8. SOLAR RADIATION

Total solar radiation, which reaches the active surface after passing through the atmosphere, is the sum of direct radiation from the Sun and arriving from space. At low solar angles (a few – one dozen degrees) the radiation is mainly diffused. Part of the stream of solar energy arriving at the ground is reflected by it and part is absorbed. The absorbed radiation heats upper layers of ground and water. It is thus a significant component of energy exchange between the atmosphere and the ground.

Unfortunately, although regular meteorological measurements have been undertaken at Hornsund for many years, with the exception of sunshine duration, actinometric observations were made at the station only in some years. The first measurements of solar radiation (direct, total and reflected) were made during the International Geophysical Year (IGY) in August 1957 – August 1958 (Baranowski 1968). Measurements were continued during the summer scientific expeditions of the University of Wrocław organized in later years (1959–1960, 1970–1974) (Baranowski 1977, Baranowski and Głowicki 1974, 1975, Pereyma 1983, Pereyma and Piasecki 1986, Pereyma and Lucerska 1988). During these expeditions records were made at the Hornsund station (9 m a.s.l.) and on the Werenskiold Glacier around 10 km NNW of the station, where measurements were made at two sites. The first was on the glacier at 383 m a.s.l. (1957–1960), and the second on its forefield – 18 m a.s.l. (1970–1974). The second set of radiation measurements were a year-long measurement series at the Hornsund station during 3rd Polar Expedition of Institute of Geophysics PAS, in 1980/1981 (Głowicki 1985).

The next series were made at the beginning of the 1990s. M. Angiel (1996) initiated them during an expedition of the Institute of Ecology PAS in 1989, within research on the heat balance of different types of tundra. However these observations were made not in the meteorological plot at the station but on a site located around 830 m NNW of it, on the uplifted marine terrace (10 m a.s.l.) at the foot of Fugleberget (in the Fuglebekken basin). Measurements were made from the disappearance of winter snow cover (15 May) to the arrival of autumnal (15 August) snow cover (Angiel 1996).

During wintering of the 12th Polar Expedition of the Institute Geophysics PAS in 1989/1990, the third year-long series of measurements at the Hornsund station was made by T. Niedźwiedź (unpublished data). In the succeeding years, measurements were continued both at the station and, after installation of new automatic instruments, in the Fuglebekken basin. This site was located around 500 m northwards from the main building of the station. It was situated on the uplifted marine terrace at the height 5 m a.s.l. (the layout of the station and its location are given in Caputa and Głowacki, 2002).

During particular expeditions, different instruments were used for measurements of solar radiation. In 1957–1960 it was a Moll-Gorczyński solar meter, in 1970–1974 – a Moll-Gorczyński thermopile produced by Kipp with recorder, during wintering 1980/1981 – Funk pyrradiometer with multivoltameter produced by KFAP, Linke-Feussner radiometer and albedometer CM7, and in

1989 – M-80 pyranometer and Schenk radiometer. During wintering 1989/90 thermoelectric balance meter M-10, universal pyranometer (albedometer) M-80 and actinometer AT-50 (all instruments of Russian production) were used. Measurements in the 1990s were made with two thermopiles MW-81 and MW-91 manufactured in Poland. Sensitivity of these sensors was 10 W/m^2, and range of measurements was from 1 to 2000 W/m^2 in the visible band. The thermopiles were placed 1.5 m above the tundra surface.

When measurements of properties of atmospheric aerosols began (within the AERONET–NASA program of the Institute of Geophysics PAS) at Hornsund in March 2004, a measuring platform was built near the roof of main building of the station. On this platform, sensors for measurement of solar ultraviolet radiation (in the ranges UV-A and UV-B), long-wave radiation and albedo of the Earth surface (CNR-1 NET-radiometer, Kipp&Zonen) and sunshine duration sensor Kipp&Zonen CSD1 were installed. In the spring of 2005 the set of sensors was supplemented with a CM 11 Kipp&Zonen pyranometer allowing for measurement of intensity of total solar radiation over the full range of the spectrum (~300–3000 nm) and recording with 1-minute resolution. Published results of these observations (Sobolewski and Krzyścin 2006) covered the period from April 16, 2005 to September 20, 2006. Unfortunately, recording of total radiation was not possible on all days during this period because of technical problems (Table 8.1). Later, in 2007–2009, complete data covering all days of the month were collected only for the summer period (June-August). Results of these measurements were obtained by the courtesy of P. Sobolewski (unpublished data).

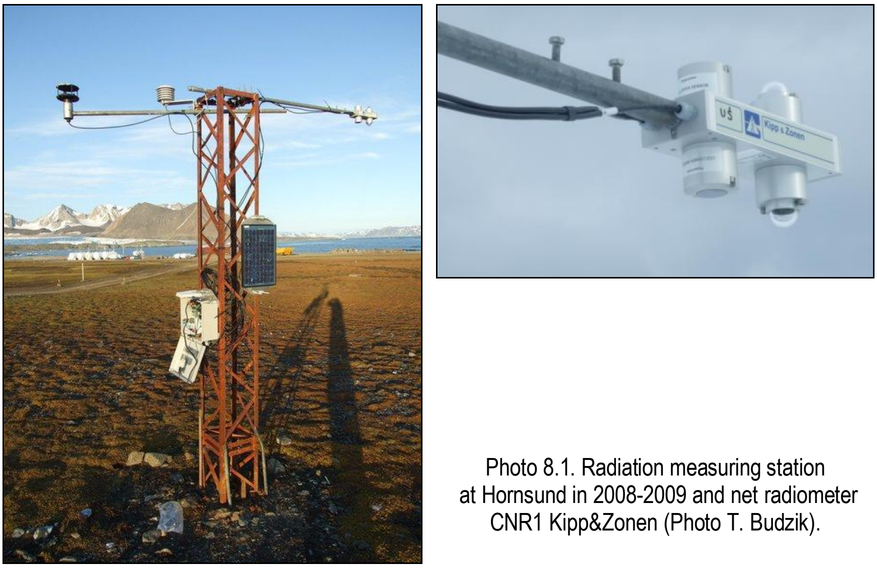

Photo 8.1. Radiation measuring station at Hornsund in 2008-2009 and net radiometer CNR1 Kipp&Zonen (Photo T. Budzik).

On April 6, 2008 the new actinometric station was opened at Hornsund. It has been built by the University of Silesia for research on radiation balances on the active surface. The site of measurements is situated around 100 m south of the main station building at a height of 7 m a.s.l. Sensors were installed on the 2.5 m high mast (Photo 8.1). The ground around the mast is dry shrub-lichen tundra (Budzik *et al.* 2009). At this station measurements of short wave and long-wave

Table 8.1. Mean monthly diurnal sums of total solar radiation [MJ·m^{-2}] at the Hornsund station, based on different sources.

