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Assessment of Variation of Winter Severity Types in the Siedlce Area

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ABSTRACT
The objective of the work was to describe the thermal and snow conditions in the winter period in the Siedlce area. The average daily air temperatures were used in addition to numbers of days with a snow cover of at least 1 cm for the years 2000–2016 obtained from the Meteorological Station in Siedlce. Dates of the beginning and end of the winter season were determined. The average temperature of the winter season was determined in addition to the degree of winter severity, according to Oskin. The average, minimum and maximum values of parameters were calculated. The probability of an occurrence of individual types of winter severity was determined. Next, principal component analysis and cluster analysis were applied, the latter to the group years in terms of the days with a given type of weather in winter. It was found that – on average – the thermal winter began on 5 December and ended on 6th March. The winter was found to have lasted for 66 days. From year to year, there was observed an increase in the average number of days with mild weather. The greatest decline was found for the days with the weather typical of slightly severe and moderately severe winter. The last study years had the highest average number of days with weather typical of mild, slightly severe and moderately severe winter, and the lowest number of the days with weather typical of severe, very severe, unusually severe and extremely severe winter.

Keywords: indicator of weather severity, winter, variation, Siedlce

INTRODUCTION AND WORK OBJECTIVE

Over the last thirty years, a very distinct increase in the average air temperature has been observed. Winters have become milder and the majority of them have been snowless, autumns have been cooler than springs and summers have become hot. A radical increase in the warming rate has been observed in the last twenty years of the 20th century and the beginning of the 21st century (Kożuchowski and Żmudzka 2001). Kożuchowski (2004) claims that warming is much more obvious in the first half of the calendar year. Winters are becoming milder and early spring occurs earlier. Many researchers have studied the 'frostiness' or 'severity' of winter by applying various indicators and assessment criteria. The published works include the paper by Bednarek et al. (1979) for the Lublin area, by Olba-Zięty and Grabowski (2007) for the Biebrza River Valley, Nowosad (1998) and Janasz (2000) for Lublin, and Majewski et al. (2011) for Warszawa. There are works for Poland, Polish regions or localities presenting thermal description of winters (Piotrowicz 2002–2003) or snow cover only (Chrzanowski 1986, Falarz 2007, Nowosad and Bartoszek 2007, Czarnecka 2012). The values of average daily, minimum and maximum air temperature were used for calculations. Paczos (1985) divided the characteristics of winter severity into three groups. The first group includes the works which used the sums of average daily temperatures below 0°C or the sums of maximum and minimum temperature above and below 0°C for the assessment of thermal conditions. However, the classification criteria based on this method are not uniform. The second group consists of the methods based on an average air temperature during winters and its deviation from the long-term mean. The following months are taken into account in the works employing these methods: November-March, December-March, December-February and even January-February. The third group focuses on the works the authors of which make use of mathematical formulas demonstrating relationships of 'the indicator of winter severity'. Classification of winters is not an easy task, due to the weather changeability and contrasts in our climate. In Poland, the meteorological conditions during winters are predominantly affected by the Icelandic low, the Azores high as well as the Russian high. The result of it is an in-season and long-term variation of winters. The full description of annual, monthly or seasonal climatic conditions requires an objective assessment of the thermal conditions or, to be more precise, determination of the relationship between the thermal conditions in a given part of the year and a long-term mean (Warakomski 1989/90). The beginning of winter is assumed to be the date when the average daily air temperature is 0°C or less (Górska-Zajączkowska and Wójtowicz 2011). In Poland, the warmest region in winter is the coastal belt in which the average temperature is 0.0°C. In the remainder of the country, the average temperature in this season is negative (Filipiak 2004). Morawska-Horawska (1991) claims that there are also heat waves or cold spells. On average, there are 3 to 5 heat waves and 2–4 cold spells during the year in Poland. The indicators of snowfall intensity and thermal severity are on the decline. The number of days with the snow cover with the thickness greater than 5, 10, and 20 cm is falling, and the number of days with the snow cover, regardless of its thickness, is increasing (Radzka 2015).

MATERIALS AND METHODS

The work presents results of observations from the Siedlce Meteorological Station for the years 2000–2016. The following data were used: average daily air temperature, average daily air humidity, and number of days when snow cover was recorded in individual months.

