4. THE ATMOSPHERIC CIRCULATION

4.1. The mean baric field

The circulation of the atmosphere over Spitsbergen and its surroundings is very diversified but develops mainly under the influences of atmospheric processes occurring in the Atlantic sector of the Arctic. The cyclogenesis near Iceland is the strongest in this region. Lows formed there usually travel NE through the Norwegian Sea and to the south of Spitsbergen, then further east to the Barents Sea, often reaching Novaya Zemlya or Franz Josef Land. These lows occasionally undergo slow filling but at times regenerate on the Arctic Front. Part of the low-pressure systems from the vicinity of Iceland moves northwards through the Greenland Sea to the Arctic interior. The most intensive cyclogenesis associated with the Iceland Low occurs in the winter half of the year. The cyclonic activity lessens during the spring, when Spitsbergen is quite often under the influence of the Greenland High or a branch of the high from the northern part of Queen Elizabeth Islands archipelago in the Canadian Arctic. The interior of the Arctic is not covered (as was earlier supposed) by a stable high-pressure system (Jones 1987), but is often an area of local cyclogenesis and quite strong dynamic interaction of highs and lows (Serreze and Barry 1988).

Research by Brümmer *et al.* (2000) showed that stronger cyclogenesis, and thus a greater number of low-pressure systems, is in the summer than in the winter in the Arctic. Pressure in cyclonal systems is distinctly higher than in the winter. The average range of pressure variability in the summer is 980–1020 hPa, at mean pressure in the centres of low-pressure systems amounting to around 1000 hPa. In addition, pressure in anticyclonal systems is distinctly lower in the summer than in the winter. In the winter, the intensity of cyclogenesis in the Arctic weakens, whereas the range of pressure changes in the winter increases, ranging from 940 to 1030 hPa, with the average pressure in the centre of lows amounting to 988 hPa.

Atmospheric pressure in Fram Strait, on the eastern side of Spitsbergen behaves in a different way. The number of cyclones over Fram Strait is higher than over the rest of the Arctic. Five cyclones per month occur there on average and an increase of cyclone number in the winter is observed in relation to the summer (Brümmer et al., 2000). This is an effect of cyclogenesis occurring in the winter over this body of water. In the summer, processes of cyclolysis dominate over Fram Strait.

Circulation factors are to a substantial degree responsible for the recent climate changes in the Arctic (Serreze and Francis, 2006) and so deserve more detailed description. Maps of the pressure field at the sea level, made for the Atlantic sector of the Arctic defined by coordinates 60–90°N and from 40°W to 70°E, are a good illustration of circulation patterns in the surroundings of Spitsbergen. These maps (Fig. 4.1–4.27) based on grid data of atmospheric pressure made available in the form of so-called "re-analysis" by NCEP/NCAR (National Centre for Environmental Prediction/National Centre for Atmospheric Research) described by Kalnay et al. (1996). Programs and data placed on the Internet site of NOAA-CIRES Climate Diagnostic Centre (NOAA 2007) were used for visualisation of these data.

The most characteristic differentiations of atmospheric pressure in the winter are seen on the map for January (Fig. 4.1). Its main feature is a broad low pressure trough stretching from the Iceland Low through the Norwegian and Barents Seas in the direction of Novaya Zemlya. Most of the lows move along the axis of this trough. Spitsbergen is situated in the northern flank of this pressure system, determining that flow of air masses from its eastern sector is typical for this area.

At the 850 hPa level (Fig. 4.2) at a height of around 1270 geopotential metres, the low pressure trough is also evident but its axis is now situated over Spitsbergen. Separate low-pressure systems emerge over the Greenland and Barents Seas that prove the existence of great cyclonal activity over these bodies of water in the winter.

Great changes in the pressure field occur in particular months and years, at times differing considerably from the average conditions. For example in January 1967 (Fig. 4.3) Spitsbergen was under the influence of the Greenland High (mean pressure in the high centre exceeded 1029 hPa). The wedge of this high extended not only over Spitsbergen but also over Iceland and the Norwegian Sea. From the northern Atlantic to Spitsbergen this generated exceptionally intensive inflow of air from interior of the Arctic.

Exceptional cyclonal activity occurred in January 2000 (Fig. 4.4). A very deep low formed near Björnöya and was long-lasting so that mean monthly pressure in its centre dropped to 990 hPa. It was the main steering centre for this month, while the normal Iceland Low weakened. An even deeper low (983 hPa) in the average pressure field was noted in January 1993. Its centre was on the border between the Norwegian and Greenland Seas.

Extreme circulation conditions favouring strong advection of warm air from the SW towards Spitsbergen occurred in January 2006 (Fig. 4.5). Lows from the area around Iceland moved through the Greenland Sea to the interior of the Arctic but did not enter the Barents Sea area. This is proven by the location of the low pressure trough. Such situations strongly influence the warming of the Arctic (Styszyńska 2005).

In February, the pressure field is similar to that of January. The gradual weakening of the low pressure trough begins in March. In April, the low-pressure system over the Norwegian Sea and Spitsbergen comes under the influence of the Greenland High. In May (Fig. 4.6), the low pressure trough decays completely and the high-pressure wedge persists over Spitsbergen. At the 850 hPa level (Fig. 4.7), at a height of 1400 geopotential metres, there is a blockade of the Atlantic influences and intensive advection of air from the northwest occurs.

At times, as for example in May 1999 (Fig. 4.8) Spitsbergen is for nearly a whole month under the influence of a broad Arctic High with its centre near the Pole. The index of cyclonicity C (Chapter 4.5) then reaches a very low negative value (C = –36). In May 1990 with a complete disappearance of the Iceland Low (there was a High of 1021 hPa in the region of Faroe Islands), a deep low (below 997 hPa) formed east of Franz Josef Land (Fig. 4.9). This caused intensive inflow of air masses from circumpolar areas to Spitsbergen. The index of southern circulation S (Chapter 4.4) fell to a very low value (S = –33). Only in June 2010 was this index S lower (–34). There was a completely contrary distribution of pressure in April 2006 (Fig. 4.10). At that time the low (around 1000 hPa) was over the Norwegian Sea and the high (over 1032 hPa) over the northern part of the Kara Sea. In these circumstances the most intensive inflow of air from the south (index S = +31) occurred over Spitsbergen and one of the biggest positive thermal anomalies recorded in the month of April. The highest mean pressure measured at Hornsund (1022.9 hPa) occurred in April 1979 (Fig. 4.11) when the Greenland High extended far to the east, beyond Franz Josef Land.

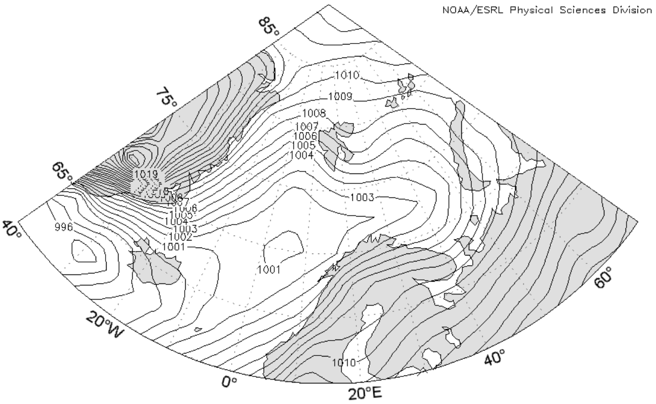

Fig. 4.1. Average pressure field [hPa] in January (1968–1996) in the Atlantic sector of the Arctic.

