6. THE WINDS

The Hornsund station is characterized by a special wind regime in comparison to the other stations of the region. This is caused by the strong influence of local conditions, both the irregular topography of the shoreline and specific location of the station in relation to it. Thus local influences are strong in the wind patterns, so that the anemometric relationships cannot be transposed to other, even close, areas and especially those situated outside the Hornsund Fjord.

Measurements of wind direction and wind velocity at the Hornsund station were made with different instruments. In 1978–2000 wind parameters were measured with the Fuess 90z electric wind meter. The automatic station VAISALA QLC-50 has been in operation at Hornsund since 1 January 2001. For wind measurements sensors WAA15A (direction) and WAV15S (velocity) situated 10 m over the ground are used. Wind velocity is measured with an accuracy of 0.1 $m \cdot s^{-1}$, and wind direction to ±5°. In the guide to the meteorological yearbook 2000/2001, Kwaczyński and Nowosielski (2001) wrote that the location of anemometric mast has not changed for the whole period of station recording. The mast is situated 150 m to the SW of the station buildings. On the same mast in July 2009 sensors of the new measuring system (Campbell CR1000) were mounted that allow for measurement of wind direction and velocity every second (Sikora *et al.* 2010). Wind gusts are noted when velocity suddenly increases and exceeds the mean wind velocity of the previous 10 minutes by at least 5 $m \cdot s^{-1}$ and this increase is not longer than 2 minutes.

During the work of the Hornsund station the number of wind observations made within a day (24 hours) has been changing. In some years instead of the standard eight observations per day only four were made – at 00, 06, 12 and 18 GMT(from July to October 1978, from July 1979 to July 1980 and in September 1982). Observations from the 4th Polar Expedition (1981/1982) were not published and are not accessible. The measurements presented here are thus not homogenous because of varying number of observations during a day as well as change of instrument. During the low frequency measurement periods some features of wind structure variability may not be seen.

6.1. The structure of wind directions

Wind blowing from the East (Fig. 6.1), along the axis of fjord is the most often observed at the Hornsund station. In the multiannual (1979–2009) wind structure record 45% of all observations were from this direction (Table 6.1). In a given year it was from 32.6% (1985) to 55.2% (2004). Winds from the East displayed the highest frequency in the each of 29 years of complete observations (Tables 18.6 and 18.7).

Winds from the NE, next in frequency of occurrence, were 2.5 times less in frequency (17.2%), ranging from 10.6% (2001) to 29.4% (1980). These winds were secondary dominant in the 24 years of record. Westerly winds replaced them in the second position only in 1988, 1989, 2001, 2002 and 2008 (Table 18.7), although in these years winds from the NE were only slightly lower in frequency. Variable winds (0.3%), winds from the SE (2.3%), S (2.9%) and N (3.1%) had the least frequency.

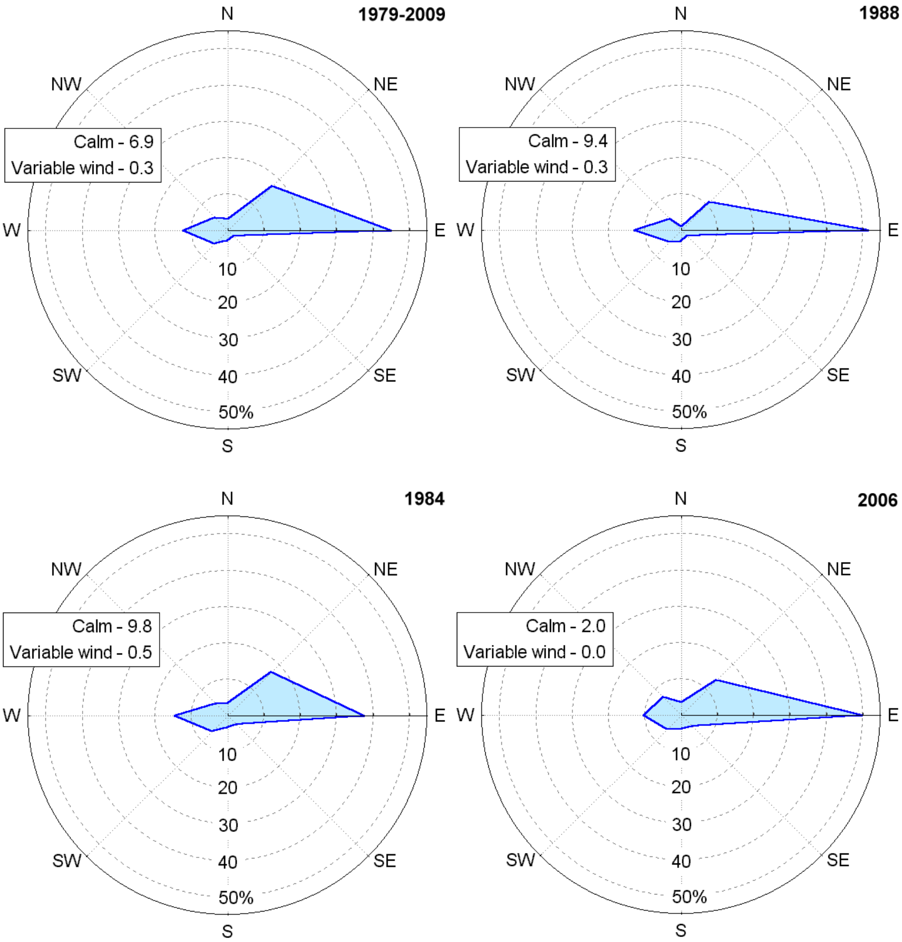

Fig. 6.1. Wind roses at the Hornsund station: multiannual mean (1979–2009), in 1988 – year with the minimum annual air temperature and in 1984 and 2006 – years with the maximum annual air temperature (–7.3°C, –2.3°C and –1.5°C, respectively).

Table 6.1. Multiannual means (Mean), the highest (Max) and the lowest (Min) frequencies [%] of wind directions at the Hornsund station and year of occurrence in 1979–2009. σn – standard deviation from the mean, * – has occurred many times.

	N	NE	E	SE	S	SW	W	NW	Variable wind	Calm
Mean	**3.1**	**17.2**	**45.0**	**2.3**	**2.9**	**5.1**	**12.1**	**5.0**	**0.3**	**6.9**
σn	0.98	5.21	6.35	0.93	0.72	1.27	2.00	1.42	0.56	2.99
Min	0.9	10.6	32.6	1.0	1.2	2.3	8.6	2.0	0.0	1.9
Year	1988	2001	1985	1996	2003	2.3	1983	1998	*	2007
Max	5.7	29.4	55.2	5.6	4.2	7.0	16.5	8.2	1.8	15.6
year	1991	1980	2004	1983	1989	7.0	1987	2001	1994	1985

Variable winds were observed only in 14 years, their frequency in the annual distribution not exceeding 1.8%. Apart from 2001 these winds were not observed after 1996. This may result from the change of the instrument in 2001. Winds from the SE, S and N occur every year but their frequency is low. Winds from the S did not exceed 4.5%, in any of the years of record, and winds from the SE and N only once each (SE – 5.6% in 1983, N – 5.7% in 1991).

In all years calm conditions (lack of wind) were also recorded. Calm periods averaged 6.9% per year, ranging from 1.9% in 2007 to 15.6% in 1985. Only in four years (1979, 1985, 1986 and 2003) were calms noted in more than 10% of all observations. Occurrence of calm conditions is associated mainly with high pressure systems when either their centres or the axes of associated wedges t linger over South Spitsbergen. Such situations were most seldom observed in the three years, 2005, 2006 and 2007, when calms in the annual structure of winds amount only 2.6, 2.0 and 1.9%, respectively.

Domination of winds from the East is marked also in multiannual (1978–2009) monthly means (Tables 6.2 and 18.6). It is seen especially clearly in the second part of thermal winter (Chapter 9), covering the period from December to April (Fig. 6.2). On average this direction accounted for 58.9% of all observations in the month of March, exceeding 70% in nine of the years. The highest frequency was in 2008 when E winds were noted in 88.3% of observations. The smallest frequency of such winds (17.7%) was observed in March 1985 (Table 6.2), when winds from the NE dominated instead. There is a similarly high frequency of the easterly winds in April (55.9%), when in five years their frequency exceeded 70%, reaching a maximum in 1994 (77.1%). Also in the first part of winter (January and February) winds from the East were very frequent, amounting to around half of all observations. The lowest frequency of winds from the East occurred in October – 34% (Fig. 6.2) but in particular years they exceeded 50% (in 1988, 2004 and 2008). In all months winds were characterized by great variability. This is indicated by differences between the highest and the lowest frequency of occurrence. The greatest variability of easterly wind frequency was in the spring and the lowest in the autumn (Fig. 6.2). Frequency of the subdominant wind direction (NE) was significantly lower and ranged from 5.4% in July to 29.6% in October. In addition, this wind direction showed great variability (Table 6.2).

