14. THE CLIMATE OF THE STATION IN THE LIGHT OF SELECTED CLIMATIC INDICES

Different types of indices are used to synthesize some of the broad features of a given climate. Such indices include oceanicity or continentality, humidity or aridity, and bioclimate measures. For the Hornsund region, a few chosen indices will be discussed to extend analysis of characteristics of the specific climatic parameters described above.

14.1. Continentality and oceanicity of the climate

The mean multiannual (1979–2009), annual amplitude of the air temperature at Hornsund was 18.4 deg, with a standard deviation of 2.13 deg. The greatest annual amplitude was 21.9 deg (1981), the smallest was 12.9 deg, recorded in 2007. Most other Spitsbergen stations have mean annual ranges of air temperature greater than at Hornsund. At those near the Greenland Sea coast it amounted 21.7 deg at Barentsburg and 21.2 deg at Ny Ålesund. At the stations in the island's interior, this increased to 23.7 deg at Svalbard-Lufthavn and 24.8 deg at Svea. The annual amplitude of air temperature at Björnöya was definitely less than at Hornsund, however (15.0 deg).

Over the research period the annual amplitude of air temperature at Hornsund showed a tendency to decline (Fig. 14.1): the trend (–0.096 $\mathrm{deg\cdot yr^{-1}}$) was statistically significant ($p< 0.023$). Trends of changes of air temperature amplitude at Ny Ålesund (–0.119 $\mathrm{deg\cdot yr^{-1}}$) and at Björnöya (–0.102 $\mathrm{deg\cdot yr^{-1}}$) were similarly statistically significant. The trend of amplitude of annual air temperature at Hornsund appears to show a quasi-periodicity of 7–8 years, with the annual amplitude reaching lowest ranges of 13–16 deg. The periodicity of maximum ranges of amplitude (22–21 deg) is less clear. In the face of the short observation period, it is hard to say if asymmetry of the sequence (Fig. 14.1) consists of a longer succeeded by a shorter cycle, and because the decline occurs more rapidly. Such regular asymmetry of the record is not observed at other stations near Hornsund.

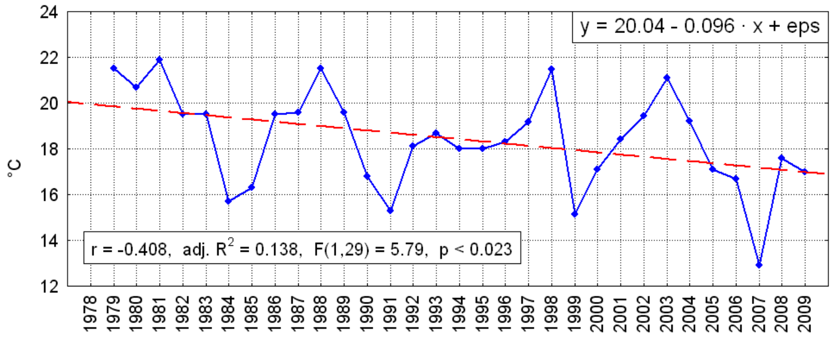

Fig. 14.1. The annual amplitude of air temperature [°C] at the Hornsund station and its trend, 1979–2009.

In face of the great variability of air temperature of the coldest month and very small variability of the warmest month (Table 9.1), it is the variability of the coldest month that determines the annual amplitude, explaining over 94% of variation at Hornsund. Years with relatively warm winters are those in which the annual amplitude suddenly decreases (Fig. 14.2). Because a positive trend is observed in the mean winter temperature (December-March), it acts to decrease the annual amplitude.

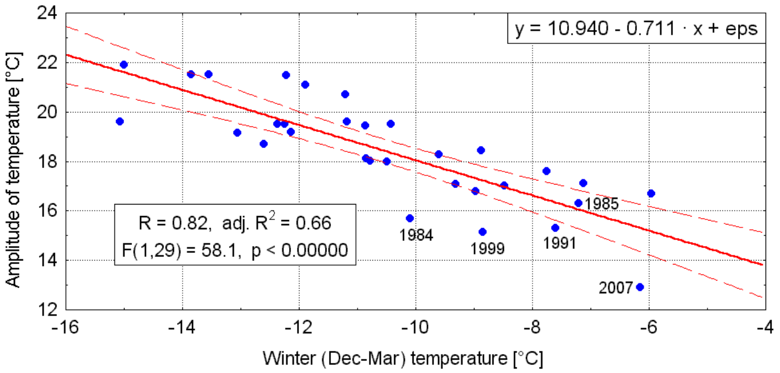

Fig. 14.2. Relationship of annual air temperature amplitude with mean winter air temperature (December-March) at the Hornsund station in 1979–2009.

The amplitude of annual temperature is commonly considered an important feature of the climate, establishing its continentality or oceanicity. The indices of oceanicity (Oc), after Marsz (1995), were calculated for Hornsund using the equation:

$$Oc = ((0.732 \cdot \varphi) + 1.767) / A$$

where φ – latitude of the station, A – the annual amplitude of air temperature. During observations at Hornsund, the mean multiannual index of oceanicity was 3.20, with a standard deviation (σn) of 0.40. This means that the Hornsund climate is oceanic over this many years period. Individual years may be assigned to three classes of climate: ultra oceanic ($Oc \geq 4.0$) in 2007; oceanic ($3.00 \leq Oc \leq 3.99$) in 1984 and 1985, 1990–1997, 1999–2001, 2004–2006, 2008–2009 (18 cases) and sub oceanic ($2.00 \leq Oc \leq 2.99$) in 1979–1983, 1986–1989, 1998 and 2002–2003 (12 cases). There were no years that could be recognized as continental ($1.00 \leq Oc \leq 1.99$).

Such a distribution of coefficients of oceanicity places Hornsund as intermediate between the insular Björnöya and the Svalbard-Lufthavn and Svea stations located in the interior of Spitsbergen (Fig. 14.3, Table 14.1). The Björnöya station has considerably stronger oceanic features than at Hornsund station (multiannual mean Oc = 3.88, σn = 0.70) and is also characterized by considerably greater variability of Oc. Eleven years (cases) of ultra-oceanicity were recorded there, but also there were two years in which annual amplitudes were big enough to rate in the sub-oceanic category. At the Svalbard-Lufthavn station steady sub-oceanic conditions (mean multiannual value of Oc = 2.53, σn = 0.33) prevailed throughout the same period. Only in three particular years (1991, 1999 and 2007) did the annual temperature amplitudes occur there, that allow classification as an oceanic climate (Fig. 14.3).

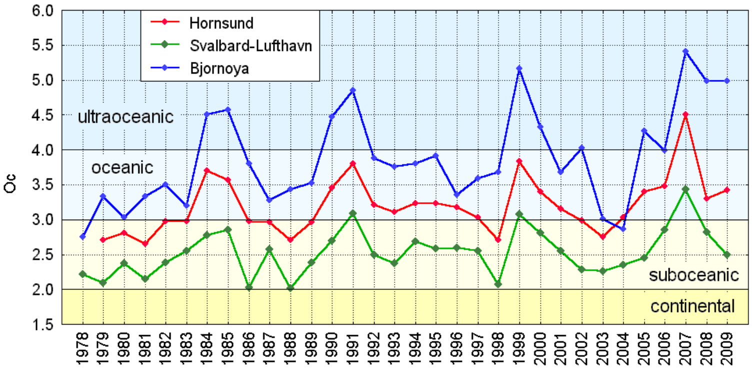

Fig. 14. 3. The course of oceanicity index (Oc) at the stations Hornsund, Svalbard-Lufthavn and Björnöya in 1978–2009.

Because there are close associations between the values of the oceanicity index (Oc) and frequency of occurrence of marine and continental air masses (Marsz 1995), it becomes possible to estimate the frequency of occurrence of the marine air masses (as % of the year) at these stations. Marine air masses prevail for 95% of the year at Björnöya, around 87% of the year at Hornsund, and only around 69% of the year at Svalbard-Lufthavn (Table 14.1).

