13. STATES OF THE WEATHER AND WEATHER SEASONALITY

13.1. Methods

Comprehensive climatology defines the climate as the multiannual weather regime, understood as the entirety of weather conditions, as well as their characteristic sequence. Application of the methods of comprehensive climatology allows investigation of the occurrence of specific states of the atmosphere and thus of specific weather conditions. In such a conception, in a simplified way the weather is described by the simultaneous state of specific values of meteorological parameters. Such an approach, besides its clearly cognitive aspects, allows determination of the influence of the climate on the behaviour of all processes operating in the geographical environment. The theoretical framework of comprehensive climatology and description of its methods are known in Polish literature first of all from papers of Woś (1968, 1970, 1995), Marsz (1987, 1992) and Olszewski (1967).

When determining the weather regime, the basic unit of data integration is a specific day characterized by the date and a few averaged and extreme values of the meteorological parameters recorded during it. In the present work, as in former papers of the author (among others, Ferdynus 1997, 2000) the meteorological parameters which were taken into account were (Table 13.1):

– thermal state of the air, defined by the mean diurnal air temperature (t_a) and diurnal extreme values (t_{max} , t_{min}) – below briefly marked T,
– cloudiness defined by the mean diurnal cloudiness, marked N,
– atmospheric precipitation (occurrence or lack of precipitation during a day), marked R,
– wind defined by the mean diurnal wind velocity (V_a) and its maximum velocity during a day, (V_{max}), short markings V.

Each day is marked with digital symbols in the following way:

– the first number records the thermal conditions (9 intervals),
– the second number describes mean cloudiness of the sky (3 intervals),
– the third number – the occurrence or lack of precipitation (2 intervals),
– the final number – the wind velocity (9 intervals).

In this system each day is described by four numbers – TNRV, and number of potential weather types in such a classification totals 486 (9 · 3 · 2 · 9). In reality, the number of states of weather recorded will be smaller because in some cases there are internal contradictions, for example, lack of cloudiness is recorded together with concurrent atmospheric precipitation. After the assignment of each day to a specific state of the weather, days were grouped according to the periods in which they occurred, and frequency of the taxonomic units thus obtained (groups, subgroups, classes and weather types) was assessed.

The basic classification unit is the ***type*** of weather, grouping all days uniformly in relation to their temperature, cloudiness, precipitation and wind velocity. The ***class*** of weather is a unit characterized by identical conditions of three of the parameters – cloudiness, precipitation and wind velocity. Highest in this hierarchical structure is the ***group*** of weather conditions, aggregating in it all days characterized by the same temperature. ***Subgroup*** of weather in which all days are characterized by the same temperature and cloudiness serves as an auxiliary unit of the classification.

Table 13.1. Classification of weather.

Symbol		Ranges	Name of weather
	9	10.0° < t_a < 19.9°C, t_{min} ≥ 0°C	very warm
	8	5.0° < t_a < 9.9°C, t_{min} ≥ 0°C	warm
	7	0.0° < t_a < 4.9°C, t_{min} ≥ 0°C	moderately warm
	6	t_{min} < 0° and t_{max} > 0°	transitional, freezing – thawing
	5	–0.0° < t_a < –4.9°C, t_{min} < 0°C	moderately cold, frosty
	4	–5.0° < t_a < –9.9°C, t_{min} < 0°C	cold, frosty
	3	–10.0° < t_a < –19.9°C, t_{min} < 0°C	very cold, frosty
	2	–20.0° < t_a < –29.9°C, t_{min} < 0°C	exceptionally frosty
	1	–30.0° < t_a < –39.9°C, t_{min} < 0°C	extremely frosty
N	1	0.0 < N < 2.0	blue sky (sunny)
	2	2.1 < N < 5.9	partly cloudy
	3	6.0 < N < 8.0	cloudy
R	0	RR = 00 mm	no precipitation
	1	RR > 00 mm	precipitation
V	0	0.0 < V_a < 1.5 m/s	calm or light air
	1	1.6 < V_a < 7.9 m/s, V_{max} < 11 m/s	breeze
	2	1.6 < V_a < 7.9 m/s, V_{max} ≥ 11 m/s	breeze with periods of strong wind
	3	8.0 < V_a < 16.9 m/s, V_{max} < 17 m/s	strong wind
	4	8.0 < V_a < 16.9 m/s, V_{max} ≥ 17 m/s	strong wind with periods of gale force
	5	8.0 < V_a < 16.9 m/s, V_{max} ≥ 30 m/s	strong wind with periods of storm
	6	17.0 < V_a < 29.9 m/s, V_{max} < 30 m/s	gale
	7	17.0 < V_a < 29.9 m/s, V_{max} ≥ 30 m/s	gale with periods of hurricane conditions
	8	V_a ≥ 30 m/s	hurricane winds

The present work is a summary of research by the author and published earlier (Ferdynus 2004, 2005, 2006, 2007, 2008 a, 2008 b). These papers were based on analysis of results of meteorological measurements and observations at the Polish Polar Station at Hornsund, 1980–2009. Data are standard records of periodic observations. The set is not continuous, however, because data from the expeditions in 1981/1982 (from July 1981 to June 1982) and from July and August 1982 are lacking.

13.2. Structure of states of the weather

13.2.1. Weather groups and subgroups

Weather groups aggregate features of the different sequences of air temperature, and subgroups – of temperature plus cloudiness. In Table 13.2, the frequency of groups and subgroups of the weather observed at Hornsund from 1980 to 2009 is presented. Two groups of weather exceeded 20% in frequency: moderately warm weather (23.0%) and transitional, freezing-thawing

(21.5%). These two groups thus occur over 40% of the time (on average over 146 days in a year). Weather groupings that reached over 10% frequency are the very cold (19.2%), cold (16.2%) and moderately cold (12.0%) weathers. Next were warm weather (5.4%) and exceptionally frosty weather (3.7%). Weather from the extreme groups should be considered accessory because it is so infrequent, amounting respectively to 0.03% (extremely frosty) and 0.01% (exceptionally warm). A frequency value of 0.01% means that this group was observed just once in 27 years of the record.

Table 13.2. Frequency of occurrence (%) of groups and subgroups of weather at Hornsund, in 1980–2009.

No	Groups	Subgroups	Weather groups		Weather subgroups	
			frequency	total	frequency	total
1	1NRW	11RW	0.03	0.03	0.03	0.03
2	2NRW	21RW	3.73	3.77	1.97	2.00
		22RW			1.41	3.41
		23RW			0.35	3.76
3	3NRW	31RW	19.20	22.96	5.05	8.82
		32RW			9.28	18.09
		33RW			4.87	22.96
4	4NRW	41RW	16.20	39.17	1.34	24.30
		42RW			6.65	30.95
		43RW			8.21	39.16
5	5NRW	51RW	12.00	51.16	0.26	39.43
		52RW			3.46	42.88
		53RW			8.28	51.16
6	6NRW	61RW	21.45	72.62	0.37	51.53
		62RW			4.32	55.85
		63RW			16.76	72.61
7	7NRW	71RW	22.95	94.57	0.33	72.95
		72RW			3.48	76.42
		73RW			18.14	94.56
8	8NRW	81RW	5.43	99.99	0.24	94.80
		82RW			1.42	96.22
		83RW			3.77	99.99
9	9NRW	92RW	0.01	100.00	0.01	100.00

The frequency of weather characterized by a maximum diurnal air temperature below 0˚C amounts cumulatively 51.6%, on average more than half of the year. Weather characterized by minimum air temperature over 0˚C encompasses just over one quarter of the year (27.4%). Weather with air temperatures passing through 0˚C occurs in the remaining part of the year, over 20%. Weather characterized by mean diurnal air temperatures between +5 and –5˚C (5NRV, 6NRV and 7NRV) encompasses over half of the average year.

The number of distinct weather groups encountered in consecutive decades (ten day spells) of the year ranges (Fig. 13.1) from three (in the first and third decade of June) to seven (in the second and third decade of January and the first decade of March). The greater number of weather groups demonstrates the greater variability of weather conditions that are observed during the autumn-winter period. This may be connected with the vigorous cyclonic activity occurring in the region of Spitsbergen.

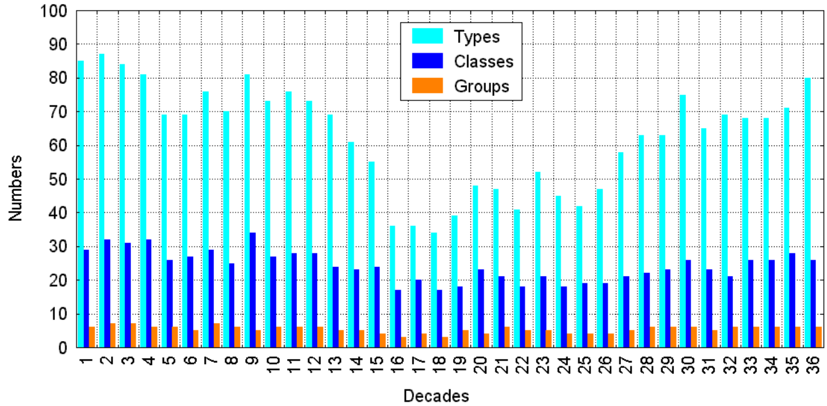

Fig.13.1. Number of groups, classes and weather types recorded at Hornsund in consecutive decades of the year.

Analysing Table 13.2 one may notice that in nearly all weather groups those with the occurrence of cloudy or overcast skies are more numerous. This is not true of the extremes, however; in the exceptionally frosty and very cold groups cloudless weather or partly cloudy weather dominates. In the exceptionally frosty group cloudless weather dominates (over 50%), and among the very cold or frosty group partly cloudy states dominate (nearly 50%). With seasonal increase in the temperature, the percentage of weather with cloudy or overcast skies increases. In the partly cloudy and cloudless sub-groups, frequency changes from over 82% in the moderately warm group, through over 70% among the transitional, freezing-thawing and moderately cold weathers to over 50% in the group of cold weathers.

13.2.2. Weather classes

A weather class includes all days that are homogeneous in terms of cloudiness, precipitation and wind velocity, regardless of the air temperature. Potentially there may be 54 weather classes with this classification, but in reality only 39 classes were observed (Table 13.3), ranging in frequency from 21.86% to 0.01%.

The frequency distribution of the weather classes demonstrates the substantial uniformity (monotony) of weather conditions – just three classes encompass nearly half of the year (47.4%). These are weather with cloudy or partly cloudy conditions, with precipitation or without it, and a breeze (311, 201 and 301). Nearly one quarter of the year is characterized by cloudy or overcast weather with breeze, with or without precipitation. Next in frequency is cloudy or overcast weather with precipitation and with a strong wind (313, 6.3%). In the fifth place is cloudless weather, without precipitation and with a breeze (101, 5.7%), and sixth is partly cloudy, with precipitation and a breeze (211, 4.6%).

Weather with a cloudy or overcast skies is observed next, namely Classes 312 (with precipitation and a breeze, with periods of a strong wind) and 303 (without precipitation and with a strong wind), having frequencies of 4.5% and 3.8%, respectively. These classes, together with those mentioned earlier, were observed at Hornsund for nearly 260 days in an average year (~70%).

Table 13.3. Frequency of occurrence [%] of weather classes at Hornsund, 1980–2009.

No	Class of weather	Frequency	Total	No	Class of weather	Frequency	Total
1	311	21.81	21.81	21	212	1.03	96.41
2	201	13.39	35.20	22	210	0.79	97.20
3	301	12.23	47.43	23	102	0.54	97.74
4	313	6.28	53.70	24	111	0.48	98.23
5	101	5.72	59.43	25	214	0.37	98.60
6	211	4.57	64.00	26	104	0.26	98.87
7	312	4.46	68.46	27	316	0.26	99.13
8	303	3.77	72.22	28	305	0.17	99.30
9	203	3.29	75.51	29	110	0.14	99.44
10	314	3.01	78.52	30	306	0.12	99.56
11	310	2.58	81.10	31	315	0.10	99.66
12	200	2.52	83.62	32	307	0.09	99.75
13	300	2.22	85.84	33	206	0.07	99.81
14	202	1.83	87.67	34	112	0.04	99.86
15	302	1.64	89.31	35	113	0.04	99.90
16	103	1.46	90.77	36	205	0.04	99.94
17	304	1.33	92.11	37	317	0.03	99.98
18	100	1.09	93.20	38	106	0.01	99.99
19	204	1.09	94.29	39	215	0.01	100.00
20	213	1.09	95.38				

These six classes of weather are clearly dominant, form the basic framework of weather structure and determine our subjectively experienced images of weather at Hornsund. This is weather with cloudy or overcast skies, with or without precipitation, and with a breeze as a rule, although there may also be strong winds. These monotonous weather conditions should be understood to reflect the strongly oceanic character of western Spitsbergen.

