11. ATMOSPHERIC PRECIPITATION

11.1. General information, materials and methods

The location of Hornsund at high latitude decides the type of climate occurring there, and also the characteristic features and variability of atmospheric precipitation (RR), which is one of the most crucial climatic components. The great importance of RR at high latitudes results from few significant factors. It is an important component of the mass balance of glaciers, plays a crucial role both in the accumulation process if it appears in the solid form as snow, and in the ablation process if falls in the liquid form as rain. RR determines the snow cover, which influences the radiational balance of these regions. One may state that RR, in a direct or indirect way, exerts influence on a number of features of the geographical environment.

The studies concerning atmospheric precipitation on Spitsbergen may be divided in relation to the problems they considered. In the oldest papers issues connected with general climatic conditions were usually considered, with RR being one of many analysed components of the climate (Baranowski 1977, Markin 1975, Pereyma 1983, Rodzik and Stepko 1985, Kierzkowski 1996, Głowacki and Niedźwiedź 1997). General analysis of RR, together with the air temperature, during instrumental observations in the Arctic including Spitsbergen, may be found in the studies of Przybylak (1996c, 1997, 2002, 2003). Analysis of multiannual variability of precipitation totals and number of days with precipitation exceeding different threshold values at Hornsund in 1978–2000 was carried out by Łupikasza (2002 a), plus issues of RR variability within the annual cycle (Łupikasza 2002b) and the changes of intensity of diurnal RR at Hornsund (Łupikasza 2009). The next group are writings in which attempts to explain the dynamics of precipitation on Spitsbergen were by atmospheric circulation (Niedźwiedź and Ustrnul 1988a, Przybylak and Marciniak 1992, Łupikasza and Niedźwiedź 2002, Niedźwiedź 2002, Łupikasza 2008a). Analysis of RR with consideration of the modes of its occurrence was undertaken relatively seldom; amongst the oldest studies one should mention the work of Baranowski (1977), in which there was broad emphasis on the genesis of snow fall, which on Spitsbergen is associated with low pressure systems wandering eastwards in the south. This study concerns the general sum of precipitation in the accumulation periods, in which RR most often occurs in the solid form. The changes of climate occurring nowadays were the motivation to consider the annual cycle and multiannual variability of RR, with its occurrence as rain or snow being taken into account (Łupikasza 2003) and the interrelationships with air temperature (Łupikasza 2008 b).

Numerical data used in this study include diurnal totals of RR from July 1978 to December 2009 and originate both from the published yearbooks and from private collections. Data from August 1981 to August 1982 are from the collection of M. Sobik, Department of Meteorology and Climatology, University of Wrocław. In order to associate RR data with atmospheric circulation a calendar of synoptic situations types elaborated by Niedźwiedź (2009) was used. The collected numerical data are not complete. Gaps both in diurnal data and term data appear from July 1 to

July 26, 1981. For the days: 04, 07, 09 and 18 July 1979 diurnal totals of RR were not measured. It should be also noted that in a small number of cases inconsistencies of term and diurnal data for the amount of precipitation and record of other meteorological phenomena were found. After detailed analysis of data, these inconsistencies were corrected. Discussing the quality of the numerical data used there is no way to avoid mention of a problem connected with the accuracy of RR measurement, which at high latitudes increases in importance. According to Aguado and Burt (1999), Spitsbergen is located in the zone where the error resulting from inadequacies in measurement methods and weather conditions may reach 20-39% of measured annual totals. One may suppose that the totals of snowfall have the highest error.

In this study the climatologic characteristics of atmospheric precipitation, both in the aggregate and with allowance for mode of occurrence (liquid, mixed and solid precipitation) were investigated. Besides the characteristics of the annual mean values and analysis of extreme values, attention was also paid to aspects of multiannual variability and synoptic conditions of RR occurrence. During the analysis, attention was concentrated on monthly and annual totals. Given that in the Polar Regions the accumulation period (September-May) is regarded as crucial for glaciological research, values of indices for this period of the year were also analysed. In addition, in the section concerning trends and other features of RR, there were also calculations for standard seasons of the year (spring: March-May, summer: June-August, autumn: September-November, winter: December-February). This will allow comparison of results with those of investigators dealing with similar problems in the other regions.

In this study, three forms of atmospheric precipitation were considered – liquid, mixed and solid. The form of precipitation was determined based on the closest temporal atmospheric records. Additional criteria were mean, maximum and minimum diurnal air temperatures measured at a height of 200 cm above the ground. In the event of the gap in the record of complete atmospheric phenomena, current and last weather (August 1, 1981 – August 15, 1982) only thermal criteria were used; hence, numerical data for this period may contain minor inaccuracies in the type of precipitation, especially in the transitional months (Łupikasza 2003).

In connection with the fact that the method of recording of the meteorological data hindered examination of each case of occurrence of precipitation, analysis was done for days with liquid precipitation (when only rainfall or drizzle occurred during the entire precipitation day), days with mixed precipitation (when both rainfall, snowfall and snow with rain together occurred during the day) and days with solid precipitation (when only snowfall occurred during the entire precipitation day). The concept of precipitation day is understand as the time from 6 am GMT of a given day to 6 am GMT of the next day, in agreement with the method accepted in most European countries.