Table 14.1. Mean (Mean), the lowest (Min) and the highest (Max) values of Oc index at the Svalbard stations, 1979-2009. σn – standard deviation of the monthly mean, MM – the annual frequency of the marine air masses (%).

Station	Oc						MM
	Mean	σn	Min	Year	Max	Year	
Ny Alesund	2.85	0.33	2.19	1981	3.40	1999	78.5
Svalbard-Lufthavn	2.53	0.33	2.01	1988	3.43	2007	68.8
Barentsburg	2.77	0.39	2.21	1998	3.85	1992	64.8
Svea	2.40	0.26	2.03	1998	3.03	2007	75.9
Hornsund	**3.20**	**0.40**	**2.65**	**1981**	**4.50**	**2007**	**86.7**
Björnöya	3.88	0.70	2.75	1978	5.41	2007	95.0
Hopen	3.13	0.58	2.42	1978	4.89	2007	83.7

Such great differentiation of marine air mass frequency at stations situated close to each other but in different settings may be interpreted as the result of powerful influence of ocean surface conditions, sea ice and the local relief of Spitsbergen on the rapid transformation of air masses occurring in this area.

14.2. The humidity of the climate

Among many possible indices, the humidity index (Wk) elaborated by N.N. Ivanov was used for description of the conditions at the Hornsund station. Its simplicity and clear physical sense is very appealing. After Okołowicz (1976) it takes the form:

$$Wk = RR/ Ev$$

and is the relationship of monthly total precipitation (RR, mm) to total evaporation in the same month (Ev, mm), expressed in percent. The monthly total evaporation is an estimated value, being function of the mean monthly air temperature (Ta) and the mean monthly relative humidity (RH), which is calculated as a product:

$$Ev = 0.0018 \cdot (25 + Ta)^2 \cdot (100 - RH)$$

The annual index Wk is calculated as a quotient of the annual total of precipitation and the annual total of Ev values. Index values higher than 100% indicate excess of precipitation over evaporation, less than 100% – evaporation exceeds precipitation in the given period. Values Wk ≥ 500% are the upper limit of Ivanov humidity scale, the so-called "fivefold surplus of humidity" or "superhumid". Wk values in the range, 500–200%, are classified as "excessively humid climate", values of 200–100% as "humid". Values smaller than 100% denote dry climates and when Wk is smaller than 20% this indicates conditions of extreme aridity (fivefold excess of evaporation over precipitation). The mean annual multiannual value of Wk index for the Hornsund station is 232%, indicating that annual average precipitation there is more than twice as great as average annual evaporation and the Hornsund climate may be classified as "excessively humid". Wk amounted to 402% in the most humid year (1994), and was still as great as123% in the least (1987). The most frequent values are in the range, 150 to 300% (26 cases), 8 cases were in the range 151–200%, 9 in the range 201–250% and 7 in the range 251–300%.

The mean monthly Wk indices (Tables 14.2 and 18.33) between July and March were in the range 200 to 400%, classifying them as "excessively humid". In April, May and June the Wk indices are humid (200–104%). Note that the months that from their diurnal and monthly air temperatures are classified as the winter, and in which steady minima of the annual temperature occur, are characterized by Wk values higher than 300%. The annual minimum humidity occurred in the month of May, reaching only 104%.

Table 14.2. Mean (Mean) monthly, annual and its standard deviations (σn) as well as minimum (Min) and maximum (Max) values of Ivanov index of climate humidity [%] at Hornsund, 1978-2009.

	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
Mean	386	366	360	196	104	143	233	269	309	241	274	358	232
σn	218	279	225	129	70	138	284	205	256	144	184	314	56
Max	978	1046	994	507	291	647	1534	779	1080	684	887	1623	402
Year	1992	1994	1981	1991	1992	1988	1994	1994	1999	2000	1993	1995	1994
Min	114	4	28	24	23	5	5	51	11	52	46	41	123
Year	1994	1988	2008	1985	1989	1987	1998	2001	1982	1995	1979	1999	1987

The relatively steady values of the annual (Fig. 14.4) and monthly Wk indices (Table 14.2) suppress the real differentiation of the climatic humdity, which is exceptionally great in the Hornsund region (Fig. 14.5). Values of standard deviations (Table 14.2) show that the least variability is in May, which is also the least humid month. For the 31 records of this month there were 15 cases (50%) in which evaporation was higher than total precipitation ($0 < Wk \leq 100\%$), including 5 cases in which the index was in the range 20.1 – 40%, 6 cases in the range 40.1 – 60%, 2 cases in the range 60.1 – 80% and 1 case in which Wk was in the range 80.1–100%.

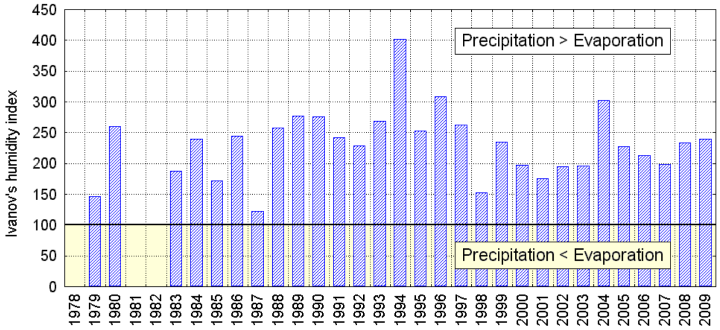

Fig. 14.4. The course of annual index of humidity [%] at the Hornsund station in 1979–2009.

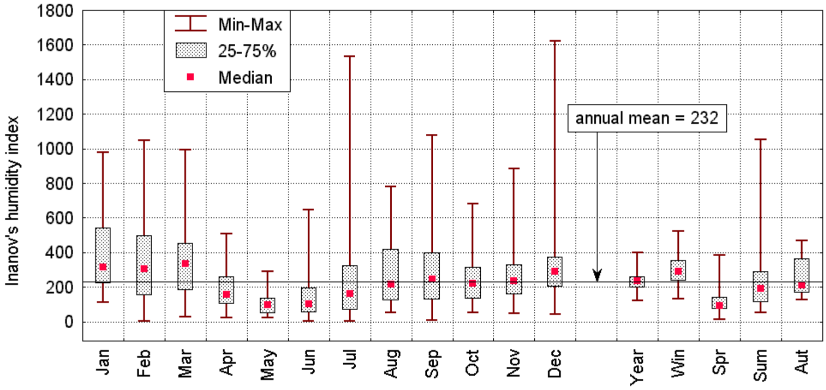

Fig. 14.5. Range of variability of the index of climatic humidity [%] at Hornsund in 1978–2009.
Thermal seasons: Win – winter (December-April), Spr – spring (May-June),
Sum – summer (July-August), Aut – autumn (September-November)

In comparison with other months, such low variability of humidity in May at Hornsund results mainly from the relatively even and small precipitation totals (19.3 mm, σn = 11.9 mm), being a reflection of the increase of frequency of anticyclonic systems over Spitsbergen and, to a lesser degree, of the relatively small variability of the air temperature affecting evaporation (Ev).

The greatest variability of humidity is characteristic of December, July, February and September (σn in Table 14.2). In the case of December (Fig. 14.6) the main reason for strong variability is the occurrence of some radically high values of the Wk index (2 cases over 1000%; 1623% in 1995 and 1066% in 1988), plus a limited number of cases of values smaller than 100% (91% in 1980, 86% in 1986, 71% in 1987 and 41% in 1999) and a quite great dispersion of values in the other cases. The main factors controlling the index values in September and December are changes of the precipitation totals, to a lesser degree the variability of air temperature. The reasons for big variability in February are similar. The differences of precipitation totals play the principal role here in the great variability.[1]

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[1] In February 1988 Wk value reached 3.8%, precipitation total in this month amounted only 0.3 mm, which was 1.1% of the multiannual mean.

