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WEATHER TYPES IN THE NORWEGIAN ARCTIC

Abstract: In order to assess the usefulness of Norwegian Arctic bioclimatic conditions for outdoor activities in the years 1971–2000, the author applied his own weather typology developed on the basis of the classification proposed by Błażejczyk (1979). The typology classified four weather groups for the study area. Atmospheric circulation types proposed by Niedźwiedź (2002) were used to determine the synoptic situations and types of favourable weather conditions for outdoor recreation, tourism and work, as well as those that may pose a threat to human life.

Key words: Norwegian Arctic, bioclimatic conditions, tourism, human thermal sensation

Introduction

Weather has a significant influence on many human activities, particularly on those performed outdoors. A number of meteorological factors influence our organisms, and thus different weather typologies are used to assess the weather complex as a whole. For the purposes of analysing the bioclimate of the Norwegian Arctic, the author modified the classification by Błażejczyk (1979). Both approaches are based on the human thermal sensation caused by the response of the thermoregulatory system to external stimuli. The human thermal sensation was determined on the basis of the cooling power of the air (H). The typology for the Norwegian Arctic was developed for the assessment of bioclimatic conditions occurring throughout the year from the point of view of the different ways in which they affect tourism, recreation and outdoor activities.

There are a few permanently populated settlements and a couple of polar research stations in the Norwegian Arctic. The total number of people living within the study area is about 3,000. According to Svalbard Tourism (www.svalbard.net 2008), about 2,080 of the population are Norwegians (90 per cent of whom live in Longyearbyen and the rest in Ny-Ålesund, Sveagruva and other places), and there are about 500 Russians in Barentsburg, and 9 Poles in Hornsund, the Polish Polar Station of the Institute of Geophysics of the Polish Academy of Sciences. In spring and summer the population increases by a few thousand tourists, though the number is rising each year (Kaltenborn and Emmelin 1993; Kluba 1993; Stewart et al. 2005; www.svalbard.net 2008). The tourists are attracted by beautiful views and the nature of the Arctic.

The earliest bioclimatic weather typologies were developed in the first half of the 20th century. In bioclimatological literature the method of Fiedorov-Chubukov has been in use since the 1960s (see Błażejczyk 1979). It classifies weather types into three groups according to their suitability for climate therapy: useful, moderately useful and non-useful. Bogucki (1967) proposed a weather typology for the analysis of biological rhythms in biometeorology. Błażejczyk (1979, 1992) based his classification on the notion of human thermal sensation triggered by the response of the thermoregulatory system to external stimuli. The first version of the classification was made to assess bioclimatic conditions in spas, holiday and recreation areas, whereas the second version (1992) can be additionally used to assess the suitability of weather for outdoor work. Danilova (1988) developed a system of weather classification for tourism, recreation and spa treatment, which she based on the physiological sensation of various states of weather. In another classification, Besancenot (1990) just used climatic indices to define suitable weather types for winter sports. The most recent biothermal-meteorological classification of weather states that can be applied to assess suitability of weather for various forms of recreation and tourism was proposed by Błażejczyk (2004). It considers the main biothermal properties of specific weather states (thermal sensation, intensity of radiation stimuli and sultriness, types of thermal responses of the organism) and selected meteorological characteristics (daily ranges of air temperature, precipitation, snow cover).

Study area, material and methods

The analysis of the Norwegian Arctic weather types makes use of daily meteorological data (cloudiness, air temperature, precipitation and wind velocity) obtained from six stations situated in the region: Ny-Ålesund (NYA), Svalbard Airport (SVA), Hornsund (HOR), Hopen (HOP), Bjørnøya (BJO) and Jan Mayen (JMA). The statistical material which was collected covers the years 1971–2000, thought the analysed data series for three stations are shorter as the stations were opened later than the others. The list of stations and their geographic locations in the Norwegian Arctic are shown in Table 1 (Steffensen et al. 1996).

