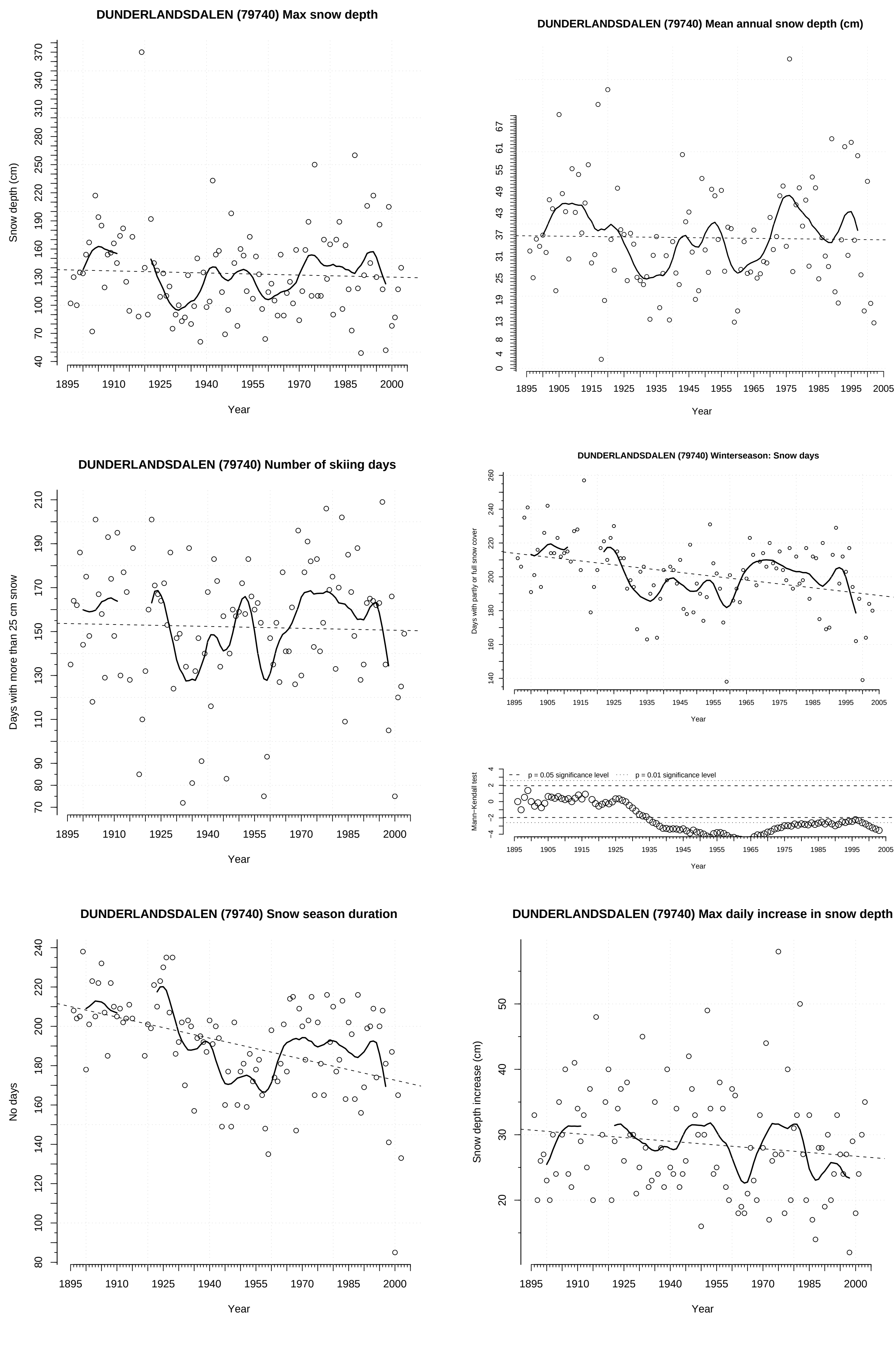


Figure 84: *Dunderlandsdalen meteorological station.*

