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REPORT NO. 07/00

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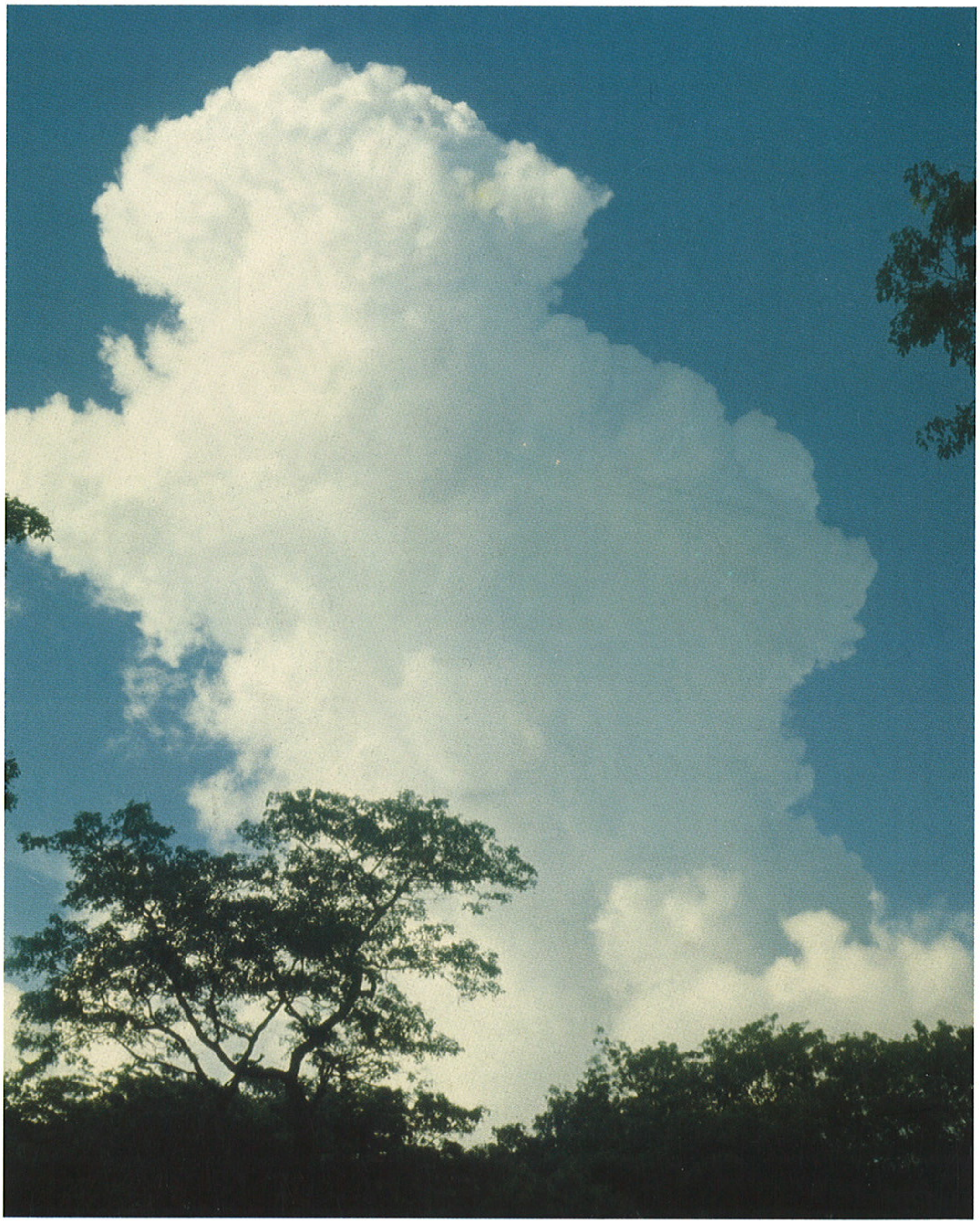

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NORWEGIAN METEOROLOGICAL INSTITUTE
P.O.BOX 43 BLINDERN , N - 0313 OSLO

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TITLE

WIND-CHILL TEMPERATURE AT SVALBARD AND JAN MAYEN

AUTHORS

P.Ø. Nordli, E. Førland and T. Niedzwiedz[1]

[1] Institute of Meteorology and Water Management, Krakow, Poland

PROJECT CONTRACTOR

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SUMMARY

The spatial differences of wind-chill temperature (TWC) at Svalbard were studied within a common reference period, 1979 – 1998. The absolute lowest TWC occurred at Hopen, -66.4°C, on 3 March 1986. Among the Svalbard series Hopen had also the lowest 5 percentile, -47.0°C. On Spitsbergen wind speed and temperature were positively correlated, and the lowest temperatures were not represented among the lowest TWC. Concerning the time series from the small artic islands, the correlation between wind speed and temperature was poor or absent.

The long-term variations were studied by Gaussian low pass filtering techniques. Local maxima and minima of TWC occurred mainly in the same decades as those of temperature. The exceptions were the Ny-Ålesund series (1979 – 1998), and the latest two decades of the Hopen series. In the long-term series from Bjørnøya, Hopen and Jan Mayen the 1960s turned out to be the decade with the lowest TWC.

The series of temperature and TWC were classified by the Niedzwiedz weather type scheme. The wind direction was found to have a major influence on temperature and TWC. In all seasons the temperature and TWC are lowest for northerly or northeasterly flow and highest for southerly flow. For TWC the difference between southerly and northerly flow is about 25°C in winter and 5-10°C in summer.

In winter the TWC drops below certain threshold temperatures more often at the stations Hopen, Svalbard Airport and Sveagruva than at the other Norwegian Arctic stations (Ny-Ålesund, Bjørnøya and Jan Mayen).

SIGNATURES

Eirik J. Førland
Eirik Førland
PROJECT LEADER

Bjørn Aune
Bjørn Aune
HEAD OF THE DIVISION

Contents

1 Introduction

During the years 1996-2001, the Norwegian Research Council Program (NRC) is running the research program «ALV» («Arktisk Lys og varme (Arctic Light and Heat»). The Norwegian Meteorological Institute (DNMI) is participating in this program through the project «Long term variations in atmospheric circulation and climate in Norwegian Arctic» (NRC-No 112890/720).

The main aims of the DNMI-project is to:
a). Establish a climatological dataset of daily values for all Norwegian Arctic stations
b). Work out comprehensive surveys of climatological statistics for the Norwegian Arctic
c). Analyse long-term variations in atmospheric circulation and climate in the Norwegian Arctic

The climate and long-term climatic variations at the Norwegian Arctic stations are described in earlier reports from the Norwegian Meteorological Institute (Birkeland (1930), Hesselberg & Johannessen (1958), Steffensen (1969), Steffensen (1982), Hanssen-Bauer et al. (1990)). An updated description of the climate at Spitsbergen, Bjørnøya, Hopen and Jan Mayen was presented by Førland et al. (1997). The present report is focusing on air temperature and especially *wind-chill temperature*.

The wind-chill temperature is an indirect measure of the heat transfer from the human skin to the ambient air. To the public, it is an important measure for the risk of frostbite and other injuries to exposed parts of the body. Wind-chill temperatures below certain thresholds may seriously hamper or even stop human activities in the Arctic. Extremely low wind-chill temperatures may also cause problems for the wild life in the area.

Methods and data for calculating wind-chill temperatures are described in sections 2 and 3, frequency distributions and extreme values are presented in sections 4, 5, 9 and 10, and in section 7 the frequencies of wind-chill temperatures below –30 and –40°C are outlined. In section 8 the wind-chill temperatures are analysed for different weather types.

2 Method of calculating Wind Chill Temperature (TWC)

The wind chill temperature is a measure of relative discomfort due to the combination of low temperatures and wind speed. It is an important measure for the risk of frostbite and other injuries to exposed part of the body.

One of the more common formulations of heat loss is developed by Simple (1945) and modified by Court (1948). Both equations have the same algebraic structure, but with different constants. The heat loss, H, from an exposed surface may be written:

$$(1) \qquad H = (A + B * \sqrt{u} + C \cdot u) \cdot \Delta T$$

where
H = Heat loss, kcal/m^2/hour. **ΔT** = Temperature difference (°C) between assumed skin temperature of 33°C and ambient temperature. **u** = Wind speed in m/s and A, B and C are constants, given by Court as: **A** = 9.00, **B** = 10.90, **C** = -1.00.

For a given temperature and wind speed there exists a corresponding temperature in calm air that gives the same heat loss from the skin. This calm air temperature is called the wind-chill temperature often abbreviated TWC. Thus, TWC is an indirect measure of the heat transfer from the skin to the ambient air. The public is supposed to have some experience or imagination of low temperature in calm air. Therefore wind-chill temperature is more easily conceived than a direct measure of heat transfer which otherwise could have been a natural choice. By use of equation (1), wind-chill temperature (°C) may be written:

$$(2) \qquad TWC = 33 + (T - 33)(a + b\sqrt{u} - cu)$$

for u ≥ 1.79 m/s, where a = 0.550, b = 0.417, c = 0.0454 (constants given by Court). Equation 2 is also shown in figure 2.1.

TWC is thus a linear function of temperature but a non-linear function of wind speed. By partial derivation of equation (2) we have:

$$(3) \qquad \frac{\partial(TWC)}{\partial u} = (T - 33)(\frac{b}{2\sqrt{u}} - c)$$

At constant temperature, the TWC-equation (2) attains a minimum value at a certain wind speed given by (4):

$$(4) \qquad u = \left(\frac{b}{2c}\right)^2$$

and with Court's constants this wind speed ≈ 21 m/s. The TWC-equation should not be used for stronger winds than about 20 m/s, i.e. stronger than 9 Beaufort (Strong gale).

From equation (3) or figure 2.1 is seen:
When the wind speed increases, then:
1) The rate of decrease of TWC decreases.
2) The rate of decrease of TWC is larger for low than for high ambient air temperatures.

The constants in the formulae are largely empirically determined and may not be strictly correct under all circumstances even for wind speeds below 20 m/s. The skin temperature for instance, will certainly not always be 33°C. It will vary from situation to situation and from individual to individual. Thus, the constants given above are not an obvious choice. One main reason for choosing just these ones is that they are in widely use, for example by the National Center for Atmospheric Research (NCAR).

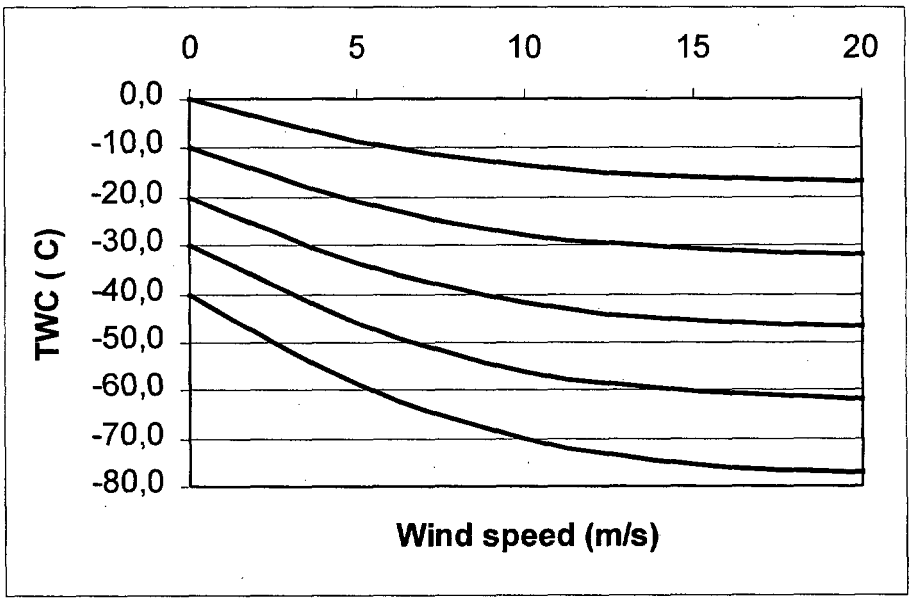

Figure 2.1. The wind-chill temperature (TWC) as a function of wind speed from Court (1948). For stronger winds than 20 m/s the TWC-equation with Courts constants should not be used.

3 Data

The Svalbard area consists of the large islands Spitsbergen, Edgeøya, Barentsøya, Nord-Austlandet and a lot of smaller islands, see map Fig. 3.1. Most of the stations run by the Norwegian Meteorological Institute (DNMI) in the Svalbard area, have been situated on Spitsbergen. But on the small islands Bjørnøya and Hopen measurements have been carried out since 1920 and 1945 respectively. Jan Mayen is situated to the north of Iceland between Greenland and Spitsbergen, and is not a part of the Svalbard area.

Since 1956 all data from the Norwegian Artic stations have been digitised on routine basis. Within the ALV project, see Ch. 1, a great effort has been made on digitising and controlling data preceding 1956. All arctic series but Green Harbour were digitised on daily basis for the three main observation hours, the morning, midday and evening observations, see table 3.1. However, only 99710 Bjørnøya, 99720 Hopen and 99950 Jan Mayen were controlled and stored in our ordinary database during the project period and it is these stations only that are used prior to 1956 in the present report. The status of DNMI's Svalbard data is shown in table 3.1. Notice that not all stations have complete data coverage, for details see Nordli et al. (1996).

Table 3.1 The Norwegian Arctic stations and their periods of observation. The periods of digitisation and control by the ALV project are also denoted in the table.

Station	Observation	Digitisation by ALV	Control by ALV	Used in this report
99710 Bjørnøya	[1]1920 – present	[1]1920 – 1955	[1]1920 – 1955	[1]1920 – 1998
99720 Hopen	1945 – present	1945 – 1955	1945 – 1955	1945 – 1998
99760 Sveagruva	1979 – present			1979 – 1998
99790 Isfjord Radio	[1]1935 – 1975	[1]1935 – 1955		
99821 Green Harbour	1911 – 1930			
99840 Svalbard Airport	1976 – present			1979 – 1998
99860 Longyearbyen	[2]1916 – 1977	[2]1916 – 1955		
99910 Ny-Ålesund	1969 - present			1969 - 1998
99950 Jan Mayen	1921- present		1921 – 1955	1956 - 1999

Since 1920 the observation hours have changed slightly. The morning observation changed from 8^h to 7^h CET 1 July 1949 and the midday observation changed from 14^h to 13^h CET 1 January 1949. The observation hour in the evening has remained unchanged at 19^h. These changes are considered to be minor changes as far as wind-chill temperature is concerned and no attempt has been made to adjust the temperatures in the period before the changes.

The other component of the wind-chill temperature, the wind speed, has been observed by instruments at all of the stations but Hopen, which got anemometer installed in 1971.

[1] Missing data: 1920.08 – 1920.08, 1941.08 – 1945.10.

[2] There are some gaps in the series, for details see Nordli et al. (1996).

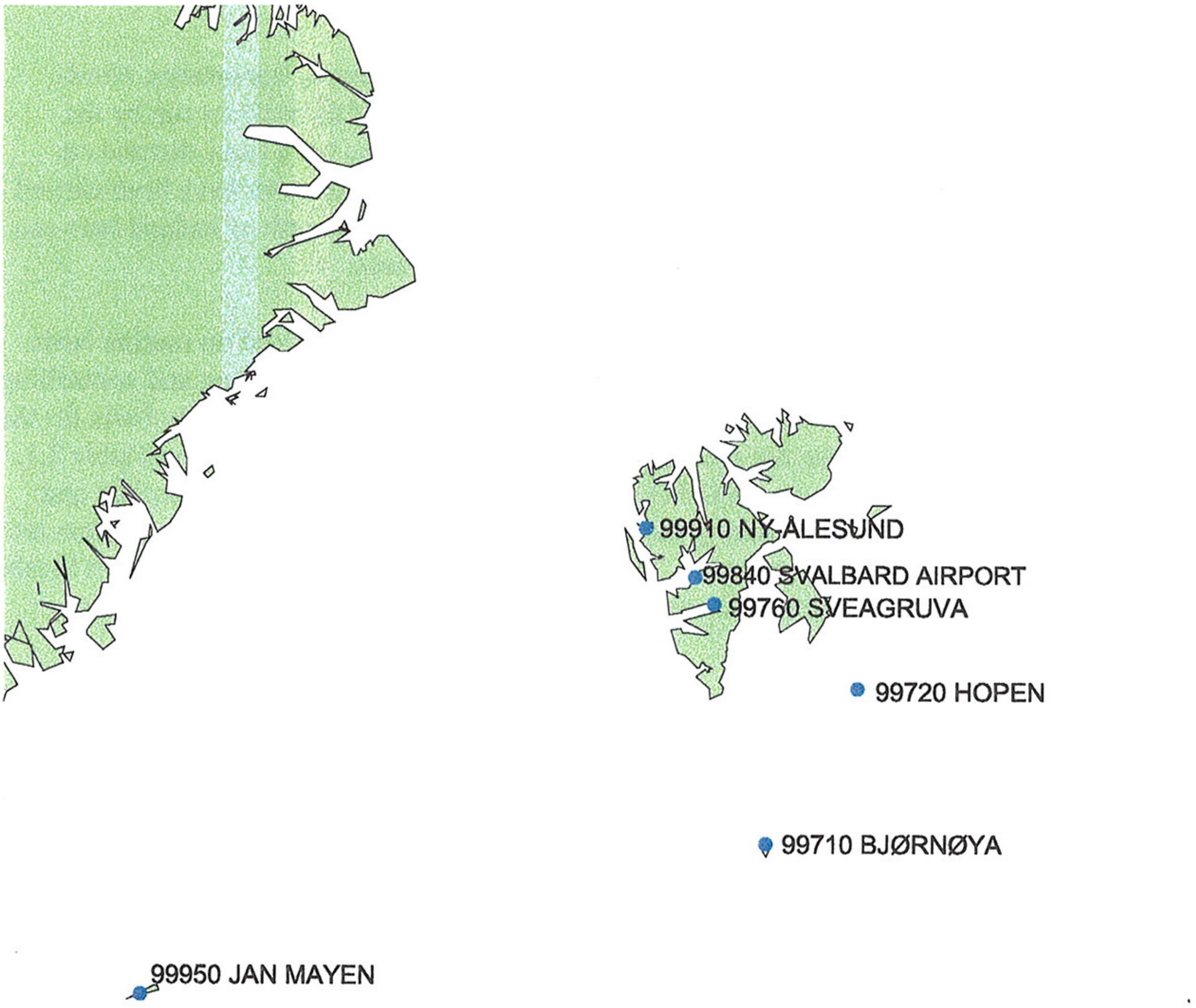

Fig. 3.1 Map of Svalbard and Jan Mayen showing the Norwegian meteorological stations in the Arctic

4 Wind chill temperatures in a common reference period (1979-1998)

It is readily seen from the climatic series of the Norwegian Arctic stations that the combination of strong winds and low temperature occur relatively frequent. It is in fact a combination that may stress the wildlife in the area and probably lead to increased mortality. Therefore the lowest wind-chill temperatures are of major concern.

In order to compare the wind-chill temperature at various sites in the Svalbard area, a common reference period is chosen. As a matter of convenience the 20 years period 1979-1998 was chosen, see table 3.1. In this period all currently run Norwegian stations have full data coverage.