Table 1. Geographic locations of meteorological stations in the Norwegian Arctic

Station	φ	λ	Height m a.s.l.	Period
Ny-Ålesund (NYA)	78°55'N	11°56'E	8	1975–2000
Svalbard Airport (SVA)	78°15'N	15°28'E	28	1976–2000
Hornsund (HOR)	77°00'N	15°34'E	10	1979–2000
Hopen (HOP)	76°30'N	25°04'E	6	1971–2000
Bjørnøya (BJO)	74°31'N	19°01'E	15	1971–2000
Jan Mayen (JMA)	71°01'N	8°40' W	10	1971–2000

The weather data was made available by the Norwegian Meteorological Institute, the Institute of Meteorology and Water Management (Gdynia Branch) and the Institute of Geophysics of the Polish Academy of Sciences in Warsaw. I would like to thank the institutions for their kind assistance.

In order to calculate the cooling power of the air the wind velocity measured at 10 m a.g.l. was adjusted to 2 m, using Milewski's formula after Kozłowska-Szczęsna et al. (1997):

$$V_z = \mathbf{V_w} \ (\mathbf{h_z}/\mathbf{h_w})^{0.2}$$

where: V_z – wind velocity at a height of h_z = 2 m,
V_w – wind velocity at the height of the wind gauge h_w.

The cooling power of the air determines the amount of heat lost from the body surface in a unit of time. This paper focuses in particular on dry cooling as it is a useful factor for the evaluation of thermal sensation in people in motion, dressed appropriately for the season. The value of H was calculated from Hill's equations (Büttner 1938, cited in Kozłowska-Szczęsna et al. 1997):

$$\boldsymbol{H = (36.5 - T)\cdot(0.20 + 0.4\cdot v^{0.5})\cdot 41.868}, \qquad \text{when } v \leq 1\ \mathrm{m\cdot s^{-1}}$$
$$\boldsymbol{H = (36.5 - T)\cdot(0.13 + 0.47\cdot v^{0.5})\cdot 41.868}, \qquad \text{when } v > 1\ \mathrm{m\cdot s^{-1}}$$

where: T – air temperature (°C), v – wind velocity ($\mathrm{m\cdot s^{-1}}$).

The value of the cooling power of the air was calculated using BioKlima 2.2 software developed by Błażejczyk and Błażejczyk (2003).

The description of bioclimatic conditions in the Norwegian Arctic that are suitable for outdoor work and recreation activities makes use of the author's own weather typology designed after Błażejczyk's classification (1979). In both typologies the elementary classifying property is the thermal sensation caused by the response of the body's thermoregulatory system to external stimuli (i.e. mainly temperature and speed of wind). In order to determine the extent of thermal sensation the cooling power of the air was used, according to the original typology. Unlike in the classification by Błażejczyk (1979), here the first hot type of weather was irrelevant as this type of weather does not occur in the study area. Therefore, five types of weather were determined (Fig. 1) and further classification was based on the amount of cloudiness, the solar factors (i.e. the polar night and the rest of the year) and the amount of precipitation. After the particular weather classes had been analysed from the point of view of their suitability for outdoor activities, they were divided into four groups (*A, B, C* and *D*), the properties of which are described under Figure 1.

The introduction of changes to certain criteria in Błażejczyk's original typology was the result of both a lack of data (e.g. daily data on the duration of fog) and the necessity of using factors that would better characterise the specific bioclimatic conditions in the Norwegian Arctic (e.g. data on the solar factor instead of sultriness, absent in the analysed area).

Additionally, the frequency of particular weather types was investigated, along with the intensity of changes occurring day by day in the Norwegian Arctic (Table 2).