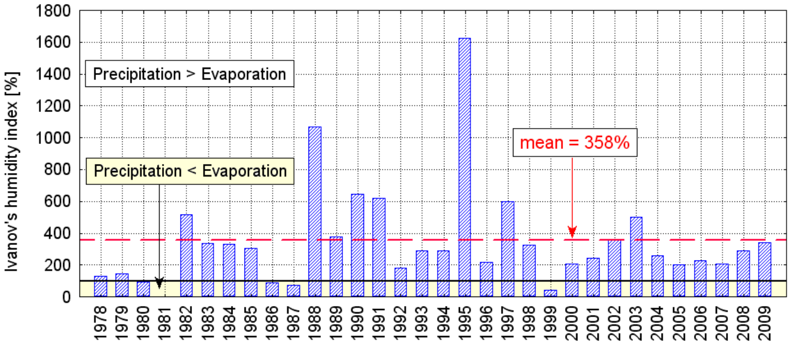

Fig. 14.6. The mean humidity index in December at the Hornsund station in 1978–2009.

Somewhat more complicated are reasons for the great variability of the humidity index in July (Fig. 14.7). Here the extremes ranged from 5.3% (in 1998) to 1534% (in 1994). The occurrence of the exceptionally low Wk index in July 1998 was associated with only a trace precipitation total (1.5 mm) and relatively high air temperature (+5.3°C). Similarly low humidity was recorded in 1979 (Wk = 5.6%, Ta = 4.9°C, RR = 1.7 mm) and in 1993 (Wk = 12%, Ta = 4.3°C, RR = 3.0 mm). The maximum recorded humidity in 1994 (Wk = 1534%) was due to exceptionally high precipitation (136.5 mm; 315% of monthly norm) at an air temperature lower than the multiannual norm (3.7°C, anomaly –0.7 deg) and exceptionally great relative humidity (94%)[2], limiting evaporation.

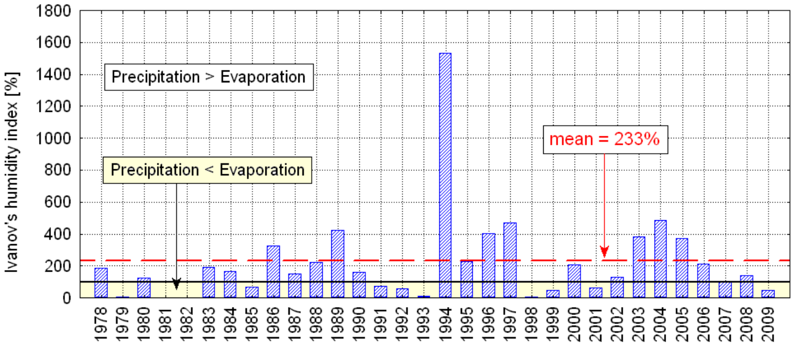

Fig. 14.7. The mean humidity index in July at the Hornsund station in 1978–2009.

The monthly distribution of cases with low or radically high Wk values seems more interesting than the values of humidity coefficient (Table 14.3). Lower values around 100% show a clear concentration between April and September, with a maximum in May or June. In April and from July to September around 20% of all years are characterized by a deficiency of atmospheric precipitation. May and June in around half of the years are "dry" and are characterized by greater or smaller, sometime extreme, shortages of precipitation. In such years the lack of precipitation in May is compensated by melt water. In June, and also in July these shortages may be compensated by

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[2] In July 1994, 23 days with appearance of fog were recorded at Hornsund.

permafrost water. Excessive drying of the ground in the area surrounding the station takes place if there are prolonged periods without precipitation and if there is a high temperature in August (≥ 5°C).

Occurrence of a "fivefold surplus of humidity" (and greater) is most probable between December and March, the period established as “winter” from monthly and diurnal air temperatures. In each of these months, every four years on average, there is a very strong excess of precipitation over evaporation. However also in this period, although with a considerably smaller probability, a month may occur with a radical deficiency of humidity. Such an example occurred in February 1988. With the negative temperatures in these months and consequent limited evaporation, from a few to one dozen mm of precipitation in water equivalent will be sufficient for equilibrium between precipitation and evaporation. This period is that of the most intensive accumulation of precipitation on glaciers.

Table 14.3. Number of occurrences of values of the humidity index (Wk) assigned to definite intervals in the months at Hornsund in 1978–2009.

Index	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
0 < Wk ≤ 100%	0	5	2	6	15	15	9	7	6	4	5	4
100 < Wk ≤ 200%	6	6	6	12	12	8	9	7	6	9	5	3
200 < Wk ≤ 300%	8	4	5	7	3	5	4	7	7	10	12	10
300 < Wk ≤ 400%	4	4	8	2	0	0	3	2	4	3	4	7
400 < Wk ≤ 500%	4	4	2	2	0	1	4	3	2	4	1	1
500 < Wk ≤ 1623%	8	7	7	1	0	1	1	4	6	1	4	6
Number of cases	30	30	30	30	30	30	30	31	31	31	31	31

Comparing the mean monthly multiannual values of the Ivanov humidity index at the Hornsund station with other stations on Spitsbergen and with Björnöya (Table 14.4) it is easily noted that it is exceptionally even. In the annual pattern of Wk at Hornsund neither the strong winter maximum appearing at the other stations nor the deep spring minimum (Ny Ålesund) or the spring summer minimum (Svalbard-Lufthavn) are evident. The Wk index over the year for the whole Spitsbergen and Björnöya reaches its minimum in the season termed the “thermal spring” (May, June) and its maximum in winter months. However the passage of Wk index from winter (December-February) to spring (March-May) is very gentle at Hornsund and on Björnöya. Generally the annual behaviour of the index at the Hornsund station is more similar to Björnöya than to the other Spitsbergen stations. It seems to be the next manifestation of “oceanicity” of climate of the SW part of Spitsbergen.

Table 14.4. Mean monthly and annual values of Wk index at Svalbard stations in 1978–2009.

Station	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Ny Ålesund	848	1047	658	314	91	82	118	164	250	218	285	664	217
Svalbard-Luft.	495	714	365	132	27	27	38	61	75	73	141	349	75
Hornsund	**386**	**366**	**360**	**196**	**104**	**143**	**233**	**269**	**309**	**241**	**274**	**358**	**232**
Björnöya	649	709	589	356	170	142	221	226	329	277	356	514	302

The annual Ivanov index of humidity does not show a statistically significant trend at Hornsund. The trend is near to zero (+0.36%· yr^{-1}, $p < 0.78$). February is the only month in which there is a significant trend (–14.8% · yr^{-1}, $p < 0.01$). The evaporation variable (Ev, mm of water column) in the index is quite strong (+1.6 mm· yr^{-1}) and displays a significant ($p < 0.0013$) annual trend which explains 30% of its variation in 1979–2009. In the monthly mean values of evaporation (Ev) positive trends are recorded in all months of the year. They are statistically significant in January, February, May, November and December. Such development in Ev trends seems to show that over the research period at Hornsund, despite the Arctic climate, evaporation played a greater and greater role in the water balance.

Monthly values of the Wk index should show stronger or weaker associations with the climatic parameters from which they are calculated. Hence Wk has very strong and highly significant associations with monthly totals of precipitation (r from 0.98 in September to 0.54 in January) and weaker (and not in all months of the year significant) associations with relative humidity (not significant in December, January, February and March). Relations with monthly air temperature are weak and unstable however; they cross the threshold of significance only in July ($r = –0.48$), September ($r = 0.61$) and October ($r=0.53$), although the air temperature between October and May and in July is strongly interrelated with Ev (from December to February $r > 0.9$).

In summer months and at the beginning of autumn (from July to October) the Wk index shows statistically significant positive relationships with cloudiness (r from 0.54 to 0.57). Monthly Wk values show clear, statistically significant relations with the Niedźwiedź (1997, 2001) indices S and W of atmospheric circulation (Table 14.5).

Table 14.5. Correlation coefficients between monthly indices of climate humidity (Wk) at Hornsund and monthly Niedźwiedź indices S and W of atmospheric circulation (Tc). Statistically significant values are shown in bold.