Cloudless weather occurred during nearly 10% of the investigated period (nearly one month), and weather with a partly cloudy sky occurs at Hornsund for nearly three months on average. Analyzing the distribution of frequency of weather with measurable wind, undoubtedly the breezy weather classes dominate (58.6%). Weather with strong winds is nearly four times less frequent (16.6%), those with a breeze and occasional spells of strong wind (9.2%), and windless weather (9.0%) are six times smaller. Comparing the frequency of weather classes with precipitation and those without, the latter has an insignificantly greater frequency? (52.6%).

In the research period there was no occurrence of the following possible classes of weather: 105, 107, 108, 114, 115, 116, 118, 207, 208, 216, 217, 308 and 318. These are those characterized by high winds regardless of precipitation and cloudiness conditions. During the cloudless and partly cloudy conditions, significant winds were observed very seldom or nearly not at all. In turn windy weather was met very often when the sky was cloudy or overcast (only those with hurricane winds were not encountered). The lack of weather classes 114, 115, 116 and 118 is due to an internal discrepancy in the classification, which is lack of cloud with concurrent atmospheric precipitation.

The number of classes of weather occurring in the consecutive decades of the year in the Hornsund record (Fig.13.1) ranges from 17 in the first decade of June to 34 in the third decade of March. The annual mean is 24, and the standard deviation is 4.50. From the first decade of April to the second decade of November the number of classes in decades is smaller than 24 (excluding the third decade of October). One may state that the warmer season is characterized by greater stability of weather conditions than the winter months. This fact, as in the case of reduced frequency of weather groups in the summer period, should be associated with the lessening of the cyclonic activity. This in turn is caused by the reduction of the thermal contrasts between the sea surface and the atmosphere.

13.2.3. Types of weather

The *type* of weather is the unit which contains all weather characterized by relative homogeneity of thermal conditions, cloudiness, precipitation and wind. This is the lowest taxonomic level in the classification. Fig. 13.2 shows the frequency of all types of weather observed at Hornsund, ranked according to their decreasing frequency, and the plot of cumulative series of these types. On the basis of this plot, a threshold of 70% on the cumulative scale was accepted as significant. Weather types plotting below this threshold were compiled in Table 13.4 and recognized as those met the most often.

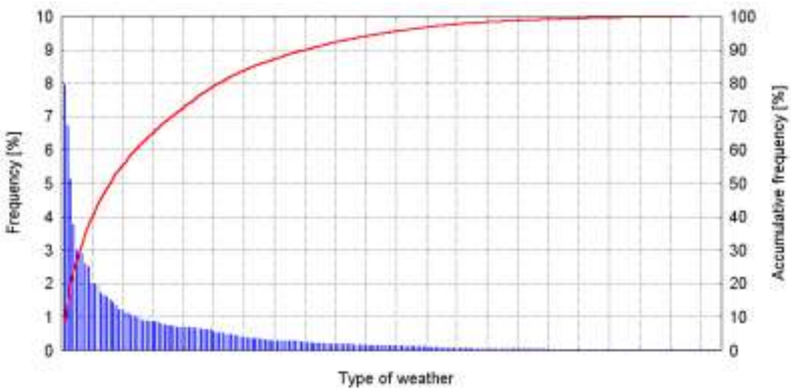

Fig. 13.2. Frequency of weather types at Hornsund in 1980–2009.

The distribution of frequencies of weather types most often encountered at Hornsund during the year is radically unequal. Among the 216 types recorded in the research period, the most frequent was moderately warm weather with cloudy or overcast skies, precipitation and a breeze, i.e. weather type 7311 (8.0%). In second place was type 6311, transitional weather, freezing-thawing, cloudy or overcast, with precipitation and a breeze (6.7%). Weather types ranking in the third and fourth places had similar frequencies (5.1 and 3.8%); these were weather types with partly cloudy sky, without precipitation and with a breeze, moderately warm (7301) and very frosty (3201).

Weather types 6301 (3.0%), 4201 (3.0%), 3101 (2.9%), 5311 (2.6%) and 4311 (2.5%) took successive places in this ranking. Together with those mentioned earlier, these types total nearly 40% of the year. Among them there are weather conditions from five groups, from the moderately warm to very cold, as a rule with cloudy or overcast skies, with or without precipitation, and with a breeze. There are no types from the extreme groups among them.

Table 13.4. Weather types dominating at Hornsund and their frequency [%], 1980–2009.

No	Type of weather	Frequency	Total	No	Type of weather	Frequency	Total
1	7311	7.96	7.96	19	5313	1.22	54.03
2	6311	6.74	14.70	20	8311	1.20	55.24
3	7301	5.11	19.82	21	2101	1.13	56.36
4	3201	3.78	23.60	22	7310	1.13	57.49
5	6301	3.02	26.61	23	4211	1.07	58.56
6	4201	2.97	29.58	24	7300	1.03	59.58
7	3101	2.91	32.49	25	7313	0.99	60.57
8	5311	2.59	35.08	26	3103	0.91	61.48
9	4311	2.51	37.58	27	4314	0.89	62.38
10	6313	2.00	39.58	28	4301	0.88	63.26
11	7201	2.00	41.58	29	7312	0.87	64.13
12	6201	1.95	43.53	30	4101	0.86	64.99
13	5301	1.73	45.26	31	4303	0.86	65.85
14	6312	1.64	46.90	32	3311	0.84	66.70
15	5201	1.61	48.51	33	4203	0.78	67.48
16	3203	1.51	50.01	34	6211	0.76	68.24
17	4313	1.45	51.46	35	3303	0.74	68.99
18	3211	1.34	52.81	36	8301	0.74	69.73

From the 216 types of weather recorded at Hornsund as many as thirty had a frequency of only 0,01%, meaning that this weather combination occurred only once in the research period of 30 years. Fourteen types were observed that occurred just twice, and 14 types appeared three times. Only ten types of weather occurred in each year of the investigated period, and so were recognized as "characteristic" for Hornsund (Ferdynus, 2007). These weather types are compiled in Table 13.5, in which the annual trends are also given and the correlation coefficient between the mean annual frequency of the specific type and the mean annual air temperature at Hornsund.

The types of weather in Table 13.5 belong to three groups; among them there are both weather conditions with partly cloudy and overcast skies, with or without precipitation and, as a rule, with

Table 13.5. Annual trend of "characteristic" types of weather at Hornsund (± standard error of estimation) and correlation coefficients between frequency of such types of weather and mean annual air temperature at Hornsund in 1980 – 2009.

No	Type of weather	Trend coefficient	p <	Correlation coefficient	p <
1	4201	0.006 (±0.031)	0.853	–0.05	0.780
2	4211	–0.003 (±0.017)	0.871	0.29	0.116
3	4311	–0.030 (±0.029)	0.305	0.11	0.565
4	5201	0.024 (±0.023)	0.299	0.02	0.904
5	5311	–0.015 (±0.026)	0.579	0.26	0.166
6	6301	–0.009 (±0.024)	0.719	–0.08	0.687
7	6311	–0.085 (±0.049)	0.095	0.04	0.843
8	6312	**0.040** (±0.018)	0.031	**0.47**	0.008
9	7301	0.046 (±0.039)	0.251	0.22	0.244
10	7311	0.112 (±0.067)	0103	**0.50**	0.004

Statistically significant values of coefficients are shown in bold.

low wind velocities. Missing from the types are these from the extreme groups – extremely cold, exceptionally cold, warm, very warm, and exceptionally warm. In comparison with a study limited to the period 1980–2006 the number of "characteristic" weather types was reduced by three, i.e. 3101, 3201 and 3203 (very cold weather with partly cloudy sky or cloudless, without precipitation and with breeze or strong wind).

The correlation coefficients between the frequency of a given type of weather in consecutive years of the research period and the mean annual air temperature are statistically significant only in the case of two types of weather, 6312 and 7311; in both cases the correlation coefficients are positive. The remaining "characteristic" types of weather show both negative (4201 and 6301) and positive (4211, 4311, 5201, 5311, 6311 and 7301) correlations with the mean annual air temperature at Hornsund, but in each case these are small and statistically not significant .

Only one type of "characteristic" weather for Hornsund (type 6312) shows a statistically significant negative trend at the level –0.040 (±0.018) per year. This value is very small, indicating a minor negative tendency rather than a trend. Looking at the values of trend coefficients in Table 13.5 it is easy to notice that among other types, in the case of cold weather the trend coefficients have negative values (with the exception of type 5201), while in the case of the warm weather types these are positive. This is reflection of changes of the air temperature at Hornsund that occurred during the research period.

In 1980–2009 the number of weather types occurring in particular decades ranges from 31 in the first decade of July to 81 in the second and third decade of January: the annual mean is 59 (σ_n = 15). Analysis of Fig. 13.1 shows that the greatest numbers occur in the cold season of the year, especially during the polar night. This is the result of the lively cyclonic activity causing frequent advection of the air masses both from the Arctic interior and from the lower latitudes.

Analysis of frequency of weather types in consecutive decades of the year also shows that there is only a small number of such types that reach or exceed a frequency of 10% in particular decades of the year. A score of 10% means that a given type of weather appears in the decade on average during one day in each year. The temporal distribution of these types of weather, described as "characteristic" by Ferdynus (2004), is unequal at Hornsund (Table 13.6). There are 26 decades in which the "typical types of weather" occur, types 3101, 3201, 4201, 6201, 6301, 6311, 7201 and 7311. Among them there are weathers from nearly all groups (except the extreme groups), those which are characterized by partly cloudy or overcast skies, lack of atmospheric precipitation as a rule and in each case a breeze. Among very cold and cold weather types, one may observe that partly cloudy skies predominate. Among transitional and warm weather types, there are both partly cloudy and overcast skies. Both the transitional weather types with cloudy or overcast skies and the moderately warm weather type with the cloudy or overcast skies are recorded as "typical" weathers definitely more often than those with a partly cloudy sky.

Analysis of Table 13.6 shows that typical types of weather are more characteristic of the warm than the cold season of the year. Starting from the third decade of May two, and even three or four typical types of weather are recorded in consecutive decades. Such behaviour is maintained in principle to the end of September, and even to the end of October and November. Four typical types of weather were recorded in the first decade of June (6201, 6301, 6311 and 7311), and three typical types of weather were observed in the third decade of June (7201, 7301 and 7311). In ten decades two typical types of weather are observed, in thirteen decades one type occurs.

Table 13.6. Frequency of typical types of weather [%] at Hornsund in 1980–2009

Type	Decades																																		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
3101																																			11	
3201										10																										
4201												11	10																	11						
6201																11																				
6301															13	17											11									
6311							10							13	19	13												11	11		11	10	13			
7201																		14																		
7301																	21	16	25	16	14	14	15	12	14	10										
7311																12	21	31	29	26	19	23	21	21	22	16										

The reasons for the unequal temporal distribution of the typical types of weather should be probably assigned to the lessening of the intensity of atmospheric circulation. To authenticate this hypothesis it is a matter of fact that that typical types appear every time there is a weather type with a breeze. During cold periods, typical types of weather are met only sporadically; these are recorded more often in the autumn than in the spring.

13.2.4. The annual structure of states of the weather

A climagram is a diagram that traces changes of structure of weather states in consecutive decades of the year. This diagram allows one to interpret not only frequency of particular classification units but also to observe the variability and succession of weather conditions. For present purposes, because of limits of the resolution that it is possible to reach, only the frequency of occurrence of groups and subgroups of weather are presented (Fig. 13.3).

Analysis of the climagrams shows that the groups characteristic of Hornsund are the transitional freezing-thawing weather and also the moderately cold as well as the moderately warm weather occurring during the whole year. These groups are characterized first of all by the cloudy or overcast state of the sky (63RV, 53RV and 73RV). Absence of cloud is limited to single decades only. Weather 6NRV and 5NRV are not observed during the polar day, whereas weather 7NRV does not occur during the polar night. Transitional, freezing-thawing weather was not recorded only in the second decade of July, and moderately cold – in the third decade of June and the first decade of July. Moderately warm weather (7NRV) conditions were not observed in the third decade of February and March. The transitional, freeze-thaw weather was regarded as that most characteristic of Hornsund climate by Ferdynus (2006).

Very cold weather appears in the first decade of October and exceptionally cold in the second decade of November and are recorded up to the second decade of April (2NRV) and the second decade of May respectively. In any decade the exceptionally cold weather does not exceed 20% in frequency, and very cold weather only reaches, or even exceeds, a frequency of 50% in a few decades.

