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Climatic Changes in Finland - Recent Findings

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Abstract

The climate of Finland during the period of meteorological observations was studied. Special attention was given to the quality and homogeneity of data used, because inhomogeneities caused by non-climatic factors can be as large as or larger than real climatic changes. The nationally-averaged mean temperature in Finland has increased during recent decades but has not yet passed the maximum of the 1930s. The transition season temperatures show opposite trends since the 1950s, with springtime warming being slightly larger than the autumn cooling. In southern Finland the spring warming has been accompanied by an earlier end of the snow cover period. A strong zonal geostrophic wind, related to a positive North Atlantic Oscillation index, was observed in connection with the recent warm winters. However, the airmasses related to wintertime westerly flows show no exceptional long-term warming. A reduction of the diurnal temperature range since the 1950s in Finland fits well with the hemispheric picture and the slightly higher mean annual precipitation during the 1961-1990 normal period compared to the 1931-1960 period is consistent with general increase over large areas of Fennoscandia.

Keywords: Finnish climate; climatic variability; temperature, snow, and precipitation changes

1. Introduction

Interest in climatic research has increased dramatically in recent years in light of evidence that changes in global climate are in progress which are due to anthropogenic causes and which may provide a threat to ecosystems and society. There are still great uncertainties in projections of future climate, however, due to an inadequate understanding of the climate system. The study of observed climatic variations can assist in advancing this understanding and provides results that can be used in the further development of climate models.

Long-term global climatological datasets based on meteorological observations (e.g. *Nicholls et al.*, 1996; *Jones*, 1994; *Hansen* and *Lebedeff*, 1987; *Vinnikov et al.*, 1990) can provide a reliable description of the global, hemispheric, and, in some parts of the world, even regional behaviour of the climate. However, they can be severely biased at a national and local scale in some parts of the world (*Moberg* and *Alexandersson* 1996). These problems arise from poor data coverage, unrepresentative stations and inhomogeneities in the original data. The magnitudes of inhomogeneities can be comparable to the real observed changes in the climate, particularly for precipitation (*Hanssen-Bauer* and *Førland* 1994). The number of meteorological stations reporting observations internationally, and the number of climatological elements reported are usually much fewer than actually observed at national level. Therefore, the global datasets contain only one or at most a few climatological elements, making it difficult to apply a physical approach where linkages between different elements are used to verify and explain observed fluctuations.

Problems of homogeneity in climatological time series formed the focus of the North Atlantic Climatological Dataset project (NACD), in which the Finnish Meteorological Institute (FMI) also participated (*Frich et al.* 1996). A large effort was undertaken to construct reliable time series for climatic research. The expertise of national meteorological institutes was used to locate old data and station history sources from national archives, and to interpret that information. It proved necessary to apply adjustments to the original published data without which the time series would have been severely biased (for Finnish examples see *Heino* 1994; *Tuomenvirta* and *Drebs* 1994).

The data and methods used in this study are described in section 2. Section 3 contains some results from the project on Climatic Changes in Northern Europe, which was part of the Finnish Research Programme on Climate Change (SILMU), focusing on the climate of Finland (cf. *Heino et al.* 1996). Firstly, nationally-averaged mean temperature fluctuations are described. Secondly, variations in snow cover are examined and their connections to the temperature changes qualitatively discussed. Thirdly, the ability of the geostrophic wind to describe temperature conditions is analysed. Finally, the diurnal temperature range and its relationships to cloudiness and short wave radiation are also described briefly along with nationally-averaged precipitation variations. Section 4 synthesises the major findings and discusses the requirements for future research.

2. *Data and methods*

The analyses presented in this paper are based on observations from the Finnish meteorological station network compiled at a monthly time resolution. Seasons are defined as three month periods, i.e. winter is December, January and February; spring March to May; etc. The Finnish data in digital form at FMI start in 1829 with air temperature records from Helsinki and by the turn of the century covers 48 stations and 12 climatic elements. In total, there are about 1000 stations and 40 elements, including data from stations reporting only precipitation. However, many of the short series from stations no longer operating are of limited value to climate change research.