Tc	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
S	–0.02	–0.26	0.02	0.03	0.09	**0.57**	**0.44**	0.17	**0.62**	**0.45**	0.34	–0.19
W	**0.38**	**0.66**	0.24	**0.45**	0.27	**0.46**	**0.52**	**0.57**	**0.53**	0.36	**0.73**	**0.34**

This shows that atmospheric circulation, via other climatic parameters (mainly air temperature, precipitation and water vapour content in the air) exerts serious influence on the variability of humidity in SW Spitsbergen. The importance of advection from the west has a particularly strong effect on increase of humidity. The Niedźwiedź (C) index of cyclonicity does not exert any major influence. This may be interpreted as the crucial role played by direction of advection but not its character (cyclonal, anticyclonal).

14.3. Wind chill

The bioclimatic conditions in the region of the Hornsund station have been presented with the help of different indices in the literature on the topic. The research periods were of different duration (from a few months to a few or a dozen years) with data of different degrees of averaging (term, diurnal, monthly) The Hill value of air cooling was estimated most often (Zawiślak 1986, Szczepankiewicz-Szmyrka and Pereyma 1992) and values of the wind chill index WCI (Araźny 2003, Owczarek 2004, Przybylak and Araźny 2005, Araźny *et al.* 2009). The WCT index that combines impact of low temperature and wind was also used to characterise bioclimatic conditions (Owczarek 2004, Przybylak and Araźny 2005). Changes of physiological deficiency, being the index of evaporation from the lungs and upper respiratory tract that may contribute to strong dehydration of organisms were investigated less frequently (Araźny 2005, Przybylak and Araźny 2005). In some research, an index of the predicted insulation capacity of clothing (Iclp) was used (Owczarek 2004, Przybylak and Araźny 2005, Araźny 2006, Araźny *et al.* 2009). The stimulation impact of atmospheric pressure changes was also investigated (Owczarek 2005). There was also an attempt to develop a typology of weathers occurring at Hornsund in relation to biothermics (Migała, Sikora and Puczko 2005).

The majority of bioclimatic indices define, one way or another, the rate of heat loss from exposed skin. These indices are functions of wind velocity and air temperature. At Hornsund in each of the winter months (December-March) a few to a dozen cold or very cold days are recorded. Negative air temperature is often accompanied by winds, sometimes even very big winds. In such conditions, even in the well-clothed man there is a substantial loss of heat, causing cooling leading to feeling cold, frostbites, and hypothermia in extreme cases. At Hornsund a lot of the work is done outside of the station buildings at all times, often for many hours. During the winter, in adverse conditions this may lead to serious risk of frostbite. For assessment of this risk the wind chill temperature index (WCT) was used in the present work.

The WCT index was developed in 2000–2002 by the meteorological services of the USA and Canada (Nelson *et al.* 2002) and measures the combined action of low air temperature and wind. This index is based on a model of heat loss from an uncovered face, with the assumption that the individual is dressed according to the weather (winter clothing) and moves with normal speed (~4.8 $km \cdot h^{-1}$). Compared to earlier indices of this type, validation of the formula was based on results of measurements and clinical research with the participation of volunteers (Report on Wind Chill ... 2003).The wind chill temperature index is calculated according to the formula:

$$WCT\ [°C] = 13.12 + 0.6215 \cdot Ta - 11.37 \cdot Vw^{0.16} + 0.3965 \cdot Ta \cdot Vw^{0.16}$$

where: Ta – air temperature [°C], Vw – wind velocity [$km \cdot h^{-1}$] at the standard 10 m height of the anemometer (if measurement of wind velocity is made at the level of face the wind velocity should be multiplied by 1.5).

Values of the WCT index were classified (Environment Canada, www.msc.ec.gc.ca) according to the degree of risk of cooling of the organism and possibility of frostbite and a scale of hazard of meteorological conditions was developed. The basis of this scale is assessment of the amount of time before the process of frostbite begins for a man dressed in winter clothing and in given thermo-anemometric conditions. Values of the wind chill temperature index (WCT) depending on the air temperature [Ta; °C] and wind velocity [Vw; $km \cdot h^{-1}$] are shown in Table 14.6. Because in meteorology wind velocity is given in $m \cdot s^{-1}$ its values are also placed in the table.

The scale of risk of chilling and frostbite in given meteorological conditions where the inputs are values of the WCT index is shown in Table 14.7. For each of the six degrees on the scale there is a different reaction of the subject and recommendations concerning protection.

The WCT index was used for Spitsbergen by Owczarek (2004) for evaluation of the experience of chill at the Hornsund station in 1991–2000, and by Przybylak and Araźny (2005) when comparing bioclimatic conditions occurring on the western coast of Spitsbergen (including Hornsund) in 1975–2000. These authors based their analyses on the mean diurnal values of Ta and Vw.

Table 14.6. Values of the WCT index [°C] showing degrees of hazard of frostbite together with the time after which this process may begin (according to Environment Canada, www.msc.ec.gc.ca)

Wind speed		Air temperature (Ta; °C)											
		5	**0**	**-5**	**-10**	**-15**	**-20**	**-25**	**-30**	**-35**	**-40**	**-45**	**-50**
1.4	**5**	4	−2	−7	−13	−19	−24	−30	−36	−41	−47	−53	**−58**
2.8	**10**	3	−3	−9	−15	−21	−27	−33	−39	−45	−51	**−57**	**−63**
4.2	**15**	2	−4	−11	−17	−23	−29	−35	−41	−48	−54	**−60**	**−66**
5.6	**20**	1	−5	−12	−18	−24	−30	−37	−43	−49	**−56**	**−62**	**−68**
6.9	**25**	1	−6	−12	−19	−25	−32	−38	−44	−51	**−57**	**−64**	**−70**
8.3	**30**	0	−6	−13	−20	−26	−33	−39	−46	−52	**−59**	**−65**	**−72**
9.7	**35**	0	−7	−14	−20	−27	−33	−40	−47	−53	**−60**	**−66**	**−73**
11.1	**40**	−1	−7	−14	−21	−27	−34	−41	−48	−54	**−61**	**−68**	**−74**
12.5	**45**	−1	−8	−15	−21	−28	−35	−42	−48	**−55**	**−62**	**−69**	**−75**
13.9	**50**	−1	−8	−15	−22	−29	−35	−42	−49	**−56**	**−63**	**−69**	**−76**
15.3	**55**	−2	−8	−15	−22	−29	−36	−43	−50	**−57**	**−63**	**−70**	**−77**
16.7	**60**	−2	−9	−16	−23	−30	−36	−43	−50	**−57**	**−64**	**−71**	**−78**
18.1	**65**	−2	−9	−16	−23	−30	−37	−44	−51	**−58**	**−65**	**−72**	**−79**
19.4	**70**	−2	−9	−16	−23	−30	−37	−44	−51	**−58**	**−65**	**−72**	**−80**
20.8	**75**	−3	−10	−17	−24	−31	−38	−45	−52	**−59**	**−66**	**−73**	**−80**
22.2	**80**	−3	−10	−17	−24	−31	−38	−45	−52	**−60**	**−67**	**−74**	**−81**
$m \cdot s^{-1}$	$km \cdot h^{-1}$	Little danger				**10–30**	**5–10**	**2–5**		**< 2**			
						Frostbite may occur in (minutes) or less							

In the light of the variability of mean monthly values of the WCT index (Tables 14.8 and 18.34) calculated on the basis of mean monthly values of air temperature and wind velocity, the wind chill hazard for people staying in an open area was not great during the period of record at the Hornsund station (1978–2009). All multiannual mean monthly values of WCT index in the cold season (November-April) fall in the category of moderate hazard (Table 14.8 and Fig. 14.8). This means

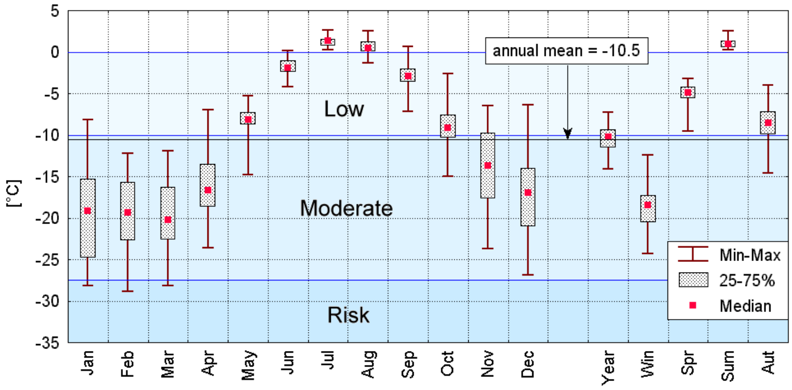

Fig. 14.8. Range of variability of values of the WCT index [°C] at the Hornsund station in 1978–2009.
Zones of hazard of cooling of organism of man staying in an open area are marked.
Thermal seasons: Win – winter (December-April), Spr – spring (May-June),
Sum – summer (July - August), Aut – autumn (September - November).

