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Variability of the predicted insulation index of clothing in the Norwegian Arctic for the period 1971–2000

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Abstract: This paper presents the spatial distribution of changes in the value of the predicted insulation index of clothing (*Iclp*) in the Norwegian Arctic for the period 1971–2000. For this study, data from six meteorological stations were used: Ny-Ålesund, Svalbard Airport, Hornsund, Hopen, Bjørnøya and Jan Mayen. The impact on the atmospheric circulation to the course of the *Iclp* index was analyzed using the catalogue of circulation types by Niedźwiedź (1993, 2002), the circulation index according to Murray and Lewis (1966) modified by Niedźwiedź (2001), the North Atlantic Oscillation Index according to Luterbacher *et al.* (1999, 2002), and the Arctic Oscillation Index (Thompson and Wallace 1998).

Key words: Norwegian Arctic, bioclimate, predicted insulation of clothing, atmospheric circulation.

Introduction

Clothing provides protection against unfavourable weather, especially in the polar regions. During unsteady weather conditions the equilibrium between the heat received and lost by humans is possible because of thermoregulatory adaptation reactions as well as adequate clothing (*inter alia*: Burton and Edholm 1955; Krawczyk 1993; Yan and Oliver 1996; Parsons 2003). The thermal insulation properties of clothing depends mainly on its thickness, number of layers, kind of fabric, texture, fashion of clothing, colour and the way it is worn. These characteristics, according to Błażejczyk (2004) influence the insulation properties of different clothing combinations (Table 1), and thus the values of particular heat streams and their exchange balance. Modern clothing can be optimally adjusted to suit the conditions of every kind of environment and physical activity to ensure thermal comfort for man.

The study of thermal insulation properties of different clothing has practical application for different working environments, for example, in the army, building

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Table 1

Basic thermal insulation of clothing (*Icl*) required to stay in open air (Krawczyk 1993)

Type	Type of clothing	Icl	
		clo	$K \cdot m^2 \cdot W^{-1}$
1.	**Summer clothing**		
1.1.	Very light		
	a) shorts	0.1	0.016
	b) shorts, shirt with short sleeves	0.3	0.045
1.2.	Light		
	a) long trousers, shirt with short sleeves	0.5	0.078
	b) frock with short sleeves	0.5	0.078
	c) light working clothing	0.6	0.093
	d) military working uniform	0.7	0.108
	e) light sport clothing	0.9	0.140
1.3.	Normal		
	a) man's woolly suit	1.0	0.155
	b) woolly jacket, skirt	1.0	0.155
	c) standard working clothing	1.0	0.155
2.	**Clothing of transition seasons (spring, autumn). Traditional European clothing worn for work**		
	a) man's suit, overcoat or jacket	1.5	0.232
	b) jacket, skirt, thin overcoat	1.5	0.232
	c) standard working clothing jacket	1.5	0.232
	d) standard military uniform	1.5	0.232
	clothing sets as in types 1.3a, b, and headgear, scarf, gloves	2.5	0.388
3.	**Winter clothing**		
3.1.	Light		
	clothing sets as in types 1.3a, b, and overcoat with wadding headgear, scarf, gloves	3.0	0.465
3.2.	Normal		
	clothing sets as above with warm underwear and boots	3.5	0.542
3.3.	Heavy (arctic)		
	fur or coat with fur lining, down jacket, fur gloves, headgear and boots, the remaining parts of clothing as in types 1.3a, b	> 4.0	> 0.620

Types of footwear and underwear are omitted.

industry, forestry, cosmonautics etc. The practical implications of this problem is that in many countries there are studies made using climatic chambers or using thermal manikins to determine different sets of female and male clothing in dependence of the type of activity (see among others: Fanger 1970; Muson and Hayter 1978; Jokl 1982; Mount and Brown 1985; Goldman 1988; Umbach 1988; Holmér 1989; Wyon 1989; Krawczyk 1993; Kind *et al.* 1995; Rissanen and Rintamäki 1997; Risikko *et al.* 1997; Nilsson *et al.* 1997, 2000; Kuklane 1999;

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Havenith 1999, 2002; Kuklane and Holmér 2000; Bouskill *et al.* 2002; Parsons 2003). In the polar and subpolar regions, where humans are exposed to severe thermal conditions, numerous technical devices are employed to lessen the thermal discomfort, *e.g.* boots or gloves heated with the help of electric batteries.

Despite numerous publications detailing the climate of the Norwegian Arctic, there are very few studies in the field of bioclimatology. Moreover, most studies refer to short periods or singular bioclimatic indices: Wójcik (1963), Szczepankiewicz-Szmyrka (1981, 1988), Marciniak (1983), Szczepankiewicz-Szmyrka and Pereyma (1984, 1992), Zawiślak (1986), Gluza (1988), Nordli *et al.* (2000), Araźny (2003), Owczarek (2004), Przybylak and Araźny (2005). The problem of predicted insulation of clothing in the Norwegian Arctic was studied only by Marciniak (1983) for Kaffiöyra, Owczarek (2004) for Hornsund and Przybylak and Araźny (2005) for the western coast of Spitsbergen.