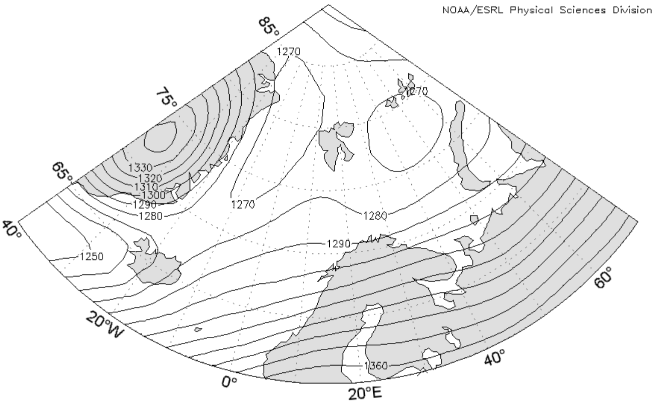

Fig. 4.2. Average baric field topography of the 850 hPa surface in January (1968–1996) in the Atlantic sector of the Arctic.

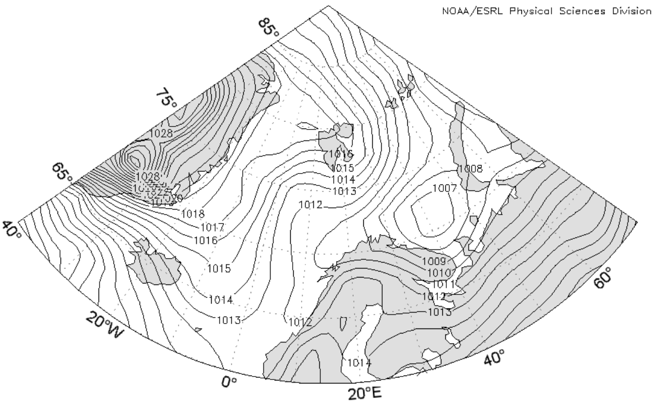

Fig. 4.3. Average pressure field [hPa] in January 1967 in the Atlantic sector of the Arctic.

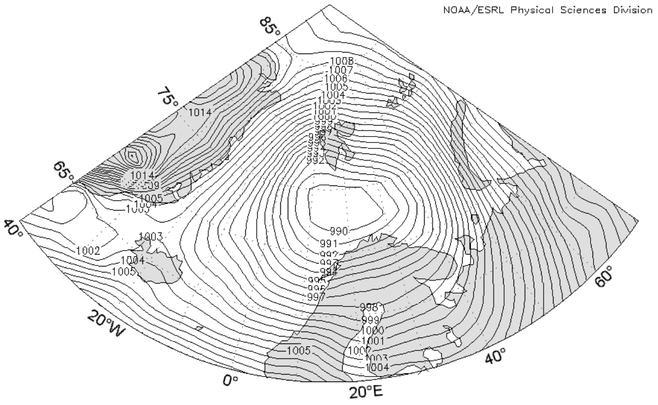

Fig. 4.4. Average pressure field [hPa] in January 2000 in the Atlantic sector of the Arctic.

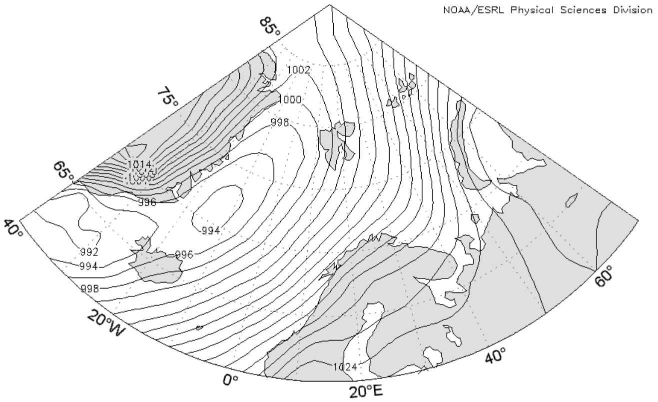

Fig. 4.5. Average pressure field [hPa] in January 2006 in the Atlantic sector of the Arctic.

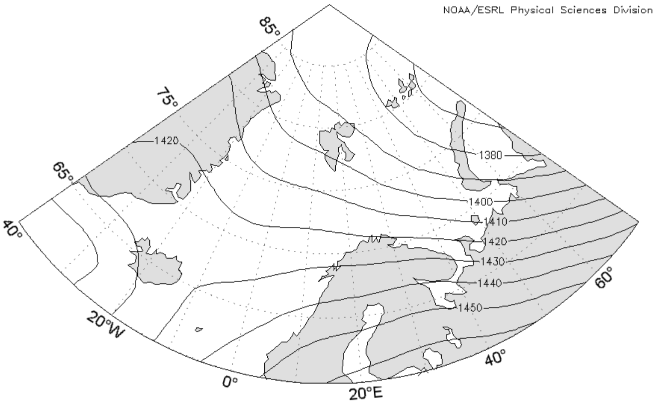

Fig. 4.6. Average pressure field [hPa] in May (1968–1996) in the Atlantic sector of the Arctic.

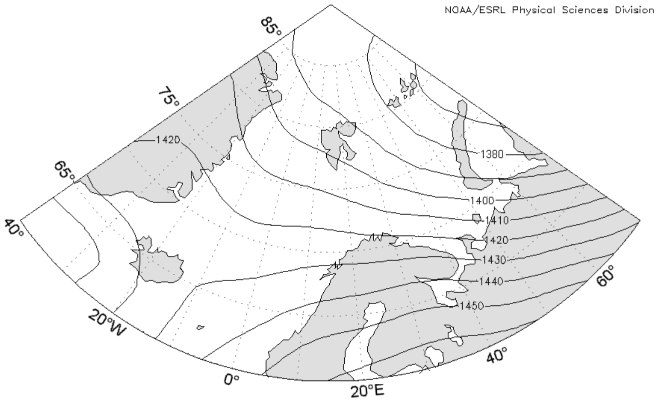

Fig. 4.7. Average baric topography of 850 hPa in May (1968–1996) in the Atlantic sector of the Arctic.

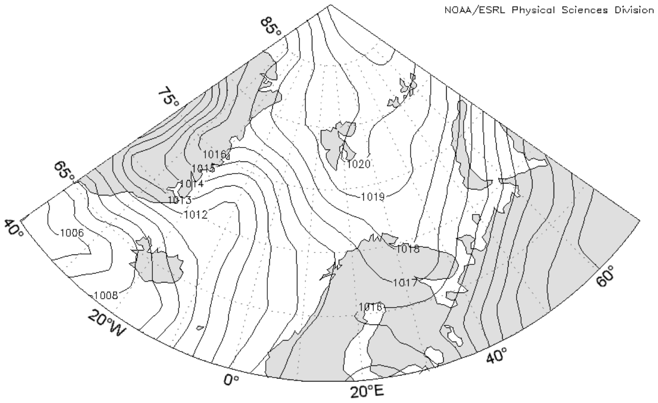

Fig. 4.8. Average pressure field [hPa] in May 1999 in the Atlantic sector of the Arctic.

