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Spatial diversity of the ice cover on the lakes of the European Lowland in the winter season 2003/2004

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Abstract: In the middle of the winter period of 2003/2004 the authors carried out synchronous measurements of the thickness of the ice cover, snow cover and the vertical distribution of water temperature in 33 lakes located in the area of northern Germany, Poland and southeast Lithuania. The area spread over the area of approx. 1200 km (8.02 – 25.50 °E), in the belt of approx. 250 km width (52.87 – 55.26 °N). The lakes are of different areas (from 75 to 595 ha) and mean depths from 3.5 to 38.7 m. Ice thickness evidently increased from 3 – 8 cm in the western part of the Mecklenburg Lakeland to 27 – 31 cm in the Vilnius Lakeland, and corresponded to the course of the thermal winter. Water thermal conditions were mostly determined by local environmental conditions, particularly hydrological and morphometric ones.

Key words: ice cover, thickness, lakes, European Lowland.

Introduction

The studies of the formation and changeability of the ice cover have been fundamental issues of limnology, particularly in recent years. This has resulted from climatic changes, clearly noticeable in the northern hemisphere (Magnuson *et al.*, 1999; Gronskaya, 2000; Górniak, Pękala, 2002; Gao, 2004). These changes have caused, among others, shortening of the periods with the ice cover and declining its maximal thickness (Gronskaya, 2000; Skowron, 2003; Marszelewski, Skowron, 2005). The different courses of ice phenomena with regard to the geographic location of the lakes still remain an important problem. The professional literature offers several works on this subject from North America and Asia (among others: Wynne *et al.*, 1998; Williams *et al.*, 2004). There are, however, no works on lake icing in the zone of the moderate transitional climate in Europe. Ice phenomena on the lakes in the moderate transitional climatic zone determine regional climatic conditions in a significant way. This significance can be seen in the same time of negative or positive air temperature values. This is reflected in, among others, the presence (or lack) of the ice cover or shore ice on the lake. These phenomena occur in the area of smaller geographic regions with strong transitional properties of the climate (e.g. in the Mecklenburg Lakeland).

Research objective, range and methods

The main research objective is to define the degree of the ice cover spatial diversity on the lakes located in the narrow belt of 250-km width (52.87 – 55.26 °N) over the distance of approx. 1.200 km (8.02 – 25.50 °E) in the middle of the winter season. The study area is delimited by the location of two extremal lakes – Lake Zwischenahner Meer (Germany) 53.20 °N, 8.02 °E and Lake Malkestas (Lithuania) 55.26 °E, 25.50 °N (Fig. 1). This problem was set against the course of the air tempe-rature measured in three months prior to the field investigations. The ice cover diversity was defined on the grounds of a series of synchronous measur-ements conducted on the 30th and 31st January 2004. The secondary objective was to determine thermal parameters during the ice-on periods for a big group of the lakes at the same time.

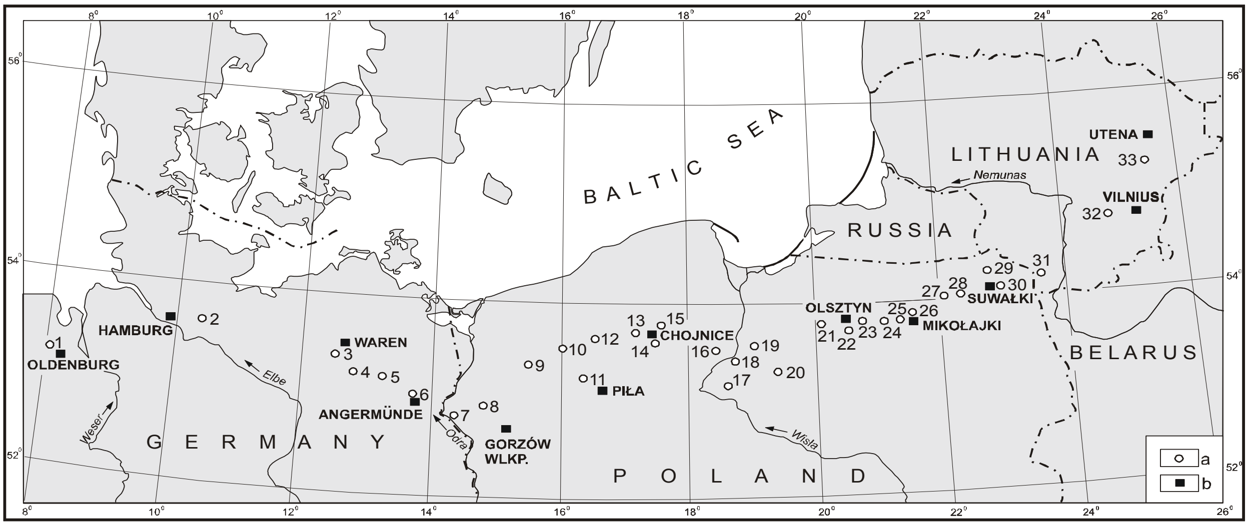

Fig. 1. Location of the studied lakes (a) and meteorological stations (b) in the European Lowland

The study comprised thirty-three lakes located in the European Lowland, which mostly covers the Mecklenburg Lakeland (4), Pomeranian Lakeland (11), Mazury Lake District (15) and the Vilnius Lakeland (2). The area of the lakes oscillates between 75 ha (Lake Grossensee) and 595 ha (Lake Myśliborskie), most frequently from 170 to 300 ha. Predominantly, these are single water body lakes with a poorly developed shoreline and concentric system of isobaths. They are characterized by the big capacity of their basins, which is confirmed by a relative rate of the depth amounting from 4.03 – Lake Gawlik to 56.09 – Lake Hańcza (Skowron, 2004). The volume of most lakes is small and often equals from 15 up to 30 mln m^3. Moreover, they considerably differ with respect to their maximal depth (from 8 m – Dambecker See to 106.1 m – Hańcza), and their mean depth (from 3.5 to 38.7 m). In the case of eleven lakes the mean depth is greater than 10 m, whereas in three water bodies it is smaller than 4.5 m. The most important morphometric data are presented in Table 1.

Field investigations were carried out on the 30th and 31st January 2004 with the help of ten observation teams. These days ended a short period of negative air temperature values in the West European Lowland, followed by a warming-up period, which did not permit comparative research.