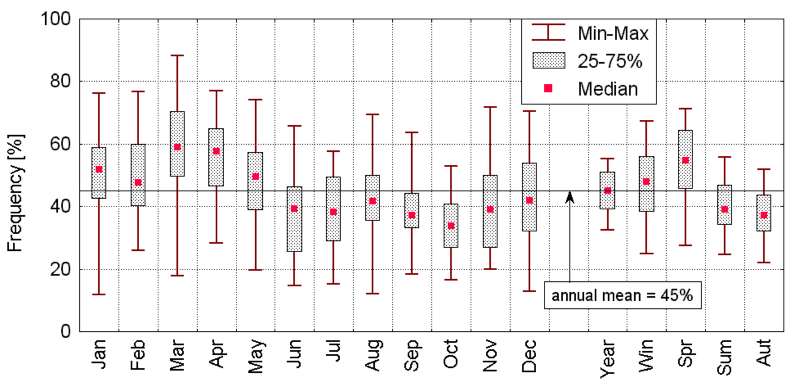

Fig. 6.2. Variability of monthly and seasonal frequency [%] of winds from the East at the Hornsund station (1978–2009). Win – winter (DJF), Spr – spring (MAM), Sum – summer (JJA), Aut – autumn (SON)

Table 6.2. Multi-annual mean (Mean) of monthly frequencies [%] of wind directions, the highest (Max) and the lowest (Min) frequencies in month and year of its occurrence at the Hornsund station (1978–2009). σn – standard deviation from the mean.

Direction		Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
N	Mean	**3.3**	**3.0**	**1.9**	**2.0**	**2.0**	**1.6**	**0.7**	**1.2**	**3.2**	**7.3**	**5.4**	**5.0**
	σn	2.54	2.17	1.81	1.94	1.74	1.30	0.69	0.87	2.19	5.10	4.01	3.75
	Min	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.4	0.8
	Year	*3	*2	*4	*5	*3	*2	*7	*4	1992	*2	*2	2003
	Max	10.5	8.9	7.7	6.7	8.5	5.8	2.4	3.3	8.3	19.8	18.3	18.5
	Year	2003	2006	1991	1999	1990	1981	*2	1979	1978	1992	1990	2000
NE	Mean	**21.4**	**20.3**	**17.6**	**14.6**	**11.7**	**6.1**	**5.4**	**10.2**	**18.2**	**29.6**	**26.9**	**25.9**
	σn	12.38	9.77	11.46	8.08	6.09	4.16	4.78	8.31	7.06	9.33	13.29	12.73
	Min	1.6	4.0	1.6	2.9	0.4	0.8	0.8	2.0	6.3	12.9	3.8	2.4
	Year	2004	1989	2004	1989	1989	2000	1983	*2	1993	2007	1993	1988
	Max	53.2	49.1	44.8	32.1	21.4	16.7	20.6	35.2	31.3	54.8	51.3	51.6
	Year	2003	1999	1999	1985	1993	1981	1981	1979	1987	1997	1980	1980
E	Mean	**50.0**	**49.7**	**58.9**	**55.9**	**48.1**	**37.9**	**38.6**	**42.9**	**38.5**	**34.0**	**39.4**	**42.1**
	σn	14.99	13.10	15.99	12.95	13.36	13.85	12.02	12.42	9.06	9.63	13.34	14.84
	Min	11.7	25.9	17.7	28.3	19.8	14.6	15.3	12.1	18.3	16.5	20.0	12.9
	Year	1985	1991	1985	28,3	1990	1985	1992	1994	2000	1980	1990	2000
	Max	76.2	76.8	88.3	77.1	74.2	65.8	57.7	69.4	63.8	52.8	71.7	70.6
	Year	2004	1998	2008	1994	2002	2007	2001	1993	1983	2008	1988	1987
SE	Mean	**1.7**	**1.4**	**1.1**	**1.9**	**2.9**	**4.0**	**5.2**	**3.4**	**2.1**	**1.2**	**1.6**	**1.7**
	σn	2.27	1.05	1.14	1.77	2.48	2.13	3.50	2.07	1.33	1.20	1.31	2.24
	Min	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.8	0.0	0.0	0.0	0.0
	Year	*6	*5	*4	*4	1998	1980	1,2	*5	2000	*3	*5	*6
	Max	10.9	3.4	4.0	7.1	10.9	10.0	19.8	8.5	5.0	4.0	4.6	9.7
	Year	2006	1988	1995	1983	1985	1983	1983	1984	2008	*2	*2	1982
S	Mean	**2.7**	**2.7**	**2.3**	**1.9**	**2.4**	**3.3**	**4.3**	**3.8**	**3.7**	**2.4**	**3.3**	**2.7**
	σn	3.01	2.94	2.07	1.69	1.91	2.59	2.10	1.87	3.01	2.36	2.51	2.49
	Min	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0
	Year	*4	*5	*2	*2	*2	*2	1985	1985	1983	*2	1983	*3
	Max	15.7	12.9	8.1	7.5	7.3	11.7	10.5	7.7	11.7	9.6	9.6	11.3
	Year	2006	2005	1996	1987	1988	1999	2000	*2	1989	1979	1993	1982
SW	Mean	**2.3**	**2.4**	**2.5**	**2.5**	**3.7**	**10.7**	**15.1**	**9.7**	**4.7**	**1.9**	**3.0**	**3.0**
	σn	2.41	2.54	2.68	2.40	2.56	5.49	6.90	4.22	3.53	1.48	3.30	4.61
	Min	0.0	0.0	0.0	0.0	0.0	1.7	2.4	1.6	0.8	0.0	0.0	0.0
	Year	*4	*6	1979	*2	2002	*2	1978	1985	1991	1999	*4	*2
	Max	9.7	10.3	10.9	9.2	10.1	29.6	30.2	17.7	15.4	6.0	14.2	25.6
	Year	2006	1991	1996	1980	1981	1999	1997	1986	2000	2000	1978	1978
W	Mean	**8.4**	**9.4**	**7.8**	**9.7**	**14.8**	**20.6**	**18.9**	**14.8**	**12.8**	**8.6**	**9.8**	**9.3**
	σn	5.77	7.14	6.04	5.89	6.54	7.98	6.79	5.96	4.87	4.91	7.41	6.62
	Min	0.8	0.9	0.0	1.3	2.8	8.8	8.5	6.0	2.5	0.8	2.1	0.4
	Year	1994	*3	1979	1992	2002	1996	*2	1999	1982	2006	*2	1999
	Max	26.6	28.1	21.0	22.9	29.4	41.7	33.1	31.9	22.5	19.0	37.1	26.0
	Year	1996	1991	1984	2003	1981	1989	1989	1994	1999	2002	1993	1978
NW	Mean	**4.8**	**5.9**	**3.1**	**5.2**	**5.8**	**5.9**	**2.9**	**3.6**	**5.7**	**6.7**	**5.2**	**5.1**
	σn	3.13	4.38	2.56	3.93	3.03	4.09	2.31	3.48	3.61	4.12	3.24	3.65
	Min	0.4	0.0	0.0	0.4	0.8	0.8	0.0	0.0	1.3	0.8	0.4	0.4
	Year	1990	*4	*4	*4	1986	1996	*2	1993	1990	*2	1983	*2
	Max	12.1	16.5	10.1	16.3	12.9	15.0	8.9	14.5	17.9	16.9	13.8	14.5
	Year	2006	1986	1986	1993	1990	1983	1994	1994	2006	*2	2001	2004

Direction		Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Variable wind	Mean	**0.3**	**0.3**	**0.1**	**0.1**	**0.2**	**0.7**	**0.6**	**0.5**	**0.6**	**0.5**	**0.3**	**0.3**
	σn	0.74	0.67	0.27	0.28	0.42	2.06	1.72	1.13	1.94	1.13	0.74	0.90
	Min	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Year	*21	*21	*23	*23	*21	*19	*19	*20	*23	*21	*22	*22
	Max	3.6	3.0	1.2	1.3	1.6	10.5	8.9	5.2	8.8	4.0	3.3	4.4
	Year	1992	1992	1984	1994	1983	1979	1994	1994	1991	1982	1991	1991
Calm	Mean	**5.2**	**5.0**	**4.6**	**6.2**	**8.4**	**9.4**	**8.2**	**9.9**	**10.5**	**7.7**	**5.2**	**4.9**
	σn	4.56	5.16	4.57	5.97	4.98	7.88	7.10	6.53	5.56	5.06	3.36	4.44
	Min	0.0	0.4	0.0	0.0	1.6	0.8	1.6	2.0	2.9	0.8	0.8	0.4
	Year	2006	1981	*2	1987	*3	2006	2005	1980	2006	1998	*2	1995
	Max	16.9	23.3	21.0	26.6	21.0	39.6	39.0	25.2	23.3	19.4	12.1	23.4
	Year	1984	2004	2004	1979	1980	1985	1978	1978	1984	1985	2003	2003

*2 ÷ *23 – number at the asterisk shows in how many years this value occurred (in 1978-2009)

In the depiction of multiannual means (Table 6.1) winds from the westerly sectors accounted for 22.2% of observations (SW – 5.1%, W – 12.1%, NW – 5.0%). The highest frequency of these winds was in the summer (June - August), when winds from the SW exceeded 10%, and from the W even 15% of all observations (Table 6.2). In the summer, participation of winds from the western sector in the particular years and months may range from 12% to over 50% of observations. Such great variability shows that only in some years may Hornsund be in the zone of domination by westerly flow. Whereas in the summer frequency of winds from the western sector increased, however the easterly winds still dominated (Fig. 6.3).