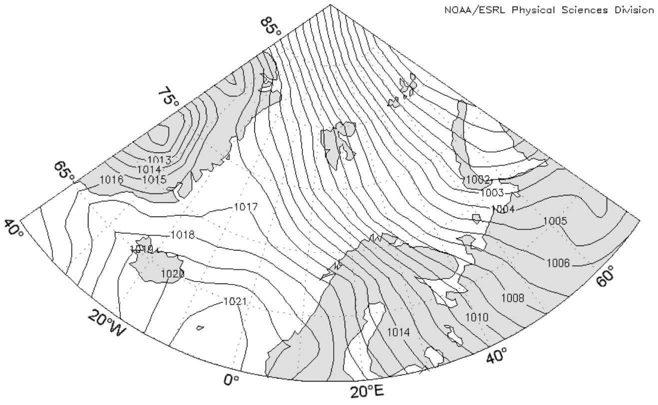

Fig. 4.9. Average pressure field [hPa] in May 1990 in the Atlantic sector of the Arctic.

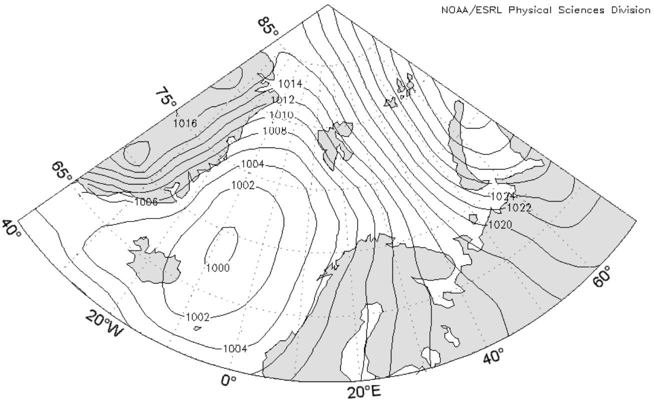

Fig. 4.10. Average pressure field [hPa] in April 2006 in the Atlantic sector of the Arctic.

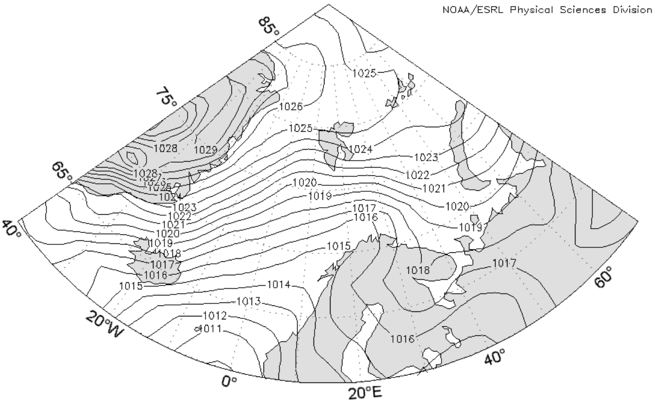

Fig. 4.11. Average pressure field [hPa] in April 1979 in the Atlantic sector of the Arctic.

In the summer the mean pressure field is very blurred, without distinct centres. In June, mean pressure gradients are very small and between Franz Josef Land and the Norwegian Sea pressure changes only one hPa, from 1012 to 1013 hPa. In July, pressure gradients are still small but higher pressure encompasses Novaya Zemlya and the SE part of the Barents Sea, whereas low-pressure systems are seen over Greenland, and northwards from Spitsbergen in the direction of the North Pole (Fig. 4.12). However, in the summer greater anomalies in the pressure field may also occur here. A tight high-pressure system (1019 hPa) that remained over the Barents Sea in July 1956 belongs to exceptional category (Fig. 4.13). In this month the lowest negative monthly index of cyclonicity (C = –38) in the whole period between December 1950 and December 2006 occurred.

The occurrence of a low northwards from Spitsbergen in the summer comes at times of intensive westerly circulation, seldom met over Spitsbergen in other months. The classical example of such conditions was the baric field in July 2005 (Fig. 4.14), when index of the western circulation W reached +16. More intensive westerly circulation has occurred in July 1994 (W = +25), August 1994 (W = +29), as well as in June 1970 (W = +31).

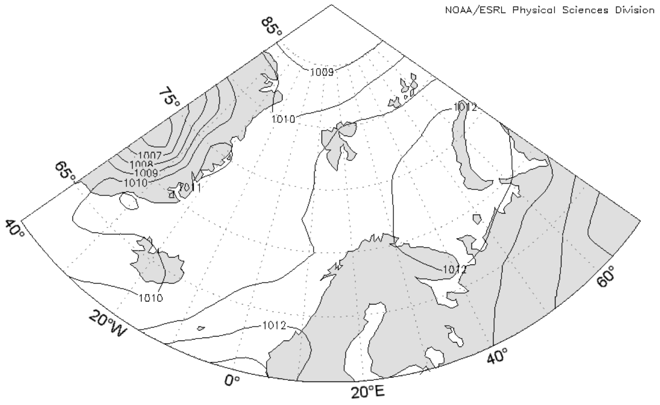

Fig. 4.12. Average pressure field [hPa] in July (1968–1996) in the Atlantic sector of the Arctic.

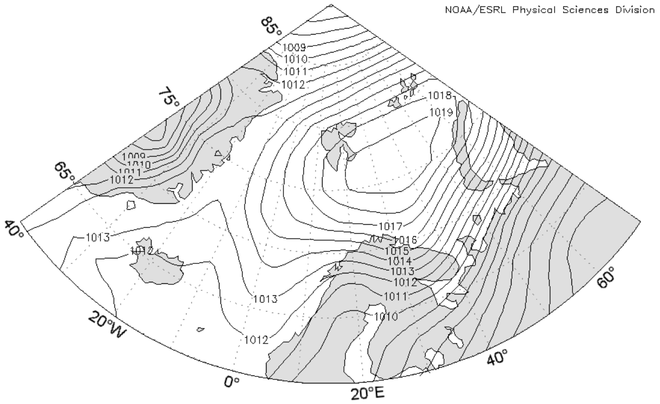

Fig. 4.13. Average pressure field [hPa] in July 1956 in the Atlantic sector of the Arctic.

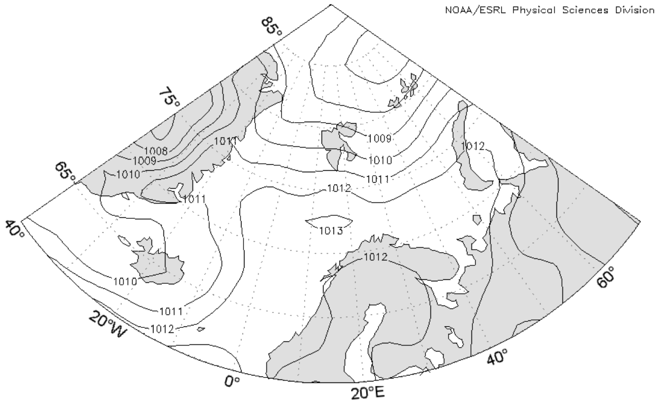

Fig. 4.14. Average pressure field [hPa] in July 2005 in the Atlantic sector of the Arctic.