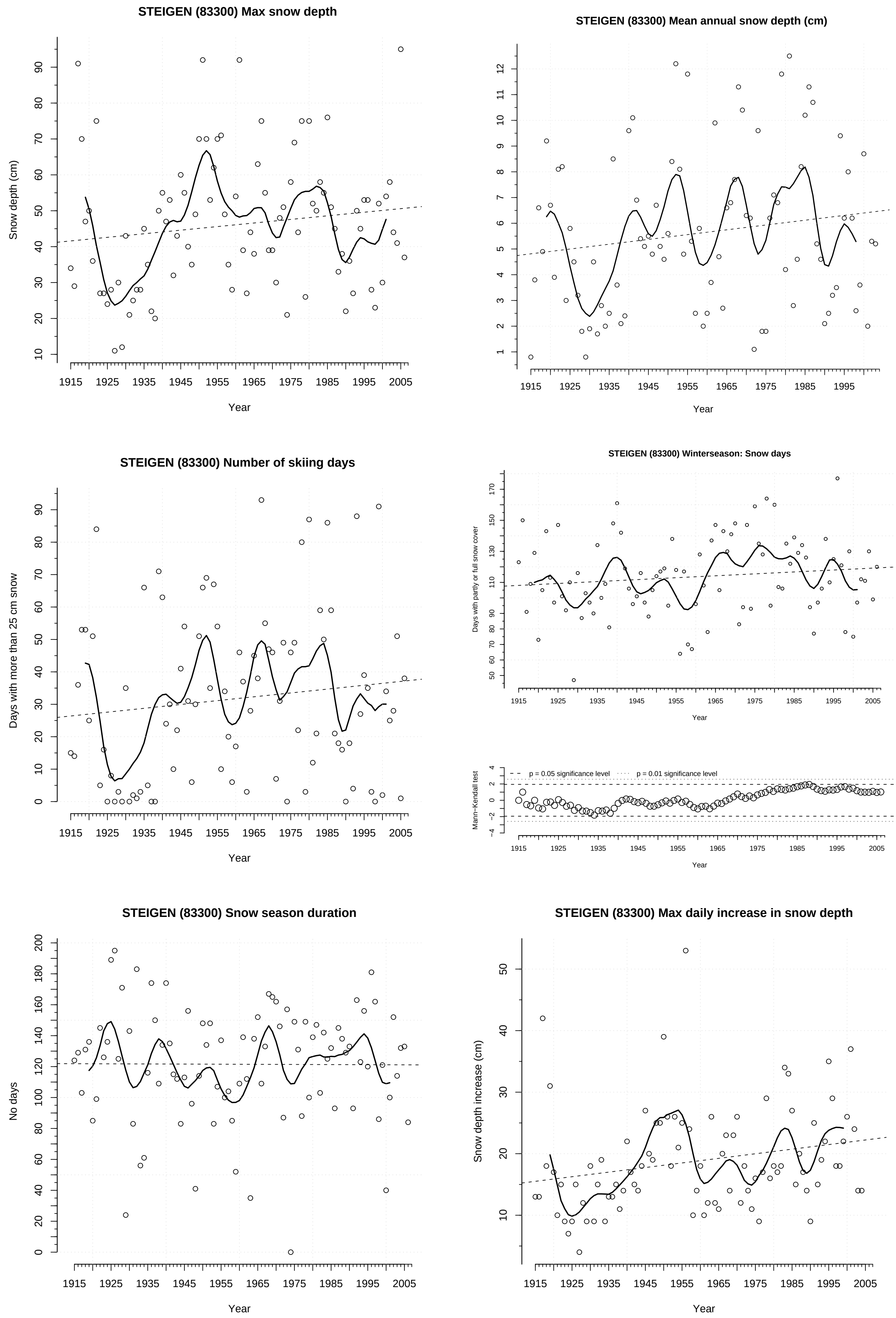


Figure 85: *Steigen meteorological station.*