The range of field investigations comprised measurements of the ice and snow cover thickness and the vertical distribution of water temperature. An ice air-hole was cut out, and the ice thickness was measured with a measuring staff. The vertical distribution of water temperature was measured every 1 m with an electric thermometer, and every 20 cm below the ice. Three up to four points were delineated in every lake, including in the deepest place, in the lateral zone (over the depth of 1.5 m), and in the depth close to the mean. The four lakes in Germany and the lakes: Morzycko and Myśliborskie did not undergo the same measurements due to either a very thin layer of ice or its lack. Prior to the measurements the authors had assumed that the thickness of the ice largely depended upon the air temperature in the period before the measurement days. In order to explain this relation, daily mean air temperature values from the 1st November 2003 to the 31st January 2004 were applied. They came from the meteorological stations located possibly closest to the studied lakes (Fig. 1). The meteorological data were obtained from the Deutscher Wetterdienst and the internet database (Global Surface Summary of Day from the website of the National Climatic Data Centre).

Moreover, the data referring to the course of the ice cover thickness on three lakes in Poland were acquired from the Institute of Meteorology and Water Management in Warsaw.

Table 1. Location and fundamental morphometric data of the lakes. Symbols: No – number of the lake as in Fig. 1, GC – geographical coordinates, A – altitude, S – surface, V – volume, D_{max} – maximal depth, D_{mean} – mean depth, C_R – relative depth index

No	Lake	GC		A	S	V	D_{max}	D_{mean}	C_R
		φ	λ	(m a.s.l.)	(ha)	(10^6 m^{-3})	(m)	(m)	
1	Zwischenahner Meer	53.20	8.02	5.6	544	13.5	5.5	2.5	–
2	Großensee	53.62	10.35	38.4	75	8.9	21.0	12.0	–
3	Dambecker See	53.37	12.49	71.8	55.3	1.95	8.0	3.50	–
4	Großer Wummsee	53.19	12.80	–	148	17.44	36.0	11.8	–
5	Wurlsee	53.22	13.30	–	92	–	28	–	–
6	Wolletzsee	53.02	13.91	43.0	310	26.86	16.0	8.7	–
7	Morzycko	52.87	14.41	52.0	317.5	49.83	60.0	14.5	12.29
8	Myśliborskie	52.96	14.86	57.5	595.0	51.94	22.3	8.4	8.83
9	Krzemień	53.37	15.54	90.9	217.5	21.92	29.2	9.6	14.72
10	Wilczkowo	53.55	16.09	122.0	290.0	23.30	26.7	7.8	10.68
11	Zamkowe	53.26	16.47	110.5	116.0	17.08	36.5	12.9	32.66
12	Ciemino	53.65	16.56	141.2	222.5	14.39	13.4	6.0	9.19
13	Krępsko	53.72	17.20	124.8	349.0	22.47	17.4	5.9	7.04
14	Mochel	53.55	17.53	113.6	150.0	11.89	12.8	6.9	12.43
15	Ostrowite	53.79	17.60	124.8	259.0	29.99	43.0	10.7	14.86
16	Stelchno	53.52	18.46	79.2	151.0	7.97	10.3	5.1	7.43
17	Chełmżyńskie	53.18	18.65	81.8	325.0	17.34	27.1	5.8	13.80
18	Rudnickie Wielkie	53.44	18.75	21.7	150.0	7.03	11.9	4.4	6.15
19	Nogat	53.58	19.07	76.8	112.5	8.58	23.0	7.3	24.83
20	Bachotek	53.30	19.47	70.8	215.0	15.39	24.3	7.2	14.12
21	Isąg	53.78	20.14	93.0	377.5	56.12	54.5	14.2	17.49
22	Linowskie	53.73	20.58	114.2	153.0	10.57	25.0	6.5	11.75
23	Tumiańskie	53.81	20.81	112.9	117.5	8.11	17.0	6.7	12.69
24	Piłakno	53.79	21.16	139.7	237.5	33.78	56.6	12.9	20.81
25	Majcz Wielki	53.78	21.45	124.6	151.0	9.86	16.4	6.0	9.92
26	Tałtowisko	53.88	21.57	116.1	310.0	45.83	39.5	14.0	18.79
27	Gawlik	54.03	22.11	131.0	414.0	24.77	12.6	6.0	4.03
28	Dobskie	54.05	22.41	158.2	143.5	18.02	43.3	11.1	37.37
29	Hańcza	54.27	22.81	227.3	291.5	120.36	106.1	38.7	56.09
30	Krzywe Węgierskie	54.10	23.00	143.3	121.0	11.87	28.5	8.4	22.46
31	Seirijis	54.20	23.83	120.3	501.2	39.8	19.2	8.0	4.82
32	Vievis	54.76	24.82	112.6	291.8	37.8	33.0	12.9	11.93
33	Malkestas	55.26	25.50	145.10	119.6	10.0	25.0	8.4	17.50

The applied methodology made it possible to analyse ice cover distribution in two categories: defining the degree of the ice cover diversity within a single lake and the ice cover spatial diversity at a supra-regional scale.

Investigation results

Air temperature plays the most significant role in the formation of ice phenomena on the lakes. Therefore, the authors paid specific attention to its course in three month prior to the field investigations. This made it possible to define accurately the start of a thermal winter in particular parts of the studied area.

On the grounds of the data coming from twelve meteorological stations (Tab. 2) it was possible to observe negative temperature in mid-November in the eastern part of the studied area merely (Suwałki, Vilnius, Utena). This cooling did not trigger a thermal winter. The authors assumed after Mako-wiec (1983) that the start of a thermal winter was marked by a day which showed a daily mean air temperature value below 0.0 °C, as counting from the half of the preceding year. This day gave a start to such an accumulated series of daily mean tempe-rature deviation from the value 0.0 °C that did not reach a positive value or 0 for a month (31 days).

The thermal winter started almost simultaneously on 23 December 2003 in the area located to the east of 16°E meridian, and a week later between 13 and 16° east longitude. It started latest (18–20 January 2004) in the area located between 13°E meridian, and Hamburg.