All data have been quality controlled and outliers have been corrected or deleted. For climate change research, however, a greater hazard than a few erroneous values is the possible inhomogeneity of time series. A perfectly homogeneous time series contains variations caused only by variations of weather and climate. This criterion is likely to be fulfilled if the measurements have been done at the same site within an unchanged environment using the same calibrated instrument according to the same method. As these requirements are never fulfilled with long time series, their homogeneity is always questionable. The homogeneity of the different Finnish climatological time series was evaluated with two complementary approaches. In the first approach, the methodological history of observations, i.e. instruments used, formulas applied, etc., was studied (*Heino,* 1994). In the second approach, adopted in the NACD-project, statistical tests were performed with the Standard Normal Homogeneity Test developed by *Alexandersson* (1986) (see *Tuomenvirta* and *Drebs,* 1994).

Two low pass filters including Gaussian weighting coefficients were used to smooth out inter-annual variability and to display long-term trends. The standard deviations of the Gaussian distribution used in the filters were 3 and 9 years, referred to hereafter as G3 and G9, which approximately corresponds to 10- and 30-year moving averages, respectively. The earliest and latest years of the filtered curves (roughly half a filter width) are shown with thin lines in the figures, because the beginning and the end of the series receive very large weights and the shape of the curves can change when new values are added.

3. *Results*

3.1 *Mean temperature changes*

National mean air temperatures for Finland were calculated as simple averages of data from eight stations (Maarianhamina, Helsinki, Lappeenranta, Jyväskylä, Vaasa, Kajaani, Oulu and Sodankylä). The stations are not evenly distributed spatially, but slightly biased towards southern Finland, because there is only one long-term station in Lapland (see Fig. 1). However, this fixed network of homogenised stations should guarantee that national temperature series are unbiased in time, which is crucial for climate change studies. The annual and seasonal mean values and standard deviations are given in Table 1.

The long-term annual mean temperatures in Finland (Fig. 2) loosely follow the behaviour of Northern Hemisphere temperature variations (see, for example, *Jones* 1994). The warming trend observed during the first decades of this century was reversed to cooling as early as in the beginning of the 1940s in Finland. During the 1980s and 1990s, Northern Hemisphere temperatures have risen to levels never before reached in the entire record. In contrast, temperatures over the same period in Finland have not yet passed the maximum of the 1930s.

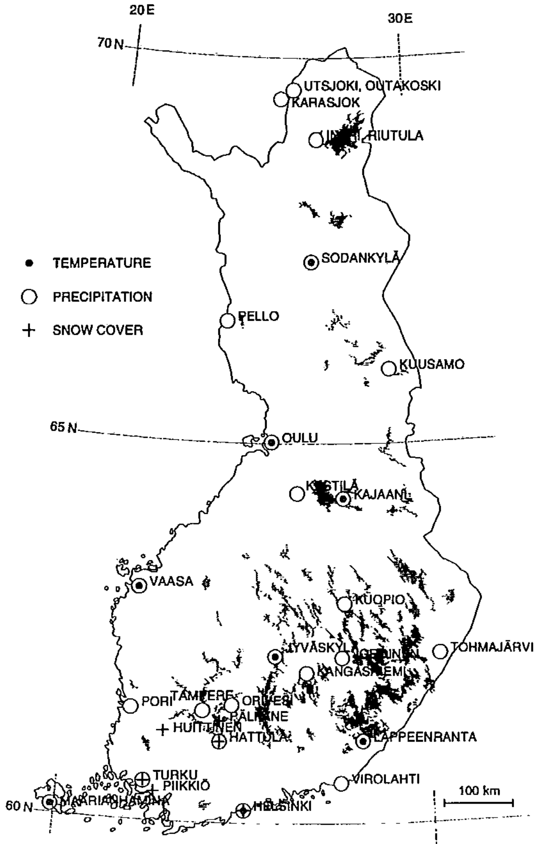

Fig. 1. Location of the meteorological stations (8 temperature, 24 precipitation and 6 snow cover) mentioned in the text.

