7. CLOUDINESS AND SUNSHINE DURATION

7.1. Cloudiness

The Hornsund station is characterized by quite cloudiness (N). The multiannual mean annual cloudiness was 5.8 octa. Minimum annual N was 5.2 octa (in 1988); maximum was 6.4 octa (in 1984). Interannual variability of cloudiness was small; the standard deviation amounted to 0.28 octa.

Over the annual course of cloudiness there is a weakly emergent cycle of variability (Table 7.1 and Fig. 7.1). Greater N, exceeding 6/8 on average, occurred between June and September, lesser (below 6/8) between October and May. Minimum cloudiness occurred in December and January, the weak maximum in August. It is clear from the monthly standard deviations (Table 7.1) that there was especially great interannual variability of cloudiness in November, December and April. Variability of N between May and October was clearly lower. The range of variability of monthly N at Hornsund was great and amounted to 4.5/8. The smallest mean monthly N was 3.1/8 (December 2003), the greatest 7.6/8 in July 1994 (Table 18.11).

Table 7.1. Mean monthly cloudiness (N; octas) at Hornsund (1978–2009) and ranges of its variability: N_{min}, N_{max} – minimum and maximum cloudiness observed in a given month, $N_{med.}$ – most often observed cloudiness in a given month (median), σ_n – standard deviation.

	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
N	5.29	5.43	5.33	5.36	5.96	6.47	6.40	6.52	6.45	5.90	5.60	5.00	5.82
σ_n	0.76	0.80	0.71	0.93	0.47	0.49	0.62	0.43	0.52	0.57	0.93	1.10	0.28
N_{min}	3.6	3.7	4.2	3.7	5.0	5.5	4.4	5.5	5.4	4.6	3.6	3.1	5.2
N_{max}	6.7	7.2	6.9	7.3	6.8	7.2	7.6	7.3	7.4	7.1	7.1	7.0	6.4
$N_{med.}$	5.3	5.6	5.3	5.5	6.1	6.5	6.5	6.6	6.6	5.9	5.8	5.1	5.9

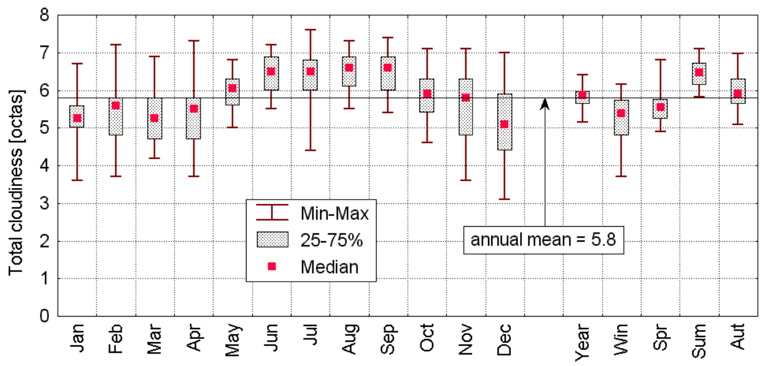

Fig. 7.1. The range of variability of cloudiness [octas] at Hornsund in 1978–2009.
Win – winter (DJF), Spr – spring (MAM), Sum – summer (JJA), Aut – autumn (SON)

Diurnal cloudiness is characterized by very great variability. Sequences of days in which cloudiness was the same, or changed in a range not exceeding one octa, were short. In synoptic observations relatively often may be found even 4 – 5 consecutive observations with N = 0. Diurnal mean N = 0 is met very seldom – to 9 days during a year (Fig. 7.2). There were also summers in which days with zero mean cloudiness were not found at all (Fig. 7.3). One of the reasons for such a situation is the occurrence of orographic clouds over the rising ground in the field of vision of observers at the Hornsund station. Such clouds change quickly together with change of wind direction, but seldom disappear. Sequences of days with mean diurnal complete cloud cover (N = 8) were recorded considerably more often.

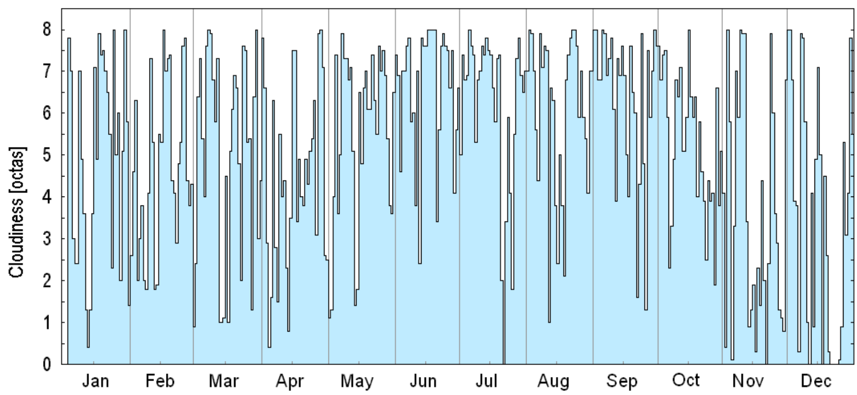

Fig. 7.2. Changes of diurnal cloudiness [octas] at Hornsund in 1988.

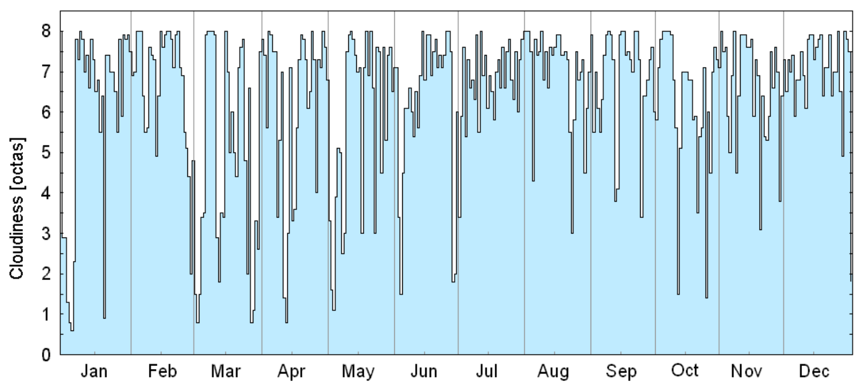

Fig. 7.3. Changes of diurnal cloudiness [octas] at Hornsund in 1984.

The frequency distribution of daily cloudiness is strongly skewed to the right. In all of the years days with mean N in the range from 7.01/8 to 8.00/8 were the most numerous on the octa scale. In particular years, the number of days with N in this range could differ significantly, even amounting to a few dozen (maximum difference is 74). In the second place were days with mean diurnal cloudiness in the range from 6.01/8 to 7.00/8 cover. In the case of this range of N, variability of number of days in particular years is significantly smaller. Characteristic features of the frequency distribution in days with definite ranges of cloudiness during a year are shown in Fig. 7.4, showing the patterns in the years of lowest (1988) and highest mean annual N (1984). Readers should be reminded that these particular years were those of mean extremes in air temperature; 1988 was the coldest and 1984 was the second (after 2006) the warmest year in the history of observations at Hornsund.

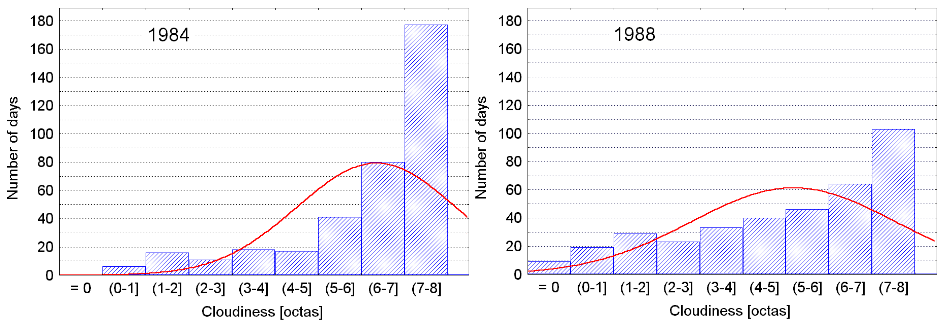

Fig. 7.4. The frequency of days with definite cloudiness [octas] at Hornsund in 1984 and 1988.

A search for statistical regularities in diurnal distribution of cloudiness as reported by consecutive synoptic observations, and in the distribution of N characterized by daily means, did not give reliable results. Differences stable in time are missing, standard errors of means of differences are greater than the differences themselves. Apparent differences are revealed only at the level of generalization of the trend in monthly means, although these are not so clear and statistically significant (Table 7.1 and Fig. 7.1).