In the tables 4.1 and 4.2 statistical characteristics of temperature and wind-chill temperature within the reference period are given, i.e. mean, standard deviation, skewness as well as some percentiles. The distributions of the two weather elements are also visualised as histograms in Figs. 4.1 – 4.4. All data are grouped by calendar seasons, i.e. Winter (Dec. – Feb.), Spring (Mar. – May), Summer (Jun. – Aug.) and Autumn (Sep. – Nov.). In the histograms the best fitting normal distribution curve is included for comparison reasons. However, in some cases the histograms show large skewness and fit the normal curve poorly.

4.1 Frequency distributions of temperature and wind-chill temperature

During *winter* the temperature distribution curves at Norwegian stations are usually skewed with a long tail to the negative side of the mean value compared to the normal curve. This is also true at Bjørnøya, but not at the stations on Spitsbergen. Here the temperature fits well to the normal curve and the skewness parameter is near zero. The Bjørnøya series, however, is very skew distributed (skewness –0.66, see table 4.1) and Hopen has a rather peculiar distribution with maxima on either side of the mean value. For all stations but Bjørnøya the standard deviations are 8-9°C, see table 4.1.

Also the wind-chill temperature series from Spitsbergen fit well to normal distributions with 2-3°C larger standard deviations than for temperature. The two maxima in the temperature distribution of Hopen are not seen in the distribution of wind-chill temperature. The Hopen series has a skew distribution with one maximum.

In *spring* and *autumn* all the histograms reveal more or less skew distributions of temperature as well as wind-chill temperature. However, there is especially one series that calls upon our attention because of its skewness. That is the Bjørnøya temperature series with a skewness coefficient of –1.21 in spring. This is also illustrated by the long negative tail of the histogram in Fig. 4.2 while the number of cases falls abruptly at the positive side of the graph.

The histograms of *summer* temperatures fit well into normal distributions, Fig. 4.3. The low standard deviations are remarkable for the arctic summer, 2-3°C for temperature and about 5°C for wind-chill temperature. Also most of the wind-chill temperature series fit a normal distribution quite well, the only exception being Ny-Ålesund. Although the temperature is normally distributed, the wind-chill temperature is not.

Table 4.1 Mean, standard deviation, skewness coefficient and correlation coefficient between temperature and wind speed at the five Norwegian stations at Svalbard, 99710 Bjørnøya, 99720 Hopen, 99760 Sveagruva, 99910 Ny-Ålesund. Reference period 1979 – 1998.

		Elem.	99710	99720	99760	99840	99910
W	Mean	T	-7.0	-13.3	-15.7	-14.6	-13.6
I		TWC	-20.8	-24.8	-26.1	-25.3	-21.6
N	Standard	T	6.6	8.9	8.8	8.5	7.9
T	Deviation	TWC	9.3	12.5	10.8	10.3	9.2
E	Skewness	T	-0.66	-0.07	0.06	-0.02	-0.13
R		TWC	-0.58	-0.34	0.07	-0.02	-0.17
	Correlation	T, TWC	0.17	0.11	0.35	0.38	0.39
S	Mean	T	-3.7	-8.6	-9.7	-9.1	-8.4
P		TWC	-15.3	-17.6	-18.1	-16.4	-14.0
R	Standard	T	5.2	7.6	8.1	8.0	7.4
I	Deviation	TWC	8.5	11.3	11.1	10.0	9.5
N	Skewness	T	-1.21	-0.63	-0.53	-0.65	-0.68
G		TWC	-0.84	-0.75	-0.43	-0.56	-0.50
	Correlation	T, TWC	-0.05	-0.06	0.10	0.21	0.15
S	Mean	T	4.1	1.9	4.9	4.8	3.9
U		TWC	-3.2	-4.0	-0.8	-0.7	0.8
M	Standard	T	2.8	2.2	2.9	3.0	2.6
M	Deviation	TWC	4.8	4.7	5.1	5.0	4.8
E	Skewness	T	0.42	-0.05	-0.10	0.19	-0.10
R		TWC	-0.09	-0.07	-0.22	-0.26	-0.89
	Correlation	T, TWC	0.15	0.11	0.03	0.07	0.01
A	Mean	T	-0.3	-3.4	-5.1	-4.8	-4.9
U		TWC	-10.7	-12.2	-12.3	-13.3	-11.1
T	Standard	T	4.5	6.4	7.4	6.8	6.4
U	deviation	TWC	7.5	9.5	9.6	10.1	9.1
M	Skewness	T	-0.99	-1.18	-0.70	-0.55	-0.45
N		TWC	-0.54	-0.82	-0.46	-0.33	-0.38
	Correlation	T, TWC	-0.07	-0.01	0.12	-0.02	0.06

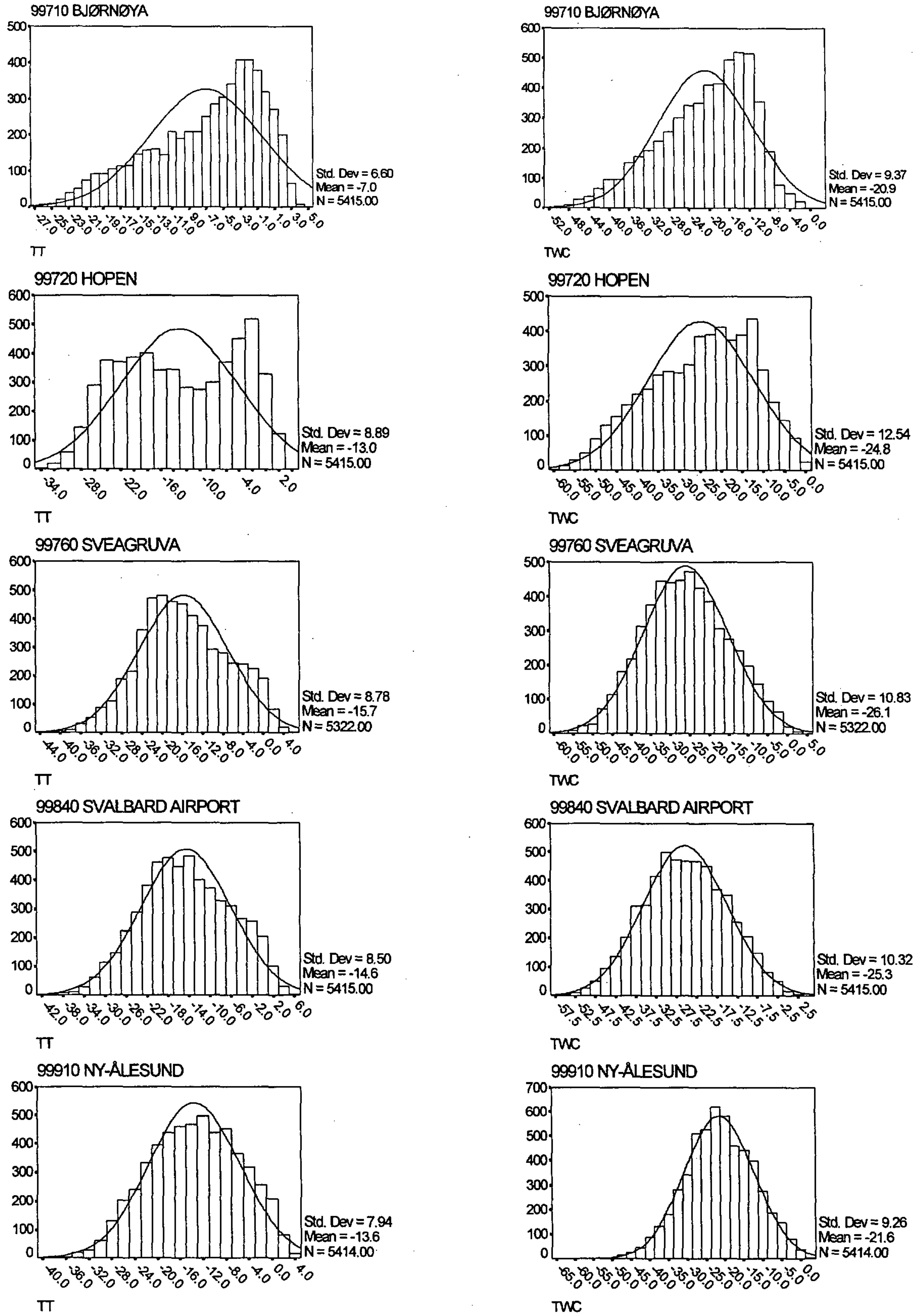

Fig 4.1 **Winter** (Dec. - Feb.). Histograms of temperature (TT) and wind-chill temperature (TWC) at the Norwegian stations at Svalbard during the reference period 1979 - 1998. For each graph the standard deviation, mean and number of cases are given.

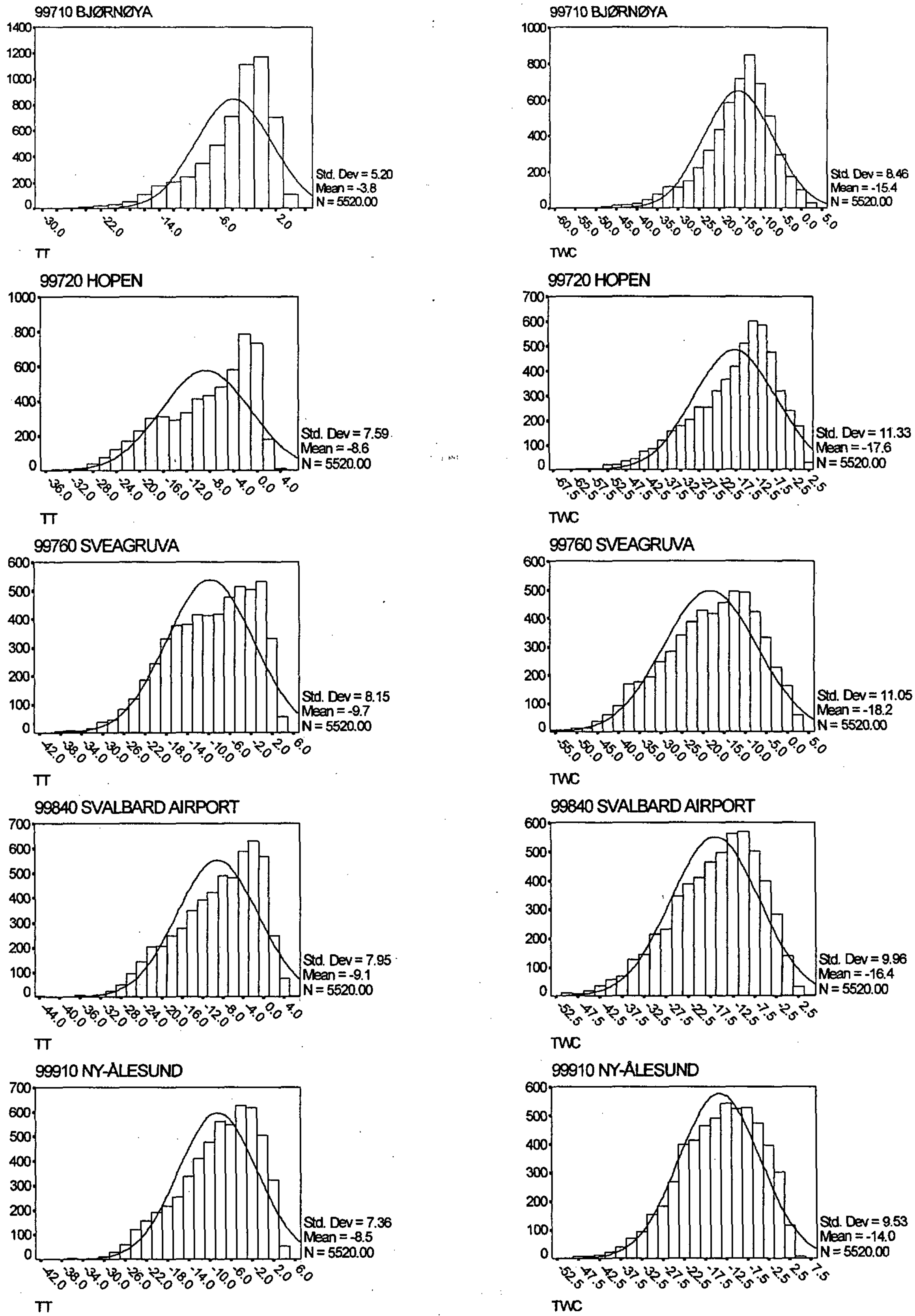

Fig 4.2 **Spring** (Mar.- May). Histograms of temperature (TT) and wind-chill temperature (TWC) at the Norwegian stations at Svalbard during the reference period 1979 - 1998. For each graph the standard deviation, mean and number of cases are given.

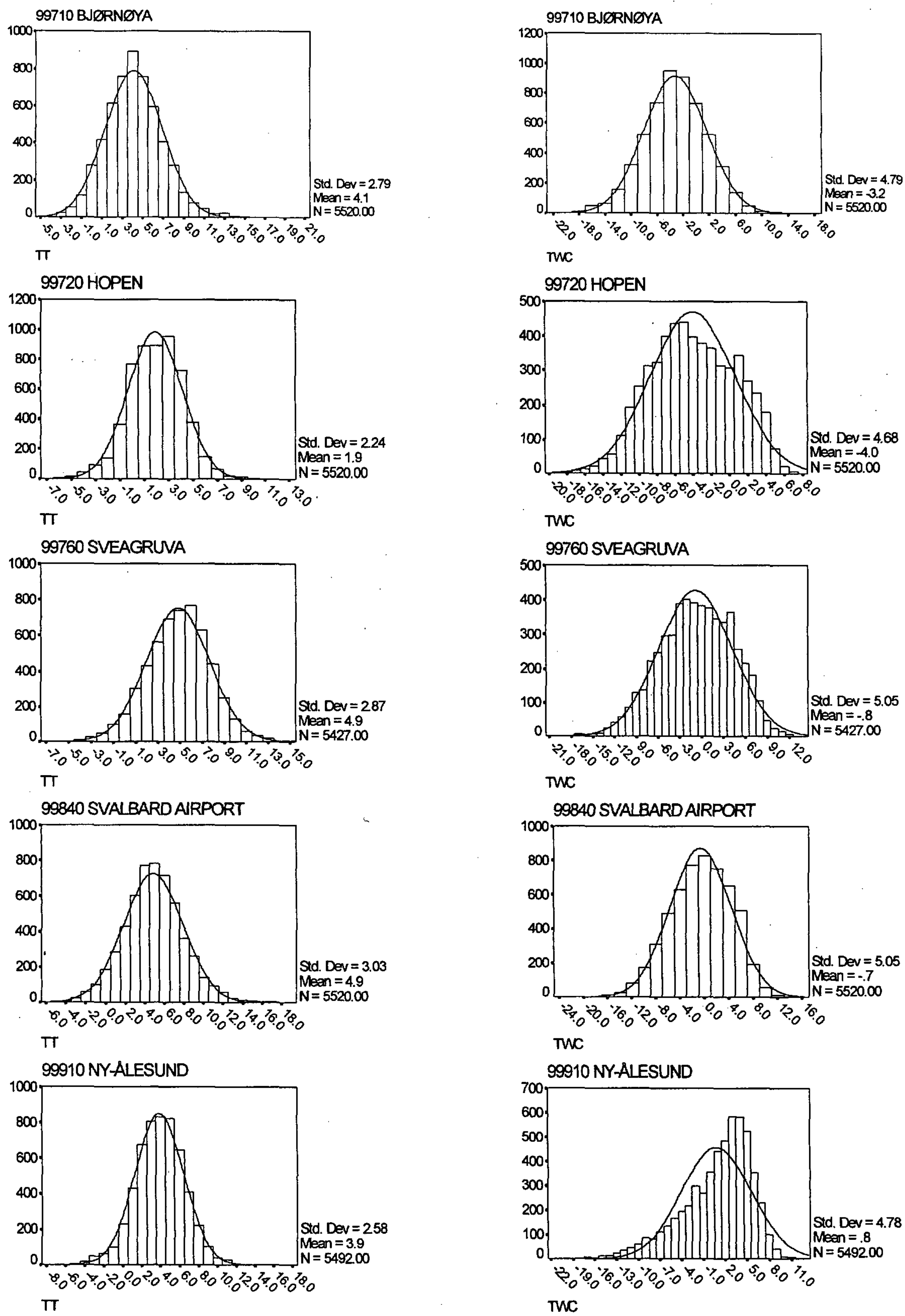

Fig 4.3 **Summer** (Jun. - Aug.). Histograms of temperature (TT) and wind-chill temperature (TWC) at the Norwegian stations at Svalbard during the reference period 1979 - 1998. For each graph the standard deviation, mean and number of cases are given.

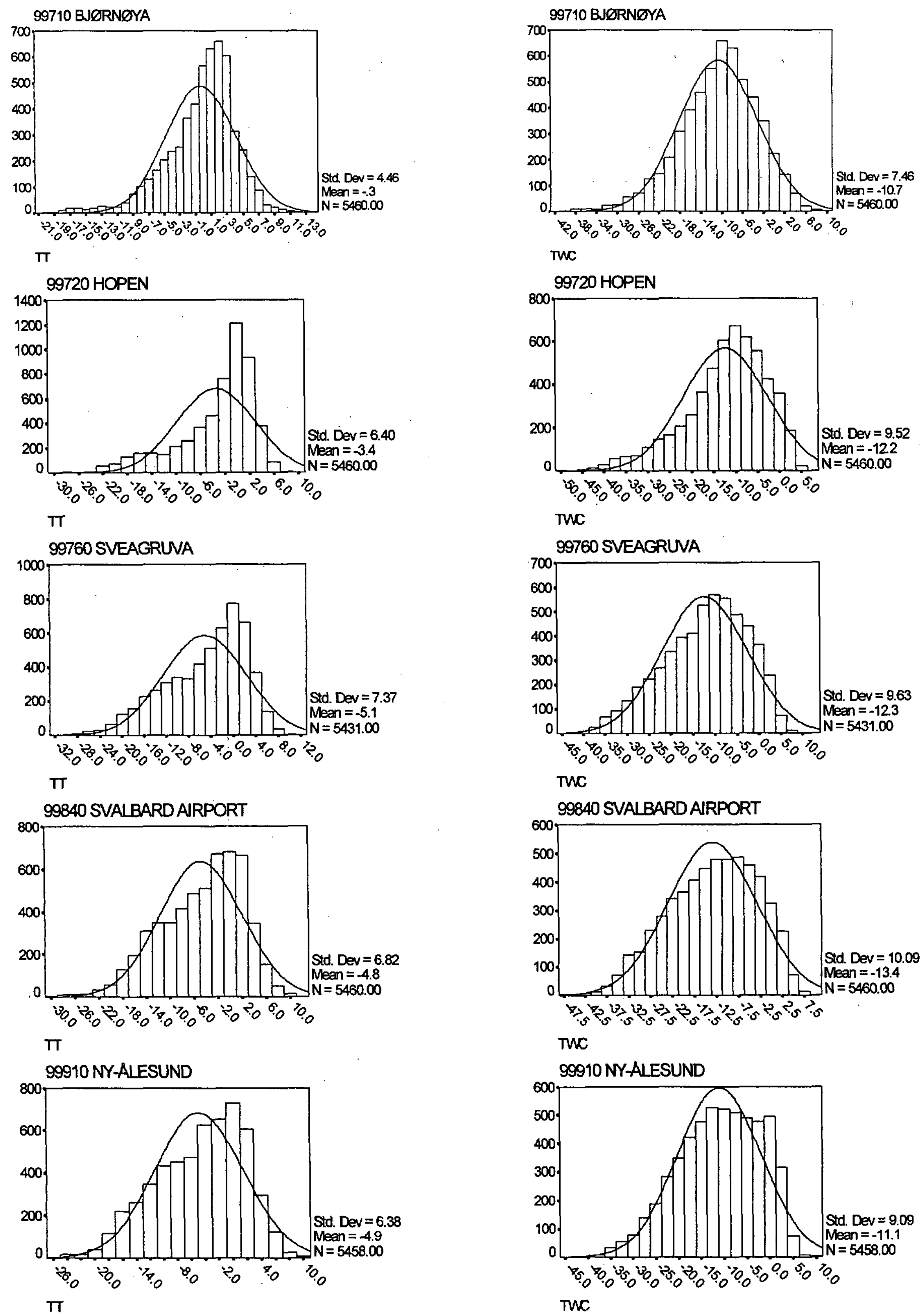

Fig 4.4 **Autumn** (Sep. - Nov.). Histograms of temperature (TT) and wind-chill temperature (TWC) at the Norwegian stations at Svalbard during the reference period 1979 - 1998. For each graph the standard deviation, mean and number of cases are given.

