16. CHANGES OF CLIMATE IN THE HORNSUND STATION REGION DURING THE METEOROLOGICALOBSERVATIONS, 1978–2009

16.1. Changes of atmospheric pressure

At the Polish Polar Station at Hornsund mean monthly pressure in December displayed the greatest variability, as proven by the highest standard deviation ±8.0 hPa. December pressure ranged from 987.3 hPa in 2004 to 1017.2 hPa in 2009. Atmospheric pressure was most stable in July, when the standard deviation amounted to only ±3.3 hPa.

At the annual scale over 1978–2009 at Hornsund, a downward trend of atmospheric pressure was found amounting to 0.4 hPa/10 years (Fig. 16.1), with irregular fluctuations in the order of 6–8 years. The greatest decrease of pressure was observed during the winter (in February –2.1 hPa/10 years). In January, the downward trend amounted to –1.2 hPa/10 years, and in December –0.5 hPa/10 years. The downward trend was also detected in September (–1.1 hPa/10 years), which was connected with a very low atmospheric pressure record in 2009 (998.2 hPa). Only in October, was any significant upward trend of this parameter noted (+0.4 hPa/10 years). In the other months, trends did not exceed ±0.4 hPa/10 years.

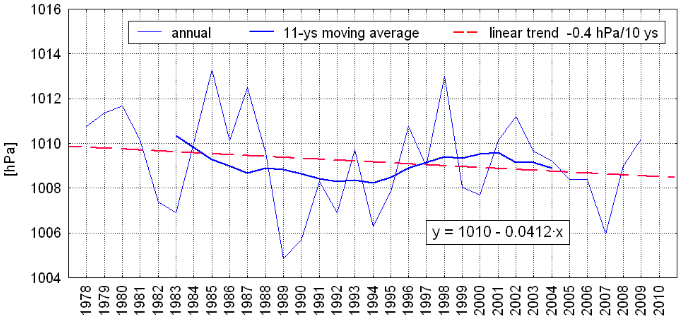

Fig. 16.1. Changes of mean annual atmospheric pressure at Hornsund, 1978–2009.

Changes of mean atmospheric pressure at Hornsund for selected months are also presented here. In January (Fig. 16.2) with the clear downward trend, the highest pressure (1016.2 hPa) was in 1979. Results from Longyearbyen show even higher pressure in January being recorded earlier, in the period 1960–1969. The clear downward trend started after 1970. A very deep minimum was recorded in January 1993 (986.6 hPa). Results from measurements at Isfjord Radio and Longyearbyen determine that it was the lowest mean monthly pressure since the beginning of recording (i.e. since 1912). Small increases of mean pressure were recorded at Hornsund in January 1998, 2004 and 2010.

Multiannual variability of pressure in May (Fig. 16.3), which is normally the month with the highest pressure, is characterized by a statistically insignificant downward trend (–0.4 hPa/10 years) and in most years by irregular fluctuations in the range ±6 hPa year to year. A four years long period of very low pressure (1989–1992) is a peculiarity in the research period. A stepwise change occurred between the lowest pressure of 1006.3 hPa in May 1992 and maximum mean atmospheric pressure of 1021.5 hPa in May of the next year. Since that time, pressure in May was usually higher than average, with the exception of a big drop to 1010.3 hPa in 2000 and exceptionally high pressure in 2008 (1021.3 hPa).

In July (Fig. 16.4) the course of pressure at Hornsund was relatively even, with numerous fluctuations every 2–5 years, considerably elevated values in 1985, 1993 (1018.7 hPa), 1997 and deep depressions occurring in 1982, 1989, 1995 (1006.2 hPa) and 1999.

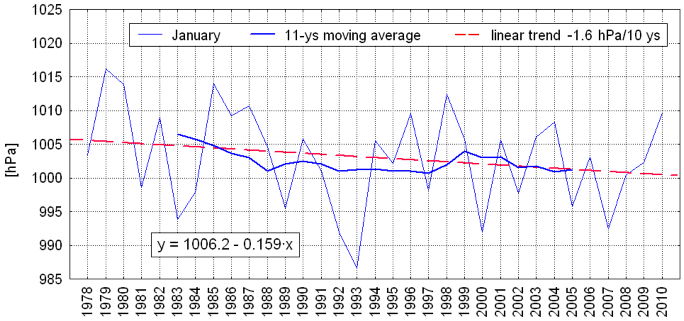

Fig. 16.2. Changes of mean atmospheric pressure in January (1978–2010).

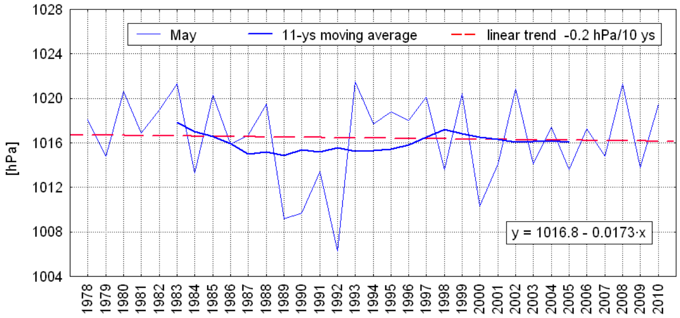

Fig. 16.3. Changes of mean atmospheric pressure in May (1978–2010).

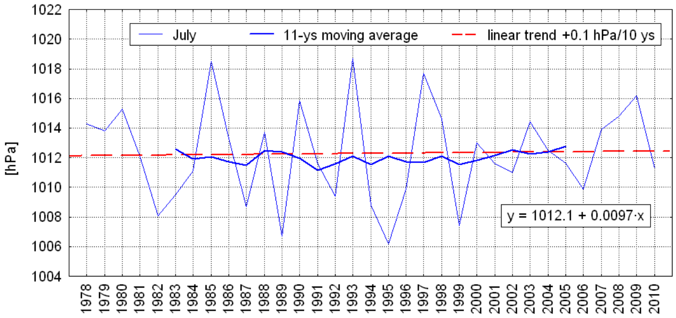

Fig. 16.4. Changes of mean atmospheric pressure in July (1978–2010).

Very small variations of mean pressure year to year are characteristic for October (Fig. 16.5), with a statistically insignificant rising trend of +0.4 hPa/10 years. The greater negative deviations from the mean were in October 1978 and 1986 (996.1 hPa) as well as 2007 (1000.3 hPa). The highest pressure occurred in October 2002 (1017.6 hPa).

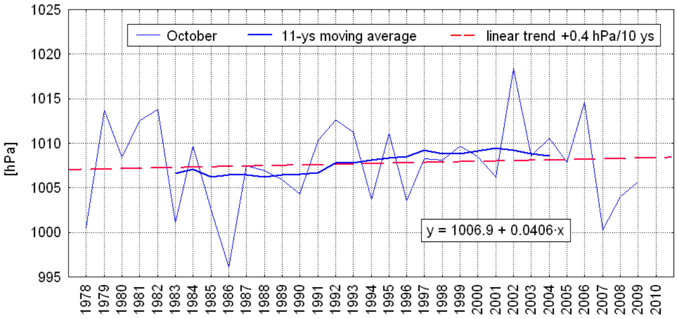

Fig. 16.5. Changes of mean atmospheric pressure in October (1978–2009).

16.2. Changes of circulation indices

At the annual scale over 1951–2009 a rising trend in the cyclonicity C index, and to a somewhat smaller degree in the indices of western circulation W and southern circulation S are observed. This indicates increased advection of warmer air from the Norwegian and Greenland Seas. The most intense increase of cyclonicity and advection of air from the South were found in January, whereas the W index increased most in December.

16.2.1. The W index of western zonal circulation

Over the multiyear record (Fig. 16.6) the biggest reduction of the eastern circulation occurred in 1976 (W = –27), and over the following three years there was substantial amplification, with the strongest effect in 1979 (W = –237). This was exceptional, the strongest (nearly stepwise) change of the W index on Spitsbergen during the past 59 years (1951–2009). Since 1986 values of this index became distinctly smaller, which may be a reason for the warming of the climate. A significant positive trend was found for annual values (+5.1/10 years) as well for the summer (+1.8/10 years) and the winter (+1.5/10 years). Over the research period the most intensive western circulation (W = +31) occurred in June 1970, and eastern circulation in December 1985 (W = –48). There were positive trends in the index in April, June, July, September and December. There were small decreasing trends only in February, May and October. During recording at Hornsund station,1978-2009, a statistically significant trend in the zonal circulation index occurred only in September (0.40(±0.16) per year; $p < 0.015$).

In January 2006 (Fig. 16.7), the previous record for the intensity of this circulation (W = +10 in January 1972) was broken (W = +12) and the thermal anomaly for this month on Spitsbergen exceeded +12 deg. There were earlier high positive values of the index in 1972 (W = +10), 1987 (W = +5) and 1998 (W = +8). Very low negative values of W occurred twice in January, in 1978 (W = –38) and 1994 (W= –41). Despite these relatively big fluctuations the W index did not show a statistically significant trend for January but after 1970 its range of fluctuations increased.

For the month of May (Fig. 16.8) an insignificant decreasing trend of W index was observed, although after 1990 its values have a more evident decreasing trend. Two periods with positive values of the W index have occurred since 1951, in 1966–1972 and 1990–1992, as well as three periods of relatively low negative values - 1951–1959, 1973–1989 and the years 2005 and 2007 (W = –28).

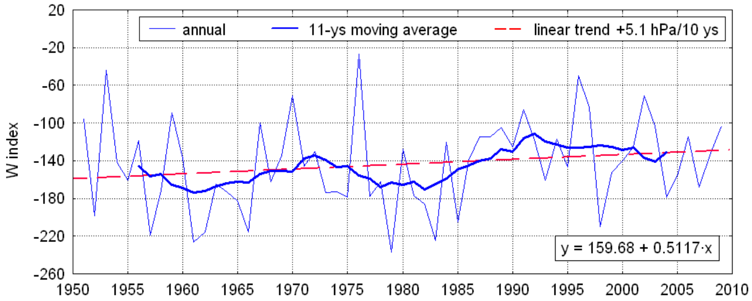

Fig. 16.6. Changes of annual values of the western circulation W index on Spitsbergen, 1951–2009.

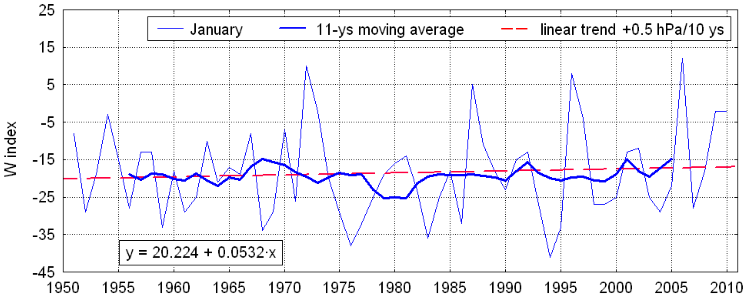

Fig. 16.7. Changes of values of the western circulation W index in January, 1951–2010.

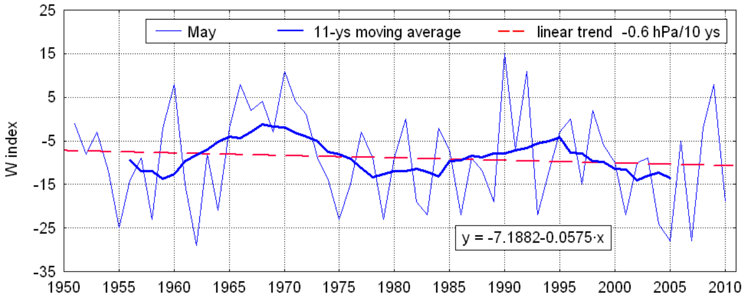

Fig. 16.8. Changes of values of the western circulation W index in May, 1951–2010.

In the month of July (Fig. 16.9), advective air flow above Spitsbergen from the western sector occurred more frequently than from the eastern sector, as expressed in the frequent occurrence of positive values of the W index: however, there is not a statistically significant positive trend. There was especially great intensification of the July western circulation in 1987–1997. The biggest stepwise change occurred between 1997 and 1998, from +20 to –23. Low values of the index (W = –19) were observed also in July 2007 and 2009.

For October (Fig. 16.10) a small decreasing trend in W is seen. It results from occurrence of a very high positive value (W= +10) in 1951 and an exceptionally deep minimum (W= –44) in 1983. A broader period of low values (W below –20) occurred in 1995–1999 and in 2006 (W = –24).

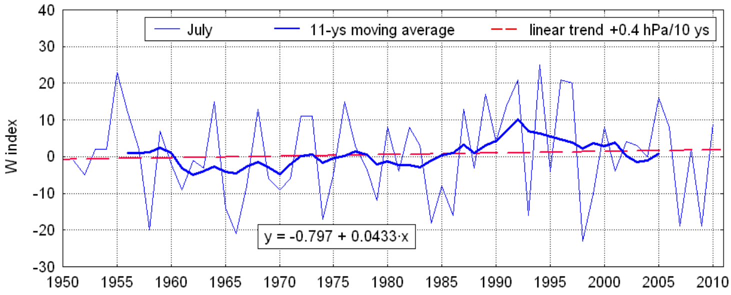

Fig. 16.9. Changes of values of the western circulation W index in July, 1951–2010.