The correlations between monthly cloudiness and monthly atmospheric pressure at Hornsund are weak. July was the only month in which there was statistical significance ($r = -0.49$, $p < 0.008$). In May, June and September correlations of cloudiness with pressure were somewhat elevated (r from –0.29 to –0.36), but did not exceed limit of significance. Such associations were absent in other months; correlation coefficients were very low and changed signs. The reason for such a situation is that variability of N develops mainly under the influence of synoptic processes. Associations were weak between character of synoptic processes and the momentary pressure values.

Association of cloudiness with the indices of Niedźwiedź (1992, 1992–1993, 1997a, b, 2001) characterizing atmospheric circulation (Table 7.2) were considerably stronger than associations with pressure. Cloudiness increased together with the increase of frequency and intensity of circulation from the southern sector between September and January and in March and April. Correlations were very strong and highly statistically significant. This association is evident because the main source of water vapour arriving at Spitsbergen is connected with advection from the southern sector (see Chapter 10.1). The positive sign of the correlation coefficient between cloudiness and the S index means also that in each case of advection from the North there must be a corresponding strong decrease of N over Hornsund in these months.

In February and July the positive influence of circulation from the western sector on development of cloudiness over Hornsund was evident; it was weaker but also statistically significant. The flow of air masses from the Greenland Sea in these months was connected with an increase of frequency

Table 7.2. Correlations of cloudiness at Hornsund (1978–2009) with the atmospheric circulation indices of Niedźwiedź (Tc): S – meridional circulation, W – zonal circulation, and C – cyclonicity. Correlation coefficients statistically significant at the level $p < 0.05$ are shown in bold.

Tc	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
S	**0.68**	–0.07	**0.61**	**0.61**	0.37	0.33	0.20	0.26	**0.70**	**0.68**	**0.73**	**0.76**
W	**0.38**	**0.52**	**0.38**	0.20	–0.32	–0.08	0.35	0.35	–0.02	–0.00	0.35	**0.39**
C	0.25	**0.43**	**0.39**	0.36	0.26	0.20	**0.56**	0.25	**0.39**	0.14	0.06	0.30

of low-pressure systems in the region of Spitsbergen (positive correlations with the C index). The association of N with the cyclonicity index was positive in all months but statistically significant only in February, July and September. This means that in the other months (particularly in October and November) changes of frequency of cyclonal situations to anticyclonal were only weakly reflected in variability of cloudiness. However, a weak tendency to increase of N together with increase of cyclonicity appeared. These conclusions concerning the relationship of N to the character of regional atmospheric circulation, do not depart substantially from the results of earlier research on data from 1978–1987 by Niedźwiedź and Ustrnul (1988, 1989).

The variability of cloudiness is strongly connected with such climatic parameters as sunshine duration, air temperature and precipitation totals. In this case, cloudiness plays a role of "controller" of variability of these parameters (Table 7.3). The variability of sunshine duration at Hornsund between March and September was almost completely determined by variability of cloudiness.

Table 7.3. Associations of cloudiness with sunshine duration (SS), mean monthly temperature (T_a), mean from the maximum daily temperatures in month (T_{max}), mean from the minimum daily temperatures in month (T_{min}) and monthly total of precipitation (RR) at Hornsund in1978–2009. Correlation coefficients significant at the level $p < 0.05$ are shown in bold.

	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
SS	#	**–0.48**	**–0.81**	**–0.90**	**–0.90**	**–0.89**	**–0.95**	**–0.83**	**–0.93**	**–0.39**	#	#
T_a	**0.78**	**0.48**	**0.74**	**0.70**	0.19	–0.03	–0.32	–0.05	**0.59**	**0.73**	**0.89**	**0.81**
T_{max}	**0.78**	**0.55**	**0.71**	**0.71**	–0.05	–0.13	**–0.47**	–0.18	**0.49**	**0.74**	**0.90**	**0.83**
T_{min}	**0.75**	**0.40**	**0.71**	**0.72**	0.30	0.09	–0.09	0.09	**0.57**	**0.74**	**0.88**	**0.80**
RR	**0.65**	**0.58**	**0.52**	**0.56**	0.19	0.27	**0.60**	**0.49**	**0.58**	**0.59**	**0.56**	**0.56**

– lack of sunshine duration in a given month (polar night)

Cloudiness between September and April showed strong positive correlation with mean monthly air temperature. This relation is in fact complicated – on the one hand N increases with air temperature because advection of warm air masses from the South contributes to increased temperature and cloudiness simultaneously. This imposes positive correlations between these variables. On the other hand – occurrence of increased N reduces radiative heat losses, particularly during the polar night and periods of a "short day", contributing to a reduction of air temperature decreases. Correlations between the cloudiness and monthly temperature became weaker and changed sign together with increase of the length of day (May-August), becoming stronger only in July. In this period, increase of N also limits outgoing radiation; there are positive correlations with mean monthly minimum temperature. The greater role is played by reduction of the inflow of solar radiation to the ground by cloudiness, however. This is proven by statistically significant negative correlation with mean monthly maximum temperature in July and not significant but negative correlations in other months of this period.

Correlation between monthly precipitation totals and cloudiness was weaker than associations with air temperature but was statistically significant for 10 months of the year, excluding only May and June. This correlation is so obvious that does not need comments.

Cloudiness at Hornsund, despite the interannual fluctuations, did not show any significant temporal changes. Trends of both annual N (+0.008 (±0.006) octa yr^{-1}) and N in particular months were very small and statistically not significant. In the monthly period the strongest trend occurred in December (+0.037 (±0.022) octa·yr^{-1}); this does not exceed the limit of significance (p = 0.107).

Comparing cloudiness at Hornsund with interior of the island (the Svalbard-Lufthavn station), it should be noted that N was significantly greater at Hornsund (Table 7.4). This happened despite the fact that the course of N in particular months (except May) and mean annual N at both stations showed strong and significant positive correlations (Table 7.5). Mean annual N at Hornsund was 0.9 octa higher than at Svalbard-Lufthavn. The greatest differences in N were evident in the period between January and June (from 1.1 octa in April and May to 0.8–1.0 octa in other months), the smallest differences were in the second part of the year – in October (0.6/8) and December (0.7/8). Cloudiness was similarly lower in the North of Spitsbergen (Ny Ålesund) than at Hornsund.

Table 7.4. Monthly mean and annual cloudiness [octa] at the stations on the western coast of Spitsbergen in 1978-2009.

Station	Jan	Feb	Mar	April	May	Jun	July	Aug	Sept	Oct	Nov	Dec	Year
Ny Alesund *	4.4	4.7	4.9	4.7	5.4	6.2	6.3	6.4	6.1	5.6	5.0	4.3	5.3
Svalbard-Lufthavn *	4.2	4.4	4.5	4.3	4.9	5.6	5.5	5.7	5.7	5.3	4.8	4.3	4.9
Hornsund	**5.3**	**5.4**	**5.3**	**5.4**	**6.0**	**6.5**	**6.4**	**6.5**	**6.5**	**5.9**	**5.6**	**5.0**	**5.8**
Björnöya *	6.1	6.2	6.3	6.3	6.8	6.8	7.0	6.9	6.9	6.7	6.5	6.0	6.5
Horn. – Svalb.-Luft.	1.1	1.0	0.8	1.1	1.1	0.9	0.9	0.8	0.8	0.6	0.8	0.7	0.9

* – data from the Norwegian Meteorological Institute (eKlima)

The reason for such differences is explained by review of daily satellite images – it comes mainly from two factors. Hornsund, situated in S Spitsbergen, was more often under the cloud cover connected with low-pressure systems passing south of the island than parts of the island situated further North (Photo 7.1). This factor determined that at the Björnöya station south of Hornsund, cloudiness was significantly higher (for 0.3 to 1.0 octa) in all months of the year.

Orographic factors played an equally important role in the development of cloud cover[1], together with the different distances of Hornsund and the Svalbard-Lufthavn station from the open waters of the Greenland Sea. Low clouds formed over the Sea (usually Stratocumulus cugen) and driven by wind into the fjords of the western coast, often did not reach as far as Longyearbyen, which is located about 40 km from the mouth of Isfjorden. At the same time, these clouds filled Hornsund to the Treskelen Peninsula or even along its entire length (Photo 7.2). It is worth noticing that at the

[1] The Svalbard-Lufthavn station is sheltered from the south by a high ridge. Westwards, northwards and eastwards from the station are large areas of Isfjorden water. The Hornsund station is sheltered by a higher ridge to the North, on which orographic clouds are formed and statically stable conditions occur more often.

same time there was no cloud cover on the mountainous interfluves between the fjords, except for some sparse orographic clouds (Photo 7.1 and 7.2).