Materials and methods

To calculate the *Iclp* index the mean daily values of air temperature and wind velocity were used from six meteorological stations situated in the Norwegian Arctic: Ny-Ålesund (NYA), Svalbard Airport (SVA), Hornsund (HOR), Hopen (HOP), Bjørnøya (BJO) and Jan Mayen (JMA). Source material was collected for the period 1971 – 2000, but the lengths of three analyzed data series are shorter (see Table 2). For Horsund during the period 1991–2000, the *Iclp* index was also calculated for the observational terms: 0, 3, 6, 9, 12,15, 18, 21 Universal Coordinated Time (UTC). List of stations with detailed geographic locations was presented among others by Steffensen *et al.* (1996). Meteorological data were obtained from the Norwegian Institute of Meteorology in Oslo and from the Meteorological Yearbooks of Horsund published by the Maritime Branch of the Institute

Table 2

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

*For all stations the observation period is from 1st January of the first year with observations to 31 December 2000.

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Table 3

Monthly and annual mean values of predicted insulation of clothing (clo) for low physical activity (M = 70 W·m^{-2}) in the Norwegian Arctic for the period 1971–2000

Station	J	F	M	A	M	J	J	A	S	O	N	D	Year
NYA*	5.35	5.40	5.22	4.89	4.04	3.43	3.08	3.18	3.66	4.42	4.78	5.21	4.39
SVA**	5.58	5.63	5.40	5.10	4.19	3.48	3.03	3.15	3.67	4.44	4.89	5.34	4.49
HOR***	5.25	5.23	5.07	4.90	4.15	3.53	3.21	3.27	3.58	4.22	4.66	5.12	4.35
HOP	5.32	5.32	5.19	5.04	4.29	3.76	3.46	3.40	3.62	4.15	4.74	5.20	4.46
BJO	4.68	4.68	4.58	4.42	3.95	3.55	3.23	3.20	3.45	3.87	4.25	4.61	4.04
JMA	4.44	4.42	4.40	4.23	3.82	3.50	3.18	3.12	3.41	3.76	4.11	4.37	3.90

of Meteorology and Water Management in Gdynia and by the Institute of Geophysics of the Polish Academy of Sciences in Warsaw.

The *Iclp* index was counted using the computer program by Błażejczyk and Błażejczyk (2003). A detailed description of the program can be found on the web page of the Institute of Geography and Spatial Organization Polish Academy of Sciences (www.igipz.pan.pl/ geoekoklimat/ blaz/bioklima.htm).

The predicted insulation of clothing was calculated according the formula of Burton and Edholm (1955). It allows to define the total insulation of clothing and the surrounding air layer as follows:

$$\mathrm{It} = \frac{0.082 \cdot \left[91.4 - (1.8 \cdot t + 32)\right]}{0.01724 \cdot M} \quad (1)$$

Using the formula of Fourt and Hollies (1970), the insulation of the surrounded air layer can be calculated:

$$\mathrm{Ia} = \frac{1}{\left(0.61 + 1.9 \cdot v^{0.5}\right)} \quad (2)$$

where: t – air temperature in °C, v – wind speed in m·s^{-1}, M – metabolism in W·m^{-2}.

For the calculation of the *Iclp* index in the Norwegian Arctic the wind speed was reduced from 10m above ground level to 2m above ground level according to the formula of Milewski 1960 (*after:* Kozłowska-Szczęsna *et al.* 1997):

$$V_z = V_w \left(\frac{h_z}{h_w}\right)^{0.2} \quad (3)$$

where: V_z – wind speed at h_z = 2 m height, V_w – wind speed at the height of the anemometer h_w.

To calculate the *Iclp* index was accepted 70 W·m^{-2} as the value of physical exertion for a man standing and 135 W·m^{-2} for a man moving at 4 km·h^{-1}. Afterwards

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the predicted insulation of clothing was calculated in clo under meteorological conditions.

The *Iclp* index was calculated by formula:

$$Iclp = I_t - I_a \tag{4}$$

Exemplary clothing sets are shown in Table 1, where 1 clo corresponds with heat resistance equal to 0.155 K·m^2·W^{-2} (ISO/DIS 9920). Clothing with insulation characteristic of 1 clo ensures sense of thermal comfort for a sitting person (M = 58 W·m^{-2}), with 21°C temperature of the environment, 50% relative humidity and air movement < 0.1 m·s^{-1}.

Based on *Iclp* values thermal conditions assessed as follows:

Iclp (clo) Thermal environment:

< 0.30 – very warm
0.31–0.80 – warm
0.81–1.20 – neutral
1.21–2.00 – cool
2.01–3.00 – cold
3.01–4.00 – very cold
>4.00 – arctic

The *Catalogue of atmospheric circulation types for Spitsbergen* by Niedźwiedź (1993, 2002) was used as basic material for the analysis of the impact of atmospheric circulation to the *Iclp* index. The author of the catalogue distinguished 21 types based on the direction of the air advection or the lack of distinct inflow and the kind of the baric system (Niedźwiedź 1993).