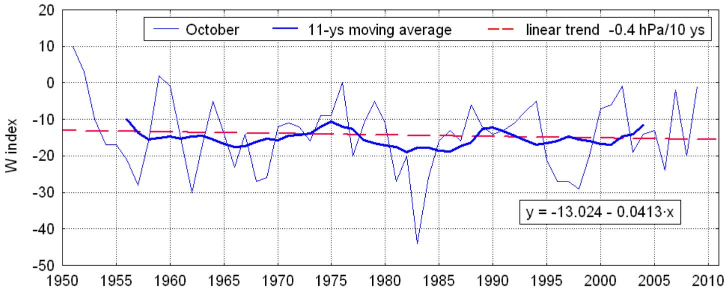

Fig. 16.10. Changes of values of the western circulation W index in October, 1951–2009.

16.2.2. The S index of southern meridional circulation

The multiyear trend of the S index (Fig. 16.11) on Spitsbergen is more even than that of the W index, with a distinct culmination in 1984–1994. There were also some single, extreme peaks in intensity of this index. Maximum intensity of the southern flow occurred in 1984 (S = +66), and that of northern flow in 1968 (S = –160). Positive values in this index started to appear after 1972. For 1951-2009, a distinct positive linear trend in annual values (+2.9/10 years) is seen, being evident also in the winter (+2.9/10 years) and in the spring (+1.7/10 years).

Only in the summer and autumn is the trend insignificantly negative (–1.3/10 years and –1.1/10 years, respectively). Over the Hornsund station record (1978-2009) trends in the S annual index did not reach statistical significance however. The highest monthly values were recorded in September 1990 (S = +32) and in May 2006 (S = +31), and the most negative in October 1980 and in May 1990 (S = –33). However, a record-breaking negative value (S = –34) has occurred since, in June 2010. Over the three years, 2004–2006, the S index was positive, which was strongly evident in big positive thermal anomalies. Over the following three years (2007–2009) however its value decreased to S= –53 (2009) or even S= –80 (2007).

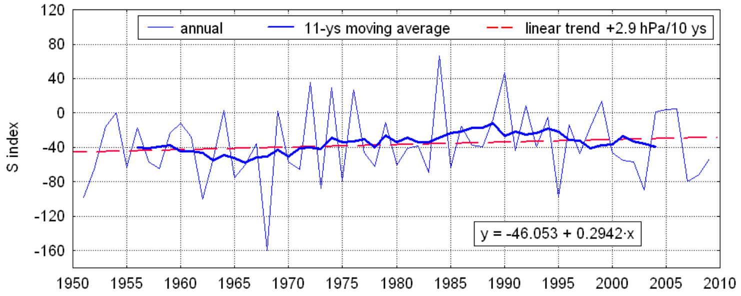

Fig. 16.11. Changes of annual values of the southern circulation S index on Spitsbergen in 1951–2009.

In January 2006 (Fig. 16.12), when the W index was highest, the intensity of the southern circulation reached the maximum value for this month recorded in the last 56 years (S = +26), causing a thermal anomaly in Spitsbergen amounting +12.6 deg. The distinct positive trend of the S index in January was +2.0/10 years. A similar situation also occurred in April 2006 (S = +31), when air temperature in Spitsbergen was 12.4 deg higher than the multiannual mean. Earlier, in April 2004 another intense episode of southern circulation (S = +17, the second in order for that month), and a thermal anomaly of +8.1 deg were recorded.

For the month of May (Fig. 16.13) the S index did not show any significant trend. Fluctuations year to year were not very big. Major anomalies occurred twice: in 1963 (S = +16) and in 1990 (S = –33). Lately there has been an increase of the index from –15 in 2006 to +9 in May 2010.

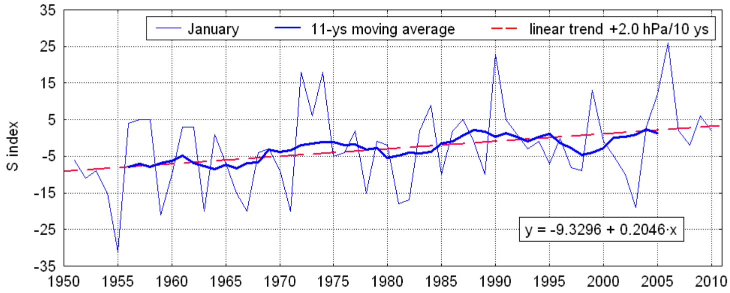

Fig. 16.12. Changes of the southern circulation S index in January, 1951–2010.

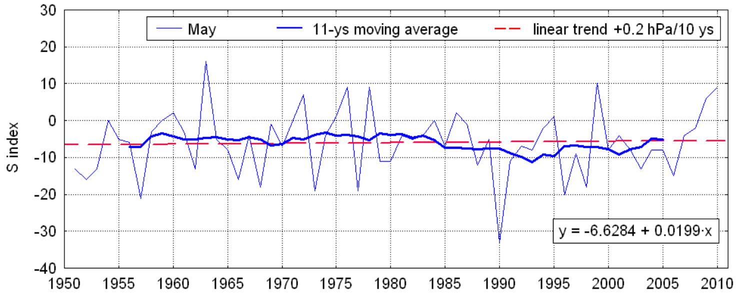

Fig. 16.13. Changes of the southern circulation S index in May, 1951–2010.

No significant trend of S index was found for July (Fig. 16.14). In 1951–1970 relatively great fluctuations year to year were recorded, and after 1985 the range increased again. In July 2004 the highest S index value (+24) was recorded and the thermal anomaly amounted to +1.8 deg. In contrast, in July 2009 a large negative value (S = –15) was recorded but this was somewhat greater than the lowest measured value in July 1963 (S = –19).

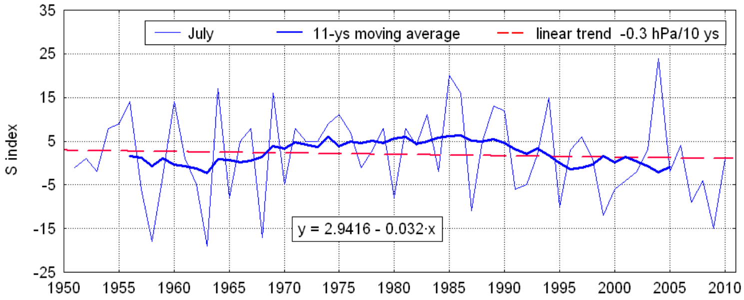

Fig. 16.14. Changes of the southern circulation S index in July, 1951–2010.

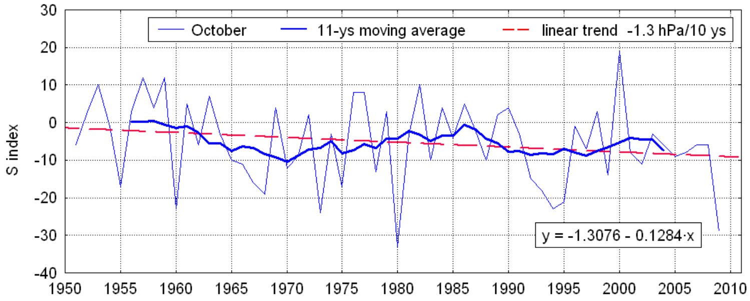

Fig. 16.15. Changes of the southern circulation S index in October, 1951–2009.

October was the only month in which a distinct negative trend of the S index (–1.3/10 years) was evident (Fig. 16.15). There was a well-defined period of low values in 1992–1995. Increase to S = +19 in October 2000 and a drop to S = –29 in 2009 were also exceptional.

16.2.3. The C index of cyclonicity

Over the multiyear record (Fig. 16.16) fluctuations of the annual index of cyclonicity were very big, with a general positive trend amounting to +14.0/10 years). The greatest activity of low-pressure systems was concentrated in 1972–1976, with a maximum in 1975 (C = +209). After 1977 much greater fluctuations year to year were recorded than before 1972. During this period both very high values of the C index (+166 in 1983, +136 in 1994, +148 in 1999 and +199 in 2007), and the lowest value (–56 in 1998) occurred. The period 1951–1970 stands out by its relatively low C values (from –40 in 1958 to +99 in 1953) and smooth course. The positive trend of the cyclonicity index was found during all seasons of the year, with the highest value in the winter (+5.1/10 years). In this season increase of C index (+4.8/10 years) in 1978–2009 (the period of record at the Hornsund station) was also statistically significant. Associated with this, there were statistically significant changes of the index at the beginning of the winter – for December (+5.6/10 years) and for January (+5.4/10 years). The greatest intensity of low-pressure circulation was measured in March 2007 (C = +39) and November 1996 (C = +37). The greatest high-pressure weather occurred in July 1956 (C = –38) and May 1999 (C = –36).

For the month of January there was a positive trend +2.8/10 years in the cyclonicity index (Fig. 16.17), the highest among all months. However this trend started only after 1970. Earlier, in 1951–1970 the index was steady and even showed a decreasing trend to the very low value of –19 in 1967. After 1972 this index reached or exceeded +30 as many as eight times, approaching +32 in 2000. During this period, a great escalation of cyclonic activity in January with high frequency of high-pressure systems also occurred. January 1977 (C = –16) and January 1998 (C = –7) may be noted as exceptions.

The cyclonicity index did not show any significant trend for the month of May (Fig. 16.18). In the multiyear record for this month, irregular fluctuations from –30 to +10 were measured.

In contrast, in July (Fig. 16.19) cyclonic activity distinctly escalated. The linear trend in the C index amounted to +1.1/10 years. After 1970 the frequency of cyclonal situations became distinctly greater than anticyclonal. Fluctuations of the C index were big, however, from –38 in 1958 and –35 in 1993 to +31 in 1982.

For October (Fig. 16.20), there was a small positive trend in the C index (+0.6/10 years). Its values are usually positive and stay close to +10. The index was negative only 11 times during 1951–2006.

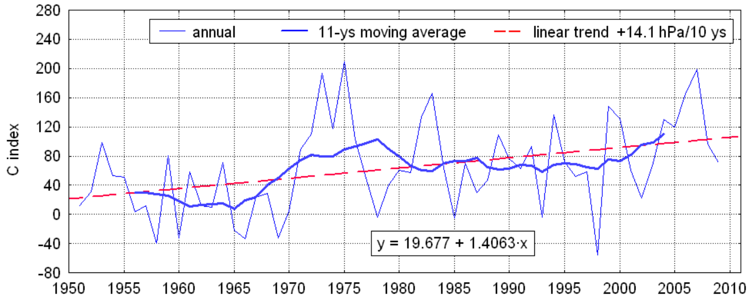

Fig. 16.16. Changes of annual values of the cyclonicity C index on Spitsbergen, 1951–2009.

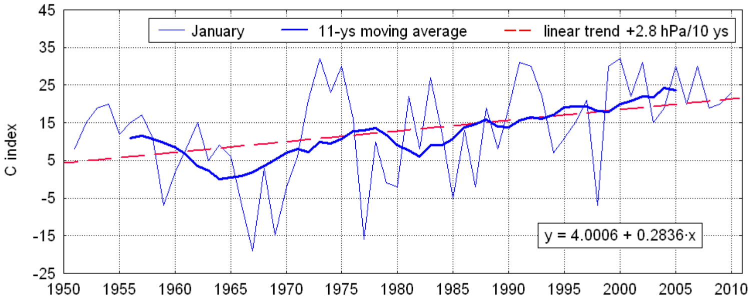

Fig. 16.17. Changes of the cyclonicity C index in January, 1951–2010.

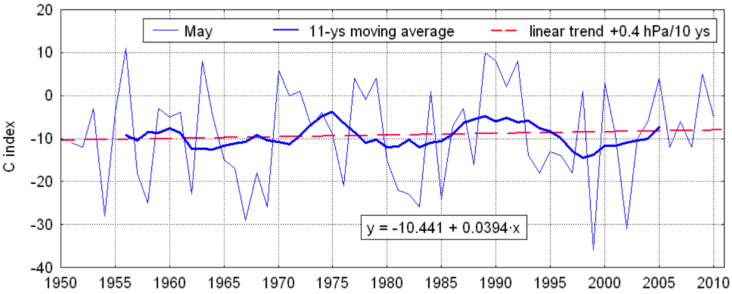

Fig. 16.18. Changes of the cyclonicity C index in May, 1951–2010.

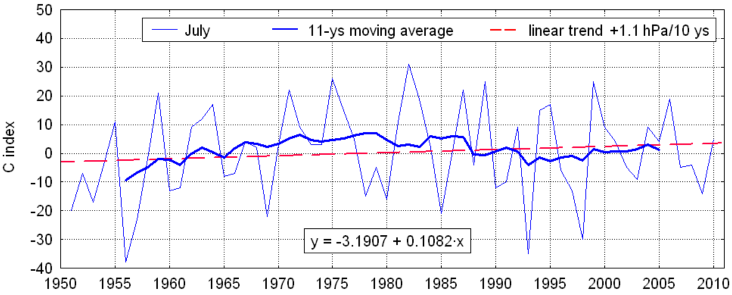

Fig. 16.19. Changes of cyclonicity C index in July, 1951–2010.

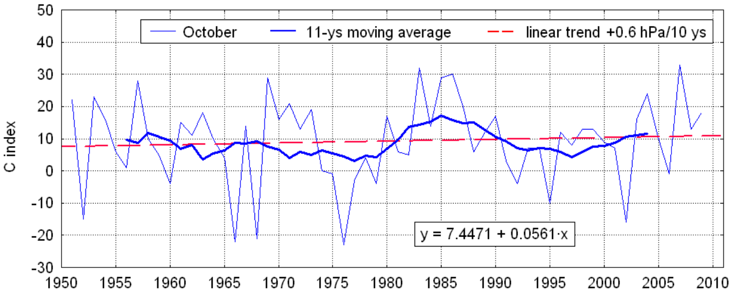

Fig. 16.20. Changes of the cyclonicity C index in October, 1951–2009.

