Chapter 2

ATMOSPHERIC CIRCULATION AND DYNAMIC CONDITIONS

2.1. Atmospheric circulation

2.1.1. Introduction

The issue of the temporal and spatial variability of atmospheric circulation and its influence on the local climate has been undoubtedly more thoroughly investigated in the area of Svalbard than in any other part of the Arctic. This is no coincidence, but a result of the empirical fact that the role of atmospheric circulation in the shaping of weather and climate conditions in the Arctic is the greatest on the Svalbard Archipelago (Przybylak 1996, 2002). The openness of the Atlantic Ocean towards the Arctic and the proximity of the Icelandic Low, which is exceptionally active in the cold seasons, are the direct causes. The key role of the Atlantic Arctic (including Svalbard) in the modelling of the changes and changeability of the Arctic climate has always encouraged scientists to make efforts to gain the most comprehensive insight into various aspects of the climate in that area and the mechanisms that control the visible changes. In consequence, there are extensive sources concerning the above-mentioned research problems, particularly in Polish academic literature and – to a lesser degree – in Norwegian (Przybylak 1992a, b; Wójcik et al. 1992; Niedźwiedź 1993, 1997a,b, 2001, 2006, 2007; Hanssen-Bauer and Førland 1998; Araźny 2008; Bednorz 2010; Łupikasza 2010; Käsmacher and Schneider 2011). Listing all or even most of the works, articles and studies here is impractical, therefore the authors have decided to mention only those, that are considered (perhaps subjectively) the most important. For further reading, the selected sources list most of the literature that we do not refer to herein.

The description of the atmospheric circulation of the studied area has been provided using the calendar of circulation types for Spitsbergen, continuously updated by Tadeusz Niedźwiedź and available at http://klimat.wnoz.us.edu.pl/#!/glowna. The principles of classification of the circulation types are given on the website and summarised in this Section. Niedźwiedź (1981) applied his own method of distinguishing circulation types in Spitsbergen, presented in his habilitation thesis. In the case of Spitsbergen (just as with the Lesser Poland area), he distinguished 21 circulation types, listed in Table 2.1. In order to increase clarity, the author of the classification used common denominations of advection direction, adding 'a' for anticyclonic (high-pressure) systems and 'c' for cyclonic (low-pressure) systems. The period concerned in this monograph is rather short (July 2010 – August 2011), therefore the influence of atmospheric circulation on the climate was analysed using the combined circulation types for Spitsbergen, as proposed by Przybylak (1992a), so that the statistical sample of the days when individual synoptic patterns occurred could be increased. Considering that there are as many as 21 circulation types, a number of them did not occur in specific months and seasons, or their frequency of occurrence is not relevant enough (Tab. 2.1). Taking them into account would compromise a reliable evaluation of the influence of atmospheric circulation on the climate.

Table 2.1. Synoptic situations (types) used in the study (after Niedźwiedź 1981)

Type of circulation	Description of synoptic situations
Na, Nc	Synoptic situations with air advection from the north
NEa, NEc	Synoptic situations with air advection from the north-east
Ea, Ec	Synoptic situations with air advection from the east
SEa, SEc	Synoptic situations with air advection from the south-east
Sa, Sc	Synoptic situations with air advection from the south
SWa, SWc	Synoptic situations with air advection from the south-west
Wa, Wc	Synoptic situations with air advection from the west
NWa, NWc	Synoptic situations with air advection from the north-west
Ca	Central anticyclonic situation, no advection, anticyclonic centre over Spitsbergen
Ka	Anticyclonic wedge, sometimes several unclear centres or a blurred area of high pressure, axis ridge of high pressure
Cc	central cyclonic situation, cyclonic centre over Spitsbergen
Bc	Cyclonic trough, blur area of low pressure or axis of cyclonic trough with different directions of air advection and front systems dividing different air masses
X	Synoptic situations which cannot be classified and barometric cols
A/C	Anticyclonic/cyclonic situation

For the purpose of generalisation of the atmospheric circulation the progression indices proposed by Murray and Lewis (1966) were applied in a form modified by Niedźwiedź (1993, 1997b). The indices enable determination of the degree of dominance of the zonal circulation (*W*), meridional (*S*) or cyclonic/anticyclonic (*C*). The *W* index defines the intensity of westerly zonal circulation (positive values) and/or easterly zonal circulation (negative values). The *S* index defines southerly (positive values) or northerly (negative values) circulation. Finally, the *C* index (cyclonicity) indicates the degree of cyclonic (positive values) or anticyclonic (negative values) activity.

2.1.2. Frequency of occurrence of the circulation types

The geographical location of Spitsbergen in the vicinity of two stationary centres of weather modification (the Icelandic Low and the Greenland High) determines the movement of air masses over the island, which then conditions the weather. According to Markin (1975), the climate conditions on Spitsbergen are primarily affected by the Icelandic Low and its long-term fluctuations and the position of the Arctic front, along which active cyclones move from the Atlantic Ocean to the west.

July 2010 – August 2011

The frequency of occurrence of all 21 and of 11 combined circulation types on Spitsbergen in the period of July 2010 – August 2011 has been shown in Tables 2.2-2.3 and Figs. 2.1-2.2.

Table 2.2. Relative frequency of occurrence (%) of synoptic patterns on Spitsbergen in the period from July 2010 to August 2011

Types of circulation	2010						2011							
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Na	·	16.1	3.3	·	3.3	3.2	3.2	·	·	·	6.5	2.0	6.5	6.5
NEa	·	12.9	3.3	9.7	13.3	6.5	9.7	·	·	·	6.5	3.0	3.2	9.7
Ea	6.5	·	·	·	3.3	9.7	9.7	7.1	·	·	·	·	·	·
SEa	3.2	·	6.7	·	·	3.2	·	10.7	·	·	6.5	·	6.5	16.1
Sa	·	·	3.3	·	·	3.2	·	10.7	·	·	·	·	·	9.7
SWa	·	·	3.3	·	3.3	·	·	·	·	3.3	6.5	·	12.9	·
Wa	16.1	3.2		·	3.3	·	·	·	·	·	3.2	·	·	·
NWa	·	3.2	6.7	·	·	·	·	·	·	3.3	3.2	13.3	·	·
Ca	·	3.2	·	·	6.7	·	·	3.6	·	·	6.5	·	·	9.7
Ka	9.7	19.4	6.7	·	3.3	·	6.5	·	3.2	3.3	9.7	6.7	12.9	9.7
Nc	9.7	9.7	.	22.6	13.3	6.5	6.5	·	35.5	6.7	6.5	6.7	3.2	6.5
NEc	9.7	6.5	3.3	22.6	1.0	16.1	9.7	·	12.9	3.3	6.5	3.3	9.7	6.5
Ec	·	·	2.0	12.9	2.0	6.5	16.1	3.6	3.2	6.7	9.7	3.3	3.2	3.2
SEc	3.2	·	1.0	·	·	12.9	9.7	21.4	·	2.0	3.2	·	6.5	6.5
Sc	9.7	·	·	9.7	·	·	3.2	7.1	3.2	6.7	·	·	·	·
SWc	6.5	3.2	3.3	6.5	·	6.5	3.2	10.7	19.4	1.0	3.2	3.3	·	3.2
Wc	9.7	6.5	6.7	6.5	·	·	·	7.1	·	1.0	3.2	3.3	3.2	3.2
NWc	·	6.5	3.3	·	·	3.2	·	3.6	·	·	6.5	·	6.5	·
Cc	·	3.2	6.7	6.5	6.7	3.2	6.5	3.6	6.5	6.7	3.2	6.7	9.7	9.7
Bc	6.5	·	3.3	3.2	6.7	3.2	12.9	3.6	9.7	13.3	3.2	3.3	9.7	·
X	9.7	6.5	1.0	·	6.7	16.1	3.2	7.1	6.5	6.7	6.5	·	6.5	·

Explanation: · - circulation type did not occur

In the analysed period, the prevailing advection brought the air masses from the northern sector (combined types: NWc+Nc+NEc and NWa+Na+NEa), especially with cyclonic circulation (20.4%) and, to a lesser degree, anticyclonic circulation (14.5%) (Fig. 2.2). The synoptic patterns forming the first of the combined types, Nc and NEc, were the most frequent (9.6 and 8.7%, respectively) of all 21 analysed circulation types, whereas the NEa type, with a frequency of 7.5%, was the fourth (Fig. 2.1). Apart from northern directions, the most common were advections from the E and SE, which – again – were notably more frequent in cyclonic situations (14.3%) than anticyclonic (6.3%). The combined types Sc+SWc+Wc and Sa+SWa+Wa occurred with a similar frequency, although slightly smaller (12.6 and 5.9%, resp.). As far as non-advective circulation types are concerned, cyclonic patterns (Cc+Bc) were also more frequent (11.2%) than anticyclonic ones (Ca+Ka, 8.7%) (Figs. 2.1-2.2). All in all, in the analysed period cyclonic situations (58.5%) outnumbered anticyclonic weather (35.4%).