Table 14.7. Degree of hazard posed by meteorological conditions, according to WCT (according to Environment Canada, www.msc.ec.gc.ca)

WCT [°C]	Risk of frostbite	Other heath concerns	What to do
–9 ÷ 0	**Low**	Slight increase in discomfort	Dress warmly, stay dry
–27 ÷ –10	**Moderate**	Uncomfortable; risk of hypothermia if outside for long periods without adequate protection	Dress in layers of warm clothing and wear a hat. Keep active
–28 ÷ –39	**Risk**: exposed skin can freeze in 10 to 30 minutes*	Risk of frostnip or frostbite: check face and extremities for numbness or whiteness. Risk of hypothermia outside for long periods without adequate clothing or shelter from wind and cold	Dress in layers of warm clothing, with an outer layer that is wind-resistant. Cover exposed skin Wear a hat, mittens or insulated gloves, a scarf, neck tube or face mask and insulated, waterproof footwear. Stay dry. Keep active
–40 ÷ –47	**High risk**: exposed skin can freeze in 5 to 10 minutes*	High risk of frostnip or frostbite: check face and extremities for numbness or whiteness. Risk of hypothermia outside for long periods without adequate clothing or shelter from wind and cold	Dress in layers of warm clothing, with an outer layer that is wind-resistant. Cover all exposed skin. Wear a hat, mittens or insulated gloves, a scarf, neck tube or face mask and insulated, waterproof footwear. Stay dry. Keep active.
–48 ÷ –54	**Very high risk**: exposed skin can freeze in 2 to 5 minutes*	Very high risk of frostbite: check face and extremities frequently for numbness or whiteness. Serious risk of hypothermia if outside for long periods without adequate clothing or shelter from wind and cold.	Dress very warmly in layers of clothing, with an outer layer that is wind-resistant. Cover all exposed skin. Wear a hat, mittens or insulated gloves, a scarf, neck tube or face mask and insulated, waterproof footwear. Be ready to cut short or cancel outdoor activities. Stay dry. Keep active.
< –55	**Extremely high risk**: exposed skin can freeze in less than 2 minutes*	DANGER! Outdoor conditions are hazardous	Stay indoors

* – in sustained winds over 14 m·s^{-1}, frostbite can occur faster than indicated

that working and staying outside may be dangerous only in the case of long-lasting stays in the field when the proper clothing is used (warm clothing of many layers, windproof outer layer and a hat). Substantial risk of chilling or frostbite is possible only sporadically in this time. The hazard of cooling is small between May and October and there is no hazard at all in the summer (July and August).

On the basis of the annual course of the wind chill temperature index (WCT) one may state that the greatest hazards created by the meteorological conditions occurred in the initial period of work at the station, in the seventies and eighties (Fig. 14.9). The hardest conditions for field work were encountered in 1988 and 1979. In 1988 these were caused first of all by the frequent, very big drops of air temperature (to –32.1°C). 1979 was one from five the windiest years observed at Hornsund. Mean annual wind velocity was 6.0 m·s^{-1}, and maximum 25 m·s^{-1}, while in all months of the cold season except December and January there were major wind storms. The best years for field work were 2006 and 1984. These were the warmest years in the history of observations at the station. The last five years (2005–2009) are characterized by mild bioclimatic conditions. In these years annual values of the WCT index are in the category of light thermal discomfort (Fig. 14.9).

Table 14. 8. Mean monthly and annual values of wind chill temperature index (WCT; °C) at the Hornsund station in 1978–2009.

Year	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
Mean	–19.6	–19.8	–19.8	–16.3	–8.3	–1.8	1.3	0.7	–2.9	–9.3	–13.7	–17.6	–10.5
σn	5.1	4.3	4.3	3.7	1.8	1.1	0.7	0.8	1.5	2.5	4.6	5.2	1.6
Max	–8.2	–12.3	–11.9	–7.0	–5.2	0.1	2.6	2.5	0.6	–2.6	–6.5	–6.4	–7.3
Year	2006	2005	2004	2006	2006	1985	1990	2002	1990	2000	2009	1984	2006
Min	–28.1	–28.9	–28.1	–23.6	–14.8	–4.2	0.2	–1.4	–7.1	–15.0	–23.7	–26.9	–14.1
Year	1981	1998	1981	1988	1979	1979	1988	1982	1982	1988	1988	1988	1988

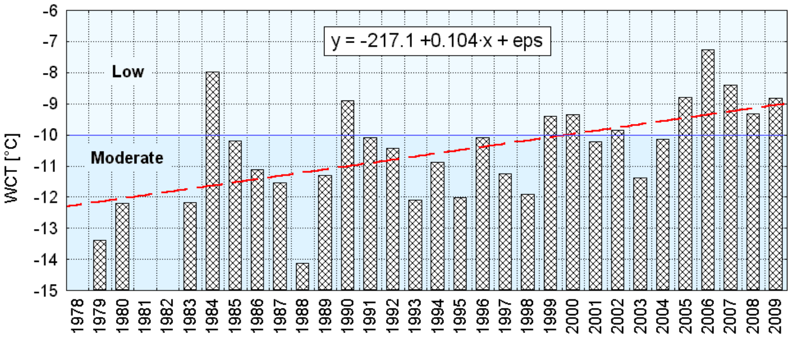

Fig. 14.9. Annual values of the WCT index [°C] at the Hornsund station and its trend. Zones of hazard for persons staying in an open area are marked.

In the research period the annual WCT index shows a tendency to increase (Fig. 14.9). In 1978–2009 there was a small positive trend (+0.104°C· yr^{-1}), statistically significant ($p = 0.001$). It explains 30% of the annual variation of the WCT index. Positive, statistically significant WCT trends occurred also in November: +0.008°C· yr^{-1}, December: +0.268°C· yr^{-1} and January +0.207°C· yr^{-1} as well as in August (+0.037°C· yr^{-1}). Such a distribution of significant trends in the index shows improvement of bioclimatic conditions in the cold season of the year at Hornsund. The trend of WCT changes over the thermal winter (December-April) amounted to +0.159°C· yr^{-1} ($p < 0.004$) and explained 24% of WCT variability in this season of the year. The trend of WCT variability in the autumn (September-November) was somewhat smaller (+0.112°C· yr^{-1}; $p < 0.007$), but explained a similar percentage (20%) of the changes occurring in 1978 - 2009. If this trend of WCT changes continues in the future, this will lead to the shortening of period during which adverse wind-chill conditions are possible in the Hornsund region.

Increase of the WCT index is caused by the considerable changes occurring in the air temperature during this time (Chapter 16.5). It is characterized by very strong positive trends in December (+0.225°C· yr^{-1}) as well as November and January (+0.185°C· yr^{-1}).