11.2. Distribution of monthly means and annual totals of precipitation

In association with the small content of water vapour in the air due to the low air temperature, the Polar Regions are relatively poor in RR (Przybylak and Marciniak 1992). The Hornsund region, under the strong influence of atmospheric circulation over the Greenland and Norwegian Seas, is characterized by relatively high precipitation for the Arctic, however (Niedźwiedź 2002). As Steffensen (1982) stated, among stations located on the western coast of Spitsbergen, only the Isfjord Radio station recorded higher RR than at Hornsund (435 mm – from data in 1951–1975). Stations

located in the island's interior record only half of the RR noted on the west coast. For example, at the Longyearbyen station in the interior the annual total of RR in 1976–1985 amounted only 208 mm, whereas at Hornsund over the same time, annual precipitation was around 406 mm. At least two times greater totals of RR occur in the mountains, on the firn fields of the glaciers (Markin 1975).

At Hornsund, the grand mean annual RR in 1979–2009 was 434.4 mm, ranging between merely 230.2 mm (1987) to 635.9 mm (1996). Comparatively high annual precipitation appears in the southern islands of archipelago: Hopen (431.6 mm) and Björnöya (415.6 mm). At the stations on Spitsbergen north of Hornsund annual RR is considerably lower (Table 11.1). At the Svalbard Lufthavn station on average 184.7 mm falls in a year, and at the Sveagruva station 264.6 mm was recorded annually (means for 1979-2002). Higher annual totals of precipitation than the maximum for Hornsund given above occurred only at the Hopen station in 1983 (755.9 mm) and in 1995 (638.9 mm), and at the Ny Ålesund station in 1993 (675.3 mm).

Table 11.1. Comparison of mean multiannual precipitation totals (mm) at Hornsund and other Svalbard stations, 1979–2009.

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Ny Alesund *	39.6	35.8	42.8	27.5	15.3	16.8	27.2	38.2	49.8	36.9	39.3	39.5	408.6
Svalbard-Luft.*	14.9	16.6	17.6	10.9	6.0	9.6	15.7	22.7	21.6	13.5	17.6	17.8	184.7
Hornsund	**30.5**	**27.8**	**28.5**	**23.3**	**19.3**	**29.4**	**41.0**	**53.0**	**64.4**	**45.2**	**38.9**	**32.6**	**434.4**
Bjornoya *	42.6	39.8	36.0	31.1	21.8	20.1	25.1	30.1	47.2	43.4	38.0	40.6	415.6
Hopen *	44.9	37.5	40.6	32.7	21.9	24.1	23.9	34.9	41.9	42.0	39.7	47.4	431.6
Hornsund – Svalbard-Luft.	15.6	11.2	10.8	12.4	13.3	20.0	25.1	29.3	44.6	32.2	20.1	15.6	250.1

* – data from the Norwegian Meteorological Institute (eKlima)

At Hornsund, the highest RR was in the warmer part of the year (Table 18.27). This is connected with the higher air temperature then, which strongly influences the water vapour content in the air, and with increase of frequency of occurrence of cyclonic situations (Przybylak and Marciniak 1992). The highest mean monthly total was in September (64.4 mm). During this month around 15% of the annual total falls. In September the highest monthly precipitation at Hornsund, amounting to 230.4 mm, was also recorded in 1999. It is worth noting that this precipitation was higher than the lowest annual total of 230.2 mm measured at the station in 1996 (Table 11.2). Relatively high RR, on average exceeding 40 mm, appeared also in July (41.0 mm), August (53.0 mm) and October (45.2 mm). These months were also characterized by a greater range of RR changes in comparison with the other months of the year. In addition, the Svalbard Lufthavn station is characterized by concentration of RR in the warmer part of the year (Table 11.1); at this station the highest monthly total was in August (22.7 mm; 12.3% of annual total), but RR in September was only slightly lower (21.6 mm; 11.7% of the annual total). Maximum RR in September appeared also at the Björnöya station (46.2 mm, 11.1% of the annual total) located to the south-west and at the Ny Ålesund station (49.8 mm, 12.2% of the annual total). September was a month abounding in precipitation also at the Hopen station (42.7 mm, 9.9% of the annual total), but precipitation totals there in January and December are somewhat higher – 44.9 mm and 47.6 mm, respectively. Both at the Hopen station and at the Björnöya station precipitation is concentrated rather in the colder part of the year, in contrast to Hornsund (Table 11.1).

Table 11.2. Mean, the highest (Max) and the lowest (Min) monthly precipitation RR totals [mm] for accumulation period (A) and year at Hornsund in 1979–2009.

Month	Mean	%	Max	Year	Min	Year	Max – Min
January	30.5	7.0	108.3	1996	4.7	1994	103.6
February	27.8	6.4	61.5	1984	0.3	1988	61.2
March	28.5	6.6	72.6	1986	1.9	2008	70.7
April	23.4	5.4	89.1	1982	2.1	1985	87.0
May	19.3	4.4	48.1	1995	5.2	1989	42.9
June	29.4	6.8	107.1	1988	1.4	1987	105.7
July	40.9	9.4	136.5	1994	1.5	1998	135.0
August	52.0	12.0	121.5	1996	11.6	1988	109.9
September	66.1	15.2	230.4	1999	2.6	1982	227.8
October	45.7	10.5	133.6	2000	6.2	1981	127.4
November	37.7	8.7	111.7	1993	7.0	1983	104.7
December	33,2	7.6	125.4	1995	3.5	1987	121.9
A	314.8	71.8	448.5	2009	160.3	1987	288.2
Year	434.4	100.0	635.9	1996	230.2	1987	405.7

A – accumulation period (September-May), % – percentage of mean monthly precipitation total in the mean annual total.