Additionally, studies were carried out on the connection between the *Iclp* index and the atmospheric circulation in the Norwegian Arctic with the help of three synthetic indices: *W* – western and *S* – southern circulation, and *C* – cyclonicity index proposed for this region by Niedźwiedź (2001). They follow the example of P, M, S and C indices proposed by Murray and Lewis (1966), however Niedźwiedź made some small modifications (the southern circulation index M was replaced by the *S* index, and the P progression index by the *W* western circulation index).

The North Atlantic Oscillation Index (*NAO*) according to Luterbacher (1999) and the Arctic Oscillation Index (*AO*) according to Thompson and Wallace (1998) were also used to study the impact of circulation conditions to the course of the *Iclp* index. They were obtained from the web pages www.cru.uea.ac.uk and www.cpc.ncep.noaa.gov, respectively.

Results

Annual predicted insulation of clothing. — In the Norwegian Arctic the demand for clothing of optimal thermal insulation properties for a standing man, us-

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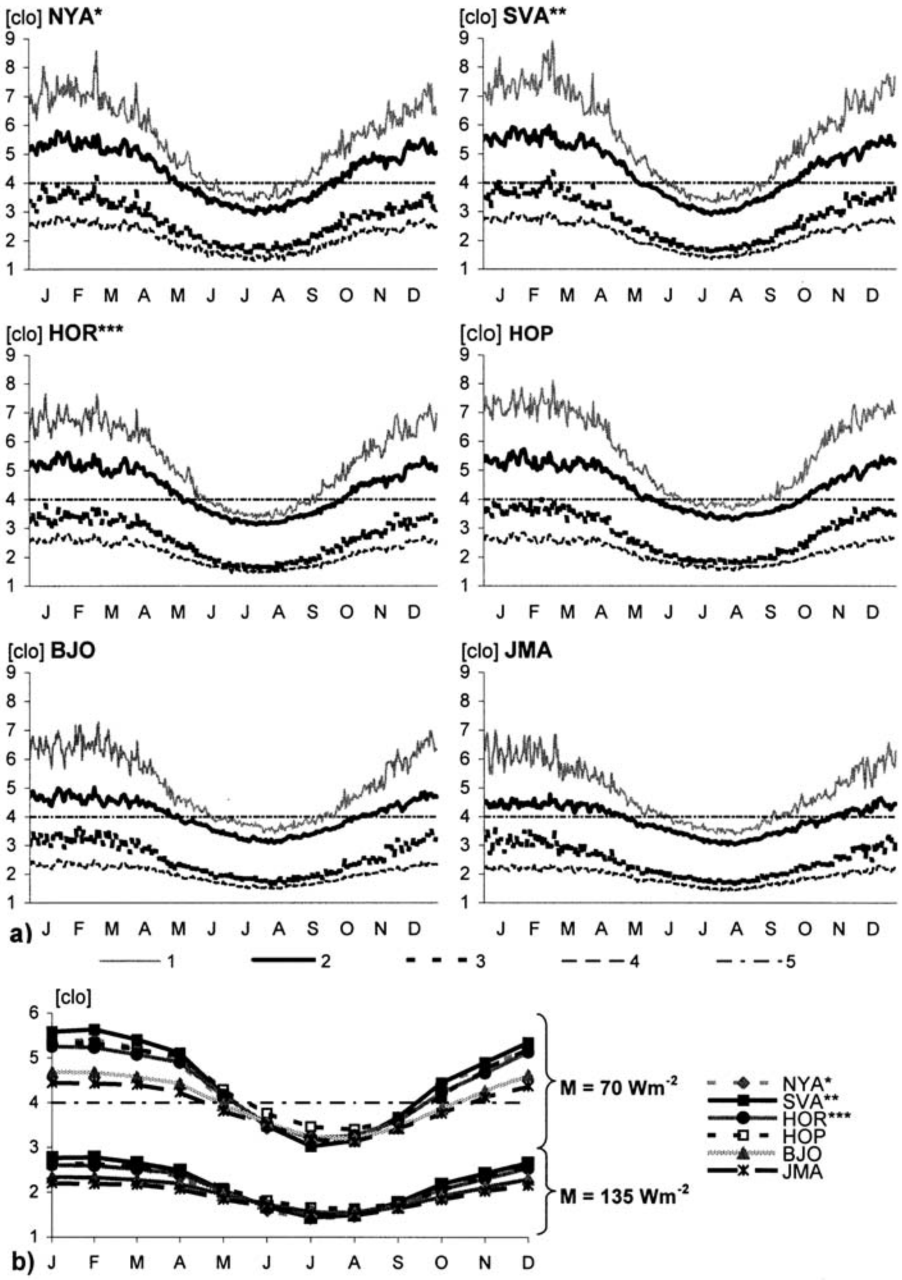

Fig. 1. Annual course of predicted insulation of clothing (clo) for low (M = 70 W·m^{-2}) and moderate (M = 135 W·m^{-2}) physical activity in the Norwegian Arctic for the period 1971–2000 on the basis of daily mean (a) and monthly mean (b) values. Keys: 1 – the highest daily mean (M = 70 W·m^{-2}); 2 – daily mean (M = 70 W·m^{-2}); 3 – the highest daily mean (M = 135 W·m^{-2}); 4 – daily mean (M = 135 W·m^{-2}); 5 – threshold between arctic and very cold thermal environment (>4 clo – arctic clothing); *1981–2000; **1976–2000; ***1979–2000.