The uniformity of wind directions along the axis of Hornsund Fjord throughout the whole year confirms the great influence of local conditions on the wind system observed at the Polish Polar Station. The rugged relief of the western coast of Spitsbergen makes that this is a common feature for all stations situated on this coast. Winds from the NE-SE sector dominate over Spitsbergen because atmospheric circulation in this region is dominated by lows formed near to Iceland and moving along the Iceland-Kara trough through the Barents Sea or through Fram Strait into the Arctic (Chapter 4). At the individual stations dominant wind directions are determined by the orientation of fjords in which they are situated, and adjacent mountain valleys. In Ny Alesund it will be SE and E winds that are concordant with the course of Kongsfjorden and glacier valleys of Kongsvegen and Kronebreen. At the Isfjord Radio station it is NE and E winds concordant with the course of Isfjorden. In Svalbard-Lufthavn – SE winds concordant with Adventfjorden and Adventdalen are dominant. Winds dominating at the stations, especially the Isfjord Radio (Steffensen 1982, Hanssen-Bauer *et al.* 1990) show similar frequencies to those dominating at Hornsund. In addition, frequency of subdominant wind at particular stations is similar to Hornsund, about one half of the dominating wind.

Winds from the western sector at Hornsund show a stable relationship with the type of zonal circulation (W) of Niedźwiedź (1993, 1997b, 2001). Correlation coefficients of frequency of the westerly wind with this type of circulation are positive and highly statistically significant in all months (Table 6.3). Winds from the SW show a similarly significant relationship, especially in the winter. Concurrent positive correlations of wind frequencies from the SW and W with the types of meridional circulation (S) and zonal (W) of Niedźwiedź, which occur in November, December and January (Table 6.3), confirm the model of Brümmer *et al.* (2000) for the active cyclogenesis occurring in the winter in the region of Fram Strait.

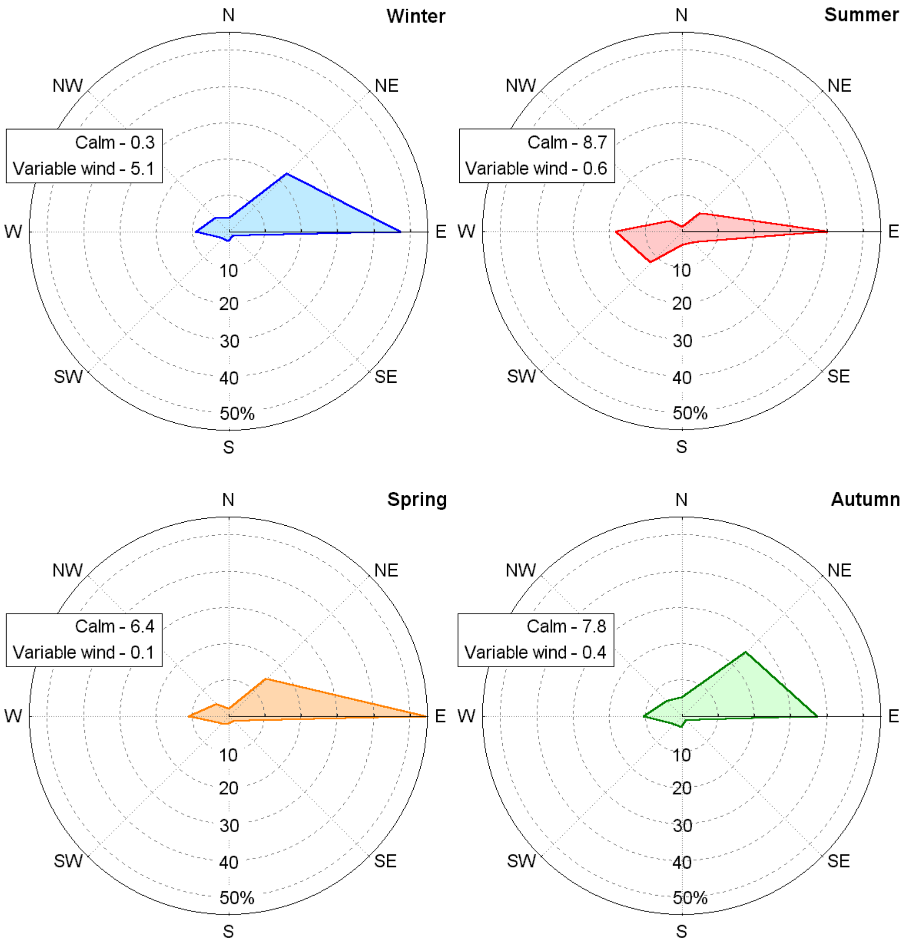

Fig. 6.3. Seasonal wind roses, percentage of frequencies, in 1979-2009. Winter (December-February), Spring (March-May), Summer (June-July) and Autumn (September-November)

The easterly winds dominating at Hornsund are very strong in the summer (June-August), and negatively associated with type of zonal circulation (W) of Niedźwiedź (r from –0.67 to –0.82, $p < 0.000$). At the same time these winds showed also negative relationships (much weaker, attaining statistical significance only in the month of August) with the index of cyclonicity (Table 6.3). This shows that the easterly winds observed in the summer were connected mainly with southern parts of the high pressure systems developing to the north of Spitsbergen. In the autumn (September-November) at the Hornsund station the frequency of easterly winds decreased and more often winds from the NE were noted, in October attaining a frequency similar to the easterlies (Table 6.2). These winds were associated with the NW or W sectors of the low pressure systems developing at that time over the Barents Sea (Chapter 4).

In particular months, as over the average year, variable winds and those blowing from the SE, S and N were most seldom observed at the Hornsund station. These winds were characterized by steady distribution during a year (Table 6.2).

Table 6.3. Correlation coefficients between circulation indices W, S and C of Niedźwiedź (Tc) and frequency of wind directions (dd) at Hornsund (1978–2009). Significant correlations ($p < 0.05$) are in bold.

dd	Tc	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
N	W	0.28	0.33	0.30	0.34	**0.54**	–0.10	0.21	0.16	–0.16	0.08	–0.17	0.04
	S	–0.26	**–0.47**	–0.35	**–0.41**	**–0.50**	–0.20	**–0.37**	–0.15	**–0.63**	–0.27	–0.35	–0.08
	C	0.01	0.06	0.02	–0.12	0.19	0.22	0.11	0.09	–0.07	**–0.40**	–0.00	0.15
NE	W	–0.23	**–0.48**	–0.22	0.19	0.02	**–0.43**	–0.15	–0.26	**–0.37**	**–0.47**	**–0.57**	**–0.37**
	S	**–0.43**	0.16	–0.13	–0.16	–0.22	0.27	–0.00	0.12	0.02	0.06	–0.33	–0.14
	C	–0.22	0.31	–0.27	0.24	–0.13	–0.10	–0.07	0.13	0.31	–0.26	0.06	0.06
E	W	**–0.52**	**–0.63**	**–0.53**	**–0.43**	**–0.64**	**–0.75**	**–0.82**	**–0.67**	–0.32	–0.20	–0.06	–0.32
	S	0.20	0.16	–0.17	**0.30**	0.30	–0.09	–0.02	0.06	–0.04	0.17	0.01	–0.02
	C	0.21	–0.23	0.27	–0.09	–0.01	–0.07	–0.27	**–0.42**	0.18	**0.39**	–0.02	0.21
SE	W	**0.44**	0.36	0.11	–0.29	–0.19	0.27	–0.15	0.06	0.04	–0.04	0.24	0.32
	S	**0.58**	0.05	**0.41**	0.26	–0.07	–0.04	–0.00	**–0.38**	–0.20	0.06	0.26	**0.38**
	C	0.12	–0.10	**0.47**	0.05	–0.18	**0.35**	0.17	–0.07	0.15	0.11	0.00	–0.34
S	W	**0.59**	**0.36**	**0.48**	0.01	0.33	**0.48**	0.22	0.20	**0.38**	**0.40**	**0.67**	**0.57**
	S	**0.47**	0.19	**0.56**	**0.40**	–0.29	**0.38**	–0.20	0.27	**0.45**	**0.33**	**0.63**	**0.56**
	C	0.16	0.07	0.08	**0.37**	–0.10	0.27	0.10	**0.38**	–0.16	–0.11	0.02	**–0.39**
SW	W	**0.79**	**0.62**	**0.71**	**0.39**	**0.40**	**0.47**	**0.46**	**0.52**	**0.64**	**0.56**	**0.49**	0.35
	S	**0.41**	–0.03	0.28	0.23	0.31	0.27	–0.05	0.21	**0.44**	0.22	**0.41**	0.12
	C	–0.05	0.23	–0.23	0.22	–0.12	0.06	0.11	0.12	–0.33	–0.25	0.05	**–0.37**
W	W	**0.83**	**0.79**	**0.84**	**0.67**	**0.74**	**0.58**	**0.85**	**0.74**	**0.55**	**0.55**	**0.69**	**0.72**
	S	0.01	–0.06	0.29	–0.06	–0.02	0.00	–0.02	–0.08	**0.23**	0.11	**0.33**	**0.31**
	C	–0.06	0.07	–0.21	0.17	0.23	–0.01	**0.38**	**0.44**	–0.03	0.03	–0.22	–0.26
NW	W	**0.55**	**0.71**	0.26	**0.45**	**0.47**	0.28	**0.49**	**0.52**	0.17	0.44	0.11	**0.39**
	S	–0.06	**–0.42**	–0.18	**–0.48**	**–0.37**	–0.34	–0.08	**–0.49**	**–0.38**	**–0.57**	–0.17	–0.06
	C	0.11	0.05	0.12	–0.24	**0.48**	0.19	0.18	**0.50**	–0.01	0.14	0.34	0.20