At Hornsund the lowest mean monthly RR, merely 4.4% of the annual total, occurred in May (19.3 mm). This month is characterized also by the smallest range of changes (Fig. 11.1). Minimum RR in May is connected with the high frequency of high-pressure systems over Spitsbergen (Niedźwiedź and Ustmul 1988a). However, the lowest recorded monthly precipitation, only 0.3 mm, occurred not in May but in February 1988. The minimum in May is a characteristic feature of the annual course of RR at most of the Spitsbergen stations. At Hornsund, from May to September inclusive, a gradual but very clear increase of monthly totals of RR is observed. In winter, there is a moderately even level, whereas in the transitional seasons of the year totals are decreasing.

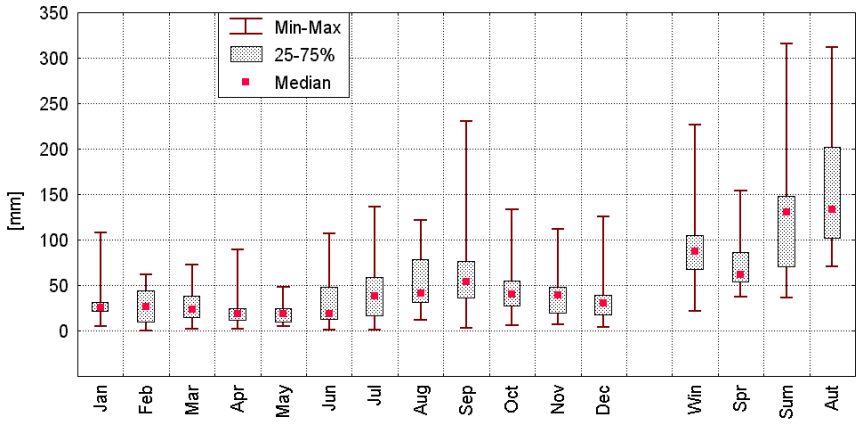

Fig. 11.1. Range of variability of monthly and seasonal totals of atmospheric precipitation RR [mm] at Hornsund in 1978–2009. Win – winter (DJF), Spr – spring (MAM), Sum – summer (JJA), Aut – autumn (SON)

The annual cycle of RR at Hornsund in consecutive years (Table 18.27) may significantly differ from the mean. During regular instrumental measurements, monthly maximum RR was recorded at least once in each month of the year with the exception of February and May.

Great differences in monthly maximum RR also occurred at the Svalbard Lufthavn station and the Hopen station. Maximum RR appeared there at least once in almost every month of the year with the exception of May at Svalbard Lufthavn and June at Hopen. At Hornsund during the 31 years (1979–2009) the highest monthly precipitation occurred 8 times in September, 5 times in July and 4 times in August and November.

At the Svalbard Lufthavn station the highest monthly RR was most often in September (7 times), and relatively often in August, February and March (5 or 4 times). At this station after 1996, however, monthly maximum precipitation occurred exclusively in the July to December period, showing that monthly maximum precipitation was moved to the second part of the year.

Such changes to some degree are observable also at Hornsund where, after 1993, monthly maxima RR also occurred only in the second part of the year, between July and December. An exception was 2006 when the highest monthly precipitation occurred in January. It should be also noted that in the earlier period, covering the 14 years from 1979 to 1992, monthly maxima were recorded only 5 times in the first half of the year (in March, April and June).

At the Björnöya station, as at Hornsund, monthly maximum RR occurred mainly in September (9 times) and October (6 times). At Ny Ålesund the highest monthly totals also appeared definitely the most frequently in September (8 times) and relatively frequently in March (5 times). At Hopen, the greatest frequency of maximum occurrence was in December (6 times).

Mean monthly minimum RR also appeared almost in each month at Hornsund. Most often these minima were recorded in May (7 times); next were 4 times each in March, April and June. The only month in which the lowest monthly total was never recorded during a year was August. For comparison, at the Björnöya and Hopen stations monthly minima usually occurred in July (11 and 10 times, respectively), at the Svalbard Lufthavn and Ny Ålesund stations in May (10 and 8 times, respectively) and in June (9 and 6 times, respectively). Pereyma (1983), Rodzik and Stepko (1985) as well as Niedźwiedź and Ustrnul (1988), who analysed atmospheric precipitation at Hornsund in other shorter periods, besides mentioning a characteristic minimum in May wrote also about equally low precipitation in December and January. Analysis of types of annual cycle of precipitation at Hornsund in consecutive years shows that in the first half of the observation period (1979–1993), the amount of precipitation was relatively small in two months (December and January). In the second half (1994–2005) increase of variability of patterns of precipitation distribution during a year in successive years was observed.

Table 11.3. Linear correlation coefficients of monthly and annual totals of atmospheric precipitation RR at Hornsund with atmospheric precipitation at the stations of western Spitsbergen in 1978–2009. Correlation coefficients significant at the level $p < 0.05$ are shown in bold.