The picture of the cold season of the year is definitely different from the picture of the warm season. The winter period is much more extended in time. Weather with negative air temperatures throughout a 24 hours span is observed as a matter of fact already in September (the first decade), however, a sudden increase of its frequency begins at the turn of September to October. The intense conversion of the thermal structure of states of weather – the nearly complete disappearance of moderately warm weather and its replacement by moderately cold to cold follows over only 3–4 decades. There is unquestionable dominance by cold and moderately cold weather (over 80%) between the second decade of December and the second decade of April. At the turn of April to May there is a renewed, revamping of the thermal structure of weather states that is no less intense than that observed at the turn of September and October. Cold weather is displaced in the first instance by transitional, freezing-thawing weather and next by the moderately warm types. The warm season, with its dominance of transitional freezing–thawing weather, moderately warm and warm types is definitely shorter and more tightly limited in time than the cold period.

The picture of the mean annual structure of states of the weather presented here is a peculiar climatic abstraction, an averaging, which does not truly reflect the real changes of weather conditions. Analysis of climagrams plotted for particular years of the investigated period (Fig. 13.4 – 13.17) will yield a more accurate picture, allowing tracing of the short-term variability of weather conditions. Comparison of climagrams prepared for the warmest year (2006; Fig.13.16) and the coldest one (1988; Fig.13.7 a) is particularly interesting. Year 2006 is characterized by a very clearly marked period with dominance of moderately warm weather types (giving a picture of a warm core), and the relatively late appearance of very cold weather types (both at the beginning and the end of the calendar year) which dominate only in a few decades of February and March as well as November and December. In January, April and May and in the autumn months transitional freezing-thawing weather was unquestionably the dominant characteristic.

The picture of the coldest year shows very early (from the beginning of October) occurrence of very cold weather. In this year (1988) a substantial percentage of exceptionally cold weather is observed. The timing of occurrence of episodes of moderately warm weather is shifted in time (is clearly delayed) and the duration of its dominance is limited to merely two decades. This year is definitely less cloudy than the warmest year. This confirms the earlier hypothesis that the percentage of weather types with cloudy or overcast states of the sky increases with the increase of temperature.

13.3. Seasonal structure of the climate in the station region

The analysis of the climagrams plotted for the complete investigated period, 1980–2009, shows that some decades are similar in relation to the structure of their weather states. In order to find decades similar to each other, the method of the 'Wrocław spanning tree' was applied, one of the taxonomic methods with a considerable measure of objectivity. Its advantage is the fact that it does not determine the number and duration of weather seasons.

Detailed description of the Wrocław spanning tree was presented by Perkal (1958, 1967), and Chojnicki and Czyż (1973) gave examples of application of this method in geographical research. Woś (1977) presented a justification for its application in the procedure of diagnosing weather seasons. Applying this method, the author has determined the weather seasons for selected stations in the Atlantic sector of the Arctic (Ferdynus 1997), and also at Hornsund (Ferdynus 2005).

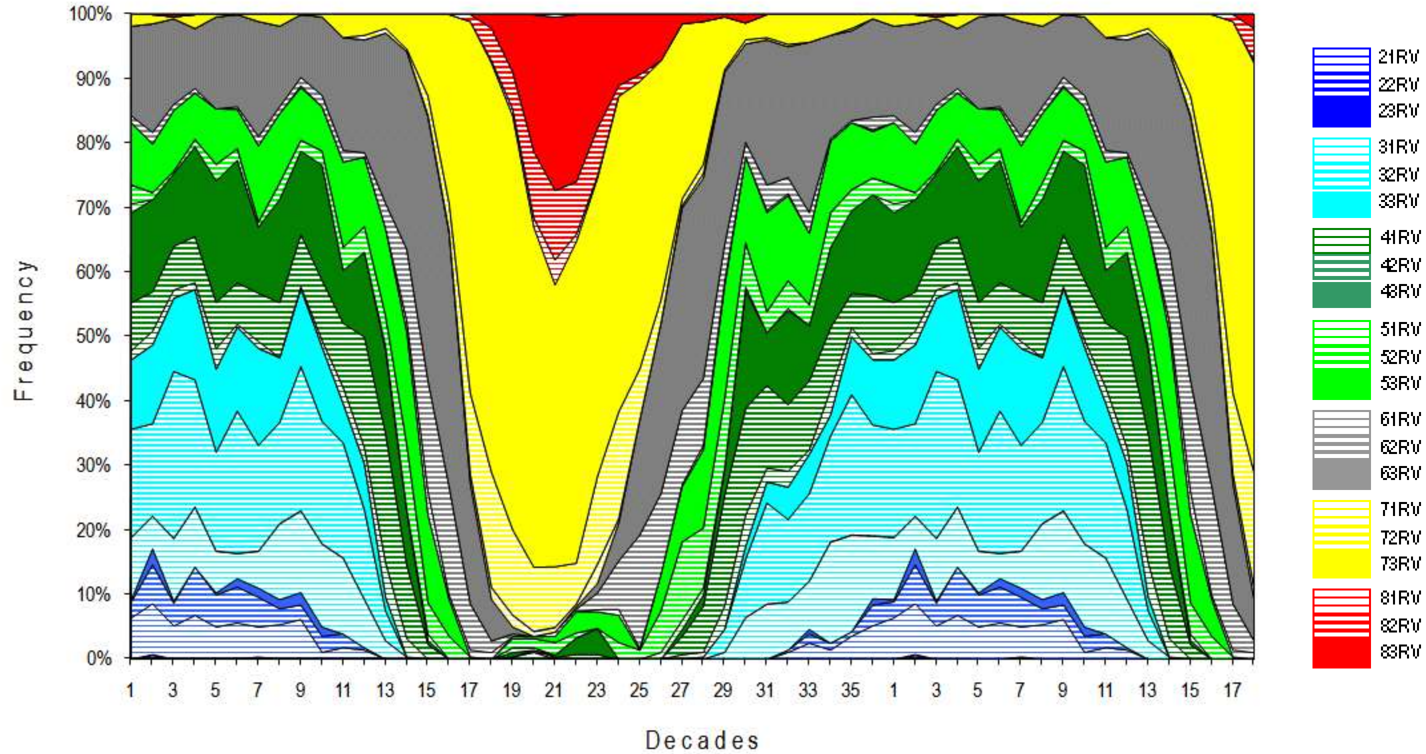

Fig.13.3. Climagram of the Hornsund station (1980–2009)

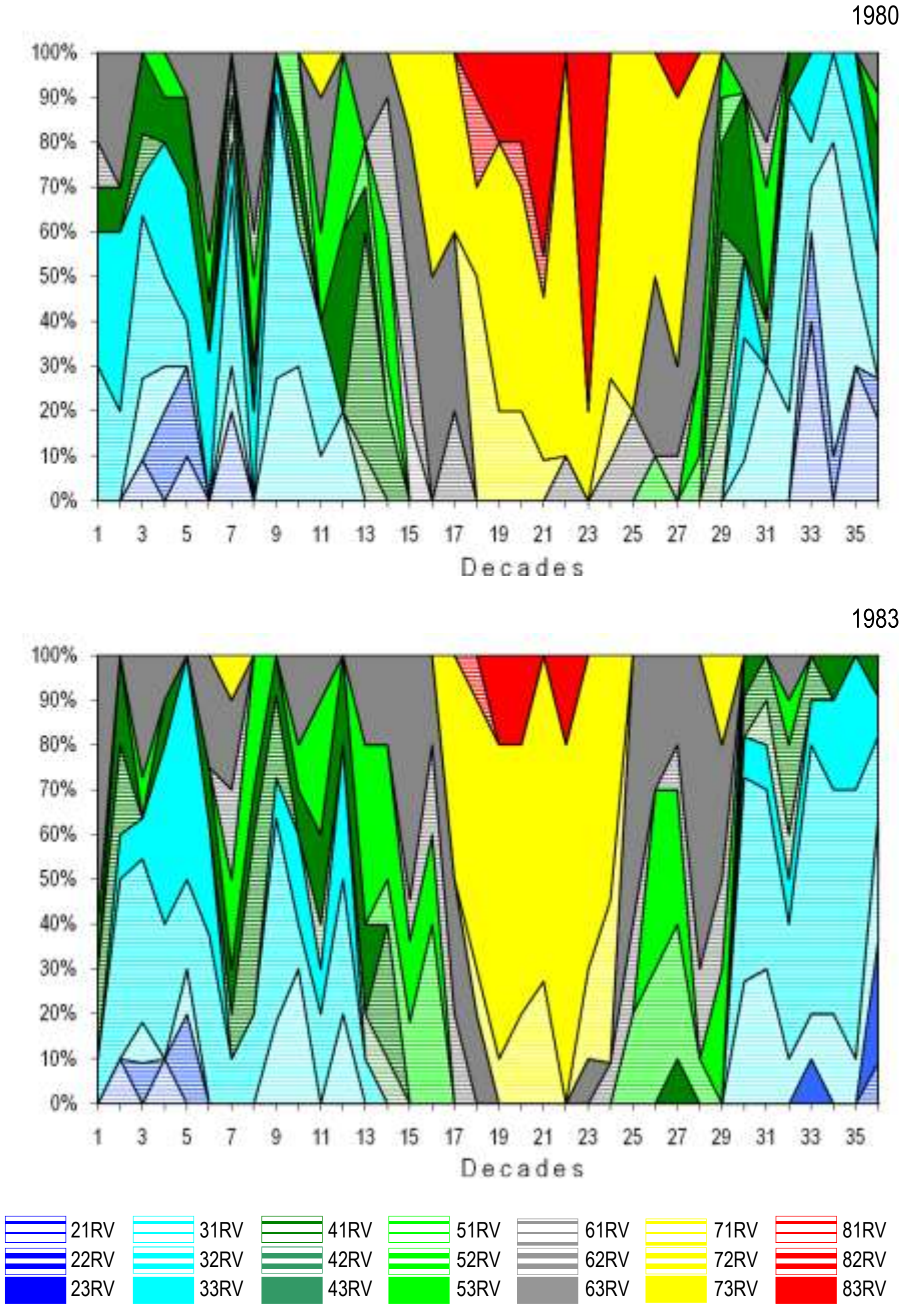

Fig.13.4. Climagrams of the Hornsund station for 1980 and 1983.

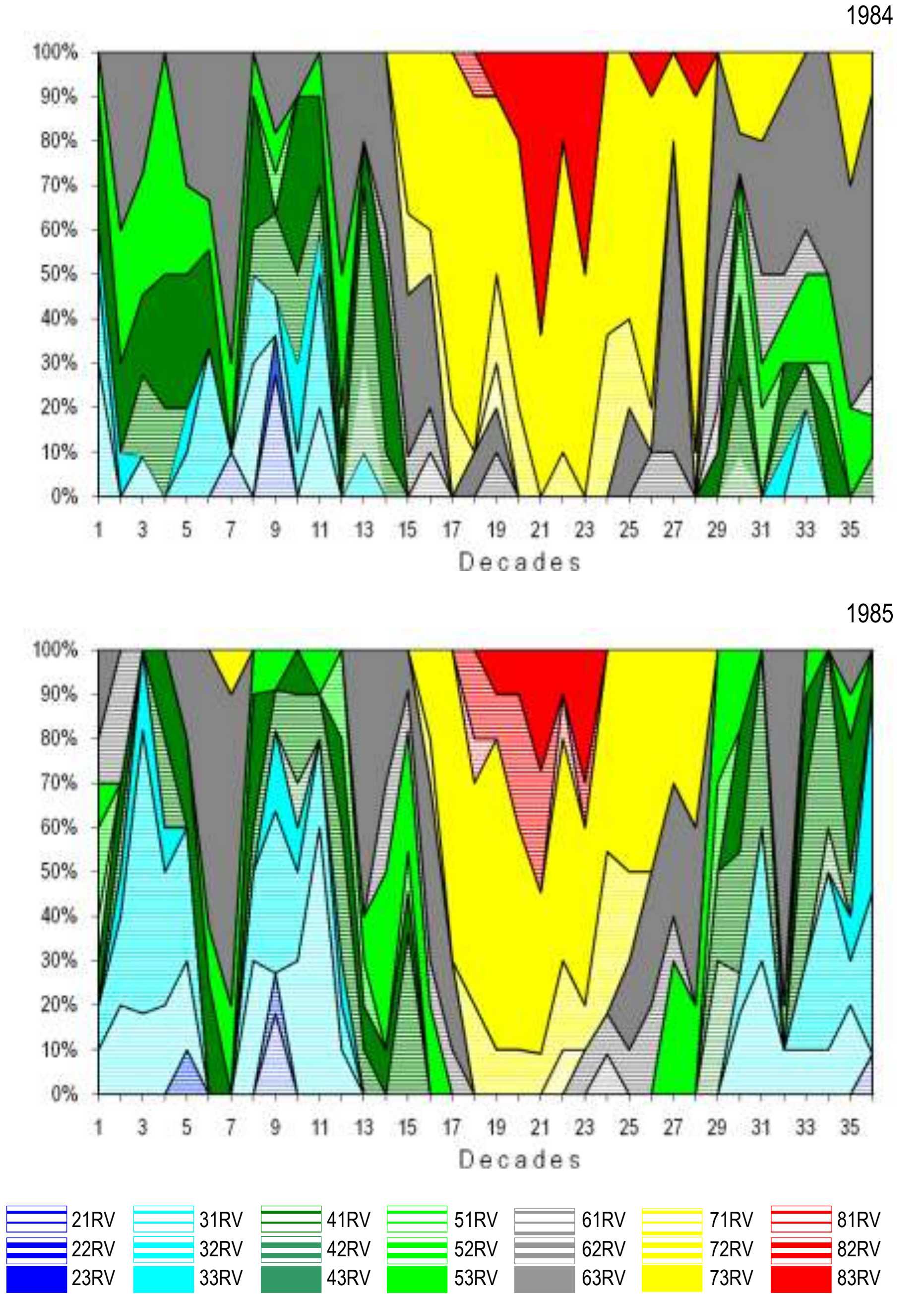

Fig.13.5. Climagrams of the Hornsund station for 1984 and 1985.