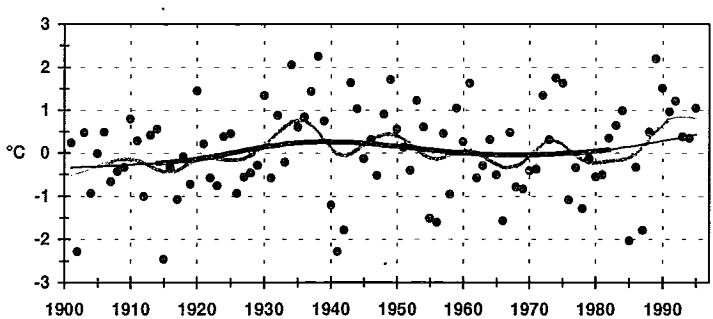

Fig. 2. Nationally-averaged annual mean temperatures in Finland, 1901-1995 (dots), as anomalies from the 1961-1990 mean. Grey line is G3 filtered series and black line G9 filtered series.

Table 1. Nationally-averaged annual and seasonal air temperatures and precipitation (means and standard deviations) for different time periods in Finland:

TEMPERATURE (°C) 8 stations	ANNUAL	WINTER	SPRING	SUMMER	AUTUMN
mean (1961-1990)	2.8	-8.3	1.6	14.5	3.6
mean (1901-1995)	2.9	-7.6	1.3	14.4	3.5
st.dev. (1901-1995)	1.05	2.72	1.48	1.06	1.33
PRECIPITATION (mm) 24 stations	ANNUAL	WINTER	SPRING	SUMMER	AUTUMN
mean (1961-1990)	580	115	99	193	173
mean (1910-1995)	574	115	100	189	170
st.dev. (1910-1995)	68	25	24	38	40

In Finland, the warmest years of the century so far have been 1938, 1989 and 1934, and the coolest ones 1915, 1902 and 1941. The three warmest (coldest) years were on average 2.2 (-2.4) degrees warmer (colder) than the mean for the normal period 1961-1990. In Finland, the warmest ten year period has been 1930-1939, which was 0.9°C warmer than the 1961-1990 mean and 0.3°C warmer than the period 1986-1995, which has been the warmest decade globally, so far (*Jones*, 1994 and updates). According to the SILMU central policy scenario (*Carter et al.*, this volume), based on the results from climate model simulations under increasing atmospheric carbon dioxide concentrations, it will take ten to twenty years before long-term annual mean temperatures have reached the level of the 1930s. The thirties may, therefore, have some value as an analogue for assessing the impacts of a future climate. The reasons for the warm anomaly during the 1930s, which covered at least Fennoscandia and northern parts of Russia, extending up to Arctic (*Tuomenvirta,* 1995), are not clearly understood, but they are very likely of natural origin.

Heino (1994) found that the frequency distribution of annual mean temperatures during the past hundred years is slightly negatively skewed and platykurtic (flat-topped). The visual interpretation of this result is that the years with large negative anomalies (larger than one and a half times 1961-1990 standard deviation) characterise cool periods. The warm episodes could be defined as periods when very cold years are missing.

The decadal-scale fluctuations in winter are larger than for the other seasons (Fig. 3a). A slight overall cooling trend has been broken with recent warm winters. Spring temperatures show the largest warming of all seasons (Fig. 3b). An upward trend since the middle of the 1950s can clearly be identified. Summer temperatures show fluctuations but no clear trend (Fig. 3c). The summers of the late thirties and early forties were outstandingly warm. In contrast to the spring, autumn temperatures display a slight falling trend starting in the 1940s (Fig. 3d). However, the present level is not yet lower than the first decades of the century.

Heino (1994) also studied the differences in monthly mean temperatures between the normal periods 1961-1990 and 1931-1960 in Finland. The winter months have cooled with the greatest cooling in December. The spring time warming extends to June. The other summer months, July and August, have cooled. As a consequence of these changes, the timing of the mid-point of the warmest phase of the summer as well as that of the coldest phase of the winter have both shifted backwards in time.