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Ny Alesund	**0.78**	**0.64**	**0.62**	**0.43**	0.13	**0.58**	**0.64**	**0.52**	**0.54**	**0.56**	**0.67**	**0.60**	0.20
Svalbard-Luft.	0.34	**0.56**	**0.55**	**0.51**	**0.42**	**0.64**	**0.78**	**0.38**	**0.62**	**0.74**	**0.52**	**0.81**	0.19
Bjornoya	0.14	–0.02	–0.21	0.19	–0.07	**0.40**	**0.36**	0.29	0.02	0.10	0.34	0.12	**0.40**
Hopen	0.30	0.05	0.13	–0.01	0.31	0.26	**0.37**	0.04	–0.06	0.11	–0.23	0.02	0.07

The multiannual patterns of monthly precipitation totals at Hornsund were almost significantly correlated with the patterns at the Ny Ålesund station (with the exception of May) and at the Svalbard Lufthavn station (with the exception of January) over the whole year. Such associations are not seen with the patterns recorded at stations located south of Hornsund on the small islands of Björnöya and Hopen. These are definitely weaker and concern only single months in the warm part of the year (Table 11.3).

11.3. High diurnal precipitation

At Hornsund mean maximum diurnal precipitation changes from 7.5 mm in May to 18.0 mm in September, surpassing a threshold of 10 mm in the months of the second half of the year, July to December (Fig. 11.2, Table 18.28). August and September were distinguished, in comparison with other months in the year, by the greatest range of changes (54.3 mm and 51.9 mm, respectively) and by standard deviations (11.6 mm and 12.7 mm, respectively) of maximum diurnal RR (Table 11.4).

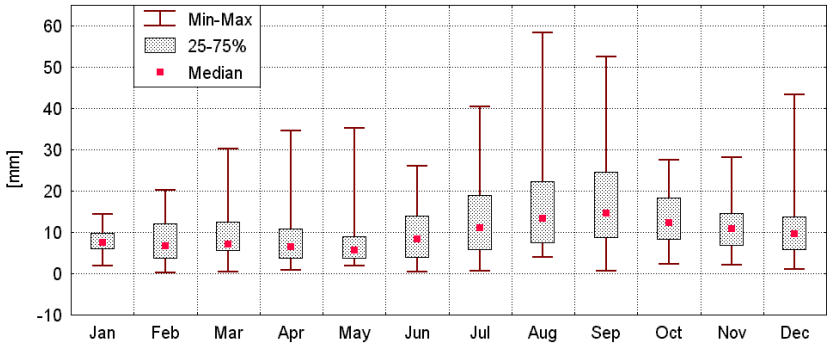

Fig. 11.2. Range of variability of monthly maximum diurnal totals of atmospheric precipitation RR [mm] at Hornsund in 1978–2009.

Table 11.4. Mean monthly maximum diurnal totals of atmospheric precipitation RR and their standard deviations (σ_n) as well as the lowest (Min) and the highest (Max) diurnal total RR in the month recorded at Hornsund, 1978-2009.

	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Mean	8.1	7.9	9.3	8.1	7.5	9.9	13.4	16.5	18.0	13.6	11.0	10.8
σ_n	3.1	5.2	6.0	6.7	6.6	7.4	9.5	11.6	12.7	7.0	6.2	7.8
Min	1.9	0.2	0.5	0.8	1.8	0.4	0.6	4.0	0.7	2.3	2.0	1.1
Max	14.4	20.3	30.3	34.5	35.3	26.0	40.5	58.3	52.6	27.6	28.1	43.4

The absolute values of the given meteorological parameters are a crucial characteristic of climatic conditions as well as mean values. Although at Hornsund atmospheric precipitation was not high, there were days during which the recorded diurnal total exceeded the mean totals characteristic of the majority of months in the year. At Hornsund, the highest absolute daily precipitation, 58.3 mm, was measured on August 1, 1994. Diurnal totals recorded on September 6,

1996 (52.6 mm), September 12, 2001 (43.9 mm), September 11, 1990 (43.6 mm) and December 3, 1995 (43.4 mm) may also be classified as very high. During the entire period of record at Hornsund there were only 6 occasions when the daily total exceeded 40 mm. There were 18 days when diurnal precipitation was higher than 30 mm (seven of them occurring in September) and 64 days when exceeded 20 mm. Selected examples of high diurnal precipitation at Hornsund, exceeding a threshold value of 20 mm, are compiled in Table 11.5.

Table 11.5. Diurnal totals of precipitation ≥ 20 mm together with the Niedźwiedź type of synoptic situation, July 1978 – July 2010.