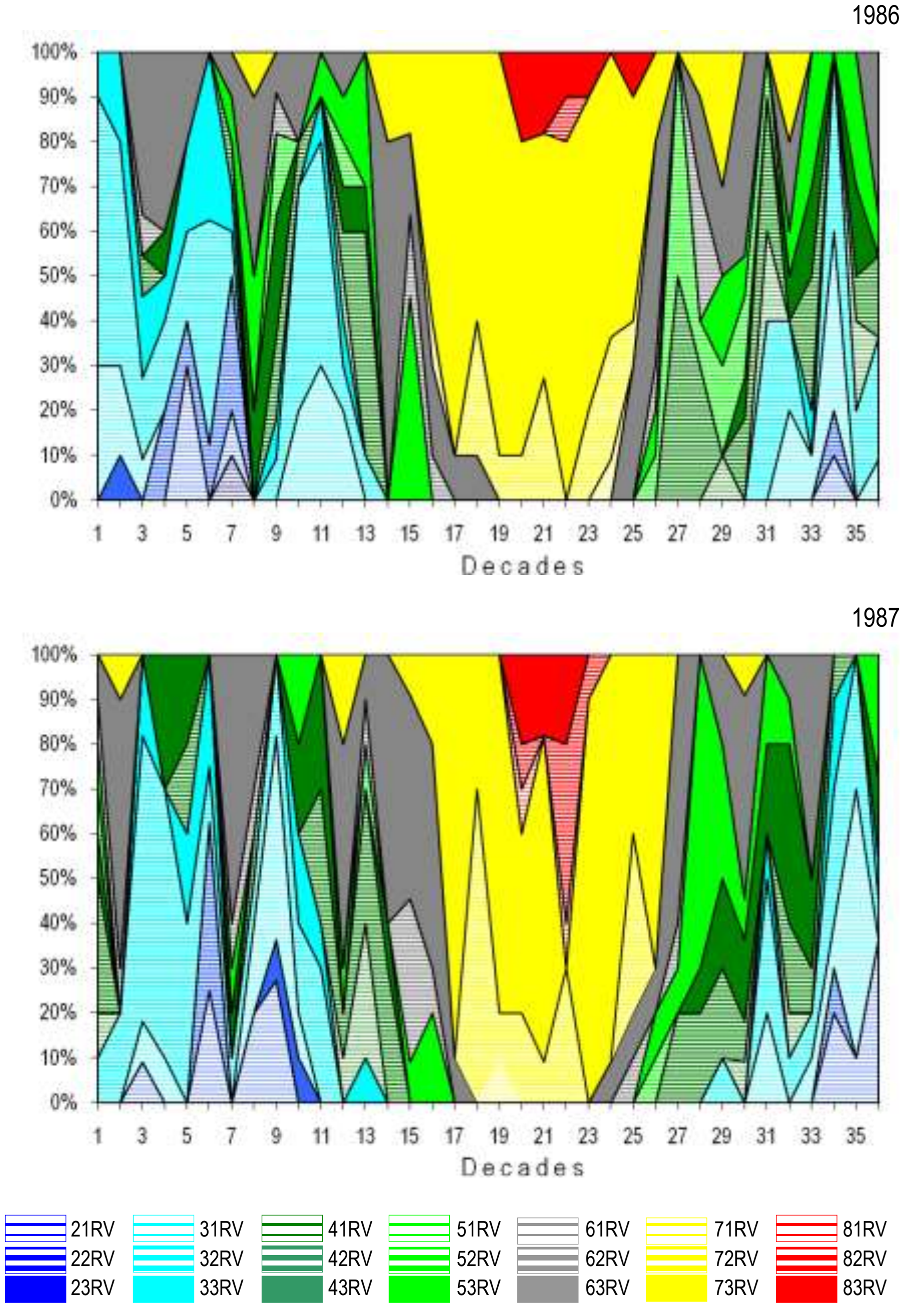

Fig.13.6. Climagrams of the Hornsund station for 1986 and 1987.

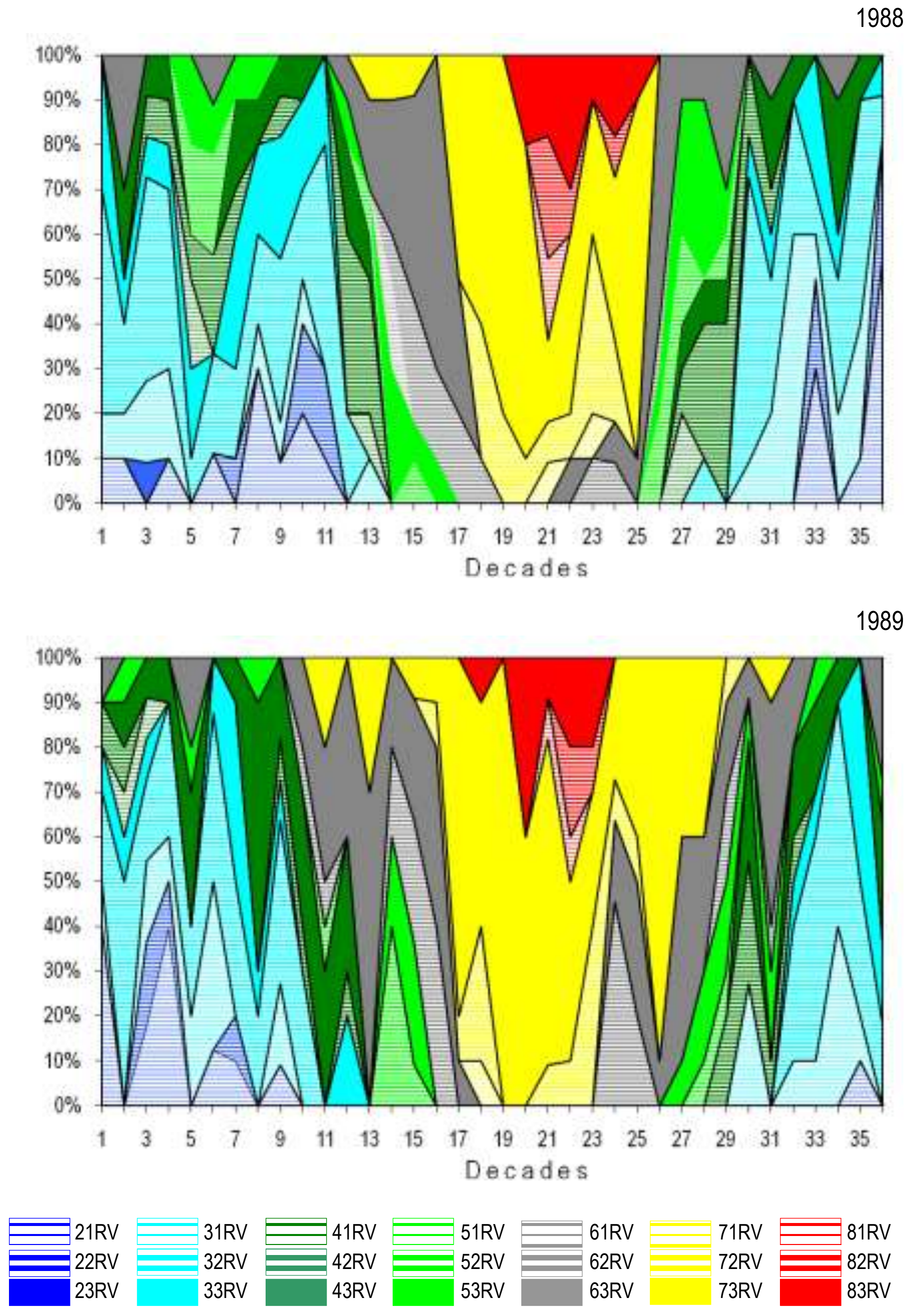

Fig.13.7. Climagrams of the Hornsund station for 1988 and 1989.

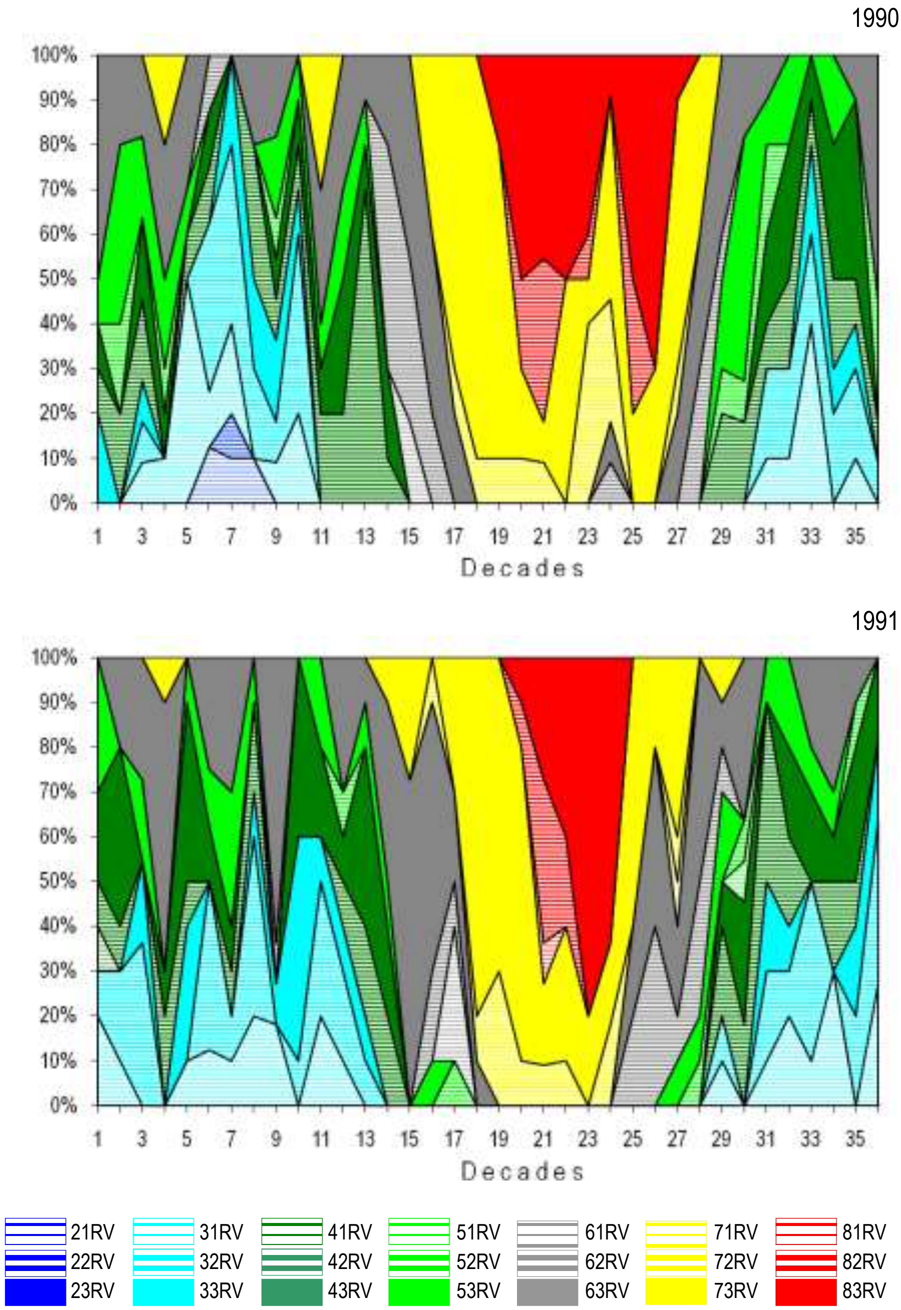

Fig.13.8. Climagrams of the Hornsund station for 1990 and 1991.