The principal features of the changes of atmospheric circulation over Spitsbergen in the second half of the 20th Century and at beginning of the 21st Century are:

1 – increase of the western circulation index, characterizing increase of frequency of inflow of air from the west, especially during the summer and winter,

2 – increase of the southern circulation index in the winter and summer, indicating an increase of frequency of air mass advection from the south and,

3 – increase of frequency of low-pressure systems in all seasons of the year, especially strong in the winter.

Because the circulation indices are monthly, the seasonal and annual totals of days (see Chapter 4) with pressure systems forcing inflow of air from a definite direction must balance.

Increase of frequency of air advection from the west implies the same decrease of frequency from the east. Similarly, increase of frequency of advection from the south indicates decrease from the north over the same time period. Advection of cool air masses from the north and east are associated with drops of air temperature over Spitsbergen, while advection of warmer air from the south and west contribute to increase of air temperature. By this means, trends of the circulation indices in particular months, seasons and years were one of the causes of air temperature change at Hornsund.

Additionally, cloudiness (Chapter 7) is closely connected with the directions of air mass inflow (circulation indices), hence changes of circulation (increase of the W, S and C indices) observed in the research period also caused changes of cloudiness, leading to its increase. In turn, increase of cloudiness brings about increase of precipitation totals and increase of air temperature.

16.3. Changes of direction and velocity of the winds

During recording at the Hornsund station changes of the directional structure and velocity of the winds are small. While over 1978–2009 small increasing trend of frequency of winds from E, S, SW and NW was observed in the annual structure (Table 16.1), only increases from E and NW were statistically significant. These explain 31% of variation of eastern winds and 11.6% variation of wind from NW in a year. A significant decrease of frequency of calms is also evident.

Table 16.1. Values of trend coefficients of annual frequency of wind directions at the Hornsund station in 1978–2009 and their statistical characteristics.

Direction	Trend coefficient	$p <$	adj. R^2
N	–0.019(±0.022)	0.377	-
NE	–0.219(±0.109)	0.054	0.099
E	**0.427(±0.116)**	0.001	0.310
SE	–0.011(±0.021)	0.597	-
S	0.003(±0.016)	0.850	-
SW	0.008(±0,033)	0.028	-
W	–0.033(±0.044)	0.461	-
NW	**0.063(±0.029)**	0.040	0.116
Calm	**–0.195(±0.056)**	0.002	0.287

Explanations: p – level of statistical significance of trend coefficient, adj. R^2 – determination coefficients adjusted to the number of degrees of freedom. Trend coefficients statistically significant shown in **bold**. Standard error of estimate is given in brackets, after the trend coefficient.

Changes of the frequency of easterly winds have a statistically significant trend in March (0.81%· yr^{-1}, $p < 0.012$), May (0.76%· yr^{-1}, $p < 0.004$), June (0.65%· yr^{-1}, $p < 0.021$), August (0.71%· yr^{-1}, $p < 0.003$) and October (0.44%· yr^{-1}, $p < 0.018$). This means that over the period, 1978–2009, increase of frequency of easterly winds during the second half of the winter (March) was 25%, the thermal spring (May, June) was 20–24%, the second half of summer (August) was 22%, and during the autumn (October) was 13.6%. In May and October the significant increase of frequency of easterly winds is accompanied by a significant decrease of occurrence of calms, while in August there was significant decrease of frequency of winds from N and NE. The strong rising trend of frequency of easterly winds in March (Fig. 16.21) results from the very low frequency of this wind direction in 1985 (only 17.7%) and its dominance in the last ten years. In 2000–2009 frequency of easterly winds in March exceeded 55% every year and in 2001, 2002 and 2008 was even 80% of all observations in that month.

Increases of frequency of wind from the NW are much weaker. Statistically significant trends occurred only in April (0.20%·yr^{-1}, $p < 0.012$) and September (0.17%·yr^{-1}, $p < 0.018$). The mean increase of wind frequency from NW was 5-6% during 31 years of observations at Hornsund. Increase of frequency of winds from NW is accompanied by a statistically significant decrease of calms in these months. Frequency of NW winds in April and September is negatively associated with the S index of Niedźwiedź (meridional circulation), and in April also positively with the W index (zonal circulation), which indicates the active cyclogenesis occurring during these periods in the region of South Spitsbergen and Fram Strait.

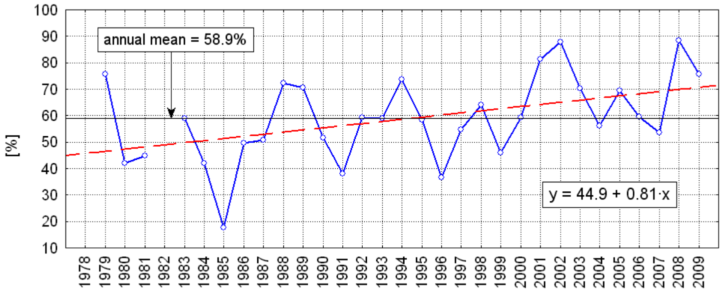

Fig. 16.21. Changes of frequency (%) of easterly winds in March, 1978–2009.

A significant decrease of frequency of calms is also evident in the research period (Table16.1). It amounts –0.195% per year and explains 29% of the variation of annual frequency of calms at the Hornsund station. The strongest drops of frequency of occurrence of calms were during the spring (April and May) and the autumn (September, October) as well as in January. During the spring the trend amounted to –0.30%· yr^{-1} ($p < 0.011$) in April and to –0.34%· yr^{-1} in May ($p < 0.000$). It was somewhat smaller during the autumn: in September (–0.28%· yr^{-1}; $p < 0.008$) and October (–0.23%· yr^{-1}, $p < 0.018$). The trend in January was relatively the weakest, but still statistically significant (–0.20%· yr^{-1}, $p < 0.035$). These trends explained ~35% in May, around 19% in April and September to 15% in October and 12% in January of the observed variability of frequency of calms. Periods when there were statistically significant decreases of frequency of calms were in those months in which drops of mean monthly atmospheric pressure were observed. This indicates that during the last 31 years in the South Spitsbergen region cyclonal activity increased both in transitional seasons of the year and in the middle of the winter (in January). January is the month in which trends in the Niedźwiedź C index of cyclonicity were also statistically significant. Other wind directions showed only isolated and very weak but statistically significant trends, occurring in different months. These trends explained from 20 to 11% of frequency of these winds. To such cases belong: decrease of frequency of wind from NE in July (–0.407%· yr^{-1}, $p < 0.023$) and August (–0.462%· yr^{-1}, $p < 0.010$), wind from N in August (–0.481%· yr^{-1}, $p < 0.007$) and wind from SE in December (–0.401%· yr^{-1}, $p < 0.025$) as well as increase of frequency of wind from W in September (0.345%· yr^{-1}, $p < 0.038$). August was the month in which statistically significant decrease of frequency of winds from N and NE was accompanied by significant increase of winds from E. The easterly winds in August were also significantly negatively associated with the cyclonicity and zonal circulation indices of Niedźwiedź. This indicates that in August, during the 31 research years, the frequency of high-pressure systems developing north of Spitsbergen increased. In September significant increase of winds from W was accompanied by statistically significant increase of winds from NW and a drop in calms.

During the Hornsund station record changes of wind velocity were small (Table 16.2). Statistically significant trends of mean monthly wind velocity occurred in May, June and November. The strongest trend was in May (Fig. 16.22), amounting to 0.048 m·s^{-1} per year, meaning that during the 31 years mean wind velocity increased by 1.5 m·s^{-1} in this month. In June increase of wind velocity in the research period may be estimated at 1.3 m·s^{-1}, and in November at 1.0 m·s^{-1}. Changes of mean wind velocity in May and June were negatively associated with frequency of westerly winds and positively with frequency of easterly winds.

Table 16.2. Values of trend coefficients of monthly wind velocities at the Hornsund station in 1978–2009 and their statistical characteristics.

Month	Trend coefficient	p <	adj. R^2
January	0.018(±0.022)	0.420	-
February	0.041(±0.029)	0.174	0.032
March	0.005(±0.027)	0.848	-
April	0.013(±0.025)	0.594	-
May	**0.048(±0.021)**	0.026	0.135
June	**0.041(±0.018)**	0.031	0.125
July	0.019(±0.016)	0.236	0.016
August	0.001(±0.020)	0.965	-
September	0.024(±0.020)	0.233	0.016
October	0.034(±0.019)	0.088	0.066
November	**0.033(±0.013)**	0.019	0.147
December	0.028(±0.022)	0.200	0.023
Year	**0.024(±0.008)**	0.005	0.229

Explanations: p – level of statistical significance of trend coefficient, adj. R^2 – determination coefficients adjusted to the number of degrees of freedom. Trend coefficients statistically significant shown in **bold**. Standard error of estimate is given in brackets, after the trend coefficient.

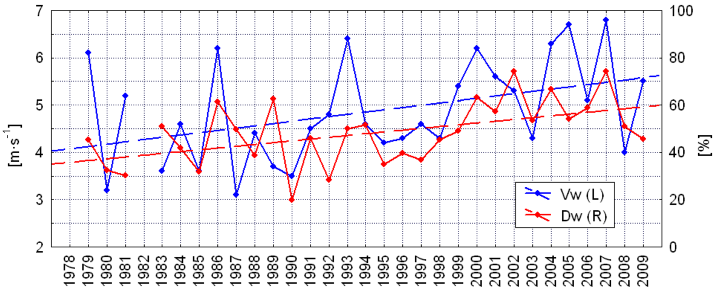

Fig. 16.22. Changes of wind velocity (Vw; m·s^{-1}) and frequency of occurrence (Dw; %) of easterly wind in May, 1978-2009.

In other months trends in wind velocity were insignificant; however, there is some regularity in values of the trend coefficients. In July and August, coefficients were close to zero while in the months of the cool season of the year, excluding January, they were relatively big. Beginning at the end of summer trend coefficients of mean wind velocity regularly increased, reaching a maximum in February, next decreasing during the equinox, to increase again in the spring when in May they reached statistical significance. Such a distribution of values of monthly trends of wind velocity reflects the increase of intensity of atmospheric circulation occurring during the research years.

The accumulation of both significant and insignificant positive monthly trends is the reason for the occurrence of a highly significant positive trend in the mean annual wind velocity. Its value amounted to 0.024 $m \cdot s^{-1}$ per year, which indicates that during the 31 years mean wind velocity increased by 0.74 $m \cdot s^{-1}$. This trend explains 23% of the annual variation of wind velocity over the period. In the seasonal depiction a statistically significant trend of mean wind velocity occurred only during the autumn (September -November); the value of this trend was 0.031 $m \cdot s^{-1}$ per year, showing that during the 31 years mean wind velocity increased by 1.0 $m \cdot s^{-1}$.

16.4. Changes of cloudiness, sunshine duration and horizontal visibility

Different chapters of this book have mentioned changes of these climatic parameters, which to a large extent are interconnected. Here a summary of the established changes will be presented. The basic changes and variability of insolation, to a large extent also of air temperature, the totals of atmospheric precipitation and horizontal visibility, reflect the changes and variability in cloudiness. The cloudiness in the research period, 1978–2009, showed a weak, insignificant rising trend of +0.008 octas per year.

Over the record of annual values of general cloudiness, three years stand out, being simultaneously characteristic and limiting. These were: 1984, when cloudiness reached the highest value (6.4 octa) in the history of observations at Hornsund, 1988 – in which cloudiness reached the lowest values (5.2 octa); the period 2004–2006 in which cloudiness was distinctly higher than average (6.2–6.1 octa).

Over 1979–1984 cloudiness increased to the moment when the highest value in the history of observations was recorded. Between1984 and 1988 cloudiness abruptly decreased, to increase again to higher than the multiannual mean for two consecutive years. Between 1990 and 2003 annual cloudiness varied in the range of ±0.2 octa, oscillating around a mean value of 5.8 octa and not showing any trend of change during these many years. In 2004 there was a distinct increase of cloudiness, which remained at an elevated level over the next two years (Fig. 16.23). Changes of cloudiness during the investigated period were in the good agreement with changes of annual air temperature. Annual temperature in turn is controlled by changes of the water temperature of the Greenland Sea (Chapter 9.5) and local atmospheric circulation. Cloudiness also influences air temperature.

Variability of meridional atmospheric circulation is the main controller of interannual variability of cloudiness (Fig. 16.24), increase of frequency of air flow from the south being favourable for increase of the cloudiness. During the research period values of the meridional circulation S index did not show any trend but, as may be seen in Fig. 16.24, there is also quite good conformity between the sequence of cloudiness and values of the S index. The reason for this is increased

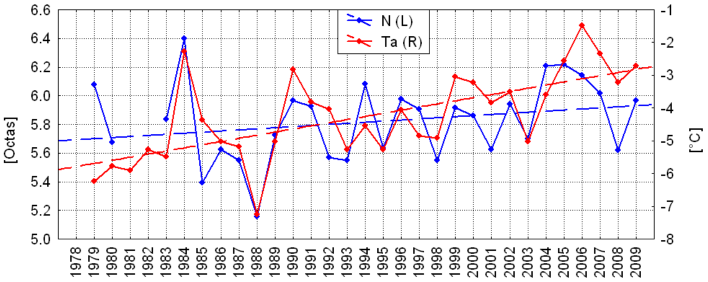

Fig. 16.23. The course of annual cloudiness (N; octas) and air temperature (Ta; °C) at the Hornsund station and their trends, 1978–2009.