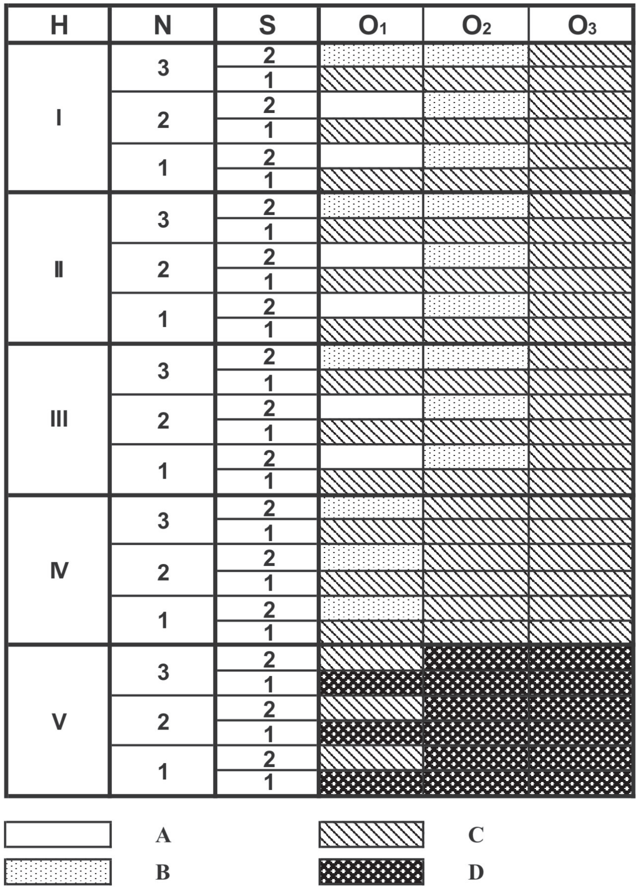

Fig. 1. Typology for the assessment of bioclimatic conditions in the Norwegian Arctic

A – weather suitable for recreation and tourism (walking, skiing, riding a snow scooter or a snowmobile etc.) and for outdoor work

B – weather in which only people with an efficient thermoregulatory system may go in for extensive recreation or work outdoors

C – weather that is unsuitable for prolonged stay or work outside buildings in polar settlements and stations

D – weather that poses a threat to human health or life

Key: Types of weather according to the cooling power of the air:
I - warm: $\leq 420.0\ W \cdot m^{-2}$, **II** - comfortable: $420.1\text{-}840.0\ W \cdot m^{-2}$, **III** - cool: $840.1\text{-}1260.0\ W \cdot m^{-2}$, **IV** - cold: $1260.1\text{-}2100.0\ W \cdot m^{-2}$, **V** – very cold $\geq 2100.1\ W \cdot m^{-2}$.
N – degree of cloudiness (0 - 10): **1** – 0.0-5.0; **2** – 5.1-9.9; **3** – 10.0; ***S*** – solar factor: **1** – polar night, **2** – the rest of the year; ***O*** – atmospheric precipitation: O_1 - 0-1.0 mm, O_2 – 1.1-10.0 mm, O_3 - >10.0 mm

Table 2. Intensity of day-by-day weather changes in the Norwegian Arctic

Symbol	Change	Characteristics
a	None	In consecutive days the same type of weather occurs: A-A, B-B, C-C, D-D
b	Little favourable	In consecutive days there is little change in the favourable types of weather: *A-B*
c	Little unfavourable	There is little change in the unfavourable types of weather: *B-C, C-D*
d	Significant and big	There are types of weather characterised by significant (*A-C*) or big changes (*A-D*)

Bioclimatic properties, seen from the point of view of heat exchange between the human body and the atmospheric environment, are shaped not only by the energy factor, but also by the dynamic factor, connected with the seasonal variability of atmospheric circulation over the Norwegian Arctic. The meaning of this factor was considered on the basis of the frequency of atmospheric circulation types in the years 1971–2000. The source for the analysis was provided by the *Catalogue of Atmospheric Circulation Types for Spitsbergen* (Niedźwiedź 2002). The author distinguished 21 circulation types, based on the advection direction or the lack of distinct inflow, and the kind of the pressure system (Niedźwiedź 2001). The station at Hornsund was used to determine the synoptic situations and types of weather that create favourable conditions for outdoor recreation and work as well as those types that may pose a threat to human life.