Windless conditions were associated mainly with the high pressure systems. Thus, it is no wonder that their frequency increased in the warm season. Increased percentage of calms noted in the summer at Hornsund may be partly a local feature – reflection of statically stable conditions. In high pressure conditions (Chapter 4) the air that flows into the trough of the fjord may be cooled by its cold surface and under cloudy conditions will linger and be calm because it is heavier. Slow changes of the synoptic situation that get the air moving outside of the fjord, are not always capable of making changes in the neighbourhood of the station.

6.2. Wind speeds

Multiannual mean annual wind velocity (Vw) at the Hornsund station was 5.6 $m \cdot s^{-1}$ (Table 6.4). Its interannual variability was small, the standard deviation (σn) being only 0.41 $m \cdot s^{-1}$. The lowest annual Vw of 4.8 $m \cdot s^{-1}$ was recorded twice, in 1985 and 1986, whereas the highest of 6.3 $m \cdot s^{-1}$ occurred only once, in 1998 (Table 18.8). The Vw display a slight but statistically significant, positive trend of 0.024(±0.008) $m \cdot s^{-1} \cdot yr^{-1}$ (Fig. 6.4), which explains 23% of the annual variance of Vw over the period of record, 1978–2009.

In the multiannual record of mean monthly wind velocities there is a clear maximum in the first months of the year, January-March. In these months Vw exceeded 7 $m \cdot s^{-1}$ (Table 6.4). After this maximum the monthly mean wind velocity dropped 1.0 $m.s^{-1}$ between March and April and 1.2

m·s⁻¹between April and May. The summer (June-August) was the least windy season, Vw did not exceeding 4 $m \cdot s^{-1}$ (Fig. 6.5). There were then distinct increases of wind velocity between September and October (0.9 $m \cdot s^{-1}$) and between October and November (0.8 $m \cdot s^{-1}$). Judging from the values of the standard deviations shown in Table 6.4 variability of mean monthly wind velocities over the years was not great, the amplitude of Vw ranging from 2.7 to 6.9 $m \cdot s^{-1}$. The greatest variability was in February and March (Fig. 6.5), when the highest mean monthly wind velocities occurred (10.9 $m \cdot s^{-1}$ in February 1998, 11.9 $m \cdot s^{-1}$ in March 1979). During the year the highest monthly means of Vw occurred the most frequently in January (10 cases) and February (9 cases). Wind velocity in November had the lowest variability.

Table 6.4. Multiannual means (Mean), the highest (Max) and the lowest (Min) monthly wind velocities [$m \cdot s^{-1}$] at Hornsund, in 1978–2009. σn – standard deviation

	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Mean	**7.0**	**7.2**	**7.1**	**6.1**	**4.9**	**3.9**	**4.0**	**4.0**	**4.4**	**5.3**	**6.1**	**6.4**	**5.6**
σn	1.06	1.42	1.28	1.18	1.07	0.93	0.79	0.98	1.02	1.01	0.73	1.11	0.41
Max	9.3	10.9	11.7	8.7	6.8	5.9	5.7	6.2	7.3	8.3	7.6	8.6	6.3
Year	1995	1998	1979	2006	2007	1996	2009	1993	1983	1998	1999	2004	1998
Min	5.1	4.9	4.8	3.7	3.1	1.6	2.0	2.3	2.8	3.5	4.9	3.9	4.8
Year	2003	1996	1985	1985	1987	1985	1978	1986	1978	1978	1979	1978	1985 1986

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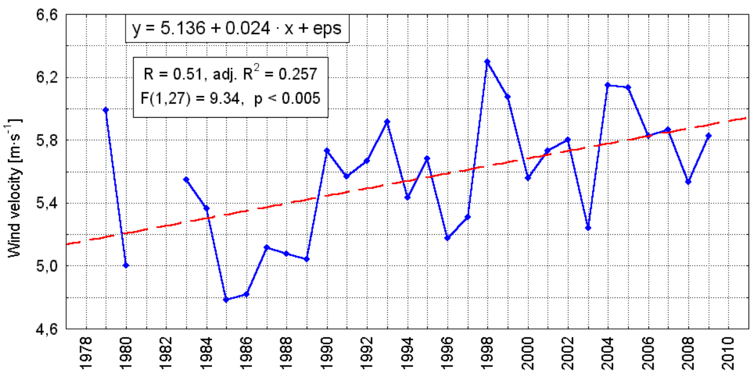

Fig. 6.4. The distribution of mean annual wind velocities [$m \cdot s^{-1}$] at Hornsund, 1979–2009.

The most often observed wind velocities (the medians) in March and April (Fig. 6.5) seem to show that these months belong more to "the winter" than to "the spring". Whereas mean wind velocities in the winter and spring seasons traditionally defined, did not show big changes (Fig. 6.5) their differentiation in the thermal seasons sharply increased (Chapter 9). From December to April the mean wind velocity was 6.8 $m \cdot s^{-1}$, in the thermal spring (May-June) it was only 4.4 $m \cdot s^{-1}$. One may therefore suppose that the thermal seasons differ not only in their temperatures but also in the wind structure. During the thermal spring the frequency of winds from the NE was also clearly lower (only 8.9%, whereas in March-May as much as 14.6%). Frequency of calm spells increased from 6.4% in March-May to 8.9% in May-June.

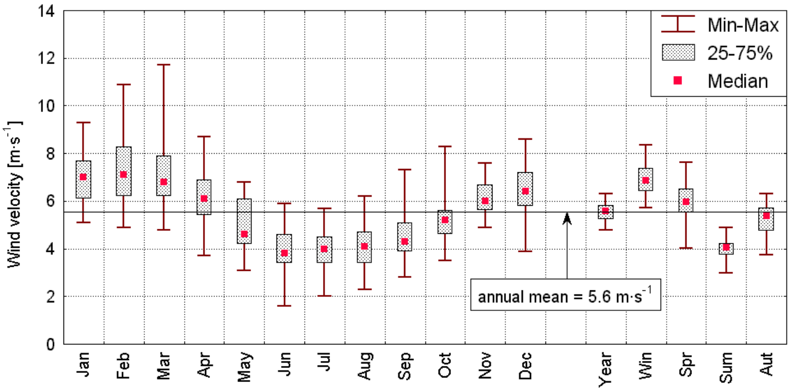

Fig. 6.5. Variability of monthly and seasonal mean wind velocity [m·s^{-1}] at Hornsund in 1978–2009. Win – winter (DJF), Spr – spring (MAM), Sum – summer (JJA), Aut – autumn (SON)

Hornsund is in the windiest region of the west coast of Spitsbergen. Higher wind velocities were noted only at the Björnöya station and at the Hopen station in the summer (Table 6.5). The greatest differences between Hornsund and stations situated further north occurred in the winter and the spring. In March mean Vw at Hornsund was 2.1 m·s^{-1} higher than at Svalbard-Lufthavn and 3.0 m·s^{-1} higher than at the Ny Ålesund station. In spite of big differences in wind intensity in the cold season of the year (from September to February and in April) changes of wind velocity at particular stations showed statistically significant associations. These were the strongest in April (r = 0.67 at Ny Ålesund up to 0.83 at Svea) and October (r = 0.48 at Ny Ålesund, up to 0.75 at Svalbard-Lufthavn). The lack of statistically significant associations with changes of wind velocity at Björnöya at the same time shows that this island remains under the influence of other pressure systems. Most frequently it is the low pressure area on the Norwegian Sea whereas Spitsbergen is under the influence of the Greenland High. Mean Vw noted at the stations of central Spitsbergen (Svalbard-Lufthavn and Svea) reach higher values than at Hornsund (Table 6.5) only in the summer (June-August). This summer increase of wind velocity at the stations situated in the interior of fjords (Svalbard-Lufthavn and Svea) should be correlated with the stronger development of mountain circulation than at Hornsund. During the high pressure weather that is frequent in the summer, at night the air cooled on the upper slopes and the mountain tops flows down to the valleys. The gravitational flows of cooled air reach higher velocities at the Svea and Svalbard-Lufthavn because behind these stations there are mountains higher than at Hornsund.