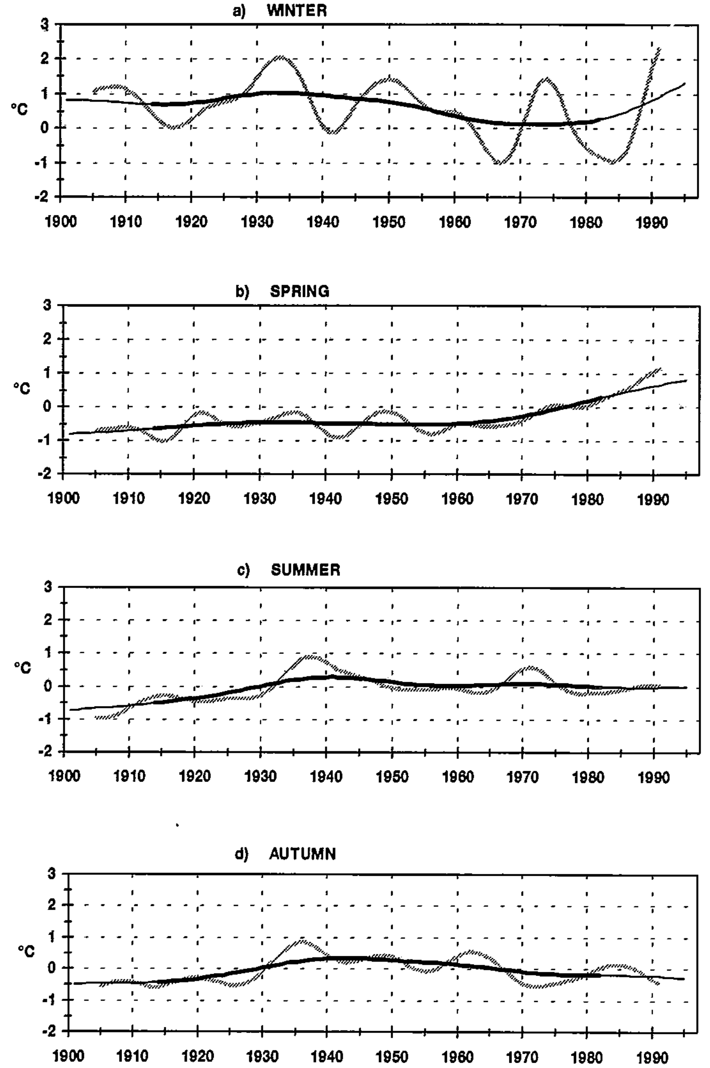

Fig. 3. Nationally-averaged seasonal temperatures in Finland, 1901-1995, as anomalies from the 1961-1990 mean: (a) December-February, (b) March-May, (c) June-August, and (d) September-November. Grey line is G3 filtered series and black line G9 filtered series.

3.2 *Snow cover fluctuations*

Groisman et al. (1994) studied the Northern Hemisphere snow cover extent observed by National Oceanic and Atmospheric Administration (NOAA) satellites during the period 1973-1992. They found a clear decreasing trend in spring snow cover extent. The effect of snow cover variations on the radiative balance was also estimated and they concluded that 'the systematic retreat of the snow cover extent during the past 20 years is related to change in snow cover feedback affecting the radiative balance and leading to an increase of springtime temperatures'.

In Finland, visual observations of snow cover were started in 1937. At least half of the ground around the observing site should be covered by snow for a day to qualify as a snow covered. Variations in the annual number of snow cover days have been relatively small in Finland, excluding the hemiboreal climatic zone, i.e. southern coastal areas and islands. Fig. 4 shows the smoothed snow cover day anomalies averaged over six stations in southern Finland. Three of the stations are coastal (Helsinki, Turku, Piikkiö) and three are inland stations (Huittinen, Hattula, Pälkäne). Having in mind the transition season temperature changes, the snow cover data were divided into two half year periods: August-January (Aug-Jan) and February-July (Feb-Jul). The mean number of days with snow cover averaged over the six stations during Aug-Jan (Feb-Jul) is 61 (65) days with a standard deviation of 14 (13) days.

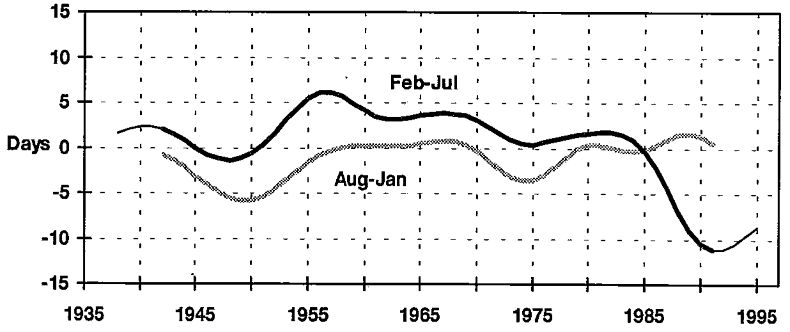

Fig. 4. Number of snow cover days during the half years August-January (grey line) and February-July (black line) in Southern Finland, 1938-1995, as anomalies from the 1961-1990 mean. Series are smoothed with the G3 filter.