Table 2.3. Relative frequency of occurrence (%) of combined synoptic patterns on Spitsbergen in the period from July 2010 to August 2011

Type of circulation	2010						2011							
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
NWa+Na+NEa	·	32.3	13.3	9.7	16.7	9.7	12.9	·	·	3.3	16.1	63.3	9.7	16.1
Ea+SEa	9.7	·	6.7	·	3.3	12.9	9.7	17.9	·	·	6.5	·	6.5	16.1
Sa+SWa+Wa	16.1	3.2	6.7	·	6.7	3.2	·	10.7	·	3.3	9.7	·	12.9	9.7
Ca+Ka	9.7	22.6	6.7	·	1.0	·	6.5	3.6	3.2	3.3	16.1	6.7	12.9	19.4
NWc+Nc+NEc	19.4	22.6	6.7	45.2	23.3	25.8	16.1	3.6	48.4	1.0	19.4	1.0	19.4	12.9
Ec+SEc	3.2	·	3.0	12.9	2.0	19.4	25.8	25.0	3.2	26.7	12.9	3.3	9.7	9.7
Sc+SWc+Wc	25.8	9.7	1.0	22.6	·	6.5	6.5	25.0	22.6	26.7	6.5	6.7	3.2	6.5
Cc+Bc	6.5	3.2	1.0	9.7	13.3	6.5	19.4	7.1	16.1	2.0	6.5	1.0	19.4	9.7
X	2.6	2.7	2.4	2.4	2.4	3.2	3.7	3.5	4.2	2.9	2.4	2.6	2.6	2.7
Anticyclonic	35.5	58.1	33.3	9.7	36.7	25.8	29.0	32.1	3.2	1.0	48.4	7.0	41.9	61.3
Cyclonic	54.8	35.5	56.7	90.3	56.7	58.1	67.7	60.7	90.3	83.3	45.2	3.0	51.6	38.7

Explanation: · – circulation type did not occur

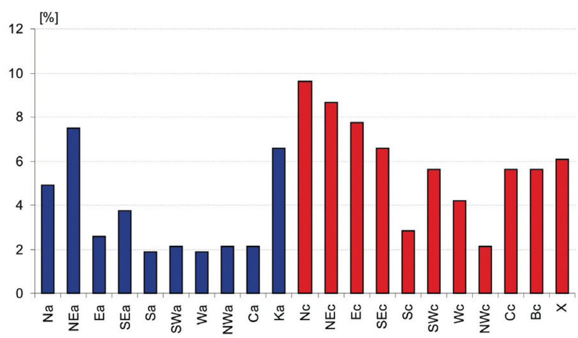

Figure 2.1. Relative frequency of occurrence (%) of atmospheric circulation types (acc. to Niedźwiedź 1981) on Spitsbergen in the period from July 2010 to August 2011

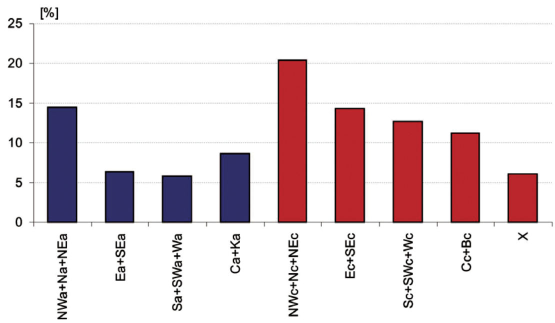

Figure 2.2. Relative frequency of occurrence (%) of combined circulation types on Spitsbergen (acc. to Przybylak 1992a) in the period from July 2010 to August 2011

Table 2.4. Anomalies in relative frequency of occurrence (%) of combined circulation types on Spitsbergen (acc. to Przybylak 1992a) in the period from July 2010 to August 2011, as compared with average values from 1950 to 2006 (Niedźwiedź 2006)

Type of circulation	2010						2011							
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
NWa+Na+NEa	-6.7	24.4	4.5	-2.9	5.9	-3.0	1.1	-12.4	-13.3	-16.1	-3.0	50.4	3.0	8.2
Ea+SEa	0.2	-12.7	-1.9	-8.6	-6.2	4.3	0.4	7.2	-14.0	-14.7	-6.6	-9.2	-3.0	3.4
Sa+SWa+Wa	4.9	-7.1	1.6	-3.7	3.4	-0.9	-3.5	7.2	-3.4	-0.3	0.9	-8.7	1.7	-0.6
Ca+Ka	-7.8	5.1	-4.6	-10.7	3.1	-6.8	-0.2	-4.1	-4.6	-7.9	-2.5	-11.7	-4.6	1.9
NWc+Nc+NEc	7.6	9.8	-12.1	25.5	3.3	4.8	-3.8	-14.3	31.5	-3.1	7.3	-4.7	7.6	0.1
Ec+SEc	-6.3	-10.4	12.5	-5.9	-0.7	-2.6	2.8	5.0	-17.4	11.3	4.0	-5.6	0.2	-0.7
Sc+SWc+Wc	8.9	-4.2	-3.0	13.0	-11.6	-3.3	-4.7	13.1	13.4	17.4	0.1	-3.7	-13.7	-7.4
Cc+Bc	-6.6	-7.9	-2.8	-3.6	-1.4	-5.8	7.6	-6.1	3.7	9.1	-3.1	-3.5	6.3	-1.4
X	-1.1	-0.8	-1.8	-0.5	0.0	0.6	1.1	0.8	1.8	0.5	0.0	-0.6	-1.1	-0.8
Anticyclonic	-9.4	9.7	-0.5	-25.9	6.2	-6.4	-2.3	-2.2	-35.3	-38.9	-11.2	20.8	-3.0	12.9
Cyclonic	3.5	-12.7	-5.4	28.9	-10.3	-7.0	1.8	-2.3	31.2	34.6	8.2	-17.5	0.3	-9.5

In order to determine the extent of influence of atmospheric circulation on weather conditions it is vital to identify the character of the circulation in the relevant period and compare it with the corresponding average circulation in a long-term reference period. Therefore, the anomalies of occurrence of the combined circulation types were analysed in comparison with their frequency in the years 1950 - 2006 (Tab. 2.4, Fig. 2.3). From July 2010 to August 2011, the frequency of a combined types was no more than 5% higher/lower than the long-term average frequency (Fig. 2.3). The highest positive anomalies were characteristic of the ‘northerly’ types (2-4%), whereas those from the south-west sector were much less frequent (0.1-1.5%). Combined types from the

E and SE directions, cyclonic and anticyclonic, occurred less often than the average (by 2.0 and 4.4%, resp.). Non-advective situations also displayed considerable negative frequency anomalies, particularly the Ca+Ka type (-3.1%). Cyclonic patterns were 2.3% more frequent, on average, and anticyclonic patterns were 5.2% less frequent.

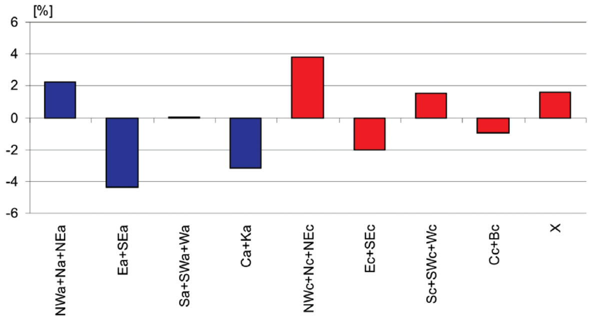

Figure 2.3. Anomalies in relative frequency of occurrence (%) of combined circulation types on Spitsbergen (acc. to Przybylak 1992a) in the period from July 2010 to August 2011, as compared with average values from 1950 to 2006 (Niedźwiedź 2006)

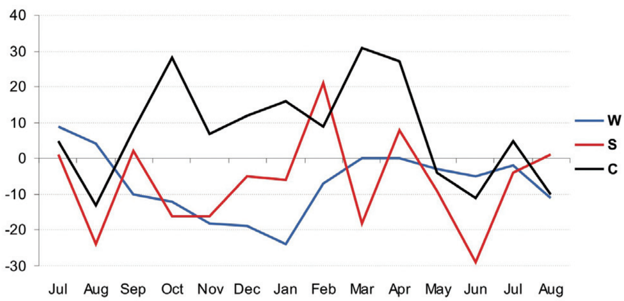

Figure 2.4. Annual course of atmospheric circulation indices W, S, C on Spitsbergen in the period from July 2010 to August 2011

An analysis of anomalies in the relative frequency of occurrence of the combined circulation types in individual months of the analysed period (Tab. 2.4) shows that the extent of their changes is much larger. In all but 3 months the anomalies exceeded more than ±10%. An exceptional deviation from the standard is exhibited by the combined types of the northern sector. Their overrepresentation in June and March 2011 and in October 2010 amounted to 50.4%, 31.5% and 25.5%, respectively. The negative anomalies were not so big and did not exceed 20%. Their respective highest values, -17.4, -16.1 and -14.7%, were observed in the following circulation types: Ec+SEc, NWa+Na+NEa and

Ea+SEa. In the spring of 2011, notably in March and April, there was a greatly increased/decreased share of cyclonic/anticyclonic patterns, exceeding 30%.