The course of daily mean air temperature values in December 2003 reveals gradual cooling of air temperature at all the stations. However, distinct cooling occurred as late as in the first ten days of

January, when the air temperature amounted from -0.14 °C in Hamburg down to -9,62 in Utena (Tab. 2, Fig. 2). In mid-January there was considerable warming of the air temperature over 0 °C, yet only to the west of Olsztyn. The harshest cooling took place at the end of January 2004, when ne-gative air temperature values were recorded at all the stations.

Table 2. Mean 10-day period (I, II, III) and monthly (M) air temperature values at the meteorological stations located in the European Lowland from the 1st November 2003 to the 31st January 2004. compiled on the grounds of the data from the Deutscher Wetterdienst and the internet database Global Surface Summary of Day from the website of the National Climatic Data Centre

Station	Geographical coordinates	Altitude a.s.l. (m)	November 2003				December 2003				January 2004			
			I	II	III	M	I	II	III	M	I	II	III	M
Oldenburg (D)	53.18 8.16	20	7.50	7.06	7.14	7.23	2.51	4.46	3.32	3.39	1.60	4.11	0.72	2.10
Hamburg (D)	53.53 9.83	13	7.03	6.54	8.01	7.19	2.97	3.57	3.14	3.29	-0.14	3.78	-1.3	0.58
Warren (D)	53.51 12.66	71	5.89	5.16	7.76	6.27	3.50	3.38	1.67	2.81	-1.79	1.86	-3.54	-1.24
Angermünde(D)	53.01 14.00	55	5.45	4.16	7.38	5.66	2.65	2.82	1.55	2.32	-3.03	1.50	-4.81	-2.20
Gorzów W. (Pl)	52.75 15.28	73	5.64	3.49	7.14	5.42	2.80	2.35	0.98	2.01	-5.02	0.87	-5.61	-3.33
Piła (Pl)	53.13 16.75	73	5.30	2.61	6.58	4.83	2.71	1.71	0.32	1.54	-6.46	0.02	-7.19	-4.63
Chojnice (Pl)	53.70 17.55	177	4.15	2.44	6.32	4.30	2.17	1.22	-0.64	0.87	-7.39	-1.02	-7.82	-5.49
Olsztyn (Pl)	53.76 20.41	135	5.60	2.04	7.23	4.96	2.07	1.78	0.01	1.24	-8.52	-1.28	-8.14	-6.05
Mikołajski (Pl)	53.78 21.58	131	5.32	1.27	6.34	4.32	1.95	1.41	-0.04	1.07	-8.62	-1.52	-9.01	-6.47
Suwałki (Pl)	54.13 22.95	186	4.85	-0.21	5.73	3.46	0.96	0.40	-1.02	0.08	-9.06	-2.36	-9.80	-7.16
Vilnius (Lt)	54.63 25.28	156	4.78	-1.12	4.98	2.88	0.21	-0.15	-1.14	-0.38	-9.43	-3.50	-9.89	-7.68
Utena (Lt)	55.50 25.60	121	4.62	-1.02	5.43	3.01	0.89	0.48	-0.18	0.38	-9.62	-3.46	-9.82	-7.70

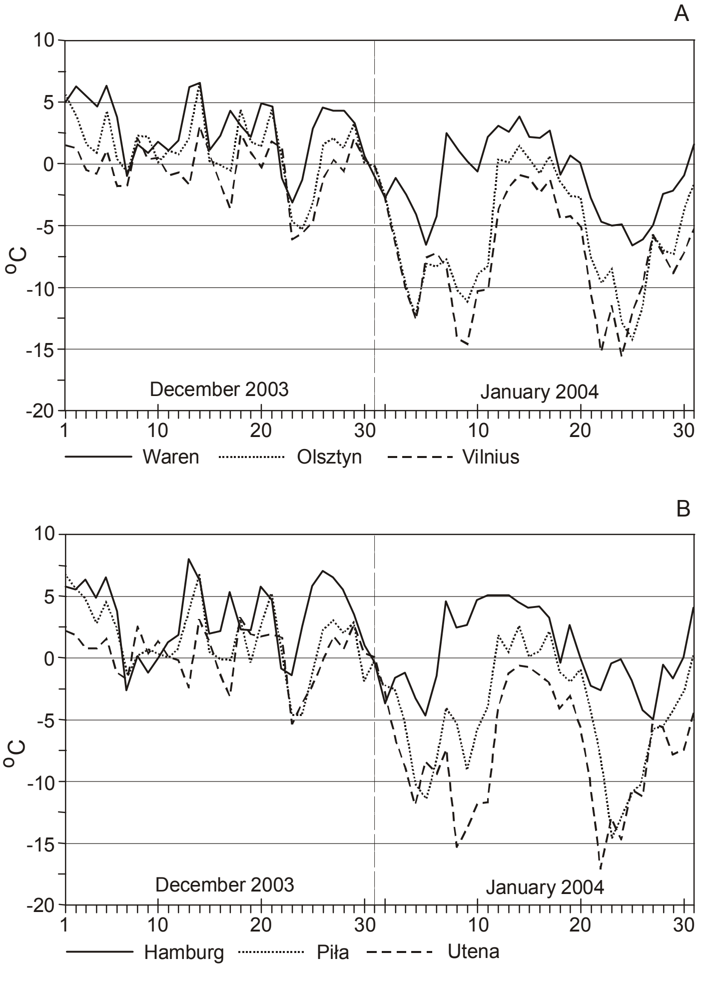

Fig. 2. Course of daily mean air temperature at the selected meteorological stations in December 2003 and January 2004 (compiled on the data from the Witterungs Report Daten 12/2003 and 01/2004 and from the Global Surface Summary of Day from the website of the National Climatic Data Centre).

Ice cover formation is related to a period referred to as a thermal winter. This period can be cha-racterised on the grounds of the course of the sums of the daily mean air temperature values recorded in the consecutive days since the start of a thermal winter. At the end of January 2004 the sum of the daily mean air temperature values (ΣD_d) varied con-siderably, and amounted from 0°C in Oldenburg and -14.5 °C in Hamburg to -253.7 °C in Vilnius (Fig. 3). These values decline eastwards and show strong correlation ($R^2 = 0.96$) with the longitude (Fig. 4).