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Table 4

Monthly and annual mean values of predicted insulation of clothing (clo) for moderate physical activity (M = 135 W·m^{-2}) in the Norwegian Arctic for the period 1971–2000

Station	J	F	M	A	M	J	J	A	S	O	N	D	Year
NYA*	2.63	2.64	2.53	2.34	1.89	1.59	1.42	1.47	1.72	2.14	2.34	2.56	2.11
SVA**	2.77	2.78	2.66	2.49	2.03	1.67	1.45	1.50	1.77	2.18	2.42	2.65	2.20
HOR***	2.61	2.59	2.52	2.42	2.01	1.68	1.51	1.55	1.72	2.06	2.30	2.54	2.13
HOP	2.64	2.63	2.56	2.47	2.08	1.81	1.65	1.63	1.75	2.04	2.34	2.58	2.18
BJO	2.34	2.33	2.28	2.19	1.94	1.73	1.56	1.54	1.68	1.90	2.11	2.30	1.99
JMA	2.20	2.18	2.18	2.07	1.85	1.69	1.51	1.48	1.64	1.83	2.03	2.16	1.90

Keys: *1981–2000, **1976–2000, ***1979–2000

ing clothing with high heat-insulating properties is extremely important. According to the mean annual value of the *Iclp* index in the study area they varied from 3.9 clo at Jan Mayen to 4.5 clo at Svalbard Airport and Hopen (Table 3). However, for man moving at 4 km·h^{-1} to maintain thermal comfort it is enough to have clothing with twice less thermal insulation (Table 4, Fig. 1). This is because heat produced metabolically due to this activity grows to 135 W·m^{-2} (*i.e.* approximately 100% more in comparison to the value produced by a man standing).

Mean daily and monthly values of *Iclp* are used for the evaluation of optimal thermal insulation properties in the Arctic. During the year the greatest heat retention is required from October to May. In the analyzed region heavy (arctic) clothing is required, but at stations Bjørnøya and Jan Mayen the requirement for such clothing is shorter by two months (Table 3, Fig. 1). During the remainder of the year across the entire region (for low physical activity) normal winter clothing is necessary. Here in the Norwegian Arctic the thermal conditions are mainly described as “very cold”.

For a person moving at 4 km·h^{-1}, clothing for transitional seasons with increased thermal insulation (2.5–3.0 clo) is necessary from December to March at Ny-Ålesund, Svalbard Airport, Hornsund and Hopen. During the rest of the year the conditions are “cool” and “cold”. Regular clothing for transitional seasons is sufficient in July and August (Ny-Ålesund and Svalbard Airport) and September (Jan Mayen).

The Norwegian Arctic has great variability in individual days regarding the demand of clothing with thermal insulation properties optimal for man. The smallest fluctuations of the *Iclp* index occur from June to September, while the greatest fluctuations occur in the winter months. The greatest absolute amplitude of *Iclp* (difference between the highest and lowest daily mean) in the analyzed region varied from 5.5 clo at Bjørnøya and Jan Mayen to about 7.0 clo at Ny-Ålesund and Svalbard Airport. On average the standard deviation calculated from daily mean

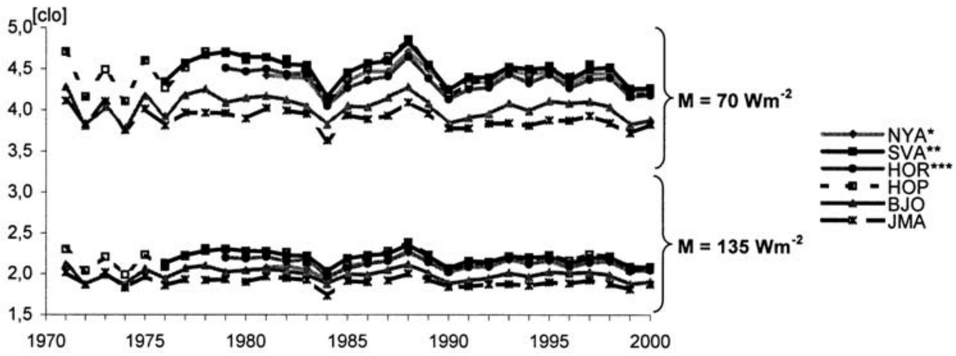

Fig. 2. Year-to-year course of mean annual values of the *Iclp* index ensuring thermal comfort for a person (in clo) with low (M = 70 W·m^{-2}) and moderate (M = 135 W·m^{-2}) physical activity in the Norwegian Arctic for the period 1971–2000. Keys: *1981–2000, **1976–2000, ***1979–2000.

values of *Iclp*, for a person standing occur about 0.5–0.7 clo with respect to changes of the insulation of clothing.