Table 7.5. Correlation coefficients of cloudiness at Hornsund with cloudiness 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	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Ny Alesund	**0.69**	**0.64**	**0.79**	**0.81**	**0.38**	**0.62**	**0.64**	**0.54**	**0.47**	**0.70**	**0.84**	**0.78**	**0.72**
Svalbard-Lufthavn	**0.63**	**0.68**	**0.73**	**0.87**	0.34	**0.65**	**0.66**	**0.43**	**0.41**	**0.69**	**0.66**	**0.83**	**0.41**
Björnöya	**0.51**	**0.47**	0.23	**0.54**	0.24	0.18	**0.49**	–0.03	0.09	0.13	0.07	**0.67**	**0.39**

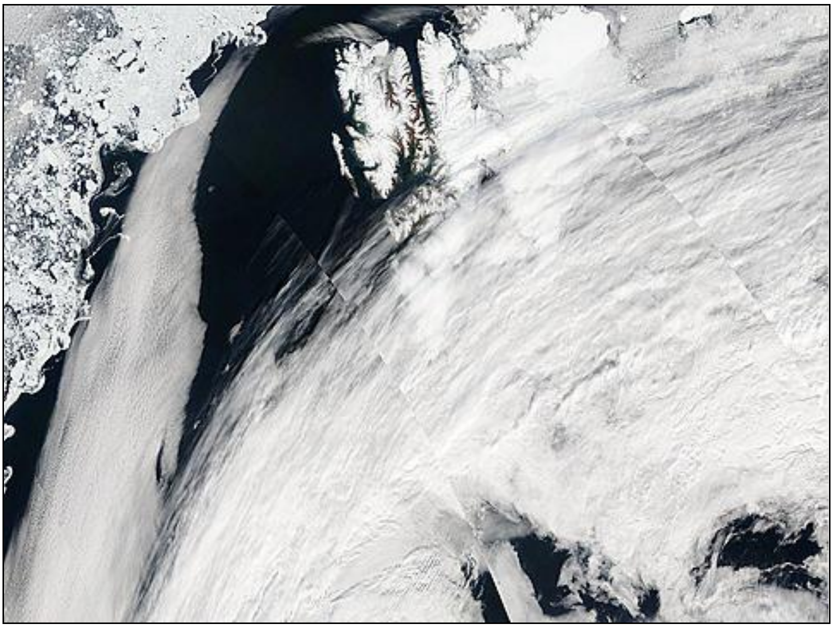

Photo 7.1. Cloud cover associated with a low pressure system from the Barents Sea covers the southern part of Spitsbergen, while at the same time the northern part of the island remains cloudless (Photo NASA Aeronet, MODIS Aqua 2 km pixel, June 17, 2007).

7.2. Clear and cloudy days

One of the traditional measures of cloudiness in climatology is the number of "clear" and "cloudy" days. Days in which mean diurnal cloudiness is less than or equal to 2/8 are considered usually as "clear" days. "Cloudy" or "overcast" are days in which cloudiness is equal to or greater than 7/8.

On average there were 33.4 clear days (9.2% of the year) and 157.8 cloudy days (43.2%) at Hornsund over the year. The smallest number of clear days in a year was 17 (in 2006); the greatest was 57 (in 1988). The smallest number of cloudy days was in 1985 (116 days), the greatest number was in 2004 (200 days). In the "statistical" year, 30–40 clear days and 140–160 cloudy days most often occurred (were the modal values).

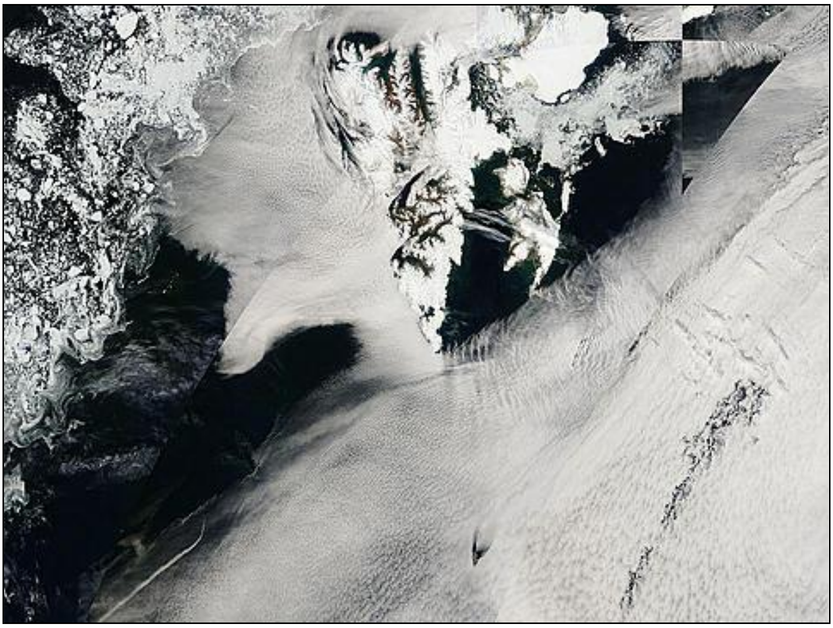

Photo 7.2. Part of a satellite image taken on August 7, 2007 (NASA, Aeronet, MODIS Aqua 2 km pixel).
Cloud cover from the Greenland Sea (Sc) arrives at the west coast of Spitsbergen.
The entrance to Hornsund Fjord is filled with clouds, fjords located to the north are filled only partly.
The dense cloud cover is missing over the southern part of Isfjorden (Longyearbyen).

The distribution of clear days over a year was approximately the reverse of cloudiness. The smallest number were observed between May and October (Table 7.6 and 18.12, Fig. 7.5). The average number of clear days in a month distinctly increased between November and April. The number of clear days in the period, May - October was in the range from zero (June and September) to two (May and October). In July and August, one clear day was most frequent (Fig. 7.5). Between November and April the number of clear days was in the range of three to five in the month. A distinct maximum frequency of clear days was evident in December, the month in which over the entire period of observations at Hornsund there was no case of zero clear days in the record. There were also four years (1980, 1987, 1996 and 2003), in which clear sky was observed for nearly half of the month (14 days) in December (Table 18.12).

Table 7.6. Number of clear days (N ≤ 2/8) and mean, minimum and maximum number of such days noted at Hornsund in particular months in 1978–2009. σ_n – standard deviation.

	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual total
Mean	4.9	4.1	4.6	4.0	1.8	0.8	1.4	0.7	0.5	1.8	3.3	5.8	33.4
σ_n	2.8	2.9	2.8	3.4	1.4	1.0	1.8	0.8	0.8	1.8	3.1	4.2	10.8
Min	0	0	0	0	0	0	0	0	0	0	0	1	17
Max	12	11	12	12	6	3	7	3	2	6	12	14	57

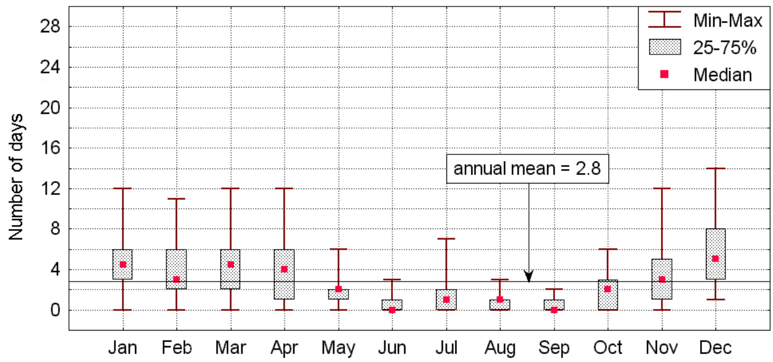

Fig. 7.5. The range of variability of clear days (N ≤ 2/8) at Hornsund in 1978–2009.

The number of cloudy days at Hornsund showed the more even annual pattern, with a distinct maximum in June, July and August (most often 16-17 cloudy days in each month) and minimum between December and April (most often 10-11 cloudy days) (Table 7.7, Fig. 7.6). In this period the smallest number of cloudy days was observed at Hornsund in January 2003 (1 day) and three days each in December 1987 and 2003, January 2007 and April 1985 and 2009 (Table 18.13). In the summer period, the cloudiest month was August 1979 in which there were 27 days with N ≥ 7 octa (Table 7.7).