Comparing values of the WCT index at Hornsund with those of other Svalbard stations one should notice that in the winter at Hornsund the risk of chilling for people staying in the open is smaller than at stations located more to the North and in the island interior (Table 14.9). Although Björnöya is windier than Hornsund, the WCT indices are somewhat higher at this station than at Hornsund because of the higher air temperature. Between November and April at all stations the risk for chilling created by meteorological conditions is moderate, and during the spring and the autumn is in the small category. Comparing values of the index at Hornsund and Ny Ålesund one should notice that at Hornsund in the spring and the summer these are somewhat lower. This results from the considerably lower wind velocities recorded in this time of year at Ny Ålesund in comparison with Hornsund.

Table 14.9. Mean monthly and annual values of the WCT index at the Svalbard stations in 1978-2009.

Station	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Ny Ålesund	–20.5	–20.8	–19.9	–15.7	–7.2	–0.7	2.9	1.7	–3.5	–11.0	–14.7	–18.5	–10.7
Svalbard-Luft.	–22.6	–22.9	–21.7	–17.3	–8.1	–1.1	3.3	2.3	–3.2	–11.5	–16.0	–20.1	–11.6
Svea	–24.3	–24.5	–23.4	–18.9	–9.2	–1.6	3.0	1.8	–3.2	–11.3	–16.6	–22.0	–12.5
Hornsund	**–19.6**	**–19.8**	**–19.8**	**–16.3**	**–8.3**	**–1.8**	**1.3**	**0.7**	**–2.9**	**–9.3**	**–13.7**	**–17.6**	**–10.5**
Björnöya	–15.0	–15.1	–14.3	–11.6	–6.7	–2.3	0.9	1.3	–1.5	–6.3	–9.9	–13.8	–7.9

To review diurnal values of the WCT index two sample years are considered: 1988 – the coldest one during the station work; 1984 the second warmest in terms of mean annual air temperature (after 2006) in the history of observations at Hornsund. Fig. 14.10 shows that risk of cooling of people organisms staying in the open air may be greater than results from analysis of monthly or longer means. Both in "the warm" and in "the cold" year, in the summer season the daily range of changes in the WCT index is small. WCT values show only small risk of organism chilling from the third decade of May to mid September on average. In July and August, when during a number of days the air temperature is positive, the feeling of thermal discomfort may occur only sporadically (when WCT < 0°C). Beginning in the second decade of September the amplitude of daily changes increases, in "the cold" years conditions of thermal discomfort may occur more and more frequently. Even when using adequate clothing, longer stays in the open may create moderate risk of chilling.

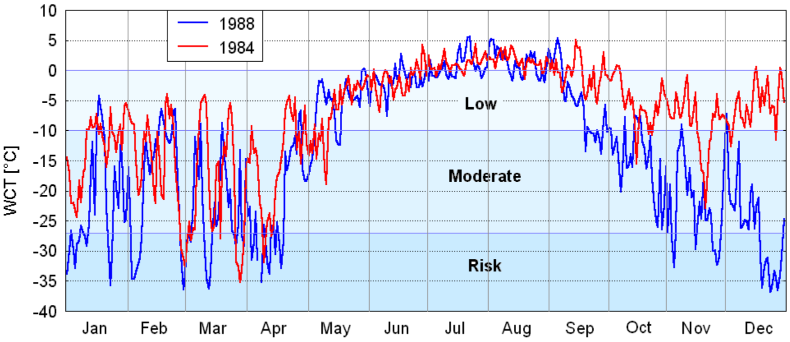

Fig. 14.10. The daily course of the WCT index at Hornsund in 1984 and 1988. Zones of risk of cooling of persons staying in the open are marked.

The risk of rapid (10 to 30 minutes) frostbite on exposed parts of the body and chilling of vital organs during long stays in the field appears at the beginning of November. From this moment up to the third decade of April the range of daily changes increases. The wind-chill (sensed) temperature ranges from –10 to below –35°C (in 1988 the lowest WCT value was –41°C). Periods of considerable risk of chilling intermingle with periods of massive advection of warm air, during which, despite the increase of wind velocity, the risk of hazardous cooling decreases, although staying in an open area without adequate protection (proper clothing) risks frostbites of exposed parts of the body.

The analysis of frequencies of mean diurnal values of sensible temperature (WCT index), divided into 5°C intervals, shows the unquestionable domination of days with values of this index in the range from 5 to –10°C in the "warm" year (Fig. 14.11). There were 257 such days in 1984 (70.4% of the year), and only 154 in 1988 (42.2% of the year). Both of these thermally contrasted summers significantly differed in the amount of time in which the light thermal discomfort (–10 < WCT < 0°C) was possible. Such small risk occurred for nearly half of the year (49%) in 1984 whereas in the "cold" year of 1988 there were only 107 days (29% of the year). In 1988 the number of days, in which sensible temperature dropped below –20°C was significant – 122 such days, whereas in 1984 there were only 37.

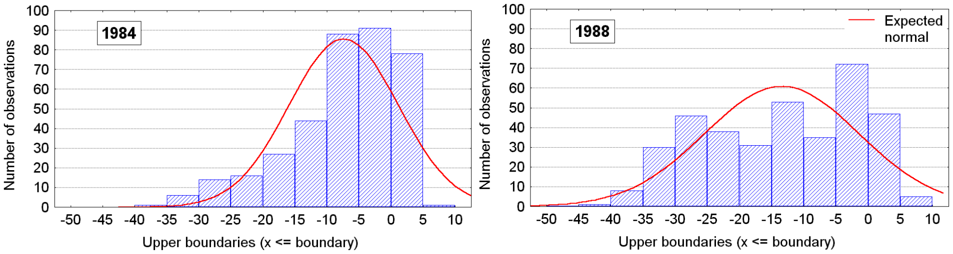

Fig. 14.11. Frequency of diurnal value of the WCT index at the Hornsund station in 1984 and 1988, in definite interval of values [°C]. Normal distribution is marked by the red line.

The frequency of days in which WCT index gave substantial risk of frostbite (≤ –28°C) in a short time (10 to 30 minutes), in the "warm" year was small (in 1984 it was ~4% of the year). In the "cold" year it was as much as four times greater (in 1988 it was 16.2%). While in 1988 such situations began to occur in November, in the warm 1984 they occurred only in March-April. At Hornsund the highest risk of frostbite for exposed skin of face or fingers (within a few minutes; WCT ≤ –40°C), occurs only incidentally even in the "cold" years (in 1988 it has taken place only once). Taking into account the progressive warming (Fig. 14.9) and the "shift" of annual minimum WCT to March, one may suppose that the tendency of WCT changes will be such that number of days with significant risk of chilling at the beginning of winter will be decreasing gradually, whereas its number in the final phase of the winter will not undergo great changes.

In the light of research by Owczarek (2004) for the decade of the nineties, in which term observations were used, the substantial risk of frostbite (10 to 30 minutes) occurred in 3.6–5.4% of observations in December (9–13 cases), 10–11% in January (25–27 cases), 13–16% in February, 8–10% in March and 0.3–1.1% in April. According to Owczarek (2004) February is the month in which the occurrence of momentary very big (within 2–5 minutes) and extreme (less than 2 minutes) risk of frostbite of exposed skin is the most frequent. In the nineties the most severe conditions occurred on February 22, 1996, when the air temperature was in the range –26.3 ÷ –27°C and wind velocity 11–13 m/s; wind-chill temperatures dropped to –38.4 ÷ –40.3°C.