Year	Feb*	March	April	May	June	July	August	Sept	Oct**	a, b, c
1957[1]	-	-	-	-	-	-	9.01[a]	2.92	0.50	a 4–31
1958[1]	0.33	3.09	9.47	13.55	13.18	11.34	11.93[a]	-	-	a 1–20
1959[1]	-	-	-	-	-	13.68	10.67[a]	-	-	a 1–18
1960[1]	-	-	-	-	-	7.63[a]	7.63	-	-	a 9–31
1970[1]	-	-	-	-	-	14.93[a]	6.88	-	-	a 6–31
1971[1]	-	-	-	-	-	9.76	7.84	3.67[a]	-	a 1–23
1972[2]	-	-	-	-	-	11.00	5.70	2.83[a]	-	a 1–23
1973[3]	-	-	-	-	10.91[a]	10.78	10.19	3.37[b]	-	a 21–30 b 1–16
1974[3]	-	-	-	-	10.28[a]	10.75	7.92	3.63[b]	-	a 21–30 b 1–16
1980[4]	-	-	-	-	-	11.30[a]	7.94	3.83	0.65	a 21–31
1981[4]	0.29	4.48	12.67	19.52	21.33	16.90[a]	-	-	-	a 1–20
1989[5]	-	-	-	-	-	-	11.62	3.31	0.65	
1990[5]	0.23	3.40	9.89	19.54	15.02	14.54	-	-	-	
1991[6]	0.65	2.52	6.64	15.26	19.86	17.65	8.36	3.63	0.59	
1992[6]	0.17	2.12	9.22	13.61	16.55	16.18	6.62[a]	2.86	-	a 22–31
1993[6]	0.09	2.51	9.31	16.05	15.77	20.72	9.52	4.37	-	
1994[6]	-	3.35[a]	-	-	13.13[b]	12.37	8.54	-	-	a 19–26 b 25–30
2005[7]	-	-	14.04[a]	17.32[b]	15.10[c1]	16.94	7.32[c2]	4.56	1.05[c3]	a 16–30 b 1–27 c1 12 days c2 8 days c3 17 days
2006[7]	0.67	4.14	9.87	17.05	17.19[a]	11.44	8.65	5.20[c]	-	a 1–20 c 12 days
2007[8]	-	-	-	-	14.66	14.32	9.56	-	-	
2008[8]	-	-	-	-	19.06	15.36	9.64	-	-	
2009[8]	-	-	-	-	19.99	17.01	9.17[a]	-	-	a 4–31
2008[9]	-	-	-	14.96	18.17	15.38	8.89	2.88	0.69	
2009[9]	0.42	2.99	11.31	–	-	-	-	-	-	
2009[10]	-	-	-	13.29	17.94	16.32	9.20	3.75	0.75	
Mean[d]	0.36	3.18	10.27	16.02	16.13	13.92	8.76	3.63	0.70	
N[d]	8	9	9	10	16	22	22	14	7	
Mean[e]	**0.36**	**3.16**	**9.80**	**15.87**	**17.41**	**14.20**	**8.63**	**3.57**	**0.64**	
σn[e]	0.21	0.82	1.74	2.41	2.57	3.01	1.39	0.63	0.09	
N[e]	8	8	8	9	11	18	16	9	6	
Max[e]	0.65	4.48	12.67	19.54	21.33	20.72	11.62	4.56	0.75	
Min[e]	0.09	2.12	6.64	13.29	13.18	9.76	5.70	2.86	0.50	

[1] – Baranowski (1977), [2] – Pereyma and Piasecki (1986), [3] – Pereyma and Lucerska (1988), [4] – Głowicki (1985), [5] – Niedźwiedź (unpublished data), [6] – Caputa and Głowacki (2002), [7] – Sobolewski and Krzyścin (2006), [8] – Sobolewski (unpublished data), [9] – Budzik *et al.* 2009, [10] – Budzik (unpublished data), * – 14 days, ** – 30 days, [a, b] – numbers of days in a month, [c] – number of days in the month, [d] – mean from all data, [e] – when observations were made in all days of a month, σn – standard deviation of a mean, N – number of data.

radiation are made with an automatic Campbell station (model CR1000) fitted with data logger and a net radiometer by Kipp&Zonen (model CNR1) consisting of two pyranometers CM-3 for measurements of short-wave radiation (305–2800 nm) and two pyrgeometers CG3 for measurements of long-wave radiation (5000–50000 nm). Recording of data is done at intervals of ten minutes (Budzik *et al.* 2009). On May 10, 2009 the Kipp&Zonen CM 11 pyranometer previously located on the platform close to the roof of the main building of the station was also moved to this mast. From this moment, all sensors have been connected to one recorder (Budzik – personal communication).

The measurement series collected at Hornsund until now allow us to determine sums of total radiation mainly for the two months of July and August. In other months, observations were made sporadically, often not covering all days of the month. Only for five seasons: 1957/58 (Baranowski 1977), 1980/81 (Głowicki 1985), 1989/90 (Niedźwiedź, unpublished data), 1991/92 (Caputa and Głowacki 2002) and 2008/09 (Budzik *et al.* 2009) may we say that there are complete annual measuring series (Table 8.1 and 8.2).

Table 8.2. Mean monthly diurnal sums of total solar radiation [$MJ\cdot m^{-2}$] in the Fuglebekken catchment and on the Werenskioldbreen and its forefield, based on different sources.

Year	Feb*	March	April	May	June	July	August	Sept	October	a, b
Fuglebekken catchment basin (5 m a.s.l.)										
1989[1]	-	-	-	19.87[a]	17.47	11.55	12.84[b]	-	-	[a] 14–31 [b] 1–15
1989[2]	-	-	-	-	-	13.05[a]	10.55	3.03	0.60	[a] 1–15
1990[2]	0.29	-	10.47	15.19[a]	-	-	-	2.58[b]	0.60	[a] 1–14 [b] 8–30
1991[2]	0.32	2.52	8.63	15.29	19.87	17.65	8.35	3.63	0.60	
1992[2]	0.14	2.13	9.23	13.61	16.53	16.26	6.92[a]	2.87	-	[a] 22–31
1993[2]	0.07	2.52	9.30	16.06	15.77	20.71	9.52	4.37	-	
1994[2]	-	3.35[a]	-	-	13.13[b]	12.35	8.42	-	-	[a] 19–26 [b] 25–30
Mean	**0.82**	**2.39**	**9.41**	**16.20**	**17.41**	**16.54**	**9.94**	**3.48**	**0.60**	
Max	0.32	2.52	10.47	19.87	19.87	20.71	12.84	4.37	0.60	
Min	0.07	2.13	8.63	13.61	15.77	11.55	8.35	2.87	0.60	
Werenskioldbreen (386 m a.s.l.)										
1957[3]	-	-	-	-	-	-	9.88[a]	4.34	-	17–31
1958[3]	-	3.54	11.09	18.22	18.47	14.84	14.26[a]	-	-	1–19
1959[3]	-	-	-	-	-	13.22	9.97[a]	-	-	1–15
1960[3]	-	-	-	-	-	13.39[a]	12.51[b]	-	-	[a] 17–31 [b] 1–26
Mean	-	**3.54**	**11.09**	**18.22**	**18.47**	**13.82**	**11.66**	**4.34**	-	
Forefield of Werenskioldbreen (18 m a.s.l.)										
1970[3]	-	-	-	-	-	13.93[a]	6.46	-	-	16–31
1971[3]	-	-	-	-	-	9.30[a]	6.96	4.55	-	17–31
1972[4]	-	-	-	-	-	9.26	6.17	2.71[a]	-	1–18
1973[5]	-	-	-	-	-	9.83	10.67	5.15[a]	-	1–15
Mean	-	-	-	-	-	**10.58**	**7.57**	**12.41**	-	

[1] – Angiel (1996), [2] – Caputa and Głowacki (2002), [3] – Baranowski (1977), [4] – Pereyma and Piasecki (1986), [5] – Pereyma and Lucerska (1988), * – 14 days, [a, b] – numbers of days in a month.

Data on the sums of direct, diffused or reflected radiation are even less accessible (Table 8.3). Only Baranowski (1977) has published such data for 1957–1959, Głowicki (1985) for the season 1980/1981 and Budzik *et al.* (2009) for the season May 2008 – April 2009. Thus, at present, our knowledge of the variability of magnitude of inflow of solar heat to the Hornsund region is irregular.

The multiannual mean daily diurnal sums calculated for those cases when there were measurements at the station in all days of the month (Table 8.1 – Mean ^{e}) in comparison with means calculated on basis of all cases (Table 8.1 – Mean ^{d}) differ by –0.47 MJ·m^{-2} in April up to 1.28 MJ·m^{-2} in June. This accounts for 7.8 to 7.4% of monthly sums. This casts doubts on the reliability of the data. To what extent means calculated from a small number (6–9) of cases represent real conditions in the region of the Hornsund station is uncertain.