4.2 Percentiles of temperature and wind-chill temperature.

Quartiles plus the 5 and 95 percentiles are calculated for all five series at Svalbard and the results are listed in table 4.2 together with the absolute maximum and minimum as well as the range. All data refer to the period 1979-1998. We will comment on some of the low wind-chill temperatures in the table especially the 5 percentile values. These are considered to allow a more reliable comparison of the series within the area than the absolute extremes, which are more affected by special weather situations. The most extreme events may occasionally hit some of the stations so that a comparison of the extremes may be too much affected by statistical noise.

In *winter* the stations 99840 Svalbard Airport and especially 99760 Sveagruva have the lowest temperatures and also wind-chill temperatures as long as median values are concerned. In the course of the winter the adjacent fjords, Isfjorden and van Mijenfjorden, freeze. This changes the climate in a more continental direction. However, low temperatures on Spitsbergen are not sufficient to get the lowest wind-chill temperature at the Svalbard area. Frequent strong winds in combination with low temperatures at Hopen account for the occurrence of the lowest 5 percentile value of all Svalbard series, -47°C. This is about 10°C lower than Ny-Ålesund. For comments on the remarkable low absolute minimum at Ny-Ålesund, see Ch. 4.3.

The *spring* resembles the winter with the lowest temperature 5 percentile values at the two fjord stations on Spitsbergen (Svalbard Airport and Sveagruva) while Hopen again experiences the lowest 5 percentile wind-chill temperature. Generally the figures are higher than in winter except for the minimum values, which for some series are lower than in winter. Again Ny-Ålesund has the highest 5 percentile wind-chill temperature of the five stations. For this percentile the wind-chill temperature difference between Ny-Ålesund and Hopen is about 8°C.

In *summer* the spatial temperature variations in the area are small, but Hopen has somewhat lower summer temperatures than the other stations. For wind-chill temperatures also Hopen is coldest, but strong winds at Bjørnøya bring its wind-chill temperatures very close to those of Hopen. However, the spatial variation for the 5 percentile is only 3.5°C. In summer many birds of passage nest at Svalbard and extreme values of wind-chill temperatures may probably be a challenge to them. At all stations values lower than -20°C are present.

In *autumn* the temperatures are considerably higher than in spring as a consequence of the heat transfer from the ocean to the air. The 5 percentiles values of wind-chill temperature are -30°C or lower at the stations Hopen, Sveagruva and Svalbard Airport.

The wind-chill temperature range varies from season to season. At the Spitsbergen stations the range is largest during winter but at the island stations Hopen and Bjørnøya the range is largest during spring. The absolute maximum range taken from in all series 1979 – 1998, is 69.6°C in spring at Hopen.

Table 4.2 Percentiles of air temperature and wind-chill temperature during the reference period 1979-1998. Observations at hours 06, 12 and 18 UTC are included.

	Elem.	Station	Range	Min.	5 %	25 %	Median	75 %	95 %	Max.
WINTER	T	Bjørnøya	31.1	-26.6	-19.8	-11.5	-5.5	-1.9	1.5	4.5
		Hopen	36.8	-33.7	-26.6	-20.7	-13.3	-4.7	-0.2	3.1
		Sveagruva	50.0	-43.5	-30.0	-22.0	-16.4	-9.3	-0.7	6.5
		Svalbard A.p.	46.9	-41.1	-28.5	-20.7	-14.9	-8.3	-0.5	5.8
		Ny -Ålesund	43.8	-39.0	-26.9	-19.3	-13.4	-7.6	-0.8	4.8
	TWC	Bjørnøya	53.7	-52.4	-38.6	-27.0	-19.3	-13.5	-8.3	1.3
		Hopen	62.0	-60.8	-47.0	-34.2	-23.4	-14.7	-6.3	1.2
		Sveagruva	63.7	-59.7	-43.4	-33.8	-26.3	-18.5	-7.7	4.0
		Svalbard A.p.	61.5	-57.4	-42.1	-32.6	-25.4	-17.8	-8.2	4.1
		Ny -Ålesund	68.5	-65.1	-37.1	-27.5	-21.6	-15.1	-6.2	3.4
SPRING	T	Bjørnøya	36.9	-30.0	-14.4	-6.2	-2.3	0.0	2.1	6.9
		Hopen	41.1	-36.1	-22.8	-14.3	-7.0	-2.2	0.7	5.0
		Sveagruva	47.2	-42.0	-24.0	-15.5	-8.6	-3.0	1.4	5.2
		Svalbard A.p.	49.7	-44.0	-23.8	-14.4	-7.7	-2.6	1.3	5.7
		Ny -Ålesund	48.7	-42.1	-22.4	-13.1	-7.3	-2.7	1.4	6.6
	TWC	Bjørnøya	64.3	-59.1	-32.1	-19.6	-14.0	-9.9	-3.3	5.2
		Hopen	69.6	-66.4	-39.2	-24.6	-15.3	-9.4	-2.1	3.2
		Sveagruva	59.8	-55.9	-37.8	-25.7	-17.0	-9.6	-1.9	3.9
		Svalbard A.p.	57.9	-53.1	-34.6	-23.0	-15.0	-8.9	-2.2	4.8
		Ny -Ålesund	59.9	-53.3	-30.8	-20.6	-13.6	-6.7	-0.2	6.6
SUMMER	T	Bjørnøya	25.7	-4.6	-0.2	2.2	4.0	5.8	8.8	21.1
		Hopen	20.5	-7.2	-1.6	0.4	2.0	3.4	5.4	13.3
		Sveagruva	22.5	-7.3	0.0	3.0	5.0	6.8	9.4	15.2
		Svalbard A.p.	24.7	-5.5	-0.1	3.0	4.8	6.7	10.0	19.2
		Ny -Ålesund	25.5	-8.0	-0.3	2.2	3.9	5.6	8.0	17.5
	TWC	Bjørnøya	38.1	-21.1	-11.2	-6.3	-3.2	0.0	4.4	17.0
		Hopen	27.6	-19.8	-11.5	-7.5	-4.2	-0.3	3.5	7.8
		Sveagruva	34.8	-20.8	-9.3	-4.3	-0.7	3.0	7.0	14.0
		Svalbard A.p.	38.5	-23.5	-9.3	-4.1	-0.4	3.1	6.9	15.0
		Ny -Ålesund	35.0	-21.6	-8.7	-1.9	1.9	4.3	6.8	13.4
AUTUMN	T	Bjørnøya	35.2	-21.0	-8.5	-2.5	0.5	2.6	5.6	14.2
		Hopen	39.1	-29.2	-17.3	-6.3	-1.3	1.0	3.6	9.9
		Sveagruva	43.9	-31.9	-19.0	-10.1	-3.5	0.6	4.2	12.0
		Svalbard A.p.	42.4	-30.2	-16.9	-9.6	-3.6	0.6	4.4	12.2
		Ny -Ålesund	37.2	-26.5	-16.3	-9.5	-3.9	0.1	3.9	10.7
	TWC	Bjørnøya	53.0	-42.4	-24.0	-15.2	-10.1	-5.6	0.6	10.6
		Hopen	57.7	-50.3	-31.0	-17.2	-10.9	-5.4	0.7	7.4
		Sveagruva	56.9	-44.9	-30.0	-18.7	-11.1	-4.9	1.7	12.0
		Svalbard A.p.	58.7	-48.3	-31.3	-20.7	-12.5	-5.5	1.6	10.4
		Ny -Ålesund	56.5	-46.1	-27.0	-17.4	-10.5	-3.7	2.2	10.4

4.3 The lowest recorded wind-chill temperatures

Bjørnøya. In all seasons the correlation between wind and temperatures is very poor. This is also characteristic for the lowest temperatures. Thus, some of the lowest temperatures are also on the list of the lowest wind-chill temperatures and some are not. Concerning the lowest TWC the wind speed was about 10 m/s or larger. The absolute minimum TWC (-59.1°C) occurred on 2 March 1986 as a combination of a temperature of –28.9°C and wind speed of 15.4 m/s (near gale). As a main characteristic the lowest wind-chill temperatures occur in March or late winter.

Most of the year Bjørnøya is surrounded by open sea, but in late winter and early spring the ice limit approaches the island. Thus, cold arctic air masses may reach the island without heating by open sea. This obviously contributes to the long negative tails of the temperature histograms in spring and winter, see Fig. 4.1 and 4.2. As already mentioned the skewness coefficient in spring is -1.21, which is the lowest coefficient in any season and at any station of Svalbard, see table 4.1.

99720 Hopen. The lowest wind-chill temperatures occur in early spring or late winter, and at those cases the wind speed is about 8 m/s or larger, see Fig. 4.5a. The frequency distribution of temperature has a rather peculiar form during winter with two maxima, one around -3°C and another one around -25°C. It is suggested that weather situations in early winter accounts for the first one and situations in late winter accounts for the second one. Within the winter season the climate around the island changes as the ice surrounds the island.

At Hopen the temperature distributions are very skew in spring and autumn. The temperature amplitude however is much smaller than for the stations on Spitsbergen. But the amplitude of the wind-chill temperature of 69.6°C in spring, is the highest recorded in the reference period without regard to station.

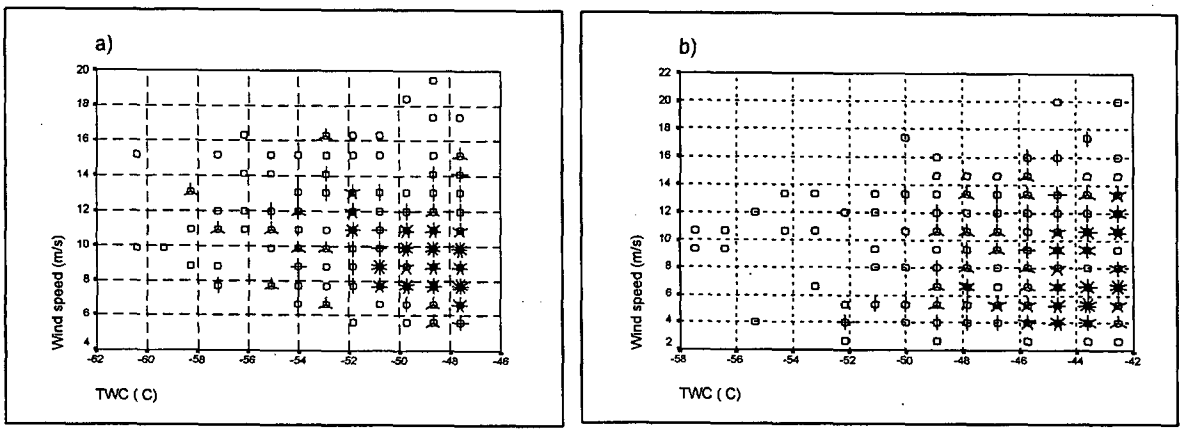

Fig. 4.5 The lowest 5 % of the wind-chill temperatures in winter for a) Hopen and b) Svalbard Airport. The number of cases in each point is shown by "sunflowers" where one pedal represents one case.

The lowest wind-chill temperature, -66.4°C, was a combination of a wind speed of 11.3 m/s and a temperature of –36.1°C. This wind-chill temperature was also the lowest recorded at Svalbard during the reference period. It occurred 3 March 1986 at 18 h.

99760 Sveagruva. At Sveagruva the wind speed and temperature are positively correlated, table 4.1, so that strong wind tends to occur at high temperature and vice versa. Different from Hopen, the lowest wind-chill temperatures do not occur simultaneously with the lowest temperatures. Thus, the extreme temperature recorded is –43.5°C observed in calm air. And for the lowest 60 temperatures, the wind speed did not exceed light breeze. The minimum wind-chill temperature, –59.7°C, occurred on 27 February 1998, a combination of an air temperature of –31.4°C and a wind speed of 11.3 m/s.

99840 Svalbard Airport. As for Sveagruva the temperature and wind speed are positively correlated, and the lowest temperatures usually occur at light winds. When the extreme temperature was recorded, –44.0°C, the wind speed was zero. The lowest wind-chill temperature, -57.4°C, occurred 27. January 1981 as a combination of –30.6°C and 10.3 m/s, temperature and wind speed respectively. The wind speed in winter exceeded 9 m/s for the five lowest TWC, see Fig 4.5b. However, in the interval of TWC between -53°C to -42°C, wind speeds of 4 – 6 m/s are common. This differs from Hopen where wind speed lower than 6 m/s represents a few cases only among the lowest 5 % of wind-chill temperatures, see Fig 4.5a.

99910 Ny-Ålesund. The 5-percentile value of the wind-chill temperature at Ny-Ålesund is higher than at the other Norwegian stations at Svalbard. This apply to all seasons, the only exception is Bjørnøya in the autumn, see table 4.2. But this relatively high 5 percentile seems not to have its counterpart on the list of absolute extreme values. In winter the extreme wind-chill temperature is -65.1°C, a combination of a wind speed of 16.5 m/s (near gale) and a temperature of -32.6°C. This very severe weather occurred on 27 January 1981. This is the lowest wind-chill temperature at any Norwegian station on Svalbard during the 20 years reference period.

The situation in Ny-Ålesund may be dangerous to the community of researchers as far as outdoor activities are carried out in winter. The distribution of wind-chill temperature shows that low values occur so seldom that the community may be unprepared when they occasionally occur.

Temperature and wind speed are positively correlated (0.39) and this applies also to the lowest temperatures. The lowest temperature of –42.1°C was observed in calm air.

5 Wind-chill temperature distributions based on maximum data length

Two of the currently run series at Svalbard are considerably longer than the reference period. These are 99710 Bjørnøya, established in 1920 and 99720 Hopen, which started regular observations in 1945 after having been established by Germany during World War II. Because of the recent digitisation, both series are now available for statistical analysis. For the other currently run stations the data series are not much longer than the reference period and no further analyses of them will be undertaken.

For comparison reasons the results of the statistical analysis based on maximum data length, **L**, are listed together with those based on the reference period, **R**, (1979 – 1998), see tables 5.1 for Bjørnøya and 5.2 for Hopen.

99710 Bjørnøya

For Bjørnøya it is readily seen that in all seasons the added years of data affect the temperature range as well as the TWC-range. In most of the seasons both absolute maximum and minimum temperature during the R-period were not the absolute extremes in the L-period. However, the very lowest observed temperature in the R-period, -30.0°C turned out to be the lowest one also of the L-period. The most extreme positive values occurred before the start of the R-period. The absolute temperature maximum of 22.6°C occurred on 22 June 1953 and the TWC maximum of 21.1°C occurred on 9 July 1972.

Table 5.1 Bjørnøya. Standard deviation (Std.), skewness (Skew.) and percentiles of air temperature and wind-chill temperature in two periods (P). The whole series 1920 – 1998 is denoted by L, and the reference period 1979 – 1998 is denoted by R. Observations at hours 06(07), 12(13) and 18 UTC are included.

	Elem.	P	Std.	Skew.	Range	Min.	5 %	25 %	Median	75 %	95 %	Max.
W	TT	L	6.5	-0.81	34.9	-28.9	-19.4	-10.4	-4.8	-1.4	1.8	6.0
I	TT	R	6.6	-0.66	31.1	-26.6	-19.8	-11.5	-5.5	-1.9	1.5	4.5
N	TWC	L	9.7	-0.68	63.5	-59.8	-38.7	-25.7	-18.2	-12.7	-6.8	3.7
T.	TWC	R	9.3	-0.58	53.7	-52.4	-38.6	-27.0	-19.3	-13.5	-8.3	1.3
S	TT	L	5.9	-0.98	44.9	-30.0	-16.3	-7.6	-2,9	-0.2	2.4	14.9
P	TT	R	5.2	-1.21	36.9	-30.0	-14.4	-6.2	-2.3	0.0	2.1	6.9
R.	TWC	L	9.2	-0.67	69.1	-59.1	-34.0	-21.4	-14.8	-10.1	-3.1	10.0
	TWC	R	8.5	-0.84	64.3	-59.1	-32.1	-19.6	-14.0	-9.9	-3.3	5.2
S	TT	L	2.9	0.35	29.9	-7.3	-0.6	2.1	3.9	5.8	9.0	22.6
U	TT	R	2.8	0.42	25.7	-4.6	-0.2	2.2	4.0	5.8	8.8	21.1
M.	TWC	L	5.1	-0.05	45.2	-23.4	-12.2	-7.0	-3.7	-0.2	4.5	21.8
	TWC	R	4.8	-0.09	38.1	-21.1	-11.2	-6.3	-3.2	0.0	4.4	17.0
A	TT	L	4.3	0.96	36.4	-22.2	-8.1	-2.3	0.6	2.7	5.8	14.2
U	TT	R	4.5	-0.99	35.2	-21.0	-8.5	-2.5	0.5	2.6	5.6	14.2
T.	TWC	L	7.2	-0.57	56.0	-45.4	-23.7	-15.1	-10.0	-5.8	0.0	10.6
	TWC	R	7.5	-0.54	53.0	-42.4	-24.0	-15.2	-10.1	-5.6	0.6	10.6

In most cases there are little differences between the percentiles of the two periods, generally less than 1°C. An exception occurs in winter where the TWC-values of the percentiles in the R-period of 25, 50, 75, and 95 all exceed those of the L-period by more than 1°C. An opposite tendency occurs in spring where the L-period is colder than the R-period by more than one degree at the 5 and 25 percentiles, and almost 0.6°C colder at the median value.