Recent decades show a decrease of snow cover during the Feb-Jul period (Fig. 4). Smoothed values at the end of the Feb-Jul curve are more than ten days shorter than the 1961-1990 mean, due to especially low values in 1989, 1990 and 1993. However, at the same time, the number of snow cover days during the Aug-Jan period has slightly increased, surpassing the number of days in the Feb-Jul period during the last decades. Since the radiative feedback effect is small during the months from October to December, the simultaneous decrease in autumn temperatures should not be interpreted as a result of snow cover forcing. Instead, both the temperature decrease and snow cover changes in autumn, can be considered as manifestations of the same forcing. In contrast, the rise in spring temperatures and reduced snow cover are likely to be linked through radiative feedback.

Variations in snow cover duration decrease towards the north. The recent springtime shortening of the snow cover season is only a few days in central Finland and the long-term behaviour shows no clear trend in northern Finland. The contrast between northern and southern Finland results from different characteristics of the snow cover. Simple correlation analysis reveals that temperatures at the beginning and end of the snow cover period largely determine the length of the period. In the south, the snow cover is thin and thus more sensitive to temperature fluctuations. The length of the snow cover season also exhibits a weak negative correlation with precipitation in southern Finland. This reflects the fact that wet winters are generally warm and have reduced snow cover. However, in northern Finland the correlation is positive since all winter precipitation is accumulated as snowpack and has to be melted in the spring.

3.3 Geostrophic wind relations to temperature

The observed climatic anomalies at mid and high latitudes can often be attributed to specific and persistent circulation patterns. The geostrophic wind vector provides a good approximation of the regional circulation strength and direction, even though it does not take into account the origin of specific airmasses. It is preferred to surface wind observations, which reflect much more the local conditions and are often inhomogeneous in time due to changes of instrument, measurement height, and site.

Lahti (1994) calculated geostrophic winds in a triangle formed by the stations Maarianhamina, Helsinki and Vaasa in south-western Finland for the period 1885-1992. These wind vectors were correlated with the average of Helsinki and Kajaani mean temperatures. *Tuomenvirta* (1995) studied seasonal temperature as a function of geostrophic wind direction and velocity for the same period 1885-1992. The highest correlation, between zonal (west-east) winds and temperature, is found in winter (0.73). 30-year running correlations vary from 0.5 to 0.8. The relationship describes the advection of the warm Atlantic airmasses with westerly winds and the cold continental air with easterlies. During the spring the strongest correlation (0.46) is found on the WSW-ENE axis. The summer wind rose differs markedly from the other seasons, the highest correlation being found on the SE-NW axis, reflecting the advection of warm continental air compared to cool north-easterlies. The maximum correlation is the lowest of all the seasons - only 0.30. In summer, the advection processes are complicated. The air masses do not have well-defined source regions and they are also transformed by short wave radiation and surface heat and moisture fluxes. In autumn, SW-NE winds give a high correlation (0.65), almost as high as the zonal winds in winter. A temperature difference between arctic and mid-latitude airmasses is evident in autumn, and by winter, the vector of highest correlation has rotated clockwise to reflect, in addition, the contrast between maritime and continental air. For this reason, the sector of high correlation is wider in winter than in autumn.

There is a strong linear relationship between winter temperature and the strength of winter geostrophic zonal flow (Fig. 5). However, the winters with the five strongest westerly and easterly flows are not the five warmest and coldest winters. Linear regression was used to estimate winter temperatures from the zonal flow. The method was adopted from *Alexandersson* (1994). The residuals, i.e. differences between observed and derived temperatures (not shown), reveal no clear trend over the past 111 years. The zonal flow has been close to or above average during 1988-1995, but the recent warm winters are not exceptional in the residual record. In addition, the wintertime North Atlantic Oscillation (NAO) index has been positive, i.e. the subtropical high over the Azores has been strong while the Icelandic low has been simultaneously deep (*WMO* 1995). This has led to large scale advection of mild airmasses from the Atlantic towards Europe.