Results

Frequency of occurrence of the weather groups and types

Four groups of weather (*A, B, C* and *D*) were distinguished in order to assess the suitability of the Norwegian Arctic bioclimate for tourism, outdoor recreation and work. The scope of the first two groups involves weather conditions that allow various forms of physical activities in the open air (*A-B*). The next two groups concern either the weather situations in which prolonged periods outdoors are not recommended (*C*), or when they are definitely prohibited due to possible threats to human health or life (*D*).

Generally, with the exception of the polar night, all periods of the year in the Norwegian Arctic are suitable for outdoor recreation and work, as the weather tends to be warm, comfortable or cool (types I, II and III), without overcast skies and with little precipitation (0-1.0 mm). In the Norwegian Arctic these weather situations were observed on average 54 days per year. On an annual basis, group *A* weather was the most frequent at NYA (95), SVA (66) and HOR (62), and least frequent at BJO (22). In the other stations it occurred for about 40 days. The annual course of group *A* weather is very uneven (Fig. 2). From November until January no weather conditions from this group occurred at NYA, SVA, HOR and HOP, whereas at JMA it did not occur in December and at BJO it did not occur in winter at all. These kinds of days are most frequent in summer. The average frequency for the whole area was 33 per cent of days per year, and the diversity reached from 16 per cent of days at BJO to 50 per cent at NYA.

Group *B* weather, suitable for outdoor tourism or work only for people with efficient thermoregulatory systems, occurs with types I, II and III with overcast skies, negligible precipitation (0–0.1 mm) throughout the year (with the exception of the polar night), as well as with any degree of cloudiness in the rest of the year and with medium precipitation (1.1–10.0 mm). This weather group also occurred with type IV (with highest frequency) regardless of the cloudiness and with little precipitation (Fig. 3). Group *B* weather tends to be very common in this part of the Arctic and reveals little spatial diversity. During the year, the average number of days with this weather is between 110 and 113 at NYA and HOR and up to 150 at BJO (140 at other stations). The days occurred from February to October at NYA, SVA and HOP, whereas at BJO the period was one month longer, ending in November. At JMA days with this class of weather occurred all year round except for December, and at HOR they did not occur in December or November. In the summer months the weather makes up 56 per cent of days, ranging from about 45 per cent at NYA and HOR to 65–69 per cent at HOP and BJO. Also in transitional periods this type of days was very frequent (Fig. 2).

Group *C* weather (Fig. 1) is unfavourable for prolonged period outdoors in the Norwegian Arctic. This group of weather situations includes types I, II, III and IV with any degree of cloudiness during the polar night, regardless of the presence of atmospheric precipitation. It also includes the same four types in the rest of the year when there is any degree of cloudiness and substantial precipitation (> 10.0 mm). Similar recommendations are valid for