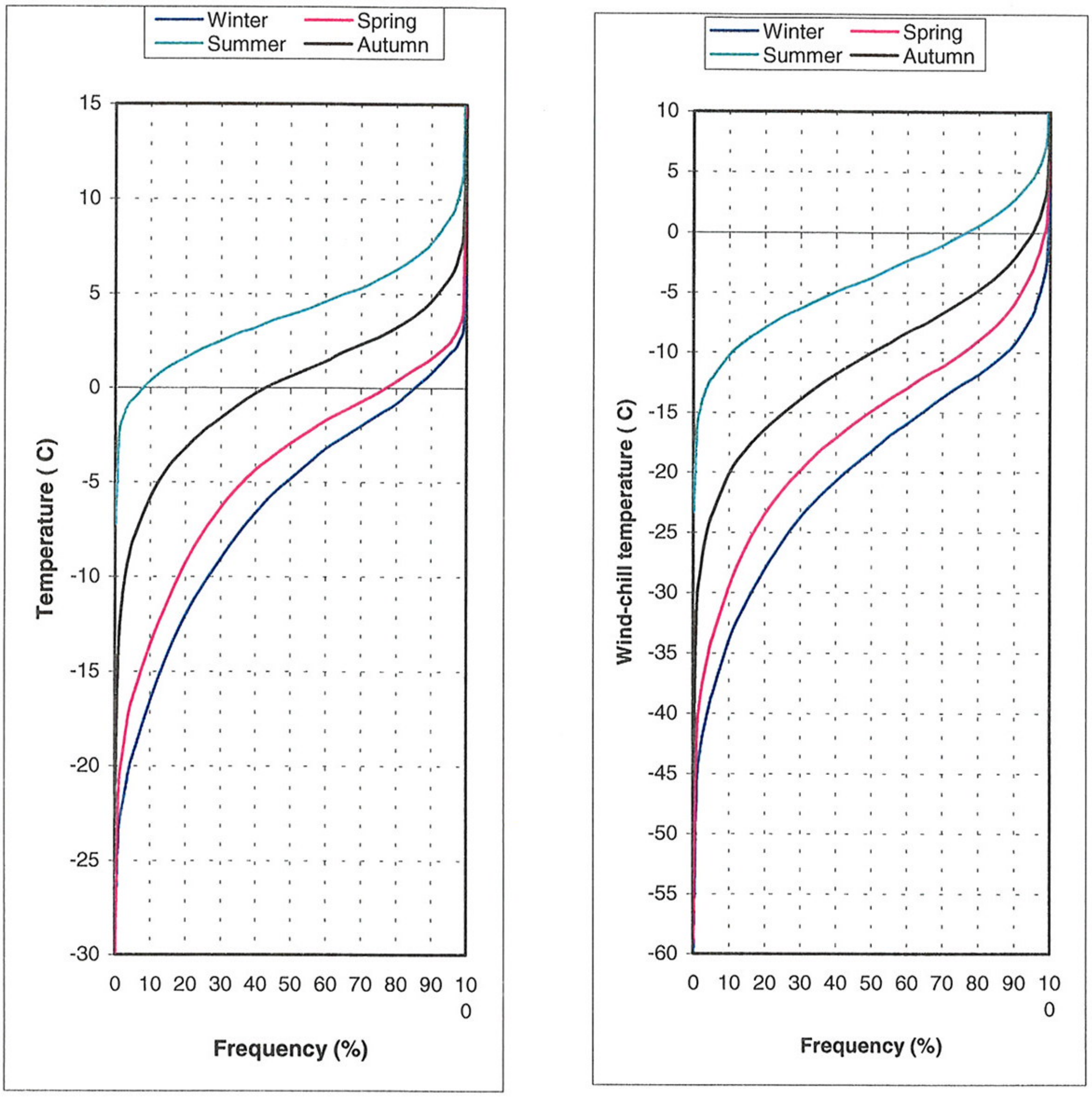

Fig. 5.1 Cumulative distribution of temperature and wind-chill temperature for 99710 Bjørnøya based on three observations a day in the period 1920 – 1998 (for missing data see footnote in chapter 3)

In Fig. 5.1 the distributions of temperature and TWC are shown for the four seasons of the year. From the diagrams the occurrence of temperature or TWC below certain thresholds may be assessed in the form of frequencies. For example, the occurrence of temperature below 0°C is about 8 % in summer, 40 % in autumn, 76 % in spring, and 85 % in winter.

99720 Hopen

The absolute minimum temperature as well as TWC occurred in the reference period (R-period). The percentiles of the R-period also turned out to be fairly representative for the whole series (L-period) in summer and autumn, but in winter and spring the periods are more different. The winter is milder in the L-period than in the R-period while the opposite is true for the spring. In many cases the differences exceed 1°C.

Table 5.2 Hopen. Standard deviation (Std.), skewness (Skew.) and percentiles of air temperature and wind-chill temperature in two periods (P). The whole series 1945.10 – 1998.12 is denoted by L, and the reference period 1979 – 1998 is denoted by R. Observations at hours 06(07), 12(13) and 18 UTC are included.

	Elem.	P	Std.	Skew.	Range	Min.	5 %	25 %	Median	75 %	95 %	Max.
W	TT	L	8.9	-0.17	40.1	-35.6	-26.5	-19.8	-12.0	-4.0	0.0	4.5
I	TT	R	8.9	-0.07	36.8	-33.7	-26.6	-20.7	-13.3	-4.7	-0.2	3.1
N	TWC	L	12.7	-0.37	66.7	-65.1	-46.4	-33.2	-22.2	-13.8	-5.1	1.6
T.	TWC	R	12.5	-0.34	62.0	-60.8	-47.0	-34.2	-23.4	-14.7	-6.3	1.2
S	TT	L	7.8	-0.53	42.9	-36.1	-23.3	-15.5	-7.4	-2.4	0.7	6.8
P	TT	R	7.6	-0.63	41.1	-36.1	-22.8	-14.3	-7.0	-2.2	0.7	5.0
R.	TWC	L	11.6	-0.68	69.7	-66.4	-40.7	-25.5	-16.7	-9.6	-2.3	3.3
	TWC	R	11.3	-0.75	69.6	-66.4	-39.2	-24.6	-15.3	-9.4	-2.1	3.2
S	TT	L	2.3	-0.15	22.5	-9.2	-1.9	0.2	1.7	3.2	5.2	13.3
U	TT	R	2.2	-0.05	20.5	-7.2	-1.6	0.4	2.0	3.4	5.4	13.3
M.	TWC	L	4.8	-0.12	36.5	-26.5	-12.2	-7.9	-4.5	-0.5	3.3	10.0
	TWC	R	4.7	-0.07	27.6	-19.8	-11.5	-7.5	-4.2	-0.3	3.5	7.8
A	TT	L	6.3	-1.30	41.0	-31.1	-17.0	-5.8	-1.2	1.0	3.5	9.9
U	TT	R	6.4	-1.18	39.1	-29.2	-17.3	-6.3	-1.3	1.0	3.6	9.9
T.	TWC	L	9.4	0.98	65.6	-58.2	-30.7	-16.5	-10.2	-5.3	0.7	7.4
	TWC	R	9.5	-0.82	57.7	-50.3	-31.0	-17.2	-10.9	-5.4	0.7	7.4

In Fig. 5.2 the distributions of temperature and TWC are shown for the four seasons of the year. From the diagrams the occurrence of temperature or TWC below certain limits may be assessed in the form of frequencies. For example, the occurrence of temperature below 0°C is about 20 % in summer, 60 % in autumn, 90 % in spring, and 95 % in winter.

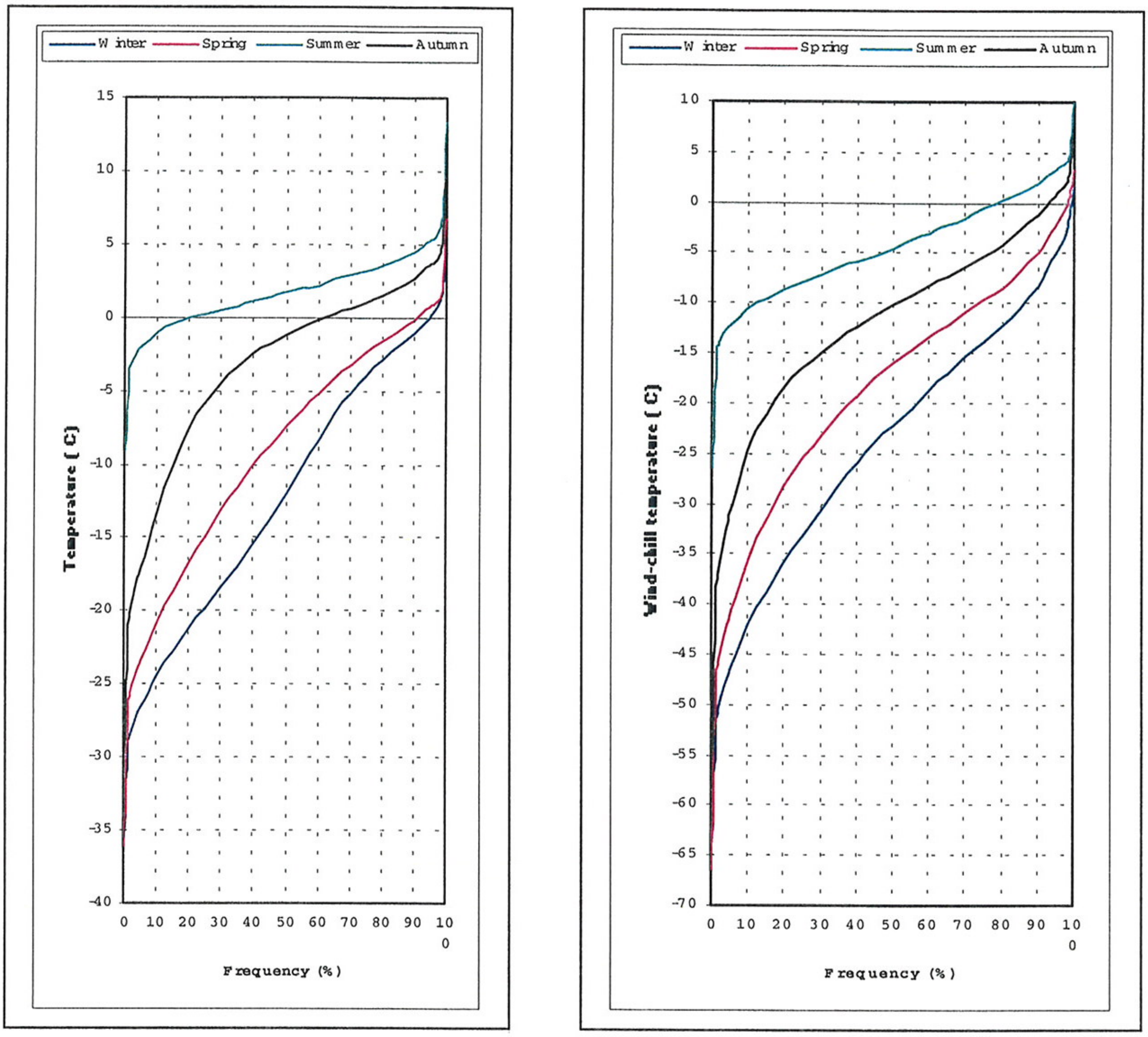

Fig. 5.2 Cumulative distribution of temperature (left) and wind-chill temperature (right) for 99720 Hopen based on three observations a day in the period 1945 – 1998.

Table 5.2 Hopen. Standard deviation (Std.), skewness (Skew.) and percentiles of air temperature and wind-chill temperature in two periods (P). The whole series 1945.10 – 1998.12 is denoted by L, and the reference period 1979 – 1998 is denoted by R. Observations at hours 06(07), 12(13) and 18 UTC are included.

	Elem.	P	Std.	Skew.	Range	Min.	5 %	25 %	Median	75 %	95 %	Max.
W	TT	L	8.9	-0.17	40.1	-35.6	-26.5	-19.8	-12.0	-4.0	0.0	4.5
I	TT	R	8.9	-0.07	36.8	-33.7	-26.6	-20.7	-13.3	-4.7	-0.2	3.1
N	TWC	L	12.7	-0.37	66.7	-65.1	-46.4	-33.2	-22.2	-13.8	-5.1	1.6
T.	TWC	R	12.5	-0.34	62.0	-60.8	-47.0	-34.2	-23.4	-14.7	-6.3	1.2
S	TT	L	7.8	-0.53	42.9	-36.1	-23.3	-15.5	-7.4	-2.4	0.7	6.8
P	TT	R	7.6	-0.63	41.1	-36.1	-22.8	-14.3	-7.0	-2.2	0.7	5.0
R.	TWC	L	11.6	-0.68	69.7	-66.4	-40.7	-25.5	-16.7	-9.6	-2.3	3.3
	TWC	R	11.3	-0.75	69.6	-66.4	-39.2	-24.6	-15.3	-9.4	-2.1	3.2
S	TT	L	2.3	-0.15	22.5	-9.2	-1.9	0.2	1.7	3.2	5.2	13.3
U	TT	R	2.2	-0.05	20.5	-7.2	-1.6	0.4	2.0	3.4	5.4	13.3
M.	TWC	L	4.8	-0.12	36.5	-26.5	-12.2	-7.9	-4.5	-0.5	3.3	10.0
	TWC	R	4.7	-0.07	27.6	-19.8	-11.5	-7.5	-4.2	-0.3	3.5	7.8
A	TT	L	6.3	-1.30	41.0	-31.1	-17.0	-5.8	-1.2	1.0	3.5	9.9
U	TT	R	6.4	-1.18	39.1	-29.2	-17.3	-6.3	-1.3	1.0	3.6	9.9
T.	TWC	L	9.4	0.98	65.6	-58.2	-30.7	-16.5	-10.2	-5.3	0.7	7.4
	TWC	R	9.5	-0.82	57.7	-50.3	-31.0	-17.2	-10.9	-5.4	0.7	7.4

6 Long term trends and variations of mean wind-chill temperature

Long-term variations of mean temperature at Svalbard have been published at different occasions (Steffensen 1969) (Nordli 1990, 1995), and most recently by Førland et al. (1997). The series have been tested for inhomogeneity on monthly basis. The work resulted in a composite, homogeneous series valid for Svalbard Airport (Nordli et al. 1996). The variation in Spitsbergen temperature has also been set into relationship with circulation changes (Hanssen-Bauer & Førland 1998). No series of wind-chill temperatures from the Norwegian Arctic stations have so far been published.

To obtain best possible monthly mean values of temperature, a formula attributed to Köppen is in regular use at DNMI (Birkeland 1935) (Høgåsen 1993). The formula includes the temperature mean of the three main observation hours. This mean has a bias compared to the true daily temperature mean, and a correction term is usually necessary, though not in Arctic during the winter season. The correction term is established by using the daily minimum temperature. However, this method can hardly be used to calculate the mean wind-chill temperatures, as wind speed is unknown at the moment of the temperature minimum.

It can be shown that the monthly mean temperature is fairly well represented by the mean of the morning and evening observations (Mohn 1877). For Arctic series this works especially well. For example the seasonal means of the Hopen temperature series calculated by this simplified method, differ by less 0,1°C from that of Köppen's formula when used for the whole observational period. As both wind speed and temperature exist at the morning and evening observations, the simplified method can easily be adopted also for wind-chill temperature calculations. In this chapter this is done for wind-chill temperature, and for comparison reasons, for temperature too.

According to the homogeneity testing of the monthly temperature values (Nordli et al. 1996) the three longest updated series at Svalbard, i.e. the Bjørnøya, Hopen and Ny-Ålesund were homogenous. However, concerning wind-chill temperature another weather element is also included, the wind speed.

At Bjørnøya anemometer was installed already at the start of the series, but the readings were converted to the Beaufort scale by the observers before they were written in the station's protocol. But since 1955 the readings are stored in our database without any transformation through the Beaufort scale. At the Hopen station it lasted until 1971 before an anemometer was installed. Before that year we have to rely on the observers ability to observe the wind speed without any use of instruments. There is no doubt about that this is a very difficult task in Arctic without a chance to observe the influence on trees by the wind force. Fortunately there have always been skilled, professional observers at the Norwegian Arctic stations.

The crew of the stations shifts from year to year. This may be an advantage when long-term variations are concerned, as the time scale of the engagements at the stations is shorter than the time scale of the variations under study. Systematic errors made by one observer one year or another can thus be regarded as noise. Also to a certain extent errors will be levelled out by the ensemble of observations from the whole crew.

All stations in the present analysis have been in operation for a minimum of 30 years and are currently cunning. In order to study variations of the series on a time scale of about 10 years a Gaussian low pass filter is chosen with the standard deviation in the distribution of 3 years.

Variations at shorter time scales are thus smoothed out. The results for the station on Spitsbergen, Ny-Ålesund, are shown in Fig. 6.1. Both temperature and wind-chill temperature are normalised to zero mean in the reference period 1979-1998.

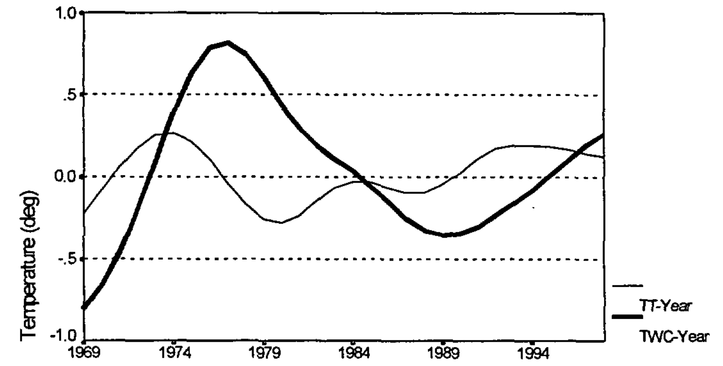

Fig. 6.1. **Ny-Ålesund.** Filtered values of wind-chill temperature (TWC), thick curve, and temperature (TT), thin curve. Gaussian filter is used with a standard deviation in the distribution of 3 years. Both TWC and TT are normalised to zero mean in the reference period 1979-1998.

For temperature the filter shows a maximum in the 1970s and a minimum around 1980. As there is a strong relationship (see Ch. 2) between temperature and wind-chill temperature one should expect that their local extremes would co-inside. But this is not true; the wind-chill temperature has a local maximum in the last part of the 1970s and a local minimum around 1990. The reason for this discrepancy may be that at Ny-Ålesund wind speed and temperature are correlated, see table 4.1, so that often low temperatures occur in calm weather situations while mild winter weather is connected to depressions with stronger wind speed.

The Hopen series can be studied during a longer time span, see Fig. 6.2. The local extremes of the temperature and the wind-chill temperature tend to occur nearly in the same years. This is also true for the maximum of the early 1970s where a difference was found in the Ny-Ålesund series. But it is not true for the last 20 years. The temperature maximum is located to the 1990s while the most recent maximum of the wind-chill temperature is located to the mid 1980s. This wind-chill maximum is not present in the Ny-Ålesund series either, see Fig. 6.1. At Bjørnøya, Fig. 6.4, the wind-chill temperature is increasing during the 1980s, but no local maximum is reached before the early 1990s.