A more generalised picture of the changes in the atmospheric circulation in the period from July 2010 until August 2011 is given by the circulation indices (*W*, *S* and *C*) presented in Figure 2.4, which clearly shows that, in nearly all the months, the prevailing air masses came from the northern and eastern sectors, as compared with the southern and western. The cyclonicity index, *C*, confirms the initial conclusion drawn from the frequency of occurrence of circulation types with a conspicuous predominance of cyclonic systems.

21 July – 31 August

In the summer season, research programmes are much more extensive than observations conducted throughout the year. Nearly all TPEs started their meteorological observations on Spitsbergen before 21 July, and this is why, in order to make the results obtained in different summer seasons comparable, the common period of 21 July–31 August was selected. An examination of the reasons for changes in weather conditions that occurred in that period has been supported by an independent analysis of the frequency of occurrence of the combined circulation types (Fig. 2.5). In the summer of 2010, northern sector types exceeded the standard frequency (their anomalies amounted to approx. 20% and 10% for the anticyclonic and cyclonic type, respectively). The X type aside, the frequency of occurrence of the other synoptic patterns was below standard. Particularly substantial negative anomalies (approx. 13%) were characteristic of easterly types, which did not then occur at all. This kind of specific atmospheric circulation was responsible for the cool summer.

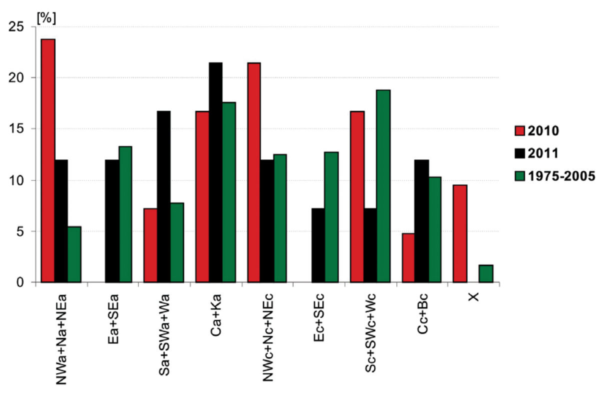

Figure 2.5. Relative frequency of occurrence (%) of combined circulation types on Spitsbergen in the period from 21 July to 31 August in 2010 and 2011, and the long-term average from 1975 to 2005

In the summer of 2011, the atmospheric circulation was much closer to the long-term course (Fig. 2.5). The greatest anomalies in the frequency of occurrence of individual circulation types in the analysed summer seasons, as compared with the long-term period of 1975–2005, were identified in the influx of air masses from the south-western sector. Their negative value (-11.7%) was recorded for cyclonic types, and the positive (9.0%) for anticyclonic types. Two other types, NWa+Na+NEa and Ec+SEc, exceeded the ±5% difference (6.5% and -5.6%, resp.). In that season, the share of anticyclonic systems was substantially higher (by 17.9%) than the standard, whereas cyclonic systems were less frequent (by 16.2%).

2.2. Atmospheric pressure

The atmospheric pressure in the Svalbard area (including Spitsbergen) has hardly ever been given close scrutiny or subjected to detailed study. It is enough to point out that in the available Norwegian publications concerning the climate of the Norwegian Arctic (Steffensen 1969, 1982; Førland et al. 1997) or of Spitsbergen only (Hanssen-Bauer et al. 1990), there are no descriptions of this meteorological element at all. The matter has barely been addressed in Polish studies as well. However, in recent years the situation has considerably improved. The most detailed studies, based on long term data collection in the whole of the Norwegian Arctic, were presented by Araźny (2008), and Niedźwiedź (2007) for the area of the Polish Polar Station in Hornsund. Other important studies analysing the problem to a larger extent (although for the summer season only) include studies of the spatial diversity of the atmospheric pressure on the west coast of Spitsbergen (Przybylak et al. 2006, 2007) and short descriptions of the changes in pressure in the summers of 2005 and 2006, observed at the base station in Kaffiøyra (Kejna and Maszewski 2007; Przybylak and Araźny 2007).

The study by Araźny (2008) shows that there is little spatial diversity in the atmospheric pressure in the Norwegian Arctic. During the AWAKE project the meteorological element was measured only in the summers of 2010 and 2011, and the statistics, as with other elements, were presented for the common period of 21 July to 31 August, practically concerning only one complete month. Table 2.12 in the same study indicates that the mean values of atmospheric pressure in August, obtained at three Spitsbergen stations (Ny-Ålesund, Svalbard Lufthavn and Hornsund) and calculated for the periods of 1975-2000, 1976-2000 and 1979–2000, respectively, differed from one another by merely 0.1 hPa. In individual years the differences were obviously greater, however still hardly evident. Analysing data collected from six stations situated on the west coast of Spitsbergen in the summers of 2006 and 2007, Przybylak et al. (2006, 2007) found the differences to reach 3.9 and 4.0 hPa, respectively, and excluding the values recorded at Svalbard Lufthavn, only 1.2 and 1.7 hPa. According to Przybylak et al. (2006), the reasons for the lower values of atmospheric pressure in both summer seasons at Svalbard Lufthavn, as compared to the other stations situated on the west coast of Spitsbergen, are hard to explain, especially given the long-term invariability referred to above.

The area investigated during the AWAKE project was a small section of the west coast of Spitsbergen, therefore the spatial diversity of atmospheric pressure should have been even smaller. For that reason, some aspects of the weather element have been dealt for selected stations representing three different regions: Kaffiøyra, Prins Karls Forland and St. Jonsfjorden.

The atmospheric pressure at all the analysed observation points was higher in the summer of 2011 than in the summer of 2010, and the average increase ranged from approx. 1.5 hPa (at LW1) to 4.0 hPa (at SJ2) (Tab. 2.5). Regarding ten-day and daily means, clearly most of them show a higher pressure in the summer of 2011 (Tab. 2.5, Fig. 2.6). The highest mean pressure of 2010 was recorded at the KH station (1012.6 hPa), and in 2011 at PK3 (1016.3 hPa). The lowest pressure in the same years was recorded respectively at SJ2 (1011.1 hPa) and at LW1 (1013.5 hPa).The spatial diversity was therefore rather small, ranging from 1.5 hPa in the summer of 2010 to 2.8 hPa in 2011.The ranges of the differences in comparison with the reference station of KH have been shown in Figure 2.7.

Table 2.5. Mean values of atmospheric pressure reduced to sea level (hPa) in the area of the Forlandsundet in the summers of 2010 and 2011

Sites	21-31 Jul		01-10 Aug		11-20 Aug		21-31 Aug		21 Jul-31 Aug	
	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011
KH	1009.1	1016.6	1012.3	1015.9	1014.5	1014.3	1014.8	1016.7	1012.6	1015.9
SAT	1007.8	1016.0	1011.0	1015.6	1013.5	1013.8	1013.8	1016.2	1011.5	1015.4
ATA	1008.8	-	1012.0	-	1014.0	-	1014.3	-	1012.2	-
GF	1008.1	-	1011.3	-	1013.4	-	1013.8	-	1011.6	-
LW1	1008.8	1014.2	1012.0	1013.3	1014.0	1011.9	1014.4	1014.2	1012.3	1013.5
LW2	1008.8	1015.6	1012.0	1014.6	1013.9	1013.2	1014.1	1015.5	1012.2	1014.8
PK1	-	1015.9	-	1015.1	-	1013.6	-	1015.9	-	1015.2
PK2	1008.3	-	1011.5	-	1013.8	-	1014.1	-	1011.9	-
PK3	1008.6	1017.0	1011.8	1016.4	1014.1	1014.7	1014.3	1017.1	1012.2	1016.3
SJ2	1007.7	1015.8	1010.9	1014.7	1012.8	1013.8	1013.3	1015.8	1011.1	1015.1

Explanation: „–„ - denotes lack of data

Regarding the 10-day means, the highest pressure was recorded in both summer seasons at most of the stations in the last eleven days of August, e.g. 1014.8 hPa (2010) and 1016.7 hPa (2011) at KH (Tab. 2.5). However, with non-standard 10-day periods the highest atmospheric pressure values, reaching 1021.1hPa on average, occurred in the summer of 2011 between 26 July and 4 August (Fig. 2.6). At all measurement sites the lowest ten-day values in the summers of 2010 and 2011 occurred towards the end of July and in mid-August, respectively (Tab. 2.5).