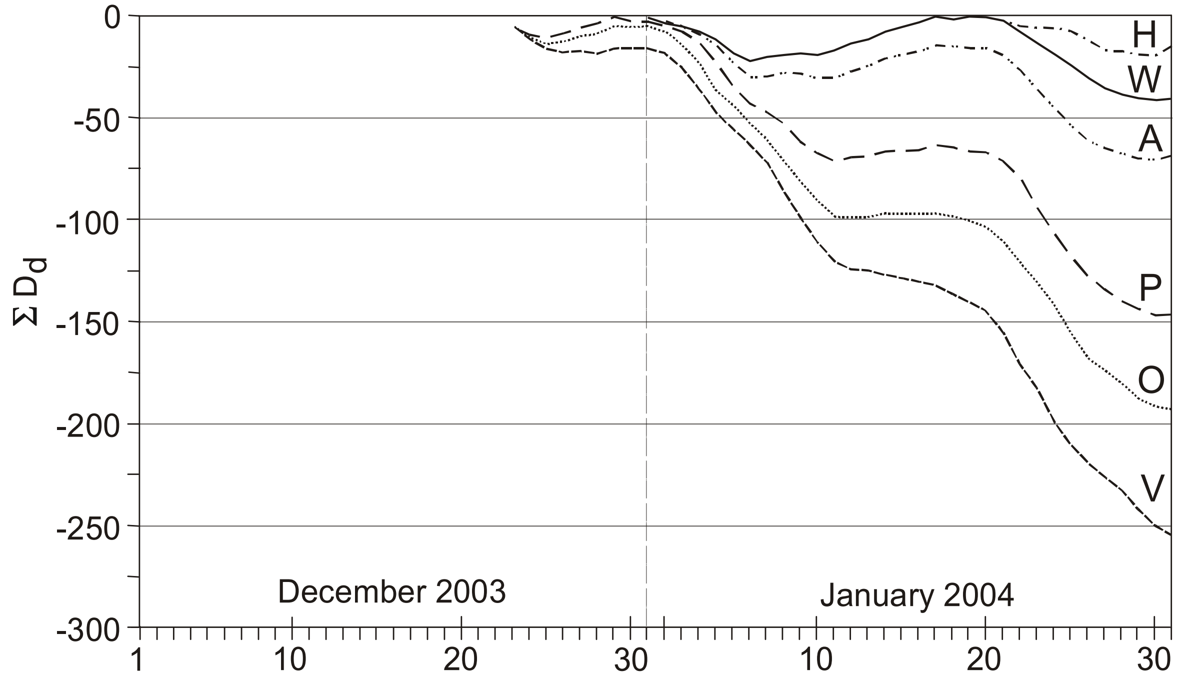

Fig. 3. Sums of daily mean air temperature (ΣD_d) since the start of the thermal winter for the selected meteorological stations. Symbols: H – Hamburg, W – Waren, A – Angermünde, P – Piła, O – Olsztyn, V – Vilnius

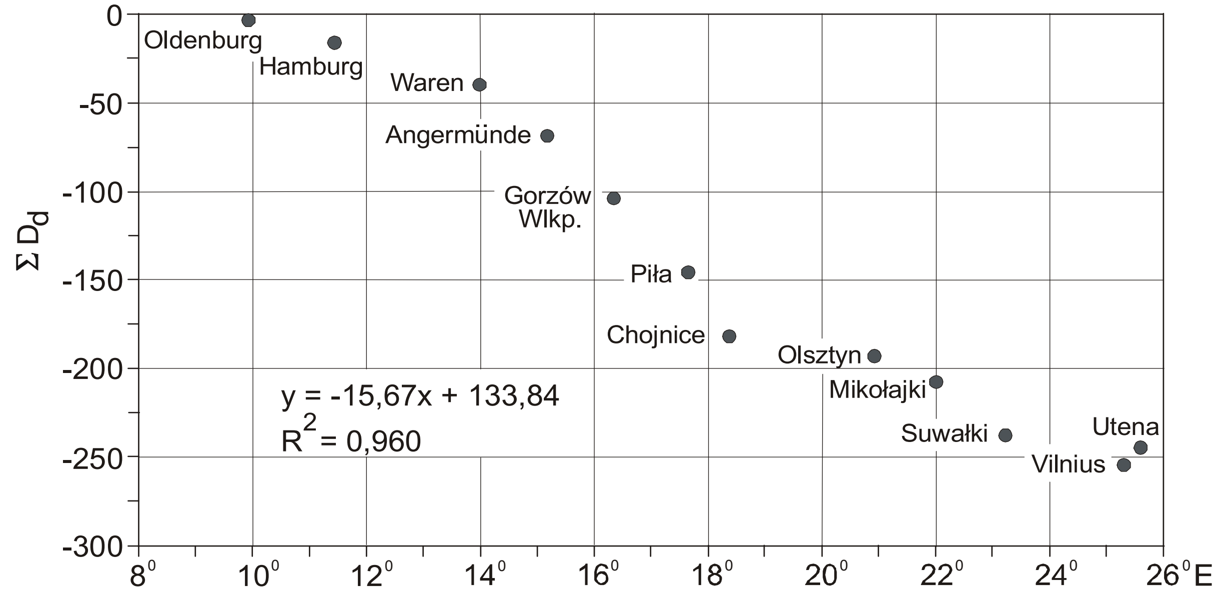

Fig. 4. Dependency between the longitude and the sums of daily mean air temperatures (ΣD_d) at the meteorological stations since the start of the thermal winter

Ice cover does not form steadily on the lakes, particularly in several physiogeographical regions. Hence, there are different ice-on and ice-off dates on the lakes. Such a situation occurred in the 2003/2004 winter season, which is confirmed by the observations conducted by the Institute of Meteorology and Water Management.

Ice cover appeared earliest on small and shallow lakes of the Mazury Lake District (Lake Bachotek – 24 December 2003), and latest in the western part of Poland (Lake Morzycko 14 January 2004). It disappeared in the opposite order: on Lake Morzycko on 7 February, and on Lake Serwy on 24 March (Fig. 5). The biggest ice thickness was recorded almost on all the lakes in North Poland in the last days of January, when the measurements were conducted. Therefore, the choice of the field measurement dates seems appropriate.