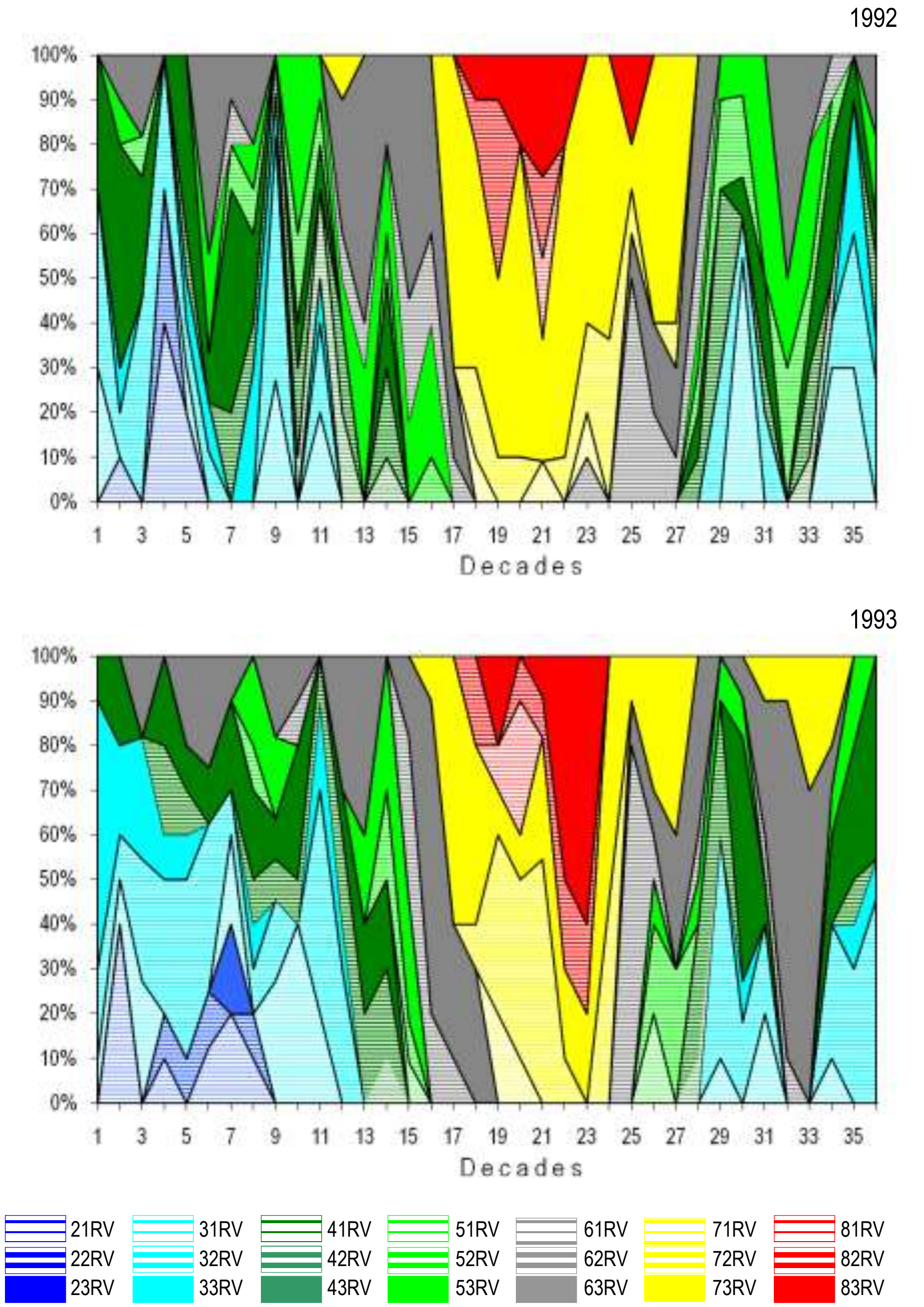

Fig.13.9. Climagrams of the Hornsund station for 1992 and 1993.

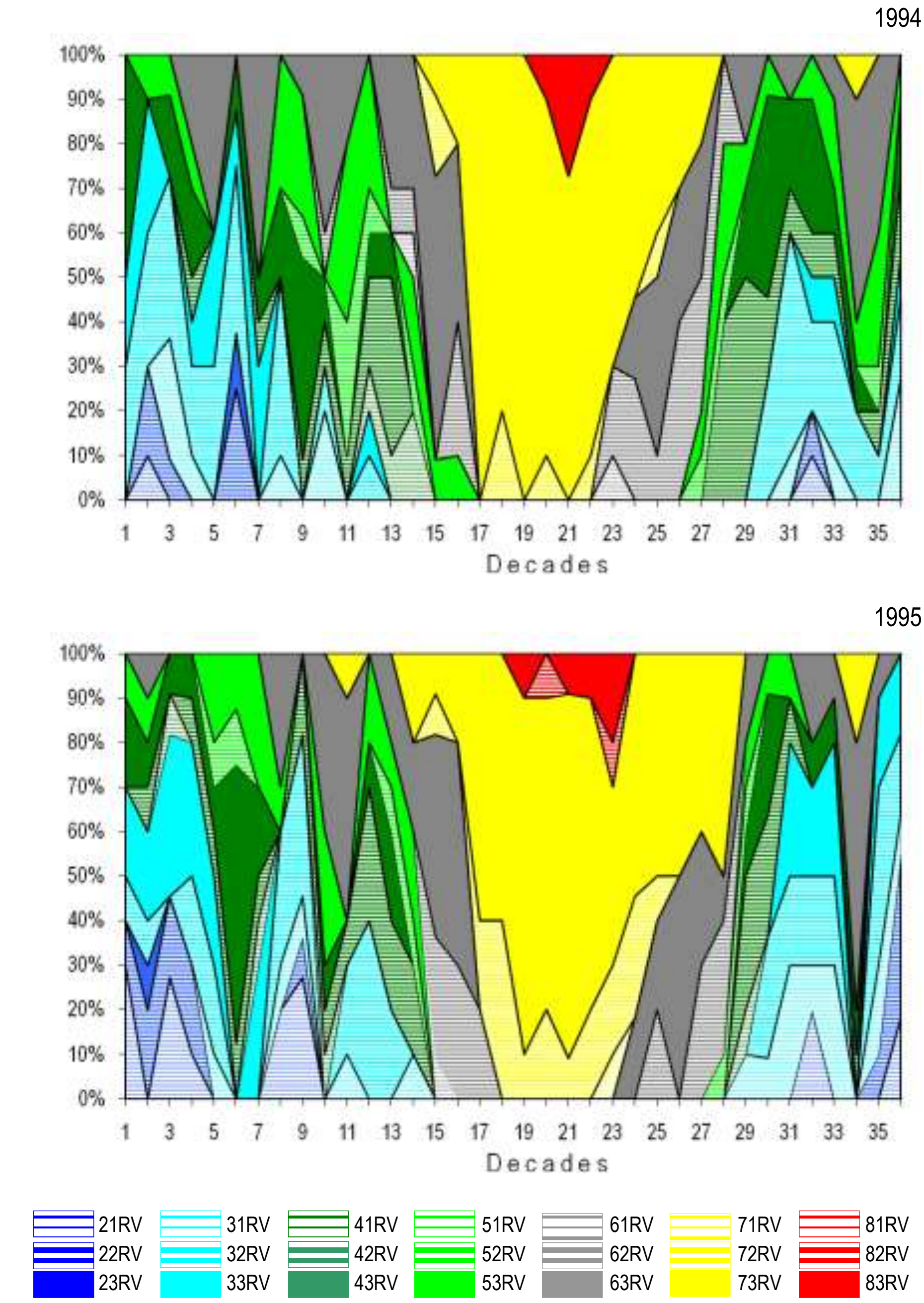

Fig.13.10. Climagrams of the Hornsund station for 1994 and 1995.

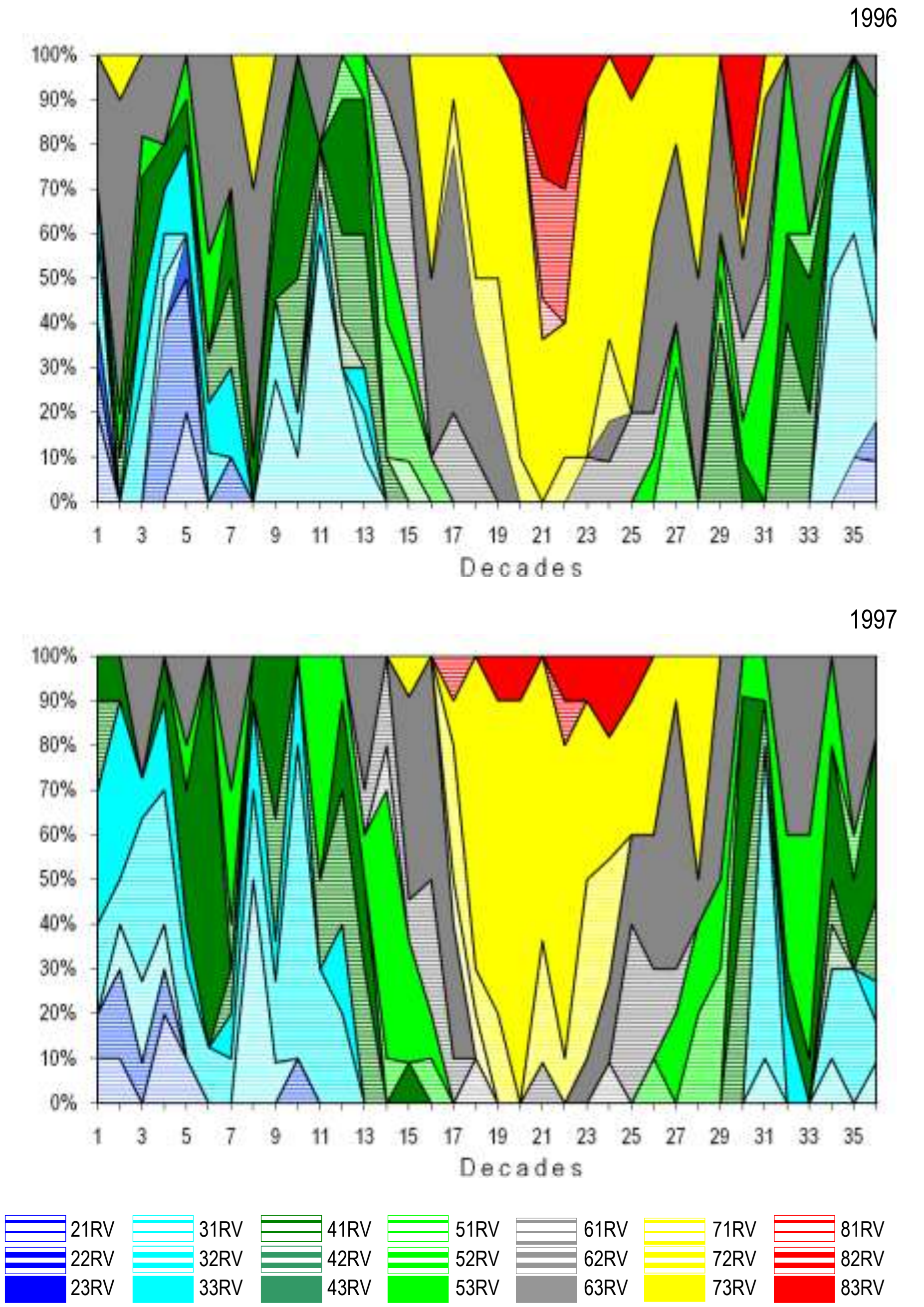

Fig.13.11. Climagrams of the Hornsund station for 1996 and 1997.