Table 7.7. Number of cloudy days (N ≥ 7/8) and mean, minimum and maximum number of such days noted at Hornsund in particular months, in1978–2009. σ_n – standard deviation

	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual total
Mean	11.3	10.7	10.7	11.0	13.9	15.8	16.6	16.8	15.6	12.6	11.7	10.6	157.8
σ_n	4.5	3.9	4.3	5.0	3.5	3.9	4.6	4.2	4.7	4.7	5.0	5.1	22.0
Min	1	4	5	3	7	9	4	9	5	3	5	3	116
Max	21	19	20	22	20	23	25	25	27	21	20	21	200

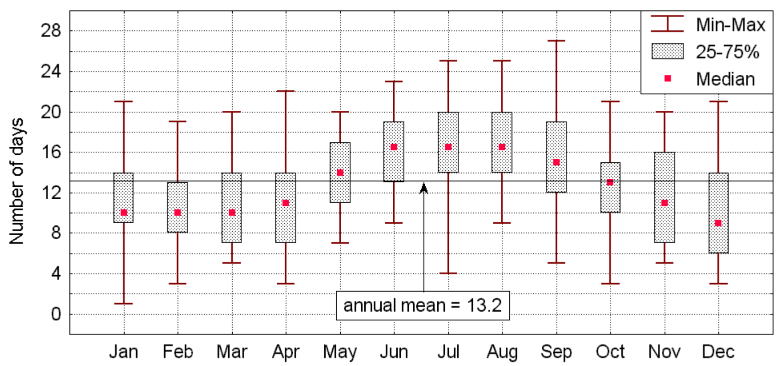

Fig. 7.6. The range of variability of cloudy days (N ≥ 7/8) at Hornsund in 1978–2009.

The interannual variability of number of clear and cloudy days in particular months was substantial. Number of clear days in April and May shows statistically significant correlations with mean monthly atmospheric pressure ($r = 0.53$ and 0.43, respectively). In other months, relationships with pressure are not significant. The number of cloudy days in June and July shows statistically significant negative associations with pressure in these months ($r = –0.37$ and –0.50 respectively). The relationships between the number of clear days and air temperature are strong, highly statistically significant between November and April (the strongest in November ($r = –0.83$) and December ($r = –0.80$)). The frequency of cloudy days shows correlations with air temperature more extended in time. Statistically significant positive relations occur between September and April, with a maximum in October ($r = 0.72$), November ($r = 0.74$) and April ($r = 0.73$). These correlations are the same as already discussed between cloudiness and other climatic parameters. Analogous relationships between the number of clear and cloudy days and the Niedźwiedź indices of atmospheric circulation are very similar) to already noted associations with cloudiness, which is understandable.

Over the full observation period at Hornsund a weak tendency for decrease in the number of clear days was evident almost in all months. In March the downward trend in clear days became statistically significant (–0.123 (±0.055) day per year; $p = 0.033$). The cumulation of other weak, individually not significant trends gave a trend in a mean annual number of clear days of –0.52 (±0.21) day per year, reaching statistical significance ($p = 0.023$).

In the pattern of number of cloudy days the annual trend was not statistically significant (+0.53(±0.47) day per year). However, the patterns of number of cloudy days in particular years shows that after a period of relatively high cloudy days during 1979–1984, there was a sudden drop in the number in 1984/1985, and between 1985 and 2005 the gradual increase of number of such days was evident (Fig. 7.7). The trend of number of cloudy days during 1985–2009 (25 years) was +1.54 (±0.51) day per year, explaining around 25% of the variability seen in this period and highly statistically significant ($p < 0.006$).

7.3. Types of clouds, manifestations of local climatic features in the cloudiness

The observational data on cloud types in the group $8N_hC_LC_MC_H$ create the greatest contradictions among all of the observations carried out at Hornsund[2]. It is possible only to summarise the main features. It is also a fact that the nature of cloud cover at Hornsund, hinders or prevents in some cases correct recording of occurrence of clouds in the standard codes of the group $8N_hC_LC_MC_H$ because of the numerous local synoptic peculiarities. The need to choose one of nine key numbers for description of the appearance of the sky when none of them are truly present necessarily leads to faults in the observational data. Low level cloud cover often obscured a greater view and created many errors and inaccuracies. The percentage frequencies of particular combinations of kinds and types of clouds at Hornsund given below should be treated solely as approximate data.

[2] Essential changes in the mode of coding (that is observation) of clouds are noticeable (among others) when the observers change, or when the time intervals between observations are increased while using the same combinations of code values, and other faults. Verification or "re-analysis" of these data is infeasible. One should clearly warn future users of these data against e.g. an attempt to discover trends in the changes of particular clouds at Hornsund or conducting analysis of change of distribution in individual years.

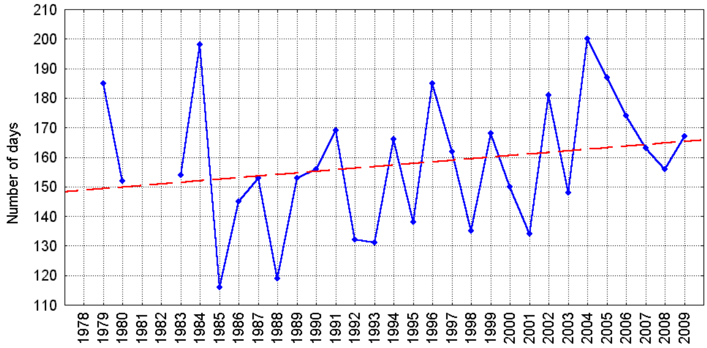

Fig. 7.7. The trend of cloudy days (N ≥ 7/8) at Hornsund, 1979–2009.

In around 18% of synoptic observations during the year at Hornsund occurrence of clouds classified as C_L was not noted. Low-level clouds (without Nimbostratus, which is assigned to the medium clouds, C_M) were most frequent. Their occurrence, when occupying much of the horizon, prohibited or impeded observation of other clouds at medium and high levels.

The typical, most often noted kind of low clouds during all seasons of the year was Stratocumulus other than cumulogenitus (C_L = 5). On average in a year, these were noted in around 65% of all synoptic observations[3]. These clouds are connected with passage of bands of cloud in cyclonal systems. Parts of them form below inversions at the peripheries of anticyclones.

However, a substantial percentage of clouds coded at Hornsund as Stratocumulus (Sc) other than cumulogenitus are in fact Stratocumulus cumulogenitus clouds. During the katabatic flow of cold air from the glacier zone, chains[4] of clouds Cumulus (Cu) are formed over sea surfaces free of ice. As time passes and as the distance over water increases, these build up vertically, but mainly horizontally, transforming into clouds of type Sc. From below these clouds form characteristic grey cylinders or rolls separated by brighter strips, arranged in lines according to currents in the air. These clouds build to especially great density over the water of the warm West Spitsbergen Current, where either the form or character of the development (because cloud cover is already formed) does not allow one to conclude that it is Stratocumulus cumulogenitus. Processes of evolution of clouds Cu into Stratocumulus cugen over the northeast part of the Greenland Sea are seen perfectly on satellite images received at the Hornsund station (Aeronet; MODIS Terra and MODIS Aqua; Photo 7.3). The probability that an important percentage of clouds coded as C_L = 5 at Hornsund is in fact Sc cugen, is considerably higher in the winter and the spring than in other seasons of the year. Such a big percentage of Sc cloud cover observed at Hornsund is the reflection of regional activity typical for this sector of the Atlantic Arctic. Stratocumulus cugen (C_L = 4) was noted very seldom, only in some particular years[5]. The mean frequency of Sc cugen was smaller than 0.5% of the number of synoptic observations.

[3] During the 2005/2006 expedition in 84.4% of all synoptic observations occurrence of such type of low clouds was noted. This value is completely unreliable.

[4] This is an effect of Langmuir circulation.

[5] Understood here to be the period from July-August of one year to July-August of the next year, which is a proof of very big differences in the quality of data.

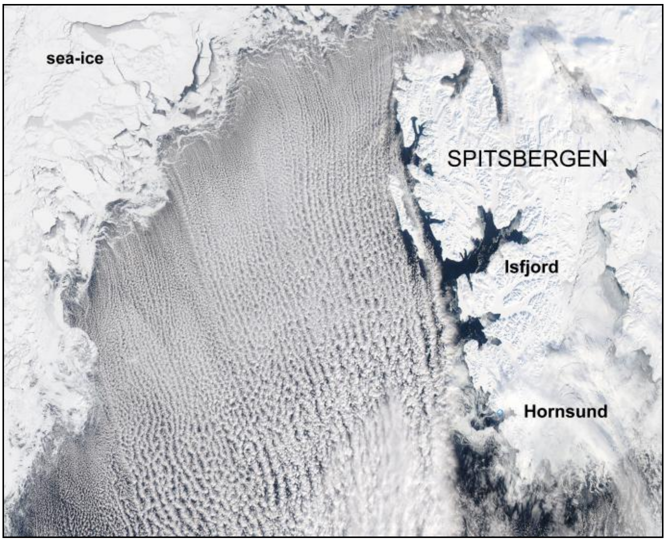

Photo 7.3. The flow of the Arctic-continental air from the N–NW. Intensive convection over the NE part of the Greenland Sea. Chains of Cumulus clouds transform gradually into Stratocumulus cugen. Over Spitsbergen, convection is not possible and over the islands and fjords of the western coast there is a lack of cloudiness with this direction of air flow. The marine forefield of Hornsund is shut out by Sc cugen clouds. Fragment of satellite image taken on April 2, 2007 (Aeronet, Hornsund, MODIS Aqua, 250 m pixels).