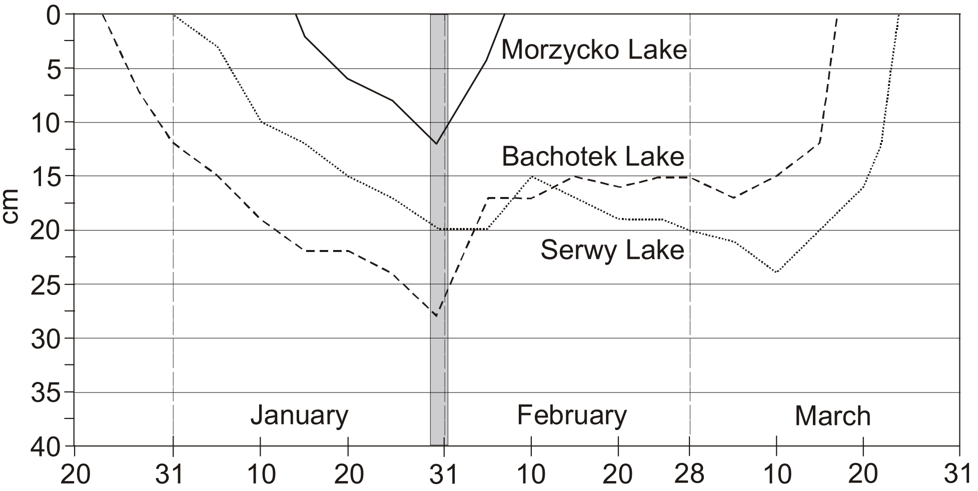

Fig. 5. Course of the ice cover thickness (I_t) on the selected lakes in the winter season 2003/2004 (the grey line marks field measurement days). Compiled on the grounds of data obtained from the Institute of Meteorology and Water Management

On the 30th and 31st January 2004 the ice cover thickness indexes increased distinctively in the eastern direction (apart from Zwischenahner Meer, where it did not form at all, Tab. 3).

Its mean thickness indexes changed from several centimetres in the west part of the Mecklenburg Lakeland (Großensee 3 cm, Dambecker See 7 cm, Großer Wummsee 8 cm), and a dozen or so centimetres in the Myśliborskie Lakeland and Drawskie Lakeland (Morzysko 12 cm, Myśliborskie 12 cm, Zamkowe 16 cm) to over 30 cm in the Great Mazurian Lake District and in the Lithuanian Lakeland (Krzywe Wigierskie 33 cm, Seirijis 31 cm).

The diversity in the ice cover thickness indexes on the west-eat line is presented in the Figure 6, which was prepared on the grounds of mean values. It must be underlined that diverse ice thickness indexes were small, and rarely exceeded 3 – 4 cm both on particular lakes and within the same lakelands. They exceeded the value of 7 cm only on three lakes: Ostrowite, Linowskie and Krzywe Wigierskie. The maximal ice thickness was most frequently noted in the lateral zone, though there were also some contrary situations (Chełmżyńskie, Linowskie, Dobskie, Gawlik, Majcz Wielki, Mochel,). In the case of several water bodies (Krzemień, Stelchno, Bachotek and Hańcza), the ice cover thickness was practically the same on the entire lake, and did not exceed 2 cm.

The distribution of water temperature in the measurement vertical in all the lakes was typical of anothermy. Directly below the ice cover (up to the depth of 0.5 m) there were minor differences of water temperature (up to 1.0°C at maximum). Yet, considerable differences of water temperature were recorded in the layers below 1.5 m (from 0.1 °C to 3.8 °C), as well as at the lake bottom (from 1.2 °C to 4.4 °C). Therefore, it results in the differences of the mean temperatures of water masses in the lakes. This mainly depended upon the depth of a lake, as well as upon other subaquatic parameters. This produced various total quantities of heat resources in the lakes (from $4.88 \cdot 10^6$ to $262.17 \cdot 10^6$ Mcal), and individual heat resources (from 0.26 to 8.99 $kcal \cdot cm^{-2}$). The most important data concerning the temperature and heat resources in the lakes are presented in the Table 3.

Table 3. Selected parameters of the ice thermal regime of the studied lakes. Symbols: IT_{mean} – mean ice thickness, WT_{mean} – mean water temperature, HR – heat resources, ST – snow thickness

No.	Lake	IT_{mean} (cm)	WT_{mean} (°C)	HR ($kcal \cdot cm^{-2}$)	HR (10^6 Mcal)	ST (cm)
1	Zwischenahner Meer	0	–	–	–	0
2	Großensee	3	–	–	–	0
3	Dambecker See	7	–	–	–	1
4	Großer Wummsee	8	–	–	–	1
5	Wurlsee	10	–	–	–	1
6	Wolletzsee	11	–	–	–	2
7	Morzycko	12	–	–	–	4
8	Myśliborskie	12	–	–	–	5
9	Krzemień	17	2.39	2.41	52.40	8
10	Wilczkowo	20	2.33	1.87	54.32	8
11	Zamkowe	16	2.41	3.06	40.62	2
12	Ciemino	21	1.48	0.96	21.27	11
13	Krępsko	17	1.92	1.23	43.06	7
14	Mochel	20	2.29	1.82	27.23	5
15	Ostrowite	17	3.13	3.62	93.73	6
16	Stelchno	20	1.30	0.69	10.38	6
17	Chełmżyńskie	20	1.89	0.96	31.15	9
18	Rudnickie Wielkie	20	0.91	0.43	6.42	5
19	Nogat	23	0.57	0.41	4.88	1
20	Bachotek	26	1.42	1.04	21.90	5
21	Isąg	22	2.55	3.79	143.09	9
22	Linowskie	25	1.12	0.77	11.80	8
23	Tumiańskie	23	1.32	0.91	10.72	7
24	Piłakno	22	2.03	2.88	68.45	6
25	Majcz Wielki	31	1.69	1.10	16.64	9
26	Tałtowisko	21	1.40	2.08	64.36	10
27	Gawlik	33	0.42	0.26	10.87	3
28	Dobskie	29	3.18	3.99	57.25	10
29	Hańcza	26	2.18	8.99	262.17	7
30	Krzywe Węgierskie	33	2.11	2.07	25.10	5
31	Seirijis	31	0.52	0.41	20.56	8
32	Vievis	28	0.87	1.12	32.83	7
33	Malkestas	27	1.58	1.32	15.82	14

Discusion

The thermal conditions of the winter season can be presented variously. This article discusses the sums of daily mean air temperatures (ΣD_d) since the start of the thermal winter up to the days when field investigations were carried out. This selection made it possible to define precisely the development of thermal conditions determining the formation and increment of the ice cover to the day of its measurements.