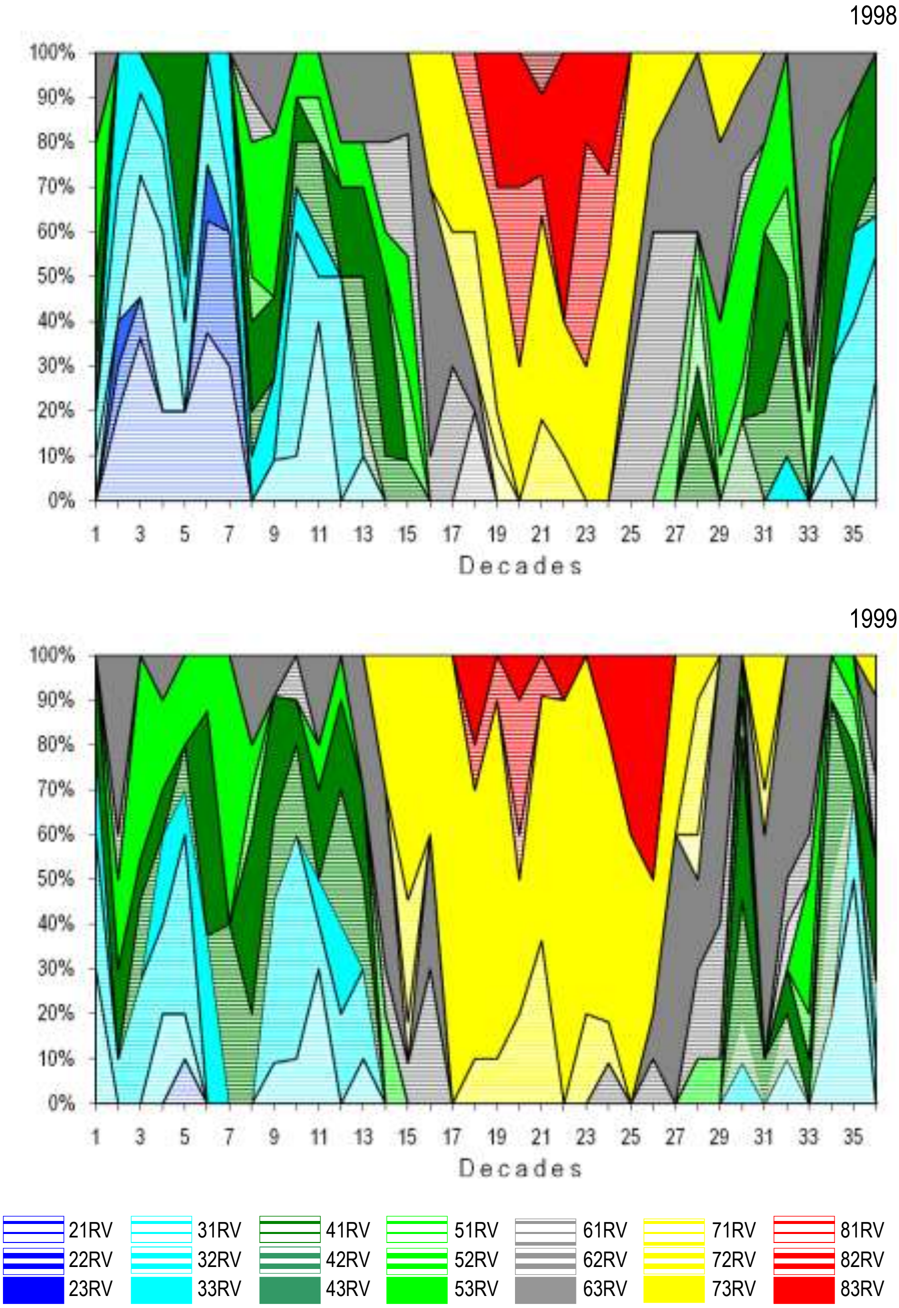

Fig.13.12. Climagrams of the Hornsund station for 1998 and 1999.

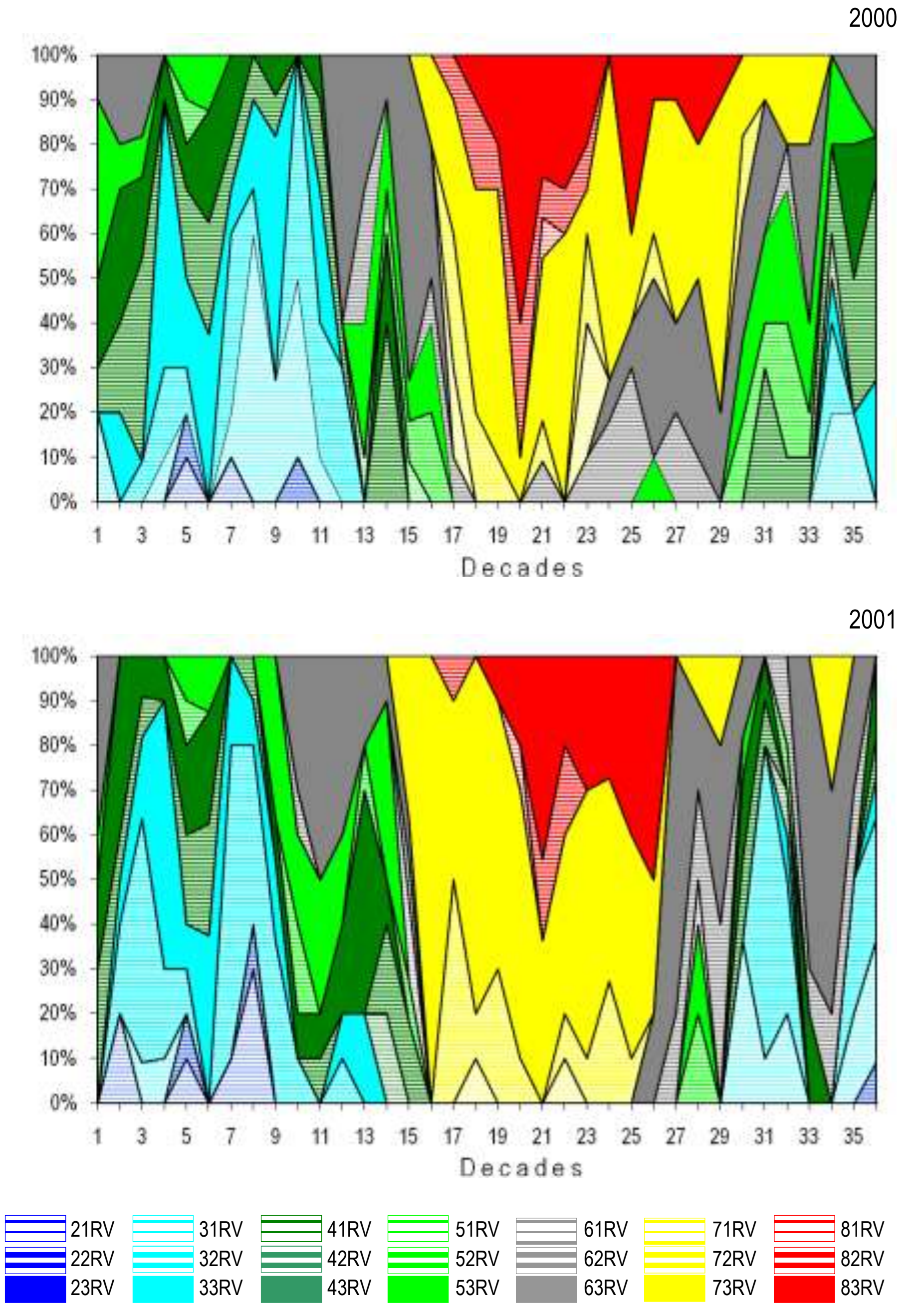

Fig.13.13. Climagrams of the Hornsund station for 2000 and 2001.

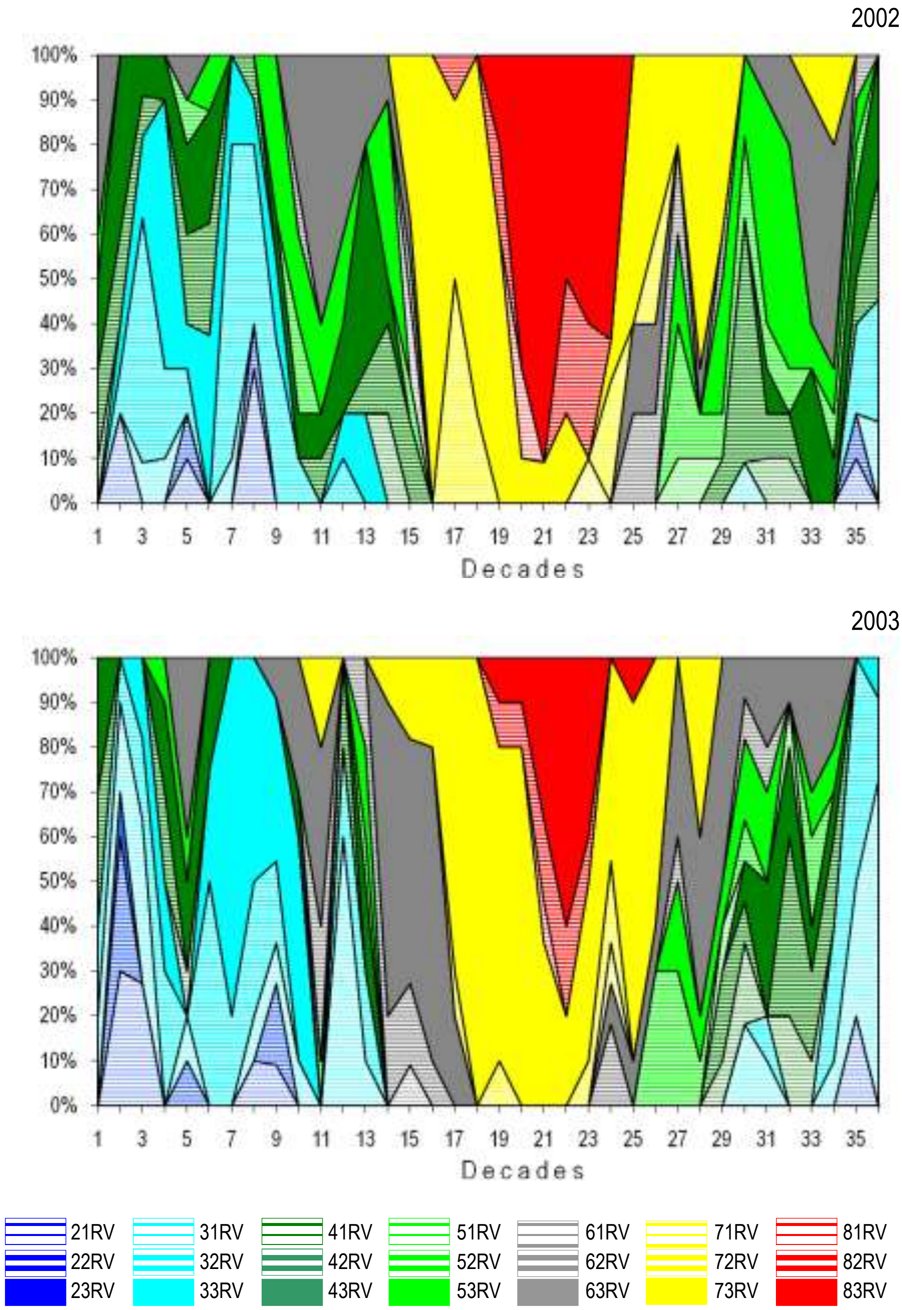

Fig.13.14. Climagrams of the Hornsund station for 2002 and 2003.

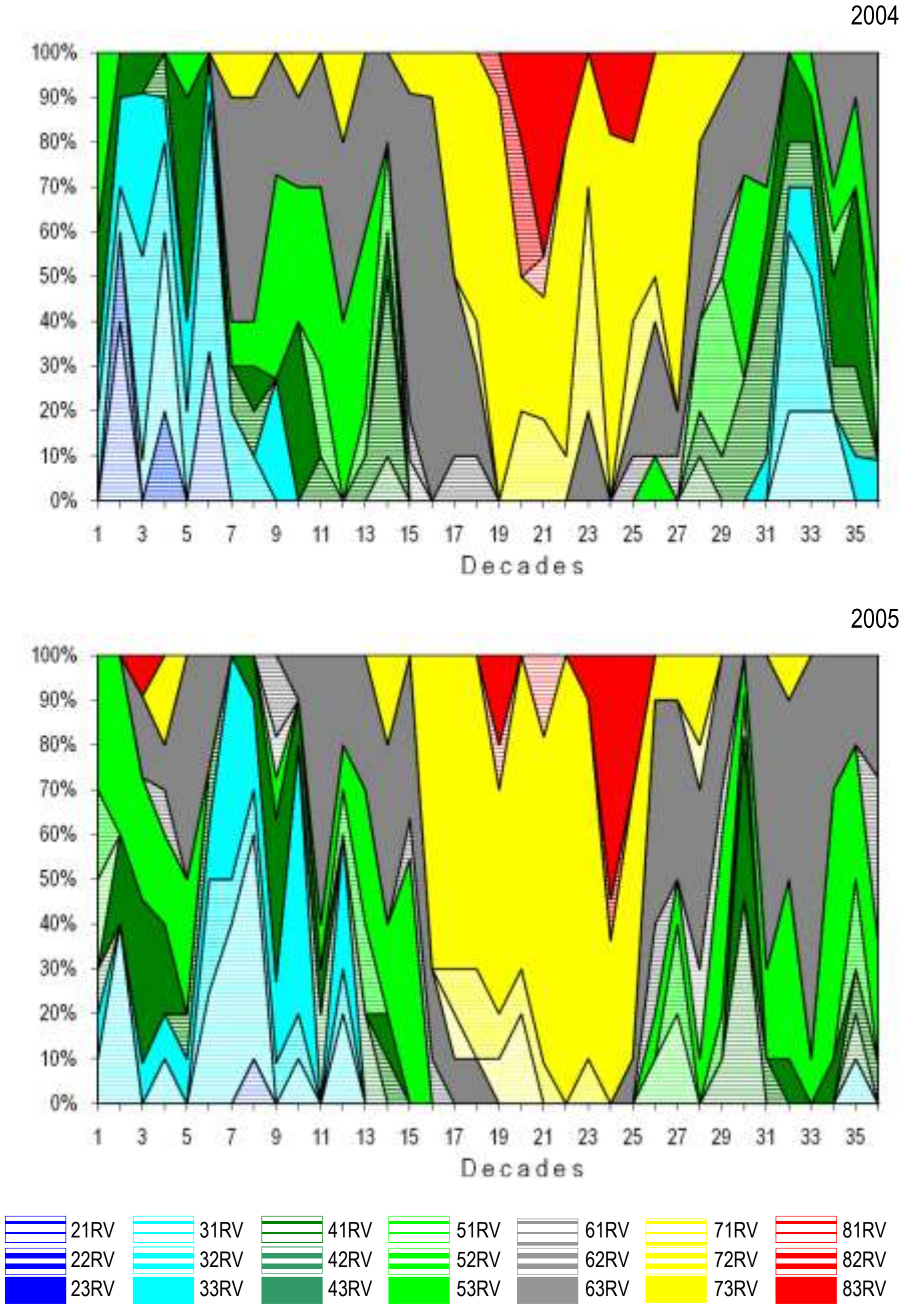

Fig.13.15. Climagrams of the Hornsund station for 2004 and 2005.