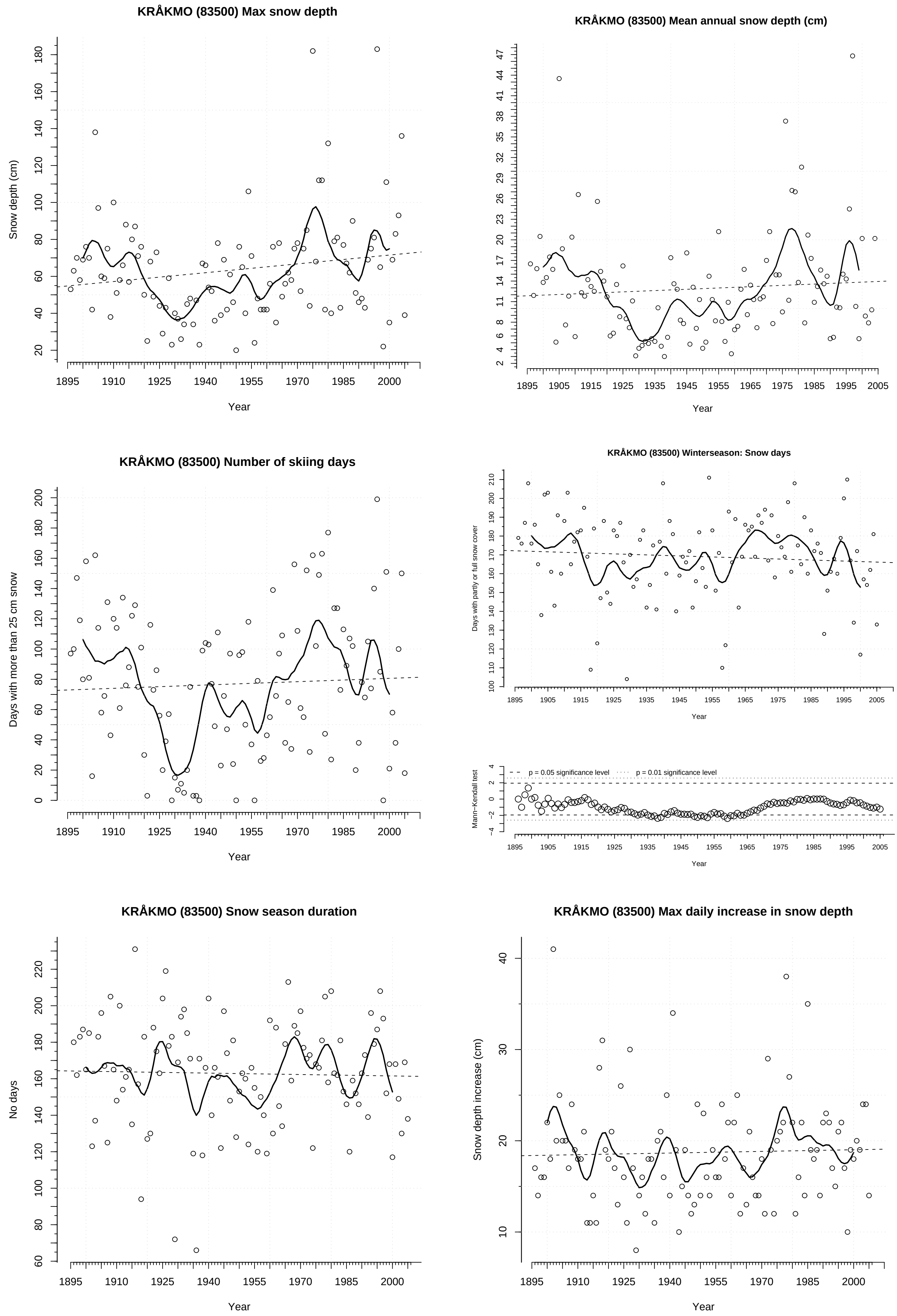


Figure 86: *Kråkmo meteorological station.*

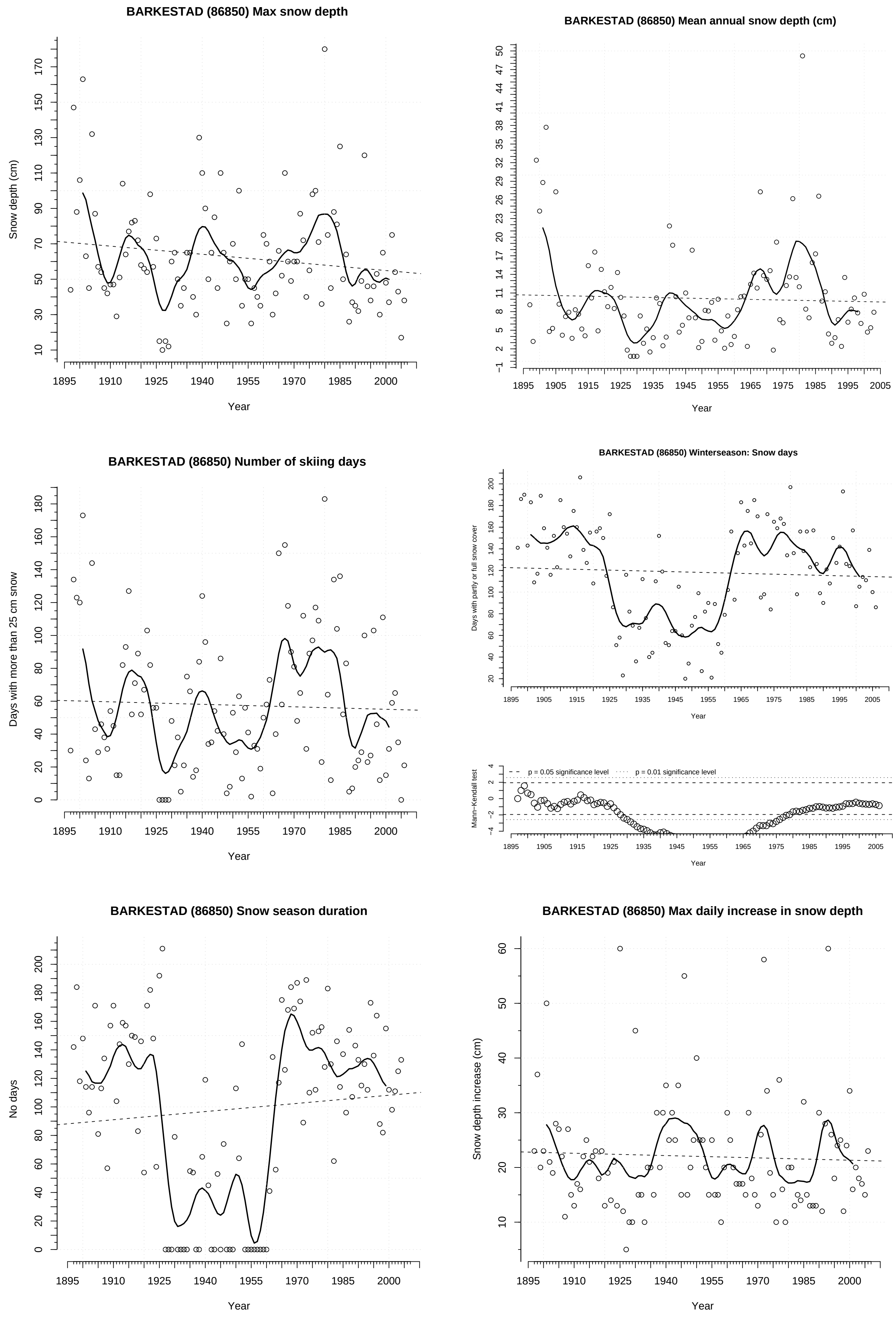