Between means calculated from measurements at the station and means from measurements in the Fuglebekken catchment there are even greater differences (Table 8.2). The greatest appear in July, when the mean from measurements in the catchment is 2.34 MJ·m^{-2} higher than the mean from measurements at the station (16.5% difference).

Differences between the measurements at the station and those made at the foot of Fugleberget in the Fuglebekken catchment may be explained by differences in the extent of screening of the horizon. Equally great differences appear between measurements made at the station, first at two sites about 120 m apart and later, from May 10, 2009, at the same place. While in July 2008 these differences were small (0.02 MJ·m^{-2}), in July 2009 they amounted to 0.69 MJ·m^{-2}. Even greater differences (2.05 MJ·m^{-2}) appeared in June 2009, when both instruments were placed on the same mast (Table 8.1).

Apparent differences may be explained by the differing accuracy of the instruments used. Precision of measurements of CM3 sensors at intensity of radiation >8MJ·m^{-2} per day is ±10% of the diurnal sum, and CM11 sensors is ±3%. The mean diurnal sum in June 2009, calculated from measurements made with CM3 sensors is only 89.7% of the diurnal sum from measurements with CM11 sensors. One may thus recognize that the differences are within the limits of the measurement error.

Another cause of differences noted may be changes in the spectral permeability of cupolas of the pyranometers because of their aging, especially the CM11 sensors which had operated for four years earlier on the previous measuring site.

In the light of the data collected (Table 8.1) one may state that at Hornsund the best radiation conditions appeared at the beginning of a polar day, in May and June, when multiannual mean monthly sums of total radiation were calculated to amount to 491.0–496.6 MJ·m^{-2} in May and 522.3–483.9 MJ·m^{-2} in June (the first value is calculated on the basis of Mean^{e}, the second one on Mean^{d} in Table 8.1). Later, as time goes on, sums of radiation decreased and amounted on average in July 440.2–431.5 MJ·m^{-2}, in August 267.5–271.6 MJ·m^{-2} and in September 107.1–108.9 MJ·m^{-2}.

It should be noted that in August, despite the duration of a polar day, the sum of total radiation was for 27–36 MJ·m^{-2} smaller than in April (294.0–308.1 MJ·m^{-2}), in which the Sun is not setting only for seven days. This considerable decrease of intensity of radiation in August (despite the polar day) is caused, first of all, by the greater cloudiness occurring in this month (6.5 octa, whereas in April it is 5.4 octa). Sums of radiation in March (98.0–98.6 MJ·m^{-2}) and September (107.1–108.9 MJ·m^{-2}) were similar. At the beginning and end of the season, in February and October, only slight amounts of solar energy reached the horizontal surface at Hornsund (in February 5.04 MJ·m^{-2}, in October 19.2–21.0 MJ·m^{-2}).

Duration of insolation at Hornsund is the longest in May (on average in 1978–2009 it was 208.1 hours). In April sunshine duration was around 19 hours shorter, and in June as much as 41 hours or more. High radiation in June results first of all from the greatest solar elevation at this time. This high radiation results to a considerably less extent from cloudiness, which is great in this time and amounts on average to 6.5 octa.

Table 8.3. Maximum and mean monthly diurnal sums of direct radiation and mean monthly diurnal sums of diffused, reflected and absorbed radiation, [MJ·m^{-2}] at Hornsund and on Werenskioldbreen, on the basis of different sources.

Year	Feb*	March	April	May	June	July	Aug	Sept	Oct	a, b
Direct solar radiation (the highest diurnal sums)										
Hornsund (9 m a.s.l.)										
1957 [1]	-	-	-	-	-	-	12.38	6.25	0.29	
1958 [1]	0.46	4.50	11.01	7.88	14.72	12.30	13.89 [a]	-	-	1–20
1959 [1]	-	-	-	-	-	13.26	11.68	-	-	
Werenskioldbreen (386 m a.s.l.)										
1958 [1]	-	5.34	11.47	19.85	16.47	12.63	14.89 [a]	-	-	1–18
1959 [1]	-	-	-	-	-	12.76	13.13 [a]	-	-	1–15
Direct solar radiation (mean diurnal sums)										
Hornsund (9 m a.s.l.)										
1989 [2]	-	-	-	-	-	-	3.868	0.633	0.090	
1990 [2]	0.023	1.122	2.707	8.367	.581	4.835	-	-	-	
Diffused solar radiation (mean diurnal sums)										
Hornsund (9 m a.s.l.)										
1957 [1]	-	-	-	-	-	-	4.92 [a]	2.13	0.46	4–31
1958 [1]	0.25	1.96	4.42	8.30	9.63	8.13	5.63 [a]	-	-	1–20
1959 [1]	-	-	-	-	-	11.43	8.42 [a]	-	-	1–18
1989 [2]	-	-	-	-	-	-	7.75	2.68	0.56	
1990 [2]	0.21	2.28	7.19	11.17	12.43	9.71	-	-	-	
Werenskioldbreen (386 m a.s.l.)										
1958 [1]	-	2.13	5.67	11.05	12.63	10.97	6.92 [a]	-	-	1–18
1959 [1]	-	-	-	-	-	9.97	7.76 [a]	-	-	1–15
Reflected solar radiation (mean diurnal sums)										
Hornsund (9 m a.s.l.)										
1980 [3]	-	-	-	-	-	1.80 [a]	1.20	0.70	0.30	21–31
1981 [3]	0.29	4.00	11.00	16.10	15.60	1.90 [a]	-	-	-	1–20
Max [c]	0.70	9.10	18.80	24.10	24.60	5.80 [a]	-	-	-	1–20
Min [c]	0.00	1.10	3.80	5.50	5.10	0.50 [a]	0.10	0.00	0.00	21–31
1989 [2]	-	-	-	-	-	-	2.07	0.66	0.43	
1990 [2]	0.17	2.60	8.06	15.73	5.38	2.10	-	-	-	
2008 [4]	-	-	-	12.49	7.15	2.22	1.41	0.50	0.45	
2009 [4]	0.33	2.49	9.51	-	-	-	-	-	-	
Mean	**0.26**	**3.03**	**9.52**	**14.77**	**9.38**	**2.01**	**1.31**	**0.60**	**0.38**	
Absorbed solar radiation (mean diurnal sums)										
Hornsund (9 m a.s.l.)										
1980 [3]	-	-	-	-	-	9.50 [a]	6.70	3.10	0.50	21–31
1981 [3]	0.00	0.50	1.70	3.40	5.70	15.00 [a]	-	-	-	1–20
Max [c]	0.20	2.30	3.00	7.80	17.30	26.10 [a]	15.20	8.00	1.40	1–20
Min [c]	0.00	0.10	0.20	1.00	0.90	3.70 [a]	-	-	-	21–31

Year	Feb*	March	April	May	June	July	Aug	Sept	Oct	[a, b]
1989 [2]	-	-	-	-	-	-	9.55	2.66	0.24	
1990 [2]	0.06	0.80	1.84	3.81	9.63	12.44	-	-	-	
1989 [5]	-	-	-	16.80 [a]	15.05	9.38	10.26 [b]	-	-	[a] 14–31 [b] 1–15
Max [d]	-	-	-	25.63	26.68	22.40	15.35	-	-	
Min [d]	-	-	-	6.38	2.69	3.41	1.84	-	-	
2008 [4]	-	-	-	2.47	11.02	13.16	7.48	2.38	0.24	
2009 [4]	0.09	0.50	1.80	-	-	-	-	-	-	
Mean	**0.05**	**0.60**	**1.78**	**6.62**	**10.35**	**11.90**	**8.50**	**2.71**	**0.33**	

[1] – Baranowski (1977), [2] – Niedźwiedź (unpublished data), [3] – Głowicki (1985), [4] – Budzik *et al.* (2009), [5] – Angiel (1996), * – 14 days, [a, b] – numbers of days in month, [c] – diurnal maximum and minimum in the season 1980/1981, [d] – diurnal maximum and minimum in the season 1989.