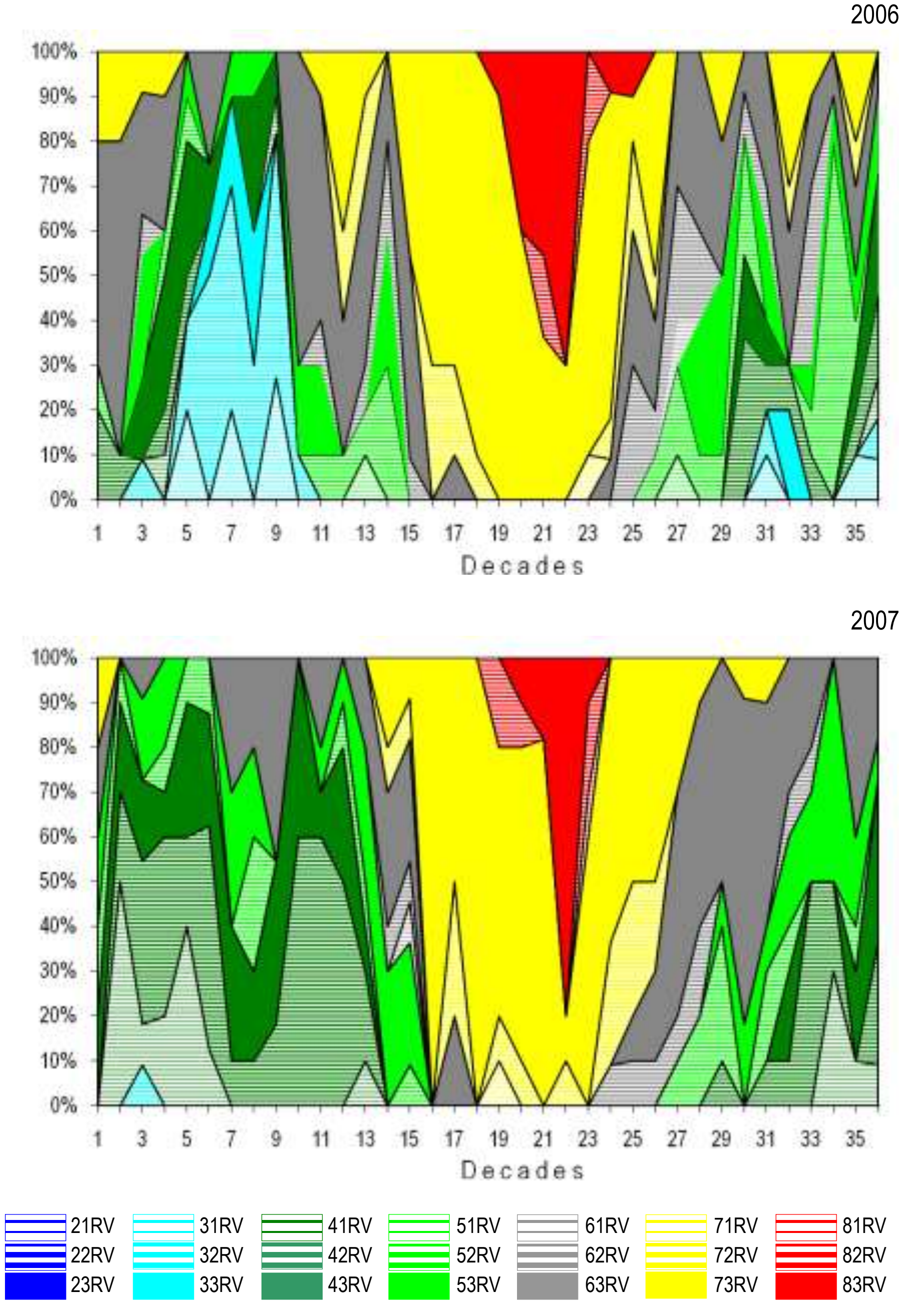

Fig.13.16. Climagrams of the Hornsund station for 2006 and 2007.

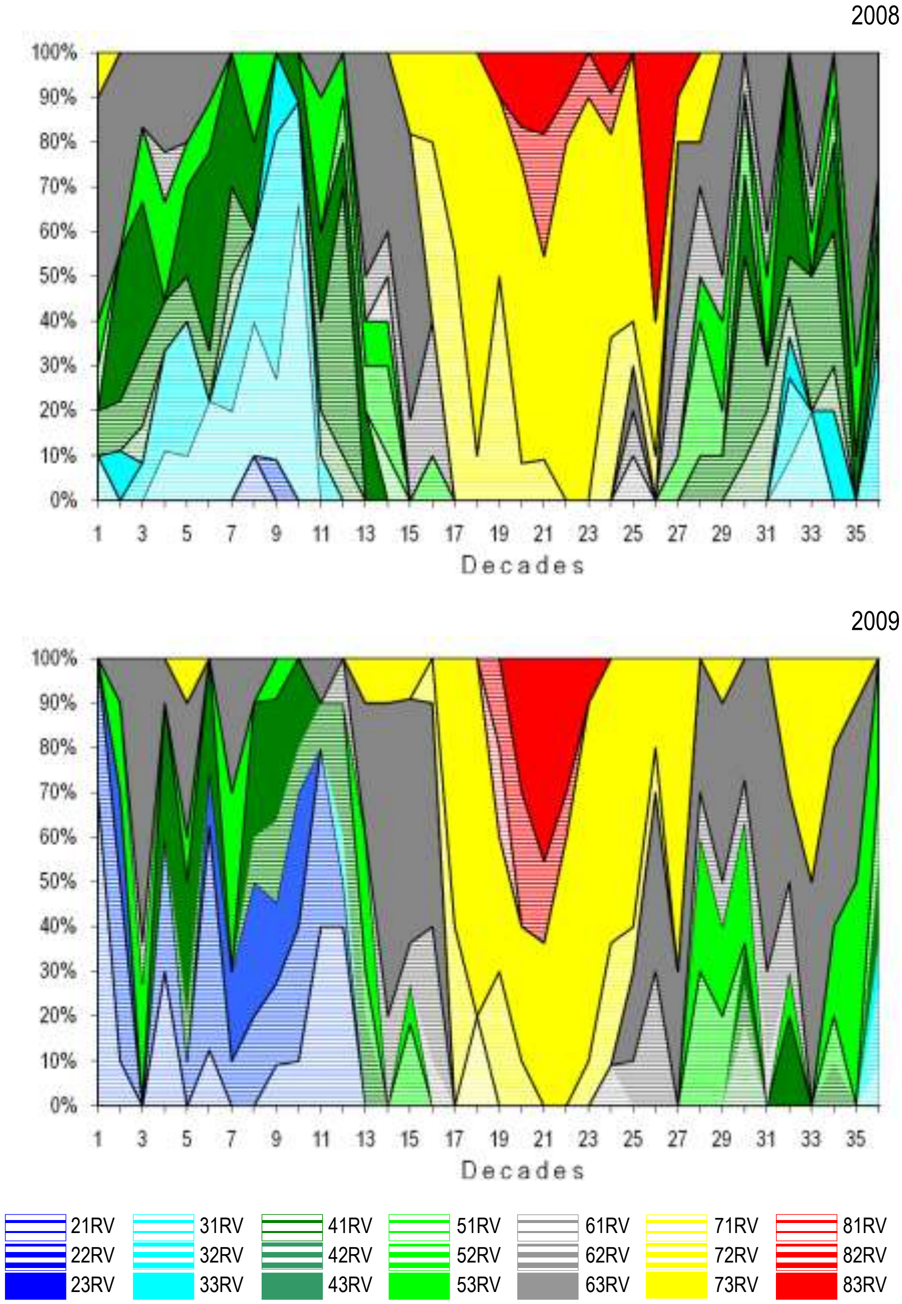

Fig.13.17. Climagrams of the Hornsund station for 2008 and 2009.

The spanning tree is a graphical picture showing on the plane the smallest distances between each pair of statistical units, in this case decades. These distances were calculated using the equation for the geometric distance (Perkal 1958):

$$d_{ik} = \sqrt{\sum_{i=1}^{p} (y_{ij} - y_{kj})^2}$$

where: d_{ik} – geometric distance between decades i and k,
i, k – decadal units (i, k = 1, 2, 3, ... , 36),
j – features considered (types of weather, their frequency),
y_{ij} – value of feature j for unit i,
y_{kj} – values of feature j for unit k.

The calculated geometric distance is the taxonomic distance, which is the measure of degree of differentiation of particular decades from the perspective of the frequency of the individual weather types. Taxonomic distances are measures of similarity between decades. The smaller their values the greater the level of similarity between given decades or groups.

After plotting the spanning tree, its division into typological classes (groups of decades encompassing decades in a defined degree of homogeneity) was made. It was considered that two subsets of the set are different if the shortest distance between a pair of decades is bigger than critical distance (D) determined by relation:

$$D = ds + 1.5 \cdot \sigma_n$$

where: ds – mean distance,
σ_n – standard deviation.

Next, the decades were arranged chronologically, with simultaneous consideration of their affiliation to particular typological classes. It was also assumed that a season could not be shorter than two consecutive decades.

The application of the procedure described above showed that Hornsund has peculiarly developed climatic seasonality, symptoms of which are both number of climatic seasons singled out and their duration. Analysis of Fig. 13.18 shows that the weather seasons singled out are not in tight association either with the thermal seasons of the year (Kierzkowski 1996, Kwaśniewska and Pereyma 2004), or with the division suggested by Przybylak (1992).

The extension of the observation series for six consecutive years (2004 – 2009), following the analysis of 2005, allowed it to be recognised that the structure of weather states changed in particular decades and also the taxonomic distances between them. This caused change of the value of critical distance and change of the duration of particular seasons; thus the internal structure also changed. The winter was prolonged at the expense of the spring and autumn. The most important features of seasons singled out are compiled in Table 13.6. These seasons are characterized by relative homogeneity of weather conditions, which is confirmed by the structure of weather states (number and frequency of recorded groups, subgroups, classes and types of weather).