Variability of predicted insulation of clothing. — In the Norwegian Arctic, analyzing the mean values of *Iclp* for the whole period for a person walking at 4 km·h^{-1}, the conditions of the thermal environment were always described as "cool" or "cold". However, for a person standing these conditions were "arctic", and sporadically "very cold". Taking into account monthly mean values, the range of conditions of the thermal environment fluctuated across a wide range. For a moving person the conditions ranged from "neutral" to "very cold", while for a person standing, from "cold" to "arctic" (Fig. 2).

The variability coefficient of annual mean values of the *Iclp* index, for a standing and moving man, at all stations varied from 3% to 4% (at Hopen it was 5% for a walking person). The highest variability was noted in winter and autumn (about 6%), and less in summer.

In this region of the Arctic, small negative annual and seasonal trends of the predicted insulation of clothing dominated (Table 5, Fig. 3). The *Iclp* index for both kinds of physical activity (small and moderate), according to annual mean values, shows a negative trend for AN3 ("areal" mean for the Norwegian Arctic in the period 1971–2000 for Hopen, Bjørnøya and Jan Mayen) as well as for AN6 ("areal" mean for the Norwegian Arctic in the period 1981–2000 for all of the 6 analyzed stations). For all seasons, the largest fall in demand for insulation of clothing occurred in autumn (for example for standing man about 0.1 clo/10 years) and for AN3 this was statistically significant ($p < 0.05$). In the remaining seasons for both types of activity the trends do not show distinct variation. Values shown in Table 5 and Fig. 3 (negative trends of the *Iclp* index) indicate a slight decrease of requirements for the thermal insulation of clothing in the Norwegian Arctic.

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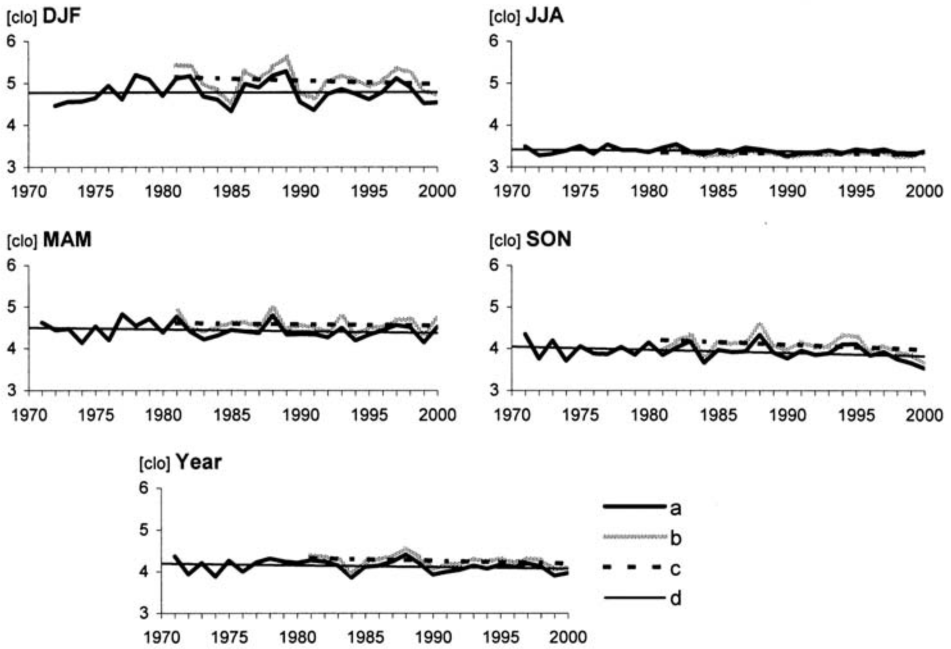

Fig. 3. Year-to-year course of mean seasonal and annual values of predicted insulation of clothing and their trends for low ($M = 70$ W·m^{-2}) and moderate ($M = 135$ W·m^{-2}) physical activity in the Norwegian Arctic for the period 1971–2000. Keys: a – AN3, b – AN6, c– linear trend of AN6, c– linear trend of AN3

Table 5

Mean seasonal and annual values of predicted insulation of clothing (clo) (a) and their trends (b) in clo/10 years for low ($M = 70$ W·m^{-2}) and moderate ($M = 135$ W·m^{-2}) physical activity in the Norwegian Arctic for the period 1971–2000

Element	Area	DJF	MAM	JJA	SON	Year
			M = 70 W·m^{-2}			
a	AN3	4.8	4.4	3.4	3.9	4.1
b		0.00	–0.04	–0.02	**–0.08**	–0.04
a	AN6	5.1	4.6	3.3	4.1	4.3
b		–0.09	–0.03	–0.03	–0.12	–0.07
			M = 135 W·m^{-2}			
a	AN3	2.4	2.2	1.6	1.9	2.0
b		0.00	–0.02	–0.01	–0.04	–0.02
a	AN6	2.5	2.2	1.6	2.0	2.1
b		–0.04	0.00	0.00	–0.06	–0.03

Keys: statistically significant trends on level $p < 0.05$ marked bold
AN3 (mean for the Norwegian Arctic in the period 1971–2000 for Hopen, Bjørnøya and Jan Mayen),
AN6 (mean for the Norwegian Arctic in the period 1981–2000 for all of the 6 analyzed stations).