Table 6.5. Multiannual (1978-2009) mean wind velocities [m·s^{-1}] at Hornsund and other stations on Svalbard.

Station	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Ny Alesund *	4.9	4.4	4.1	3.6	2.9	2.7	2.7	2.7	3.2	4.1	4.6	4.9	3.7
Svalbard-Lufthavn *	5.8	5.5	5.0	4.4	4.1	4.3	4.7	4.1	4.2	5.3	5.9	5.9	4.9
Svea *	5.5	5.5	5.7	4.9	4.3	4.5	4.9	4.3	4.0	4.5	5.1	5.1	4.9
Hornsund	**7.0**	**7.2**	**7.1**	**6.1**	**4.9**	**3.9**	**4.0**	**4.0**	**4.4**	**5.3**	**6.1**	**6.4**	**5.6**
Björnöya *	8.7	8.7	8.3	7.4	6.3	5.8	5.6	5.5	6.5	7.6	8.1	8.3	7.2
Hopen *	6.2	6.1	5.9	5.2	4.3	4.3	4.6	4.6	5.2	6.0	6.0	6.2	5.4

* – data from the Norwegian Meteorological Institute (eKlima)

Taking into account the fact that wind velocity depends on the pressure gradient, and this in turn on the pressure field developing over the larger area, so distribution of mean monthly wind velocities described during the year indicates the periods of relative stability of the pressure field in the Spitsbergen region and the increased anticyclones in the summer as well as periods of escalation of cyclonic circulation and increase of baric gradients in the winter connected with t them, and during conversion of baric field from the winter to the summer and vice versa (Chapter 4).

Analysis of the association of the mean monthly wind velocity with the indices of Niedźwiedź (1993, 1997b, 2001) characterizing atmospheric circulation in the region of Spitsbergen shows that Vw at the Hornsund station is most strongly influenced by the frequency of zonal circulation occurrence (Table 6.6). In the winter (from December to March), in the spring and the summer (from May to August) and in October wind velocity is the higher the more frequently there are easterly winds blowing along the fjord.

Table 6.6. Correlation coefficients between the circulation indices W, S and C of Niedźwiedź (Tc) and monthly as well as annual wind velocity at Hornsund (1978–2009). Significant correlation coefficients ($p < 0.05$) are shown in bold.

Tc	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
W	**–0.38**	**–0.65**	**–0.60**	–0.11	**–0.49**	**–0.51**	**–0.74**	**–0.53**	–0.16	**–0.40**	–0.17	**–0.40**	–0.35
S	0.35	0.28	0.13	**0.81**	0.23	0.14	–0.02	0.33	0.30	0.33	0.35	0.20	0.20
C	0.19	**0.40**	–0.03	0.36	0.11	0.28	–0.17	0.10	**0.49**	0.17	0.31	**0.54**	0.14

This relationship may be explained as "channelling" of the air flow along the axis of the fjord, which is accompanied by an increase of wind velocity that steepens the pressure gradient ("tunnel effect"). The flanks of Hornsund Fjord are high mountains and an ice cap with glaciers discharging from it. This means that air resting on the higher elevated areas may undergo strong radiative cooling and begin flow downwards (katabatic wind). This air flowing to the fjord forms a strong wind blowing along the axis of the bay. In the winter and in the transitional months, at times of high pressure weather which on the open water is accompanied by weak winds or calm conditions, after a lengthy night favourable for radiative cooling, strong katabatic winds may be formed, flowing down the steep slopes of the fjord, which at the station will be registered as gusty eastern winds, often of high velocity. In turn, in the summer when lows occurring in the region of Spitsbergen are shallow and the high pressure wedges separating them are large enough that pressure gradients are very small, easterly winds blowing along the bottom of the fjord will be strengthened (tunnel effect) and their velocity will be higher than those of winds over open ground. In the winter the frequency of the easterly circulation (negative index W of Niedźwiedź) explains from 40% in February and 34% in March to 11-13% in December and January of the variance of wind speeds measured at Hornsund. In the summer (in July) it explains as much as 53% of wind speed variance (Fig. 6.6).

Positive correlation coefficients between Vw and indices of meridional circulation (S) and cyclonicity (C) show that each time there is inflow of air from the south associated with lows moving through the Greenland Sea into the Arctic or lingering in Fram Strait, wind speed should increase at the Hornsund station. This relationship is highly statistically significant in April when it explains 64% of wind velocity variance. The relationship of Vw to atmospheric pressure is similarly

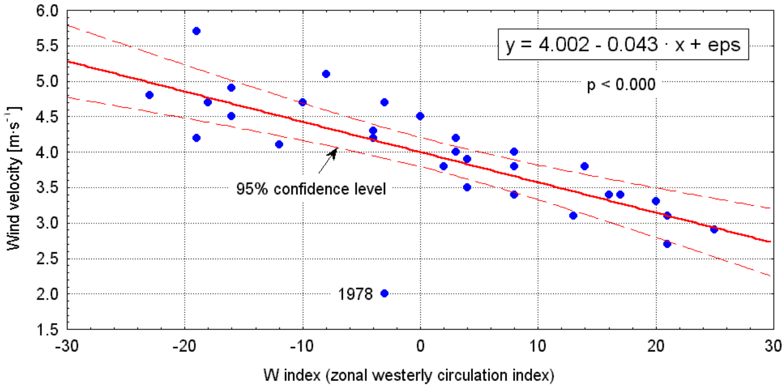

Fig. 6.6. Relation of mean wind velocity [m·s^{-1}] at the Hornsund station in July with the value of the index W (western zonal circulation) of Niedźwiedź, in 1978–2009.

significant at the station, the correlation being negative in July and August. This indicates that in these months wind velocity increased together with the drop of mean pressure. However the relationships were not statistically significant (excluding the September to November period). Thus, beyond the statement that these relationships were slightly stronger and more stable from November to February no other regularities can be noted here.

At the Hornsund station, despite the small mean monthly wind speeds, winds of great velocity were also recorded: gale force (V_w > 17 m·s^{-1}) and hurricane (V_w > 30 m·s^{-1}). The range of maximum wind speeds that was recorded during 24-hour term observations is shown in Fig. 6.7 and in Table 6.7. The highest mean maximum wind velocities over the period occurred in the cold period from October to April. In the given year most often maximum wind speeds were noted in December (9 cases) and January (7 cases). These months, together with February, were characterized by the highest means, exceeding 20 m·s^{-1}. The lowest means of maximum wind velocities occurred in the summer (June-August), these did not exceed 15 m·s^{-1}. There were summers in which in June and July maximum wind speeds during the windiest day did not exceed 10 m·s^{-1} (July 1978, June and July 1987, July 1991, July 1996 –Table 18.9).

Table 6.7. Multiannual means (Mean), the highest (Max) and the lowest (Min) maximum wind velocities [m·s^{-1}] at Hornsund in 1978–2009 (from synoptic observations). σn – standard deviation.

	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Mean	**20.5**	**20.6**	**20.1**	**18.9**	**16.0**	**13.8**	**13.4**	**14.9**	**15.5**	**18.2**	**18.7**	**20.6**	**17.5**
σn	3.98	3.71	3.62	2.89	3.86	3.33	3.08	2.42	3.16	3.00	2.95	4.04	1.13
Min	14	14	13	13	8	6	7	10	10	13	13	13	6
Year	1988	1980	2001	1993	1987	1987	1987	2003	1986	1995	1995	1996	1987
Max	31	29	29	24	24	23	19	21	21	24	25	33	33
Year	2006	1981	2003	2004	2000	1993	1986	2007	1978	1986	1983	2006	2006

During the observation period at Hornsund there were years with distinctly higher wind activity in which mean annual maximum velocities exceeded 18.5 m·s^{-1}. These were: 1983 (18.6 m·s^{-1}), 1986 (19.0 m·s^{-1}), 1993 (19.8 m·s^{-1}), 2004 (18.6 m·s^{-1}), 2005 (18.9 m·s^{-1}), 2006 (19.3 m·s^{-1}) and

2009 (18.5 m·s-1). Years with distinctly smaller wind activity were: 1980, 1987, 1988, 1991, 1996, 1997 and 2001. In these years mean annual maximum wind velocity was not reaching gale force strengths.