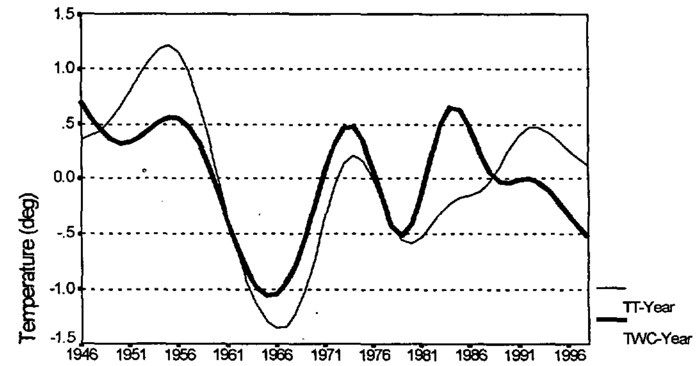

Fig. 6.2. **Hopen.** Filtered values of wind-chill temperature (TWC), thick curve, and temperature (TT), thin curve. A Gaussian filter is used with a standard deviation in the distribution of 3 years. Both TWC and TT are normalised to zero mean in the reference period 1946-1998.

The Hopen series have three local maxima of wind-chill temperature, in the 1950s, in the early 1970s and as already mentioned in the 1980s, all of about the same magnitude. A high value seems also to occur in 1946, but this value of the filtered curve may be false because of the lack of data from the preceding years.

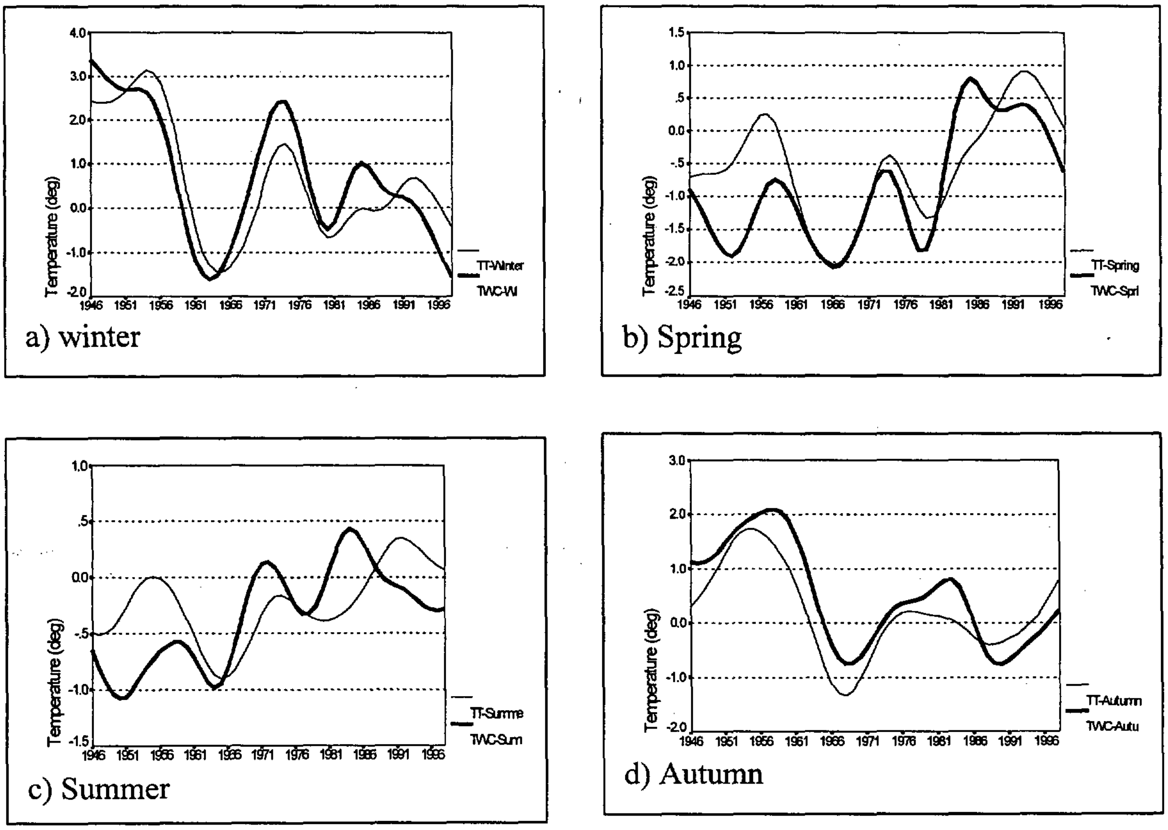

Fig. 6.3 **Hopen.** Filtered values of wind-chill temperature (TWC), thick curve, and temperature (TT), thin curve. The filter is of Gausian type with standard deviation in the distribution of 3 years. Both TWC and TT are normalised to zero mean in the reference period 1946-1998.

The curves representing the annual averages bear a striking resemblance to those representing the winter. The main reason is the much larger variability in winter than in the other seasons. Therefore the local extremes of the annual averages can be traced back to those of the winter season, Fig. 6.3a. In the case of Hopen this is also strengthened by the situation during spring where also the local extremes occur nearly in the same years as for the curve of the yearly averages.

The long-term trends seem to vary from season to season, see Fig. 6.3a-d for Hopen. However, not all increasing or decreasing sequences of the series have caught our particular interest. In our analysis we have searched for periods with significant trends. To decide the question of significance, the non-parametric Mann-Kendall test with level 0.05 is chosen. For its use in meteorology, see for example Sneyers (1990) or Tuomenvirta et al. (1998).

Despite the large variations on a decadal scale, the Hopen wind-chill temperature series for the winter season seems to have a decreasing trend since the start of the series in 1945. This trend is, however, not significant at the 0.05 level when Mann-Kendall test statistic is applied. In spring the wind-chill temperature seems to increase during the last part of the observational period. This increase is significant at 0.05 level from 1982 to present, 1998. But test of the whole series reveal no significant trend.

During summer the increasing trend in the wind-chill series is significant from the start to 1994, but because of the decrease in summer wind-chill temperature during the latest years, the whole series is not significantly increasing. In autumn the series seems to have decreased since the start of the series. This was also significant from the start to 1995, but increasing wind-chill temperature in the latest years makes the increase insignificant up to present.

Summing up, significant trends are detected within the seasonal time series of Hopen, but no trend lasts through the entire observational period, 1945 – 1998. This result is also consistent with the testing of the series of annual means, Fig. 6.2. The decrease from the start to the 1960s is significant, but during the whole observational period there is no significant trend.

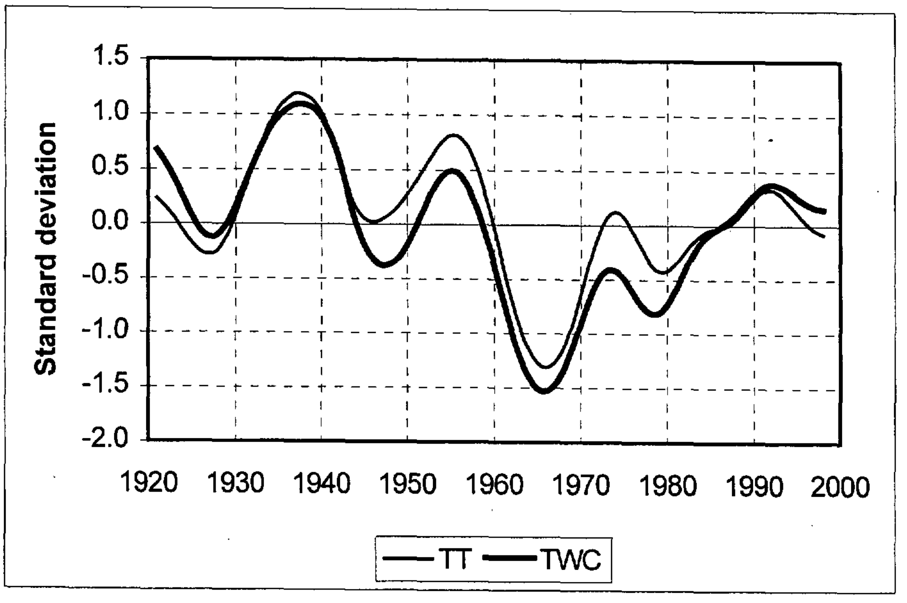

Fig. 6.4. **Bjørnøya.** Filtered values of wind-chill temperature (TWC), thick curve, and temperature (TT), thin curve. A Gaussian filter is used with a standard deviation in the distribution of 3 years. Both TWC and TT are normalised to zero mean in the reference period 1979-1998.

The long-term variation of wind-chill temperature at Bjørnøya is shown in Fig. 6.4. It is readily seen from the filtered value curves that on the maxima and minima are located in the same decades for temperature and wind-chill temperature. The maxima of the 1950s and 1970s, minima of the 1960s and around 1980 also coincide with those of Hopen, while the recent maxima in the Hopen series of the 1980s in the Bjørnøya series is displaced to the 1990s.

From the start in 1920 to the 1960s the Bjørnøya wind-chill temperature has decreased significantly, and the 1960s turns out to be the minimum value for the whole Bjørnøya series. The increase from 1960 to present also is significant. However, the whole Bjørnøya series has no significant trend.

7 Long-term trends and variations of the frequency of some threshold wind-chill temperatures

Wind-chill temperature below certain thresholds may seriously hamper or even stop human activities in the Arctic. For construction work for instance, this certainly will be the case even if such activities are well planned and the workers are equipped for Arctic conditions. Facing extremely low wind-chill temperatures, problems may also arise for the wild life. The stress thresholds are not well known and they certainly vary from species to species. In the present study we have chosen thresholds of wind-chill temperature of -30°C and -40°C without having any particular species or activity in mind.

The three longest Arctic series, Ny-Ålesund, Hopen and Bjørnøya are studied. Within each cold season, from December one year to March next year, the total number of cases below the thresholds were counted. The night observation is missing and the observation hours are thus unevenly distribution throughout the day. However, this is not expected to seriously bias the frequency of wind-chill temperature because temperature as well as wind speed are approximately randomly distributed throughout the day during the cold season.

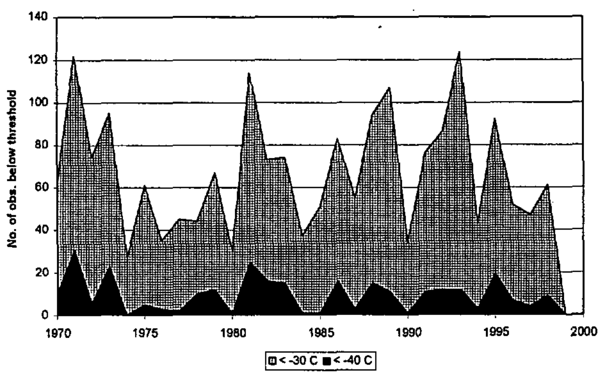

Fig. 7.1 Ny-Ålesund. No. of observations of wind-chill temperature below the thresholds -30°C and -40°C during the observational period, 1970 – 1998. In the data set three observations per day are included.

The annual number of observations of wind-chill temperatures below –30°C varies considerably in Ny-Ålesund, see Fig. 7.1, from a minimum of 27 in 1974 to a maximum of 124 in 1993. In several years there are no observations of wind-chill temperature below -40°C while the maximum value of 31 occurred in 1971. No long-term trends are detected in the number of days below the thresholds. However, one period in the late 1970s shows very low values. Some high values are clustering in the early 1970s and early 1980s, and as far as the threshold -40°C concerned, also in the early 1990s.

The wind-chill temperature at Hopen more often than at Ny-Ålesund lies below the thresholds, see Fig. 7.2 (notice the different scales of the two figures). The correlation between the wind-chill temperatures at the two stations is remarkably poor. For example in the late 1970s only a few wind-chill temperatures below the thresholds are present in the Ny-Ålesund series, while a local maximum is present in the Hopen series just in the same years. In 1979 there were 255 cases below the -30°C threshold at Hopen, the highest number of the whole series, 1946 – 1998.

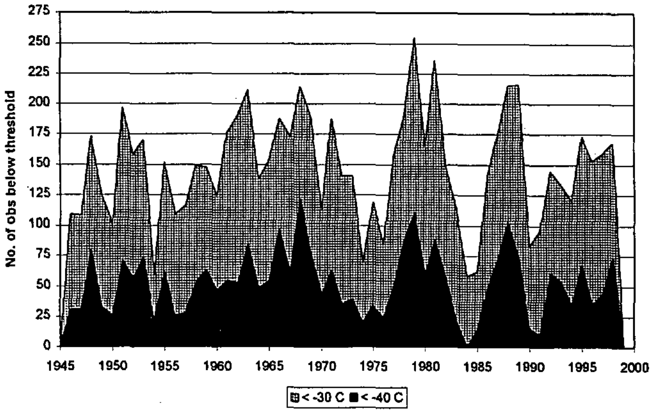

Fig. 7.2 Hopen. No. of observations of wind-chill temperature below the thresholds -30°C and -40°C during the observational period, 1970 – 1998. In the data set three observations per day are included.

No significant trend is seen in the Hopen series of wind-chill temperatures, but in the latest 20 years there are many examples of large interannual variations. Thus, after the peak around 1980, the years 1984 and 1985 followed with only 58 and 62 cases respectively of wind-chill temperature below -30°C and in 1984 there was no one below -40°C. In the late 1980s wind-chill temperatures again frequently fall below the threshold values.

At Bjørnøya the series of threshold frequencies of wind-chill temperature may be studied from 1921 – present, with the gap in the observations during four years during World War II. The number of cases below the thresholds seems to be negatively correlated with the filtered long-term curves of Fig. 6.4. The cold decade of the 1960s includes far more cases below the thresholds than any other decade.

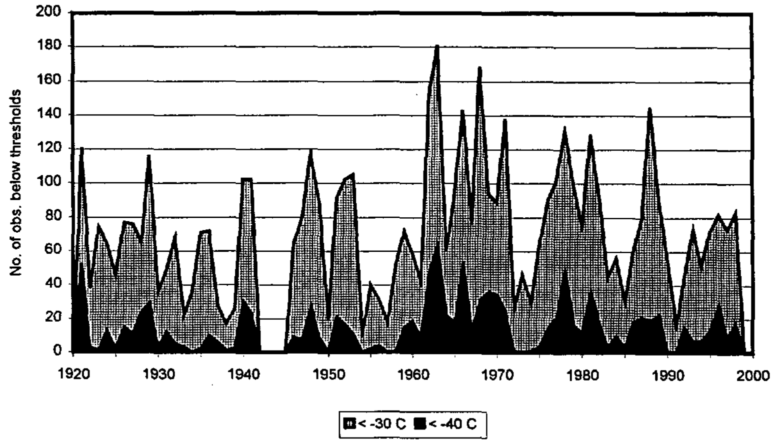

Fig. 7.3 Bjørnøya. No. of observations of wind-chill temperature below the thresholds -30°C and -40°C during the observational period, 1921 – 1941, 1946 – 1998. In the data set three observations per day are included. Cases in December are counted among the cases for the next year.

The frequencies undergo considerable annual variations. For the threshold -30°C the minimum occurred in 1954, only 10 cases, while in 1963 there were 181 cases, which is the maximum value. For the threshold -40°C there has been 7 years without a single observation below the threshold, and two of them were consecutive years, 1957 and 1958. The maximum value, 63 cases, occurred in the same year as for the threshold -30°C, in 1963.

8 Wind-chill temperature under special weather types

01 – Na, northern anticyclonic
02 – NEa, north-eastern anticyclonic
03 – Ea, eastern anticyclonic
04 – SEa, south-eastern anticyclonic
05 – Sa, southern anticyclonic
06 – SWa, south-western anticyclonic
07 – Wa, western anticyclonic
08 – NWa, north-western anticyclonic
09 – Ca, central anticyclonic, centre over or very near Spitsbergen
10 – Ka, anticyclonic wedge, ridge etc.
11 – Nc, northern cyclonic
12 – NEc, north-eastern cyclonic
13 – Ec, eastern cyclonic
14 – SEc, south-eastern cyclonic
15 – Sc, southern cyclonic
16 – SWc, south-western cyclonic
17 – Wc, western cyclonic
18 – NWc, north-western cyclonic
19 – Cc, centre of cyclone above or very near Spitsbergen
20 – Bc, cyclonic trough
21 – X, col or unclassified situation

The daily atmospheric circulation patterns on Spitsbergen have been classified[1] (Niedzwiedz 1993). The work resulted in a calendar of 20 mesoscale weather types. The classification was based on the direction of the geostrophic wind at sea level and whether the circulation was cyclonic or anticyclonic. In order to obtain an easy readable catalogue, each weather type got a letter code. The direction was denoted by capital letters, and at the end of these was added a subscript, "a" for anticyclonic and "c" for cyclonic circulation. Eight directions were distinguished: N, NE, E, SE, S, SW, W, NW. By combining the eight symbols for direction with the two for circulation, 16 possible weather types occurred. For example, Wa and Wc denote anticyclonic and cyclonic air advection from West, while Ea and Ec denote anticyclonic and cyclonic air advection from East.

Four additional weather types were included, characterised either by the lack of advection or by very variable directions of the air flow towards Spitsbergen. These were:
Ca - central anticyclonic circulation, Ka - anticyclonic wedge, Cc - central cyclonic circulation, and Bc - cyclonic trough.

To get the classification scheme complete, it was also necessary to have a group for the types, which could not be classified by the system. This group was denoted by X. A complete list of the weather types is listed in the frame above. Alternatively the weather type code may be numerical with numbers from 1 to 20 and in addition No. 21 for the unclassified situations. The correspondence between the letter and number codes is also shown in the frame.

Both wind-chill temperature and temperature was grouped by season and by weather type at Hopen and Ny-Ålesund for the periods of overlapping between observation and weather type classification. That is for Hopen 1950.01.01 – 1997.07.04 and for Ny-Ålesund 1969.01.01 – 1997.07.04. Within each weather type mean values and standard deviations were calculated and listed, see appendix 1, tables 1-4. The mean values are also shown graphically in the figures 8.1 – 8.4 together with the 95% confidence intervals for the means. The calculation of the confidence intervals is based upon an assumption of random variables. This is not strictly true for daily weather data, which tend to be auto-correlated. However, on grouping the data in weather types, the auto-correlation weakens, and for the types containing the fewest cases,

[1] At the moment of weather type classification the period 1950.01.01 – 1997.07.04 was available. In addition all January month since 1899 have been classified. The classification is based on the German synoptic maps, Europäischer Wetterbericht, 1976 – to present, Täglicher Wetterbericht, 1873-1975. In the period 1899 - 1950 US Weather Bureau's historical maps for the Northern Hemisphere have also been used.