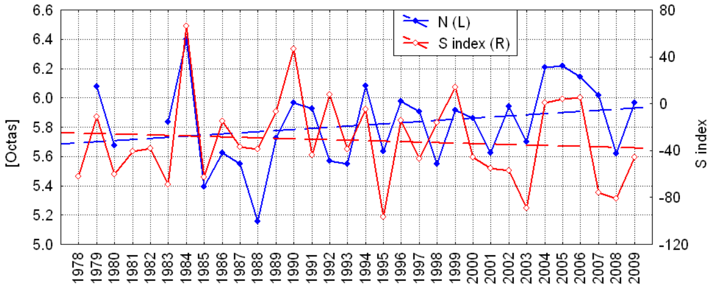

Fig. 16.24. Annual cloudiness (N; octas) at the Hornsund station and values of Niedźwiedź zonal circulation S index and its trends, 1978–2009.

inflow of water vapour from the south, and also of that from the surface of the Greenland and Barents Seas close to Spitsbergen. In a multiple regression equation in which cloudiness (N) is the dependent variable, the S index and annual SST of the Greenland Sea over the axis of the West Spitsbergen Current (grid 76°N, 10°E) are independent variables, the latter variables combined to explain 36% of annual cloudiness variation, meridional circulation explaining ~21%, and SST around 15% of the variation[1]. It cannot be ruled out that in the increase of cloudiness recorded at Hornsund, the increasing proportion of inflow of air from the south interacted with an additional factor, the specific location of the station which is favourable for the formation of orographic clouds when winds are southerly. Besides the meridional circulation the cyclonicity C index characterizing activity of low-pressure systems over Spitsbergen also has an influence on cloudiness. In the recording period the value of this index increased +1.82 per year (Fig. 16.25), although this was statistically insignificant. Variability of the annual C index explained around 20% of variation of cloudiness. With increase of cyclonicity there is increase in frequency of low-pressure systems together with concurrent fields of cloudiness.

Together with the statistically weak increase of cloudiness, the number of cloudy days increased also (+0.5 day per year) and number of clear days decreased (–0.5 day per year). Decrease of number of clear days during the year was statistically significant ($p < 0.023$). Considering monthly distribution, the strongest decrease of clear days occurred in March (–0.12 day per year, $p < 0.033$) as well as in November (–0.10 day per year) and December (–0.13 day per year).

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[1] Estimation of both regression coefficients in this equation is statistically significant at $p < 0.01$.

Insolation is controlled by variability of cloudiness. Variability of annual cloudiness explained 34% of variability of annual insolation, even though the duration of insolation is shorter than a full year. In the course of annual insolation there is a weak, statistically insignificant decreasing trend (–2.1 hour per year). In particular months the strongest reductions of insolation were in May (–0.9 hour per year), as well as in June and July (–0.5 hour per year). February (+0.1 hour per year), September (+0.4 hour per year) and October (+0.2 hour per year) were months in which there was an increase of insolation. Comparing trends in insolation with the Niedźwiedź indices of atmospheric circulation (1992, 2001, 2006) one finds a strong relation (R = 0.73, adj. $R^2 = 0.51$, $p < 0.0000$) with the C index of cyclonicity. It is suggested that the main factor causing a trend to decreased insolation is increase of cloudiness connected with the increased low-pressure system activity over Spitsbergen during the research period (Fig. 16.25).

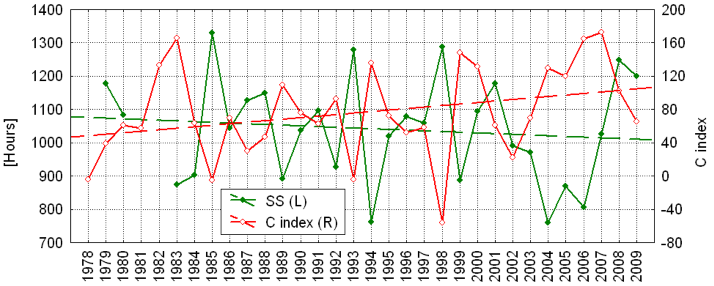

Fig. 16.25. Annual values of sunshine duration (SS; hours) at the Hornsund station and the cyclonicity C index of Niedźwiedź and its trends in 1978–2009.

The record of horizontal visibility does not show any clear trends. The number of days with fog increased somewhat (+0.32 day per year) but this was not statistically significant. During a year changes of number of days with fog showed weak, although statistically significant, positive associations with cloudiness in January, April, October and November. Changes of cloudiness explained from 18% in April to 12% in October of the variation of number of days with fog. The associations of days with fog with air temperature showed a similar temporal distribution. Changes of number of days with fog significantly correlated with changes of air temperature in January, April, May, July, September and November. In addition, these associations explained only small percentage (10–18%) of variability of number of days with fog. Comparing fog days with the Niedźwiedź indices of atmospheric circulation there are positive, statistically significant associations with the index of meridional circulation in January, April, September and November. The main controller of interannual variability of number of days with fog was variability of meridional atmospheric circulation, like the case of cloudiness. This circulation is favourable for the inflow of warm and humid air to Hornsund, which cools rapidly when touching the cold water of the fjord. This leads to the formation of advective fog. Because of the strong local modification of wind directions at the station caused by the topography when there is flow from differing directions across the forefield of Hornsund, the statistical associations of number of foggy days with wind directions were also weak. Observations of fog formation from the sea during the navigation season seem to show in the station vicinity there are distinct associations with wind direction and wind velocity over the fjord and its forefield.

The weak, statistically insignificant increase of cloudiness and similarly weak changes of insolation connected with it merge in the warming that was observed. Considering reasons of these changes, we may state that processes of atmospheric circulation play the main role in forcing of changes of cloudiness and insolation. Other factors strongly influencing increase of air temperature, such as increase of sea surface temperature or changes of sea ice cover are of secondary importance in the case of these climatic parameters.

16.5. Changes of air temperature

Changes of air temperature at Hornsund were already of interest 20 years ago. The first paper on this subject was by Wielbińska (1992) who investigated changes of annual temperature, finding a positive sub trend in the 13–14 years record, 1978–1991. Later, Kierzkowski (1996) used the somewhat longer sequence from 1979–1995 to confirm the positive trend, which was estimated at +0.097°C· yr^{-1}.

For the present work, 1979–2009, a systematic increase of air temperature was observed in all months of the year. This indicates that the general trend for warming of the Spitsbergen region is continuing. Estimation of the trend coefficients however, shows that these trends are statistically significant for eight of the months only (Table 16.3).

Table 16.3. Values of monthly and annual trend coefficients of air temperature
at the Hornsund station,1979–2009, and their statistical characteristics.

Month	Trend coefficient	adj. R^2	p <	*Tau* of Kendall	p <
January	**+0.185 (±0.077)**	0.1395	0.0219	**0.2540**	0.0447
February	**+0.131 (±0.061)**	0.1061	0.0413	**0.2657**	0.0358
March	+0.034 (±0.063)	0.0000	0.5936	0.0302	0.8113
April	+0.099 (±0.062)	0.0497	0.1199	0.1249	0.3237
May	**+0.072 (±0.022)**	0.2371	0.0032	**0.3772**	0.0029
June	**+0.047 (±0.012)**	0.3116	0.0007	**0.3926**	0.0019
July	+0.016 (±0.010)	0.0437	0.1304	0.1391	0.2633
August	**+0.023 (±0.010)**	0.1268	0.0258	**0.2811**	0.0238
September	**+0.050 (±0.023)**	0.1003	0.0432	0.1966	0.1139
October	+0.054 (±0.037)	0.0337	0.1590	0.1700	0.1714
November	**+0.185 (±0.064)**	0.1938	0.0068	**0.3030**	0.0148
December	**+0.225 (±0.069)**	0.2363	0.0028	**0.4162**	0.0008
Year	**+0.096 (±0.021)**	0.4031	0.0001	**0.5140**	0.0000

Adj. R^2 – determination coefficient adjusted for number of degrees of freedom, p – level of statistical significance of trend coefficient. Trend coefficients statistically significant shown in **bold**.
In parentheses after trend coefficients the standard error of estimate is given.

The strongest and most statistically significant increase of air temperature was observed in December. The real value of the trend in this month was in the range, 0.156–0.294°C· yr^{-1}, with the most probable value being 0.22–0.23°C· yr^{-1}. This means that air temperature in December increased 2.2–2.3°C over ten years. The occurrences of statistically significant positive trends of air temperature were concentrated in three periods – in the winter (November, December, January and February), the spring (May and June) as well as August and September.

The period of occurrence of stronger trends in the course of air temperature started at the beginning of winter (November) and lasted until February. Such a distribution of trend coefficients during the winter is the cause of the shift of annual minimum of air temperature at Hornsund from the first half of the winter to its end already mentioned earlier (see Chapter 9.2 and Fig. 16.26).

Up to 2006 a very strong, statistically significant, positive trend of air temperature (+0.177°C· yr^{-1}) occurred for April, yielding an increase of temperature of this month in 1978–2006 from around 1°C to nearly 2.5°C per 10 years. After the shift of the annual minimum temperature to April in 2007 and 2009 and the very low temperature for this month that was recorded in 2007 (Table 18.16), the trend calculated for 1978–2009 was decreased nearly two times to merely +0.099°C· yr^{-1} and became statistically insignificant (Table 16.3).

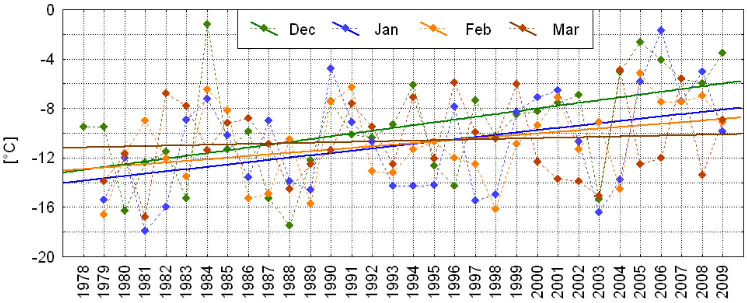

Fig. 16.26. Inclinations of the trend lines of monthly air temperature (°C) of successive months from December to March at Hornsund in 1978–2009. Values of trends are given in Table 16.3.

Statistically significant trends, although weaker than in the winter, occurred in the spring season, May and June. A relatively weak trend in June (+0.047°C· yr^{-1}) was however highly significant ($p < 0.0007$) and explained around 31% of air temperature variation in this month.

The trend in July was not significant whereas in August it became significant (+0.023°C· yr^{-1}) again and explained around 13% of observed variability. Occurrence of a positive trend in this month that was stronger than in July shows that in the final years of the research period the mean August temperatures slowly came to approximate those of July.

Assessment of the significance of temperature trends in particular months using the Kendall *tau* test shows its general conformity with assessment by a t test. The Kendall *tau* test trend for September however has a lesser significance, $p < 0.15$ (level of confidence = 15%; Table 16.3). Other tests of significance of estimation of trend coefficients give results similar to those obtained by the t test.

The cumulative significant and insignificant positive monthly trends in the course of annual temperatures yield the highly significant trend reported in Chapter 9.1. Its true value may be estimated to be in the range from 0.075 to 0.117°C· yr^{-1}. This trend explains over 40% of annual temperature variation in the investigated period (see values of adjusted determination coefficients – adj. R^2 in Table 16.3).

Calculations of air temperature trends for "seasons of the year" or climatic seasons show that the strongest increase at Hornsund occurred in the winter (December-February). Its value in 1978–2009 was +0.179(±0.054)°C· yr^{-1} and explained 25% of winter temperature variation for the research period. The winter trend is highly significant statistically ($p < 0.002$). This determines that the real increase of temperature, December-February, is within the range of 1.3 to 2.3°C per 10 years. The second strongest correlation of trend coefficient to trend is in the autumn. Temperature in September-November increased 0.096(±0.030)°C· yr^{-1}. This trend coefficient is highly significant statistically ($p < 0.003$), and the trend explains 23% of autumn temperature variation over 1978–2009. The real increase of air temperature during the autumn is in the range from 0.07 to 0.13°C· yr^{-1}, i.e. 0.7 to 1.3°C per 10 years. The rate of air temperature increase trend in the spring (March-May) is in third place. Its values (+0.068(±0.035)°C· yr^{-1}) are smaller than the autumn trend and are not statistically significant ($p < 0.058$); they explain around 9% of air temperature variation during the spring. The trend in the summer (June-August) explains the greatest percentage of temperature variation in this period (28%), despite its value being the smallest among all seasonal trends (+0.029(±0.008)°C· yr^{-1}); it is highly significant statistically ($p < 0.0014$). In sum, at Hornsund, 1979–2009, all climatic seasons except the spring were characterized by statistically significant increases of the air temperature.

Occurrence of strong, statistically significant positive trends of air temperature in the spring (March-May) is reported in numerous papers on changes of climate in the Arctic. Rigor *et al.* (2003, Fig. 9, section Spring) estimated this trend in the Spitsbergen region to be ≥ 2.5°C per decade[2]. Occurrence of strongest positive temperature trends in the spring may distinguish the latest period of warming of the Arctic from the warming in the 1930s and ‘40s, when the strongest seasonal positive trends were recorded during the winter (December-February; e.g. Przybylak 2003, Johannessen *et al.* 2005). Trends at the turn of autumn to winter (November-December) were not in general discussed in these papers. In calculations of seasonal trends for the autumn (September-November) and winter (December-February) one of these months goes into the autumn average column, the other into the winter average. As a result, statistically significant trends in particular months may be lost in the insignificant trends of other months assigned to these seasons of the year.

In the Arctic temperature trends during the winter are found to be quite strong, but weaker than trends during the spring. Autumn trends are in general very weak and statistically not significant. Rigor *et al.* (2003) for all Spitsbergen estimated the autumn trend as close to zero (in the range from –0.5 to +0.5°C per decade), and for northern Spitsbergen even as negative (–1.5 to –0.5°C per decade). It must be noted that there are substantial differences between the results of seasonal analysis of trends of air temperature at Hornsund in the present report and the statements in the literature.