This very big influence of the insolation factor on radiation budgets in the spring and at the beginning of the summer confirms the comparison of mean diurnal sums of radiation from this period in 1958 and 1981. Whereas in 1958 sunshine duration was small (182.2 hours in May, 107.7 hours in June), in the same months in 1981 it was very high, in May greater by nearly 82 hours, and in June by 58 hours. Such great differences in the duration of insolation contributed to significant increase in the mean diurnal sums, which were over 6 MJ/m^2 higher than the same diurnal sums in 1958 (Table 8.1).

Low-level clouds, often of orographic origin and with a small thickness, dominate at the Hornsund region. For that reason terrain situated higher, far from the coast may often be above the cloud ceiling. Hence, it may get more radiant energy from the Sun than other places situated on the coast. At the measuring site on Werenskioldbreen (386 m a.s.l.), located only 10 km from the Hornsund station, in all months of 1958 higher mean diurnal sums of total radiation were recorded than at Hornsund (Table 8.1 and 8.2). During this time (March-August) the sum of total radiation at this site was 204.6 MJ/m^2 (11%) greater than at Hornsund. On these grounds, one may suppose that spring-autumn increase of sums of total radiation in the Hornsund region amounts to 53 MJ/m^2 per 100 m of elevation.

When comparing measurements made at Hornsund and at the Werenskioldbreen forefield, the great influence of local conditions on the amount of arriving solar energy is clearly shown. Pereyma and Lucerska (1988) considered that the lower values of total radiation at the forefield of the Werenskioldbreen in 1970–1974 at the beginning of the summer (in July) were caused by formation of convection clouds, more frequent here than at Hornsund fjord. In the remaining part of the summer-autumn season (August-September) diurnal sums of total radiation were in general higher at the Werenskioldbreen forefield. Pereyma and Lucerska (1988) explained this by reduction of cloudiness when leaving Hornsund fjord. According to Pereyma and Lucerska (1988), the improvement of radiation conditions at this site is connected with the location on the leeward (in relation to the most frequent E and SE wind directions) side of the mountain massif and occurrence of the foehn winds. An additional influence on the total radiation recorded here may be increased diffused radiation caused by the nearby glacier surface.

The main component of the total radiation measured at Hornsund is diffused radiation. In the light of measurements made in 1957–1959 and 1989–1990 (Table 8.1– 8.3) it accounted for 46.7% of the mean diurnal sum of total radiation in April 1958, rising to 92% in October 1957.

Comparison of two observational series shows that in particular years diffused radiation may change greatly, especially in the summer; e.g. in July 1959 the contribution of diffused radiation to total radiation was as much as 83.6%, whereas in July 1990 it was only 66.7% (Table 8.3). On the coast, the quantity of diffused radiation is substantially influenced by not only cloudiness and the structural types of clouds but also the type of ground. During a snowless spring or autumn the contribution of diffused radiation may be strongly reduced. At the higher areas, e.g. at Werenskioldbreen, the share of diffused radiation in the total radiation is slightly smaller in both the transient seasons and in the summer (Table 8.4). Because processes of reflection play the main role in the creation of diffused radiation from the upper surface of clouds and absorption of radiation during its penetration through the cloud cover, so if the site at the glacier is often above the cover of low clouds more direct radiation may arrive at this place than at Hornsund.

Table 8.4. Percentage of diffused radiation in the mean diurnal sum of total radiation at Hornsund (1957–1959, 1989–1990) and on Werenskioldbreen (1958–1959).

Year	Feb	March	April	May	June	July	Aug	Sept	Oct	[a]
Hornsund (9 m a.s.l.)										
1957	-	-	-	-	-	-	54.6[a]	72.9	92.0	4–31
1958	75.6	63.4	46.7	61.3	73.3	71.2	47.2[a]	-	-	1–20
1959	-	-	-	-	-	83.6	78.9[a]	-	-	1–18
1989	-	-	-	-	-	-	66.7	81.0	86.2	
1990	91.3	67.1	72.7	59.9	82.8	66.8	-	-	-	
Werenskioldbreen (386 m a.s.l.)										
1958	-	60.0	51.1	60.1	68.8	73.4	48.5[a]	-	-	1–18
1959	-	-	-	-	-	75.4	77.8[a]	-	-	1–15

[a] – numbers of days in a month

For the heat balance of the ground not only total radiation from the Sun arriving at the surface but also radiation absorbed by this surface is important. In the light of measurements made in the 1980/81 season by Głowicki (1985), in the 1989/90 season by Niedźwiedź (unpublished data) and in the 2008/2009 season by Budzik *et al.* (2009) it may be stated that as long as the ground surface is covered by snow, only a small part (0–27%) of total radiation arriving is absorbed by the active surface (Table 8.5).

Table 8.5. Percentage of absorbed radiation in mean diurnal sums of total radiation and magnitude of albedo (%) of the ground at Hornsund in 1980–1981, 1989–1990 and 2008–2009.

Year	Feb	March	April	May	June	July	Aug	Sept	Oct	[a]
1980	-	-	-	-	-	84.1[a]	84.9	81.7	53.8	21–31
1981	0.0	10.7	13.2	17.5	26.9	88.8[a]	-	-	-	1–20
Albedo	100	89	87	82	73	14	15	18	46	
1989	-	-	-	-	-	-	82.2	80.4	36.9	
1990	26.1	23.5	18.6	19.5	64.2	85.6	-	-	-	
Albedo	74	76	81	80	36	14	18	20	64	
2008	-	-	-	16.5	60.7	85.6	84.1	82.6	35.0	
2009	22.0	16.7	15.9	-	-	-	-	-	-	
Albedo	78	83	84	83	39	14	16	17	65	

[a] – numbers of days in a month.

This quantity abruptly increased after disappearance of the snow cover; in July, August and September it exceeded 80% of the total radiation. At this time the physical features of the rocky or patchy tundra determined that reflected radiation was very small. The mean monthly albedo at this time was small and ranged from 14 to 20%, whereas in the winter and in the spring exceeded 73%, reaching a maximum of 81–87% in April (Table 8.5). Kupfer *et al.* (2006) gave very similar values of albedo for the Koldewey station (Ny Ålesund); the lowest albedo was also recorded in July and August, 14–16% on average. During the autumn, when as at Hornsund, snow falls periodically at Ny Ålesund, albedo increased to 33% on average in September and 53% in October (in 1993–2001). The greatest albedo at the Koldewey station was recorded in May, 80% on average. In months with "permanent" snow cover changes of albedo from day to day were small and were connected with the different capacity of fresh and old snow for reflecting solar radiation by. At Koldewey station in 1993–2001 albedo in May ranged from 74% in 1995 to 86% in 1998 (Kupfer *et al.* 2006). During the autumn (September, October) when snow falls but a permanent snow cover is not yet formed, albedo undergoes very big changes from day to day. In this time at Hornsund, albedo may range from little to nearly 90% (Budzik *et al.* 2009).

From analyses of Głowicki (1985) of the annual sum of total radiation, which amounted to 2611 $MJ \cdot m^{-2}$ in the 1980/81 season, the active surface absorbed less than half (41%). Somewhat more energy arriving from the Sun (52.5%) was absorbed by the active surface in the 1989/90 season. According to calculations by Niedźwiedź (1993), of the annual sum measured in this season, amounting 2395 $MJ \cdot m^{-2}$, 1258 $MJ \cdot m^{-2}$ is absorbed radiation. The 2008/2009 season was similar, the active surface absorbing 1196.7 $MJ \cdot m^{-2}$, which was 51.9% of the total solar radiation. According to measurements of Budzik *et al.* (2009) monthly sums of the short wave radiation balance in this season ranged from 408 $MJ \cdot m^{-2}$ in July 2008 to 1 $MJ \cdot m^{-2}$ in February 2009. Maximum momentary values of absorbed short wave radiation ranged from 12.1 $W \cdot m^{-2}$ in February 2009 to 576.5 $W \cdot m^{-2}$ in June 2008 and 598.2 $W \cdot m^{-2}$ in July 2008.