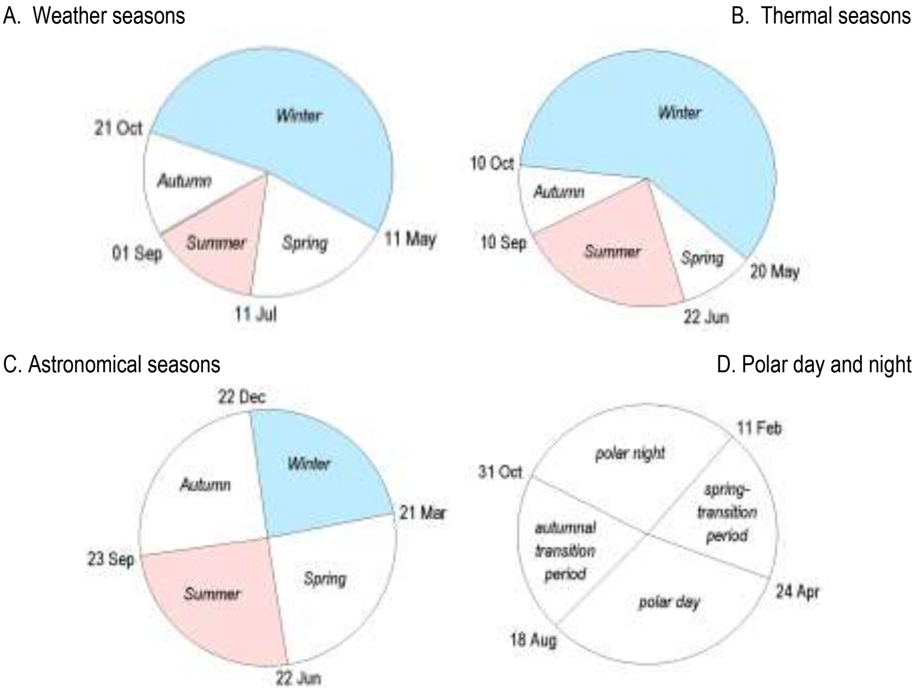

Fig.13.18. Comparison of the beginning and the end of weather seasons at Hornsund, set by weather structure (A) with limits of thermal seasons (according to Kwaśniewska and Pereyma 2004) – (B) and seasons resulting from activity of astronomical factors (C, D).

13.3.1. Winter (October 21 – May 10)

The winter is the longest and the most differentiated weather season. The differentiation of weather conditions confirms both the number and frequency of the classification units used here. From October 21 to May 10, eight weather groups of were observed. The very cold (35.6%) dominate with the merely cold weather type subdominant (24.8%). Next are the transitional, freezing-thawing (6NRV) and the moderately cold weather (5NRV), which occur with frequencies of 17.2% and 13.0% respectively. From the other groups most numerous is the exceptionally cold weather (2NRV, 7.1%). Weathers of the extreme groups: the moderately warm (7NRV), the extremely cold (1NRV) and the warm (8NRV) are only accessory components, appear sporadically and their frequency is minimal. Although these weather groups do not play a significant role in the formation of weather conditions in this season, they should be mentioned because they indicate the range of temperature associated with extreme weather conditions.

In the winter, weather with negative air temperatures throughout the 24 hours is most frequent, as should be expected in this region. These make up over 80% of all days. There are nearly 18% of days with passage of air temperature through 0˚C and only a little over 2% of days have positive air temperature maintained over a 24 hours span. Analysing cloudiness, one should report that the winter is the only season at Hornsund in which the cloudless and partly cloudy weathers dominate those with cloudy or overcast skies. Substantial drops of the air temperature (strong radiation losses, with lack of direct insolation) are observed then.

The minimum frequency of the windless weather(TNR0), besides the overwhelming domination of cold conditions, is the peculiarity of this season. Weather with the low wind velocities definitely dominate. However, during this period windy weather is also prominent – weather with strong winds (TNR3), storm winds (TNR6), and even hurricane winds (TNR8) is recorded. The substantial percentage of weather with high winds are due to the greater (than in the warmer season of the year) baric gradients.

Table 13.6. Selected features of climatic seasons at Hornsund in 1980–2009.

Seasons	Winter	Spring	Summer	Autumn
Beginning End Duration (days)	October 21 May 10 212	May 11 July 10 61	July 11 August 31 52	September 1 October 10 40
Groups of weather (max,., min) Dominating group [%] Subdominating group [%]	3, 4, 6, 5, 2, 7, 1, 9 3NRV – 35.6 4NRV – 24.8	7, 6, 5, 4, 8, 3 7NRV – 41.4 6NRV – 33.3	7, 8, 6, 5, 4, 9 7NRV – 60.6 8NRV – 29.4	6, 7, 5, 4, 8, 3 6NRV – 38.6 7NRV – 30.9
Frosty weathers [%] Transitional weathers [%] Warm weathers [%] Weathers 5, 6, 7 NRV [%]	80.6 17.2 2.8 32.3	21.9 33.3 44.8 86.0	5.7 4.2 68.5 90.1	26.4 38.6 35.0 87.1
Number of weather classes Dominating class [%] Subdominationg class [%}	39 311 – 17.2 201 – 13.3	28 311 – 26.1 301 – 22.9	28 311 – 30.0 301 – 20.3	27 311 – 26.0 301 – 16.1
T1RV [%] T2RV [%] T3RV [%]	15.1 33.5 51.3	4.3 26.5 69.3	3.0 23.0 74.0	2.6 28.8 68.6
Number of weather types Dominating types [%]	167 6311 – 7.0 3201 – 6.9 3101 – 5.4	118 7311 – 13.9 7301 – 11.0 6301 – 7.6	85 7311 – 21.3 7301 – 14.3 8311 – 6.0	100 7311 – 11.7 6301 – 7.1 7301 – 6.4

Among 171 types of weather recorded in this season types 6311 weather (transitional, freezing-thawing, with cloudy or overcast skies, with precipitation and breeze), 3201 (very cold, with partly cloudy sky, without precipitation and with breeze) and 3101 (very cold, cloudless, without precipitation and with breeze) are dominant. Cumulatively, they make up nearly 20% of all days of this season.

During the winter 39 different classes of weather occurred, but for nearly half of all days of this season there were just five. These were: T311 (weather with cloudy or overcast skies, with precipitation and breeze), T201 (weather with partly cloudy sky, without precipitation, with a breeze), T101 (cloudless weather, without precipitation and with a breeze) and T313 (weather with cloudy or overcast skies, with precipitation and a strong wind) as well as T312 (weather with cloudy or overcast skies, with precipitation and a breeze, with periods of strong wind).

Weather types with positive air temperatures during the day appear only sporadically. Their cumulative frequency amounts to 2.2%; these are the moderately warm or warm types, with cloudy or overcast states of the sky, with precipitation and a strong wind. Among transitional, freezing-thawing weather in the winter (making up over 17% of total number of days of this season) weather with cloudy or overcast skies dominates.

13.3.2. Spring (May 11 – July 10)

The spring is more uniform in relation to its weather structures than the winter. In this season six groups of weather occur. Moderately warm (7NRV, with a frequency 44.4%) and freezing-thawing (6NRV, 33.3%) weathers dominate. The next groups of weather are the moderately warm (5NRV, 11.3%), cold (4NRV, 9.2%) and warm (8NRV, 3.4%). The extremely cold weather (3NRV) has the minimum frequency (1.4%).

Days with positive air temperature during the day make over one half of the spring season. Frequency of occurrence of cold weather amounts to 21.89%. Nearly 90% of all days of this season are characterized by air temperatures around zero ($-5.0°C < t_{mean} < +5.0°C$). In comparison with the preceding season, in the spring days with cloudy or overcast skies (75% of days), days with atmospheric precipitation and also days with cloudy skies and simultaneous precipitation are observed more frequently. The frequency of high winds decreases, and weather types with extreme wind velocities are not recorded at all.

During the spring only 118 types of weather occurred (over 33% less than in the winter season) and types belonging to the moderately warm class dominate. These are types 7311 (with cloudy or overcast state of the sky, with precipitation and a breeze), 7301 (with cloudy or overcast state of the sky, without precipitation and with a breeze). Types 6301 (transitional, frosty-thawing, with partly cloudy sky, without precipitation and with a breeze) in third place. Cumulatively they are over 33% of all weather types encountered in this season.

From the classes of weather one may assert that the spring is more homogeneous than the winter, because one class is observed on average for 15 days, that is 25% of season's duration. the three most frequently recorded classes of weather last for over 60% of the season's duration. Most often observed are T311 (with cloudy or overcast state of the sky, with precipitation and a breeze), T301 (with cloudy or overcast state of the sky, without precipitation and with a breeze) and T201 (with partly cloudy state of the sky, without precipitation and with a breeze).

13.3.3. Summer (July 11 – August 31)

The structure of the weather states shows that the summer is the most homogenous season. During the summer only four groups of weather appeared, with two of them, the moderately warm (7NRV) and the warm (8NRV) encompassing over 95% of the season. Transitional, freezing-thawing weather has a frequency of 4.45%. The summer is the season in which the very warm weather (9NRV) was recorded, which appeared only once during 27 years.

During the summer, a very high frequency (over 95%) of weather with minimum diurnal air temperatures higher than 0°C is observed. In the remaining part of this season, the freezing-thawing temperature range is recorded. Weather with air temperatures around zero occur during over 90% of summer duration. This is the most cloudy and rainy season. Cloudless weathers appear only sporadically (3.0%). Although weather types with breeze are unquestionably dominant, weather with strong winds and occasional hurricane winds are a prominent percentage of this season.

The occurrence of 28 weather classes was recorded during the summer. Weather of classes: 311 (30.0%) and 301 (20.3%) clearly dominates. These two classes of the weather encompass over half of the season.

Three types of weather comprise over 40% of all recorded types. The first is type 7311 (moderately warm, with cloudy or overcast skies, with precipitation and a breeze, 21.9%), and the second 7301 (moderately warm, with cloudy or overcast state of the sky, without precipitation and with a breeze, 14.3%). The warm weather with the same cloudiness but with precipitation and a breeze has a frequency of 6.0%.

13.3.4. Autumn (September 1 – October 20)

Six groups of weather were recorded during this season. The freezing-thawing groups (6NRV, 38.6%) and the moderately warm groups have similar frequency (7NRV, 30.9%) and dominate Hornsund during the autumn. The moderately cold group (5NRV, 17.6%) and the warm group (7.8%) as well as the cold group (4.1%) are recorded more rarely. This is the only season in which frequency of the transitional and warm weathers groups is similar. In this season weather with air temperatures passing through 0°C occur on average 36 days (for 40 days of its duration). Such a distribution of weather groups y and the dominance of transitional weathers shows the temporary character of this period.

The autumn is characterized by a significant frequency of the windy weathers: with a strong wind and also with a breeze with periods of strong wind, stormy weather is also recorded. Cloudy or overcast skies dominate, as in the spring.

Two weather classes, T311 (with cloudy or overcast skies, with precipitation and breeze) and T301 (with cloudy or overcast skies, without precipitation and with a breeze) make cumulatively over 40% of the autumn duration. In the autumn 27 classes of weather were observed.

Among dominating types of weather are 7311 (moderately warm, with cloudy or overcast state of the sky, with precipitation and a strong wind, 11.9%), 6311 (transitional, freezing-thawing, with cloudy or overcast skies, without precipitation and with a breeze, 7.1%) and 7301 (moderately warm, with cloudy or overcast skies, without precipitation and with a strong wind, 6.4%). In total, 1000 different types of weather were recorded in this season.

13.3.5. Remarks on the observed climatic seasonality

The weather seasons at Hornsund are characterized by a small degree of internal contrast in conditions (Ferdynus 2005). Duration of the winter (212 days – over half of the year) and its number of weather types (167) show that it is the most dynamic season in relation to the variety of weather. The summer is different, lasting only 52 days and characterized by the most monotonous and homogenous structure. During the summer only 85 weather types occurred (33% less than in the winter) and two dominating types encompassed nearly 40% of this season on average. The spring and the autumn are characterized by a similar structure of weather states, although the autumn is shorter and more dynamic than the spring, having 11 more types of weather. The autumn is also colder than the spring. In both these periods transitional weather types, freezing-thawing play a significant role; they encompass 40% of the autumn duration and nearly 35% of the spring duration. The overwhelming dominance of weather types with mean diurnal air temperatures in the range from –5 to +5°C (over 90%) is also interesting.

The weather seasons defined here do not refer to the thermal or astronomic seasons of the year. These seasons do not show associations with the beginning or the end of polar day and night either (Ferdynus 2005). Both the beginnings and ends of the seasons show substantial shift of time of their occurrence in relation to the distribution of insolation. The winter and the autumn at Hornsund undoubtedly lead their calendar counterparts, by four and three weeks respectively. Both the spring and the summer lag (are delayed) in relation to it, by five and two weeks in relation to beginning of the calendar spring and summer. After the winter the duration of the consecutive weather seasons is characterized by is characterized by shorter and shorter duration (212, 61, 52 and 40 days respectively).

One should regard both shift of the beginning and the end of the weather seasons and their duration as specific features of the Hornsund climate. The subpolar climate with oceanic features such as Hornsund represents characterized among others by substantial elongation of the transitory seasons of the year, and especially the autumn. In the case of Hornsund the fact that the autumn lasts only 40 days should be associated with the location of this station at high latitudes (φ = 77°00´N) and with the local conditions of its environment, first of all with periodic formation of sea ice cover on the Barents Sea east of Spitsbergen, which cuts off the flow of heat from the ocean to the atmosphere and contributes to earlier "winter arrival" and thus shortening of the autumn.