Similar discrepancies are found when comparing trends in annual temperature. For a similar period (1976–2001) Forland and Hanssen-Bauer (2003) gave values of trends of annual air temperature at the Svalbard-Lufthavn station of +0.078°C, at Hopen +0.084°C, at Svea[3] as much as +0.184°C· yr^{-1}. Polyakov *et al.* (2003) estimated the long-term (1875–2000) trend of air temperature in the Atlantic Arctic to be +0.094°C per 10 years.

Comparison of values and temporal trends of air temperature at Hornsund with the earlier literature appears to be not very useful here. The value of a trend is very strongly dependent on its

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[2] On the basis of data for 1979–1997.

[3] Values of trends from other stations were omitted, being statistically not significant according to these authors.

location in time, the beginning and end of the series for which the trend is calculated. Seemingly insignificant changes of the length of the observational sequence and/or shift in its location in time result in trend coefficients that are not strictly comparable, either in the values or the statistical characteristics. Only trends calculated strictly for the same periods should be compared.

Values of air temperature trends from the surrounding stations for precisely the same calendar period are not found in literature. Therefore values of trends at Hornsund and stations in the neighbourhood – Björnöya, Hopen, Svalbard-Lufthavn, Barentsburg, Svea and Ny Ålesund for the specific timespan 1979–2009 are estimated here. Trends of temperature were calculated for the calendar year and for the natural thermal seasons distinguished earlier (Chapter 9.4) to be consistent with main features of the course of the thermal year at Hornsund. The winter is understood in this division as the period from December to April inclusive (five months), the spring as May and June (two months), the summer is limited to July and August (two months) and the autumn lasts from September to November (three months). With such "natural seasons" of variability in air temperature having been assigned, we may also expect to obtain a different distribution of trends of seasonal air temperatures than are described in numerous other papers.

For 1979–2009 the trend of annual air temperature at Hornsund was +0.096(±0.021)°C· yr^{-1}. Trends greater than at Hornsund and everywhere highly statistically significant occurred at Hopen (+0.133(±0.028)°C· yr^{-1}) and Svalbard-Lufthavn (+0.124(±0.025)°C· yr^{-1}). Almost the same as at Hornsund was the trend at Barentsburg (+0.098(±0.022)°C· yr^{-1}). Annual trends at Ny Ålesund (+0.091(±0.021)°C· yr^{-1}), Björnöya (+0.082(±0.019)°C· yr^{-1}) and Svea (+0.082(±0.023)°C· yr^{-1}) were somewhat weaker than at Hornsund.

The temperature trend at Hornsund during the thermal "winter" (December-April) was positive (+0.134(±0.037)°C· yr^{-1}) and statistically significant ($p < 0.001$). Greater than at Hornsund, positive and everywhere statistically significant winter trends occurred over the same time at Ny Ålesund (+0.131(±0.040)°C· yr^{-1}), Svalbard-Lufthavn (+0.170(±0.047)°C· yr^{-1}), Barentsburg (+0.149(±0.043)°C· yr^{-1}) and Hopen (+0.190(±0.052)°C· yr^{-1}). Only at Björnöya (+0.107(±0.032)°C· yr^{-1}) and at Svea (+0.113(±0.045)°C· yr^{-1}) were the rates of increase during the winter smaller than at Hornsund, although the differences were statistically insignificant. The spring (May-June) is also characterized by a positive trend in air temperature. At Hornsund the trend was +0.060(±0.016)°C· yr^{-1} and was significant at $p < 0.001$. Trends higher than at Hornsund were observed at Svalbard-Lufthavn (+0.093(±0.020)°C· yr^{-1}), Hopen (+0.074(±0.017)°C· y r^{-1}), Ny Ålesund (+0.069(±0.019)°C· yr^{-1}), Barentsburg (+0.068(±0.018) °C· yr^{-1}) and Björnöya (+0.066(±0.020)°C· yr^{-1}). Only at Svea (+0.052(±0.019)°C· yr^{-1}) was the rate of increase of air temperature smaller. Throughout the region ”spring” trends were statistically significant.

During the thermal "summer" (July-August) the temperature trend at Hornsund was positive and statistically significant (+0.020(±0.009)°C· yr^{-1}, $p < 0.041$; Fig. 16.27). Of the nearby stations only Svea was very similar (+0.026(±0.012)°C· yr^{-1}; $p < 0.043$). At Ny Ålesund (+0.031(±0.013)°C· yr^{-1}), Barentsburg (+0.036(±0.016)°C· yr^{-1}), Björnöya (+0.039(±0.016)°C· yr^{-1}), Hopen (+0.052(±0.014)°C· yr^{-1}) and the Svalbard-Lufthavn station (+0.054(±0.015)°C· yr^{-1}) the summer trends were higher, and also stronger in statistical significance. At the two latter stations the summer trend was more than two times greater than at Hornsund.

During the autumn (September-November) the air temperature trend at Hornsund was considerably higher than during the summer (+0.097(±0.032)°C· yr^{-1}) and statistically significant

($p < 0.005$). Trends stronger than at Hornsund were recorded at Hopen (+0.118(±0.039)°C· yr^{-1}) and Svalbard-Lufthavn (+0.104(±0.035)°C· yr^{-1}), weaker than at Hornsund at Svea (+0.087(±0.040)°C· yr^{-1}), Björnöya (+0.076(±0.024)°C· yr^{-1}), Ny Ålesund (+0.070(±0.033)°C· yr^{-1}), and Barentsburg (+0.063(±0.033)°C· yr^{-1}) where this trend is statistically insignificant.

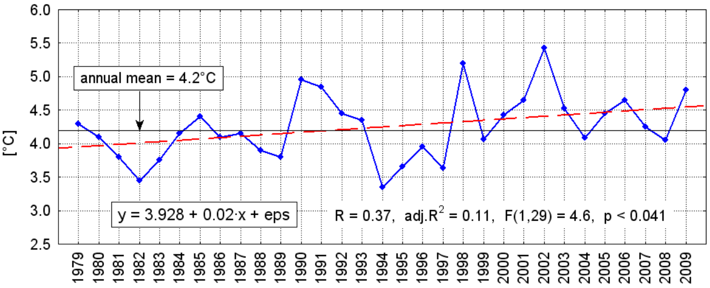

Fig. 16.27. The mean air temperature (°C) during the thermal summer (July-August) and its trend.

For 1979–2009 the air temperature trends at Hornsund were thus positive and statistically significant in all thermal seasons (Fig. 16.28). The strongest trend occurred in the winter, a not much weaker trend (or taking into account the standard error of estimation of trend, almost the same trend) was detected in the autumn. The trend in the spring, although mentioned in the literature as the strongest among seasonal trends, was weaker than trends of both the winter and autumn (Table 16.4). Stronger increase of air temperature during the autumn than in the spring was found not only at Hornsund but also throughout the whole region. The weakest, but still statistically significant, air temperature trend occurred during the summer, both at Hornsund and throughout the region.

Table 16.4. Coefficients of trends of air temperature (°C·yr^{-1}) and standard errors of estimate (values in parentheses) for the thermal seasons at Hornsund and surrounding stations in 1979–2009. Trends statistically not significant ($p > 0.05$) are marked with an asterisk.

Station	Winter (Dec-April)	Spring (May-June)	Summer (July-Aug)	Autumn (Sep-Nov)
Ny Ålesund	+0.131(±0.040)	+0.069(±0.019)	+0.031(±0.013)	+0.070(±0.033)
Barentsburg	+0.149(±0.043)	+0.068(±0.018)	+0.036(±0.016)	+0.063(±0.033)*
Svalbard-Lufthavn	+0.170(±0.047)	+0.093(±0.020)	+0.054(±0.015)	+0.104(±0.035)
Svea	+0.113(±0.045)	+0.052(±0.019)	+0.026(±0.012)	+0.087(±0.040)
Hornsund	**+0.134(±0.037)**	**+0.060(±0.016)**	**+0.020(±0.009)**	**+0.097(±0.032)**
Björnöya	+0.107(±0.032)	+0.066(±0.020)	+0.039(±0.016)	+0.076(±0.024)
Hopen	+0.190(±0.052)	+0.074(±0.017)	+0.052(±0.014)	+0.118(±0.039)
Jan Mayen	+0.092(±0.025)	+0.064(±0.014)	+0.072(±0.011)	+0.063(±0.018)

From the review of seasonal trends presented in Table 16.4, it is apparent that changes of temperature occurring at Hornsund are not some peculiarity of this station but match the changes throughout the region. Occurrence of the strongest trends in those periods in which insolation is restricted (autumn, winter) attracts our particular attention. The same results were obtained when comparing trends in "natural seasons" and the popular “typical” climatic seasons (December-February and March-May).

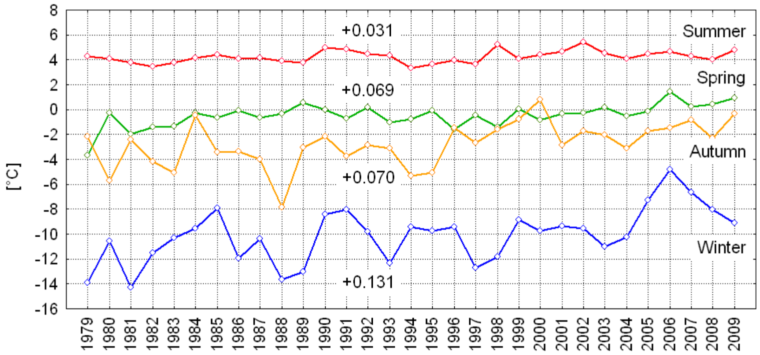

Fig. 16.28. The mean temperatures of the "natural" thermal seasons [°C yr^{-1}] at Hornsund, 1979–2009. Winter (December-April), spring (May-June), summer (July-August), autumn (September-November).

Over 1979–2009 the strongest warming in the Spitsbergen region was during the winter and autumn, that is from September to February if applying the widely-accepted seasonal division of year, or from September to April inclusive if taking the natural thermal seasons. Such temporal distribution of the trends is consistent with the main processes determining variability of air temperature at Hornsund, that is changes of sea surface temperature and sea ice cover (discussed in Chapter 9.5) and their final product of heat flux from the ocean to the atmosphere, and with atmospheric circulation.

16.6. Changes of precipitation

Besides general trends, changes of climatic conditions may also include short-term trends and the significant changes of parameters year to year. In this chapter the multiyear variability of the basic precipitation indices – totals of precipitation during a year, in the accumulation period and in subsequent seasons, with divisions for liquid, solid and mixed precipitation, will be characterized. Changes of frequency of occurrence of these phenomena will also be analysed.

16.6.1. The multiannual variability of precipitation totals

In the multiyear sequence (1979–2009) of annual totals of atmospheric precipitation at Hornsund, a few characteristic periods may be distinguished. In the first, encompassing the period from the beginning of observations to 1988, annual totals were distinctly lower than in later years. In this period the highest annual precipitation (1982) only insignificantly exceeded the 30-year mean value (434.4 mm), and amounts in the other years rarely exceeded 350 mm; the lowest annual total precipitation of 230.2 mm was recorded in 1987 and the total of 260.3 mm in 1979 was also exceptionally low. In the following period, 1989–2000, annual totals of precipitation in the driest years were not much lower than the 30-year mean value and in the wettest years exceeded 500 mm. The highest were in 1996 (635.9 mm) and in 1994 (600.0 mm). The characteristic feature of the variability of annual precipitation at Hornsund in 1987–1996 was a clear rising trend. After 2000 annual totals of precipitation increased again, but at a slower rate in principle to the end of the observation period (Fig. 16.29).

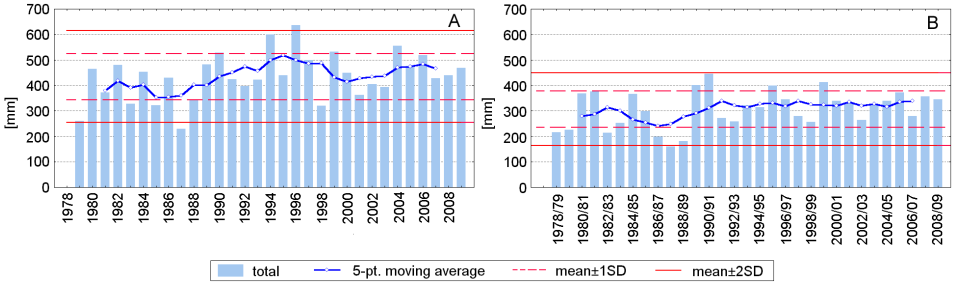

Fig. 16.29. Multiannual pattern of precipitation totals: annual (A) and during the accumulation period (B) at Hornsund in 1978–2009.

In the period from the end of the ‘70s to the beginning of the ‘90s total precipitation in the accumulation period, like the annual total, was lower than the mean value relatively often (when standard deviations are subtracted). From the beginning of the ‘90s to the end of the observations total precipitation in the accumulation period was not characterized by distinct changes; there are not even short term trends, as is seen in the curve of moving averages fluctuating around 330 mm (Fig. 16.29).

At Hornsund, each season displays a different temporal pattern of precipitation. The spring season (March-May) usually contributes the smallest amount to the annual total and is also characterized by the least variability of precipitation year after year (coefficient of variability = 38.1%). The highest total spring precipitation at Hornsund was 153.7 mm (1982) and the lowest 37.3 mm (1999), a range of variability of 116.4 mm. Totals for the spring in 1979 (37.5 mm) and 2008 (39.8 mm) and 134.3 mm in 2004 may also be classified as extreme. The most evident feature of multiannual variability of spring precipitation is its downward trend in 1982–1999. The period 1997–2004 is noteworthy because there was a sequence of spring seasons with low totals of precipitation (<60 mm) and small interannual variability. In the final years of observation spring precipitation totals were again low, with values close to the 30-year mean with the standard deviation subtracted (Fig. 16.30).