14.4. Positive and negative degree-days

An important feature of climate is its severity. It determines the occurrence of ablation processes in the summer and snow accumulation in the winter. At high latitudes, because of the limited solar radiation, the period in which mean daily air temperature exceeds 0°C ($Ta \geq 0°C$) has fundamental importance for determining the timing and extent of thermal ablation. Monthly or seasonal totals of positive mean daily air temperature (PDD – positive degree-days) are named "potential indices of heat" (Braithwaite 1995) and characterize the intensity of ablation of glacier ice (among others; Khodakov 1965, Krenke and Khodakov 1966). On Spitsbergen the PDD index was used among others for estimates of ablation on glaciers of Nordaustlandet (North-Eastern Land; Schytt 1964) and on Austre Brøggerbreen near Ny Ålesund (Lefauconnier and Hagen 1990). In the Hornsund region the PDD index was used to estimate ablation of the Hans Glacier (Jania and Głowacki 1996, Szafraniec 2002). Total negative mean daily air temperatures (NDD negative degree-days or FDD – frost degree-days, the "potential index of cold") indicates the energy potential for ice formation. Knowledge of NDD on land allows estimation of winter snow accumulation and on the sea may be used for estimates of sea ice growth (Zubov 1963, Styszyńska and Wiśniewska 2002).

At Hornsund the mean multiannual (1978–2009) annual number of days with mean diurnal air temperatures exceeding 0°C amounts to 140 (Tables 14.10 and 18.21), with a standard deviation of 14.5 days. The greatest number of such days (171) occurred in 2006, the least (108) in 1979 (Fig. 14.12). The annual number of days with $Ta \geq 0°C$ shows a statistically significant rising trend (8 days per 10 years, $p < 0.009$). Similarly significant, although weaker, is the increase in the number of such days in June (2 days per 10 years). Over the research period only in July was the mean daily air temperature 0°C or higher in all days of the month. In August only once (in 1994) did the mean daily air temperature drop below zero. In other months of the ablation season (June-September) the mean number of days with $Ta \geq 0°C$ exceeded 21 (Table 14.10) and were characterized by greater variability. In June the number of days with $Ta \geq 0°C$ ranged from 16 (1979) to 30 days (1986, 2002, 2003, 2006, 2007), and in September from 3 (1982) to 30 days (1990, 1999).

In the accumulation season (October-May) the mean multiannual monthly numbers of days with diurnal $Ta \geq 0°C$ are small and range from 1.1–1.6 in January, February and March, to 7.2–7.3 at the beginning and end of the season in October and May (Table 14.10). In particular years the number of such days may change in individual months over a range of nil to one dozen. In October the greatest number of days (22) with diurnal $Ta \geq 0°C$ occurred in 2000, in November (18) in 1993, in December and January 13 (1984 and 2006), in March 12 (1996) and in May 17 (2006). Only in February was the frequency of thaws very small. In this month most often such days do not occur at all or are a small number – from one day to a maximum five days (1990, 1991, and 2005). Occurrence of frequent thaws in the accumulation period exerts vital influence on the formation and metamorphosis of snow cover. Winter warmings (maximum up to 12–17 days in a month; Table 14.10) on the whole are not able to bring about total destruction of the snow cover although they may cause some big thaws. Such warmings decrease the thickness of snow cover and increase accumulation of melt water on the surface and inside the snow cover. During the ensuing cooling this water freezes to forming naled ice on the surface and a layer of icy snow inside the snow cover. Liquid precipitation observed during warmings is favourable for processes of humid metamorphosis. As a result occurrence of winter ice layers in the snow will impede further infiltration of water into it and inhibit the rate of spring and summer snow and ice melting.

Table 14.10. Mean monthly and annual numbers of days with positive mean daily air temperature at the Hornsund station, 1978–2009.

Month	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
Mean	1.6	1.1	1.4	2.3	7.3	26.2	31.0	30.9	21.7	7.2	4.4	2.7	140.0
σn	2.6	1.5	2.5	3.4	3.9	3.7	0.0	0.4	6.1	4.3	4.6	3.3	14.5
Max	13	5	12	17	13	30	.	31	30	22	18	13	171
Min	0	0	0	0	0	16	.	29	3	0	0	0	108

At Hornsund the mean multiannual (1978-2009) accumulated total of positive degrees amounts to 422.2°C and ranges from 310.4 (1994) to 551.0 (1990). The biggest values occurred in July and August (Fig. 14.13, Tables 14.11 and 18.22). In July the highest value (171.3) occurred in 2002 and the lowest (110.7) in 1997. Somewhat bigger changes of PDD took place in August – from 93.3 (1994) to 165.1 (2002). September is characterized by the biggest range of PDD variability. In this month in 1982 only in three days did mean diurnal air temperature somewhat exceed 0°C and the monthly PDD total reached only 1.2 degree-day. There was a different situation in September 1990 when mean diurnal air temperature was higher than 0°C every day, and the monthly PDD value was 134.4. Over the research period in the months of June and August there were statistically significant, increasing trends of PDD (8.5 per 10 years in June, 6.8 per 10 years in August). Such a trend was also evident in the all ablation season (June - September) and amounted to 21.3 degree-days per 10 years ($p < 0.038$). In the accumulation season (October-May) range of PDD variability is small (Fig. 14.13, Table 14.11) and in particular months does not exceed 24 degree-days.

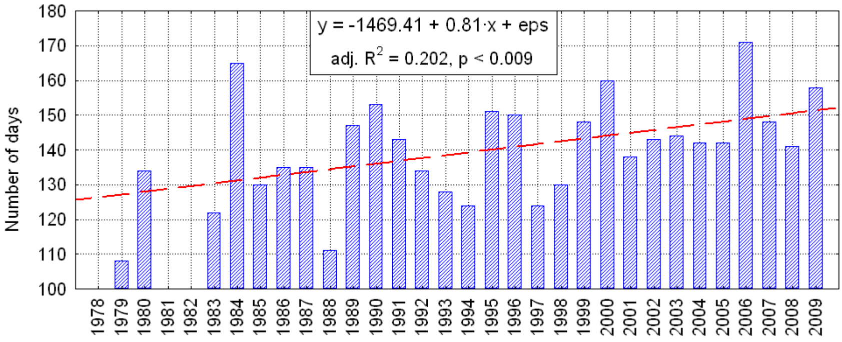

Fig. 14.12. Annual number of days with positive mean daily air temperature at Hornsund in 1978–2009.

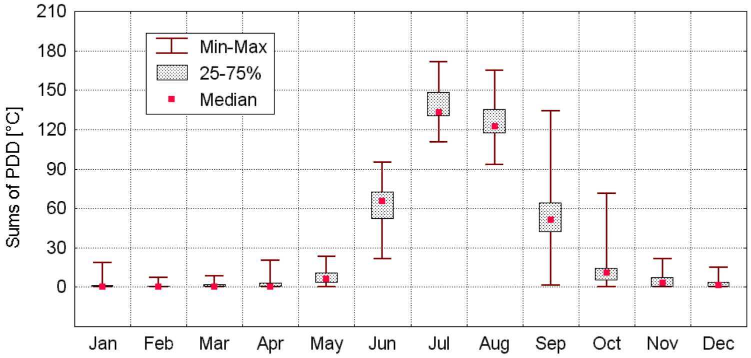

Fig. 14.13. Range of variability of positive degree-days PDD totals at the Hornsund station in 1978–2009.

From November to April in many years there was no single day at Hornsund in which mean diurnal air temperature reached positive values (Table 14.11). The largest number of such cases was in March (17), February (14) and January (13): these fall in general in different years. In the period 1978-2009 there were two accumulation seasons, in which no mean diurnal air temperature ≥ 0°C was recorded during six consecutive months. These were periods from November 1980 to April 1981 and from October 1988 to March 1989. The year 2006 was also exceptional, in January, April and May the greatest PDD totals for those particular months in the all period of observations were recorded at Hornsund (18.8, 20.6 and 23.4, respectively).

Table 14.11. Mean monthly and annual totals of positive degree-days PDD
at the Hornsund station in 1978–2009.