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Table 6

Mean monthly and yearly number of days with *Iclp* index > 4 clo for low (M = 70 W·m^{-2}) physical activity in the Norwegian Arctic for the period 1971–2000

Station	J	F	M	A	M	J	J	A	S	O	N	D	Year
NYA*	29.2	26.9	28.6	26.9	16.4	1.8	4.6	0.2	.	22.5	25.4	28.3	210.6
SVA**	29.2	26.8	28.5	27.8	17.8	1.4	4.4	.	.	22.6	25.6	28.1	212.3
HOR***	28.4	26.0	27.4	26.6	16.9	1.0	4.3	.	.	18.9	23.1	27.5	200.1
HOP	27.6	25.2	26.4	26.1	20.5	4.6	9.7	.	.	16.9	22.0	27.0	206.0
BJO	24.6	22.3	22.8	22.1	12.5	1.7	4.0	.	.	10.0	18.3	23.5	161.9
JMA	21.3	19.3	21.1	19.3	8.6	0.6	1.9	.	.	8.3	16.4	20.3	137.1

Keys: *1981–2000, **1976–2000, ***1979–2000

Number of days with different categories on insulation of clothing. — For a person standing, in the Norwegian Arctic clothing with high heat insulation properties is required. During 93% of the year thermal conditions can be described as “very cold” and “arctic”. Thus to maintain thermal comfort regular winter clothing (>3–4 clo) is necessary from 118 days at Svalbard Airport to 199 days at Jan Mayen, and arctic clothing (>4 clo) from 137 days at Jan Mayen to 212 at Svalbard Airport (Table 6). For August and September heavy clothing is not required in this region. During the year (for a person standing) the conditions are “cold” in the thermal environment (about 25 days) and very rarely (about 1%) “cool”. Such conditions were mainly noted in the warmer part of the year, when clothing for the transitional seasons was necessary.

The distribution of *Iclp* index in this region for a person moving at 4 km·h^{-1} is characterised by smaller values. In the Norwegian Arctic conditions of the thermal environment from “very warm” to “arctic” occur for this type of activity. At Hornsund, Bjørnøya and Jan Mayen “arctic” conditions do not occur and at Svalbard Airport and Bjørnøya “very warm” conditions are never recorded. During the year people walking at 4 km·h^{-1} require clothing for transitional seasons (1.5–3.0 clo) for 83% of the time. In summer regular clothing is enough, while in winter clothing with higher heat insulation is required. Fewer days (70%) are required to maintain thermal comfort with clothing for transitional seasons at Ny-Ålesund and the highest number of days (90%) occur at Bjørnøya. During the remainder of the year (for a man walking) regular winter clothing was necessary, varying from 3 days at Jan Mayen to 42 days at Svalbard Airport.

Diurnal *Iclp* index. — The diurnal *Iclp* index, for a person at rest, is presented in Fig. 4 for Hornsund station. It shows little variation across month or season. The diurnal range of *Iclp* index does not exceed 0.4 clo. Therefore, to maintain thermal comfort for a person during the day only one set of clothing is enough. Under polar

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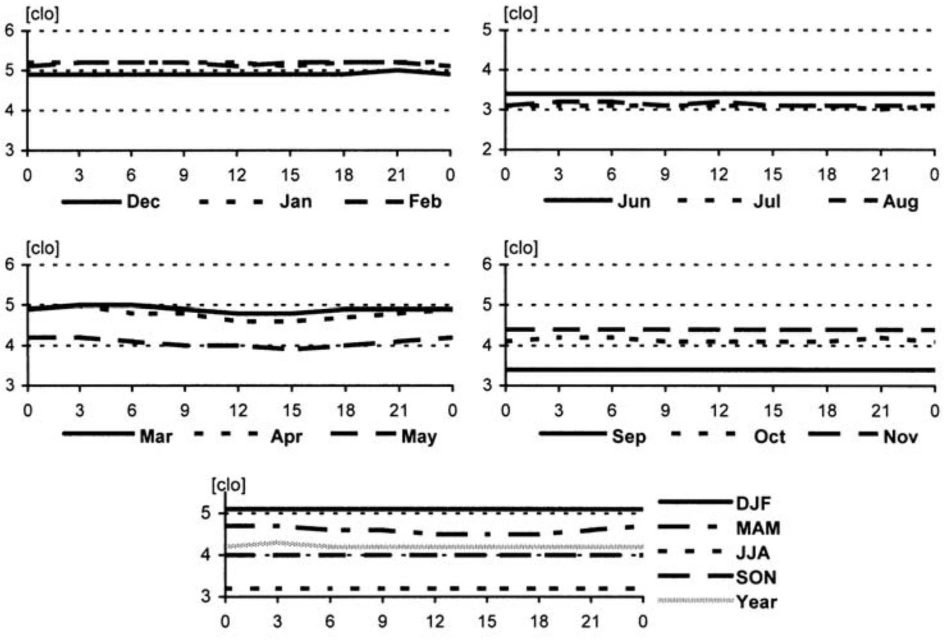

Fig. 4. Mean monthly (J, F, etc.), seasonal (DJF, MAM, JJA, SON) and annual (Year) courses of daily predicted insulation of clothing (clo) for low ($M = 70$ W·m^{-2}) physical activity at Hornsund for the period 1991–2000.

conditions, for a person at work this is practical. The lowest mean values of the insulation index of clothing occurred at 21 UTC in July (3.0 clo), while the highest (5.2 clo) was noted during January and February.