The revamping of the baric field begins in September. Baric gradients increase and the low pressure trough appears south of Spitsbergen, extending there from beside Iceland (Fig. 4.15). This type of baric field is characteristic for the whole period between September and March. In connection with transformation of the baric field in the autumn there is sometimes intensive meridional circulation. Among all the months, the strongest inflow of air from the southern sector was in September 1990 (Fig. 4.16). A steep pressure gradient between the low over the Norwegian Sea (below 1004 hPa) and the high eastwards to Franz Josef Land (over 1020 hPa) caused an increase of the circulation index to S = +32. In turn, the lowest index S = –33 (identical to May 1990), proving that there is strong air flow from the northern sector, was caused by the baric situation in October 1980 (Fig. 4.17), when Spitsbergen was situated between the broad Greenland High (1029 hPa) and the low over Novaya Zemlya (below 1003 hPa).

In November and December (Fig. 4.18) there is further growth of the low pressure trough between Spitsbergen and Scandinavia. Simultaneously an independent low-pressure system develops over the Norwegian Sea. In December 1985 (Fig. 4.19) the greatest atmospheric pressure gradients appeared over Spitsbergen and intensity of the eastern circulation reached an extreme value (circulation index W = –48).

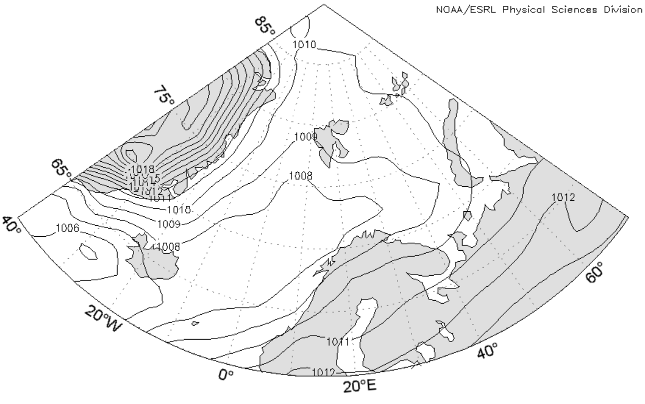

Fig. 4.15. Average pressure field [hPa] in September (1968–1996) in the Atlantic sector of the Arctic.

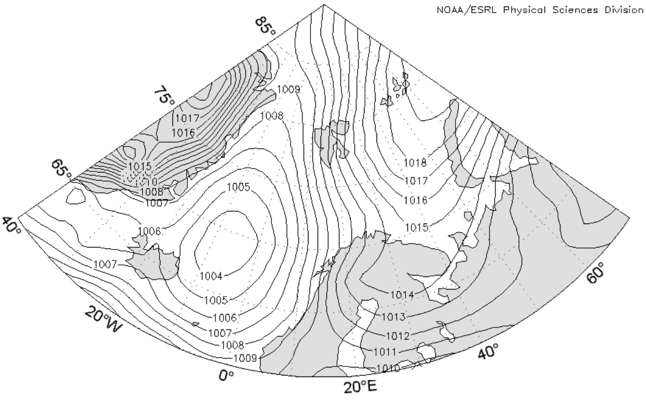

Fig. 4.16. Average pressure field [hPa] in September 1990 in the Atlantic sector of the Arctic.

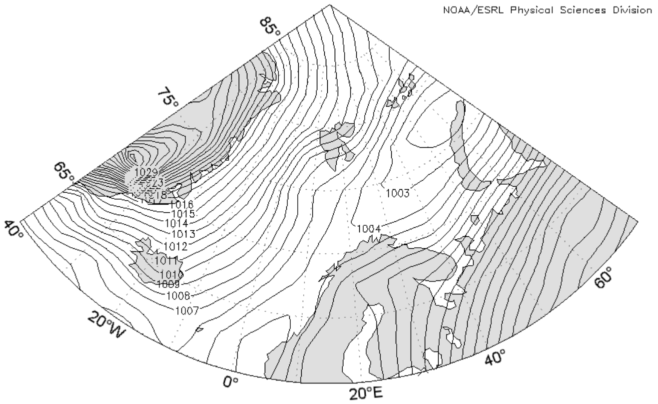

Fig. 4.17. Average pressure field [hPa] in October 1980 in the Atlantic sector of the Arctic.

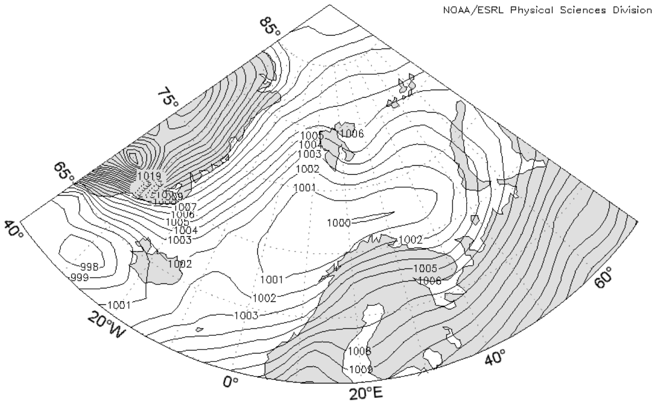

Fig. 4.18. Average pressure field [hPa] in December (1968–1996) in the Atlantic sector of the Arctic.

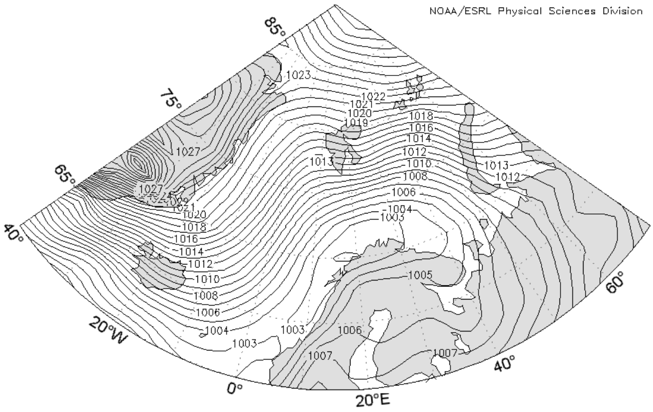

Fig. 4.19. Average pressure field [hPa] in December 1985 in the Atlantic sector of the Arctic.

4.2. The frequency of occurrence of the circulation types

Circulation in the Atlantic sector of the Arctic has been the subject of many papers (Przybylak 1996b). It is most accurately determined for Spitsbergen (Niedźwiedź 1992, 1997b, 2001). In a later part of this monograph, the frequency of circulation types and characteristics of three indices describing the main features of atmospheric circulation over Spitsbergen will be synthesised from December 1950 to September 2010, and also for nearly ten years of the 21st century. Regular work on the catalogue of circulation types for this region of the Arctic permit this (Niedźwiedź 2010). A classification of 21 circulation types referred to the well-known typology of H.H. Lamb (1972) and circulation indices was described earlier (Niedźwiedź 1992, 1992-1993, 1997a). For the entire Northern Hemisphere, and also for the Arctic, Ustrnul (1997) developed an objective classification of atmospheric circulation, 1901–1995, based on the pressure data from centres on a regular geographical grid.