Figure 87: *Barkestad meteorological station.*

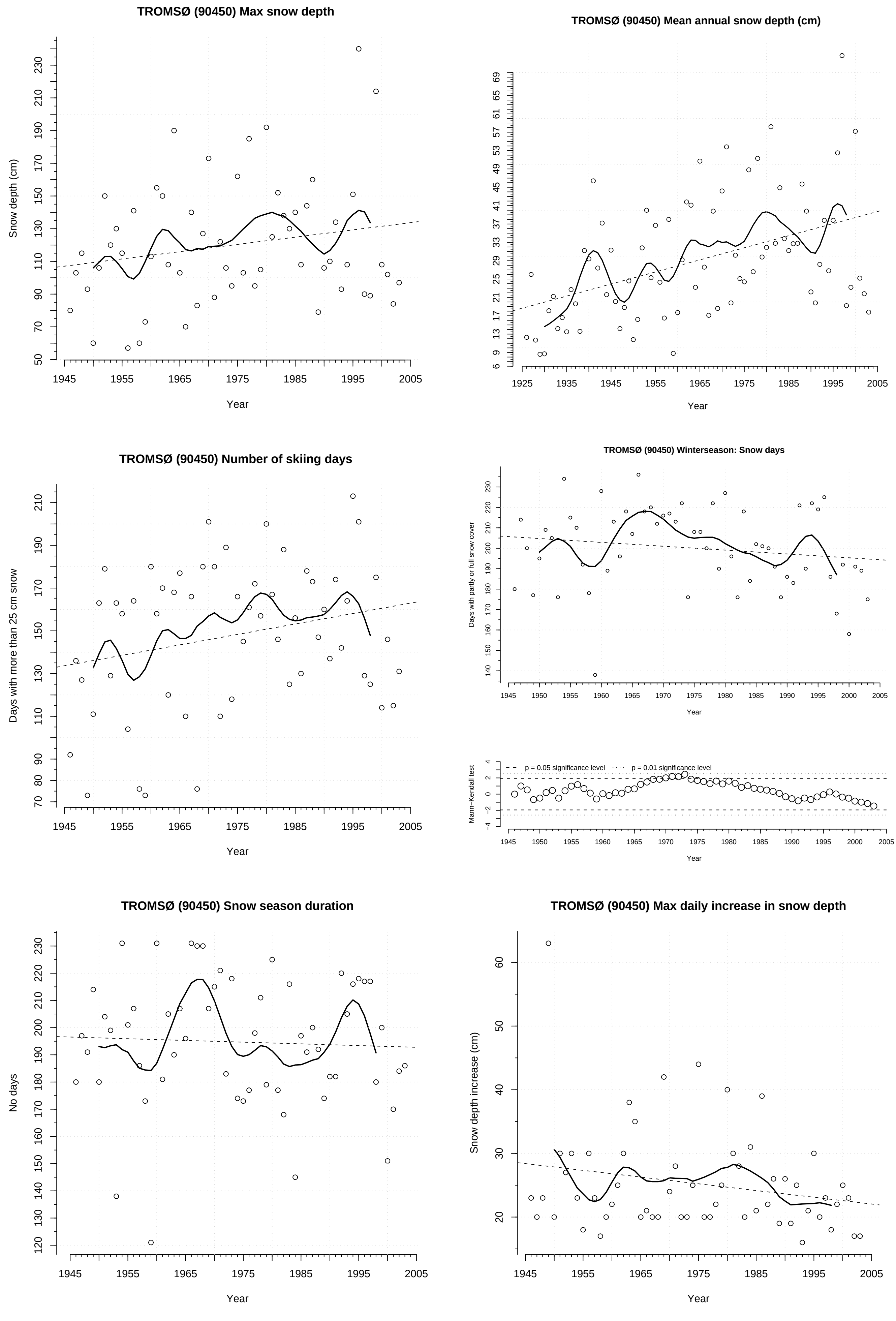