Month	RR [mm]	Date	Circulation type	Month	RR [mm]	Date	Circulation type
Jan	**22.3**	2010 Jan 26	Bc	**Sep**	43.6	1990 Sep 11	Sc
	20.8	2010 Jan 17	SWc		38.2	1994 Sep 02	SWc
Feb	**20.3**	2005 Feb 15	SWc		33.0	1996 Sep 19	SWc
Mar	**30.3**	2004 Mar 03	SWc		32.7	1999 Sep 11	Sc
	20.6	1983 Mar 01	SWc		32.2	1999 Sep 01	SWc
Apr	**34.5**	1982 Apr 06	Ec		27.5	2008 Sep 14	SWa
	25.2	2004 Apr 26	SWc		27.2	1999 Sep 27	Sc
May	**35.3**	2006 May 04	Sa		26.8	1993 Sep 26	Sc
Jun	**26.0**	1992 Jun 13	SWc		25.3	1999 Sep 12	Sc
	25.8	1983 Jun 13	Bc		26.0	2008 Sep 20	SWc
	25.1	1994 Jun 29	SWc		24.7	2007 Sep 27	SWc
	20.2	1996 Jun 2	SWa		24.0	2009 Sep 26	Ec
	20.2	2006 Jun 18	SWc		22.7	2004 Sep 04	Sc
Jul	**40.5**	1986 Jul 28	Sc		21.9	1980 Sep 28	Sc
	33.1	1994 Jul 19	SWc		20.9	1999 Sep 14	Sa
	29.7	1978 Jul 30	SWc	**Oct**	**27.6**	2000 Oct 05	SWc
	25.4	2005 Jul 11	SWc		27.1	1998 Oct 06	SWc
	25.3	1996 Jul 23	Sc		26.1	2000 Oct 04	Sc
	20.3	1988 Jul 14	Sc		25.1	1994 Oct 10	Sc
	20.3	2004 Jul 30	SWa		24.2	2004 Oct 01	SWc
Aug	**58.3**	1994 Aug 01	SWc		24.1	2009 Oct 30	x
	33.4	1990 Aug 30	Sa		21.4	1980 Oct 04	SEc
	32.4	2004 Aug 21	SEc		21.7	2009 Oct 23	Ka
	31.7	1989 Aug 02	SEc		21.0	1994 Oct 31	SEc
	27.6	1999 Aug 30	Sc		20.8	2009 Oct 17	Cc
	27.0	2008 Aug 10	Cc		20.5	1999 Oct 16	Bc
	26.7	2000 Aug 02	SWc	**Nov**	**28.1**	1978 Nov 08	Sc
	22.0	1996 Aug 29	SWc		27.2	2009 Nov 04	Bc
	22.6	1982 Aug 07	Ka		20.8	2009 Nov 01	SWc
	20.5	2004 Aug 20	SEc	**Dec**	**43.4**	1995 Dec 03	SWc
Sep	**52.6**	1996 Sep 06	SWc		32.7	1995 Dec 25	Wc
	43.9	2001 Sep 12	Sc		20.2	2002 Dec 07	SWa

High diurnal precipitation (>20.0 mm) appeared most often at Hornsund between August and October. Among the 64 cases of occurrence of RR exceeding the threshold of 20 mm, 10 cases were recorded in August, 17 in September and 11 in October. The lowest maximum precipitation was in January; for most of the years of record, the highest diurnal total RR in January amounted to only 14.4 mm (January 16, 2006), a relatively low value in comparison with the remaining

months. Diurnal precipitation in January exceeded the threshold value of 20 mm for the first time in 2010, occurring twice – on January 17 and 26.

In the opinion of Niedźwiedź (2002), at Hornsund once every 70 days one may expect occurrence of diurnal precipitation exceeding 10 mm, once every 200 days – higher than 20 mm, and once for 600 days – 30 mm and greater. Diurnal precipitation higher than 40 mm may be expected once for 1750 days, i.e. more or less once in five years, and RR higher that 50 mm may occur once in 14 years. An attempt to estimate greater precipitation (not yet recorded at the Hornsund station) was made by Niedźwiedź (2002), showing that the chance of occurrence of precipitation of 60 mm is once in 40 years, whereas RR around 70 mm and greater should be classified as rare phenomena, occurring in this region less once in a century.

11. 4. Number of days with precipitation

A crucial characteristic of precipitation conditions is frequency of occurrence, both over the year and for shorter periods. In this study the annual incidence of all precipitation, including trace amounts (>0.0 and <0.1 mm) and number of days with RR ≥0.1 mm was analysed. Precipitation at Hornsund occurred for an average of 242.5 days, that is 66.4% of the days in a year (Tables 11.6 and 18.29), but only around 46.7% (170.7 days) were days when RR exceeded the threshold measurement accuracy of the pluviometer (≥0.1 mm) (Tables 11.7 and 18.30). This means that the frequency of trace precipitation, < 0.1 mm, amounts on average to 19.7% of days in the year. At other Spitsbergen stations percentage of days with precipitation ≥0.1 mm ranged from 36.8% (Sveagruva, mean for 1979–2002) to 66.5% (Björnöya); at the Svalbard Lufthavn station it amounted to 51.4% days in a year.

Table 11.6. Mean, the highest (Max) and the lowest (Min) number of days with precipitation ≥0.0 mm for months, accumulation period (A) and year at Hornsund in 1979–2009.

Month	Mean	%	Max	%	Year	Min	%	Year
January	21.7	70.1	31	100.0	1990	15	48.4	1980
February	19.4	68.6	27	93.1	1984	9	31.0	1988
March	19.8	63.9	29	93.5	2004	10	32.0	2006
April	18.4	61.3	28	93.3	2006	11	36.7	2009
May	19.9	64.1	29	93.5	1992	11	35.5	1980
June	18.5	61.6	27	90.0	1999	9	30.0	1997
July	17.4	56.2	30	96.8	1994	3	9.7	1997
August	19.6	63.5	27	87.1	1982	12	38.7	2003
September	21.7	72.5	27	90.0	1989	11	36.7	1982
October	23.2	74.9	30	96.8	1997	16	51.6	1995
November	21.8	72.7	29	96.7	1998	14	46.7	1980
December	210	67.7	29	93.5	2004	12	38.7	1996
A	186.6	68.3	219	80.2	1989*	152	55.7	1987
Year	242.5	66.4	275	75.3	1990	200	54.6	1980

* the same value occurred also in 1990, A – accumulation period (September-May),
% – percentage of days with precipitation ≥0.0 mm in month, accumulation period and year.

Table 11.7. Mean, the highest (Max) and the lowest (Min) number of days with precipitation ≥0.1 mm for months, accumulation period and year in 1979–2009.