The circulation types were divided into two groups: a – anticyclonal (high pressure) and c – cyclonal (low pressure). When assigning particular types of circulation to a defined group, authors followed first of all the anticyclonal or cyclonal curvature of isobars, and in the case of a linear isobars situation it only was described as anticyclonal when atmospheric pressure over the larger part of Spitsbergen was higher than 1013 hPa. A separate circulation type "x" was assigned in the case of a baric saddle or when it was impossible to explicitly determine synoptic situation because of the blurred baric field. The frequency of occurrence of such uncertain situations does not exceed 3% in the annual scale. For anticyclonal situations, eight advection types were recognised, depending on the direction of inflow of air masses to Spitsbergen: Na, NEa, Ea, SEa, Sa, SWa, Wa and NWa. Two stagnation situations were marked as Ca – centre of the high over Spitsbergen and Ka –anticyclonal wedge or ridge of the high pressure spreading over the investigated area. Eight analogous advective situations create the cyclonal types: Nc, NEc, Ec, SEc, Sc, SWc, Wc and NWc. Two remaining situations arise with unusually variable advection in the case of appearance of the centre of the low over Spitsbergen (Cc), and the occurrence of a cyclonal trough (Bc).

A few examples of these circulation types are shown on attached isobar maps for the Atlantic sector of the Arctic. Fig. 4.20 shows a classical anticyclonal situation NEa on April 8, 1988. Spitsbergen was under the influence of the Greenland High whereas the low was located in the southern part of the Barents Sea. Between these systems air flowed over Spitsbergen from the NE, from the vicinity of Franz Josef Land. The same direction of air flow, but with a deep low centred over the southern Barents Sea extending its influence as far as Spitsbergen (Fig. 4.21) occurred on December 19, 2003. This type of circulation was classified as NEc.

Lows passing along the eastern coast of Greenland and through the Greenland Sea cause the advection of very warm air masses from the SW to Spitsbergen. A classical example of situation SWc from January 8, 2006 is shown in Fig. 4.22. On August 10, 1997 there was a deep low (979 hPa) over Franz Josef Land (Fig. 4.23). Spitsbergen was also under the influence of this low and isobar pattern caused intensive advection of air from the NW (circulation type NWc).

The next examples are of situations without advection. The synoptic map of April 10, 1996 is shown in Fig. 4.24. On this day, a centre of high pressure (1042 hPa) was over Spitsbergen (circulation type Ca). This was the strongest high that occurred during the period of meteorological observations at Hornsund. However, Spitsbergen is very often under the influence of a high-pressure wedge or ridge (circulation type Ka). For example, on October 29, 2000 (Fig. 4.25) such a ridge of

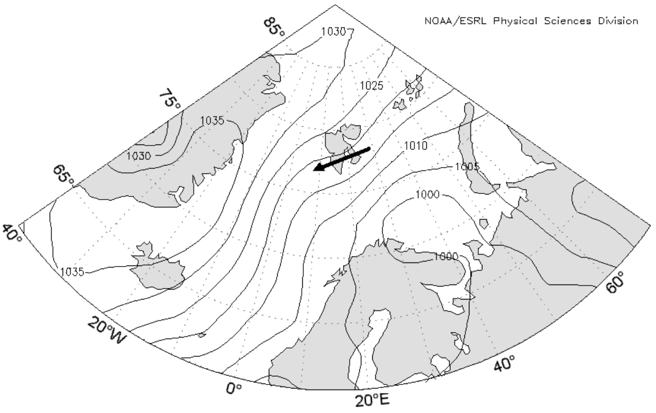

Fig. 4.20. Pressure field [hPa] characteristic for circulation type NEa – April 8, 1998, 12 UTC. Arrow shows direction of advection of air masses over Spitsbergen.

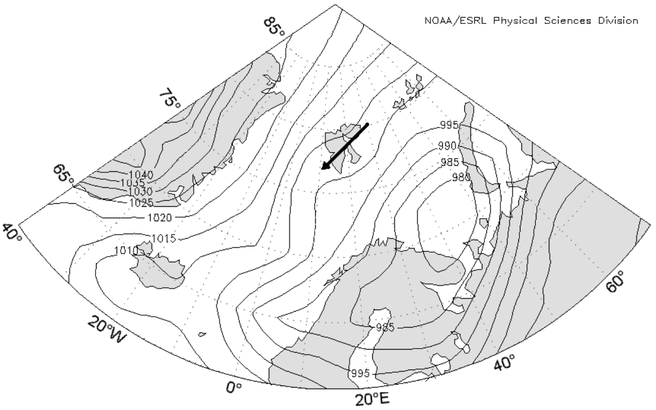

Fig. 4.21. Pressure field [hPa] characteristic for circulation type NEc – December 19, 2003, 12 UTC. Arrow shows direction of advection of air masses over Spitsbergen.

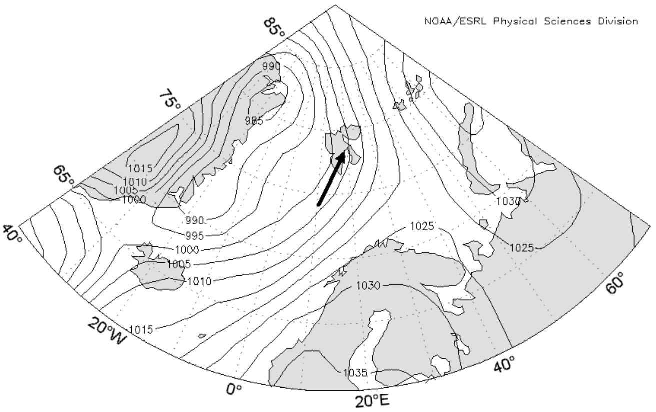

Fig. 4.22. Pressure field [hPa] characteristic for circulation type SWc – January 8, 2006, 12 UTC. Arrow shows direction of advection of air masses over Spitsbergen.

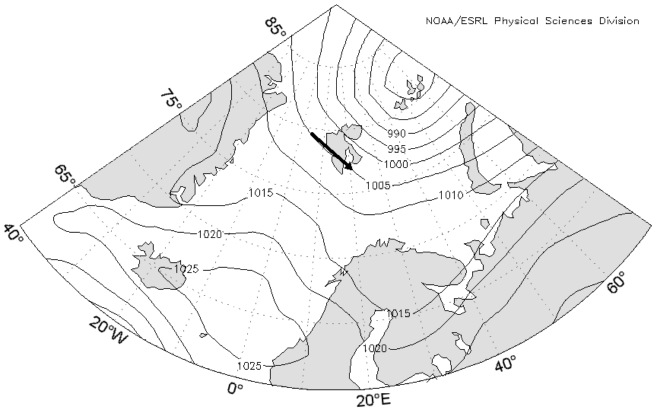

Fig. 4.23. Pressure field [hPa] characteristic for circulation type NWc – August 1997, 12 UTC. Arrow shows direction of advection of air masses over Spitsbergen.