The analysis of the meteorological observations and the computation of the value of the sum of the daily mean air temperatures (ΣD_d) made it possible to distinguish three sectors which differ with respect to the decline rate. The first sector comprises the area from Oldenburg to Angermünde, where the decline amounted to 11.7 $\Sigma D_d \cdot 1^o \lambda^{-1}$ on average. Another is located between Angermünde and Chojnice and can be characterised by the biggest decrease (31.9 $\Sigma D_d \cdot 1^o \lambda^{-1}$ on average). The third sector with an average decline of 7.8 $\Sigma D_d \cdot 1^o \lambda^{-1}$ starts in the vicinity of Chojnice and stretches to Utena. Similarly, the ice cover spatial distribution on the west – east line reveals three distinctive sectors (Fig. 6). The first (western) one starts in the vicinity of Hamburg (Großensee) and runs up to the Drawskie Lakeland (lakes: Krzemień and Wilczkowo). It showed stable and big increase in the ice cover thickness, 3.0 $cm \cdot 1^o \lambda^{-1}$ on average. The second (central) sector – of the steady ice thickness and minor fluctuations – covers the area from Lake Wilczkowo to Lake Rudnickie Wielkie. And the third (eastern) sector, with the distinctive increase in the ice cover thickness (1.4 $cm \cdot 1^o \lambda^{-1}$ on average) and its fluctuations among neighbouring lakes (up to 10 cm), is located to the east of the Vistula River valley. The differentiated sectors relate to the air temperature conditions expressed in the sum of the daily mean air temperature values (ΣD_d) since the start of the ther-mal winter (compare Fig. 4). This is confirmed by strong dependency between the ice thickness on the lakes and ΣD_d during the thermal winter. These re-lations were presented in the case of the lakes loca-ted in the neighbourhood of the meteorological sta-tions, whose data were applied in this study (Fig. 7). It can be assumed, therefore, that there is considerable dependency between the ice cover formation and the longitude in this part of Europe. On the other hand, investigations carried out in the central part of North America showed significant dependency between the ice cover formation and the latitude, proving the dominance of the meridian circulation (Williams *et al.*, 2004).

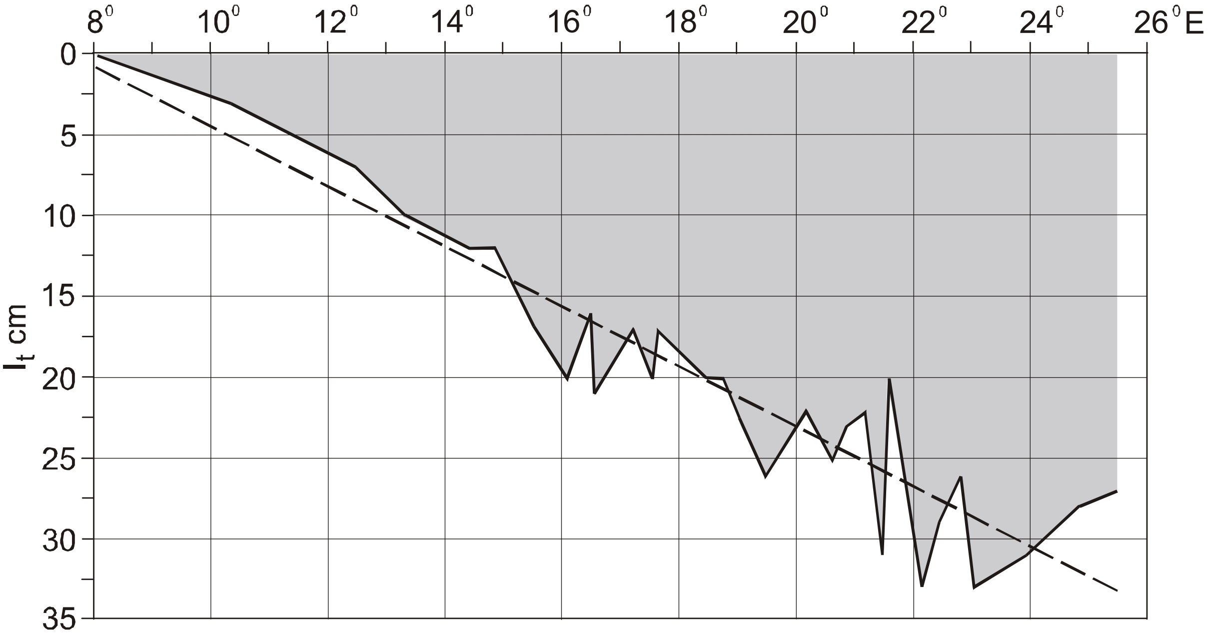

Fig. 6. Diversity in the ice cover thickness on the studied lakes on the 30th and 31st January 2004