Sc cugen clouds behave curiously at Hornsund. Depending on the direction of air flow (W or E), clouds Sc entering the trough of Hornsund Fjord gradually grow thin and are torn (Photo 7.4 and 7.5). Frequently during the flow of Sc clouds from the East, dense cloud cover to the east is clearly seen, when over the station itself and the mouth of the fjord cloud cover is discontinuous, with a great share of Cu fra clouds (Photo 7.6). The reverse sequence of cloud cover changes is observed in the case of flow of air from the West. During "shore parallel" flow on the leeward side of the island clouds disappear, forming a belt of "clear" sky of differing width, most often a few to a dozen kilometres. At times Sc clouds forced into the topographic trough by winds from the west completely fill the fjords on the west coast of southern and central Spitsbergen. In the face of the low cloud base and its not so strong vertical development, plus cooling of the land surface in the winter and the spring, at the same time cloud cover is missing over the higher land areas (Photo 7.7). For that reason the results of radiation measurements at the Hornsund station can not serve as reliable data for different type of balance estimates (e.g. glaciological) for higher areas nearby. The supply of solar energy is considerably greater there.

The second type of low clouds in frequency of occurrence at Hornsund was C_L = 6, Stratus nebulosus or Stratus fractus, but not in bad weather or both together. This key mode was reported in around 6% of the synoptic observations. This value is definitely underestimated. The occurrence of these clouds is usually accompanied by complete cloud cover ($N = N_h = 8$), their base is most often at the height of only 150–250 m a.s.l., because higher land is obscured by the clouds (Photo 7.8). On the higher ground, this is reported as occurrence of fog. The frequency of occurrence of such type of cloud cover decreases at Hornsund at the turn of winter and spring (in March, April and May).

Photo 7.4. Stratocumulus over the Hornsund station; summer 2005. Very weak western wind. Base of clouds at the height of around 450–500 m a.s.l. Almost continuous cloud cover over the Greenland Sea; when crossing the shore line it grows thinner and looses density, gaps appear in it through which the sun is shining (see Photo 7.5). Photo taken from Isbjörnhamna (Photo A.A. Marsz).

Photo 7.5. Stratocumulus over the land. In the foreground Baranowski Peninsula, behind it the Hans Glacier. When moving over the land the cloud grows thinner and disappears over higher areas. Summer 2005, photo taken few minutes after Photo 7.4 (Photo A.A. Marsz).

Photo 7.6. Stratocumulus over the eastern part of Hornsund trough, with flow of air from the east, from above the Storfjorden. Over the eastern part of Hornsund (Brepollen) there is a complete cloud cover, but as the air flows westwards clouds gets torn and thin down, transforming into Cu and Cu fra (Photo A.A. Marsz).

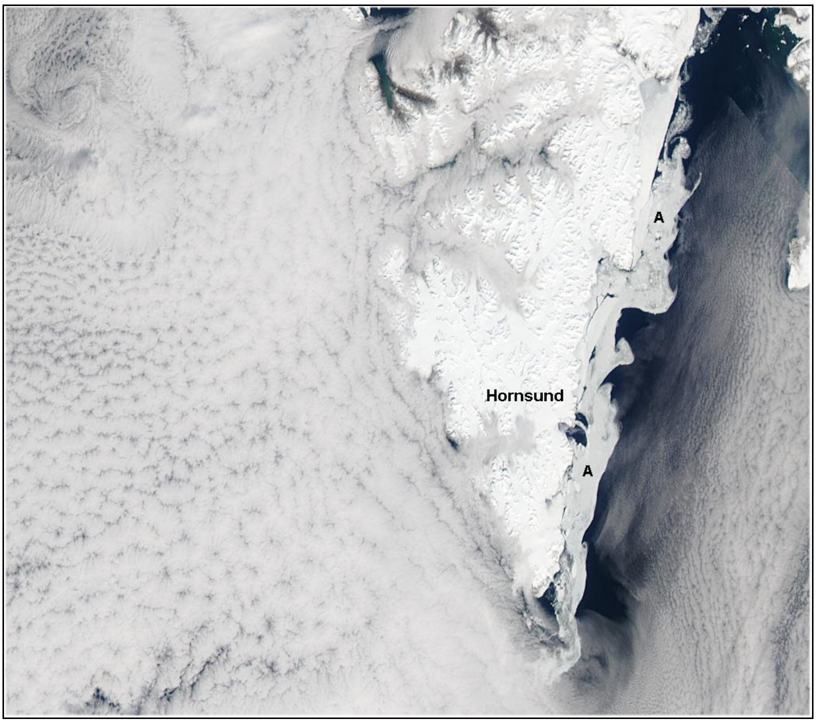

Photo 7.7. Cloudiness over the southern part of Hornsund with gentle flow of air from the west. Aeronet, Hornsund, MODIS Aqua, 250 m pixel. On June 19, 2007 – cloudiness Sc cugen over the Norwegian Sea „flows" into fjords, including Hornsund, filling it completely. Over higher areas of cooled land and on the leeward side of the island, cloud cover is missing. White band along the eastern coast, marked as "A" is sea ice transported from Storfjorden southwards. The western wind pushed this part of the ice (which had been carried out to the western coast of Spitsbergen by the Sörkapp Current) eastwards.

Photo 7.8. Hornsund Fjord, the northern shores (the region of Gnålodden and entrance to Burgerbukta); summer 2005. Stratus nebulosus with the lower base around 200 m a.s.l. (Photo A.A. Marsz).

The third most frequent low clouds were a combination of Stratus fractus or Cumulus fractus during bad weather, or both together (pannus), usually below Altostratus or Nimbostratus (C_L = 7). This code number was noted on average in around 4% of all synoptic observations. Problems appeared with correct recording also in the case of this code number at Hornsund. In a large number of such cases is co-occurrence of stratus (usually St, not St fra.) with a cover of higher clouds. Formation of Stratus clouds at low elevation (100–200 m) and small thickness (100–150 m) is typical for Hornsund. These clouds, on the whole with limited horizontal extent, very often form on the windward slopes of the mountains during light wind conditions, an indication of their orographic genesis. These are not clouds of "bad weather" in traditional, widely accepted meaning of this term and such situations should be coded as C_L = 6. Certainly, situations occur also, in which cloudiness corresponds relatively precise to description in the key (see Photo 7.9). Presumably also classified as C_L = 7 were cases when below the cover of Altostratus clouds or continuous cover of Altocumulus clouds there were more or less broad patches of St clouds with bases at different elevations (example – see Photo 7.10).

Cumulus mediocris or Cumulus congestus clouds, alone or occurring with Cumulus humilis or/and Stratocumulus, or Cu fra., with bases on the same level (C_L = 2), were noted relatively seldom. These were recorded on average in around 3% of synoptic observations, distinctly more often in June, July, August and September than in other months. A similar percentage of observations (around 2.5%) were situations in which clouds Cumulus and Stratocumulus, but not Sc cugen, with bases at different levels (C_L = 8) occurred. C_L appeared more often in the warm part of a year.

Other low-level block C_L cloud types (C_L – 1, 3, 4, 9) occurred extremely rarely. This allows us to suppose that they are not playing an important role in the formation of cloudiness at Hornsund (or there are errors in recording, e.g. Cb capillatus noted few times in the consecutive synoptic observations during the expedition 2004/2005, including middle of the winter).

Photo 7.9. Hornsund, view to fjord mouth from Isbjörnhamna, in foreground the rocky reef being extension of the Wilczek Cap. Cloud cover Altostratus translucidus, below it banks and single clouds St fra and Cu fra. To the left in the middle, upper part of the photo are seen virgo with Cu fra. Middle of August 2005 (Photo A.A. Marsz).

Photo 7.10. The view toward Hornsundtind massif (1431 m a.s.l.) from Brepollen (eastern part of Hornsund Fjord) in June 2006. Layers of thin St clouds with bases at different levels under a continuous Ac cloud cover are seen (Photo J.A. Marsz).