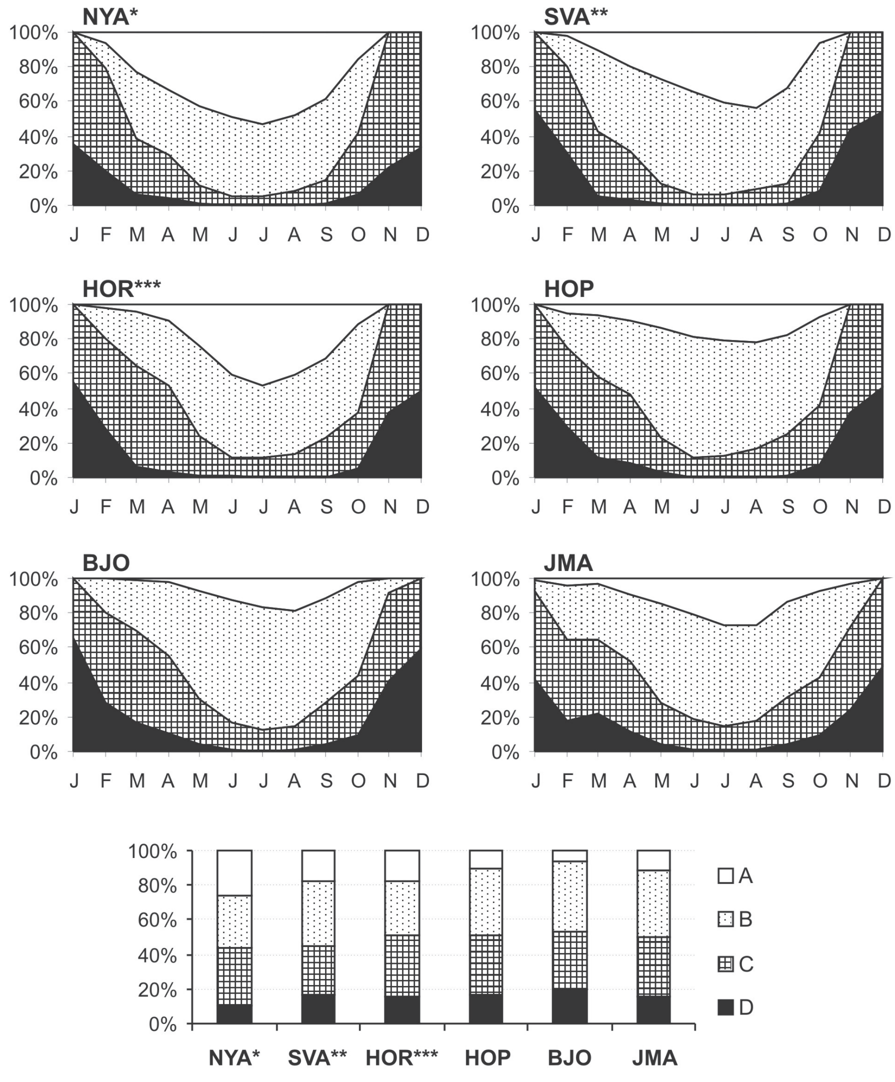

Fig. 2. Annual course of frequency of occurrence (%) of the weather groups in the Norwegian Arctic in the years of 1971–2000; Key: see Figure 1

type IV weather situations with any degree of cloudiness during the polar night and with medium precipitation (1.1–10.0 mm) and for type V with any degree of cloudiness in the rest of the year and with little precipitation. In the area of the Norwegian Arctic these weather situations occurred on aver-

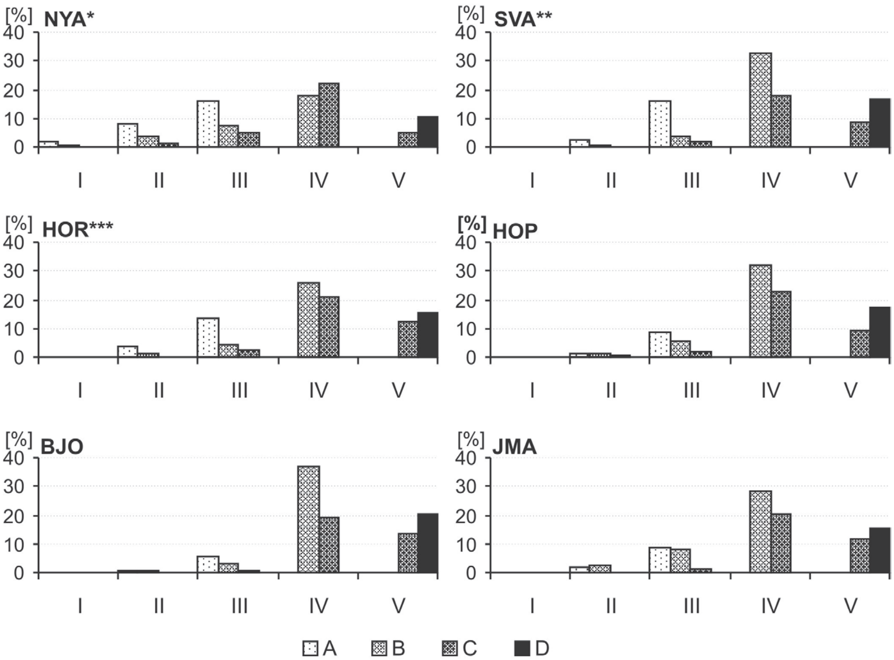

Fig. 3. Relative frequency of occurrence (%) of individual weather types (I, II etc.) and groups (A, B etc.) in the Norwegian Arctic in the years of 1971–2000; Key: see Figure 1