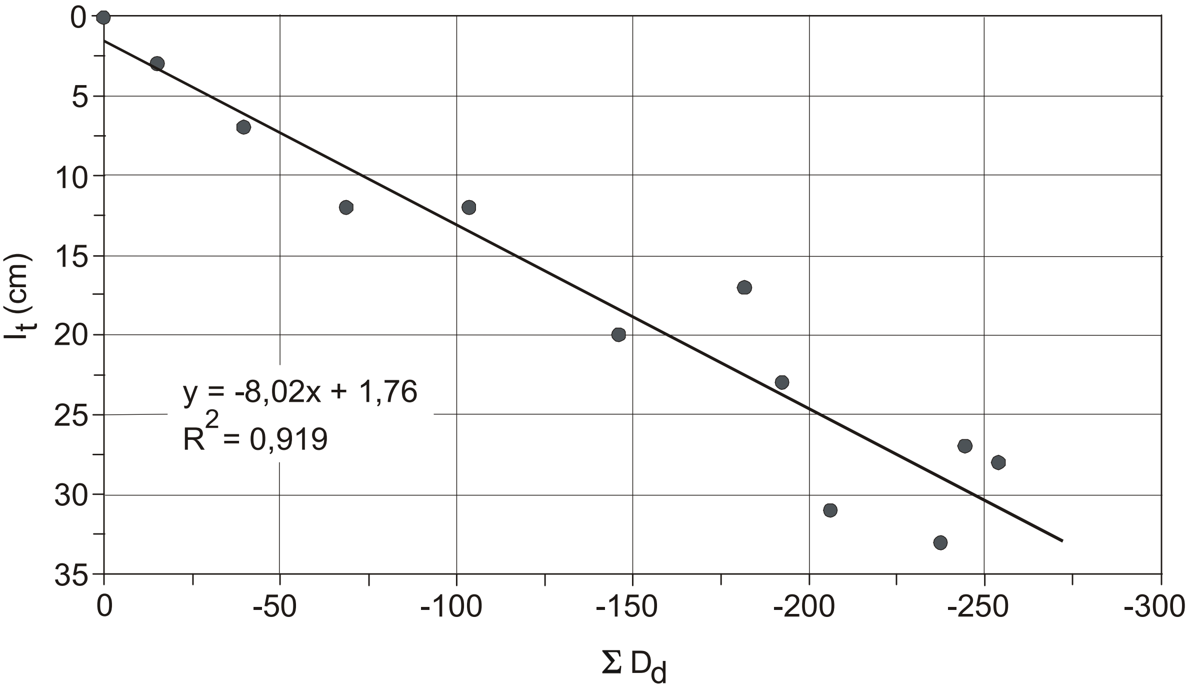

Fig. 7. Dependency between the ice cover thickness on the lakes (I_t) and the sum of daily mean air temperatures (ΣD_d) during the thermal winter

The formation of the ice cover must have also depended upon the thickness of the snow cover. There was its steady increase from 0 do 8 cm in the western part of the studied area. Its thickness varied a lot on the lakes located in the central part, even those in a close neighbourhood (from 5 do 11 cm). Even bigger difference occurred in the eastern part (from 1 to 14 cm). However, due to such a big number of objects and investigations conducted in an expedition form it has been difficult to determine the appropriate dependency between the ice cover increment and the presence of snow on the ice. Moreover, there is hardly any knowledge on snow balance on the ice during the winter season. Thus, the accurate determination of the role of snow in the ice cover formation may seem to be possible only on the grounds of the results of stationary examinations.

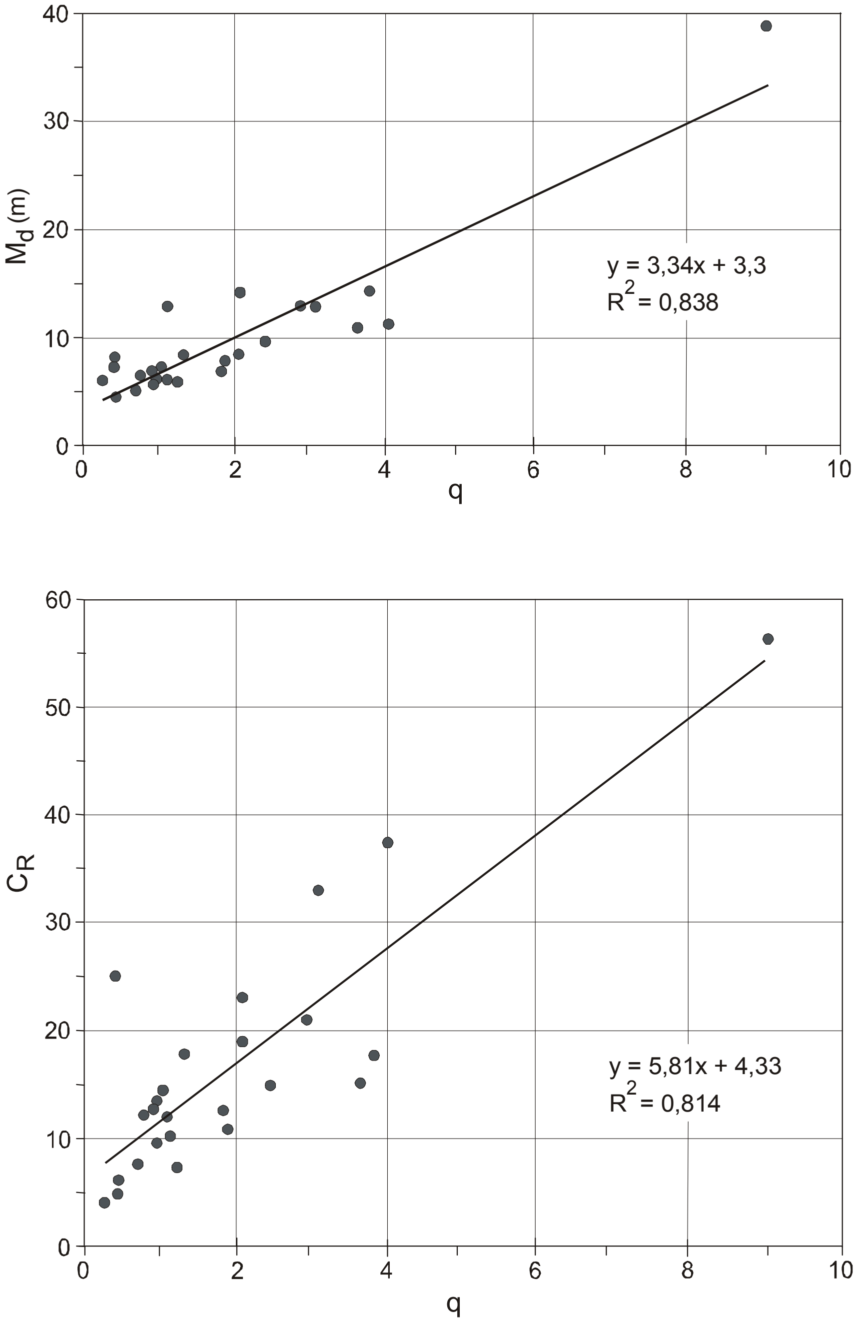

Fig. 8. Dependency between the amount of heat in the lakes q (kcal·cm^{-2}) and the selected lake parameters: A – mean depth, B – relative depth

The thermal regime of lake waters is another problem directly related to the ice cover formation and its spatial diversity in a given lake. The measurement results do not indicate any clear dependency between the ice cover thickness and water tem-perature. It is visible both in the temperature values of the water just below the ice cover, and also in the deepest places of the lakes. This means that both the ice thickness and the course of the thermal win-ter do not clearly determine the thermal conditions of a lake and its heat resources. After the ice cover formation, the thermal regime is determined by a ser-ies of elements, such as: lake volume, maximal and mean depth, integrity of the lake basin, vertical distribution of the capacity, and hydrological and hydrogeological conditions, among others

The above remarks prove some essential dependencies between heat resources and the mean depth of a lake (Fig. 8a), and heat resources and the capacity of the lake basin (Fig. 8b). In both the cases neither the geographical location of the lakes nor the ice cover thickness were of much significance. Therefore, it may be concluded that these were local factors that determined the existing dependencies.