Figure 88: *Tromsø meteorological station.*

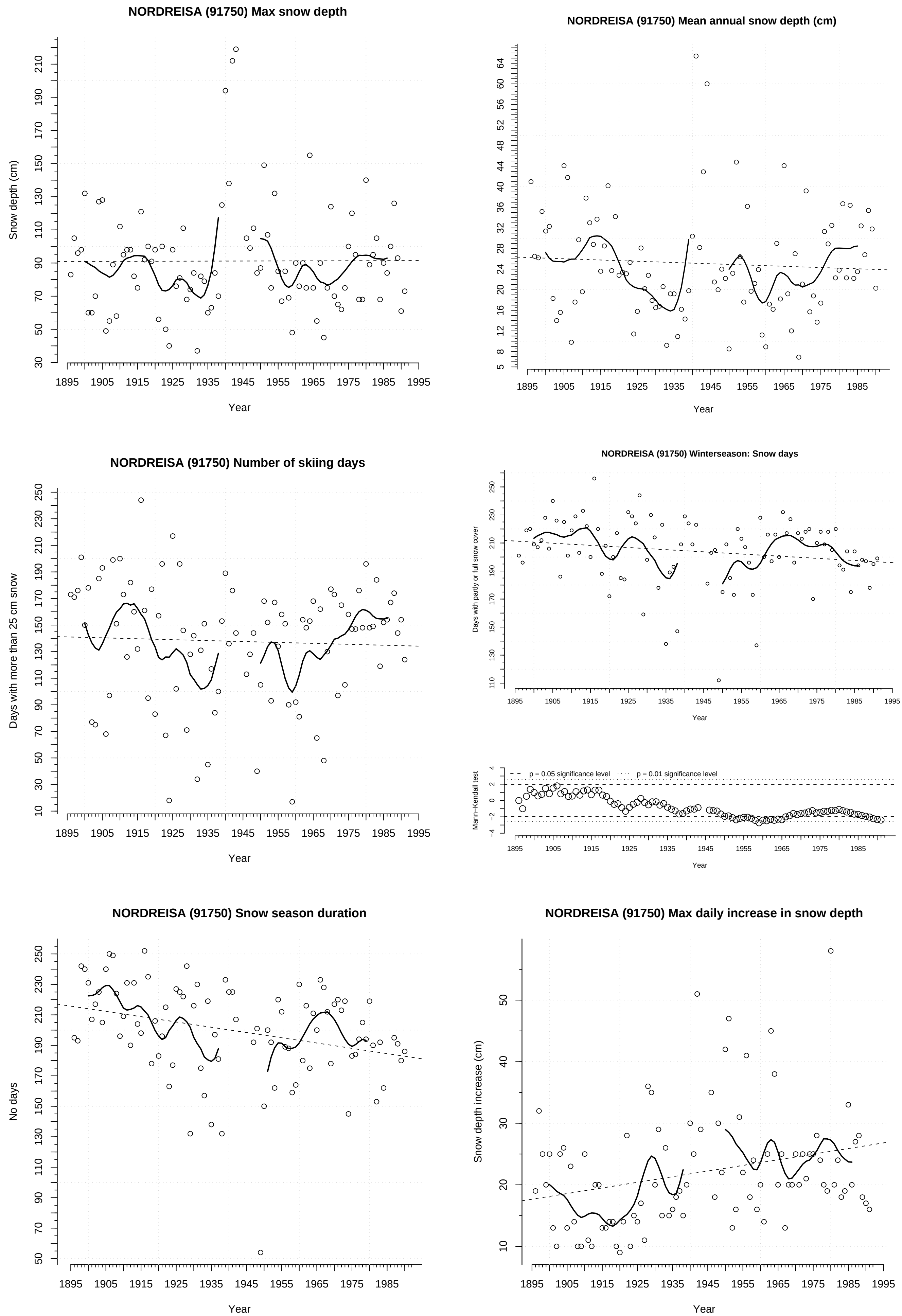