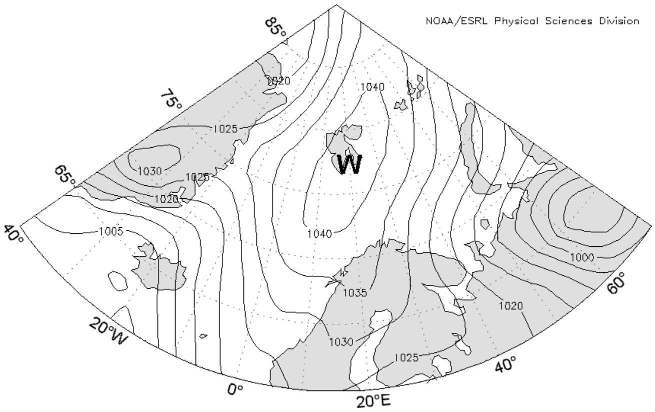

Fig. 4.24. Pressure field [hPa] characteristic for circulation type Ca – April 10, 1996, 00 UTC. W denotes centre of the high over Spitsbergen.

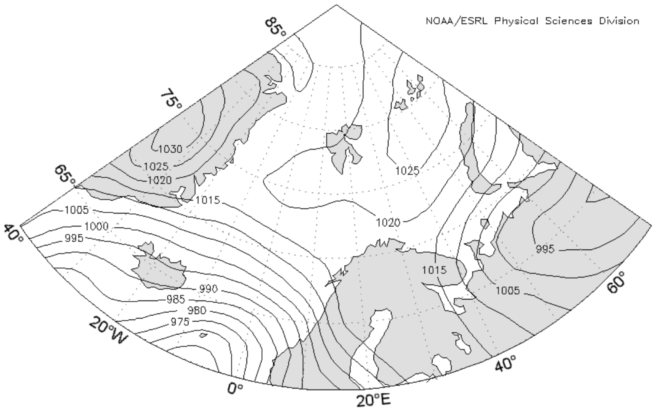

Fig. 4.25. Pressure field [hPa] characteristic for circulation type Ka – October 29, 2000, 12 UTC

high pressure with a weak gradient spread over Spitsbergen, connecting the Greenland High with a high centred over Franz Josef Land.

In turn, an example of synoptic situation Cc is shown in Fig. 4.26. On January 31, 1993, the centre of the deepest low (947 hPa) ever recorded during the meteorological observations at Hornsund, was centred precisely over Spitsbergen. At other times Spitsbergen is in a low-pressure trough (Bc). Such type of circulation is showed for June 9, 1995 (Fig. 4.27), when the axis of such a trough with a small gradient extended from the Pole through Spitsbergen to the northern part of the Scandinavian Peninsula.

The frequency of occurrence of situations of high pressure over Spitsbergen is shown in Table 4.1, and situations of the low pressure in Table 4.2. On the annual scale, the most frequent occurrence over Spitsbergen is the high-pressure wedge or ridge (Ka – 10.4%). Over the year this type of circulation was most seldom in November and December (6.1%), and most frequent in May (16.5%). From May to August, it occurred with a frequency exceeding 15%.

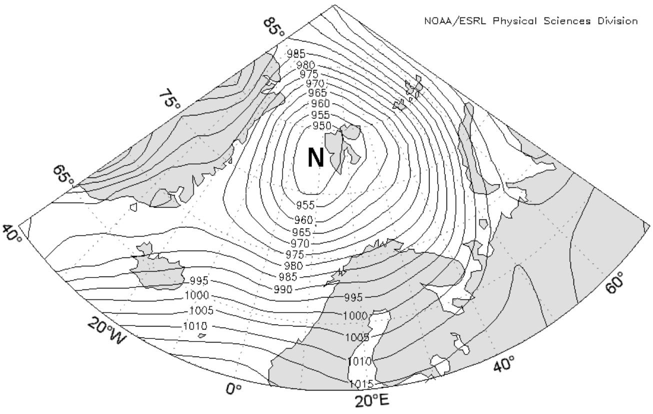

Fig. 4.26. Pressure field [hPa] characteristic for circulation type Cc – January 31, 1993, 06 UTC. N denotes centre of the low over Spitsbergen.

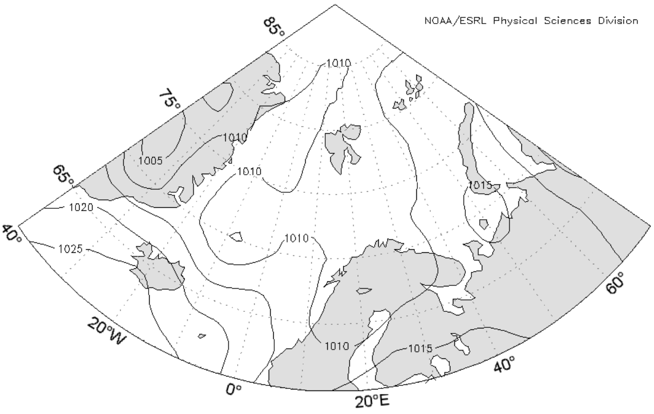

Fig. 4.27. Pressure field [hPa] characteristic for circulation type Bc – June 9, 1995, 12 UTC.

Table 4.1. Frequency of occurrence [%] of anticyclonal (a) types of circulation over Spitsbergen (December 1950 – September 2010)

Month	Na	NEa	Ea	SEa	Sa	SWa	Wa	NWa	Ca	Ka	a
January	3.3	7.9	6.3	2.6	1.8	1.0	0.7	0.4	0.8	5.9	30.5
February	2.9	7.9	8.6	3.3	1.2	1.8	0.4	0.9	0.9	6.8	34.8
March	2.8	9.9	9.6	3.8	1.3	1.5	0.4	0.5	0.8	6.7	37.2
April	7.1	11.2	9.1	5.4	1.8	1.1	0.9	1.2	1.6	9.4	48.7
May	7.8	8.3	9.3	4.1	2.4	2.8	3.8	2.2	2.2	16.5	59.2
June	5.2	4.8	5.4	3.6	1.1	3.2	4.1	3.7	2.4	15.7	49.1
July	2.4	2.5	4.8	4.9	2.3	4.7	4.1	2.1	1.9	15.6	45.3
August	3.2	2.8	6.8	5.1	2.7	4.0	3.3	2.5	1.9	15.9	48.3
September	3.5	3.6	5.4	2.8	1.9	1.8	1.3	1.6	1.3	9.8	33.1
October	4.2	6.7	5.5	2.9	1.5	1.2	0.9	1.4	1.0	9.8	35.2
November	2.8	6.8	6.4	3.0	1.2	1.1	0.7	0.6	0.6	6.1	29.4
December	3.8	7.9	6.2	2.2	2.1	1.6	0.7	0.5	0.5	6.1	31.7
winter	3.3	7.9	7.0	2.7	1.7	1.5	0.6	0.6	0.7	6.3	32.3
spring	5.9	9.8	9.3	4.4	1.8	1.8	1.7	1.3	1.5	10.9	48.4
summer	3.6	3.4	5.7	4.5	2.0	3.9	3.9	2.8	2.1	15.7	47.5
autumn	3.5	5.7	5.8	2.9	1.6	1.4	1.0	1.2	1.0	8.6	32.6
year	**4.1**	**6.7**	**7.0**	**3.6**	**1.8**	**2.2**	**1.8**	**1.5**	**1.3**	**10.4**	**40.3**