The Hornsund station has the highest mean multiannual maximum wind speeds of all the Svalbard stations (Table 6.8). The biggest differences between stations of this region are seen in the cold period. In December multiannual mean maximum Vw at Hornsund was 5.8 m·s-1 higher than at Svea and 3.8 m·s-1 higher than at Svalbard-Lufthavn. In March mean maximum Vw at Hornsund was 5.0 m·s-1 higher than at Svea and 4.2 m·s-1 higher than at Svalbard-Lufthavn. In the summer differences between Hornsund and stations of central Spitsbergen decreased and were in the range from 1.5 to 3.3 m·s-1.

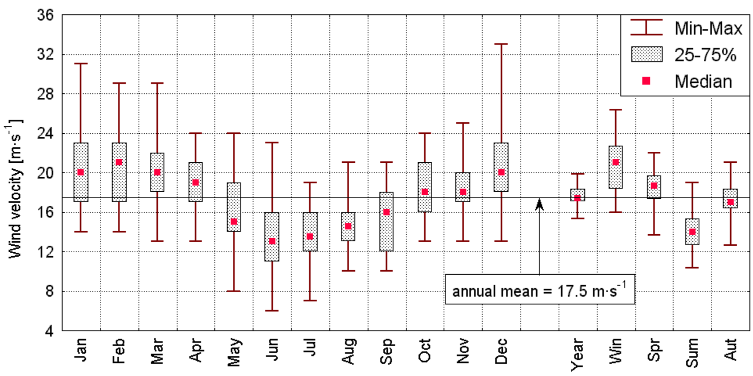

Fig. 6.7. Variability of maximum wind velocity [m·s-1] at the Hornsund station in 1978–2009 (from synoptic observations). Win – winter (DJF), Spr – spring (MAM), Sum – summer (JJA), Aut – autumn (SON)

Gales (Vw 17 > m·s-1) occurred mainly in the winter and in transition seasons of the year (Fig. 6.8). Only in some years (Table 18.9) did they occur during the summer (June-August) and then only for one day or less. Winds in the Hornsund region reach high velocities for relatively short periods only. Overall, gales lasted for just a few hours, seldom more than a dozen (Fig. 6.9). Only sporadically were gales blowing for an entire day. The largest number of gales were recorded in 1979 and 1986 (during 65 synoptic observations), the lowest number in 1988, 1996 and 1997 (during 4, 8 and 9 synoptic observations respectively).

Table 6.8. Multiannual (1978-2009) mean maximum wind velocities [m·s-1] at Hornsund and other Svalbard stations from synoptic observations.

Station	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Ny Alesund *	18.1	16.7	16.6	14.9	12.5	10.0	9.9	11.2	12.5	14.1	16.7	17.8	21.0
Svalbard-Lufthavn *	16.6	16.7	15.9	15.2	12.6	12.0	11.9	11.6	13.3	14.3	16.4	16.8	20.0
Svea *	15.1	15.6	15.1	14.5	12.0	11.8	11.9	11.8	12.5	13.4	14.9	14.8	18.4
Hornsund	**20.5**	**20.6**	**20.1**	**18.9**	**16.0**	**13.8**	**13.4**	**14.9**	**15.5**	**18.2**	**18.7**	**20.6**	**24.4**
Bjornöya *	19.3	18.7	18.7	17.2	14.9	13.4	13.4	13.6	15.7	18.1	18.2	19.6	22.5
Hopen *	16.6	14.6	14.5	13.2	11.1	10.5	11.5	11.4	12.6	15.0	14.3	15.4	18.8

* – data from the Norwegian Meteorological Institute (eKlima)

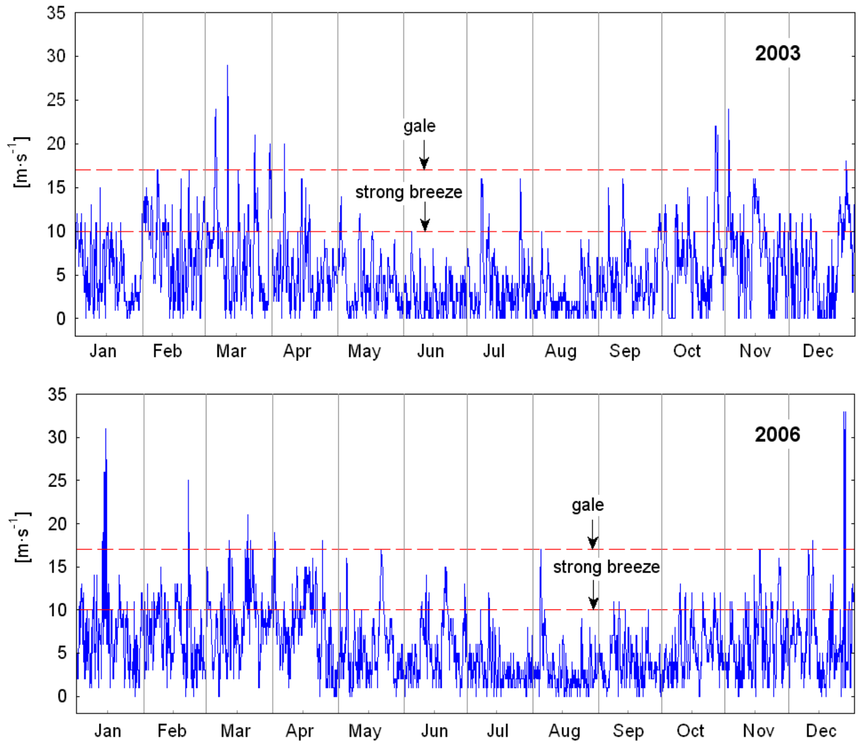

Fig. 6.8. Wind speeds [m·s^{-1}] at the Hornsund station in 2003 and 2006, from synoptic observations. Limits of strong breeze (Vw > 10 m·s^{-1}) and gale (Vw > 17 m·s^{-1}) are marked with dashed lines.

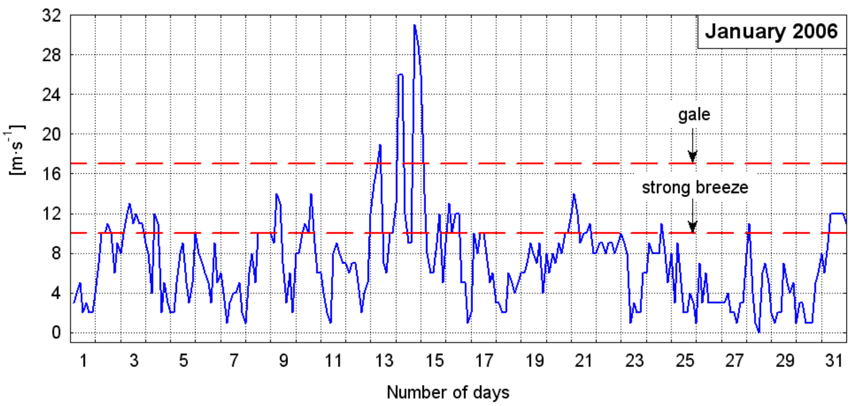

Fig. 6.9. Wind speeds [m·s^{-1}] at the Hornsund station in January 2006 according to synoptic observations. Limits of strong breeze Vw > 10 m·s^{-1}) and gale (Vw > 17 m·s^{-1}) are marked with dashed lines.

Hurricane wind speeds (Vw > 30 m·s^{-1}) were noted at the Hornsund station during synoptic observations only twice: on January 14, 2006 (31 m·s^{-1}) and December 27, 2006 (33 m·s^{-1}). Possibly very high winds occurred more often. However, winds in this region attained such velocities overall only for a relatively short time. If the times of intense winds fell between periods of synoptic observations before June 2000, they were not noted in meteorological yearbooks. In the 21st Century after the change to instruments allowing for measurement every 2 seconds (or even 1 second) gusts of hurricane force winds have been observed many times. In the light of these data it was found that winds with velocities exceeding 40 m·s^{-1} may occur at the Hornsund station (Table 6.9). The strongest gust, 49 m·s^{-1}, was noted on November 30, 2011 and 46 m·s^{-1} was noted on February 4, 2002 and on March 7, 2003. In both cases it was easterly wind associated with a deep low pressure system developing over the Greenland and Norwegian seas (Fig. 6.10).