The frequency of occurrence of mean daily pressure in the studied summers has been shown in intervals of 2 hPa for the three stations (KH, PK3 and

SJ2), representing the aforementioned three areas of investigations (Fig. 2.8). There are visible differences in the distribution of atmospheric pressure in both seasons. In the summer of 2010 the distribution was nearly normal, whereas in 2011 it was substantially negatively skewed. A greater similarity in the distribution patterns is visible between the stations at KH and PK3, situated on opposite sides of the Forlandsundet. In the summer of 2010, the mean daily values of atmospheric pressure occurred the most frequently in the ranges of 1010.1-1012.0 hPa (17–20%), and least frequently at 1000.1–1002.0 hPa (< 2%). In the summer of 2011, they occurred the most often in the ranges of 1020.1-1022.0 hPa (approx. 18%) and were the least frequent at 996.1-998.0 hPa (approx. 0.5%).The number of ranges in 2011 was 1.5 times bigger than in 2010.

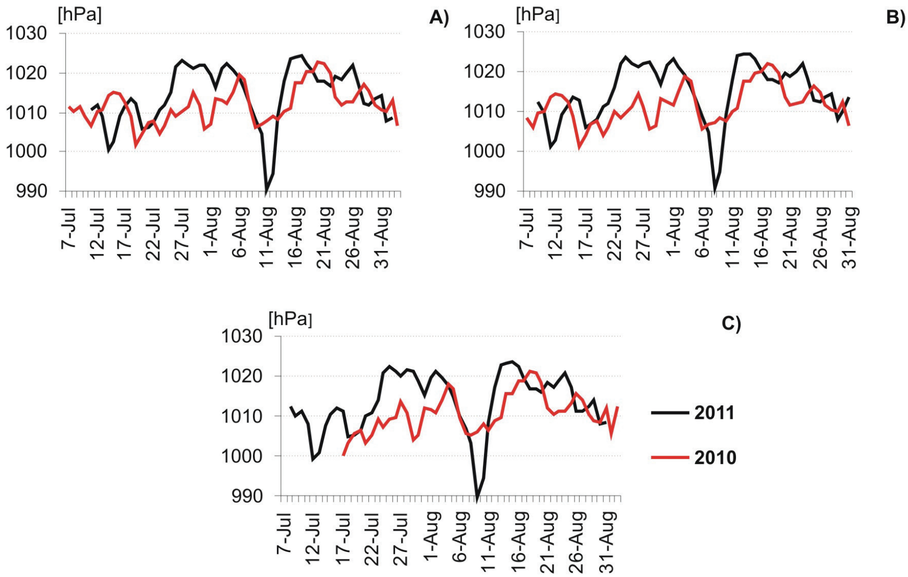

Figure 2.6. Courses of atmospheric pressure reduced to sea level (hPa) at A) the Base Station (KH), B) PK3 and C) SJ2 in the summers of 2010 and 2011

From the beginning of the summer season to mid-August the pressure generally rises and then gradually begins to fall (Fig. 2.6). However, at the beginning of the second ten-day period the values deviate from the trend. In both years pressure drops lasting for a few days were observed, some of which were particularly big in the summer of 2011, reaching below 990 hPa.

The highest atmospheric pressure in the area of our investigations occurred at PK3 and KH, exceeding 1023 hPa (2010) and 1025 hPa (2011) (Tab. 2.6).

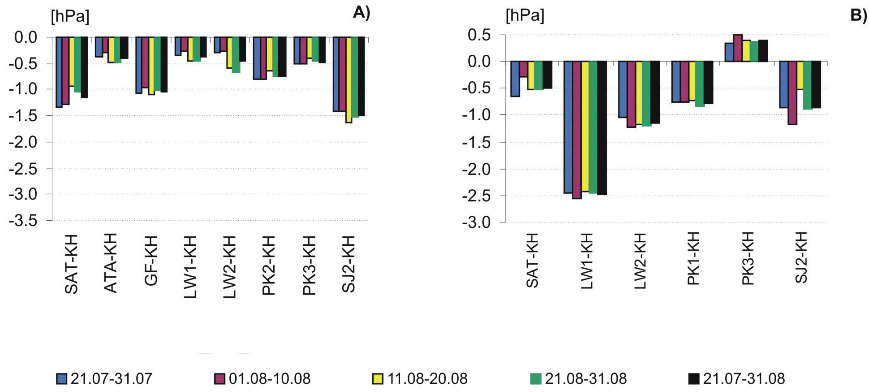

Figure 2.7. Differences of atmospheric pressure reduced to the sea level (hPa) between the Base Station (KH) and the other measurement sites in the area of the Forlandsundet in the summers of 2010 (A) and 2011 (B)

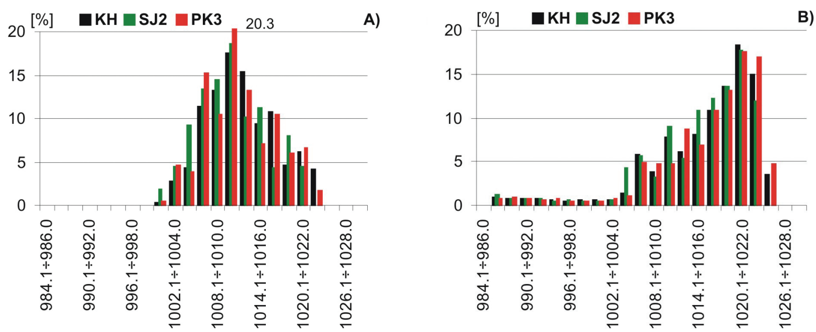

Figure 2.8. Relative frequency of occurrence (%) of the mean daily pressure in intervals of 2 hPa at KH, SJ2 and PK3 stations in the summers of 2010 (A) and 2011 (B)

The spatial diversity of the values was not significant, reaching 1.6 hPa (2010) and 3.1 hPa (2011). In the summer season in 2011 the highest values of atmospheric pressure at all stations exceeded 1020 hPa in all ten-day series of the common period, however in 2010 the pattern was observed at most of the stations and in most of the ten-day periods.

The lowest values of atmospheric pressure in the common period of 21 July to 31 August were slightly above 1000 hPa in the summer of 2010, but ranged between 985 and 987 hPa in 2011 (Tab. 2.7).

The spatial diversity of atmospheric pressure, just like with the maximum recorded values, was not big and amounted to 1.5 hPa in 2010 and 2.5 hPa in 2011. Nevertheless, the diversity of these values during the polar summer was several times greater, particularly in 2011 (Tab. 2.7, Fig. 2.6).

Table 2.6. Maximum values of atmospheric pressure reduced to sea level (hPa) in the area of the Forlandsundet in the summers of 2010 and 2011

Sites	21–31 Jul		01–10 Aug		11–20 Aug		21–31 Aug		21 Jul–31 Aug	
	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011
KH	1015.7	1023.9	1021.1	1023.9	1023.4	1025.1	1023.6	1022.6	1023.6	1025.1
SAT	1014.1	1022.9	1019.8	1023.7	1022.2	1024.6	1022.3	1022.3	1022.3	1024.6
ATA	1015.4	–	1020.8	–	1023.0	–	1023.0	–	1023.0	–
GF	1014.2	–	1020.3	–	1022.0	–	1022.1	–	1022.1	–
LW1	1015.2	1021.1	1020.8	1021.1	1022.8	1022.5	1022.9	1020.4	1022.9	1022.5
LW2	1015.3	1022.4	1020.7	1022.6	1022.9	1023.9	1023.0	1021.7	1023.0	1023.9
PK1	–	1023.1	–	1023.1	–	1024.4	–	1021.9	–	1024.4
PK2	1014.9	–	1020.5	–	1022.7	–	1022.8	–	1022.8	–
PK3	1015.3	1023.9	1020.7	1024.6	1023.1	1025.6	1023.1	1023.0	1023.1	1025.6
SJ2	1014.1	1023.0	1019.7	1022.5	1021.7	1024.0	1022.0	1021.9	1022.0	1024.0

Explanation: „ – „ - denotes lack of data

Table 2.7. Minimum values of atmospheric pressure reduced to sea level (hPa) in the area of the Forlandsundet in the summers of 2010 and 2011