Impact of atmospheric circulation on the predicted insulation of clothing

Predicted insulation of clothing and types of the atmospheric circulation. — Atmospheric circulation in the Norwegian Arctic has a considerable role compared to other regions. Its greatest influence can be observed during the polar night, when no solar radiation reaches the ground. To analyze the impact of atmospheric circulation on the predicted insulation of clothing, the catalogue of circulation types by Niedźwiedź (1993, 2002) was used.

Values of the *Iclp* index is compared to the background of circulation conditions in the Norwegian Arctic and is presented for the example of Hornsund. At Hornsund for the period 1979–2000 cyclonic types of circulation dominated during 58.4% of the days, whereas anticyclonic types formed the weather during 38.1% of the time. Unclassified types of circulation comprised 3.5% of the cases.

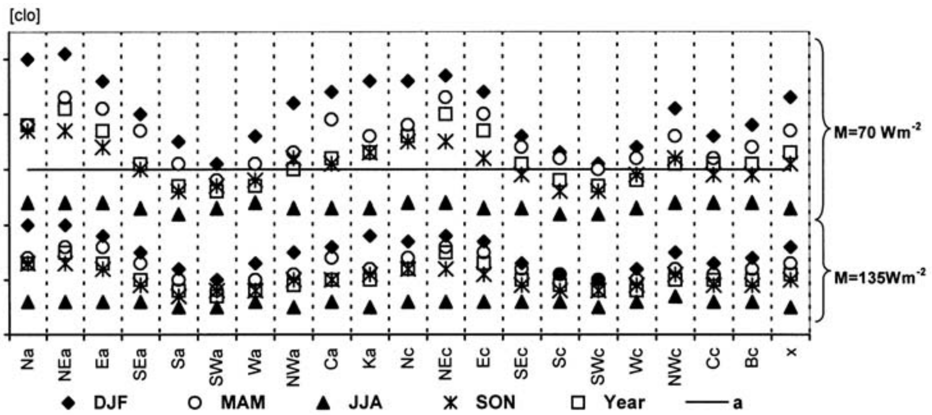

Fig. 5. Mean seasonal (DJF, MAM, JJA, SON) and annual (Year) values of the *Iclp* index (in clo) for low (M = 70 W·m^{-2}) and moderate (M = 135 W·m^{-2}) physical activity with different circulation types at Hornsund for the period 1979–2000. Keys: 1 – threshold (4 clo) between arctic and very cold thermal conditions.

Higher than average values of the annual mean *Iclp* index (for an active and inactive person) for different circulation types, were recorded in the case of air advection from directions N, NE and E (independently of the baric situation). The remaining types had negative anomalies of the index (of which the greatest occurred with cyclonic and anticyclonic types from the S-SW-W sector) (Fig. 5).

For an inactive person from June to September, the synoptic conditions were described as mainly “very cold”. In July during the anticyclonic system, there was a transition to the higher class of thermal environment described as “cold” with less requirement for clothing.

During the winter, clothing with the highest thermal insulation is required. For an inactive person, there is a large requirement for increased clothing, at least 5 clo, observed from December to April with advection from N, NE and E (cyclonic and anticyclonic) and in cases of situations without, advection of Ca and Ka.

For an inactive person the daily mean demand for insulation clothing in the case of the anticyclonic macrotype was only 0.1 clo higher in comparison to cyclonic conditions. For an active person moving at 4 km·h^{-1} to maintain thermal comfort (independently of the baric system) the same kind of clothing was necessary. The highest daily mean value of the *Iclp* index (in the case of M = 70 W·m^{-2}) occurred on 16 January 1981 (7.7 clo) with NEc situation. The lowest mean daily demand for clothing for an inactive person occurred on 2 July 1979 (1.8 clo) with Ec type.

Predicted insulation of clothing and atmospheric circulation indices. — Three indices of western *(W)*, southern (*S*) and cyclonicity (*C*) also give a synthetic image of the atmospheric circulation (for the example of Hornsund) in this region of the Arctic. Niedźwiedź (2001) has shown detailed analysis of annual and sea-

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Table 7

Correlation coefficient between the values of *Iclp* index and circulation indices (*W, S, C*) at Hornsund for the years 1979–2000

Index of circulation	J	F	M	A	M	J	J	A	S	O	N	D	Year
W	–0.12	–0.05	–0.35	–0.12	–0.19	**–0.52**	0.20	0.19	–0.29	0.24	**–0.39**	**–0.37**	–0.30
S	**–0.80**	**–0.43**	**–0.52**	**–0.63**	–0.14	–0.07	–0.06	**–0.52**	**–0.70**	**–0.75**	**–0.80**	**–0.85**	**–0.60**
C	–0.30	**–0.42**	–0.29	–0.18	–0.02	0.16	**0.42**	**0.46**	0.18	–0.23	–0.24	**–0.37**	–0.20

Keys: calculated for M = 70 $W \cdot m^{-2}$, correlation coefficients statistically significant on $p < 0.05$ level marked bold.

sonal values over Spitsbergen for the period 1951–2000. During this period there was a growth in the index of western circulation (especially in summer and autumn), southern circulation (winter and summer) and in the cyclonic activity (winter and autumn).