In the discussion of low cloud cover at Hornsund some local peculiarities should be mentioned. To such peculiarities surely belongs the formation of strange orographic clouds as a result of interaction of „warmed land" and the cold water in the fjord and convergence of air streams ascending the slopes. In final phase of the summer, the relatively non-glaciated surfaces on the southern and south-western shore of Hornsund are strongly warmed. In windless conditions and a low solar elevation there may be slow inflow of air from fjord to land. This air warms up and rises up the slopes. In the face of its very high humidity, already after rising only 70–100 m in elevation condensation begins and slope fog is formed, with rising clouds hanging on the slopes. Where the mountain ranges are long and narrow, forming elongated sharp ridges, streams of air from both sides of the range may converge over ridge crests and clouds in the shape of a fluffy "hat" or "mushroom" are formed there, reaching 200–400 m above the ridge (Photo 7.11).

Throughout southern Spitsbergen strong orographic effects are evident in the low-level cloud cover. Typically there are rapidly changing waves of clouds with different spatial scales. The biggest such groups of low wave clouds may be observed over the sea (Photo 7.12), where they drift parallel to the shores of the island and in many cases are perfectly seen on satellite images. Because the views from the Hornsund station are obstructed by mountains cloud waves of such scales are logged by the observer as nearer, misidentified belts of Stratus clouds. Lesser banks of lenticular clouds Cumulus lenticularis (Cu len.), at times duplicates, often appear over the fjord (Photo 7.13); their actual spatial extent is however considerably greater and is not restricted to the fjord. Equally frequent, especially in the cover of medium clouds (Altocumulus), is occurrence of characteristic herringbone wave patterns (Photo 7.14). When wind flows from the S to NW the normal view observed from the station are orographic clouds above the rises of the land – in particular over Hohenlohefjellet, Wurmbrandegga and mountains situated further east and over rises located on the northern shore of the fjord (Rotjesfjellet, Ariekammen – Fugleberget range or Sofiekammen).

From among all observations of clouds of code C_M, in situations when clouds at this elevation could be observed, 35–36% of observations showed their absence (C_M = 0). Most often noted among medium level clouds was Ac translucidus (C_M = 3). These clouds were noted in around 25% of the synoptic observations in which it was possible to observe medium clouds at all. In approximately half of the cases of C_M = 5, these clouds covered the sky in such a way that it was not possible to observe high clouds (C_H = /). Second in frequency of occurrence (around 17% observations) Altocumulus translucidus or opacus was noted in two or more layers, or Altocumulus opacus in a single layer that was not gradually covering the sky, or Altocumulus with Altostratus or Nimbostratus (C_M = 7). Altostratus opacus or Nimbostratus (C_M = 3) were noted with a distinctly lower frequency (around 7–8% observations). Clouds recorded as C_M = 7 and 3 seem to occur[6] with somewhat higher frequency during the autumn and beginning of the winter. Their frequency decreased at the end of winter and in the spring (in March, April and especially in May).

Wave clouds of the medium level (C_M = 4; banks of Altocumulus translucidus and lenticularis) occurred equally frequently (around 7.5% of observations) as As and Ns. Usually both were accompanied by an increase of wind speed. The average distribution of temporal frequency of wave clouds at medium elevations did not show any statistical regularities, although in particular

[6] In some years, those in which observations of cloudiness appear to be reliable.

Photo 7.11. View toward the southern shore of Hornsund Fjord. From the left – slopes of Tsjebyshjevfjellet massif, from the right – Wurmbrandegga range, between it - Gåshamna and lowering of Gashamnöyra. Fog and slope clouds to the left side and cloud formed as a result of convergence of air warmed by the bedrock and rising on the slopes of Wurmbrandegga are seen. Middle of August 2005, around 01 CET (Photo A.A. Marsz).

Photo 7.12. Magnificent wave clouds on the frontier of Spitsbergen and sea. June 2005 (Photo J.A. Marsz).

years their occurrence was in quite distinct periods. The least frequent occurrence was of C_M = 6, 8 and 9 (fractions of one percent, observed only in some years).

High-level clouds (C_H) displayed extremely unequal distribution over time. In the records that are comprehensible, these clouds appeared in short series of a few to one dozen consecutive observations. In particular years occurrence of these temporal clusters were very variably distributed and one cannot categorically ascertain that they definitely showed any stable temporal preference. In around one third of the years of observations a weak tendency for increase of frequency of high clouds from February to May was evident. This is a result of the decrease in those years of low and medium level cloud cover making it possible to observe the high clouds rather than any real increase of frequency of high clouds in these years.

Photo 7.13. Cumulus lenticularis and elongated strips of Cu and Cu fra below a cover of Ac clouds over the land, looking northwards from Hornsund Fjord (Austre Torellbreen). July 2005 (Photo A. Styszyńska).

Photo 7.14. View toward the coast of Spitsbergen northwards from Hornsund Fjord (Torell glaciers). Wave structure of Ac clouds. Below the cover of medium clouds there are Cu and Cu fra clouds, over mountain ridges (in the right side) low orographic clouds are seen. Weak easterly wind. July 2005 (Photo A. Styszyńska).

In particular years, when more restricted low and medium cloud cover observation of high clouds, 25 to 47% (!) of such cases was coded as C_H = 0, meaning a lack of clouds at high elevations. The most frequent kind of high clouds (around 21% of observations) was Cirrostratus not gradually spreading over the sky and not covering it completely (C_H = 8). Similar cirrus fibratus or uncinus sky (C_H = 1) occurred with a little smaller frequency (around 17%). Cirrus spissatus in the form of tangled bundles or in banks and not showing any rapid changes in time (C_H = 2), was noted on average in around 6–7% observations. Cirrus in strips and/or Cirrostratus or only Cs gradually covering the sky on the average was noted only in 5–6% observations. Other clouds at high level were noted with vestigial frequency, appearing in records only in some years (for instance, somewhat surprising – C_H = 5 (Ci and/or Cs overcastting the sky but not reaching elevations greater than 45° over the horizon).

In conclusion, one may state that local features of cloudiness of the Hornsund region are recorded most clearly in the structure of low-level clouds. An interesting feature of cloudiness of this part of Spitsbergen and surrounding water is "overrepresentation" of Sc and the occurrence of long lasting, very broad cover of Ac translucidus clouds, below which low clouds are developing.

7.4. Sunshine duration

In spite of potentially great duration of sunshine (SS) during the polar summer, the mean annual total of hours of sun at Hornsund is small; averaged over 1978–2009 it amounted to 1039.7 hours, less than 25% of the potential duration[7]. The interannual variability of SS is very big; the smallest duration was 760.1 hours recorded in 2004, the biggest 1330.1 hours in 1985 (Table 18.14). Sunshine duration only insignificantly higher than the minimum was also noted in 1994 (760.9 hours). The difference between maximum and minimum annual SS recorded at Hornsund amounts to 570 hours, ~75% of the minimum sunshine duration. The most frequent observed annual duration at Hornsund is from 1000 to 1100 hours of sunshine (modal).

Mean monthly totals of sunshine duration are shown in Table 7.8. It is easy to see that the greatest duration occurred at the beginning of the polar day in May (~208 hours), well before the culmination of potential insolation. Even in April SS was greater (~189 hours) than in June (~167 hours), although the polar day begins only on April 24. Mean SS in June (167±55 hours) and July (161±63 hours) are practically the same, not statistically different. Generally, the pattern of mean monthly values of SS at Hornsund is distinctly asymmetrical (Fig. 7.8 and 7.9). Between February and May there was a rapid increase of SS, between May and October – a slow decrease.

The course of diurnal totals of sunshine in a specific year (Fig. 7.8) reproduces the main features of the monthly progression. The asymmetry of the pattern in most of years is evident in it. The increment of diurnal totals of SS is faster at end of the winter/beginning of the spring than the decrease of duration after May-June. Some years, especially those in which insolation was greater than the mean, had distinctly more symmetric course of diurnal totals of SS for the year (e.g. 1988).

The mean multiannual daily total of sunshine was 2.85 hours (2^h53^m). This value is a statistical abstraction and largely misleads, even for the sake of occurrence of polar night. In particular years mean diurnal totals change strongly, like other statistical characteristics of insolation. It is typical

[7] Potential sunshine duration, or maximum possible. During a day, the time from the sunrise to sunset. In other periods (decade, month, year) – total of these diurnal values.

Table 7.8. The mean monthly sunshine duration (SS) and relative sunshine duration (r.SS), minimum sunshine duration in a given month (SSmin) and exchanged for relative sunshine duration (r.SS min), maximum sunshine duration in a given month (SS max) and exchanged for relative sunshine duration (r.SS max). Sunshine duration in hours, relative sunshine duration as relation of real sunshine duration to potential sunshine duration (1978-2009). σ_n – standard deviation.