Sites	21–31 Jul		01–10 Aug		11–20 Aug		21–31Aug		21 Jul–31 Aug	
	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011
KH	1002.9	1005.5	1001.6	998.1	1006.7	986.9	1009.8	1011.2	1001.6	986.9
SAT	1001.8	1005.0	1000.3	998.0	1005.5	986.3	1008.9	1010.6	1000.3	986.3
ATA	1002.3	–	1001.7	–	1006.1	–	1009.3	–	1001.7	–
GF	1001.5	–	1000.8	–	1005.8	–	1008.8	–	1000.8	–
LW1	1002.3	1002.9	1001.8	995.5	1006.1	984.9	1009.3	1009.2	1001.8	984.9
LW2	1002.7	1004.2	1001.8	996.5	1006.0	985.7	1009.0	1010.5	1001.8	985.7
PK1	–	1004.5	–	998.0	–	986.2	–	1010.5	–	986.2
PK2	1002.4	–	1000.7	–	1005.6	–	1009.1	–	1000.7	–
PK3	1002.6	1005.9	1001.0	999.1	1006.0	987.4	1009.4	1011.7	1001.0	987.4
SJ2	1001.1	1004.5	1000.6	996.7	1004.9	986.9	1008.0	1010.7	1000.6	986.9

Explanation: „–„ - denotes lack of data

The diurnal course of averaged pressure in the analysed seasons hardly changes at any of the measurement points (Fig. 2.9). The diurnal ranges of the averaged courses do not exceed 0.5 hPa, yet two maximum values (at midday hours and at 'night') and two minimum values (in the morning and in the evening) can be identified. A different diurnal course of pressure can be observed only at GF, where only one maximum (during 'night' hours) and one minimum (in the remaining hours) can be identified (Fig. 2.9D). Averaged seasonal courses of atmospheric pressure in other areas outside the Forlandsundet are also very stable, however the distribution of their maximum and minimum values is different.

As for Hornsund, Araźny (2008) reports that, for example, in the ten years between 1991 and 2000 the maximum values occurred at 12:00-15:00 UTC, whereas the minimum values were at 03:00-06:00 UTC. At Calypsobyen (Maria Curie-Skłodowska University station) and at the Ebby Valley (Adam Mickiewicz University station), in the summer season of 2005 the minimum was observed in the morning hours, whereas in the rest of the day the atmospheric pressure values were higher, yet remained at the same level (*Cf*. Fig. 3 in Przybylak et al. 2006). On the other hand, in that year at the Base Station (KH) the diurnal course of atmospheric pressure was similar to the one shown in Figure 2.9A.

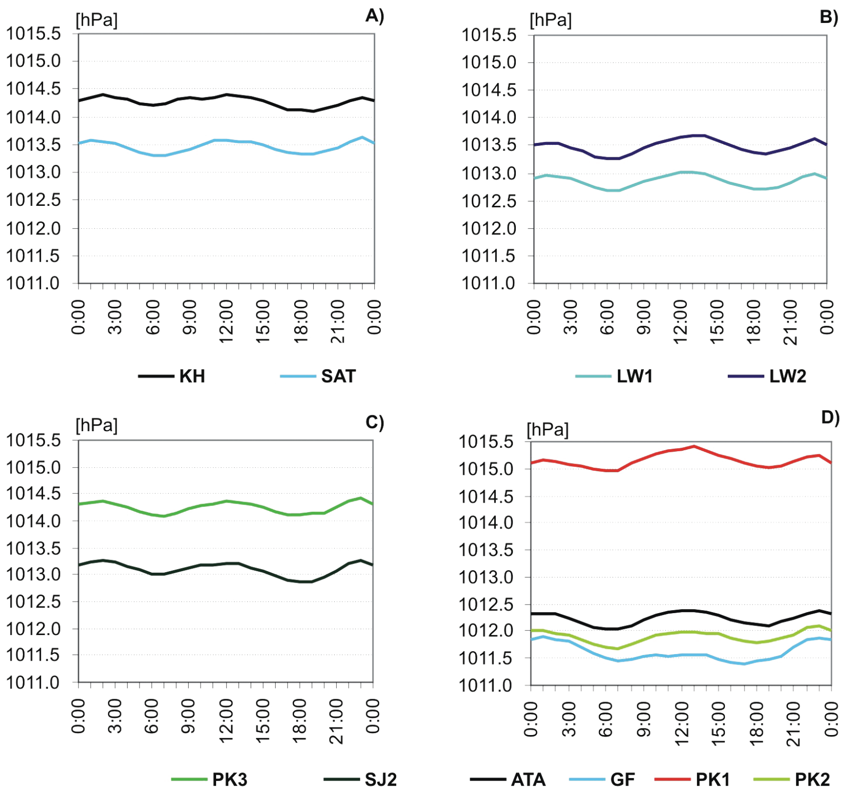

Figure 2.9. Average diurnal course of atmospheric pressure [hPa] reduced to sea level in the area of the Forlandsundet: A-C –from summer seasons of 2010 and 2011 and D – from selected summer seasons at ATA (2010), GF (2010), PK1 (2011), and PK2 (2010)

2.3. Wind

2.3.1. Introduction

The area of the Forlandsundet is small enough to display a homogeneous set of circulation conditions in the synoptic scale. These have a key role in determining the occurrence and range of changes in the direction and speed of wind. In the case of the lowlands there should not be any significant variability in the wind parameters, which should be consistent with the prevalent atmospheric circulation. However, the mountainous area of Forlandsundet has very diverse surface features with big height differences. Thus, a 'working' presumption can be made that the wind there must be considerably varied in terms of direction and speed, i.e. it should be considerably affected by the local conditions.

So far, such correlations have been observed in Svalbard (including Spitsbergen) mainly on the basis of data obtained from permanent Norwegian meteorological stations or temporary stations operated mostly in the summertime during various scientific expeditions (e.g. Steffensen 1969, 1982; Leszkiewicz 1977; Wójcik 1982; Wójcik and Marciniak 1983; Marciniak and Przybylak 1983; Hanssen-Bauer et al. 1990; Wójcik and Kejna 1991; Wójcik and Przybylak 1991; Kejna and Dzieniszewski 1993; Marciniak et al. 1993; Førland et al. 1997; Araźny 1999, 2002; Kejna 2002; Przybylak and Szczeblewska 2002; Przybylak et al. 2006; Kejna and Maszewski 2007a; Przybylak and Araźny 2007; Przybylak et al. 2007a; Araźny 2008; Maszewski and Wyszyński 2008). Yet in either case the stations were always situated in the tundra, near the coast.

The literature regarding the occurrence and characteristics of local winds in Spitsbergen is also quite abundant. For the area of the Kaffiøyra, the issues were addressed by, for example, Wójcik and Przybylak (1985) and Kejna (1989 a, b). Similar studies for the area of Hornsund were presented by Pereyma (1983) and Pereyma and Piasecki (1984).

On the other hand, there are very few studies dealing with the inland areas of Spitsbergen, the mountains or the glaciers. As for the area of the Kaffiøyra, the first attempt to change this was made in the summer of 2005 when two Davis automatic weather stations were installed at the Waldemar Glacier – at its front (ATA) and on the firn field (LW2) – to record a number of parameters, including wind speed and direction (Przybylak et al. 2007b). In the summer of 2006 another station was sited right at the front of the glacier (LW1) (Kejna and Maszewski 2007b), where measurements were taken every summer until 2011. As part of the AWAKE project, in the summer season of 2010 the measurements were substantially expanded to include 5 more sites (SAT, PK1, PK3, SJ2 and GF) situated in different places, characterised by dissimilar local conditions (cf. Section 1.2). This is the most developed network of measurement points employed to record the meteorological element on Spitsbergen.

2.3.2. Wind direction

Wind direction is particularly prone to changes related to the orography and topography of the terrain. The results of measurements performed in the summer seasons of 2010 and 2011 (i.e. from 21 July to 31 August), broken down into the 16 points, have been collected in Table 2.8 and Figure 2.10. Looking at the information shown there, considerable diversity in the frequency of occurrence of individual wind directions in the summer is evident.