Month	Mean	%	Max	%	Year	Min	%	Year
January	15.9	51.3	23	74.2	2006	5	16.1	2003
February	14.5	50.8	23	82.1	1984	2	6.9	1988
March	14.4	46.3	24	77.4	1996	6	19.4	2002
April	12.5	41.7	20	66.7	1989	7	22.6	2000*
May	11.9	38.3	19	61.3	1995	2	6.5	2002
June	12.2	40.4	21	70.0	1999	5	16.7	2000
July	13.2	42.5	27	87.1	1994	2	6.5	1979
August	15.2	48.9	23	74.2	2006	7	22.6	2003
September	15.9	52.8	24	80.0	1999	7	23.3	1982
October	15.4	49.7	24	77.4	1999	5	16.1	1981
November	15.4	51.0	26	86.7	1990	7	23.3	1983
December	14.3	46.0	26	83.9	1993	6	19.4	1987
A	129.8	47.5	174	63.7	1990	102	37.4	1987
Year	170.7	46.7	217	59.3	1984	133	36.4	2003

* identical value occurred also in 2007 and 2008, A – accumulation period (September-May), % – percentage of days with precipitation ≥ 0.1 mm in the month, accumulation period and year.

At Hornsund there were three months when frequency of days with RR>0.0 mm exceeded 70% on average – September 72.5%, October 74.9%, November 72.7%. January 1990 was unique in the record, when RR was recorded every day. Very frequent precipitation (for nearly 97% of days in the month) occurred also in July 1994, October 1997 and in November 1998. In turn, July 1997 was characterized by least number of days (around 10% of days) with precipitation (Tables 11. 6 and 18.29).

The number of days with RR ≥0.1 mm reached or exceeded 50% in August (48.9%), September (52.8%), October (49.7%), November (51.0%), January (51.3%) and February (50.8%). July 1994 and November 1993 are noteworthy because the frequency reached around 87% then. Noteworthy also are February 1998, May 2002 and July 1979 when precipitation ≥0.1 mm appeared only two days in each(Tables 11.7 and 18.30).

The annual courses of number of days with precipitation >0.0 mm and with precipitation ≥0.1 mm both display bimodal character, a feature which is observed at most of the Spitsbergen stations. In both cases the maximum frequency at Hornsund occurs at the beginning of the climatologic autumn; in September in the case of precipitation ≥0.1 mm, and October in the case of precipitation >0.0 mm. The second maxima were recorded in January or February.

For the case of minimum frequency of precipitation days, the situation was slightly different. The principal minimum of number of days with precipitation ≥0.1 mm appeared, as in the case of precipitation totals, in May (38.3% of days in the month). July was characterized by the lowest frequency of number of days with precipitation >0.0 mm (around 56.2% days in the month). In May, days with precipitation >0.0 mm occurred more often (on average for 19.9 days, or around 64%) than in March, April, June and July. Such a situation emphasizes the greater frequency of trace precipitation in May. The second minimum in both cases appeared in December (Fig. 11.3). At the other meteorological stations, the principal minima of number of days with precipitation ≥0.1

mm occurred usually in June or sporadically in July (Hopen). The second minima appeared in December, as at Hornsund.

The annual pattern of number of days with RR >0.0 mm and RR ≥0.1 mm, like the distribution of RR totals during a year, is characterized by considerable multiannual variability (Tables 18.29 and 18.30), especially with reference to the months of maximum and minimum frequency. During the period of record the highest monthly number of days with RR >0.0 mm was recorded the most often in October (eight times) and only slightly less often in September and November (six times each). Monthly maximum of frequency of such days never occurred between April and July. Monthly minima of number of days with RR >0.0 mm most often occurred in March, June and July (six times each). Somewhat different was the occurrence of extreme values of number of days with RR ≥0.1 mm. In 1979-2009, the greatest monthly number of such days occurred most often in September (seven times) and March (six times). The smallest monthly number of days with RR ≥0.1 mm was recorded usually in April and July (six times each). Monthly maxima and minima of frequency of days with RR ≥0.1 mm at Hornsund may be recorded in any month.

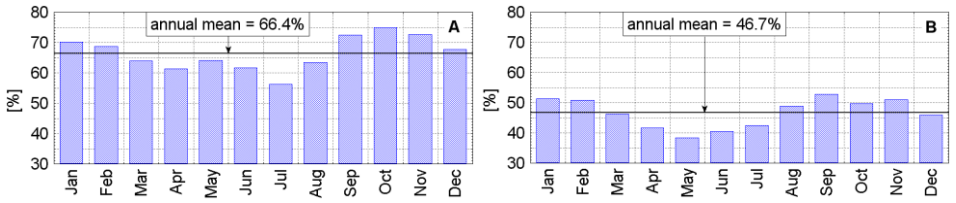

Fig. 11.3. Mean share (%) of number of days with RR >0.0 mm (A) and RR ≥0.1 mm (B) in the total number of days in a month at the Hornsund station in 1979–2009.