In the multiyear record of summer (June-August) and autumn (September-November) precipitation distinct rising trends dominated, occurring in 1985–1994 and 1982–2000 respectively. The next common feature in the pattern of these seasons is the small variability of precipitation totals over 2002–2006 (Fig. 16.30).

In the autumn it is also worth noting the period, 1989–2001, when totals oscillated around 200 mm many times, significantly exceeding the mean. In that period, also, the highest autumn total precipitation was recorded at Hornsund, 312.3 mm in the autumn of 1999. The last three autumn seasons (2006, 2007 and 2008) were relatively wet, around 200 mm.

An interesting period in relation to multiannual variability of summer precipitation is 1993–2001, which was characterized by exceptionally great changeability of the totals (Fig. 16.30). A good example is the sequence1993–1996, when the sequence of total summer precipitation was 66.1 mm (1993), 316.0 mm (1994), 73.5 mm (1995) and 233.9 mm (1996). Between 2004 and the end of the investigation summer precipitation totals have distinctly decreased.

In the multiannual pattern of precipitation in the winter season (December-February) some short-term trends appeared at the beginning. However, analysis of the succeeding years permits

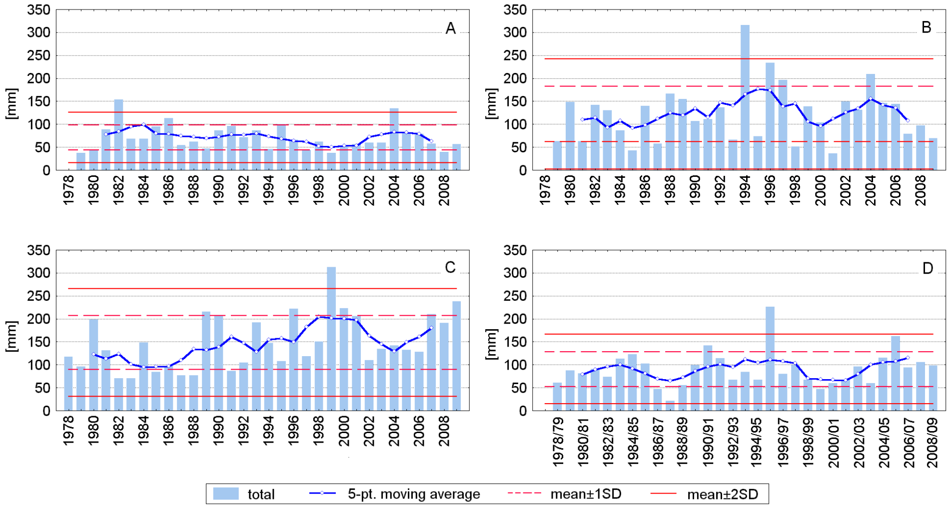

Fig. 16.30. Multiannual course of seasonal precipitation totals at Hornsund in 1978–2009.
A – Spring (March-May), B – summer (June-August), C – autumn (September-November),
D – winter (December-February).

a division of the entire observation period into just two sub-periods. During the first, encompassing the seasons from 1978/79 to 1991/92, precipitation oscillated around the multiannual mean but was distinctly higher than in the second period. Moreover, significant decrease of winter precipitation was recorded in the second half of the ‘80s, especially low totals appearing during three successive winters – 1986/87 (46.5 mm), 1987/88 (21.4 mm) and 1988/89 (55.9 mm). During the second sub-period, beginning in the winter of 1992/93, precipitation was mostly lower than the mean, with the exception of a few seasons (5 of 14 seasons). However among this series of winters of generally lower than average precipitation, the highest total precipitation of the whole observation period occurred in the winter of 1995/96. In the first five years of the 21st Century total winter precipitation at Hornsund increased (Fig. 16.30), and in the last three seasons (i.e. from the winter of 2006/07) reached around 100 mm and was a little higher than the mean (93.4 mm).

16.6.2. Variability of rainfall and snowfall totals

The trend of totals in liquid, mixed and solid precipitation shows changes in the proportions of precipitation at Hornsund, both during the accumulation period and over the full year. Considering the calendar year first, we may note that from the beginning of the observation period to around 1984, at Hornsund the biggest share in the annual precipitation occurred as snowfall and the smallest was mixed precipitation. In the middle of the ‘80s annual totals were low but mixed precipitation distinctly predominated over both liquid and solid. From the end of the ‘80s to 2005 continuously, rainfall has contributed the biggest part of the annual total. Since 2006 mixed precipitation once again has constituted a somewhat bigger share of the annual total than liquid precipitation. Amongst the most crucial features of multiannual variability of liquid precipitation was a very distinctly marked small share in the annual total from the beginning of observations in 1979 (38.4%) to 1985 (19.1% of annual total), and next a persistent rising trend. At the end of 20th

Century, the share of rain in the annual total exceeded 50% and was maintained at this level at the beginning of the new century. In 1999 liquid precipitation contributed as much as 61.3% of annual precipitation. Since the beginning of the 21st Century, the share of liquid precipitation has gradually decreased and in 2009 was only 32.1% of annual precipitation. Both liquid and mixed precipitation have been characterized by downward trends, but this is exceptionally strong and persistent in the case of solid precipitation. The maximum share of snowfall to the annual total (58.1%) was recorded in 1982 and minimum (14.7%) in 1999. Since 2001 snowfall has averaged around 23% of annual total precipitation. The share of mixed precipitation in the annual total also decreased when averaged over the research period, yet was characterized by a bigger range of changes (from 8.7% in 1982 to 49.9% in 1998) and more frequent changes of directions of short-term trends than the snowfall (Fig. 16.31). A consistent and rapid increase of the share of mixed precipitation in the annual total of precipitation since 2000 should be noted. The same trends in changes of type of precipitation occurring at Hornsund were described by Førland and Hanssen-Bauer (2003) for the Norwegian Arctic.

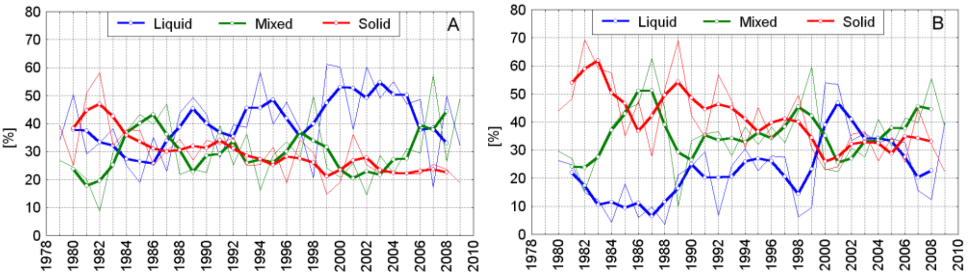

Fig. 16.31. Multiannual course (moving average of 3 points) of percentage [%] of solid, liquid and mixed precipitation at Hornsund in the annual total (A) and in the accumulation period (B), 1978–2009.

From the point of view of glaciology, temporal changes of the proportions of different types of precipitation are especially significant during the accumulation period. During the first half of instrumental measurements at Hornsund, i.e. from 1978/79 to the 1993/94 season the largest share of precipitation fell to the ground in the form of snow. The only exceptions were the 1984/85 and 1986/87 seasons, when mixed precipitation was predominant. The 1994/95 season marks the beginning of a time in which percentages of different precipitation over the full accumulation period starts to change significantly. From 1994/95 to 1998/99 alternatively the biggest part of the precipitation fell as snow or mixed precipitation in successive accumulation seasons. Without question in the majority of years from 1978/79 to 1998/99, rainfall contributed the smallest share during the accumulation period. Quite exceptional therefore were the seasons at the end of the last century (1999/00 and 2000/01), in which rainfall was dominant. Since 2004/05 the biggest share of precipitation in the accumulation period has been mixed precipitation (Fig. 16.31).

The years 2001/02–2006/07 are also an Interesting period, when shares of particular types of precipitation over the entire accumulation period displayed little variability year to year, especially in the case of rainfall. The characteristic feature in the initial seasons of the new century (to around 2004/05-2005/06) was the year-to-year change in type of dominant precipitation. In the multiyear record of the accumulation period, a gradual decrease of the share of solid precipitation is seen, from 64.1% of entire total in the season 1981/82 to 22.1% in the season 2008/09. Liquid precipitation is characterized by changes in the opposite direction, but they are less smooth in comparison to snowfall. Rain contributed the smallest part of precipitation in the accumulation season in the first half of the ‘80s (around 10% of entire total). Since the second half of the ’80s, its share increased until the end of the 20th Century, when the highest value, 46.9% of the total, was recorded. In this period one exception was the 1997/98 season, when liquid precipitation made up only 14.8% of the total. The share of rain in the accumulation season has gradually decreased since 2001/02 (Fig. 16.31).

The contribution of mixed precipitation to accumulation season totals increased from the beginning of the programme to the mid ‘80s, changing from 21.4% to 52.1%. It then decreased again to 26.4% at the end of ’80s.In the remaining part of the record it was characterized by smaller (1990/91–1995/96) or bigger (1996/97–2000/01) ranges of changes year to year (Fig. 16.31). The downward trend of the share of rainfall in the accumulation season after 2000/01, noted earlier, was accompanied by a distinct increase of the share of mixed precipitation.

16.6.3. Variability of the number of days with precipitation > 0.0 mm

At Hornsund the annual number of days with precipitation > 0.0 mm (i.e. including trace precipitation) ranged from 200 days (1980) to 275 days (1990) and during most of the investigated period varied within one standard deviation (±σn) of the mean. Up to the beginning of the ‘90s the annual number of precipitation days distinctly increased, then later (to 2002) showed a definite downward trend. Over 2002-2009 mean number of days with precipitation > 0.0 mm (250.9 days) was higher than the multiannual mean by around 10 days. The rainiest years at Hornsund were those in the first half of the 1990s (Fig. 16.32).

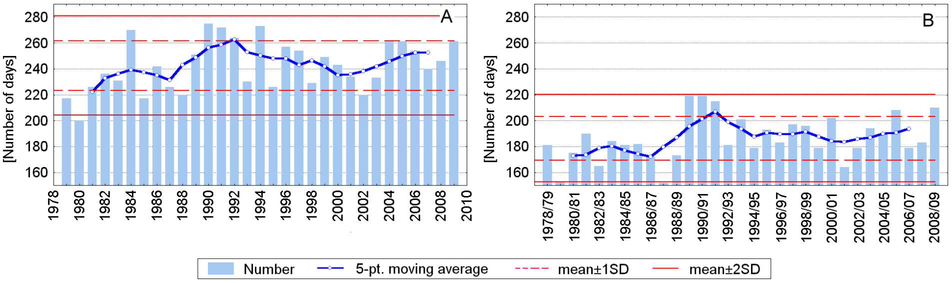

Fig. 16.32. Multiyear pattern of number of days with precipitation > 0.0 mm at Hornsund during the year (A) and during the accumulation season (B), 1978–2009.

Similar features of variability characterize the number of precipitation days during the accumulation period and spring season. During the former there were on average 186.4 days with precipitation > 0.0 mm. The maximum (219 days) was recorded in the seasons of 1989/90 and 1990/91. During 1978/79–2008/09 the accumulation period divides into two sub-periods, 1978/79–1988/89 and 1993/92–2008/09, which differ clearly by their mean values (173.5 days and 189.8 days, respectively). During the spring at Hornsund on average there were 58.1 days with precipitation > 0.0 mm. During the wettest spring, 1992, precipitation was recorded on 78 days. During the spring of 1980, the least wet, it was limited to 40 days. In the other seasons, the precipitation index displays individual features of multiannual variability similar to the case of precipitation totals.

The number of days with precipitation during the summer varied from 38 (1990) to 77 (1994), a range of 39 days. These values may be regarded as extreme because they exceed then range of the mean plus two standard deviations. Further, the greatest number of days with precipitation > 0.0 mm were recorded in the ’90s, which was also characterized by the biggest variability year to year. Over the summer season, a downward trend dominated during the years 1982–2003. Number of precipitation days in the autumn increased from the beginning of regular measurements at Hornsund until the end of 20th Century, but during this period both the lowest (49 days in 1982) and the highest (79 days in 1989) number were recorded. The general rising trend of number of days with precipitation > 0.0 mm during the final decades of the 20th Century (1979–2000) was interrupted by a relatively low number in the first half of the ’90s. During the first years of the 21st Century (2001–2009) there was substantial variability year to year. During the winter precipitation days were relatively few in the ‘80s (1984/85–1989/90) with a minimum of 59 in the winter of 1987/88 and a decreasing trend since the beginning of the ‘90s. The maximum number of days (78) was recorded in the winter seasons of 1983/84 and 1989/90 (Fig. 16.32 and 16.33).