Table 2.8. Relative frequency of occurrence (%) of wind directions in the Forlandsundet area in the summers of 2010 and 2011

Direction	KH		SAT		ATA		LW1		LW2		PK3		SJ2		GF	PK1
	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011
N	5.4	4.0	1.1	7.1	0.0	0.7	0.6	6.5	3.3	1.8	7.6	21.0	3.3	1.0	2.8	2.0
NNE	1.7	3.8	1.0	7.8	0.5	0.4	2.1	32.5	3.7	1.6	9.2	13.5	3.0	1.1	1.0	6.8
NE	1.6	3.1	0.4	3.1	1.8	1.6	11.0	15.5	3.8	2.4	3.0	6.2	14.1	10.4	1.1	4.2
ENE	0.7	0.8	0.4	6.6	12.5	12.3	20.3	6.8	5.0	4.0	1.3	2.7	20.1	24.1	1.4	0.6
E	0.6	0.3	3.0	7.6	17.0	24.9	13.1	3.7	9.1	9.2	0.6	0.5	7.2	15.2	3.6	1.2
ESE	1.0	1.1	22.3	10.4	12.0	13.8	6.0	5.2	13.4	15.0	0.5	0.4	2.9	3.0	28.0	11.7
SE	13.1	15.2	12.2	6.4	5.3	9.9	3.4	1.6	4.1	3.3	1.0	10.2	1.9	1.0	11.0	9.2
SSE	17.6	22.8	6.6	5.1	3.0	3.9	2.0	1.3	2.0	4.0	8.8	3.2	3.3	1.2	2.7	10.6
S	10.4	12.4	2.0	2.6	2.9	2.4	1.6	1.6	5.8	3.6	24.1	6.0	2.4	2.3	1.1	12.0
SSW	2.2	1.8	0.7	4.5	3.8	1.5	2.4	5.1	16.8	4.8	13.0	13.6	1.7	1.4	2.2	10.0
SW	2.6	0.9	1.2	5.0	3.6	2.1	3.8	5.3	10.5	14.9	7.0	6.8	4.2	2.2	2.3	5.7
WSW	2.1	0.8	1.5	3.8	3.1	1.9	12.6	1.9	5.0	9.6	1.8	2.8	13.2	5.7	1.4	2.3
W	1.6	2.4	2.2	5.3	5.4	2.7	6.5	1.6	1.5	4.3	1.9	1.5	13.1	17.4	3.5	4.0
WNW	2.3	3.0	5.8	6.2	19.4	5.0	4.0	0.8	1.0	1.3	2.3	0.6	2.4	5.8	17.2	3.1
NW	12.0	10.3	33.1	14.5	3.6	8.8	2.3	1.1	0.7	1.0	6.7	0.5	1.0	0.1	13.3	3.4
NNW	22.2	14.0	5.9	3.7	0.2	1.0	1.2	1.1	1.4	1.3	8.9	7.2	0.8	0.1	0.6	5.0
C	2.9	3.4	0.7	0.5	6.0	7.0	7.1	8.4	12.9	17.9	2.2	3.3	5.4	8.0	6.8	8.2

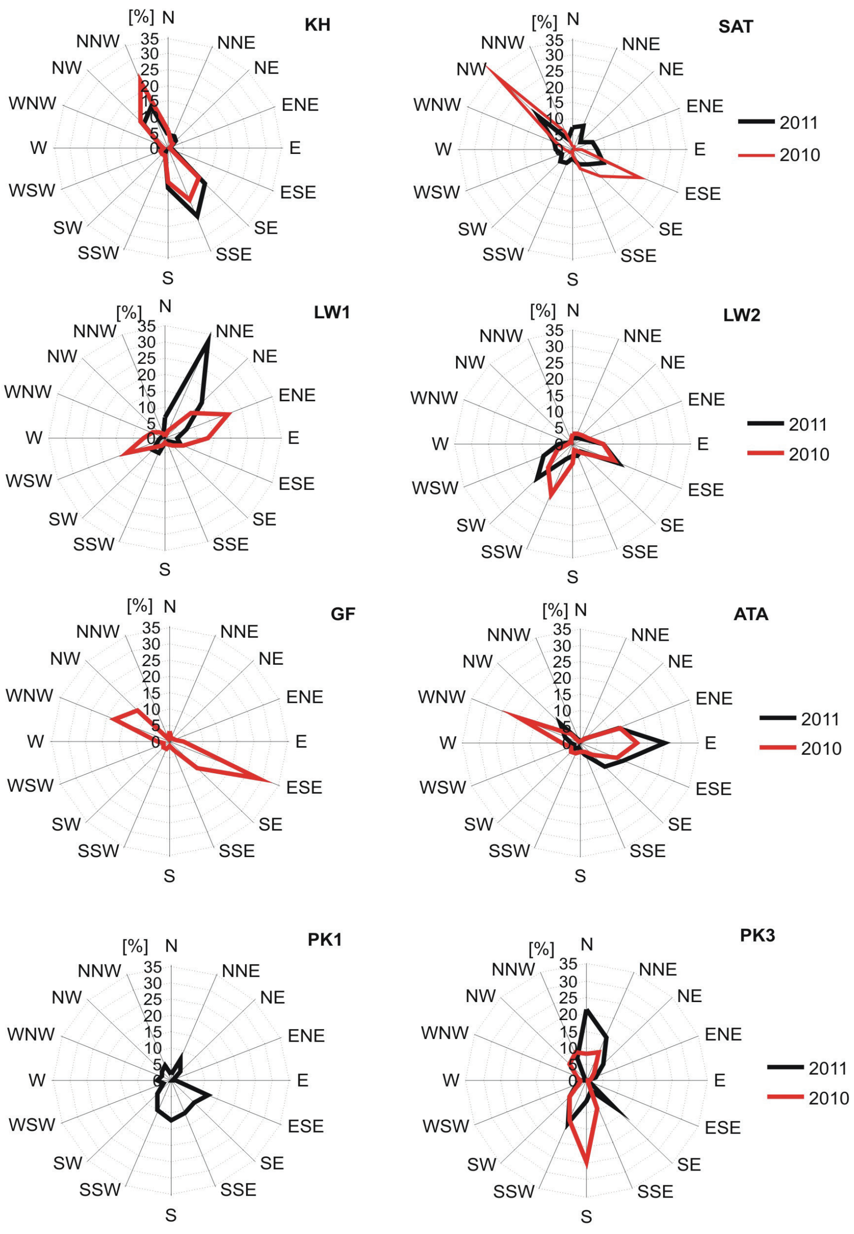

Figure 2.10. Frequency of wind directions in the Forlandsundet area in the summers of 2010 and 2011

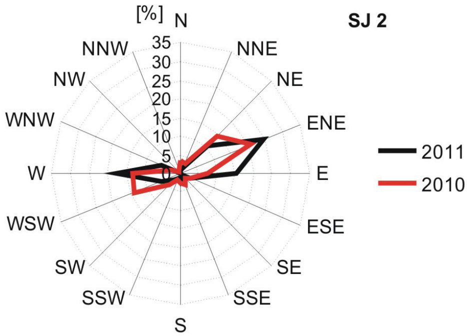

Figure 2.10. cont.

A certain similarity in wind roses can only be seen comparing SAT and GF with ATA and SJ2 sites. All the other patterns are significantly different, which means that the influence of local conditions on the direction of wind is a decisive factor in all but some cases. For example, the site located on the firn field of the Waldemar Glacier (LW2), surrounded by mountain ranges, displays the greatest frequency of influxes of air masses from upper part of within the field (katabatic wind) and from the SW and the SSW, i.e. the directions in which the glacial tongue extends. The LW1 site, situated at the very front of the Waldemar Glacier, is clearly affected by katabatic winds. On the other hand, the winds have a smaller influence on the ATA site, which is only about 200 m away from the glacier's front, but at the same time 7 m higher than LW1. Heavy air carried by the katabatic wind, having descended the glacier, must be turning south onto the lower terrain, where the Waldemar River has its source. Similarly, the wind directions in the area of measurements (PK1 and PK3) on Prins Karls Forland clearly follow the course of river valleys cutting across the island from the south to the north. The wind directions on St. Jonsfjorden (SJ2) are fully consistent with its axis (Fig. 2.10).

With such an abundance of source data on hand, it was decided to determine to what extent the wind directions in the analysed areas refer to the general atmospheric circulation described in Section 2.1. For that purpose, the frequency of wind directions was totalled up for the following three sectors of air mass influxes: NW+N+NE, E+SE and S+SW+W, using combined types of circulation. Figure 2.11 shows a comparison of the frequency of occurrence of air mass influxes in the free atmosphere from the three sectors and their frequency of occurrence near the ground surface. An analysis of the data leads to the conclusion that the results obtained for the east part of Prins Karls Forland (PK3) and the Kaffiøyra are the most compatible with the general circulation of the air (the differences are generally smaller than 10%). The local conditions affect the actual atmospheric circulation the most at ATA and LW2. It is also noteworthy that the general direction of the air mass influx from the S+SW+W sector is the least affected by the local conditions. Apparently, the biggest discrepancy between the directions of the air mass influx in the free atmosphere and at the ground occur with the circulation from the east sector (E+SE) (Fig. 2.11). Also, the influx of air masses from the north sector (NW+N+NE) coincides with substantial influence of the local conditions on the observed wind directions.