Figure 89: *Nordreisa meteorological station.*

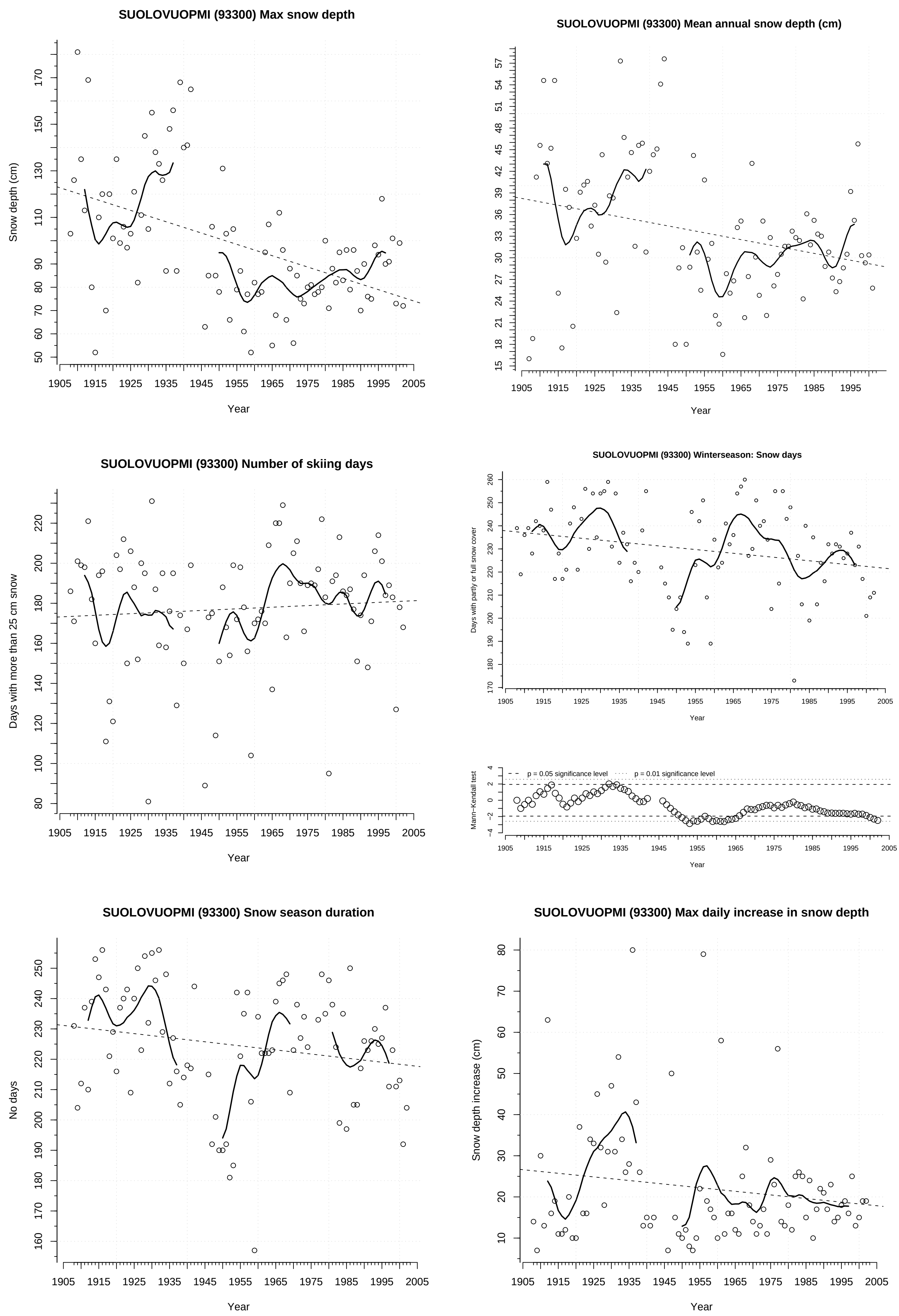


Figure 90: *Suolovuopmi