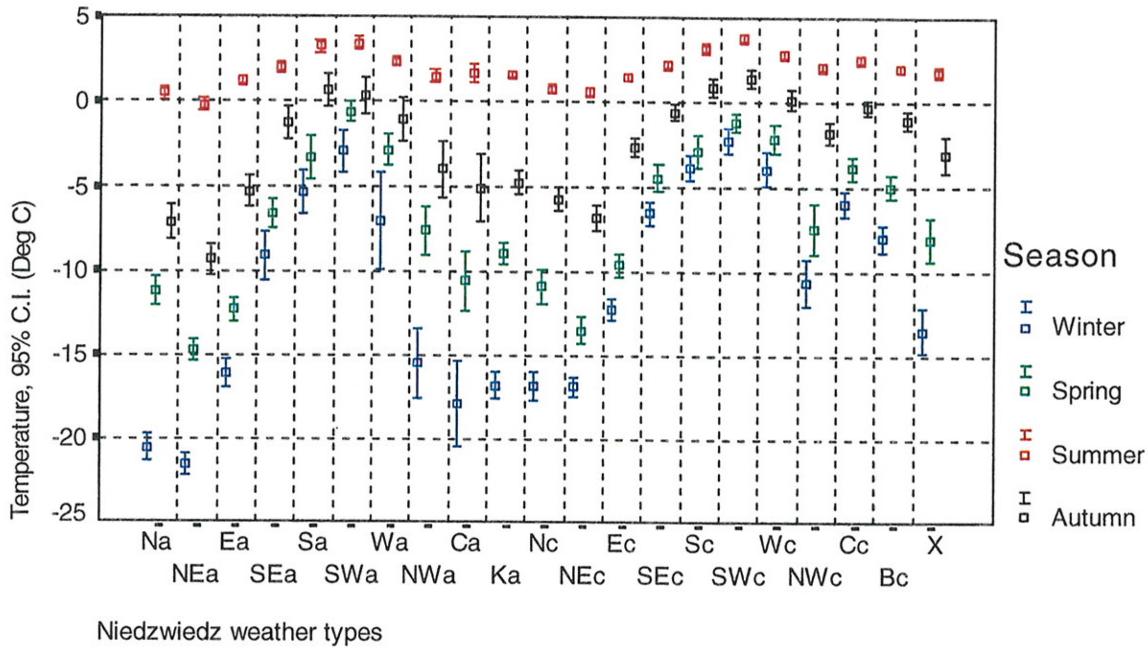

Fig. 8.1 **Hopen.** Mean temperature in the period 1950.01.01 – 1997.07.04 computed separately for each Niedzwiedz weather type in the seasons, Winter (Dec. – Feb.), Spring (Mar. – May), Summer (June – Aug.), and Autumn (Sep. – Nov.).

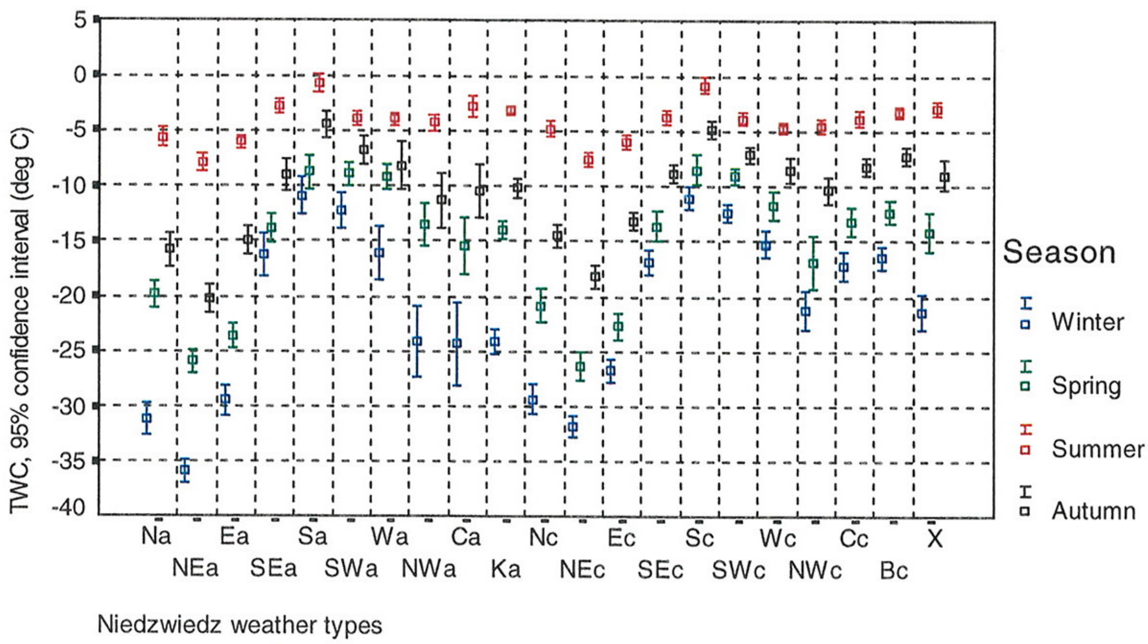

Fig. 8.2 **Hopen.** Mean wind-chill temperature in the period 1950.01.01 – 1997.07.04 computed separately for each Niedzwiedz weather type in the seasons, Winter (Dec. – Feb.), Spring (Mar. – May), Summer (June – Aug.), and Autumn (Sep. – Nov.).

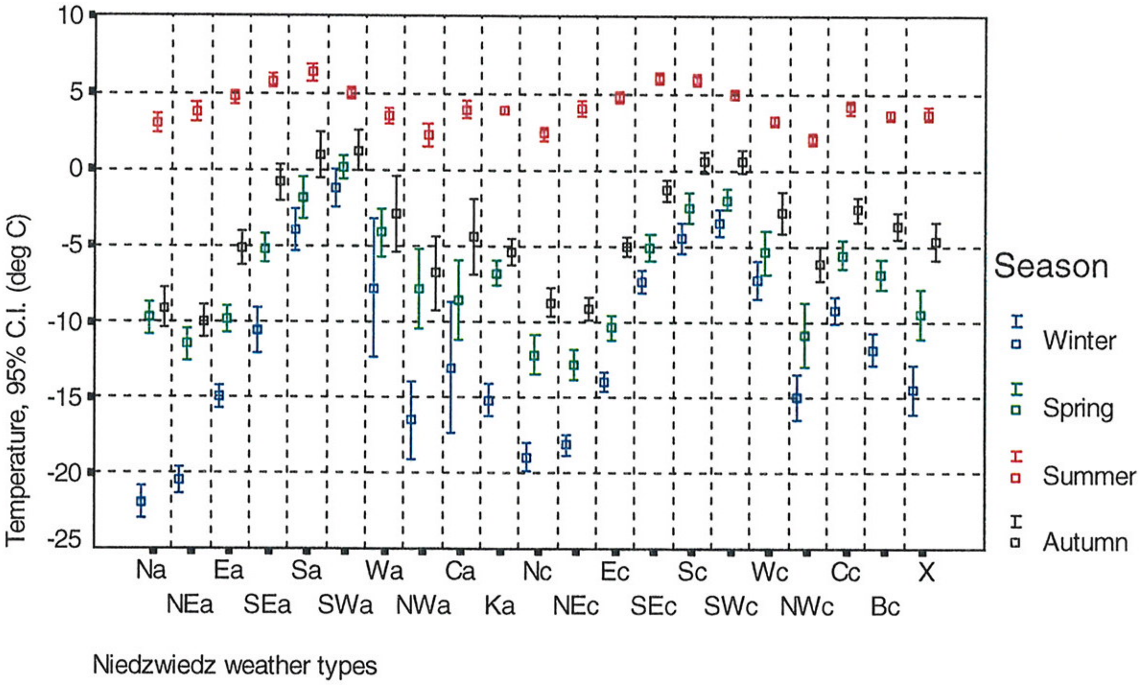

Fig. 8.3 **Ny-Ålesund.** Mean temperature in the period 1969.01.01 – 1997.07.04 computed separately for each Niedzwiedz weather type in the seasons, Winter (Dec. – Feb.), Spring (Mar. – May), Summer (June – Aug.), and Autumn (Sep. – Nov.).

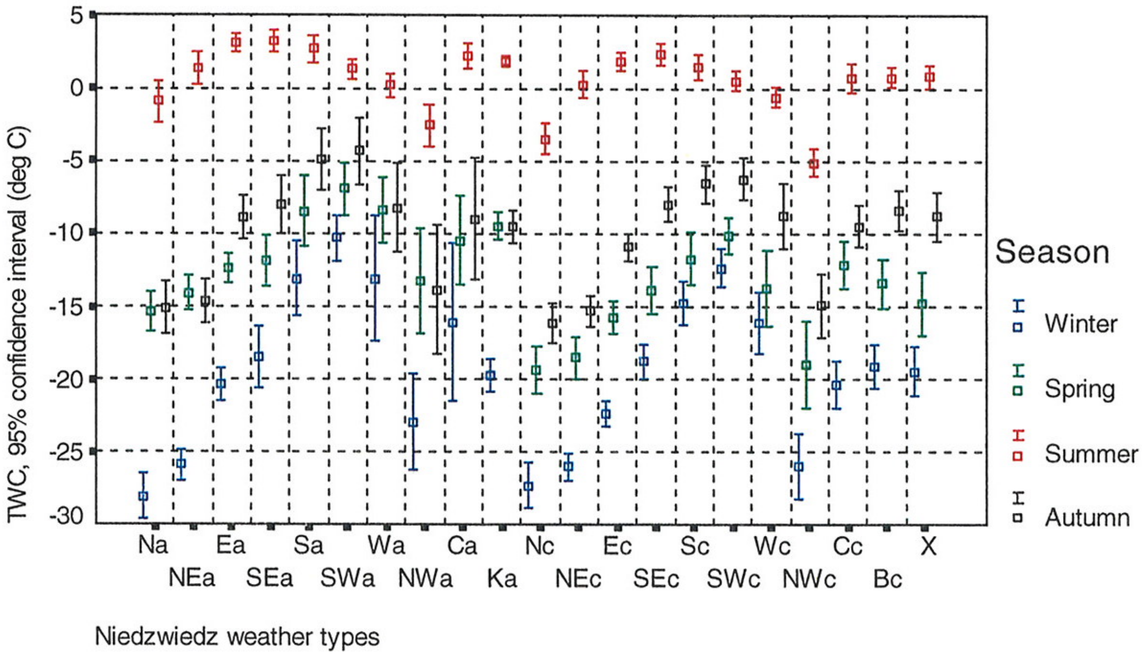

Fig. 8.4 **Ny-Ålesund.** Mean wind-chill temperature in the period 1969.01.01 – 1997.07.04 computed separately for each Niedzwiedz weather type in the seasons, Winter (Dec. – Feb.), Spring (Mar. – May), Summer (June – Aug.), and Autumn (Sep. – Nov.).

it disappears. Thus, the confidence intervals are considered to be mostly reliable, but may be somewhat too small for the most common weather types.

Looking at the figures 8.1 – 8.4 it is immediately seen that the grouping by weather type has a tremendous influence on both temperature and wind-chill temperature. It is the wind direction that to a large extent governs the temperatures. For example for Hopen the largest difference of mean values occurs between the types NEa and SEa in winter. The difference amounts to 19°C for temperature and 25°C for wind-chill temperature.

In all seasons the mean temperatures and wind-chill temperatures are highest under southerly flow and lowest under northerly flow. The amplitude, however, varies with season. During summer the amplitude is only about 5°C for temperature and 5-10°C for wind-chill temperature. During winter the amplitude is three or four times larger than in summer. At Hopen the amplitude is appreciably larger during spring than during autumn, but in Ny-Ålesund the magnitude of the seasonal amplitude does not differ much between spring and autumn, see figures 8.1 – 8.4.

Under southerly flow the climate at Svalbard is mild even in winter. For Hopen and Ny-Ålesund at weather types Sa, SWa, Sc, SWc the mean temperature is ca. -5°C or even milder. Under those weather types the seasonal differences are exceptionally small, i.e. within an interval of 10°C.

The standard deviation varies considerably with weather type, see the tables 1-4 in appendix 1. For some weather types the standard deviations are of about the same size as the standard deviation of the whole ensemble of observations during the seasons. For others the standard deviations reduce to about one half of that of the whole ensemble. This applies especially to the southern and southwestern circulation types, cyclonic or anticyclonic. The Niedzwiedz weather types prove thus to be a useful classification scheme not only for the mean values but also for the standard deviations.

The weather types 1 – 8 representing eight directions of anticyclonic flow have their cyclonic counterparts in weather types 11 – 18. Types 1 & 11, 2 & 12 etc. may be considered as paired types within common flow sectors. The differences of temperature and wind-chill temperature between paired types are however small compared to the much larger differences caused by different flow directions. For many paired types the difference is so small that its significance may be questioned. The significance of the differences is tested by the Student's t-test and the results listed in table 8.1. Capital and small letters denote significance at the 0.01 and 0.05 level respectively.

In fact far from all differences turned out to be significant. For wind-chill temperature at Hopen for instance, only 3 out of 40 tests revealed significant results at the 0.01 level. It seems therefore fruitful to establish a simplified set of Niedzwiedz weather types that does not distinguish between anticyclonic and cyclonic flow. Further simplification was done by joining the high-pressure types 9 and 10 and the low-pressure types 19 and 20. The symbols used for this simplified set is listed in table 8.1, first column.

Table 8.1 Significance of differences between anticyclonic and cyclonic flow within common sectors taken from Niedzwiedz weather types, is shown in the 8 first rows. In addition the significance of the differences between types 9 and 10, and between 19 and 20 is also shown, see the "High" and "Low" rows. The seasons are denoted with self-explanatory symbols, and capital letters and small letters are used for significance at levels 0.01 and 0.05 respectively. Lacking notation means no significant difference.

Flow Direction	Hopen TWC	Ny-Ålesund TWC	Hopen T	Ny-Ålesund T
N		SP, SU	WI,au	WI,SP
NE	WI, au	SP	WI, sp, su, AU	WI
E	WI, au	WI, SP ,SU, au	WI, SP, AU	WI
SE	su		WI, SP	WI
S		Sp	wi	
SW		Sp		WI, SP
W	SP	SP	wi, su	
NW	sp	sp, SU	WI, su, au	
High				
Low			WI, sp, SU, AU	WI

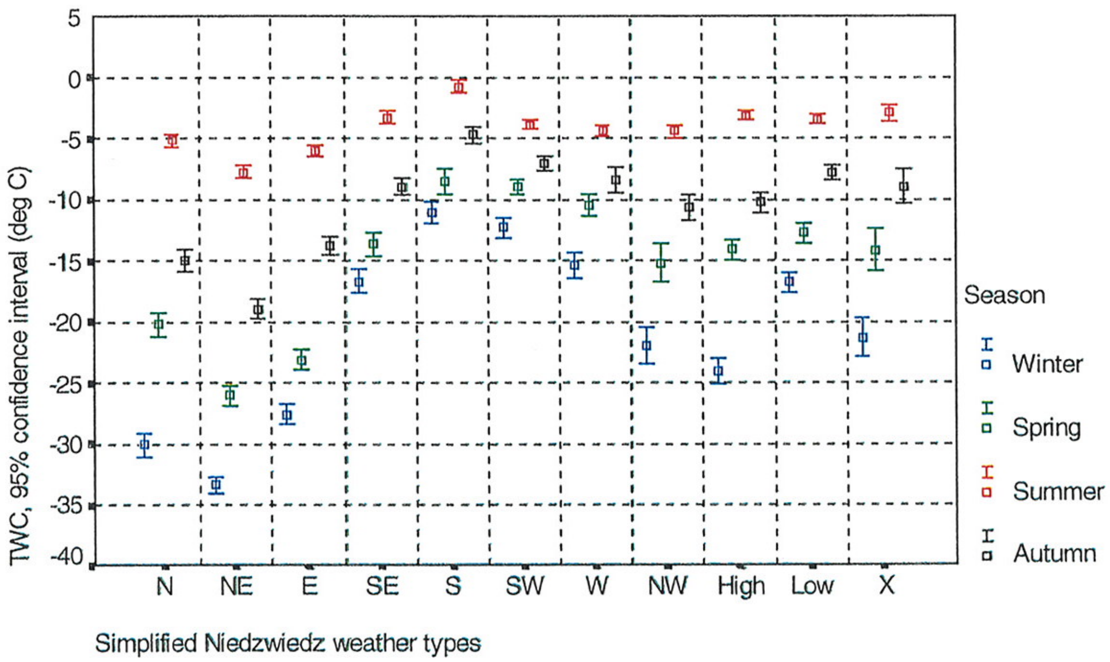

Fig. 8.5 **Hopen.** Mean wind-chill temperature in the period 1950.01.01 – 1997.07.04 computed separately for each simplified Niedzwiedz weather type in the seasons, Winter (Dec. – Feb.), Spring (Mar. – May), Summer (June – Aug.), and Autumn (Sep. – Nov.).

This simplified system reduces the number of types from 20 to 10. Applied on wind-chill temperature at Hopen very little significant information is lost compared to the use of the full scheme, compare Fig. 8.5 (simplified scheme) and 8.2 (full scheme). A disadvantage of using the full Niedzwiedz scheme is also that for some weather types there are only few observations and the confidence intervals of the mean values are large. For example the weather types Ca and NWa comprises only 0.6% respectively 1.2% of the observations

(Niedzwiedz 1993). In the simplified scheme these types enter the NW and High types respectively and the confidence intervals reduces several degrees.

Fig. 8.5 clearly demonstrates the influence of flow direction on wind-chill temperature at all seasons, however, the influence is far greater in winter and spring than in summer. The mildest wind-chill temperatures occur under southerly flow while the lowest ones occur under northeasterly flow.

The simplified scheme is neither applied to the Ny-Ålesund data nor to the temperature data from Hopen as testing of paired types shows that many differences are significant. Thus, valuable information might have been lost if the simplified scheme was used. For the Hopen temperature data about one half of the differences is significant at the 0.05 level. Whether the circulation is anticyclonic or cyclonic at Hopen, is important for temperature but not for wind-chill temperature. Thus, strong winds under the occurrence of cyclonic circulation to a large extent compensate for the low temperature under anticyclonic circulation, making the wind-chill temperature differences between paired types of wind-chill temperature small and often insignificant.

In the period 1951.01.01 – 1997.07.04 the series of temperature and wind-chill temperature were classified by the Niedzwiedz weather type scheme. The grouping by weather types has a tremendous influence on both temperature and wind-chill temperature. It is the wind direction that to a large extent governs the temperatures. In all seasons the temperature and wind-chill temperature are lowest for northerly or northeasterly flow and highest for southerly flow. For wind-chill temperature the difference between southerly and northerly flow is about 25°C in winter and 5-10°C only in summer.

For he Hopen the differences of wind-chill temperature between cyclonic and anticyclonic circulation under the same wind direction were for most weather types not significant. A simplified scheme of weather types grouped by wind direction only could thus be used at Hopen without loosing valuable information.

9 Wind-chill temperature at Jan Mayen.

Jan Mayen is not included in the Svalbard group of islands and is therefore treated separately. It has a more southwesterly position than Svalbard and is situated at about the same latitude as the northern tip of the Norwegian mainland, Fig. 3.1. However, the cold East Greenland current influences the climate at Jan Mayen while the warm Norwegian current influences the climate at the Norwegian mainland, and makes the climatic conditions at the northernmost tip of Norway far more favourable than at Jan Mayen.