Table 4.2. Frequency of occurrence [%] of cyclonal (c) types of circulation and type "x" over Spitsbergen (December 1950 – September 2010)

Month	Nc	NEc	Ec	SEc	Sc	SWc	Wc	NWc	Cc	Bc	c	x
January	4.9	13.2	14.3	8.6	5.1	4.6	2.2	1.9	5.6	6.5	66.8	2.6
February	5.1	10.3	13.1	7.1	4.5	5.7	1.7	2.1	5.9	7.1	62.5	2.7
March	4.7	11.3	14.3	6.9	3.3	4.5	1.4	1.3	5.7	6.8	60.3	2.5
April	4.3	7.9	8.4	6.6	3.4	3.9	1.7	1.6	5.8	5.3	48.8	2.5
May	4.9	4.6	5.8	3.7	2.3	3.4	1.8	2.3	3.6	6.0	38.5	2.3
June	5.8	5.7	5.7	3.3	2.0	4.6	3.4	4.1	4.6	8.7	47.8	3.1
July	4.7	3.6	5.5	4.1	4.0	6.6	5.9	4.1	3.1	9.5	51.0	3.7
August	4.9	4.1	4.8	5.4	3.9	5.4	4.4	4.1	3.8	7.4	48.3	3.4
September	8.0	7.8	9.4	8.3	4.7	4.9	3.1	3.8	5.4	7.1	62.6	4.3
October	6.6	10.7	10.8	7.6	3.9	3.7	1.8	3.0	5.9	7.9	61.8	3.0
November	6.6	11.5	12.9	8.3	5.4	5.2	1.2	1.9	7.2	7.6	67.9	2.7
December	5.2	13.5	14.1	8.1	4.0	3.8	2.1	2.1	5.8	7.1	65.7	2.6
winter	5.1	12.4	13.9	8.0	4.5	4.7	2.0	2.0	5.7	6.9	65.1	2.6
spring	4.7	8.0	9.5	5.7	3.0	3.9	1.6	1.7	5.0	6.1	49.2	2.4
summer	5.1	4.5	5.3	4.3	3.3	5.5	4.6	4.1	3.8	8.5	49.1	3.4
autumn	7.1	10.0	11.1	8.1	4.7	4.6	2.0	2.9	6.2	7.5	64.0	3.4
year	**5.5**	**8.7**	**9.9**	**6.5**	**3.9**	**4.7**	**2.6**	**2.7**	**5.2**	**7.2**	**56.8**	**3.0**

The second most frequent occurrence is the cyclonal situation with advection of air from the east – Ec (9.9%). Between October and March this is a dominating circulation type, with its frequency maximum in January and March (14.3%). This type of circulation is noted the least in August (4.8%). Situation NEc is characterized by similar frequency (8.7%), ranging from 3.6% in July to 13.5% in December. Anticyclonal situations with the same directions of advection: Ea (7.0%) and NEa (6.7%) also occur quite often.

The centre of a high (Ca – 1.3%) and anticyclonal situations NWa (1.5%), Wa and Sa (1.8%) occurred with the least frequency over Spitsbergen. Advection of air from the south and south-west, from the area of the Greenland and Norwegian Seas contributed to large thermal and precipitation anomalies. In this group cyclonal situations (SWc – 4.7%, Sc – 3.9%) were more frequent than anticyclonal (SWa – 2.2%, Sa – 1.8%). Situation SWc most seldom occurred in May (3.4%) and October (3.7%) and most often in July (6.6%). Frequency of situations Sc changed from 2.0% in June to 5.4% in November.

The appearance of particular types of circulation changes a lot year in, year out (Table 4.3). Situations Ec and NEa (3.2) were characterized by the greatest variability, as evidenced by their standard deviations. In 1983 the frequency of type Ec reached 19.5%, whereas in 1958 it was only 4.4%. For type NEc extreme fluctuations were even greater, from 4.1% in 1990 to 19.7% in 1975. Variability of frequency in advection situation SWc ranged from 1.9% in 1968, 1998 and 2009 to 11.5% in 1976. There were years when some situations did not appear at all: Ca (six times), Sa (in 1964 and 2007), SWa (1961), NWa (2004), and Wc (1998).

Table 4.3. Mean and extreme annual frequencies of occurrence (%) of circulation types (Tc) over Spitsbergen in 1951–2009; a – anticyclonal types, c – cyclonal types

Tc	Anticyclonal types										
	Na	NEa	Ea	SEa	Sa	SWa	Wa	NWa	Ca	Ka	a	-
mean	4.1	6.7	7.0	3.6	1.8	2.2	1.8	1.5	1.3	10.4	40.3	-
σ_n	1.2	3.2	3.0	1.6	1.2	1.3	0.8	0.9	1.1	2.3	7.5	-
max	6.6	14.5	18.4	8.2	5.2	7.1	4.1	4.4	5.2	16.2	55.1	-
year	1991	1962	1966	1998	1954	1956	1967	1958	1998	1969	1958	-
min	1.6	1.6	2.7	0.8	0.0	0.0	0.5	0.0	0.0	5.5	24.1	-
year	1999	1999	2002	1986	1964; 2007	1961	1975; 1986; 1989; 2007	2004	1971- 1973; 1977; 1992	1973	1975	-
Tc	Cyclonal types										
	Nc	NEc	Ec	SEc	Sc	SWc	Wc	NWc	Cc	Bc	c	x
mean	5.5	8.6	9.9	6.5	3.9	4.7	2.6	2.7	5.2	7.2	56.8	3.0
σ_n	2.1	2.9	3.2	2.3	1.7	1.8	1.2	1.1	1.5	2.0	7.3	1.2
max	10.1	19.7	19.5	12.3	9.0	11.5	6.6	5.2	8.8	12.9	73.7	6.3
year	2007; 2008	1975	1983	1990	1974	1976	1976	1951	1959	2006	1975	1995
min	1.6	4.1	4.4	2.5	0.5	1.9	0.0	0.8	2.5	3.8	42.7	0.8
year	1960	1990	1958	1951; 1980	1987	1968; 1998; 2009	1998	1957	1998; 2008	1976; 1984	1958	1980

Spitsbergen is situated near to the zone of the Arctic Front and is distinguished by increased cyclonal activity (56.8% days in the year). Situations with high pressure occurred for 40.3% of the days, remaining 3% falling into the baric saddles and indefinite situations (x). Of interest is the annual sequence of frequency of high-pressure systems (a) and low-pressure systems (c) shown in Fig. 4.28. Cyclonic activity in the winter and autumn surpasses 60% of days, reaching in

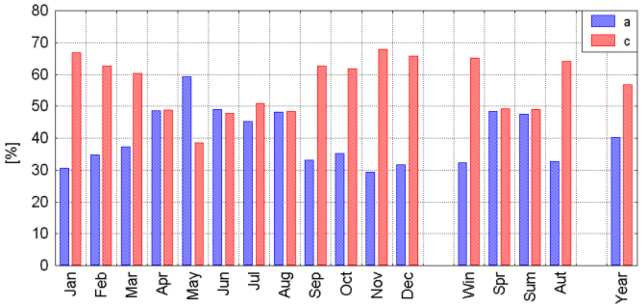

Fig. 4.28. Frequency of occurrence of anticyclonal (a) and cyclonal (c) circulation types over Spitsbergen in particular months, seasons (Win – winter, Spr – spring, Sum – summer, Aut – autumn) and in the year (Year), in 1951–2009.