Information on solar radiation over a longer time (e.g. for the entire period of observations at the station) can only be estimated because the measurements of incoming total radiation at Hornsund up to the present allow only for fragmentary recognition of changes in this region. For this purpose a method elaborated by Styszyńska (1995) was used. If data on cloudiness and sunshine duration are available, with this method it is possible to calculate the total radiation arriving at the surface. Styszyńska (1997) undertook the first such attempt for the Hornsund station for the period, 1978–1995.

The method allows for estimates of total radiation that may arrive during a month at a given place, with all astronomical factors (distance between the Earth and Sun, latitude and time of day), processes of reducing solar radiation in the atmosphere (transparency of the atmosphere, cloudiness) and local features of the site (potential insolation allowing for obstruction of the horizon) being taken into account. In this method the equation of Paltridge and Platt (1976) is used to determine changes of distance between the Earth and the Sun. Declination of the Sun is calculated with the Spencer (1971) equation, and the optical mass of the atmosphere with the equation of Kasten (1966).

At high latitudes, the value of total radiation calculated with the Styszyńska (1995) equations may contain some errors. They result on the one hand from the possible underestimate of measured sunshine duration[1] and the other from some under specifying of the fast changing cloudiness. An additional factor, not allowed for in equation applied and which may increase diffused radiation, is phenomenon of multiple reflections (ice reflection) of solar radiation arriving at the earth in conditions of long lasting snow and ice cover[2].

These errors may be eliminated by introduction of radiation correction coefficients calculated with the Styszyńska equations. Lack of ability to count it makes that correction coefficients must be estimated empirically. For the analyses its value was determined by comparing the measured and calculated values. For this purpose all available values of monthly total radiation at Hornsund were used, which were computed for all days in the month. For the season 1957/58, it was 18 cases in July, 16 in October, 11 in June, 9 in May and September, 8 in February, March and April, and 6 in October. Estimates of monthly sums of total radiation arriving at the Hornsund station were done for these months, for which values of mean general cloudiness and sums of real sunshine duration were also known. In the calculations a solar constant Io = 1367 W·m^{-2} was used. Results of calculations are presented in Table 8.6. In months in which measurements were made, measured values are given in the table.

In comparison with the first attempted estimate made for the period 1978–1995 (Styszyńska 1997), in which the value of the correcting coefficient was based on multiannual means (1950–1960) of total radiation at the Isfjord Radio station, the present results based on observations of radiation at Hornsund give somewhat greater sums in the summer (May - August) and somewhat smaller for the remaining months. The calculated mean monthly diurnal sums show good agreement with the acceptable values measured at the station. Only in single cases do these differences exceed 10% (Table 8.7). It appears that this lesser agreement of calculated values with measured ones should be attributed to underestimation of cloudiness (the possibility of making mistakes in observations of cloudiness is much greater than with measurements of sunshine duration). If one assumes the accuracy of estimates of degree of coverage of the sky by clouds and its random distribution during a month, so major differences in insolation may result from characteristics of the different cloud types. For example in April, at the same general cloudiness value N = 5.6/8 in 1981 a sunshine duration of 219.6 hours was recorded, in 1994 it was 183.4 hours and in 2000 only 159.1 hours. In August, at general cloudiness of 6.1/8, in 1990 sunshine duration of 178.4 hours was recorded and in 1992 only 94.2 hours. In the light of the analysis (Table 8.7), the estimates obtained were considered reliable. The estimated multiannual mean monthly sums of radiation (Table 8.7) differed from such means calculated on the base of observations (Table 8.1, row Mean ^{e}) by 0.2 MJ/m^2 in February, 0.6 MJ/m^2 in October, 1.4 MJ/m^2 in June, 1.8 MJ/m^2 in March, 3.4 MJ/m^2 in April, 4.1 MJ/m^2 in September and 13.0 MJ/m^2 in May. Somewhat greater differences appeared only in August (21.9 MJ/m^2) and July (31.8 MJ/m^2). These differences however make up

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[1] At times of low elevation in the sky and low solar angle, the increasing intensity of incoming radiation is very small, so that the heliograph is not recording insolation even if it appears. In addition to the threshold sensitivity of heliograph there may be additional factors decreasing the recorded insolation, such as fog, precipitation, low blizzards and hoarfrost depositing on the heliograph sphere.

[2] The peculiar "trap" of diffused radiation creates between the ground formed by a continuous snow or ice cover and a cover of low stratus clouds. Results of research by Diačenko and Muchenberg (1981) reveal the significant role of the effect of ice blink in increasing the sum of radiation. These results show that in Polar Regions the albedo of ice and snow surfaces is 3–6% greater when there is a cover of low clouds than when there is cloudless sky.

only 7–8% of the multiannual means and fit within the range of measurement error of some instruments, e.g. the CM3 Kipp&Zonen sensors.

The characteristic feature of the distribution of monthly total radiation is its great variability both within the year and from year to year (Table 8.6). Over the Hornsund station record the multiannual mean annual sum of total radiation may be estimated to be 2305.3 MJ/m^2. It ranged from 2055.2 MJ/m^2 (2004) to 2560.6 MJ/m^2 (1998). Given the small interannual variability of the general cloudiness, the interannual differences of radiation sometimes exceeding 330 MJ/m^2 (between 1993 and 1994, or 1998 and 1999) may be considered surprisingly great.

Table 8.6. Measured and estimated monthly and annual sums of total solar radiation [MJ·m^{-2}] at the Hornsund station. Measured values in bold, σn – standard deviation of the mean.

Year	Feb	March	April	May	June	July	Aug	Sept	Oct	Annual total
1978	-	-	-	-	-	-	247.5	140.3	18.9	-
1979	3.8	88.7	312.2	477.5	538.0	591.3	307.0	99.2	19.1	2436.8
1980	3.7	105.1	302.9	580.6	571.1	**350.3**	**246.1**	**114.9**	**20.2**	2294.9
1981	**8.1**	**138.9**	**380.1**	**605.1**	**639.9**	**523.9**	-	-	-	-
1982	-	-	-	-	-	-	-	127.5	18.8	-
1983	3.0	82.0	285.9	464.8	547.2	449.9	261.4	101.7	19.3	2215.2
1984	3.3	101.7	277.1	491.7	514.9	478.1	254.4	98.6	18.2	2238.0
1985	3.2	99.9	357.4	499.7	558.9	535.7	324.7	116.0	20.3	2515.8
1986	4.3	92.1	349.1	455.2	497.4	436.5	318.8	126.3	21.9	2301.6
1987	5.0	115.7	272.6	550.6	523.0	464.9	313.2	116.5	15.6	2377.1
1988	6.0	101.1	321.4	552.4	493.9	504.2	329.1	117.0	18.6	2443.7
1989	6.0	101.5	232.2	493.2	540.3	348.9	**360.2**	**99.3**	**20.2**	2201.8
1990	**3.2**	**105.4**	**296.7**	**605.7**	**450.6**	**450.7**	341.4	103.0	**20.5**	2377.2
1991	**9.1**	**78.1**	**199.2**	**473.1**	**595.8**	**547.2**	**259.2**	**108.9**	**18.3**	**2288.9**
1992	**2.4**	**65.7**	**276.6**	**421.9**	**496.5**	**501.6**	266.8	**85.8**	20.7	2138.0
1993	**1.3**	**77.8**	**279.3**	**497.6**	**473.1**	**642.3**	**295.1**	**131.1**	24.0	2421.6
1994	3.6	81.5	297.1	511.7	417.6	**383.5**	**264.7**	106.4	22.3	2088.4
1995	3.0	107.3	293.8	512.8	578.3	400.0	288.4	105.2	23.8	2312.6
1996	3.1	78.5	340.4	579.3	464.0	491.8	291.0	99.0	15.3	2362.4
1997	3.3	100.7	321.2	470.2	628.3	404.5	275.8	122.6	17.8	2344.4
1998	5.4	86.1	350.4	528.5	608.8	539.4	293.1	128.5	20.4	2560.6
1999	3.0	91.3	322.8	495.3	438.2	496.3	247.8	75.8	22.9	2193.4
2000	3.6	104.3	286.0	418.6	642.6	489.0	340.1	101.2	15.0	2400.4
2001	4.1	112.0	324.1	505.9	619.6	454.6	319.3	85.6	23.4	2448.6
2002	3.0	94.6	207.2	558.9	523.2	456.5	302.8	140.7	18.4	2305.3
2003	3.6	94.2	291.8	493.6	449.4	456.1	303.9	101.3	20.2	2214.1
2004	6.0	70.3	179.4	479.8	479.8	445.2	271.9	103.0	19.8	2055.2
2005	6.0	99.6	285.8	488.9	402.2	**525.1**	216.8	**136.8**	19.1	2180.3
2006	**9.4**	**128.3**	**296.1**	**528.6**	451.5	**354.6**	**268.2**	136.7	19.0	2192.4
2007	5.3	78.6	296.1	532.5	**439.8**	**443.9**	**296.4**	118.7	19.7	2231.0
2008	4.5	112.7	346.5	**463.8**	**558.5** *	**476.5** *	**287.2** *	**86.4**	**20.7**	2356.8
2009	**5.9**	**92.7**	**339.3**	**412.0**	**569.0** *	**516.6** *	285.2	**112.5**	**22.5**	**2355.7**
Mean	4.5	96.2	297.4	505.0	523.7	472.0	289.4	111.2	19.8	2305.3
σn	1.92	16.36	46.56	50.49	68.95	68.00	33.15	17.08	2.27	123.27
Max	9.4	138.9	380.1	605.7	642.6	642.3	360.2	140.7	24.0	2560.6
Min	1.3	65.7	179.4	412.0	402.2	348.9	216.8	75.8	15.0	2055.2