Attention should be paid to the observation that the mean monthly number of days with RR ≥0.1 mm did not change significantly during a year both at Hornsund and at the other stations on Spitsbergen. Mean range of changes of number of such precipitation days during a year amounted 4.0 days at Hornsund, and ranged from 4.6 days to 8.4 days at the other stations (Björnöya). This feature is associated with the distinct differentiation of peak monthly RR during a year, reflecting seasonal changes of mean diurnal RR which may be regarded as the index of intensity of daily precipitation. The annual cycle of intensity of diurnal precipitation in a monthly depiction stresses the annual course of monthly totals of precipitation. Hornsund is characterised by the greatest monthly differentiation of mean diurnal RR, with a maximum in September (4.6 mm) and minimum in May (1.6 mm), giving a range amounting to 2.5 mm. Great differentiation of intensity of diurnal RR was also observed at the Svalbard Lufthavn station (from 3.6 mm in July to 1.4 mm in March, a range of 2.3 mm). At the other stations ranges of mean diurnal precipitation during a year were significantly smaller (Sveagruva: 1.4 mm 1979-2002; Hopen 1.0 mm; Björnöya: 0.8 mm).

11.5. The annual cycle of atmospheric precipitation, taking the modes of occurrence into consideration

From the point of view of glaciology, an extremely crucial matter is determining what proportions of RR fall as liquid, mixed or solid precipitation. At Hornsund during a year the greatest part of RR

occurs in the liquid form, as rain or drizzle (44%); around 30% falls in the solid form and around 26% has the mixed form. Each of these forms of RR may occur at any time during the year at the Hornsund latitude. Nevertheless, the particular types of RR in general and over all precipitation days show distinct differentiation during the annual cycle.

Rain supplies the greatest part of RR between June and September. In the warmest months of the year, July and August, it accounts for over 90% of the total (Fig. 11.4 a). The annual pattern of snow fall in monthly total RR is the opposite. From January to April, solid precipitation makes up around 60% of precipitation, and the contribution of mixed precipitation is also substantial (from 27.0 to 38.4% of the total). In warmer part of the year, which at Hornsund may be defined as the period from June to September, the contribution of solid precipitation to the monthly totals ranges from scarcely 0.3% (July) to 6.4% (June). From October to December, both solid and mixed precipitations contribute greater and greater proportions of the monthly totals.

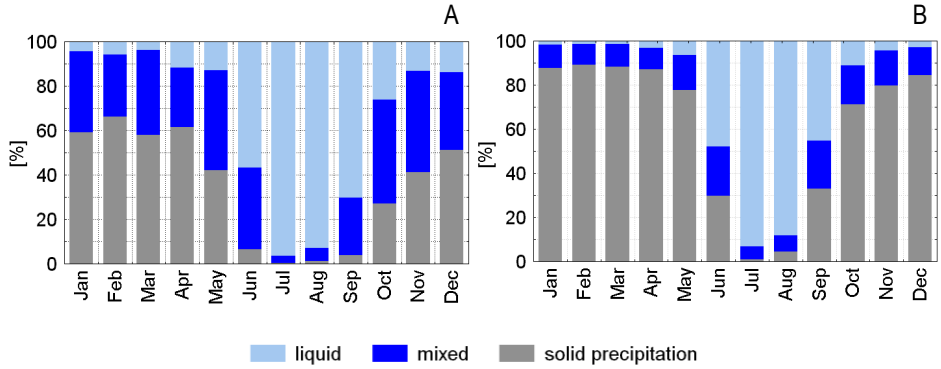

Fig. 11.4. Percentage of solid, mixed and liquid precipitation in monthly totals (A) and in monthly number of days with precipitation (B) at Hornsund, 1979–2009.

Comparing percentage of solid and mixed precipitation in the total RR and number of days with precipitation in January-June, one may conclude that during mixed precipitation distinctly more water reaches the surface than during snow fall (Fig. 11.4). Mixed precipitation has the smallest range over the annual course, both in relation to contribution to monthly totals and to monthly number of days with RR. In contrast to rain or snow, mixed precipitation in any month supplies neither the greatest proportion of total RR nor the number of days with precipitation. Mixed conditions occur in a greater number of days with precipitation in June and September than in the other months (22.6 and 20.0%, respectively). Mixed precipitation in May, October and November contributed a greater proportion to monthly totals RR (45.1%, 46.7%, 45.7%, respectively) than in the other months (Fig. 11.4 b).

11.6. Associations of precipitation with atmospheric circulation

At Spitsbergen, atmospheric circulation plays a crucial role in the development of weather. It influences the height and intensity of precipitation to a considerable degree. Its role is also manifested in the development of very intense precipitation.

At Hornsund the highest mean diurnal totals of RR occurred most often during the advection of warm and humid air from the South-West (6.1 mm) and the South (4.6 mm), when the archipelago was under the influence of low pressure systems. Inflow of air from these directions favours development of relatively large amounts of precipitation in anticyclonal situations also. Mean diurnal precipitation totals reached 3.8 mm at situation SWa and 2.9 mm at Sa (Fig. 11.5).

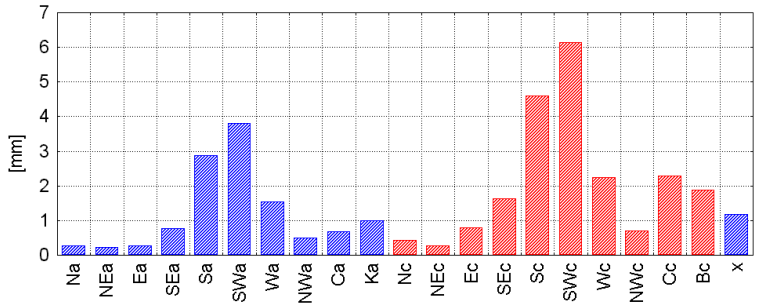

Fig. 11.5. Mean diurnal totals of atmospheric precipitation RR [mm] and the circulation types of Niedźwiedź (1979–2009).