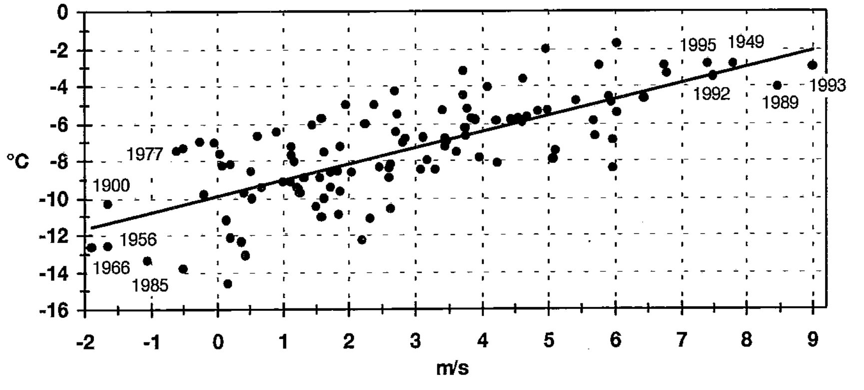

Fig. 5. Zonal geostrophic wind versus temperature in winter, 1885-1995. Pressure data are from Maarianhamina, Helsinki and Vaasa. Temperatures are the averages of Helsinki and Kajaani. Years with the five strongest easterly and westerly flows are marked. Winters are dated by the January (e.g. 1966 is the winter from December 1965 to February 1966).

The results obtained here support the findings of *Alexandersson* (1994) for Southern Sweden, that recent temperature fluctuations are not unique and do not require an explanation such as the enhanced greenhouse effect directly acting on the temperature characteristics of wintertime airmasses. However, it should be remembered that the enhanced greenhouse effect may also lead to changes in regional circulation patterns.

3.4 *Diurnal temperature range (DTR)*

Since there are serious inhomogeneities in the earlier maximum and minimum temperature records (mostly due to station relocations) the analysis performed here extends back only to the 1940-50s, since which time the majority of observing stations have been located at the same sites (e.g. airport weather stations and observatories).

An analysis of monthly mean maximum and minimum temperatures showed that increases in maximum temperatures have been less than those in minimum temperatures. Thus, the diurnal temperature range (DTR) shows a decrease in Finland by approximately 0.5°C since the 1950s. This is roughly the same as reported by *Karl et al.* (1993) in their study of about 50% of the whole hemisphere. The corresponding seasonal changes were also studied. It appeared that the decrease of the annual DTR is mostly explained by decreases in spring and summer, while the DTR in autumn and winter has remained at about the same level despite large inter-decadal changes in winter.

According to *Karl et al.* (1993) no human-induced local effects can provide a satisfactory answer to the widespread decrease of the DTR, although among many variables, changes in cloudiness gave the best explanation of the decline. Cloudiness data from the stations used in the DTR calculations in Finland were found to be strongly correlated (about -0.8) with the DTR on a monthly and seasonal basis. In general, cloud cover tends to reduce both incoming solar and outgoing long-wave radiation at surface. Since cloudiness has experienced a recent increase in the Finland and the duration of bright sunshine a corresponding decrease (*Heino,* 1994), this appears to be a reasonable explanation of the DTR changes in Finland as well.

3.5 *Precipitation changes*

Due to the large natural variability of precipitation in time and space, changes of precipitation are more difficult to generalise than those of temperature. The Finnish network of precipitation stations was poor before 1909, which was also the year of a nation-wide change of instrument, so the calculations of areal averages of precipitation were extended back only to the year 1910 (Fig. 6). National mean precipitation was calculated as a simple average of homogeneous data from 24 stations. One northern Norwegian station (Karasjok) was included to give more weight to Lapland, but the distribution of stations is still biased towards southern Finland (see Fig. 1). Time-varying measurement biases must be adjusted before analysing precipitation data (*IPCC,* 1996), and although, the Finnish time series have been adjusted, they may still contain some inhomogeneities.