	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
SS	0	6.0	92.3	188.7	208.1	167.1	160.9	122.6	75.5	22.1	0	0
σ_n	-	6.10	29.46	64.86	46.51	54.97	62.90	38.44	29.71	9.98	-	-
r.SS	-	0.07	0.26	0.32	0.28	0.23	0.22	0.18	0.18	0.11	-	-
SS min	-	0.0	40.8	52.2	116.8	74.8	50.3	54.5	21.5	4.3	-	-
r.SS min	-	0.0	0.12	0.09	0.16	0.10	0.07	0.08	0.05	0.02	-	-
SS max	-	21.9	159.9	307.7	295.6	263.9	348.4	207.4	140.7	40.4	-	-
r.SS max	-	0.27	0.45	0.52	0.38	0.35	0.50	0.29	0.32	0.21	-	-

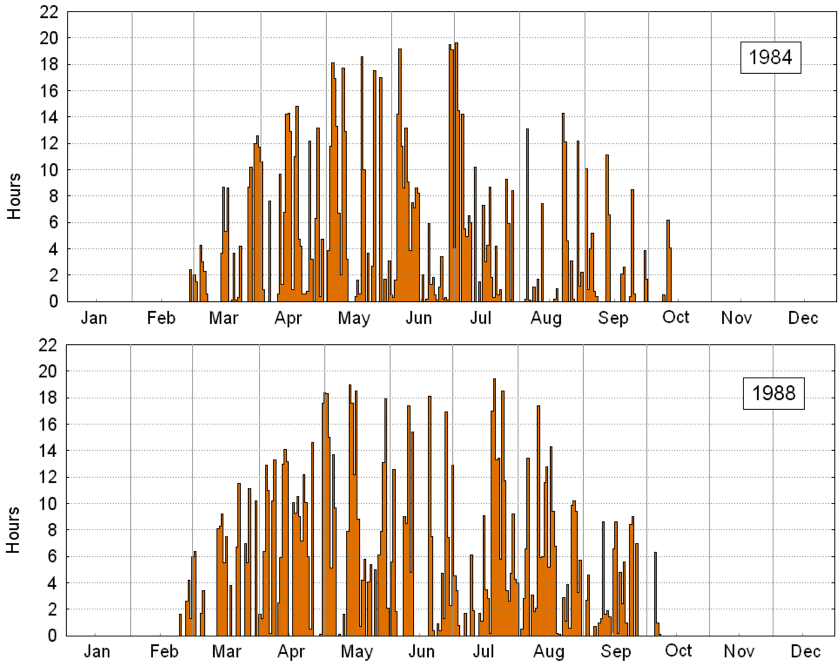

Fig. 7.8. The course of diurnal totals of sunshine duration in 1984 and 1988 at the Hornsund station.

for all years, although with differing numbers, that days without any insolation dominate, i.e. sunshine duration is equal zero. In second place in frequency were days with SS from 0.1 to 5 hours; the mean multiannual diurnal total was included in this range.

The greatest diurnal totals of sunshine duration at Hornsund exceeded 18 hours (maximum 20.4 hours on May 23, 2007). Such large totals may occur during a polar day and were most frequently recorded in 1 to 6 days in a year. Despite the theoretical possibility for maximum sunshine to equal 24 hours during a polar day, at Hornsund such great values are never observed because the station is shielded from the North by the Ariekammen – Fugleberget mountain range that rises to more than 500 m a.s.l. This range shadows the station when the sun is in the north. The maximum possible duration during the highest solar declinations, between June 10 and July 2, is 20.5 hours.

The orographic factor is important; at the Barentsburg station (situated not so far from Hornsund), where heliographs are not shielded from the North by terrain obstacles, sunshine duration in June and July is distinctly greater than at Hornsund (Table 7.9 and Fig. 7.9). North of the heliographs at Barentsburg are the open waters of the wide Isfjorden, allowing unimpeded insolation. Similarly greater insolation was recorded at the Ny Ålesund station between March and August (Table 7.9). At this station the higher insolation is connected both with differing sheltering of the horizon and with the distinctly lower cloudiness in these months (Table 7.4). As a result annual insolation at Ny Ålesund was in almost all years for which measurements are accessible, significantly higher than at Hornsund (Fig. 7.10).

Table 7.9. Mean monthly and annual sunshine duration [hours] at Hornsund and Barentsburg in 1978-2009 and at Ny Alesund in 1993–2004

Station	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Ny Alesund *	0	0.0	78.0	260.1	315.7	225.1	191.9	145.6	77.3	0.8	0	0	1294.5
Barentsburg **	0	5.5	83.4	164.1	197.4	186.3	195.0	119.2	62.3	22.2	0	0	1035.4
Hornsund	**0**	**6.0**	**92.3**	**188.7**	**208.1**	**167.1**	**160.9**	**122.6**	**75.5**	**22.1**	**0**	**0**	**1039.7**
Horn.– Barent.	-	0.5	8.9	24.6	10.7	–19.2	–34.1	3.4	13.2	-0.1	-	-	4.3

* – data from Budzik (2005), ** – data from RIHMI-WDC[8]

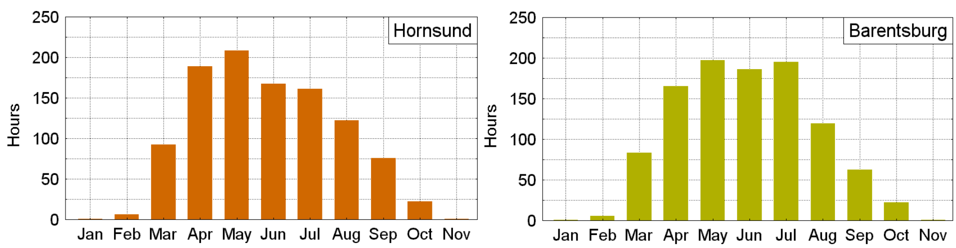

Fig. 7.9. Mean monthly sunshine duration [hours] at Hornsund and Barentsburg in 1978–2009.

Monthly total sunshine duration at Hornsund was characterized by great interannual variability (Table 7.8 and Fig. 7.11). The amplitude of insolation changes in particular months and value of the standard deviation (σ_n) in relation to the monthly mean both demonstrate this. Over the investigated period especially great variability of insolation was evident in July. The ratio of the minimum (50.3 hours; 1994) to the maximum-recorded insolation (348.4 hours; 1993) was approximately 1:7. In April the variability of insolation was smaller than in July, (but also very great (1:5.9; minimum – 52.2 hours in 2004, maximum – 307.7 hours in 2009). The smallest interannual variability of monthly insolation was in May, minimum to maximum duration observed in this month was 1:2.5 (116.8 hours in 2009 and 295.6 hours in 1980).

8 RIHMI-WDC – Russian Research Institute of Hydrometeorological Information – World Data Centre.

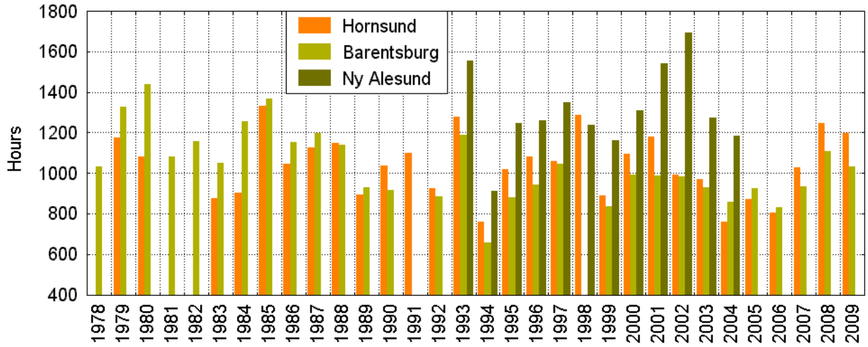

Fig. 7.10. Annual totals of sunshine duration at Hornsund, Barentsburg and Ny Alesund in 1978-2009.

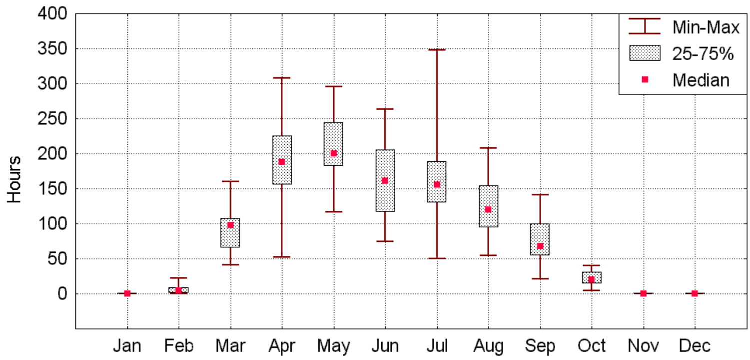

Fig. 7.11. The range of variability of totals of monthly sunshine duration [hours] at Hornsund in 1978–2009.