* – mean from data of Budzik and Sobolewski (see Table 8.1)

Table 8.7. Relation of the mean monthly diurnal sum of total radiation at Hornsund measured to calculated by the way of estimates for selected months and years.

Season (year)	Feb	March	April	May	June	July	Aug	Sept	Oct
1957/58	0.878	0.961	0.933	0.925	0.900	0.883	1.086	0.964	1.073
1980/81	1.374	1.410	1.325	1.135	1.120	-	1.083	1.166	0.956
1989/90	0.682	1.094	1.163	1.097	1.128	0.999	1.088	1.123	0.962
1991	2.257	0.859	0.747	1.156	0.930	1.078	0.948	0.857	0.812
1992	0.791	0.769	1.010	1.015	0.893	0.947	-	0.749	-
1993	0.437	0.810	0.938	0.976	1.003	0.996	1.004	1.026	-
1994	-	-	-	-	-	1.324	1.004	-	-
2005	-	-	-	-	-	1.055	-	1.310	-
2006	2.445	1.293	1.616	1.077	-	1.096	1.031	-	-
2007	-	-	-	-	0.968	1.035	0.915	-	-
2008	-	-	-	1.008	0.907	0.923	0.993	0.855	0.969
2009	1.591	1.125	1.014	1.045	1.015	0.949	0.942	1.047	0.984
Mean	1.105	1.040	1.093	1.048	0.985	1.026	1.009	1.011	0.959

Differences in monthly sums may be also very big (Fig. 8.1), especially in July. The lowest multiannual mean monthly sum was in February (4.51 MJ/m^2), which is not surprising because in this month the Sun is over the horizon for only 14 days, and the longest day is only 7 hours and 33 minutes. In October, when the Sun is above the horizon for nearly all of the month (30 days) the sum of total radiation, although four times greater than in February is also very small (19.84 MJ/m^2). The greatest monthly sums were obtained when the Sun is highest (Table 8.6, Fig. 8.1). Multiannual means in May, June and July exceed 470 MJ/m^2, reaching maximum in June (523.7 MJ/m^2). However, the mean for May was only for 18.7 MJ/m^2 smaller. The June maximum was distinct (15 times in the 30 investigated years), the highest sums appeared in May somewhat more seldom (11times), and in July sporadically (5 times). An especially distinct maximum in July was in 1993 when the sum of total radiation was 170 MJ/m^2 higher than the average for this month. In the summer season July is the month in which there may be the greatest differences in the amount of solar energy reaching the ground at Hornsund. The greatest monthly sum was nearly two times greater than the minimum. This means that in July, in the full summer, the amount of heat supplied to the system may be no more than it normally receives in the spring (in April) or in the autumn (in September). This demonstrates that the rates of many physical, chemical and biotic processes dependent upon radiant energy (thermal) may differ strongly in the same months of consecutive years.

The greatest increments from month to month in the amount of total radiation arriving at the horizontal surface at Hornsund occurred in transitory periods (Fig. 8.1), in the spring, between March and April, (for 201 MJ/m^2), between April and May (for 208 MJ/m^2) and in the autumn, between August and September (for 178 MJ/m^2). This is partly caused by the greater diurnal increments of the Sun declination at this time particularly in March and September, and changes in the height of the Sun and duration of the day during the year. As a result there is an abrupt increase (from March to May) or fall (from August to September) of the possible insolation. This sudden spring increase of radiation sums is additionally caused by the relatively low cloudiness (5.4–6.0) at this time. In the autumn, because of constantly great cloud cover (6.4–6.5), monthly falls of the radiation sums are more even.

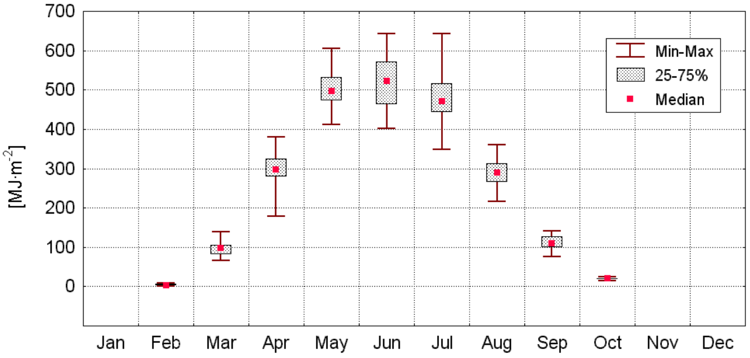

Fig. 8.1. The range of variability of monthly sum of total radiation [MJ·m^{-2}] at Hornsund, according to the data from Table 8.6.

Comparison of estimated mean monthly and annual sums of total radiation at Hornsund with those measured at other stations on Spitsbergen may be done by reference to the Isfjord Radio or the Ny Alesund stations. At the Isfjord Radio station located 1°φ northward from Hornsund and on the southern coast at the entrance to a fjord, the mean monthly diurnal sums of total radiation were, somewhat lower in all months except April than those estimated for Hornsund (Table 8.8). The smaller amount of solar energy at Isfjord Radio is understandable because the Sun reaches lower elevations there although the day is a little longer. Another shortcoming of this comparison is that the data from Isfjord Radio are from 1951–1960, whereas the Hornsund data are from 1978–2009. Additionally at Isfjord Radio in the 1950s cloudiness was on average for 0.2–0.4 octa higher in particular months that was recorded there in 1978–2009 (the Svalbard-Lufthavn station).