age for 120 days per year. Spatial diversity ranges from 102 days at SVA to 131 days at HOR. Group *C* weather was present throughout the year (Fig. 2) and most days with this type of weather were observed in winter, when they accounted for about 50 per cent of the days in the area (from 64 per cent at NYA to 42 per cent at BJO). In summer, this weather class occurred occasionally (for about 11% of days).

Group *D* weather creates favourable conditions for infections (e.g. colds) and poses threats to human health (e.g. frostbite) or even life (hypothermia). It occurs with type V (very cold) situations, regardless of the degree of cloudiness and with little precipitation during the polar night and in the rest of the year, regardless of the degree of cloudiness and with medium-to-high precipitation (Figs. 1 and 3). The most unfavourable weather occurred in the Norwegian Arctic on an average of 59 days per year with the lowest occurrence frequency at NYA (40 days), and the highest at BJO (73 days). In the winter months, human exposure to this weather throughout the area accounted for 43 per cent of the time. The strictest weather conditions were the most frequent at BJO (52 per cent of days), HOR, SVA and HOP (about 46 per cent), and the least at NYA (30 per cent). Group *D* weather days never occurred at NYA in summer and did not occur in July and August at HOR. In the rest of the stations they occurred throughout the year, however occasionally in summer.

Intensity of changes of weather conditions

The climate and bioclimate of the Norwegian Arctic are characterised by considerable variability of weather conditions from day to day, season to season and year to year (Araźny 2008). In circumstances like these the human organism has to quickly adapt to the changing weather situations when staying outside. According to Błażejczyk (1992) a high variability of weather conditions affects not only physiological processes but also the human psyche (Hoffman 2002). The influence is particularly emphasised during long-term stays in polar areas, when the people are isolated from the outside world (cf. Kwarecki 1980; Terelak 1982).

The classification of the intensity of day-to-day changes in weather conditions in the Norwegian Arctic is shown in Table 2. It distinguishes four categories of changes (a, b, c, d).

Weather conditions with no day-to-day changes within a weather group occurred in the Norwegian Arctic with an annual frequency ranging from 50 per cent (JMA) to 58 per cent of days (HOR). Favourable weather conditions also have an advantageous annual course, as the frequency of changes within one type was at least 40 per cent in the whole area throughout the year.

Little favourable changes (between the weather groups referred to as *A* and *B*) from day to day between 8 (BJO) and 19 (NYA) per cent of days, on average. From November to December such changes in most stations occurred sporadically or not at all. Little favourable changes were most frequent between May and September, when they accounted for 15–30 per cent of changes in the whole area.

Small interdiurnal weather changes, nevertheless defined as unfavourable (with changes between *B*-*C* and *C*-*D*), revealed some spatial diversity of occurrence, ranging from 20 per cent of days at NYA to 32 at BJO and JMA.