meteorological station.*

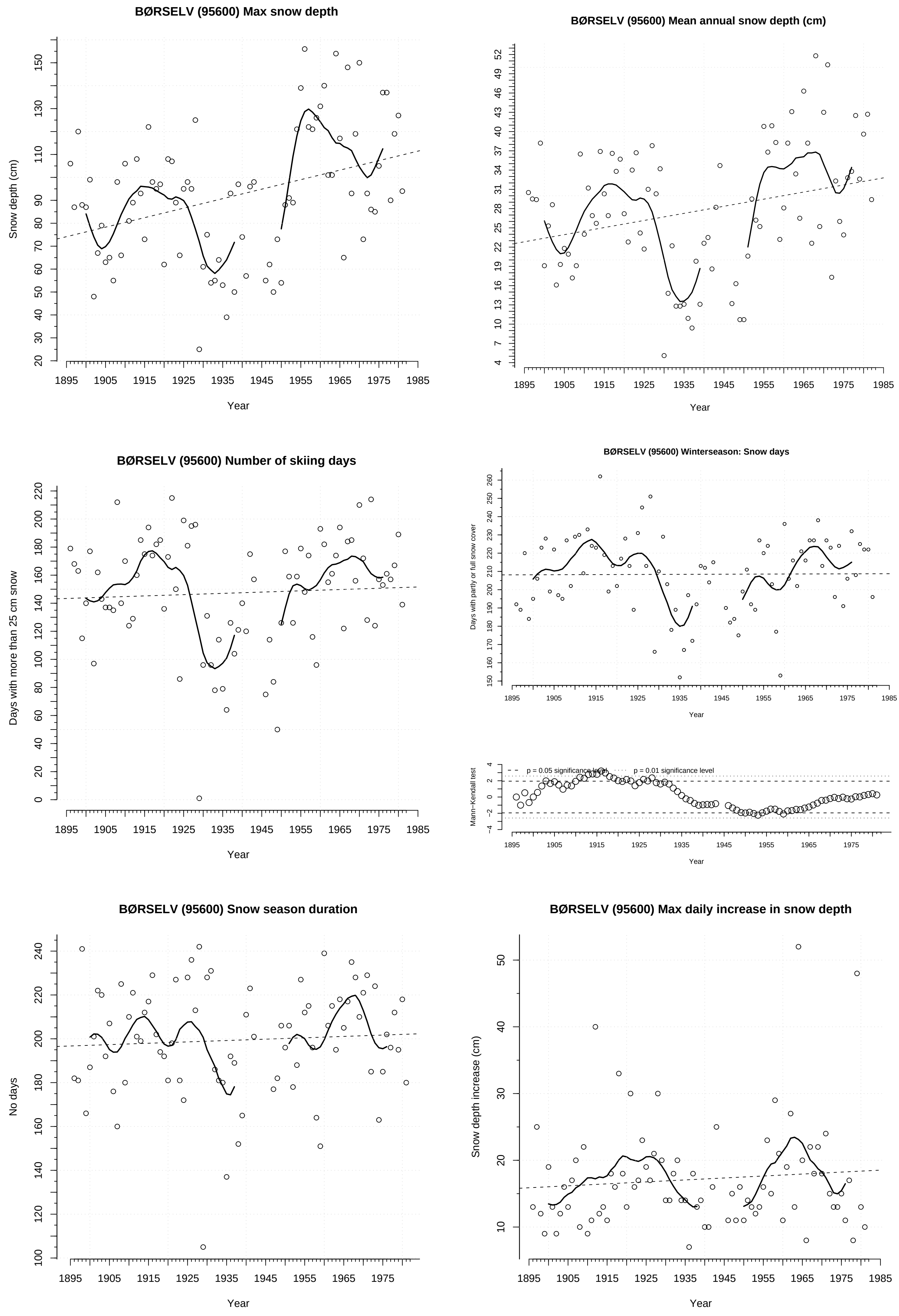


Figure 91: *Børselv meteorological station.*