A similar comparison with the Ny Alesund station located somewhat further northward includes the period of comprehensive work at the Hornsund station, 1989–2003 (Budzik 2004). In these years the Hornsund station in April, May and June received on daily average 1.05, 2.35 and 2.33 MJ/m^{2,} respectively, less radiant energy than the Ny Alesund station (Table 8.8). The greater total cloudiness of 0.4 octa recorded in these years at Hornsund in April and May reduced the insolation time and caused the differences in the amount of radiant energy. At the beginning of annual insolation (in February and March) as well as in the summer and autumn (from July to October), the Hornsund region received on average somewhat more solar energy (from 0.18 MJ/m^2 in February to 1.13 MJ/m^2 in August) than Ny Alesund (Table 8.8). There were similar amounts and differences of total radiation at Hornsund and Ny Alesund in May 2008 – March 2009 (Budzik *et al.* 2009). This may be interpreted as the effects of local factors. It should be remembered that Hornsund is under the influence of low-pressure systems moving south of Spitsbergen considerably more often than is Ny Alesund situated further north (Chapter 7.1). Such synoptic situations are favourable for occurrence of great cloudiness at Hornsund.

The very strong associations of the total radiation with general cloudiness and sunshine duration are obvious. Because variability of cloudiness develops mainly under the influence of synoptic processes it is no wonder that monthly sums of radiation also show associations with specific types of atmospheric circulation (Chapter 7). In transitional seasons of the year, March to May and September to October, the amount of radiant energy at Hornsund increases with increase of frequency and intensity of circulation from the north. These correlations are very strong and,

Table 8.8. The mean monthly possible sunshine duration (SSp) and real sunshine duration (SS), general cloudiness (N) and diurnal sums of total solar radiation (R) at the Isfjord Radio, Ny Alesund and Hornsund stations.

Element	Feb	March	April	May	June	July	Aug	Sept	Oct
Isfjord Radio (φ = 78°04'N, λ = 13°38'E) in 1951–1960									
SSp [1]	-	252	530	744	720	744	686	347	88
SS [1]	-	77	229	254	165	154	132	74	13
N[2]	-	5.4	4.7	5.7	6.1	6.4	6.4	6.1	6.1
R_Q [3]	-	4.46	14.37	26.07	32.24	27.69	17.69	6.84	1.08
R measured [4]	-	**2.84**	**10.33**	**15.67**	**17.03**	**13.78**	**8.91**	**3.77**	**0.54**
Hornsund (φ = 77°00'N, λ = 15°33'E) in 1978–2009									
SSp	14.8	271.4	452.6	588.3	609.5	612.6	533.5	353.3	105.8
SS	6.0	92.3	188.7	208.1	167.1	160.9	122.6	75.5	22.1
N	5.4	5.3	5.4	6.0	6.5	6.4	6.5	6.4	5.9
R computed	**0.32**	**3.10**	**9.91**	**16.29**	**17.46**	**15.23**	**9.34**	**3.71**	**0.66**
Hornsund (φ = 77°00'N, λ = 15°33'E) in 1989–2003									
N	5.4	5.3	5.4	5.9	6.3	6.4	6.4	6.5	5.8
R computed	**0.28**	**2.97**	**9.60**	**16.27**	**17.61**	**15.19**	**9.57**	**3.54**	**0.67**
Ny Alesund (φ = 78°56'N, λ = 11°57'E) in 1989–2003									
N [5]	4.5	5.0	4.9	5.5	6.2	6.4	6.5	6.2	5.6
R measured [6]	**0.10**	**2.52**	**10.65**	**18.62**	**19.94**	**14.53**	**8.44**	**3.35**	**0.32**
R Horn.– Ny Al. 1989–2003	0.18	0.45	–1.05	–2.35	–2.33	0.66	1.13	0.19	0.35

[1] – possible and real sunshine duration, multiannual means [hours] according to Markin (1975),
[2] – total cloudiness [octas] – multiannual means, according to Norsk Meteorologisk Arbok (1952–61),
[3] – mean monthly diurnal sum of possible total radiation [MJ·m^{-2}] according to Markin (1975),
[4] – mean monthly diurnal sum of measured total radiation [MJ·m^{-2}] according to Markin (1975),
[5] – total cloudiness [octas] – multiannual means, according to Norsk Meteorologisk Arbok (1952–61),
[6] – mean monthly diurnal sum of measured total radiation [MJ·m^{-2}] according to Budzik (2004).

particularly in September, highly statistically significant (Table 8.9). This association is obvious because dry air with low humidity flows over Spitsbergen with advection from the northern sector. The negative sign of the correlation coefficient between the sum of total radiation and Niedźwiedź S index (southern circulation) means that with each instance of advection from the South there will be a corresponding decrease of the amount of radiant energy reaching the ground. In the summer (in July) the influence of zonal circulation on the stream of radiant energy from the Sun is evident, weaker but also statistically significant. It increases together with increase of frequency of occurrence of advection from the East in this month, connected with occurrence of high-pressure systems over Spitsbergen (negative correlation with the C index). In the remaining months, changes of zonal, cyclonal or anticyclonal circulation were weakly reflected in monthly sums of the total radiation.

The mean monthly air temperature shows significant associations with respective sums of total solar radiation only in the transitional periods: in the spring (in March and April) and in the autumn (in September; (Table 8.9). These correlations have a negative sign, which means that the greater the inflow of solar radiation during the short day, the lower is the air temperature. This greater supply of solar energy is possible only when there is not great cloudiness, which means that during the succeeding night there is no impediment to outgoing radiation, which contributes to the decrease of air temperature. At the same the small cloud cover reduces the possibility of precipitation; hence, associations of precipitation with sums of total radiation also have negative signs, and in the transitional periods (March–April and September) and in the summer achieve statistical significance.

Table 8.9. Correlation coefficients between monthly sums of total radiation of the Sun and the values of the indices of atmospheric circulation of Niedźwiedź: S – meridional circulation, W – zonal circulation, and C – cyclonicity; mean monthly air temperature (T_a), mean from diurnal maximum temperatures (T_{max}) and minimum temperatures (T_{min}) in the month and monthly precipitation total (RR) at Hornsund in 1978–2009. Correlation coefficients statistically significant at the level $p < 0.05$ are shown in bold.

Element	Feb	March	April	May	June	July	Aug	Sept	Oct
S	0.11	**–0.51**	**–0.50**	**–0.47**	–0.33	–0.10	–0.18	**–0.73**	**–0.53**
W	0.04	–0.31	–0.10	0.16	0.04	**–0.41**	–0.20	–0.26	0.20
C	–0.06	**–0.42**	–0.24	–0.29	–0.14	**–0.50**	–0.33	–0.16	–0.01
T_a	0.26	**–0.65**	**–0.54**	–0.20	–0.25	0.28	0.06	**–0.70**	–0.41
T_{max}	0.23	**–0.69**	**–0.55**	–0.05	–0.13	**0.53**	0.28	**–0.68**	–0.39
T_{min}	0.27	**–0.64**	**–0.56**	–0.31	–0.35	0.09	–0.08	**–0.70**	**–0.39**
RR	0.10	–0.32	**–0.63**	–0.13	**–0.36**	**–0.50**	**–0.42**	**–0.67**	–0.26

The sums of total radiation, despite significant interannual fluctuations, do not show any longer temporal changes. The trends of both annual values and the values in particular months are very small and statistically not significant. Trends of general cloudiness and sunshine duration also do not show statistical significance. Solar radiation arriving at Hornsund is characterized also by big variability from day to day. The greatest variability is observed during a polar day; it decreases in the spring and autumn (Fig. 8.2 and 8.3). In the summer, the greatest diurnal sums may be 5–8 times higher than minimum sums recorded in these months. In May and June, maximum diurnal sums may reach nearly 30 MJ/m^2 per day. Later, in July and August, both the value and amplitude

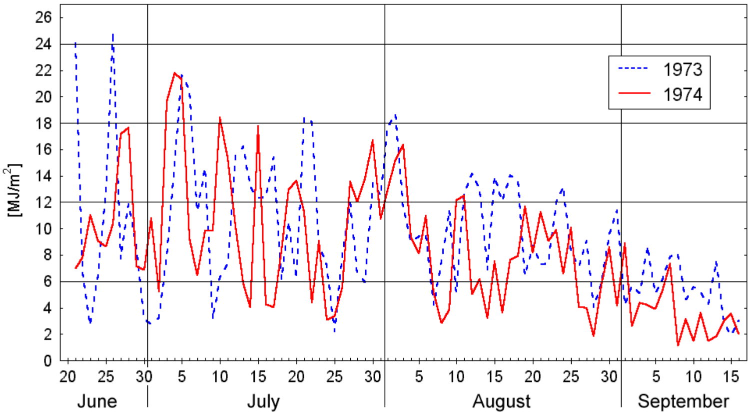

Fig. 8.2. The course of diurnal sums of total radiation [MJ·m^{-2}] at Hornsund in the seasons: 21 June – 16 September 1973 and 21 June – 16 September 1974 (according to data of Pereyma and Lucerska, 1988).