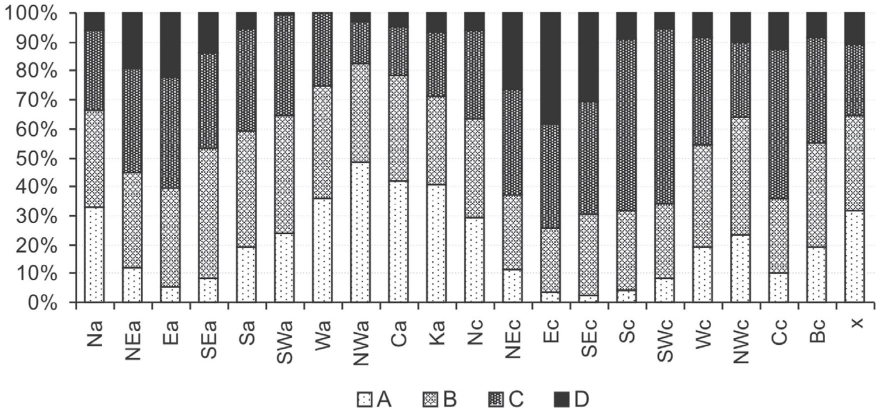

Fig. 4. Frequency of occurrence (%) of weather groups (*A, B, C* and *D*) with individual circulation types at Hornsund in the years of 1979-2000; Key: see Figure 1

In the annual course the changes occurred in all months, however they were only half as frequent in summer than in the rest of the year.

In the Norwegian Arctic region, the least frequent changes are day-to-day substantial weather changes (*A-C*) or big weather changes (*A-D*). The least favourable changes, from a human point of view, occurred there on average between 3 (BJO) and 6 (JMA) per cent of days per year. The most uncomfortable winter weather changes either did not occur or were very rare.

Relationship between atmospheric circulation and weather

One of the reasons for the high variability of weather conditions in the Norwegian Arctic is the intense atmospheric circulation over the area (Niedźwiedź 2003). This property of the polar bioclimate involves adaptation to frequently changing weather conditions. The weather groups and the local circulation conditions have been presented using the example of HOR station. There is a strong correlation between the individual weather groups proposed by the author and the circulation types distinguished by Niedźwiedź (2002).

During the year, group *A* weather – useful for outdoor recreation, tourism and work – occurred most often with anticyclonic circulation (NWa, Ca, Ka, Wa, Na), especially from the western sector (Fig. 4). On the other hand, the same weather was the least frequent with the SE flow, whether from the low or the high.

Group *B* weather, suitable for outdoor tourism or work only for people with efficient thermoregulatory systems, displays a similar frequency for all types. Its frequency was a few per cent higher only with anticyclonic circulation from the southern sector, and analogously it was a few per cent lower with eastern flow of air masses from the low.

Group *C* weather, described as unfavourable for prolonged outdoor periods in the Norwegian Arctic, is most often connected with cyclonic circulation from the southern sector (Sc, SWc, SEc). This class of weather was the least frequently recorded with anticyclonic types of NWa and Ca (Fig. 4).

Group *D* weather, characterised by posing the possible threats to human health or life, was the least frequent when the air masses flowed from the eastern sector (E, SE, NE), regardless of the baric system. This weather was the least frequent with the anticyclonic inflow of air masses from the western sector. It should be noted that only with Wa type of circulation was group *D* weather not observed.

Summary

The assessment of the bioclimatic conditions occurring during the year in the Norwegian Arctic from the point of view of their usefulness for tourism, outdoor recreation and work was performed on the basis of the author's own weather typology. It is based on the response of the human organism to various meteorological situations in which thermal stimuli are the most crucial factors. In the Norwegian Arctic, weather that is suitable for outdoor recreation and tourism and optimal for work in the open air occurred on 14 per cent of days annually. The weather when only people with an efficient thermoregulatory system may go for intensive recreation or work outdoors was observed throughout the whole area on average on 36 per cent of days per year. Unfavourable weather conditions that restrict prolonged periods outdoors in the settlements and polar stations of the Norwegian Arctic make up 33 per cent of days. The last weather group, creating favourable conditions for infections and posing threats to human health or life, was observed on average on 16 per cent of days per year. The applied typology proved Ny-Ålesund station to be distinctly advantageous in terms of bioclimatic conditions and – at the same time – indicated that the worst conditions occur at Bjørnøya. The analysis of the correlation between individual weather groups, as proposed by the author, and the types of circulation distinguished by Niedźwiedź demonstrated that the most unfavourable thermal sensations are most likely to occur with an inflow of air masses from the western sector, regardless of the coincident baric system.

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