Table 6.9. Maximum wind gust [m·s^{-1}] at the Hornsund station (July 2000 – August 2012)

Year	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual max
2000	-	-	-	-	-	-	19	25	30	38	30	30	38
2001	33	33	35	**41**	32	23	24	31	32	27	33	36	41
2002	32	**46**	37	**42**	28	20	19	20	24	27	26	35	**46**
2003	23	35	**46**	35	25	16	29	16	31	**41**	36	26	**46**
2004	35	33	29	**41**	30	23	27	31	28	35	**44**	**41**	44
2005	**45**	36	32	**42**	34	22	19	31	37	33	37	35	45
2006	34	**43**	33	38	32	24	23	29	24	23	33	33	43
2007	30	26	30	37	36	24	-	-	-	-	-	-	37
2008	-	-	-	-	-	37	24	18	31	37	34	29	37
2009	29	38	37	24	33	31	24	31	36	30	33	39	39
2010	36	35	35	31	26	29	18	20	23	35	35	35	36
2011	34	31	39	41	25	24	35	25	26	30	**49**	**43**	**49**
2012	30	35	38	32	**43**	27	39	39	-	-	-	-	**43**

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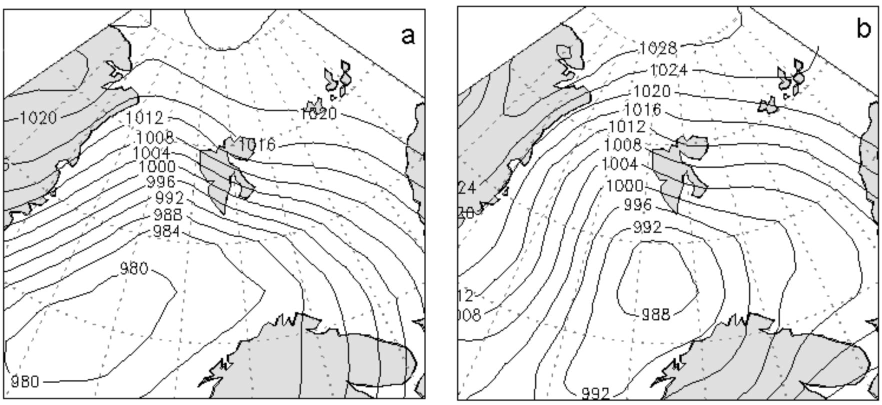

Fig. 6.10. Pressure field [hPa] at sea level in the Spitsbergen region on: (a) February 4, 2002, at 18 GMT and (b) on March 7, 2003 at 12 GMT; after NOAA/ESRL Physical Science Division (http://www.cdc.noaa.gov/cdc/data.ncep.reanalysis.html)

Strong breezes (Vw ≥ 10 m·s^{-1}) were noted throughout the whole year although in the summer their frequency was in general small. At this time longer periods of gentle winds could occur. At Hornsund in 1978-2009 the number of days with mean daily wind velocity exceeding the threshold of 10 m·s^{-1} in the summer (June-August) ranged from zero to 10 days (Fig. 6.11). At the station there were three years (2002, 2006, and 2008) when during the summer no one day with mean Vw ≥ 10 m·s^{-1} was noted (Table 18.10). Most days with strong breezes were in the winter (up to 35 days in 1995) and in the spring (up to 33 days in 2008). On average in January, February and March there was ~7 days in the month with daily mean Vw ≥ 10 m·s^{-1}. Such wind velocities in particular months were noted when zonal circulation dominated in the region of Spitsbergen. At this time, easterly winds blowing along the fjord bottom were the most frequent. The maximum number of such days was 21 in March (1979, 2008), 15 in February (1998, 2002) and 14 in January (1990, 1995, 2004). At the Polish Polar Station mean daily wind velocity exceeding the threshold of 10 m·s^{-1} was noted on average during 47 days during the year and ranged from 28 days in 1996 to 73 days in 2004 (Table 18.10).

Days when strong breeze (Vw ≥ 10 m·s^{-1}) blew for the whole day (for 24 hours) during all eight synoptic observations were observed at Hornsund relatively seldom. On average the number of such days was 8.9 in the year. The largest number of such days (25) was noted in 1998, the fewest in 1992 – only one day. Much more often strong breeze was observed for a time shorter than one day, most frequently from 0.1 to 3.0 hours (Fig. 6.12).

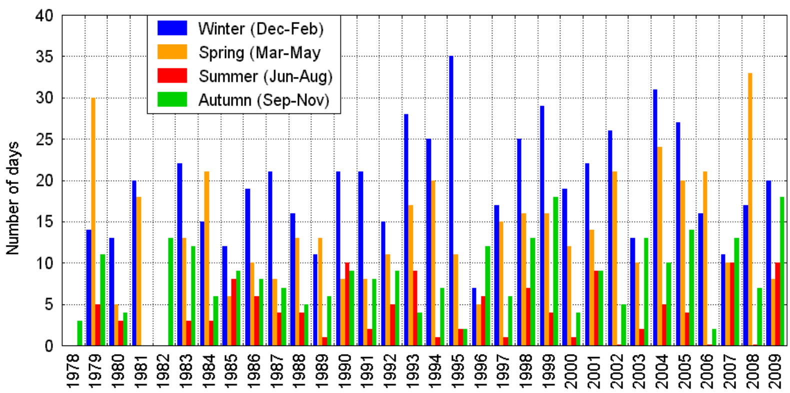

Fig. 6.11. Seasonal number of days with the daily mean Vw ≥ 10 m·s^{-1} in 1978–2009.

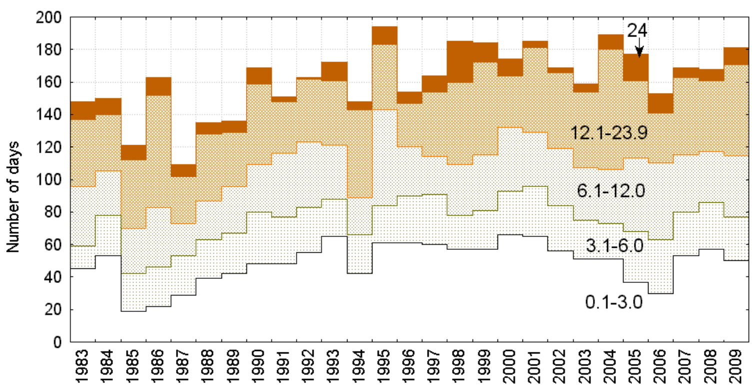

Fig. 6.12. Number of days with strong breeze (≥10 m·s^{-1}) blowing at Hornsund during intervals: 0.1-3.0, 3.1-6.0, 6.1-12.0, 12.1-23.9 and 24 hours.

Over 1983-2009 such cases were observed on average during 49 days in the year (from 19 days in 1985 to 66 days in 2000). Similarly often (on average 44 days, from 27 in 1996 to 74 in 2004) there were days during which strong breeze blew continually for more than half of the day (Fig. 6.12 – from 12.1 to 23.9 hours). Days with strong breezes blowing from 6 to 12 hours (on average 34 days, from 20 in 1987 to 59 in 1995) and from 3 to 6 hours (on average 26 days, from 14 in 1983 to 33 in 2006) were somewhat less.

6.3. The associations between wind directions and speeds

Unquestionably, the majority of high wind speeds was noted when winds were blowing from the eastern sector (Fig. 6.13) during the passage of deep low pressure systems over southern Spitsbergen, with which sudden drops of pressure are associated. In some years gale force ($V_w > 17\ m{\cdot}s^{-1}$) was also reached by the westerly winds (1985, 1986, 1987, 1991, 1993, 1998, 2002) and north-westerlies (1986, 1994, 2005, 2006). Most often however there were only single events: hurricane winds ($V_w > 30\ m{\cdot}s^{-1}$ - which before June 2000 were registered only during synoptic observations) were noted when winds were from the NW (310–330°) in 2006 (in January – 1 time, in December – 3 times). The association of wind velocities with wind directions in four selected years is shown in Fig. 6.13. 1984 was the coldest year recorded at the Hornsund station, 1988 and 2006 were the warmest years and in 1987 gales occurred from the western sector. On Fig. 6.13 wind directions are expressed in ten degree units (according to numbers of key to a code for wind observations). In 1984 during synoptic observations 64 gale force events were noted, in 1987 – 48, in 1988 – 12, and in 2006 – 32 events.

A similar distribution of wind directions and velocities was observed in particular months. Comparison of the patterns in January 1987, 2006 and July 1987, 2006 (Fig. 6.14) allows it to be stated that in the summer as well as in the winter the highest velocities occurred with winds from the eastern and north-eastern and western and north-western (E, NE, W, NW) sectors. The eastern and western sectors are concordant with the orientation of Hornsund Fjord, which channels the flow of air and contributes to the strengthening of the wind. The preference for the NE and NW sectors is due to secondary orientation of wind forced by orography upon large scale movements of air from the North. There are high mountains ranges north of the station, the Ariekammen massif nearby and the Sofiekammen, Skoddefjellet and Torbjörnsenfjellet – Rotjesfjellet ridges further away. The Ariekammen massif efficiently blocks inflow from due North whereas the Hans Glacier valley and to a lesser degree Revdalen are places of formation of strong katabatic winds which at the station are from NE (Hans Glacier) or NW (Revdalen). In both cases there are significant increases of gustiness and speed as a result of the topography. There is an increase in the proportion of NE winds at the expense of winds from the N. This primarily to strong breezes and hurricanes.