Month	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
Mean	1.6	0.9	1.1	2.1	7.2	62.1	138.8	126.6	55.2	13.2	4.8	2.6	422.2
σn	3.7	1.9	1.8	4.0	5.6	16.8	15.6	16.7	25.7	14.0	5.8	3.7	59.7
Max	18.8	7.3	8.4	20.6	23.4	95.3	171.3	165.1	134.4	71.1	21.4	15.2	551.0
Min	0.0	0.0	0.0	0.0	0.0	21.6	110.7	93.3	1.2	0.0	0.0	0.0	310.4

The negative mean daily air temperature totals (NDD negative degree-days) is named "potential index of cold". At the Polish Polar Station the mean multiannual total of NDD amounts –1922.3 degree-days, its standard deviation is 462.2. The greatest value (–2990.3) occurred in 1988, the smallest (–865.6) in 2006 (Tables 14.12 and 18.23). In 2006 the greatest number of days with Ta ≥ °C also occurred. There were very big NDD values in 1979 (–2599.1) and 1980 (–2508.4) as well. Over the time span, 1978–2009, annual accumulated negative degree-days showed a tendency to decrease at the rate of 32.4 degree-days per 10 years; this trend is highly significant statistically ($p < 0.000$). Similarly large and significant was the trend of NDD changes in the accumulation season, October-May (30.4 degree-days per decade, $p = 0.000$). Trends of NDD changes in November and December (around 70 degree-days per 10 years) are also highly significant ($p<0.004$) as well as in May (23 degree-days per 10 years) and June (3.6 degree-days per 10 years).

Table 14.12. Mean monthly and annual accumulated degree-days of frost (NDD)
at the Hornsund station, 1978–2009.

Month	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
Mean	–333.3	–304.3	–333.9	–258.4	–92.9	–4.4	0.0	–0.1	–16.1	–117.9	–198.1	–293.3	–1922.3
σn	124.2	90.5	94.0	93.8	38.9	6.2	0.0	0.3	17.6	52.9	118.7	127.2	462.2
Max	–554.0	–465.2	–521.6	–427.1	–226.4	–24.8	0.0	–1.6	–58.8	–244.9	–448.1	–542.6	–2990.3
Min	–72.8	–150.8	–155.0	–31.0	–27.8	0.0	0.0	0.0	0.0	–13.9	–36.3	–52.6	–865.6

At Hornsund months at the beginning of the accumulation season (November, December and January) are characterized by the greatest NDD variability (Fig. 14.14). In November range of the index was from –36.3 in 2009 to –448.1 in 1988, in December from –52.6 in 1983 to –542.6 in 1988 and in January from –72.8 in 2006 to –554.0 in 1981. In the second half of the accumulation season, especially in February, there is smaller variability. Renewed increase in NDD variability in March and April may be explained by the observation that after 2004 there was a distinct shift of occurrence of greatest NDD values in the year to these months (March in 2004, 2006, 2008; April in 2007 and 2009). Earlier, the greatest NDD values were observed most frequently in January and February. This phenomenon may be a reflection of some ”tuning” of the atmospheric circulation (Chapter 9.5), which should be connected with changes of sea ice cover and heat resources in the North Atlantic water and in that transported to Spitsbergen by the Norwegian Current.

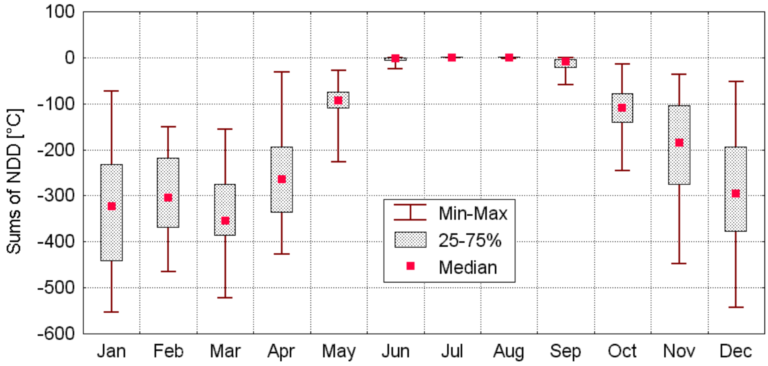

Fig. 14.14. Range of variability of NDD totals at the Hornsund station, 1978–2009.

From the point of view of the possibility of ablation it is very important to stress how differences of totals of positive and negative degree-days are developing. These determine the intensity of ablation processes. In 1978-2009 positive values of this difference occur in the period from June to August (Table 14.13). Omitting June 1979, in all years of the research period ablation processes could operate in June, July and August, well into the period of the longest day and great increase of insolation. In the seventies and eighties there were years when ablation in September was substantially limited by occurrence of frost; in 1979, 1982, 1986, 1988 and 1993. The strongest inhibition of snow and ice cover melting occurred in September 1982 when difference between total positive and negative degree-days amounted to –51.8°: in other noted years, PDD and NDD differences were smaller, being –29.5 in 1978, –27.8 in 1986, –21.5 in 1988 and –4.3 in 1993. The role of these coolings (in general, short-lived) is insignificant in the process of glacier ice melting and leads to some slowing of ablation rates at the most. During September cool spells snowfall may happen but the snow will melt during the ensuing warming.

Table 14.13. Differences between mean monthly and annual totals of PDD and NDD at the Hornsund station, 1978–2009.

Month	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
Mean	–331.7	–303.4	–332.8	–256.3	–85.6	57.7	138.8	126.5	39.1	–104.7	–193.4	–290.7	–1500.0
σn	126.0	91.5	95.0	96.8	41.8	21.8	15.6	16.8	39.6	62.5	112.8	129.3	500.9
Max	–54.0	–143.5	–152.6	–10.4	–4.7	95.3	171.3	165.1	134.4	57.2	–18.5	–37.4	–347.5
Year	2006	2005	2004	2006	2006	2002	2002	2002	1990	2000	2009	1984	2006
Min	–554.0	–465.0	–521.6	–427.1	–226.4	–3.2	110.7	91.7	–51.8	–244.9	–448.1	–542.6	–2646.5
Year	1981	1979	1981	1988	1979	1979	1997	1994	1982	1988	1988	1988	1988

At Hornsund large energy potential for ice formation occurs not only during the polar night (November – mid February) but also the other months of the accumulation season, particularly March and April. The multiannual means in consecutive months of the accumulation season, beginning in October and ending in May show that the differences of PDD and NDD totals (Table 14.13) have negative values. The most severe winters occurred in the decade of the eighties when NDD indices in the accumulation season (October - May) exceeded –2500 (Fig. 14.15). The NDD index was –2891 in the accumulation season 1980/1981, –2718 in 1988/1989, –2672 in 1978/1979, –2548 in 1987/1988. The mildest winters occurred in the present century, particularly after 2004, when NDD index in the accumulation season did not exceed –1600. It was only –997 in the accumulation season 2005/2006, –1083 in 2006/2007, –1250 in 2009/2010, –1432 in 2007/2008 and –1500 in 2004/2005. Given that the PDD index in the ablation season (June-September) does not show strong temporal changes, the NDD index calculated for the accumulation season (October-May) is characterized by a statistically significant positive trend (32 degree-days per year), p = 0.00007) explaining 41% of NDD variation in this time.

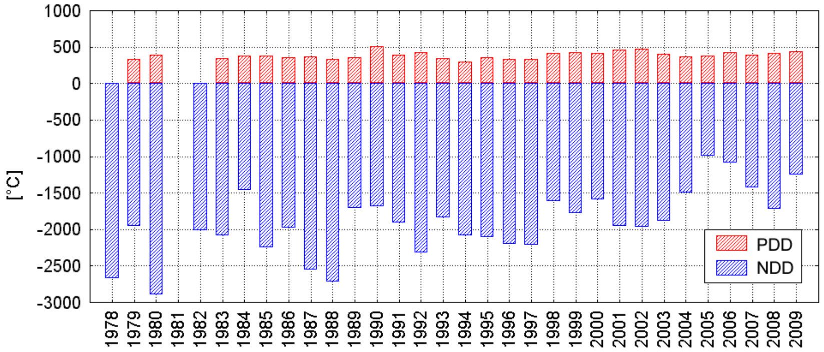

Fig. 14.15. The course of totals of positive degree days (PDD) in the ablation period (June-September) and negative degree days (NDD) in the accumulation period (October-May) at Hornsund, 1978–2009.