The winter temperature at Jan Mayen is described by its distribution in Fig. 9.1, left. The distribution is skew with the long tail to the left, against low temperatures. The wind-chill temperature in winter are also skew in the same direction, but to a lesser extent, see Fig. 9.1, right. Like at Hopen and Bjørnøya in the Svalbard area, both temperature and wind-chill temperature are in most cases less skew in summer and autumn, see table 6.1. In spring the distribution of temperature is as skew as in winter and in spring the distribution of wind-chill temperature is even more skew, cf. table 9.1

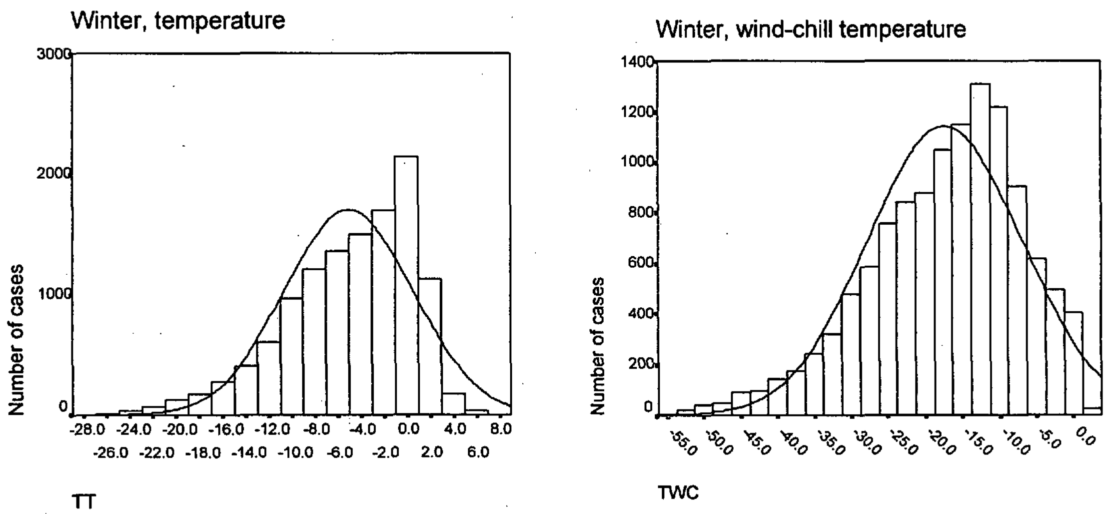

Fig. 9.1 Distributions of temperature (left) and wind-chill temperature (right) in the winter season (Dec. – Feb.) at Jan Mayen in the period 1956 – 1999.

In table 9.1 the percentiles of the distribution of temperature and wind-chill temperature are shown as well as the range, standard deviation and skewness. The lowest wind-chill temperature occurred 22 February 1963 and was –56.4°C. It should also be noted that the lowest wind-chill temperature during spring is not much higher, -55.1°C, which occurred 5 March 1969. The median wind-chill in winter, spring and autumn is somewhat higher than calculated for the Svalbard stations. This is true whether the median values of tables 4.2 and 9.1 are compared directly (note that the two tables comprise different observational periods), or the percentiles are compared within the common reference period, 1979 – 1998.

In Fig. 9.1 the cumulative distribution of wind-chill temperature at Jan Mayen is showed in the four seasons. From the figure the relative number of cases below predefined thresholds is readily seen. For example a wind-chill temperature below -10°C occurs 10 % of all cases in summer, 42 % in autumn, 60 % in spring and 75 % in winter.

Table 9.1 Jan Mayen. Standard deviation (Std.), skewness (Skew.) and percentiles of air temperature (TT) and wind-chill temperature (TWC) during the period 1956 – 1999. The winter season is denoted Wi, spring Sp, summer Su, and autumn Au. Observations at hours 06, 12 and 18 UTC are included.

	Elem.	Std.	Skew.	Range	Min.	5 %	25 %	Median	75 %	95 %	Max.
W	TT	5.6	-0.82	37.2	-28.4	-15.8	-8.5	-4.1	-0.6	1.9	8.8
I	TWC	10.4	-0.64	58.5	-56.0	-36.7	-23.8	-15.8	-9.9	-2.2	2.5
S	TT	4.6	-1.08	35.6	-26.4	-11.8	-5.5	-1.8	0.3	2.4	9.2
p	TWC	9.6	-0.63	63.2	-55.1	-30.1	-19.0	-11.9	-5.7	-0.8	8.1
S	TT	2.4	-0.12	18.1	-4.2	0.0	2.5	4.2	5.7	7.7	13.9
u	TWC	5.6	-0.41	28.8	-17.4	-11.9	-5.7	-1.0	2.9	6.3	11.4
A	TT	4.2	-0.75	30.5	-17.0	-7.3	-2.1	0.9	3.3	6.0	13.5
u	TWC	8.0	-0.48	49.2	-40.2	-23.0	-13.9	-8.3	-3.1	3.2	9.0

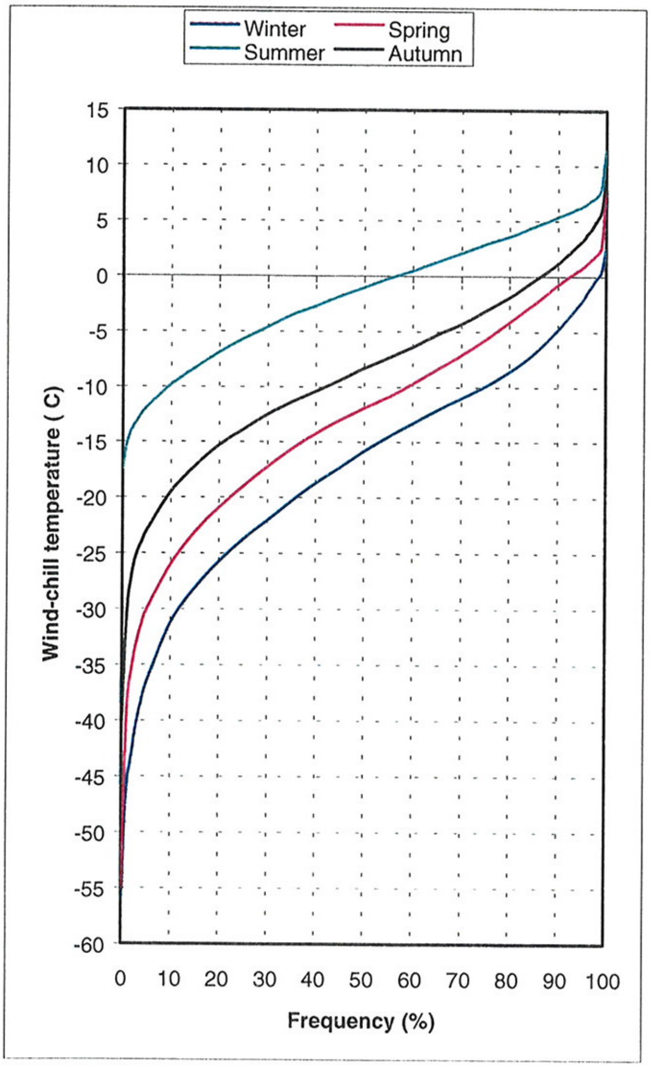

Fig. 9.1 Cumulative distribution of wind-chill temperature for 99950 Jan Mayen based on three observations a day in the period 1956 – 1999.

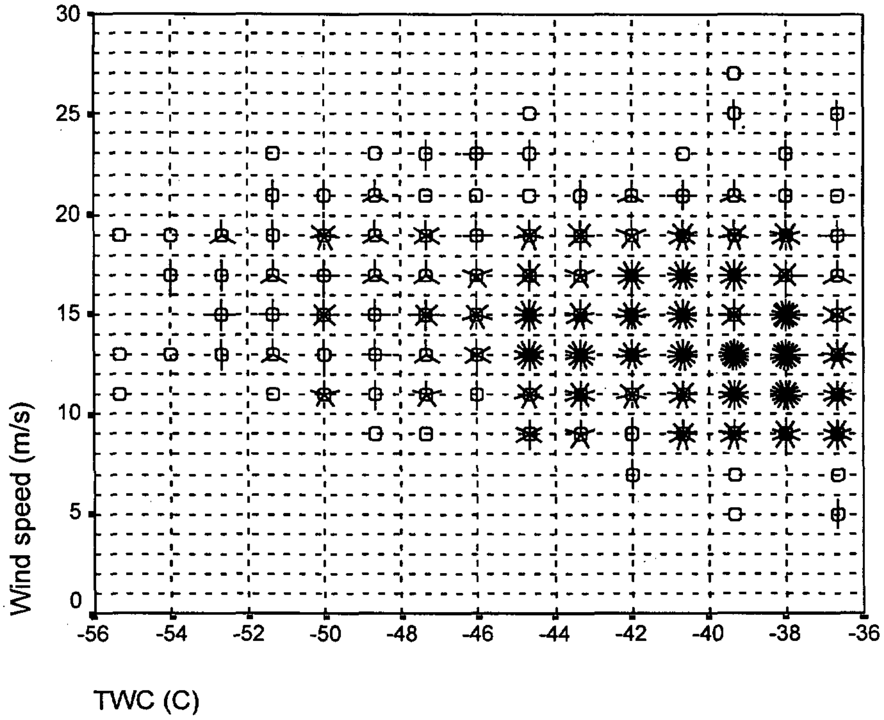

Fig. 9.2 The lowest 5 % of the wind-chill temperatures in winter for Jan Mayen in the period 1956 – 1999. The number of cases within each point is shown by "sunflowers" where one pedal represents one case.

Wind-chill temperature lower than –36.7°C comprises 5 % of the observations during winter. These are plotted in Fig. 9.2 together with the wind speed. For the lowest wind-chill temperatures the wind speed are concentrated in the interval 10 – 20 m/s. In the interval of wind-chill temperature between -45°C and –36°C, the most numerous cases for wind speed are located in the interval 10 – 15 m/s.

The variation of mean temperature and mean wind-chill temperature in the period 1956 – 1999 is shown in Fig. 9.3. The method of calculation of mean temperature is given in Ch. 6. Both temperature and wind-chill temperature are standardised to zero mean and unit standard deviation in the reference period 1979 - 1998. After the standardisation the values have been filtered by a Gaussian low pass filter to visualise variations on a decadal time scale. Both curves have characteristic minimum values in the 1960s and both temperature and wind-chill temperature have increased significantly up to present. The two curves almost coincide and the increased wind-chill temperature must be caused by an increased temperature rather than a decreased in wind speed.

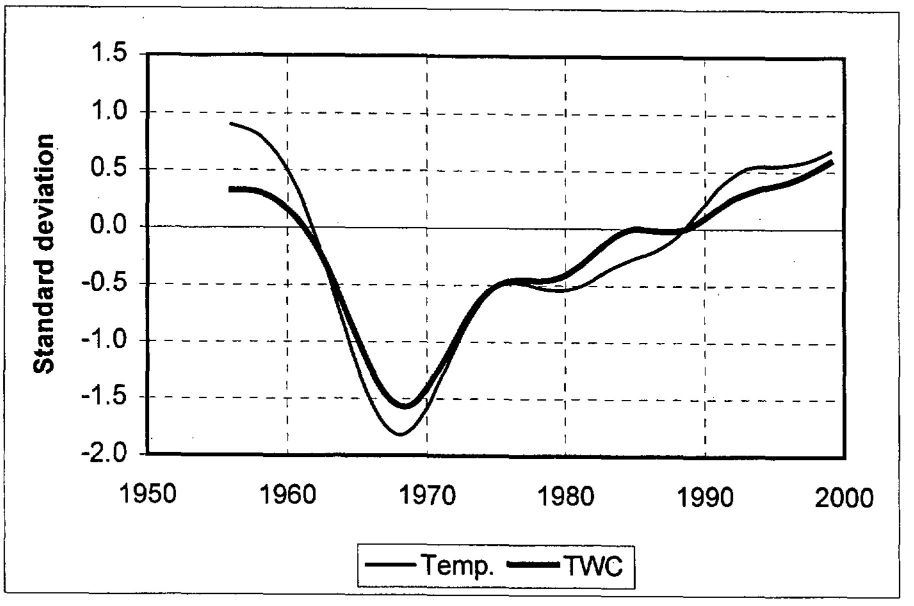

Fig. 6.4. Jan Mayen. Filtered values of wind-chill temperature (TWC), thick curve, and temperature (TT), thin curve. A Gaussian filter is used with a standard deviation in the distribution of 3 years. Both TWC and TT are normalised to zero mean and unit standard deviation in the reference period 1979-1998.

10 Distributions of wind-chill temperatures in the period 1979 – 1998 and their spatial differences

During the 20-year period, 1979 – 1998, the cumulative distributions of the Norwegian Arctic series are shown in the figures 10.1 (winter) and 10.2 (summer). The distributions of the Sveagruva series bore a strong resemblance to those of Svalbard Airport. The curves could hardly be separated in the diagrams, and the Sveagruva series are therefore omitted. The diagrams are intended for a broad outlook of the wind-chill temperature differences between the stations, and for information on wind-chill temperatures (TWC) near to the extremes, see Ch. 4. The comments in this chapter only apply to percentiles in the range 5 – 95 %.

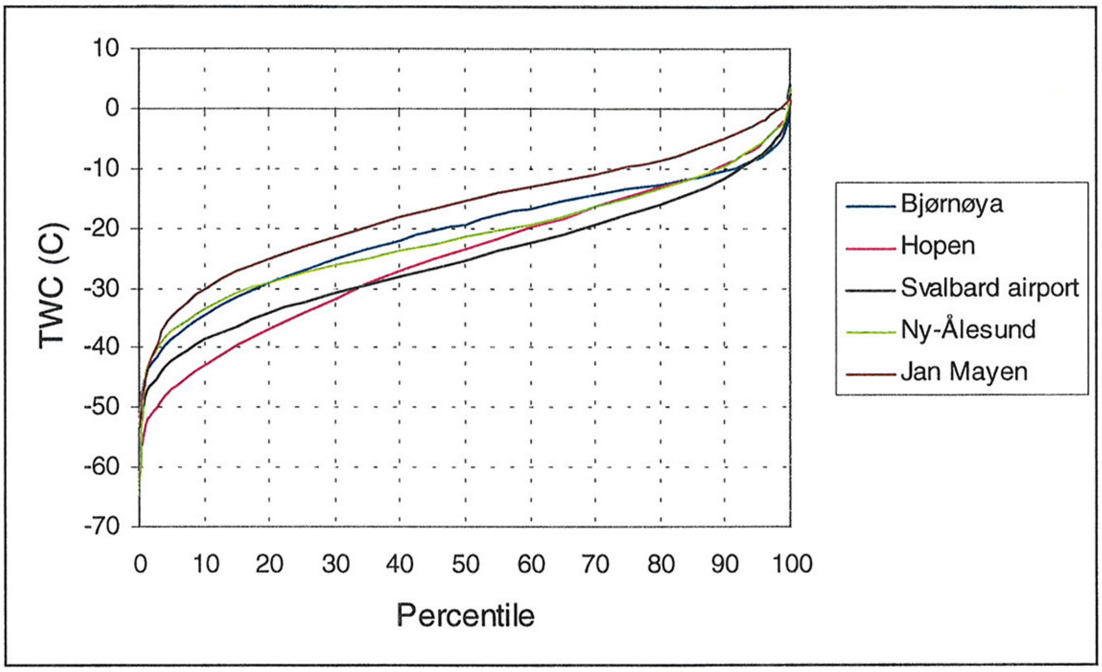

Fig. 10.1 **Winter** (Dec. – Feb.). Cumulative distributions of wind-chill temperature based on three observations a day for the Norwegian Arctic stations in the period 1979 – 1998.

In **winter** there are higher wind-chill temperatures (TWC) at Jan Mayen than in the Svalbard area. As should be expected due to its southern and maritime position, Bjørnøya has the highest TWC of the Svalbard stations for most of the percentiles shown in the diagram.

The curves of the Hopen and Svalbard Airport series intersect near the 33-percentile, and to the left of this point the lowest TWCs belongs to Hopen, and to the right of the point the lowest TWCs belongs to Svalbard Airport.

In Fig. 10.1 is also shown that the spatial range of the TWCs depends on the percentile. The range decreases somewhat as the percentiles increases.

Fig. 10.1 also gives information of threshold frequencies, i.e. how often the TWC drops below fixed threshold. For example the TWC drops below the threshold -30°C 10 % at Jan Mayen, 18 % at Bjørnøya and Ny-Ålesund, and 33 % at Svalbard Airport, Sveagruva (not shown) and Hopen. TWCs below thresholds lower than -30°C occur most frequently at Hopen, while TWCs below thresholds higher than -30°C occur most frequently at Svalbard Airport.

In **summer** the highest TWCs at the Norwegian Arctic stations occur at Ny-Ålesund, while the lowest TWCs occur at the small island station, Hopen, Fig. 10.2. The Bjørnøya series has somewhat higher TWCs than Hopen, but the differences are within an interval of 2°C.

The spatial range for given percentiles of TWCs in summer is roughly the half of that in winter. In summer the range seems to be largest around the 50 percentile and are narrowing towards both sides, Fig. 10.2.

The relative number of cases below fixed thresholds is readily taken out from Fig. 10.2. For example temperatures below 0°C occur at about 35 % of the time at Ny-Ålesund, 55 % at Svalbard Airport, Sveagruva (not shown) and Jan Mayen, 75 % at Bjørnøya, and 77 % at Hopen.

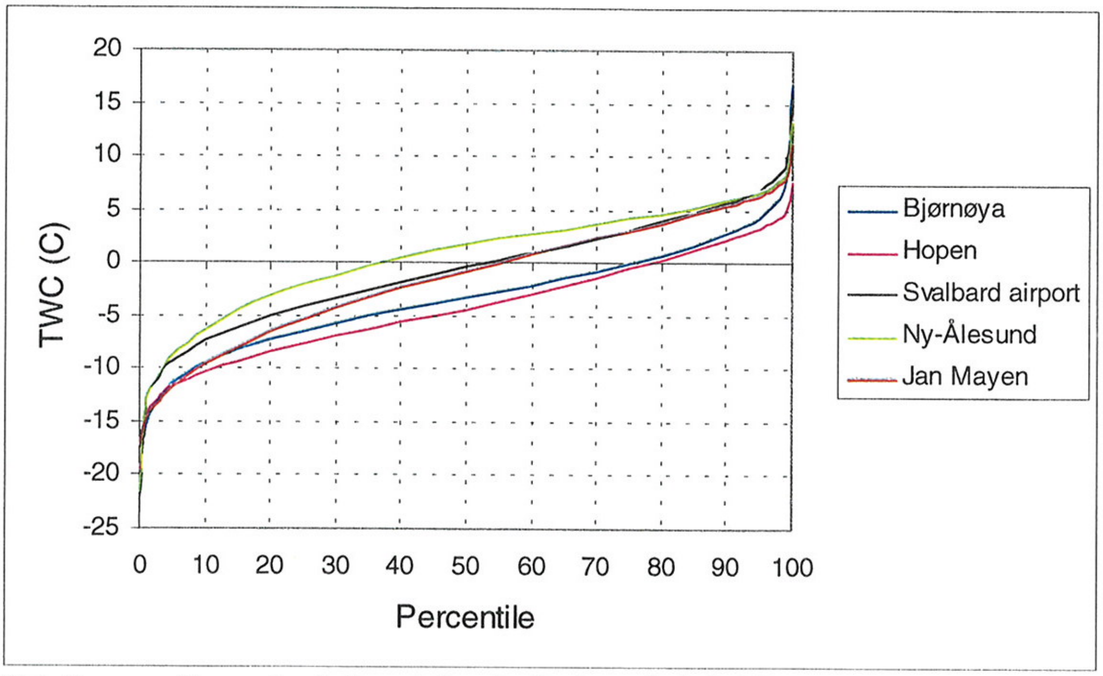

Fig. 10.1 **Summer** (Jun. – Aug.). Cumulative distributions of wind-chill temperature based on three observations a day for the Norwegian Arctic stations in the period 1979 – 1998.