An increase in precipitation over land in high latitudes of the Northern Hemisphere has been reported by *Nicholls et al.* (1996). This has also been observed in Europe. *Groisman et al.* (1991) reported an increase in annual precipitation over the former Soviet Union of about 10%/100yr. *Hanssen-Bauer et al.* (1995) report an 8-

14% increase in annual precipitation during this century over Norway. *Alexandersson* and *Eriksson* (1989) found slightly smaller increases over southern and northern Sweden. The Finnish records (1910-1995) show no clear long-term trend. Most of the increase in eastern Norway and Sweden occurred before 1910, but still Finland seems to be a local minimum of precipitation increase during this century in northern Europe.

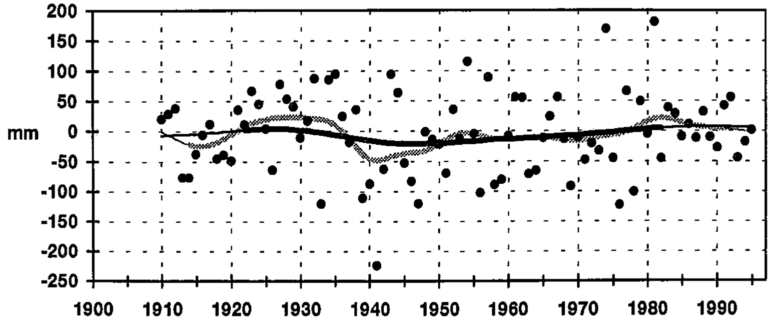

Fig. 6. Nationally-averaged annual mean precipitation in Finland, 1910-1995 (dots), as anomalies from the 1961-1990 mean. Grey line is G3 filtered series and black line G9 filtered series.

Secular variations of annual precipitation in Finland include the wet years of the 1920s and 1930s followed by a dry period of the 1940s. More recently, the precipitation has increased somewhat. The wettest years of the period were 1981 and 1974 (180 and 170 mm above the 1961-1990 mean, respectively), and the driest one by far, 1941 (-220 mm).

Winter precipitation had a small maximum in the late 1950s (Fig. 7). Springs show a decrease from the wet decades of the 1920s and 1930s. Recent changes are negligible. Summers and autumns show more variable features. This is partly due to the fact that precipitation amounts are much higher than in winter and spring (see Table 1). The summer precipitation curve has a wave like shape with slight rising trend. Very recently autumns have been dry. It should be noted that the large natural variability of precipitation in time and space causes Finnish seasonal precipitation trends to be less reliable than corresponding temperature trends although they are determined from a larger number of stations.

Heino (1994) compared the spatial distribution of annual mean precipitation for the latest normal period 1961-1990 with the previous normal period 1931-1960 based on homogenised time series. A similar study was made by *Førland et al.* (1996) for the whole North Atlantic region. On average the annual mean precipitation has increased by about 20-30 mm in Finland between the two periods. The improvement of the measuring equipment in 1980/1981 is not an explanation for the increase because the records have been adjusted for it. Seasonal changes have also mostly been positive. Changes of mean monthly precipitation amount at individual stations between these two periods show both positive and negative changes. Precipitation has increased slightly in the latter half of the year. Since August precipitation has increased, its position as the rainiest month of the year has strengthened. February precipitation amounts are smallest, although March is the driest month when precipitation is expressed in terms of mm per day.