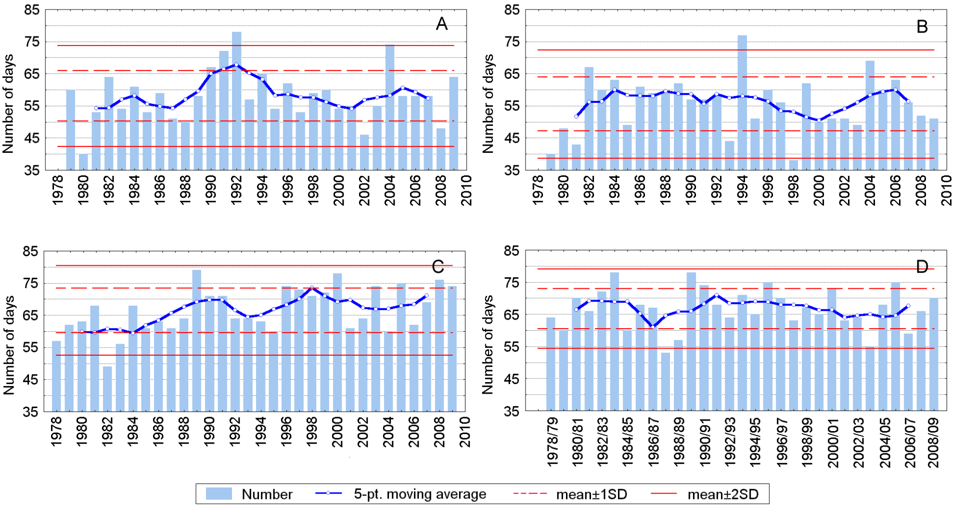

Fig. 16.33. Multiannual pattern of number of days with precipitation > 0.0 mm during the seasons at Hornsund, in 1978–2009. A – spring (March-May), B – summer (June-August), C – autumn (September-November), D – winter (December-February).

16.6.4. Variability of number of days with precipitation ≥ 0.1 mm

The annual number of days with measurable precipitation at Hornsund ranged between 133 (2003) to 217 (1984). Over the period 1978–2009 there was substantial variability. Years with relatively large numbers of days with precipitation ≥ 0.1 mm, were 1984, 1990, 1996 and 1997 (around 200 precipitation days). Such days were relatively few in 1988 (142 days), 1993 (147 days), 1998 (143 days) and in 2003. From the beginning of the 1990s the annual number of such days at Hornsund gradually but irregularly decreased, from 201 days in 1990 to 133 days in 2003. After 2003 (2004–2009) the number of days with precipitation was characterized by lesser variability year to year but usually was bigger than the multiyear mean. The full year decreasing trend evident between 1990 and 2003 appeared also in number of these days in the accumulation period and in the spring and winter seasons. In the accumulation period it may be noted that 1987/88 and 2003/04 had the smallest number of days with measurable precipitation (103 and 102 days respectively), while in 1990/91 the number of days with precipitation ≥ 0.1 mm exceeded the mean plus 2 standard deviations (x ±2σn), totalling 174 days. Since the 2003/04 season the number of days with precipitation ≥ 0.1 mm at Hornsund has shown a delicately emerging rising trend (Fig. 16.34).

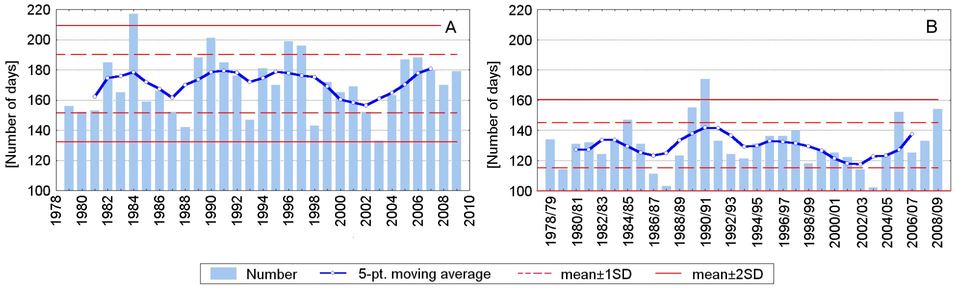

Fig. 16.34. Record of number of days with precipitation ≥ 0.1 mm during a year (A) and during the accumulation period (B) at Hornsund in 1978–2009.

A distinctive feature of the precipitation record during the accumulation period is the sequence of four seasons, 1987/88–1990/91, when there was a sudden increase of frequency of precipitation ≥ 0.1 mm, from 103 days in 1987/88 to 174 days in 1990/91 (Fig. 16.34). A similar increase is seen in winter values for the same years; in the winter 1987/88 only 22 days, while in the winter 1990/91 as much as 67 days, an increase of 45 days. These were the two extreme values of measurable precipitation days, exceeding the range of the mean ±2 σn. During the accumulation period, in the winter, and also during the full year there were substantial changes of number of precipitation days ≥ 0.1 mm for a short period at the end of investigated period (2003–2005 or 2006) also; the number of days with precipitation ≥ 0.1 mm during the accumulation period increased from 102 days (2003/04) to 152 days (2005/06), a change of 50 days. In the winter season it increased from 21 days (2003/04) to 59 days (2005/06), a change of 38 days. The number of days with precipitation ≥ 0.1 mm during a year increased from 133 days (2003) to 188 days (2006), a change of 52 days.

Number of days with precipitation ≥ 0.1 mm during the spring season in successive years usually fell within the mean ±σn. The extremes were the spring of 1982 (52 days) and 2002 (22 days). The years 1999–2004 had relatively few precipitation days, when the floating 5-point mean in the successive years oscillated around the mean plus 1σn.

The smallest range of variability among all seasons (26 days) was recorded during the autumn. Deviations about the mean in successive years were bigger in the case of positive deviations than negative one. Days with precipitation ≥ 0.1 mm at Hornsund were least in the autumn season of

1983 (35 days), but only insignificantly bigger in 1986, 1991, 1995 (37 days in each year) and 2004 (39 days). The largest number of days occurred in 1996 (61 days), very similar to 1989 (60 days) and 1984 (57 days). Generally, number of days of measurable precipitation during the autumn increased from the beginning of research period to the end of the last decade of 20th Century and decreased insignificantly later. These trends are seen most clearly in the 5-years moving averages (Fig. 16.35).

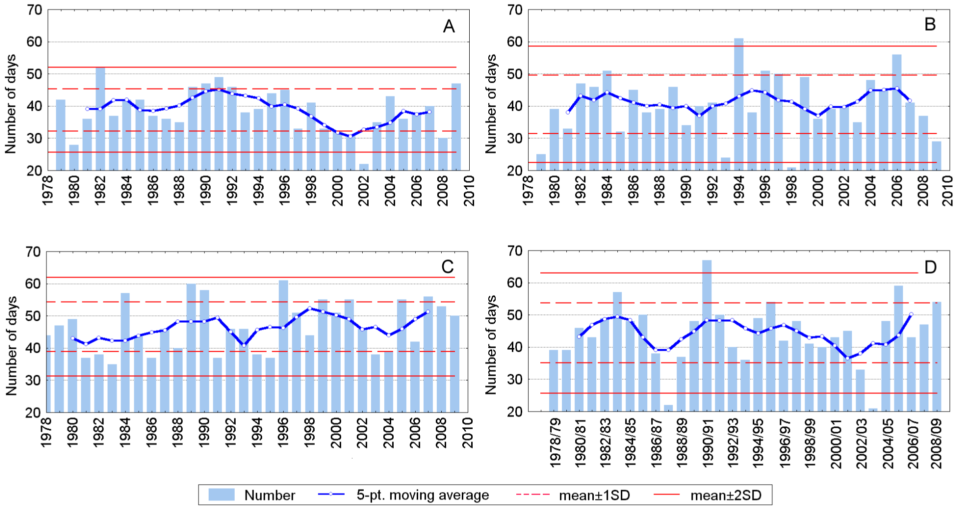

Fig. 16.35. Number of days with precipitation ≥ 0.1 mm in the seasons at Hornsund,1978–2009.
A – spring (March-May, B – summer (June-August), C – autumn (September-November),
D – winter (December-February).

The characteristic feature of multiannual variability of number of days with precipitation during the summer are some short-lived trends. Between 1984 and 1993 precipitation days decreased from 51 to 24 days, suggesting a quite distinct downward trend which however was smoothed by considerable change year to year between extremes noted for 1984 and 1993. In 1992–2000 variability of number of days with measurable precipitation was even bigger, for example 61 days in the summer of 1994, but only 21 days in 1998. After 2000 there was a rising trend until 2006 (55 days), which exceeded the maximum of 1984, but not that of 1994 (Fig. 16.35). After the 2006 summer precipitation days appeared at Hornsund more and more rarely. In 2009 only 29 days of measurable precipitation were recorded.

16.6.5. Variability of number of days with rainfall and snowfall

The number of days with rainfall, snowfall and mixed precipitation during the observations at Hornsund maintained similar proportions. During the year days with solid precipitation were the largest in number, ranging from 120 in 1980 to 182 in 1994. Over the multiannual record of days with snowfall, two sub-periods may be distinguished, with dissimilar directions of trend and different variability year to year. Up to the beginning of the ‘90s numbers of days with snow increased, while after 1990 until the end of 20th Century they decreased again, showing substantial fluctuations year to year. Increase of days with snow occurred again after 2002. Comparison of changes of number of days with precipitation and precipitation totals provides information on changes of the precipitation intensity. At Hornsund the intensity of snowfall over most of the period did not show distinct change; only at the beginning of observations, 1979 to around 1985, was the intensity of snowfall bigger than in later years (Fig. 16.36). However, we should show substantial caution when interpreting this formulated conclusion and keep in mind that accuracy of measurements done in the initial period of observations may have influenced the results obtained.

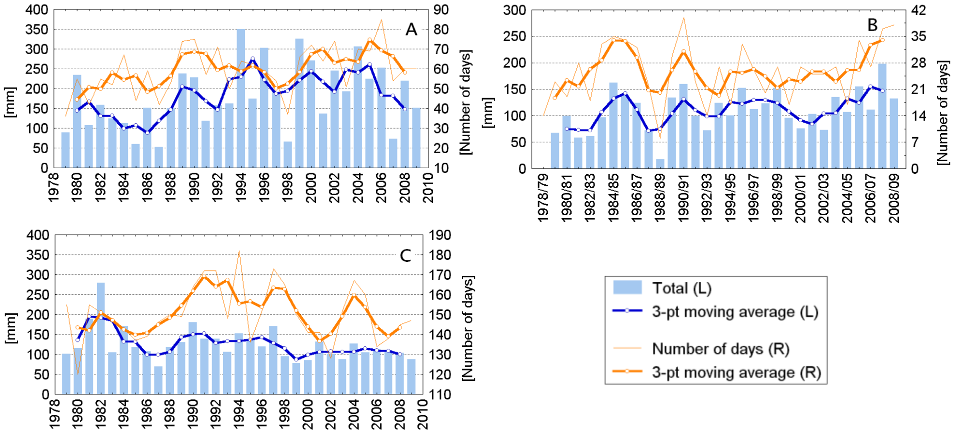

Fig. 16.36. Number of days with precipitation and totals of precipitation [mm]: liquid (A), mixed (B) and solid (C) during the year at the Hornsund station, 1979–2009.

Rainfall was second in frequency of occurrence during the year. It was considerably less frequent (58 days in a year on average) than snowfall (152 days in a year on average). In the period 1979–2009 numbers of days with rain increased however as did contribution of liquid precipitation to the annual total of all precipitation, as noted earlier. Three characteristic sub-periods may be distinguished, within which days with rainfall in successive years appeared with similar frequency. In 1979–1988 around 50 days of liquid precipitation were recorded on average; in the succeeding period, 1989–1999, the number increased to 60 days, and in 2000-2006 was even more frequent at over 69 days during the year on average. In the final years of the record annual number of days with rain ranged from 54 in 2007 to 60 days in 2008 and 2009. It is interesting to compare the changes of number of days with the liquid precipitation totals. Intensity of rainfall at Hornsund distinctly increased in the second half of research period after 1992 (Fig. 16.36). The number of days with mixed precipitation were least during the year (around 31 days per year on average); it is characterized by distinct fluctuations in successive years but with decrease in their range. The second feature of the mixed precipitation record was a weak downward trend after the middle ‘80s but since 2002 the number of days with mixed precipitation has increased consistently almost year to year (Fig. 16.36).

Multiyear variability of number of days with particular types of precipitation was somewhat different during the accumulation period. Days with snowfall, occurring for around 145 days on average, were the unquestionable majority as in the full calendar year. In contrast to the full year, however, mixed precipitation was second in frequency (25 days on average), and rainfall appeared most rarely (16 days on average). During the accumulation period there were similar trends in changes, although their range was clearly weaker. During all years of observations in the last Century the number of days with rainfall did not change in a noticeable way. The second half of the '80s is noteworthy because rainfall was then the most seldom. At the turn of the Century a sudden increase in number of days with liquid precipitation occurred, reaching 37 days in the 2000/2001 season. However, in the following seasons, i.e. after 2000/2001, number of days with rainfall decreased again (Fig. 16.37).