Final remarks

In recent years the maximal thickness indexes of the ice cover have demonstrated considerable changeability. They have increased eastwards, and rarely exceeded 50 – 60 cm (Sziwa, 2002). Their mean values changed from 18 cm in the west part of Poland to over 30 cm in the eastern part of the Mazury Lake District. Thus, it may be assumed that the investigation results presented in this work were gathered in a period with the ice cover mean thickness indexes.

The spatial diversity of the ice cover on the lakes of the Central European Lowland in the winter season 2003/2004 proves growing importance of the zonal atmospheric circulation, which has been mentioned in several climatic studies (Degirmendżic *et al.*, 2000, Marsz, Żmudzka, 2001). Despite this, it may not be concluded that the spatial diversity of the ice cover will be alike in the years to come. Moreover, due to the exceptionally changeable climatic conditions in this part of Europe we slightly different ice conditions on the lakes may be expected almost every year. Therefore, further research is indispensable to work out a model of the formation and development of the ice cover regime on the lakes of the European Lowland.

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Streszczenie

W dniach 30 – 31 stycznia 2004 roku autorzy przeprowadzili serię synchronicznych pomiarów grubości lodu i pokrywy śnieżnej oraz pionowego rozkładu temperatury wody na 33 jeziorach Niżu Europejskiego (ryc. 1). Głównym celem przeprowadzonych badań (w 3 – 4 punktach na jeziorze) było określenie stopnia zróżnicowania przestrzennego grubości pokrywy lodowej na wybranych jeziorach, położonych w strefie wyraźnego oddziaływania klimatu umiarkowanego przejściowego. Jeziora objęte badaniami położone były w pasie o szerokości ok. 250 km (52.87 – 55.26°N) na odcinku o długości ok. 1.200 km (8.02 – 25.50°E). Obszar badań wyznacza położenie skrajnych jezior – Zwischenahner Meer (Niemcy) 53,20°N,

8,02°E oraz Malkestas (Litwa) 55,26°E, 25,50°N (tab. 1). Były to przeważnie jeziora jednoakwenowe, z mało rozwiniętą linią brzegową i koncentrycznym układem izobat. W analizie wyników badań uwzględniono ponadto dane meteorologiczne z 12 stacji (ryc. 2, tab. 2).

Zróżnicowanie grubości lodu rozpatrzono na tle przebiegu zimy termicznej (wyznaczonej według M. Makowiec, 1983) oraz wartości sumy średnich dobowych temperatur powietrza z okresu od jej początku do dnia, w którym wykonano pomiary terenowe. Na koniec stycznia 2004 roku suma średnich dobowych temperatur powietrza (ΣD_d) była zróżnicowana w szerokim zakresie i wynosiła od 0 °C w Oldenburgu i -14,5 °C w Hamburgu do -253,7 °C w Wilnie (ryc. 3). Wartości te obniżały się w kierunku wschodnim i wykazały silną korelację ($R^2 = 0,96$) z długością geograficzną (ryc. 4). W wyniku tego dni początku i końca występowania pokrywy lodowej na poszczególnych jeziorach przypadały w różnych terminach (ryc. 5). Z kolei pomiary grubości pokrywy lodowej wykazały wyraźne jej zwiększanie się w kierunku wschodnim od 3 do 33 cm (poza Zwischenahner Meer, na którym nie wystąpiła w ogóle, tab.3). Przyrostowi grubości lodu w kierunku wschodnim nie towarzyszyły liniowe kierunki zmian temperatury masy wodnej jezior ani zasobów ciepła (tab.3). Ich zróżnicowanie uzależnione było od wielu czynników, głównie o charakterze lokalnym.

W rozkładzie przestrzennym grubości pokrywy lodowej na linii zachód – wschód (ryc. 6) w wyróżniono trzy odmienne odcinki pod względem wielkości jej wzrostu przypadającej średnio na jeden stopień długości geograficznej: zachodni (3,0 $\mathrm{cm \cdot 1^{o}\lambda^{-1}}$), środkowy (ze stałą grubością lodu) i wschodni (średnio 1,4 $\mathrm{cm \cdot 1^{o}\lambda^{-1}}$). Odcinki te nawiązują do warunków temperatury powietrza wyrażonych sumą średnich dobowych temperatur powietrza od początku zimy termicznej (por. ryc. 4), potwierdzając silny związek między grubością lodu na jeziorach a sumami średnich dobowych temperatur powietrza w okresie zimy termicznej (ryc. 7). Nie stwierdzono natomiast związku między grubością lodu a miąższością warstwy śniegu, gdyż przy tak dużej liczbie obiektów badań i braku szczegółowych danych na temat od początku zimy nie było to możliwe. Udokumentowano natomiast, że zarówno grubość lodu jak i przebieg zimy termicznej (związane z położeniem geograficznym jezior), nie posiadały wyraźnych związków z termiką wody oraz z zasobami ciepła. O reżimie termicznym decydowało szereg innych elementów, takich jak np. objętość jeziora, głębokość maksymalna i średnia, zwartość misy jeziornej (ryc.8), pionowy rozkład pojemności oraz warunki hydrologiczne i hydrogeologiczne.

Wyniki badań potwierdziły wzrastające znaczenie strefowej cyrkulacji atmosferycznej. Nie można jednak założyć, że w następnych sezonach zimowych przebieg omawianego zjawiska będzie identyczny. Dlatego też przewiduje się dalsze badania, które umożliwią opracowanie modelu występowania i kształtowania się reżimu pokrywy lodowej na jeziorach Niżu Europejskiego w zależności od warunków klimatycznych.

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