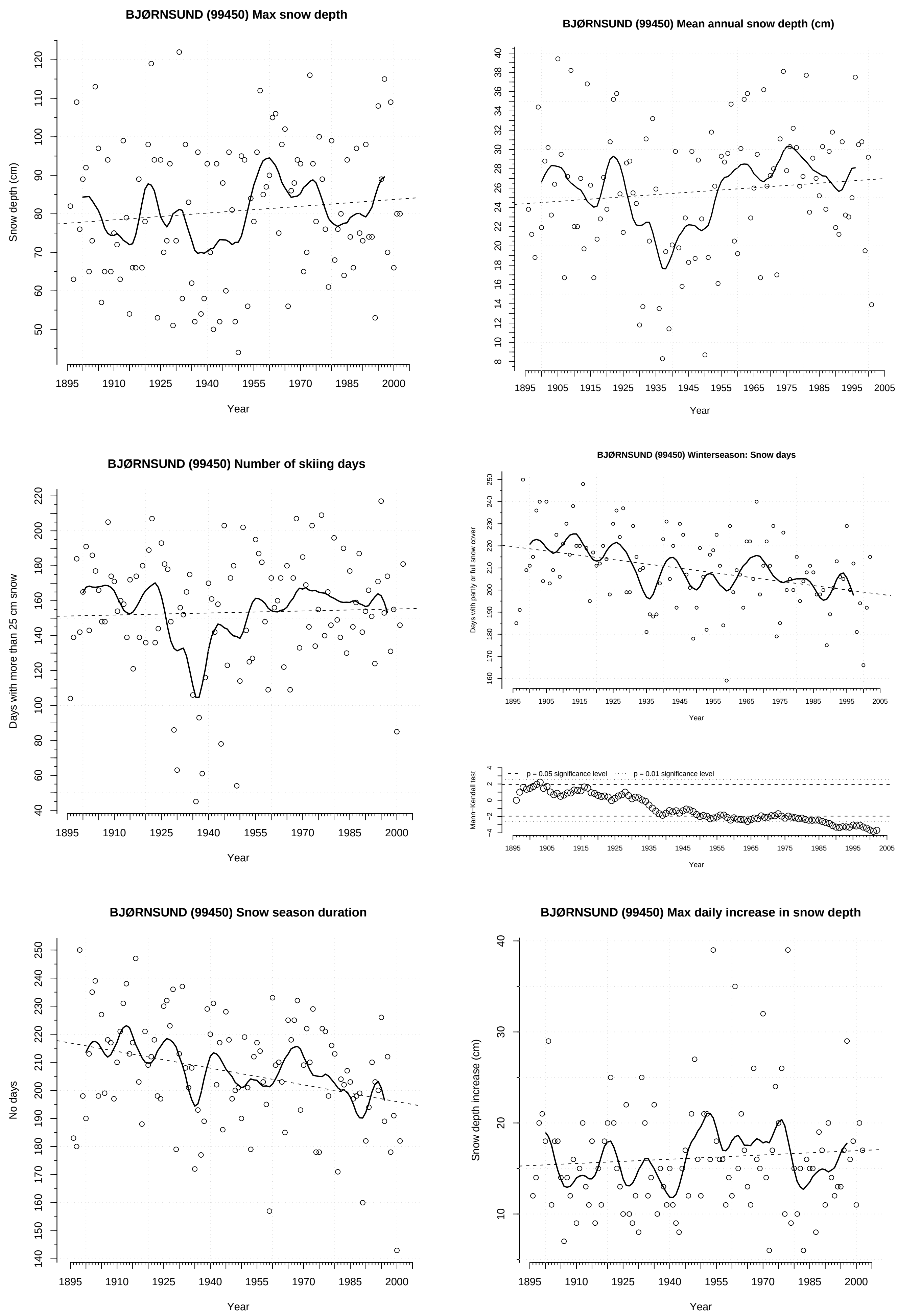


Figure 92: *Bjørnsund meteorological station.*