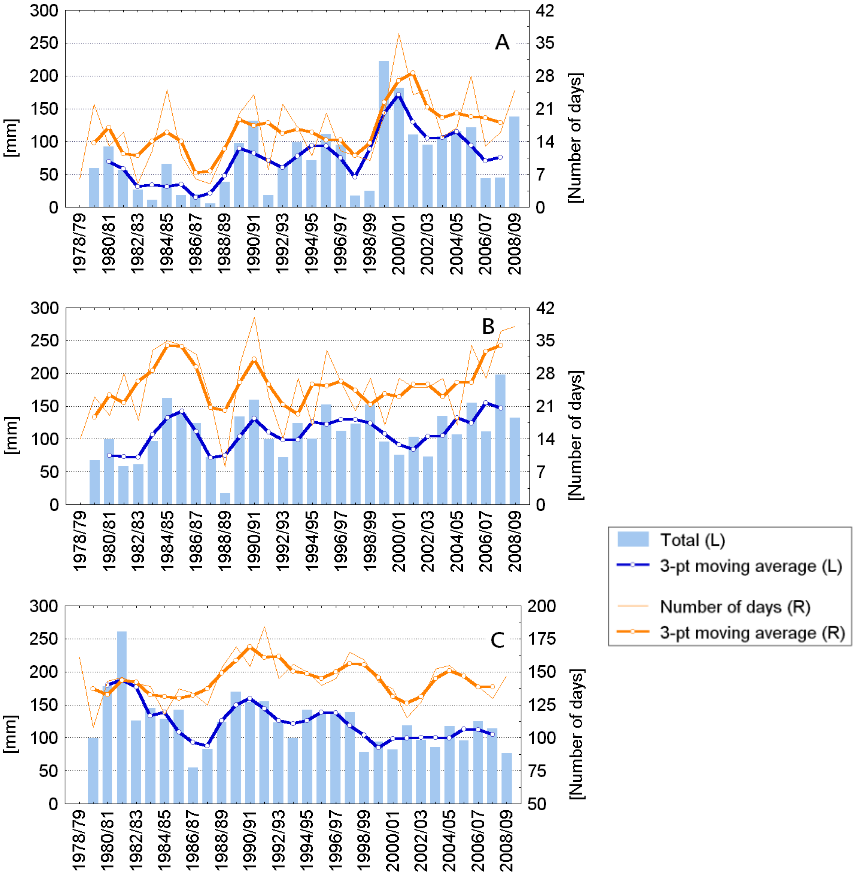

Fig. 16.37. Number of days with precipitation and totals of liquid (A), mixed (B) and solid (C) precipitation during the accumulation period at the Hornsund station, 1979–2009.

Although one may speak of an increase in rainfall intensity during the accumulation period, it was considerably weaker than in the case of the complete year. Similar variability characterizes the record of accumulation period solid and mixed precipitation over the full calendar year. The difference is that the number of days with mixed precipitation oscillates around the mean and does not show any noticeable changes for the most of investigated period. Since the 2001/2002 season an increase of number of days with mixed precipitation was observed at Hornsund, accompanied by a drop in the number of days with rainfall, as mentioned earlier (Fig. 16.37).

16.6.6. General trends of changes in atmospheric precipitation

In the light of global changes of climatic conditions in recent years that are most clearly seen in the air temperatures it is also worth checking if these changes are observed in the records of atmospheric precipitation. Given that precipitation is not subject to a normal distribution, the non-parametric Mann-Kendall test was used to determine the statistical significance of general trends in the multiannual course. Analysis of trends was done for the monthly, seasonal and annual characteristics of precipitation, as well as its values in the accumulation period. Additionally, determination coefficients (%) were calculated to establish by what percentage an adjusted trend line explains variations of particular characteristics of the precipitation (Table 16.5 and 16.6). It should be emphasized however that results of trend analysis may differ significantly in both quantity and trend directions, depending on the time ranges selected.

Table 16.5. Trends of changes (for 10 years) of values of selected precipitation characteristics at Hornsund in 1979–2009.

Characteristics		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total	T [mm]	+4.2	–5.2	–2.7	–2.1	–0.6	–2.6	+5.0	+3.7	+12.4	+7.3	**+9.2**	**+6.9**
	R^2 [%]	3.4	6.4	2.0	1.0	0.2	0.9	2.1	1.0	5.5	5.5	11.5	7.1
Number of days with precipitation	T [dni]	+1.0	–0.5	–0.1	+0.3	+0.6	+0.1	+1.4	–1.0	–0.3	**+1.6**	**+2.2**	**+2.1**
	R^2 [%]	5.7	1.0	0.0	0.4	1.4	0.1	4.5	5.0	0.6	17.4	22.5	16.4
Number of days with precipitation ≥0.1 mm	T [dni]	–0.2	**–1.5**	–0.6	–0.8	–0.1	–0.1	+1.0	–0.1	–0.1	+0.5	+1.9	**+1.7**
	R^2 [%]	0.2	8.2	1.3	4.5	0.1	0.1	2.5	0.0	0.0	1.0	10.7	8.7
Total:													
Liquid precipitation	T [mm]	-	-	-	-	-	–0.2	+4.9	+1.5	+9.8	+3.5	-	-
	R^2 [%]	-	-	-	-	-	0.0	2.2	0.2	4.2	1.8	-	-
Mixed precipitation	T [mm]	+3.6	+0.5	+0.4	+0.5	–1.7	–2.1	0.0	+2.3	+2.8	+5.0	**+5.4**	**+4.9**
	R^2 [%]	4.1	0.2	0.1	0.6	3.7	3.2	0.0	11.9	3.1	5.8	8.2	11.4
Solid precipitation	T [mm]	–1.2	**–6.8**	–2.8	–4.4	–0.6	–0.2	-	–0.1	–0.4	–1.2	–0.7	+0.2
	R^2 [%]	1.8	19.9	10.6	7.0	1.1	0.6	-	0.1	1.9	1.6	0.4	0.0
Number of days with:													
Liquid precipitation	T [dni]	-	-	-	-	-	**+1.6**	+1.2	–0.3	+0.8	+0.4	-	-
	R^2 [%]	-	-	-	-	-	11.0	3.9	0.4	2.4	0.9	-	-
Mixed precipitation	T [dni]	+0.7	–0.3	–0.2	+0.1	+0.2	–0.6	+0.1	–0.2	–0.7	+0.2	+0.8	**+1.3***
	R^2 [%]	6.9	2.3	0.8	0.5	0.8	4.4	0.6	0.8	7.3	0.5	6.2	18.4
Solid precipitation	T [dni]	–0.1	–0.2	+0.3	–0.1	–0.1	–0.8	-	**–0.4**	–0.5	+1.0	+0.9	+0.6
	R^2 [%]	0.5	1.2	0.3	1.6	0.0	10.8	-	5.7	5.7	2.6	4.0	2.3

Statistically significant changes are shown in **bold** at the level p = 0.1 and underlined at the level p = 0.05. Trends significant at the level p = 0.01 are additionally marked with an asterisk.

At Hornsund most of precipitation characteristics that were investigated do not show statistically significant trends over the multiyear record. General totals of precipitation during months from the first half of a year (between February and June) were characterized by a downward trend, whereas precipitation totals from July to the end of the year and in January had a rising trend. Among the mentioned trends, only rising trends in November (+9.2 days/10 years) and December (+6.9 days/10 years) are important from the statistical perspective. These trends, statistically significant at the level 0.05, explain 11.5% and 7.1%, respectively of variation of the amount of monthly precipitation. In the case of seasonal values the rising trend of precipitation totals during the autumn ($p \leq 0.01$), reaching around 29 mm per 10 years and explaining around 19% of the variation, rank as statistically significant. Total precipitation during the accumulation period and during the year also significantly increases (Table 16.6). It is worth mentioning here that the rising trend of annual total precipitation over 1979–2009 (32.5 mm/10 years) is smaller than that for 1979–2005 (43.8 mm/10 years).

Table 16.6. Trends (T, per 10 years) and determination coefficients (R^2) of seasonal values of selected characteristics of precipitation at Hornsund in 1979–2009.

Characteristics		Spring	Summer	Autumn	Winter	AP	Year
Total	T [mm]	–5.4	+6.1	**+28.9***	+6.4	**+26.0**	**+35.5**
	R^2 [%]	3.1	0.8	18.9	2.2	10.6	12.4
Number of days with precipitation	T [days]	+0.8	+0.6	**+3.5**	–0.1	+6.3	**+7.4**
	R^2 [%]	0.8	0.4	20.3	0.0	11.2	12.0
Number of days with precipitation ≥0.1 mm	T [days]	–1.5	+0.8	+2.3	+0.2	+0.3	+1.6
	R^2 [%]	4.4	0.7	6.8	0.0	0.0	0.5
Total:							
Liquid precipitation	T [mm]	+3.5	+6.1	**+17.9**	**+4.5**	**+28.2***	+32.2
	R^2 [%]	7.0	1.0	10.3	9.0	23.2	13.1
Mixed precipitation	T [mm]	–0.8	+0.2	+13.2	**+10.3**	+16.1	**+21.7**
	R^2 [%]	0.2	0.0	12.6	11.5	14.7	17.4
Solid precipitation	T [mm]	–7.8	–0.2	–2.1	**–8.2**	**–17.8**	**–17.9**
	R^2 [%]	12.3	0.3	2.4	15.6	17.5	15.7
Number of days with:							
Liquid precipitation	T [days]	+0.6	+2.6	+1.7	**+0.7**	**+3.4**	**+5.6**
	R^2 [%]	5.5	6.9	6.0	16.1	16.5	18.7
Mixed precipitation	T [days]	+0.1	–0.7	+0.2	**+1.8**	+1.9	+1.4
	R^2 [%]	0.1	2.5	0.2	9.4	4.8	1.6
Solid precipitation	T [days]	0.0	**–1.3**	+1.4	–0.4	+1.1	+0.4
	R^2 [%]	0.7	17.2	0.5	0.0	2.1	0.0

Statistically significant changes are shown in **bold** at the level $p = 0.1$ and underlined at the level $p = 0.05$. Trends significant at the level $p = 0.01$ are marked additionally with an asterisk. AP – accumulation period.

Frequency of days with precipitation at Hornsund, 1979–2009, increased during the majority of months (with the exceptions of February, March, August and September). These trends were statistically significant ($p \leq 0.05$) only in October (+1.6 days /10 years), November (+2.2 days/10 years) and December (+2.1 days/10 years). In November a linear trend explained 22.5% of variation of number of precipitation days and it was the biggest determination coefficient among all monthly values. Number of days with precipitation increased also during the autumn (+3.5 days/10 years) and during the year (+7.4 days/10 years), and a linear relation explained over 20% of the variation of number of days with precipitation during the autumn but only 12% of the variation during a full year. The direction of trend of number of days with precipitation ≥0.1 mm is differentiated by month. Significant changes of this characteristic were found only in February, when number of days with precipitation ≥0.1 mm decreased by 1–5 days/10 years, and in December when there was a reverse trend of +1.7 days/10 years. In both cases a linear trend explained just a little over 8% of the variation.

Results of analysis of trends in the different types of precipitation are also interesting. These may be manifestations of changes of climatic conditions taking place at Hornsund. Despite the fact that trends of monthly number of days and monthly totals of particular types of precipitation are mostly not significant statistically, it is worth paying attention to the direction of the general changes. Trends in monthly characteristics of liquid precipitation are positive, with the exception of June for total liquid precipitation, and August for number of days with liquid precipitation. The direction of trends in mixed precipitation totals was positive for the most of the months also, while trends of number in days of mixed precipitation over the year were variable. Totals of snowfall consequently decreased in almost all months (with exception of December), while number of days with snowfall increased from October to December and in March, but decreased in the other months (Table 16.5). Among the above-mentioned statistically significant trends were increases of mixed precipitation totals in November and December, increase of number of days with liquid precipitation in June and number of days with mixed precipitation in December, as well as decrease of number of days of solid precipitation in August. These linear trends explained at most 18.4% of variation (number of days with mixed precipitation in December; Table 16.5). Changes of seasonal totals and numbers of days with different types of precipitation were similar. Increase of liquid precipitation totals was statistically significant during the autumn (+17.9 mm/10 years), the winter (+4.5 mm/10 years) and during the accumulation period (+28.2 mm/10 years). A linear trend explained 23.2% of variation of liquid precipitation totals during the accumulation period. Number of days with liquid precipitation significantly increased during the winter (+0.7 day/10 years), during the accumulation period (+3.4 days/10 years) and during the full year (+5.6 days/10 years). Linear trends in these cases explained at most 18.7% of variation of liquid precipitation totals (Table 16.6). All statistically significant trends of seasonal and annual characteristics of mixed precipitation were positive. During the winter both the total (+10.3 mm/10 years) and number of days (+1.8 days /10 years) with mixed precipitation significantly increased. During the full year significant changes are found only in total mixed precipitation (+21.7 mm/10 years). In the case of snowfall some significant decrease of its totals during the winter (-8.2 mm/10 years), during the accumulation period (–17.8 mm/10 years) and during the full year (–17.9 mm/10 years) was the primary observation. Frequency of days with solid precipitation significantly decreased during the summer (–1.3 days /10 years). Determination coefficients for these trends are shown in Table 16.6.

Given that one of the factors influencing the mode of occurrence of atmospheric precipitation is the air temperature (Przybylak 2002, Førland and Hansen-Bauer 2003, Łupikasza 2008b), some of the established trends that lack statistical significance may still be manifestations of changes of the thermal relationships observed during recent years in the Arctic. As was shown by Przybylak (2007), in the middle of the ‘90s air temperature in the Arctic suddenly increased, especially during the autumn and winter. The statistically significant increase of totals and number of days with liquid precipitation observed during the autumn and winter only may be connected to some extent with this trend in air temperature. Results of the trend analysis are concordant with results of earlier research based on data for 1979–2002 (Łupikasza 2003) and confirm the results of Førland and Hanssen-Bauer (2003).

Simple regression analysis shows that the positive trend in annual total precipitation at Hornsund in 1979–2009 (+3.55(±1.75) mm/year) is statistically significant ($p < 0.051$) and explains around 9% of its variation. This is an increase significantly stronger than the increase of annual precipitation totals of around 2.5% during a decade that was estimated by Førland and Hanssen-Bauer (2003) for the Norwegian Arctic for the 20th Century. Those authors linked increased annual precipitation with increase of the proportion of liquid precipitation in the annual precipitation totals. According to them (Førland and Hanssen-Bauer, 2003), precipitation gauges measure liquid precipitation much more precisely, whereas measurement of solid precipitation is underestimated because of wind action. As a result, the observed increase of annual precipitation totals may be in greater part the result of change of conditions of catching precipitation in the measuring devices than a result of real increase of the mass of falling water.