Frequency of occurrence of winds from definite directions at the Hornsund station, whether weak, strong or very strong depends on the type and intensity of atmospheric circulation dominating in a given season (year). This in turn is stimulated in part by the state of the surface water surrounding Spitsbergen (Chapter 3.3). Analysis of the correlation of frequency of occurrence of wind directions data with the index $LF_{1\text{-}4}$ characterizing changes of heat resources introduced by the Norwegian Current ($LF_{1\text{-}4}$) to the West Spitsbergen Current has shown that there is significant

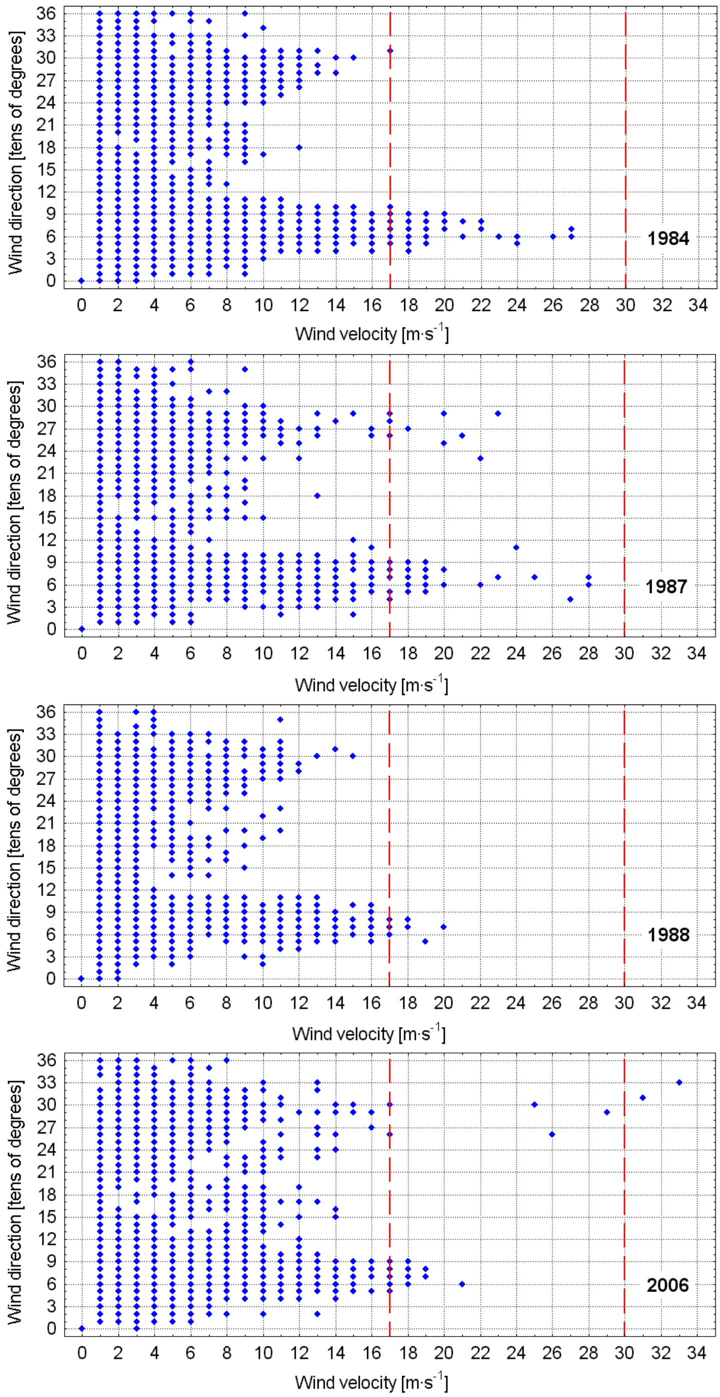

Fig. 6.13. Distribution of wind directions (in code key) and velocity [m·s^{-1}] during synoptic observations at the Hornsund station in 1984, 1987, 1988 and 2006. Thresholds for gales (17 m·s^{-1}) and hurricanes (30 m·s^{-1}) are marked with dashed lines. Wind velocity equal zero marks calm.

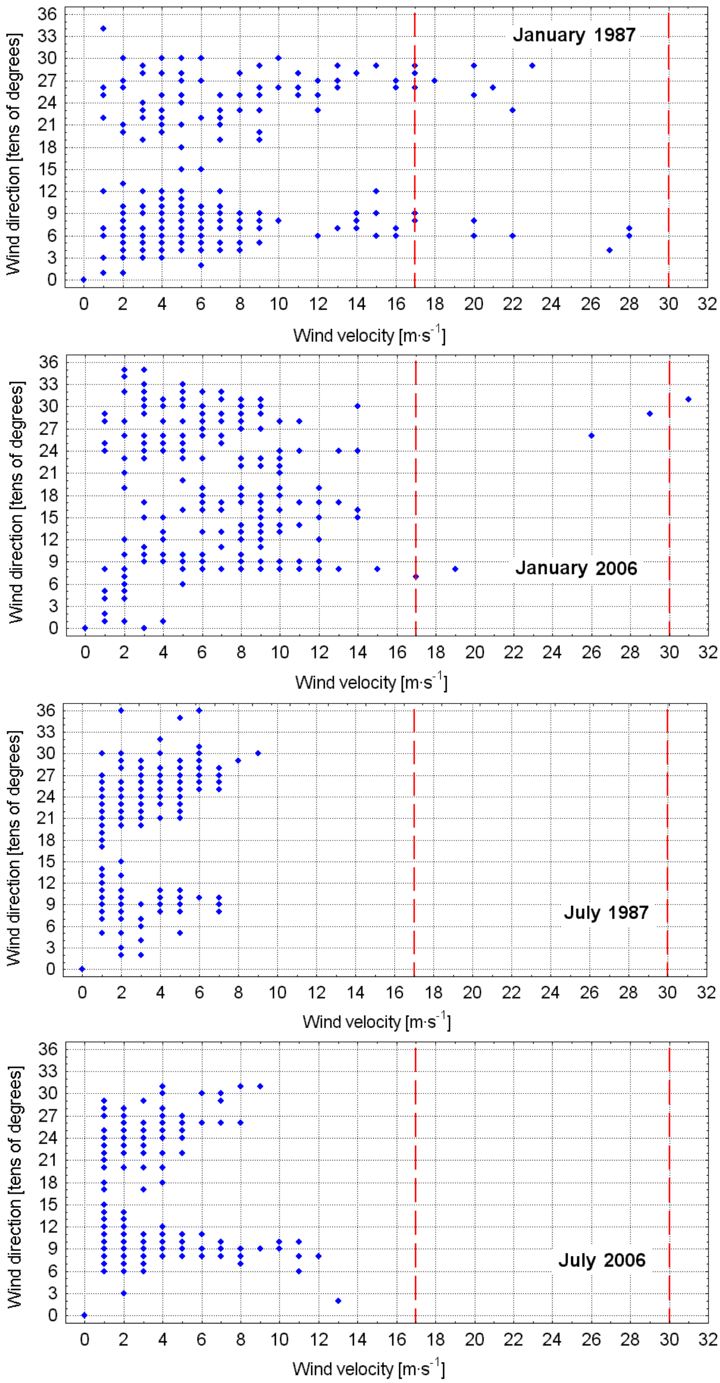

Fig. 6.14. Distribution of wind directions (in key code) and velocities [m·s^{-1}] during synoptic observations at the Hornsund station in January 1987, 2006 and July 1987, 2006. Thresholds for gales (17 m·s^{-1}) and hurricanes (30 m·s^{-1}) are marked with dashed lines. Wind velocity equal zero marks calm.

positive correlations with annual frequency of winds from the East ($r = 0.63$, $p < 0.000$) and NW ($r = 0.39$, $p < 0.037$) and negative correlations with frequency of calms ($r = -0.59$, $p < 0.001$). This finding indicates that the appearance of the warmer water in the Greenland Sea (the West Spitsbergen Current) contributes to increase in frequency of the low pressure systems on the western side of Spitsbergen, and thus to increase of the frequency of easterly winds and reduction of calms. Presumably, warmer water in the eastern part of the Greenland Sea when there is a belt of ice in the western part of this sea strengthens the pressure gradient in the central troposphere. This favours more intensive cyclogenesis over the Greenland Sea and Fram Strait. The LF_{1-4} index correlates also positively and significantly with annual wind velocity ($r = 0.56$, $p < 0.002$, $n = 29$). Within the seasons the strongest correlations are with wind velocity in the autumn (September-November; $r = 0.44$, $p < 0.016$).

Annual wind velocity is also relatively strong correlated ($r = 0.62$, $p < 0.0004$, $n = 29$) with values of the DG_{3L} index from the preceding year. The annual frequency of calms is correlated weakly ($r = -0.43$) but statistically significantly ($p < 0.030$) with the same index. Because the index value from the preceding year indicates SST behaviour in the West Spitsbergen Current and the Barents Sea (Chapter 3.3) these associations are evidence that increase of heat resources in the seas surrounding Spitsbergen is associated with increase of wind activity in this part of the Atlantic Arctic. Such a picture conforms well with our other conclusions on the effects of heat exchange between the ocean and the atmosphere in this region (Chapter 3.3).