The interrelation between amount of precipitation and atmospheric circulation at Hornsund showed some variability over the year (Fig. 11.6). In all seasons, the greatest mean diurnal totals came from the inflow of air from the SW in low-pressure systems. However, amount of this precipitation changed distinctly, from 5.3 mm in the spring to 8.0 mm in the autumn. Moreover, in the summer and in the autumn mean diurnal precipitation in type Sc (7.2 mm and 5.5 mm, respectively) was comparable with that in type SWc.

In all seasons the largest diurnal precipitation was recorded during the inflow of air from the South and/or the Southeast, and also during impinging of high-pressure systems on Spitsbergen. In such situations in the autumn and in the winter, the highest diurnal precipitation was undoubtedly associated with type SWa (5.9 mm and 3.6 mm, respectively). In the autumn moderate precipitation was also relatively high in types Wa (3.3 mm) and Sa (3.1 mm). In the summer and in the spring mean diurnal precipitation in type Sa (3.9 mm and 2.5 mm, respectively) was slightly higher than in type SWa (3.7 mm and 2.2 mm, respectively). Throughout the entire year the lowest diurnal precipitation was associated with the inflow of Arctic cold air from the North, regardless the character of the baric system (Fig. 11.6).

Considering the associations of precipitation with atmospheric circulation, it is also worth to pay attention to synoptic circumstances when there are high diurnal totals. To explore this, all total diurnal precipitation accumulations ≥20.0 mm in consecutive months of a year were selected. 64 cases of such precipitation events were chosen for compilation in Table 11.5. It is seen that big precipitation events are tightly correlated with the occurrence of two synoptic situations: the southwestern (SWc) and the southern (Sc) cyclonal (Niedźwiedź 2002). Among the 64 cases singled out, as many as 25 occurred during situation SWc and 15 during Sc, totalling 62% of the selected cases. The precipitation events that occurred on April 6 1982 (34.5 mm), August 7 1982

(22.6 mm) and October 23 2009, should be recognized as very exceptional. This precipitation occurred with situation Ec in the April 6 1982 event and type Ka for August 7 1982 and October 23 2009: the first two cases were preceded by type SWc conditions.

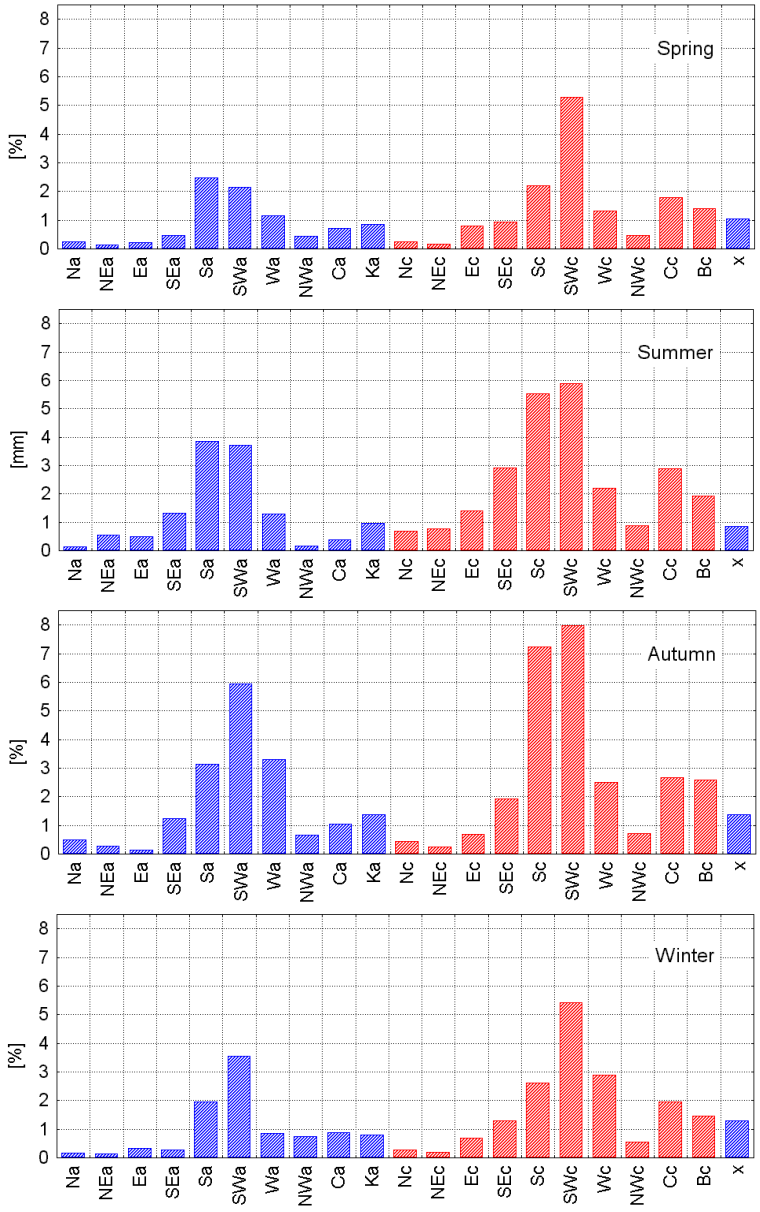

Fig. 11.6. Mean seasonal daily totals of atmospheric precipitation [mm] at Hornsund with types of circulation by Niedźwiedź, in 1979–2009.