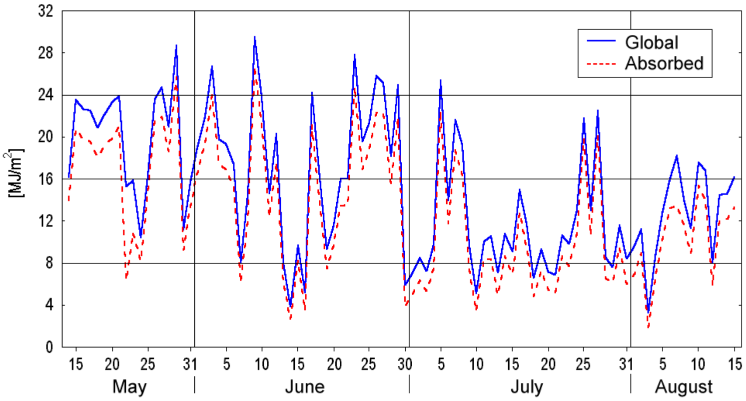

Fig. 8.3. The course of diurnal sums of total and absorbed radiation [MJ·m^{-2}] at Hornsund in 14 May – 15 August 1989 (according to data of Angiel 1996).

decrease. According to observations of Angiel (1996) the great differentiation in the inflow of solar energy is dependent on the type of weather on a given day at the Hornsund station. The mean diurnal sums of total radiation on fine days without precipitation and with high insolation may be nearly three times higher than those occurring in days with precipitation and fog, with complete cloud cover and without sunshine.

The diurnal sums of reflected radiation also show great differences (Fig. 8.3). According to Angiel (1996), in summer the highest mean diurnal sums of reflected radiation were recorded on fine days or days with moderate cloudiness (partly cloudy?), without precipitation and with very high insolation (2.8 MJ/m^2); whereas the smallest (1.9 MJ/m^2) were during days with precipitation and without insolation. During fine days, with very high insolation and without precipitation, 12% of total radiation was reflected from the active surface, whereas in days with precipitation and without insolation over 22% was reflected (Angiel 1996).

According to Angiel (1996), in the spring-summer period after disappearance of snow cover in the region there were very favourable conditions for absorption of solar energy by the active surface and it is independent of the weather type in a given day. The highest mean daily sums of this radiation (up to 20.5 MJ/m^2) were recorded during fine days, without precipitation and with very big insolation. In days with moderate cloudiness, without precipitation and with insolation the mean diurnal sum of absorbed radiation may reach 18.5 MJ/m^2, whereas in overcast days without precipitation and with weak insolation, up to 12.1 MJ/m^2. The active surface absorbs less solar energy in days with precipitation. In such conditions, with weak insolation it may be no more than on average 8 MJ/m^2, and without insolation merely 6.4 MJ/m^2. Taking into account that in May in the region of South Spitsbergen anticyclonal circulation in general dominates, characterized by weather without precipitation, with small cloudiness and very big insolation, so precisely in this month there will be the highest mean diurnal sums as well as diurnal maxima and amplitudes of absorbed radiation of the entire spring-summer period.

The diurnal courses of total radiation are symmetric at Hornsund, with the maximum around midday very clearly emphasized on sunny days (Table 8.10). The distribution of mean hourly sums of this radiation recorded at the station in the season 1980/81 is shown in Table 8.10 From data given

Table 8.10. The mean hourly sums of total radiation [MJ·m^{-2}] measured at the Hornsund station in the season 1980/1981 (calculated from data of Głowicki, 1985)

Hour	July*	August	Sept	Oct		Feb	March	April	May	June	July**
01	0.1044	0.0252	-	-	.	-	-	0.0072	0.1368	0.2448	0.1656
02	0.1152	0.0324	-	-	.	-	-	0.0144	0.1656	0.2844	0.1836
03	0.1584	0.0504	-	-	.	-	-	0.0432	0.3024	0.4068	0.2772
04	0.1836	0.0936	-	-	.	-	-	0.1044	0.4068	0.5184	0.3672
05	0.2484	0.1728	0.0108	-	.	-	-	0.2196	0.5040	0.6264	0.5256
06	0.3636	0.2664	0.0396	-	.	-	0.0252	0.3744	0.6840	0.8244	0.6732
07	0.5364	0.3672	0.1080	-	.	-	0.0756	0.5580	0.8712	0.9792	0.8028
08	0.6660	0.4644	0.1944	0.0144	.	-	0.1656	0.7416	1.0692	1.2492	0.8576
09	0.7560	0.5292	0.2916	0.0468	.	-	0.2988	0.9072	1.2384	1.3428	1.0512
10	0.8568	0.6120	0.3780	0.0792	.	0.0018	0.4248	1.0476	1.3680	1.4112	1.0872
11	0.8244	0.6876	0.4356	0.1116	.	0.0432	0.5472	1.1628	1.5300	1.5192	1.1808
12	0.8568	0.7128	0.4608	0.1440	.	0.0720	0.6372	1.2204	1.5804	1.5516	0.9180
13	0.8496	0.7524	0.4500	0.1440	.	0.0756	0.6192	1.2456	1.5156	1.5516	1.2456
14	0.8676	0.6732	0.4248	0.1008	.	0.0612	0.5832	1.1736	1.4868	1.4760	1.2528
15	0.8460	0.5868	0.3708	0.0576	.	0.0324	0.4824	1.0440	1.4004	1.3536	1.1268
16	0.6912	0.5364	0.2844	0.0216	.	0.0072	0.3384	0.8964	1.1952	1.2312	0.9936
17	0.6012	0.4608	0.2052	0.0036	.	-	0.1908	0.6984	1.0224	1.1052	0.9180
18	0.5184	0.3240	0.1188	-	.	-	0.0828	0.5184	0.8388	0.9324	0.7704
19	0.4356	0.2160	0.0432	-	.	-	0.0216	0.3420	0.7128	0.7344	0.6264
20	0.3168	0.1764	0.0108	-	.	-	-	0.1928	0.5688	0.6372	0.4140
21	0.2124	0.1008	-	-	.	-	-	0.0900	0.3816	0.4824	0.3240
22	0.1332	0.0576	-	-	.	-	-	0.0360	0.2232	0.3600	0.2412
23	0.1008	0.0288	-	-	.	-	-	0.0144	0.1728	0.2664	0.1980
24	0.0972	0.0216	-	-	.	-	-	0.0108	0.1548	0.2376	0.1908

* – data from July 21 to 31, 1980, ** – data from July 1 to 20, 1981, between November and January there is a polar night

in this table the highest hourly sums (exceeding 1.5 MJ/m^2) occurred in May and June, with the maximum in May (1.58 MJ/m^2). Such great hourly sums are possible only in cloudless conditions. In April and July, the mean maximum hourly sums in general did not exceed 1.25 MJ/m^2, while in July the maximum moved to the early afternoon hours (around 14 LT; Table 8.10). During a polar day, in seven (in June) to twelve (in July) "night" hours the mean hourly sums do not exceed 0.5 MJ/m^2. During cloudy weather, the hourly quantities may be around two times lower, and the diurnal courses may have irregular character. Budzik *et al.* (2009) found the similar course of hourly sums of total radiation.