November 67.9%. Only in May does the frequency of high-pressure systems (59.2%) considerably exceed that of low-pressure systems (38.5%). In June this difference is smaller (a = 49.1%, c = 38.5%). In April and August there is a state of equilibrium, whereas in other months lows occurred significantly more frequently than highs.

The inflow of air from the eastern sector is characteristic for Spitsbergen. Considering only the directions of advection of air masses, without taking into account the type of baric system, the most frequent occurrence of just two directions: E (16.9%) and NE (15.3%) is evident in the annual scale. Flow of air from the NW (4.2%) and W (4.4%) occurred the most seldom during the year. Inflow of air masses over the Barents Sea thus occurred over four times more frequently than from the Greenland Sea.

Particular directions of advection over Spitsbergen show variability over the annual course. The NE direction occurred with increased frequency from October to April, with maxima in December (21.4%) and March (21.3%). It reached a minimum in the summer – in July (6.1%) and August (6.9 %). Flow of air from the east was as much as 19% of days from November to March, with a maximum in March (23.9%). The minimum was in July (10.3%) and other months of the Arctic summer.

The frequency of flow of warmer air masses from the SW had a distinct culmination in the summer, reaching 11.2% in July. Advection from the south was less variable than from the SW and reached the highest frequencies between July and September, when it attained 6.7%. In contrast, June was distinguished by the drop of frequency of flow from the south to 3.1%. Advection of air from the western sector was characterized by the most regular annual cycle of all directions. Direction W reached a sharp maximum in July (10.1%), while minimum frequency was noted in March (1.8%). Direction NW also reached the highest frequency in the summer (maximum 7.7% in June), and minimum also in March (1.8%).

4.3. Index of zonal circulation – western (W)

To generalise, variability of circulation is best rendered by three simple indices: W – the western circulation, S – the southern circulation, and C – cyclonicity. Indices P, M, S and C proposed by Murray and Lewis (1966) were taken as the model, to which the author introduced small modifications (change of the index of meridional circulation M for index S, and change of the index of progression P for the index of the western circulation W). The indices are expressed by means of abstract numbers, being sum of weight points attributed to particular types of circulation that occurred in a given period. The indices are used for ready assessment of atmospheric circulation over the whole month, season or year. These indices are not suitable for description of circulation in periods shorter than a month. The method of calculations of these indices was described earlier (Niedźwiedź 2001). In the present work, monthly, seasonal and annual values of indices were updated and placed in Appendix 1 *in extenso*, for the period from December 1950 to September 2010. The annual course of particular indices is described below and presented in Fig. 4.29, whereas its multi-annual variability will be discussed in Chapter 16.2.

Between May and August all circulation indices are characterized by small values, indicating the diminished intensity of circulation processes. Between November and March, differences between indices are the greatest, proving the vigorous dynamics of the baric systems.

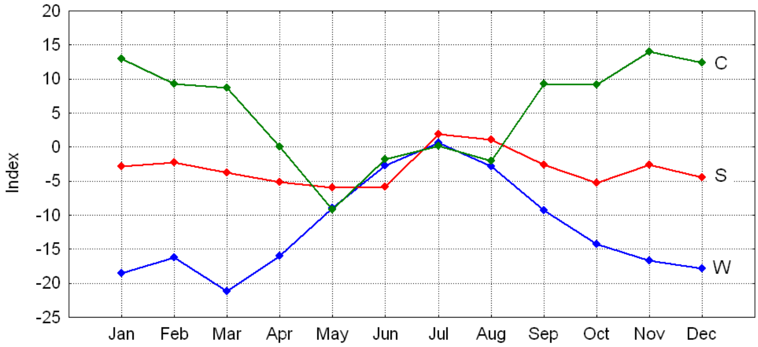

Fig. 4.29. Annual course of circulation indices over Spitsbergen in 1951–2009:
W – western circulation, S – southern circulation, C – cyclonicity.

Index W (Fig. 4.29, Appendix 1.1) determines intensity of zonal circulations: western (positive values) or eastern (negative values). A zonal form of circulation is characteristic for Spitsbergen, with the eastern component (index W = –144) dominating first of all between October and April (in March W drops to –21). This circulation weakens in the summer when index W approaches zero, even taking a positive value in July (+1). The most intensive eastern circulation was noted in December 1985 (W = –48). The greatest intensity of western circulation was in June 1970 (W = +31). In seasons of the year extreme western circulation occurred in the summer of 1994 (W = +45), and of eastern circulation in the winter of 1978/1979 (W = –101).

4.4. Index of meridional circulation – southern (S)

Index S (Fig. 4.29, Appendix 1.2) is a measure of the intensity of meridional circulation. Its positive values indicate flow of air from the southern sector and negative – from the northern sector. Forms of meridional circulation, despite relatively small frequency of their occurrence, exert considerable influence on the variability of temperature (Niedźwiedź 2001). The northern component dominated distinctly on Spitsbergen (index S = –37 for year) over the southern, with the greatest intensity in May and June (S = –6). Only in July (S = +2) and August (S = +1) is the reverse situation observed.

The strongest northern circulation before 2010 occurred in October 1980 and May 1990 (S = –33). An even lower index S of -34 was noted in June 2010. The most intensive advection of air masses from the south was noted in September 1990 (S = +32) and April 2006 (S = +31) that brought to substantial positive thermal anomalies at Hornsund.

Among seasons of the year the most intensive advection of air from the south was in the winter of 2005/2006 (S = +31) and in the summer of 1953 (S = +30). In turn, the greatest intensity of air flow from the north occurred in the spring of 1951, in the summer of 2010 (S = –57), and also in the winter of 1962/1963 (S = –50) when the cold Arctic air reached far southwards into the interior of Europe.

4.5. Index of cyclonicity (C)

Index C (cyclonicity) measures the activity of lows (positive values) or of highs (negative values). Domination of the low-pressure systems (index C = 63 for a year) is characteristic feature of Spitsbergen, especially in the period between September and March (C= +14 in November). Equilibrium in the frequency of cyclonal and anticyclonal circulation occurred between April and August. Only in May did the various forms of the high pressure have a quantitative advantage over the lows and the index of cyclonicity dropped to –9 (Fig. 4.29, Appendix 1.3). Small negative values of this index (C = -2) were found again in June and August, C = 0 occurred in July.

The greatest low-pressure activity was observed in March 2007 (C = +39) and November 1996 (C = +37), as well as in December 1953 and March 1975 (C = +36). The greatest activity of high-pressure systems was in July 1956 (C = –38) and May 1999 (C = –36). Among seasons of the year the most cyclonal weather occurred in the winter of 1974/1975 (C = +85) and in the autumn of 2007 (C = +75). The greatest anticyclonal activity was in the summer of 1969 (C = –81) and in the spring of 1958 (C = –62).