Conclusions

The distributions of temperature as well as wind-chill temperature reveal the climatic differences of the Svalbard area. The series from Spitsbergen in winter have distributions close to the normal one, while the distributions of the Bjørnøya and Jan Mayen series were skew with a long tail to the negative side. The distribution of the Hopen temperature series had two maxima. These are probably a result of different climatic condition on the island when the island is surrounded by open sea or by sea ice.

Temperature and wind speed are positively correlated for the three Spitsbergen series that was investigated, while these weather elements are not correlated for the Hopen and Bjørnøya series. The lowest wind-chill temperatures also belong to the sample of lowest recorded temperatures on Bjørnøya and Hopen, but not on Spitsbergen. On Spitsbergen the lowest temperatures are accompanied by very low wind speed. The lowest wind-chill temperatures are found when temperature is about 10°C higher than the extreme.

The spatial distribution of wind-chill temperature at Svalbard was studied during a reference period 1979 – 1998. The station where the absolute lowest wind-chill temperature occurred was Hopen. The Hopen series has also the lowest 5-percentile value among the Svalbard stations. The highest 5-percentile value occurred at Bjørnøya and Ny-Ålesund. However, next to Hopen, Ny-Ålesund experienced also the lowest wind-chill temperature in the period.

The long-term variations of temperature and wind-chill temperature were studied by a Gaussian low pass filter in order to visualise variations on a decadal time scale. At Ny-Ålesund (1979 – 1998) the local minima and maxima of wind-chill temperature were not located in the same decades as those of temperature. The reason for this discrepancy is that temperature and wind speed are positively correlated, and low temperature tends to occur together with week winds and vice versa.

At Hopen (1946 – 1998) the local maxima and minima of wind-chill temperature are located in the same decades as those of temperature except in the 1980s and 1990s. This applies to all seasons except autumn where they are located in the same decades during the whole period of observation. This is also true for Bjørnøya (1921 – 1998) and Jan Mayen (in the period of investigation, 1956 – 1999). In the long-term series from Bjørnøya, Hopen and Jan Mayen the 1960s turned out to be the decade with the lowest TWC.

In the period 1951.01.01 – 1997.07.04 the series of temperature and wind-chill temperature were classified by the Niedzwiedz weather type scheme. The grouping by weather types had a tremendous influence on mean values both for temperature and wind-chill temperature. It is the wind direction that to a large extent governs the temperature variations. In all seasons the temperature and wind-chill temperature are lowest for northerly or northeasterly flow and highest for southerly flow. For wind-chill temperature the difference between southerly and northerly flow is about 25°C in winter and 5-10°C in summer.

For Hopen the differences of wind-chill temperature between cyclonic and anticyclonic circulation under the same wind direction were for most weather types not significant. A simplified scheme of weather types grouped by wind direction only could thus be used at Hopen without loosing valuable information.

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Appendix 1

Table 1 Mean temperature for Hopen in the period 1950.01.01 – 1997.07.04 computed separately for each Niedzwiedz weather type (see Ch. 8) in four seasons, Winter (Dec. – Feb.), Spring (Mar. – May), Summer (June – Aug.), and Autumn (Sep. – Nov.).

		MEAN	ST.D	CASES			MEAN	ST.D	CASES
	Winter	**-12.4**	**8.8**	**4242**		**Summer**	**1.9**	**2.2**	**4266**
1	Na	-20.5	5.0	154	1	Na	.5	2.1	136
2	NEa	-21.5	6.2	389	2	NEa	-.1	2.4	149
3	Ea	-16.0	7.5	302	3	Ea	1.2	2.0	263
4	SEa	-9.0	7.6	110	4	SEa	2.0	2.2	207
5	Sa	-5.3	5.3	68	5	Sa	3.3	1.8	93
6	SWa	-2.9	4.7	64	6	SWa	3.5	2.2	178
7	Wa	-7.0	7.4	29	7	Wa	2.4	1.9	169
8	NWa	-15.4	5.6	30	8	NWa	1.5	2.1	125
9	Ca	-17.8	6.8	29	9	Ca	1.7	2.3	84
10	Ka	-16.8	7.0	285	10	Ka	1.6	2.2	646
11	Nc	-16.8	6.1	196	11	Nc	.8	1.7	191
12	NEc	-16.8	7.0	544	12	NEc	.6	1.6	185
13	Ec	-12.2	8.3	576	13	Ec	1.5	1.7	224
14	SEc	-6.5	6.4	308	14	SEc	2.2	1.8	187
15	Sc	-3.7	4.7	171	15	Sc	3.2	2.2	147
16	SWc	-2.2	5.2	200	16	SWc	3.8	1.9	246
17	Wc	-3.8	4.7	89	17	Wc	2.8	1.8	201
18	NWc	-10.5	6.2	79	18	NWc	2.1	1.7	164
19	Cc	-5.9	5.8	239	19	Cc	2.5	1.9	172
20	Bc	-7.9	6.6	269	20	Bc	2.0	2.0	345
21	X	-13.4	6.9	111	21	X	1.8	2.0	154

		MEAN	ST.D	CASES			MEAN	ST.D	CASES
	Spring	**-8.6**	**7.6**	**4324**		**Autumn**	**-3.2**	**6.3**	**4186**
1	Na	-11.1	6.4	245	1	Na	-7.0	6.3	160
2	NEa	-14.7	6.9	451	2	NEa	-9.2	7.3	266
3	Ea	-12.2	7.0	406	3	Ea	-5.2	7.3	255
4	SEa	-6.6	5.8	180	4	SEa	-1.2	5.2	126
5	Sa	-3.2	5.6	80	5	Sa	.6	3.9	73
6	SWa	-.5	2.7	84	6	SWa	.3	4.0	57
7	Wa	-2.8	3.7	70	7	Wa	-1.0	3.8	36
8	NWa	-7.5	5.5	62	8	NWa	-3.9	5.5	45
9	Ca	-10.5	6.4	52	9	Ca	-5.0	6.2	43
10	Ka	-8.9	6.9	479	10	Ka	-4.7	6.2	358
11	Nc	-10.9	7.1	195	11	Nc	-5.6	6.0	276
12	NEc	-13.4	7.4	343	12	NEc	-6.7	7.2	414
13	Ec	-9.6	7.6	416	13	Ec	-2.6	5.7	475
14	SEc	-4.3	5.7	223	14	SEc	-.5	4.2	331
15	Sc	-2.8	5.3	129	15	Sc	.8	3.8	187
16	SWc	-1.1	3.6	190	16	SWc	1.3	3.7	190
17	Wc	-2.0	3.6	72	17	Wc	.1	2.8	87
18	NWc	-7.4	6.3	70	18	NWc	-1.8	3.5	114
19	Cc	-3.8	5.3	230	19	Cc	-.2	3.3	267
20	Bc	-4.9	5.6	247	20	Bc	-1.0	4.5	295
21	X	-8.0	6.4	100	21	X	-3.0	6.0	131

Table 2 Mean of wind-chill temperature for Hopen in the period 1950.01.01 – 1997.07.04 computed separately for each Niedzwiedz weather type (see Ch. 8) in four seasons, Winter (Dec. – Feb.), Spring (Mar. – May), Summer (June – Aug.), and Autumn (Sep. – Nov.).

		MEAN	ST.D	CASES
Winter		**-23.9**	**12.6**	**4242**
1	Na	-31.0	8.8	154
2	NEa	-35.8	10.4	389
3	Ea	-29.3	11.7	302
4	SEa	-16.2	10.3	110
5	Sa	-10.8	7.0	68
6	SWa	-12.2	6.2	64
7	Wa	-16.0	6.2	29
8	NWa	-24.1	8.4	30
9	Ca	-24.3	9.9	29
10	Ka	-24.0	9.7	285
11	Nc	-29.3	9.7	196
12	NEc	-31.6	11.4	544
13	Ec	-26.7	12.4	576
14	SEc	-16.8	9.6	308
15	Sc	-11.0	6.8	171
16	SWc	-12.3	6.2	200
17	Wc	-15.2	5.6	89
18	NWc	-21.2	7.7	79
19	Cc	-17.2	9.7	239
20	Bc	-16.4	8.8	269
21	X	-21.3	8.2	111

		MEAN	ST.D	CASES
Summer		**-4.1**	**4.7**	**4266**
1	Na	-5.5	4.8	136
2	NEa	-7.9	4.9	149
3	Ea	-6.0	4.2	263
4	SEa	-2.7	4.5	207
5	Sa	-.6	3.9	93
6	SWa	-3.8	4.4	178
7	Wa	-3.9	3.9	169
8	NWa	-4.2	4.3	125
9	Ca	-2.7	4.3	84
10	Ka	-3.1	4.7	646
11	Nc	-4.8	4.8	191
12	NEc	-7.5	4.3	185
13	Ec	-5.9	4.9	224
14	SEc	-3.7	4.6	187
15	Sc	-.7	4.1	147
16	SWc	-3.8	4.1	246
17	Wc	-4.6	3.7	201
18	NWc	-4.5	4.1	164
19	Cc	-3.8	4.8	172
20	Bc	-3.1	4.5	345
21	X	-2.9	4.3	154

		MEAN	ST.D	CASES
Spring		**-17.7**	**11.6**	**4324**
1	Na	-19.7	9.6	245
2	NEa	-25.8	11.3	451
3	Ea	-23.5	11.1	406
4	SEa	-13.8	8.5	180
5	Sa	-8.7	6.6	80
6	SWa	-8.8	4.9	84
7	Wa	-9.1	4.8	70
8	NWa	-13.4	7.6	62
9	Ca	-15.3	9.2	52
10	Ka	-13.9	9.2	479
11	Nc	-20.7	10.8	195
12	NEc	-26.3	12.1	343
13	Ec	-22.6	12.6	416
14	SEc	-13.5	10.2	223
15	Sc	-8.4	7.9	129
16	SWc	-9.0	5.0	190
17	Wc	-11.7	5.3	72
18	NWc	-16.8	10.1	70
19	Cc	-13.1	9.3	230
20	Bc	-12.3	8.7	247
21	X	-14.1	8.9	100

		MEAN	ST.D	CASES
Autumn		**-11.6**	**9.5**	**4186**
1	Na	-15.7	9.9	160
2	NEa	-20.2	10.4	266
3	Ea	-14.8	10.2	255
4	SEa	-9.0	7.9	126
5	Sa	-4.3	5.0	73
6	SWa	-6.7	5.0	57
7	Wa	-8.1	6.3	36
8	NWa	-11.3	8.1	45
9	Ca	-10.4	8.0	43
10	Ka	-10.1	8.1	358
11	Nc	-14.5	8.9	276
12	NEc	-18.1	11.0	414
13	Ec	-13.1	9.1	475
14	SEc	-8.8	7.6	331
15	Sc	-4.8	5.7	187
16	SWc	-7.1	4.7	190
17	Wc	-8.5	5.3	87
18	NWc	-10.3	6.2	114
19	Cc	-8.2	7.0	267
20	Bc	-7.2	7.2	295
21	X	-8.9	8.1	131

Table 3 Mean temperature for Ny-Ålesund in the period 1969.01.01 – 1997.07.04 computed separately for each Niedzwiedz weather type (see Ch. 8) in four seasons, Winter (Dec. – Feb.), Spring (Mar. – May), Summer (June – Aug.), and Autumn (Sep. – Nov.).

Mean	St.d	Cases			Mean	St.d	Cases		
	Winter	-13.0	7.8	2586		Summer	4.2	2.5	2610
1	Na	-21.7	5.1	91	1	Na	3.0	2.7	71
2	NEa	-20.3	5.7	176	2	NEa	3.8	2.7	79
3	Ea	-14.8	4.9	157	3	Ea	4.7	2.5	135
4	SEa	-10.4	6.0	62	4	SEa	5.8	2.6	127
5	Sa	-3.8	4.0	37	5	Sa	6.3	2.0	63
6	SWa	-1.1	3.3	31	6	SWa	5.0	2.2	110
7	Wa	-7.7	8.5	16	7	Wa	3.5	2.4	99
8	NWa	-16.3	5.3	19	8	NWa	2.3	2.7	59
9	Ca	-12.9	7.9	16	9	Ca	3.9	1.8	52
10	Ka	-15.0	7.4	185	10	Ka	3.9	2.4	390
11	Nc	-18.7	5.2	135	11	Nc	2.4	2.2	118
12	NEc	-17.9	6.2	329	12	NEc	4.0	2.2	101
13	Ec	-13.8	5.9	393	13	Ec	4.8	2.3	134
14	SEc	-7.2	5.3	200	14	SEc	6.1	2.3	133
15	Sc	-4.3	5.4	117	15	Sc	5.9	2.0	120
16	SWc	-3.4	5.2	143	16	SWc	4.9	1.7	164
17	Wc	-7.1	5.3	70	17	Wc	3.3	1.9	154
18	NWc	-14.8	5.6	58	18	NWc	2.0	2.1	115
19	Cc	-9.1	5.1	135	19	Cc	4.1	2.0	91
20	Bc	-11.7	6.3	142	20	Bc	3.6	2.3	194
21	X	-14.3	6.8	74	21	X	3.7	2.0	101

		Mean	St.d	Cases			Mean	St.d	Case
	Spring	-7.9	7.2	2667		Autumn	-4.8	6.6	2548
1	Na	-9.6	6.3	143	1	Na	-9.0	6.4	93
2	NEa	-11.4	7.5	218	2	NEa	-9.9	6.2	125
3	Ea	-9.7	6.7	242	3	Ea	-5.1	6.1	125
4	SEa	-5.1	4.6	99	4	SEa	-.8	4.4	58
5	Sa	-1.7	4.5	45	5	Sa	.9	4.6	40
6	SWa	.2	2.7	55	6	SWa	1.2	4.0	40
7	Wa	-4.0	4.7	38	7	Wa	-2.8	4.4	15
8	NWa	-7.7	6.7	28	8	NWa	-6.7	5.8	25
9	Ca	-8.4	7.5	34	9	Ca	-4.4	5.0	18
10	Ka	-6.7	7.1	305	10	Ka	-5.3	6.4	218
11	Nc	-12.0	7.3	130	11	Nc	-8.6	6.4	205
12	NEc	-12.7	7.2	214	12	NEc	-9.1	6.4	295
13	Ec	-10.2	6.8	294	13	Ec	-4.9	6.2	341
14	SEc	-5.0	5.1	139	14	SEc	-1.3	5.0	209
15	Sc	-2.3	4.9	96	15	Sc	.5	4.0	126
16	SWc	-1.8	4.1	137	16	SWc	.6	4.1	118
17	Wc	-5.2	5.5	58	17	Wc	-2.7	4.5	45
18	NWc	-10.6	7.5	51	18	NWc	-6.1	4.4	63
19	Cc	-5.4	5.5	136	19	Cc	-2.5	4.6	135
20	Bc	-6.7	6.1	140	20	Bc	-3.6	5.6	157
21	X	-9.3	6.4	65	21	X	-4.6	5.9	97

Table 4 Mean of wind-chill temperature for Ny-Ålesund in the period 1969.01.01 – 1997.07.04 computed separately for each Niedzwiedz weather type (see Ch. 8) in four seasons, Winter (Dec. – Feb.), Spring (Mar. – May), Summer (June – Aug.), and Autumn (Sep. – Nov.).

		MEAN	ST.D	CASES
	Winter	**-20.9**	**9.4**	**2586**
1	Na	-27.9	7.5	91
2	NEa	-25.7	7.1	176
3	Ea	-20.2	7.0	157
4	SEa	-18.3	8.1	62
5	Sa	-12.9	7.7	37
6	SWa	-10.1	4.3	31
7	Wa	-12.9	8.0	16
8	NWa	-22.7	6.9	19
9	Ca	-15.9	10.1	16
10	Ka	-19.6	7.7	185
11	Nc	-27.1	9.2	135
12	NEc	-25.8	8.9	329
13	Ec	-22.2	8.4	393
14	SEc	-18.6	8.6	200
15	Sc	-14.6	8.0	117
16	SWc	-12.1	7.9	143
17	Wc	-16.0	8.8	70
18	NWc	-25.8	8.6	58
19	Cc	-20.2	9.4	135
20	Bc	-18.9	9.1	142
21	X	-19.3	7.2	74

		MEAN	ST.D	CASES
	Summer	**.8**	**4.8**	**2610**
1	Na	-.8	6.1	71
2	NEa	1.4	4.9	79
3	Ea	3.1	3.5	135
4	SEa	3.3	4.1	127
5	Sa	2.7	3.7	63
6	SWa	1.3	3.6	110
7	Wa	.2	4.2	99
8	NWa	-2.4	5.4	59
9	Ca	2.3	3.0	52
10	Ka	1.9	3.7	390
11	Nc	-3.3	5.8	118
12	NEc	.3	4.6	101
13	Ec	1.9	3.9	134
14	SEc	2.4	4.3	133
15	Sc	1.5	4.7	120
16	SWc	.6	4.2	164
17	Wc	-.4	4.6	154
18	NWc	-4.9	5.3	115
19	Cc	.8	4.6	91
20	Bc	.8	4.6	194
21	X	.9	4.1	101

		MEAN	ST.D	CASES
	Spring	**-13.3**	**9.4**	**2667**
1	Na	-15.1	8.3	143
2	NEa	-13.9	8.8	218
3	Ea	-12.2	7.8	242
4	SEa	-11.7	8.7	99
5	Sa	-8.3	8.0	45
6	SWa	-6.8	6.6	55
7	Wa	-8.3	6.8	38
8	NWa	-13.1	9.2	28
9	Ca	-10.3	8.8	34
10	Ka	-9.3	8.1	305
11	Nc	-19.2	9.5	130
12	NEc	-18.3	10.5	214
13	Ec	-15.6	9.3	294
14	SEc	-13.7	9.6	139
15	Sc	-11.5	8.7	96
16	SWc	-9.9	7.2	137
17	Wc	-13.6	9.8	58
18	NWc	-18.8	10.6	51
19	Cc	-12.0	9.4	136
20	Bc	-13.2	10.0	140
21	X	-14.6	8.9	65

		MEAN	ST.D	CASES
	Autumn	**-10.7**	**9.2**	**2548**
1	Na	-15.0	8.8	93
2	NEa	-14.6	8.2	125
3	Ea	-8.9	8.4	125
4	SEa	-8.0	7.4	58
5	Sa	-4.9	6.6	40
6	SWa	-4.3	7.2	40
7	Wa	-8.2	5.5	15
8	NWa	-13.8	10.7	25
9	Ca	-8.9	8.3	18
10	Ka	-9.4	8.3	218
11	Nc	-16.1	9.8	205
12	NEc	-15.2	9.2	295
13	Ec	-10.9	8.8	341
14	SEc	-7.9	8.3	209
15	Sc	-6.5	7.4	126
16	SWc	-6.2	7.8	118
17	Wc	-8.7	7.5	45
18	NWc	-14.9	8.5	63
19	Cc	-9.4	8.3	135
20	Bc	-8.3	8.9	157
21	X	-8.8	8.3	97