Comparison using such measures as relative sunshine duration[9] is more convenient than comparison of absolute duration expressed in hours at different times during the year because the duration of the day at the latitude of Hornsund changes very rapidly and particular months have different numbers of days. Analyzing values given in Tables 7.8 and 18.15 it is easy to notice that the greatest relative SS occurred on average in April, and neighbouring March and May also had greater relative sunshine than the other months.

Taking into account both the distribution of number of hours of insolation in particular months and the distribution of relative SS at Hornsund, one notes that the period of the end of winter and spring distinct more sun. The annual changes of cloudiness are the reason. During the period in which the Sun was over the horizon, the smallest monthly cloudiness occurred in March and April. Additionally, in these months and in May the composition of clouds changed – the proportion of low clouds decreased and medium and high-level clouds increased. The heliograph records

[9] The relative sunshine duration (r.SS) is the relationship of the real sunshine duration (SS) to potential sunshine duration (maximum possible; SSp) at the same time (day, decade, month, year). It is given by decimal fraction, defining how much of possible insolation is real Sun time at a given station. Value of r.SS multiplied by 100% gives the same in %.

insolation in conditions when there are high clouds between the sun and the instrument[10]. Hence in these months the increase of relative sunshine duration was disproportionally greater than the decrease of cloudiness. Decrease of cloudiness between March and May was due to the reduction of the intensity of circulation processes at the end of winter. The frequency of occurrence of low pressure systems, together with their accompanying fields of cloud fell over central parts of the Atlantic Arctic at that time. In addition, atmospheric pressure increased, especially in May when it reached its maximum in the annual cycle.

The insolation at Hornsund between March and September is regulated primarily by changes of cloudiness. Correlations between cloudiness and SS were very strong (Table 7.3), correlation coefficients being in the range –0.81 to –0.95. Variability of cloudiness in July explained around 88% of the variation of SS in this month (Fig. 7.12), in September and April – 82%, in May and June – 81%, in August – 69% and in March – 66%. The influence of variability of cloudiness on changes of SS abruptly decreased in February and October (variability of N explains 22% and 7% of variation of SS in these months). The reason of so strong a decrease of the influence of cloud cover changes is a clearly formal factor – an abrupt shortening of the duration of the day[11].

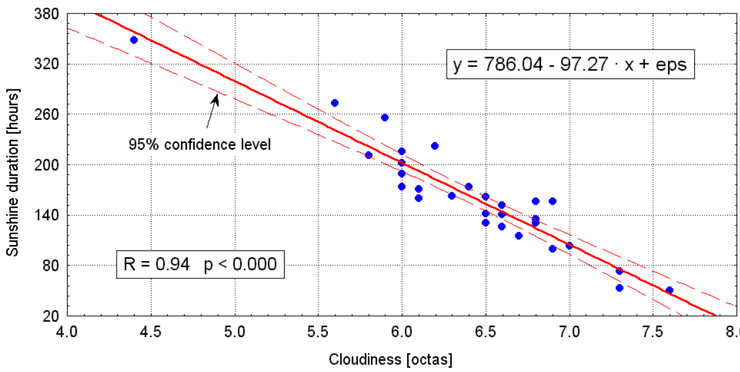

Fig. 7.12. The relationship between sunshine duration and cloudiness at Hornsund in July (1979–2009).

Meteorological factors other than cloudiness do not exert a greater influence on variability of insolation at Hornsund. If significant correlations occurred between them (e.g. between precipitation totals and sunshine duration in March, April, July, August and September (–0.69), minimum temperature in March, April (–0.76 !) and September, etc.) it is an effect of regulatory activity of

[10] In February and October, when the height of Sun over the horizon is very low, despite the sunshine and illumination of the heliograph, the instrument may not record insolation when the intensity of solar radiation is below the threshold of instrument sensitivity (0.2–0.3 cal·cm^{2}·min^{-1} (0.84–1.25 J)). This factor exerts some influence on insolation recorded in these months, contributing to its underestimation.

[11] Cloudiness may change over the entire day; mean diurnal cloudiness is calculated from synoptic observations, which in February and October fall in most cases in the night hours (e.g. on 20 February the duration of the day at Hornsund is l 5 hours and 12 minutes, on 15 October – 6 hours and 48 minutes). Variability of cloudiness in the night hours cannot exert influence on the variability of insolation. Hence associations between insolation and cloudiness in these months weaken, although they still are statistically significant.

cloudiness both on insolation and on the given parameter. Some associations, such as correlations with the Niedźwiedź indices of atmospheric circulation (e.g. in all months in which insolation occurred there are negative correlations with the S index that are statistically significant from March to June (April: r = –0.73) and in September (–0.7), negative correlations with the index of cyclonicity (C) – significant in March, April, July (–0.6) and September) were a reflection of influence of circulation factors on variability of cloudiness and, because of this, of the patterns of insolation.

It is worth noting the fact that between monthly sunshine duration and air temperature at Hornsund, from February to June and from September to October there were negative correlations (!), especially great in April (r = –0.74) and September (r = –0.60), indicating that with an increase of insolation air temperatures decreased. A complicated relationship between the direction of advection of air masses, air temperature and cloud cover[12] is revealed here and, second, the regulatory role of cloudiness in both insolation and the magnitude of long wave radiation losses. Only in July (r = +0.38) and August (r = +0.11) do the correlations of sunshine duration with temperature change to positive, showing that with increase of SS now the air temperature also increases. This summer relationship between air temperature and SS is weak, however, and only in July is it statistically significant. A result of such relationships is the apparently paradoxical view of the association between annual air temperature and annual sunshine duration shown in Fig. 7.13, in which temperature decreased in proportionally with the increase of duration of insolation and increase of inflow of radiant energy of sun to the surface of terrain.

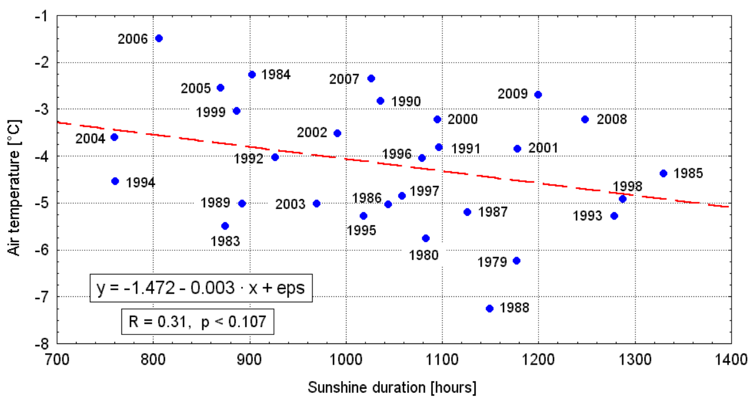

Fig. 7.13. The relation between annual air temperature [°C] and annual total of sunshine duration [hours] at Hornsund in 1978–2009.

The annual sunshine duration at Hornsund during the period of investigation decreased at a mean rate of 2.1 hours per year. This weak trend is not statistically significant (Fig. 7.14). In the

12 Advection from the south (increase of the S index of Niedźwiedź) will bring about, during the whole year, increase of air temperature and water vapour contained in the air. Increase of vapour pressure brings about an increase of cloudiness. In the case of advection from the North the situation is reversed (decrease of temperature, water vapour content in air and cloudiness occur). Therefore, direction of advection controls both air temperature and cloudiness, and cloudiness next controls air temperature.

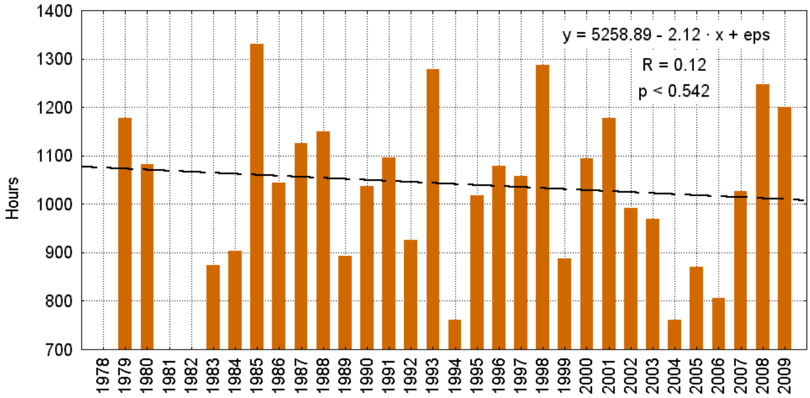

Fig. 7.14. Annual total sunshine duration [hours] at Hornsund in 1979–2009.

same period annual air temperature increased and this increase was statistically significant. At the Barentsburg station situated not so far from Hornsund, the annual decrease of SS was considerably more distinct (10.4 hours per year), statistically significant ($r = -0.57$, $p < 0.001$) and explaining 30.4% of variation of SS at this station.