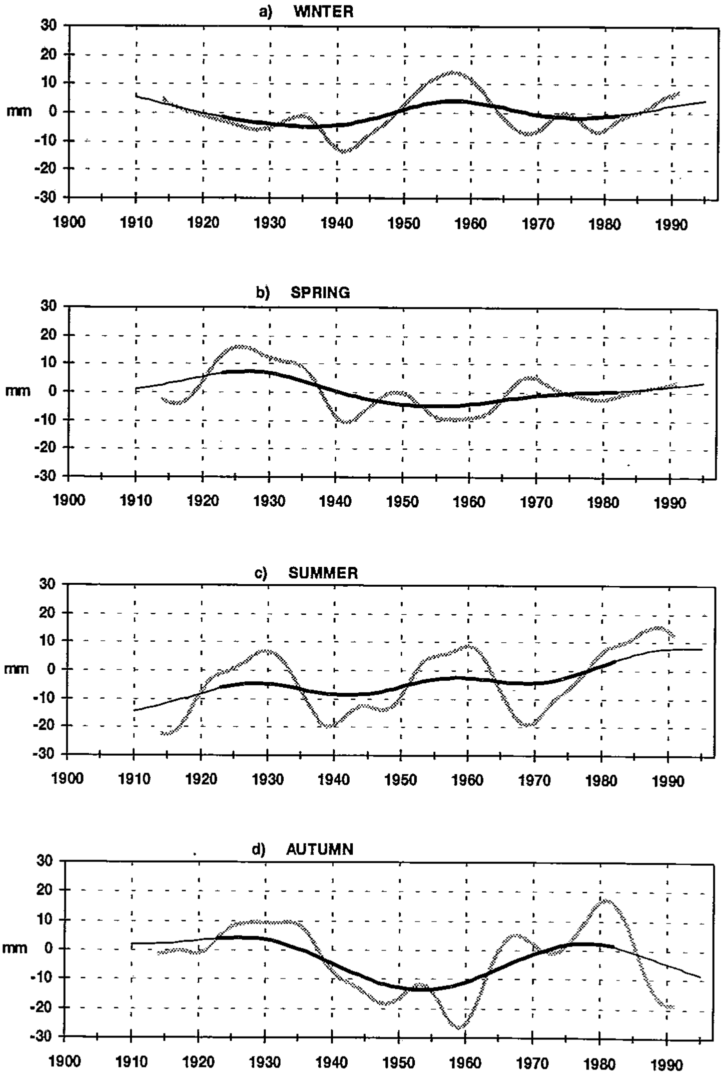

Fig. 7. Nationally-averaged seasonal precipitation in Finland, 1910-1995, as anomalies from the 1961-1990 mean: (a) December-February, (b) March-May, (c) June-August, and (d) September-November. Grey line is G3 filtered series and black line G9 filtered series.

4. *Discussion*

The climate of Finland has remained basically little changed during the present century. However, some short- and long-term variations are identifiable. They include: the warm 1930s in Fennoscandia, northern parts of Russia and adjacent Arctic areas; springtime warming and autumn cooling since the 1950s; a small reduction in snow cover days in southern Finland connected to spring warming; and a reduction in diurnal temperature range related to a recent increase in cloudiness and decrease in sunshine duration. Most of the changes observed in the Finnish climate during this century appear to fall within the range of the natural climatic variability.

In many cases circulation pattern changes are believed to be responsible for climate anomalies. For example *Førland et al.* (1996) compare the last two normal periods (1931-1960 vs. 1961-1990). They show that in the Fennoscandian areas exposed to orographic precipitation from humid westerlies of North-Atlantic origin, the precipitation increase has been much larger than in Finland. The patterns of precipitation change indicate changes in atmospheric circulation between the two normal periods. The simple geostrophic wind vector approach cannot satisfactorily explain observed variations of climate but can be used as a simple evaluation method. In this study, it helped to quantify that the recent warm winters (1989-1993) in Finland are due to strong westerly flows.

The results also demonstrate that the previous normal period, 1931-1960, was unrepresentative both of recent decades and of the century as a whole. The most recent normal period, 1961-1990, represents much better the climate during the whole period of instrumental observations in Finland. On the other hand, the anticipated warming and possibly increased precipitation due to greenhouse gas induced climatic forcing might lower the representativeness of the present standard normal period and new normal values should be adopted in the future.

Past climatological observations, and especially the present normal period 1961-1990, are much used in long-term planning and decision-making as the "best guess" for the future. While the past can, indeed, provide a valuable guide to the future, new influences affecting the global climate, such as greenhouse gas forcing, may alter climate in a manner unprecedented in the historical past. Thus, historical information should be complemented with information from climate model calculations, which attempt to account for these new influences.

Recent findings have demonstrated the influence of anthropogenic aerosols on radiative forcing at a global scale (*IPCC/WG1* 1996). However, the radiative forcing has a very strong regional pattern. The human-made aerosols typically concentrate near and downstream of industrial regions. It will be an important task to quantify their effects on the local climate. Therefore, climate monitoring and analysis remain as important tools for understanding the regional climatic response and are also of the utmost importance for the calibration and validation of improved climate models.

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