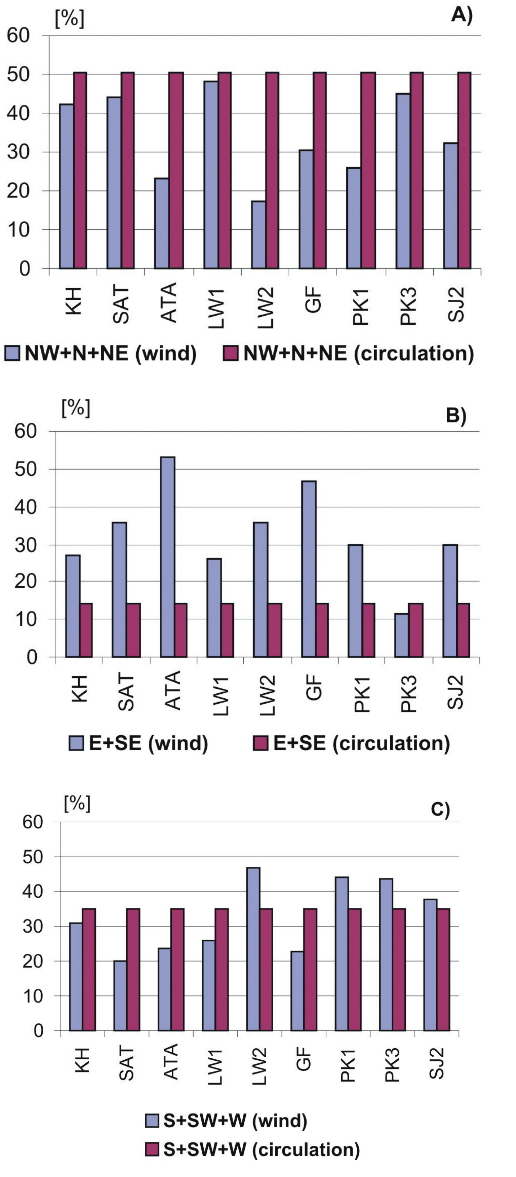

Figure 2.11. Average relative frequency of occurrence (%) of the following circulation types: A) NW+N+NE, B) E+SE, C) S+SW+W and wind directions: NW+N+NE, E+SE, S+SW+W in the area of Forlandsundet in the summers of 2010 and 2011 (GF and PK1 sites – 2010 data only)

2.3.3. Wind speed

The friction occurring between the air masses and the swept surface decreases their speed – the rougher the surface the bigger the decrease. Anemological conditions are also largely influenced by the positioning of mountain ranges in relation to the influx of the prevalent air masses. In the area of the Forlandsundet the relief is varied and the highest mountains are over 1000 m a.s.l., therefore the wind speed there varies heavily, as well, in terms of the average values (Tab. 2.9) and the maximum values (Tab. 2.10).

Table 2.9. Average wind speed (ms^{-1}) in the area of the Forlandsundet in the summers of 2010 and 2011

Sites	21–31 Jul		01–10 Aug		11–20 Aug		21–31 Aug		21 Jul–31 Aug	
	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011
KH	5.8	5.3	6.1	6.0	5.8	4.1	3.5	2.5	5.3	4.5
SAT	5.6	5.4	5.9	5.9	6.0	4.2	3.7	2.6	5.3	4.5
ATA	2.0	2.8	2.3	2.8	3.0	2.4	1.5	1.0	2.2	2.3
GF	5.6	–	5.3	–	6.9	–	2.9	–	5.1	–
LW1	1.8	1.7	1.6	2.2	2.6	2.1	1.3	1.0	1.8	1.7
LW2	1.9	1.7	1.8	2.3	1.8	2.5	1.1	0.9	1.6	1.8
PK1	–	3.5	–	5.1	–	3.5	–	1.5	–	3.4
PK3	3.3	3.5	3.9	4.7	3.5	3.8	1.7	1.8	3.1	3.4
SJ2	1.6	2.0	2.0	1.9	1.9	2.9	1.0	0.7	1.6	1.9

Explanation: „–„ - denotes lack of data

In the analysed summer seasons, the highest average wind speed values (5.3 ms^{-1} in 2010 and 4.5 ms^{-1} in 2011) were recorded at the Kaffiøyra site (KH) and on the Sarstangen Peninsula (SAT). These two areas are mostly open terrain. A slightly lower wind speed value (5.1 ms^{-1} in the summer of 2010) was recorded on the hilltop of Mt. Gråfjellet (GH), situated at 345 m a.s.l. This value, in theory, should be the closest to the wind speed in the free atmosphere. According to the authors of the relevant publications referred to in the Introduction above, the wind speed at KH was increased by the tunnelling effect observed along the Forlandsundet. The effect is undoubtedly encountered on the Sarstangen (SAT). Considering the fact that the PK3 site (located on the east side of Prins Karls Forland) shows the smallest disturbance of inflowing air masses in relation to the general circulation and that is situated in a shielded bay, surrounded by mountains, one could reduce the influence of the tunnelling effect on the measured wind speeds and claim that perhaps these results are best qualified to represent the dynamic conditions of the analysed area. If this were true, the tunnelling effect could be estimated at 1-2 ms^{-1}. At most of the rest of the sites, the recorded wind speeds are much lower, being particularly low on the Waldemar Glacier and in its immediate vicinity (LW1 and LW2) and at St. Jonsfjorden (SJ2) (Tab. 2.9 and Fig. 2.12).

An analysis of the 10-day values in both summer seasons (Tab. 2.9 and Fig. 2.12) shows that the highest average wind speed was observed in the first ten days of August, and the lowest in the last eleven days of the month. Nevertheless, the highest value of the average wind speed of all the ten-day periods (6.9 ms^{-1}) fell on the second ten days of August 2010 at the GF site. The lowest value (0.7 ms^{-1}) was observed at SJ2 in the last eleven days of August 2011.

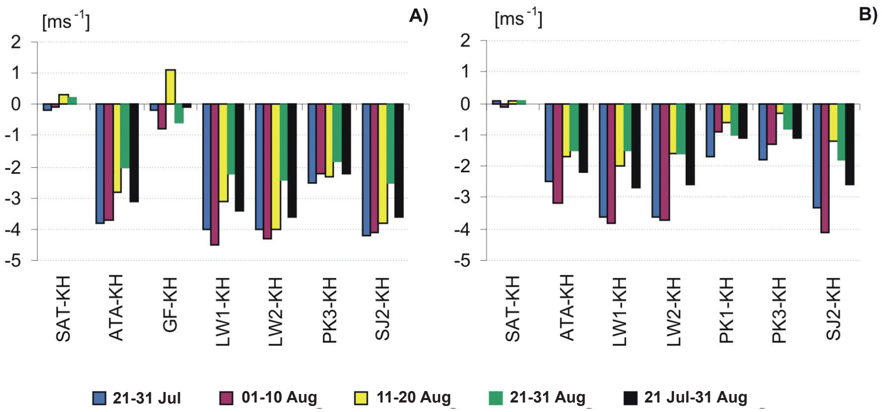

Figure 2.12. Differences in wind speed (ms^{-1}) between the Base Station (KH) and the other measurement points in the area of the Forlandsundet in the summers of 2010 (A) and 2011 (B)

In this article, the wind speed divisions proposed by Bartnicki (1930) have been slightly modified. The scale enables a verbal description of the wind speed and provides a general characteristic of anemological conditions prevailing at the relevant stations:

0.0 ms^{-1}	calm
0.1 – 2.0 ms^{-1}	very light
2.1 – 5.0 ms^{-1}	light
5.1 – 10.0 ms^{-1}	moderate
10.1 – 15.0 ms^{-1}	strong
>15.0 ms^{-1}	very strong

At a majority of the sites, although primarily on the Waldemar Glacier and its forefield (LW1, LW2) and at SJ2, in the summer seasons of 2010 and 2011, very light and light winds occurred the most often (Fig. 2.13). The predominance of very light winds was particularly noticeable in the summer of 2010, when this kind of wind was observed at SJ2 and LW1 65.3% and 61.0% of the time, respectively. Slightly faster winds were recorded at the sites located near the Forlandsundet (KH, SAT) and on the ridge of Mt. Gråfjellet (GF), ranging from light to moderate. Strong winds seldom occurred at GF (9.4%), KH (9.1%) and SAT (7.5%), mostly in the summer of 2010, and were not observed at SJ2 at all (Fig. 2.13). In the same season, very strong winds were recorded at KH and GF with a frequency of 0.6% and 4.4%, respectively.

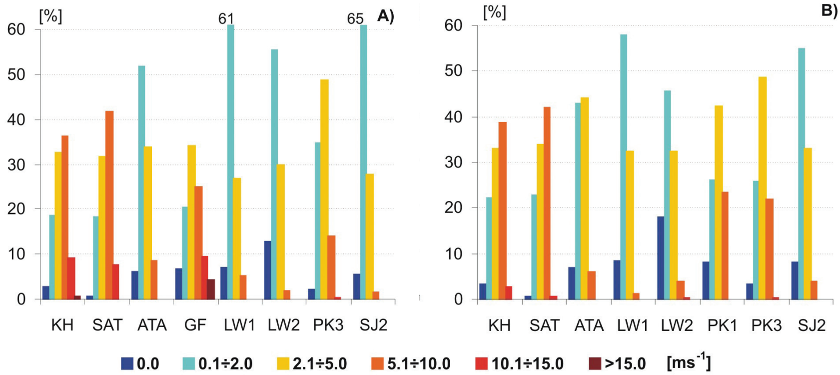

Figure 2.13. Relative frequency of occurrence [%] of wind speeds [ms^{-1}] in the division proposed by Bartnicki (1930, modified) in the area of the Forlandsundet in the summers of 2010 (A) and 2011 (B).