These circulation indices were used to evaluate the impact of atmospheric circulation to the bioclimatic conditions in this part of the Arctic. In the period 1979–2000 they were characterized by large year-to-year variability. For this region high cyclonic activity was characteristic with mean annual value of the index *C* equal to +70. According to Niedźwiedź (2001), the most active period of cyclones, was 1971–1977 with highest value of index *C* in 1975 (+209), while the lowest occurred in 1998 (–56).

The predicted insulation of clothing (for a person with low physical activity) the impact of southern circulation index is distinctly marked from August to April. During this period all correlation coefficients are significant ($\alpha = 0.05$ level), and the greatest part of the variability of this bioclimatic coefficient can be interpreted by circulation in winter (see Table 7). Significant correlation was also noted between the predicted insulation of clothing and the western circulation index in June, November and December. Therefore, during the year, air circulation with a northern component causes an increased requirement for thermal insulation of clothing sets for people in this region.

Predicted insulation of clothing and the North Atlantic Oscillation Index. — In recent years the impact of atmospheric circulation on elements of the climatic system has been studied using the North Atlantic Oscillation Index (NAO) and the Arctic Oscillation Index (AO). However, this has been the first study to use these indices to study the predicted insulation of clothing in the Norwegian Arctic. NAO is the most commonly known index of atmospheric circulation for the northern Atlantic and Europe. It is a teleconnexion system expressing pressure differences between the main baric systems of this region: anticyclone over the Azores and cyclone over Iceland. In this paper the index given by Luterbacher *et al.* (1999, 2002) was used. We also studied the impact of bioclimatic conditions in this region using

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Table 8

Correlation coefficients between the mean monthly values of the predicted insulation of clothing and NAO and AO indices at Horsund for the years 1979–2000

Index	J	F	M	A	M	J	J	A	S	O	N	D	Year
NAO	–0.14	–0.27	–0.11	**–0.48**	0.17	–0.06	–0.05	0.25	–0.22	**–0.73**	**–0.65**	–0.35	–0.26
AO	–0.13	–0.09	–0.13	–0.14	–0.14	0.02	0.26	0.17	0.32	–0.16	–0.04	–0.18	–0.26

Keys: in case of small physical activity M = 70 W·m^{-2}, correlation coefficients statistically significant on $p < 0.05$ level marked bold.

the AO used by Thompson and Wallace (1998). AO is the dominating pattern of variability of the atmospheric circulation in regions north of 20°N, (between 37°N and circumpolar regions [80–90°N]). Its regional manifestation on the area of the North Atlantic is NAO. Therefore both indices are strongly correlated (Mysak 2001).

This image of the influence of NAO to the bioclimatic conditions in the Norwegian Arctic is more complicated if we analyze the correlation coefficients calculated for monthly mean NAO indexes and *Iclp* for the station at Horsund. Significant correlations between the characteristics studied were found in April, October and November. In the autumn the correlation coefficients for some biometeorological indices exceed 0.60 and they are statistically significant (α = 0.05 level) (Table 8). The strongest correlations in the autumn are caused by the intensification of the atmospheric circulation in this region.

The AO has a smaller influence on the predicted insulation of clothing than the NAO in the Norwegian Arctic. Analysing the mean monthly correlation coefficients between *Iclp* index and AO we notice the lack of significant impact to the value of the predicted insulation of clothing.

Conclusions

The predicted insulation of clothing for an inactive person must be characterised by high heat retention properties in the Norwegian Arctic. In the case of low physical activity, arctic clothing is required from October to May. When a person's activity is moderate (moving at 4 km·h^{-1}) clothing with twice less thermal insulation is enough to maintain thermal comfort. The diurnal ranges of *Iclp* index suggest that in order to reach thermal comfort for a person during the entire day, only one set of clothing is required.

In the Norwegian Arctic there is a distinct correlation of the values of *Iclp* with different circulation types (Niedźwiedź 1993, 2002). The greatest requirement for clothing with high thermal insulation properties for a person in winter and early

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spring is when air mass advections occur from the north-eastern sector, independently of the baric system. When air advection occurs with less dynamic and higher temperatures from the southern and western sectors, less insulation is enough in this region. The impact of atmospheric circulation to the formation of bioclimatic conditions in the Norwegian Arctic is also distinct, when it is described with the help of circulation indices (*W, S, C*). Among them atmospheric circulation characterised using the *S* index has the largest influence, for which statistically significant correlations were found from August to April. The calculations also showed a correlation of the NAO with the mean monthly *Iclp*, where significant correlations were found in October, November and April. No correlations were found, however, between the predicted insulation of clothing and the AO. The trend of the mean annual and seasonal values of the predicted insulation of clothing for low and moderate physical activity are slightly negative. This means that in the Norwegian Arctic in recent years the demand for insulation of clothing is decreasing.

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