Only at the GF site did all the wind speed divisions occur. The condition of calm was the most frequent at LW2, both in the summer of 2010 (12.9%) and in 2011 (17.9%). It was the least frequent at the stations situated close to the Forlandsundet (KH, SAT and PK3) – Figure 2.13.

The maximum recorded wind speeds in the area of the Forlandsundet were generally higher than 10 ms^{-1} in all periods, often exceeding 20 ms^{-1} (Tab. 2.10).

Table 2.10. Maximum wind speeds (ms^{-1}) in the area of the Forlandsundet in the summers of 2010 and 2011

Sites	21–31 Jul		01–10 Aug		11–20 Aug		21–31 Aug		21 Jul–31 Aug	
	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011
KH	13.9	13.4	21.9	16.1	18.8	14.8	12.5	14.8	21.9	16.1
SAT	13.4	14.3	18.8	15.2	18.3	13.9	11.6	14.8	18.8	15.2
ATA	10.3	14.3	19.7	14.8	17.4	16.1	11.2	11.2	19.7	16.1
GF	15.2	–	23.7	–	27.7	–	14.8	–	27.7	–
LW1	10.7	10.3	17.4	14.3	20.1	14.3	8.9	12.1	20.1	14.3
LW2	13.4	10.7	19.7	27.7	14.3	14.8	9.4	14.8	19.7	27.7
PK1	–	11.2	–	17.0	–	17.0	–	10.3	–	17.0
PK3	15.6	11.6	17.9	22.8	25.5	13.0	12.1	13	25.5	22.8
SJ2	8.9	8.9	14.3	13.0	11.2	13.9	7.2	11.6	14.3	13.9

Explanation: „–„ - denotes lack of data

In the summer season of 2010, the highest absolute wind speed value (27.7 ms^{-1}) was recorded on Mt. Gråfjellet on 16 August. In 2011, the highest wind speed of the same absolute value was measured on the firn field of the Waldemar Glacier on 8 August, which was quite surprising, as the average wind speeds recorded at that site were usually some of the lowest. The irregularity of the phenomenon is further emphasised by the fact that it was the only point where the maximum speed of wind was higher at that time than in the summer of 2010 and by as much as 8 ms^{-1} (Tab. 2.10). What could have caused the strong anomaly? In order to find an explanation, a detailed analysis was performed of the wind conditions, as well as of the temperature and humidity in the area of the Waldemar Glacier and at the Kaffiøyra, concerning the time before and after the maximum wind speed was recorded at LW2 (Fig. 2.14).

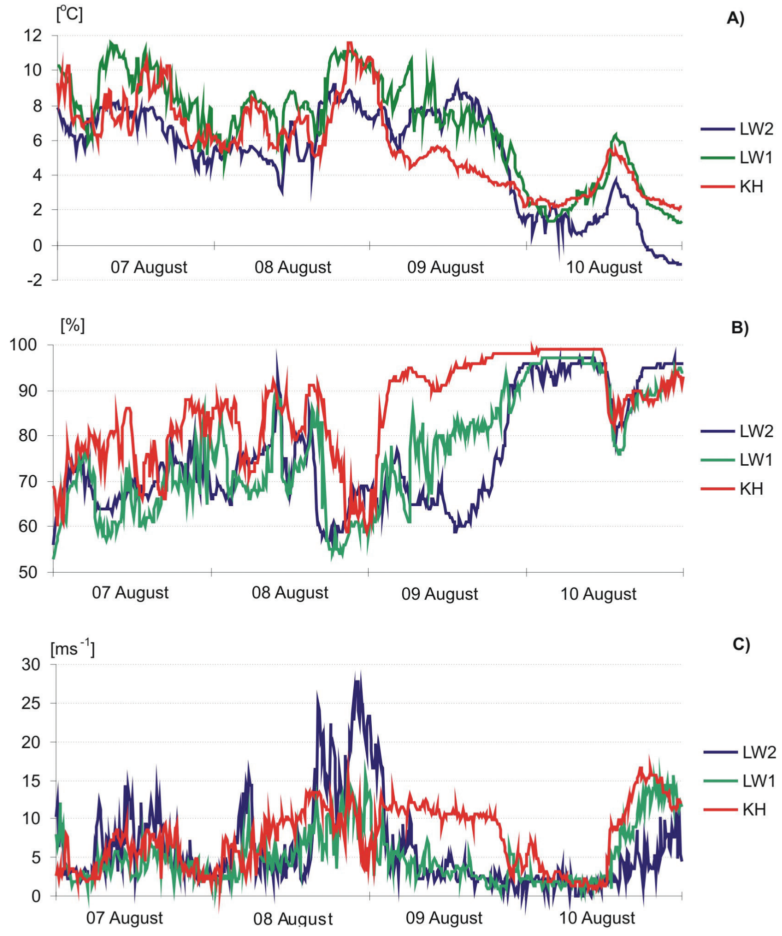

Figure 2.14. The temperature of air (A), the relative humidity (B) and the maximum speed of wind (C) at the LW2, LW1 and KH sites, 7-10 August 2011

The analysis proved beyond doubt that the immediate cause of the high wind was a local foehnic wind, as evidenced by strong rises in the maximum temperature (by 4-5°C) and a drop of relative air humidity (by approx. 30%), which was also recorded at LW1 and KH. The foehnic wind that brought the high wind speed values lasted about 12 hours only; from 3:00 pm on 8 August until 3:00 am on 9 August. Such evidently higher maximum wind speeds in the time frame given above as compared with preceding and following periods (Fig. 2.14) were also recorded at LW1, but not at the Kaffiøyra.

The wind speed in the area of our interest follows a clearly diurnal cycle. Its maximum values at all sites occurred in the afternoon, whereas the minimum values were recorded during 'night' hours (Fig. 2.15). The changes usually ranged from 0.5 to 1.5 ms^{-1}. The range was the greatest at the mountain site of GF (approx. 2.5 ms^{-1}), and the smallest on the firn field of the Waldemar Glacier (<0.5 ms^{-1}).

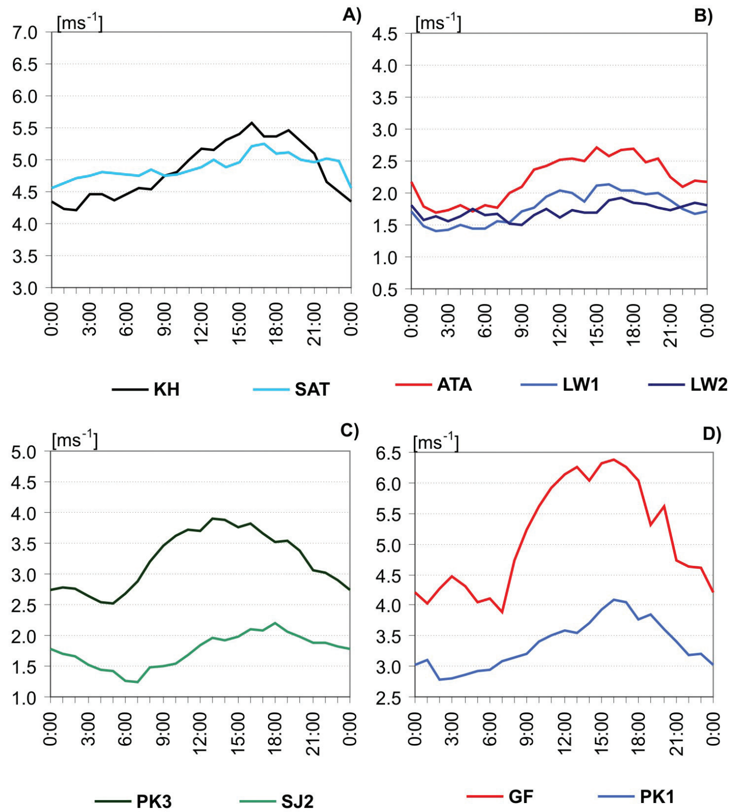

Figure 2.15. Average diurnal course of wind speed (ms^{-1}) *in the area of the Forlandsundet: in the summer seasons of 2010 and 2011 (A-C), and in selected summer seasons (D) at: GF (2010) and PK1 (2011)*

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