The dates of the beginning and end of thermal winter were determined based on the formulas suggested by R. Gumiński. Determination of the beginning and end of each season in a given year may be difficult because temperature changes day to day in an irregular pattern and, in the case of thermal winter, raises above and falls below 0.0°C several times during 24 hours. The thermal seasons of the year are determined based on long-term data. Relying on average values of long-term daily temperatures for consecutive days of the year seems to be the most accurate. As not all stations have such information, the dates when the temperatures cross the threshold values are calculated in a simplified manner based on the average monthly temperature and using the formulas by R. Gumiński. He takes into account the following assumptions:

- the average monthly temperature falls on the 15th day of the month,
- each month has 30 days,
- a change in temperature (increase, decline) from month to month takes place steadily.

The following formulas were used for calculations:

$$x_1 = \frac{t_p - t_1}{t_2 - t_1} 30 \quad x_2 = \frac{t_1 - t_p}{t_1 - t_2} 30 \qquad (1)$$

where: t_p – threshold temperature,
t_1 – average air temperature in the month preceding an occurrence of the threshold temparature,
t_2 – average air temperature in the month following an occurrence of the threshold temperature,
x_1, x_2 – number of days.

The first formula was used to determine early spring, which marks the end of winter, whereas the second one to determine the beginning of winter. The formulas were utilised to determine the dates of the beginning and end of seasons in consecutive years of the studied 16-year period, using threshold temperatures for individual seasons of the years as t_p, and average monthly temperatures in each studied year as t_1 and t_2. The calculated number of days was added to the 15th day of the preceding month. When the sought value is higher than 15, one has to pay attention to the actual number of days in this month while adding it. This is the way to obtain the sought date which will be the beginning or end of the next season of the year. The number of days and the average air temperature of thermal winter were calculated. Seven types of weather can be distinguished based on the indicator of climate severity which reflects weather severity in the winter season. The weather severity indicator, drawn up by Oskin is very important in the assessment of bioclimatic conditions of the winter period for recreational purposes. In not only takes into account the wind speed and air temperature but also the coefficients describing air humidity (F), absolute altitude of the locality (Hk) and daily amplitude of air temperature (At).

The following formulas were used to assess weather severity:

$$SO = (1 - 0.06 \cdot t) \cdot (1 + 0.20 \cdot v) \cdot \cdot (1 + 0.0006 \cdot Hk) \cdot F \cdot At \quad (2)$$

where: SO – climate severity indicator (Oskin's),
t – air temperature,
v – wind speed,
Hk– absolute altitude of the locality,
F – coefficient reflecting air humidity,
At – coefficient reflecting daily amplitude of air temperature.

According to Oskin, there are no marked changes in the functioning of the human heart and airways up to 400 metres above sea level. In the localities which are situated below this altitude, the value Hk is assumed to be 0. If relative air humidity is higher than 60%, the value F=0.90. When humidity is higher, F is calculated using the following formula:

$$F = 0.005 \cdot RH + 0.645 \quad (3)$$

where: F – coefficient describing air humidity,
RH – relative air humidity.

When daily air temperature amplitude (dt) is up to 4°C, the coefficient At equals 0.85. If dt is higher than 18°C, At is 1.25. In the remaining cases, the daily air temperature amplitude is calculated in the following way:

$$At = 0.025 \cdot dt + 0.7998 \quad (4)$$

where: At – coefficient describing the daily amplitude of air temperature,
dt – daily amplitude of air temperature higher than 4°C and lower than 18°C,

In order to assess the weather severity according to Oskin, appropriate SO values have to be assumed:

SO	**Weather severity of the winter period:**
1 and less	mild weather
more than 1 to 2	slightly severe eather
more than 2 to 3	moderately severe weather
more than 3 to 4	severe weather
more than 4 to 5	very severe weather
more than 5 to 7	unusually severe weather
more than 7	extremely severe weather

In the analysis, the following basic statistical measures were calculated: mean, minimum, maximum and standard deviation. In order to examine the changes in phenomena (types of weather) over the years 2000–2016, dynamics indicators were used: chain indices, average rate of increase, fixed-base indices (the year 2000 was assumed to be the base year) (Sobczyk, 2007).

Fixed-base indices with the constant base (2000=100%) and chain indices (calculated year to year) were computed according to the formula:

$$I = \frac{y_1}{y_0} \times 100\% \quad (5)$$

where: I – dynamics index,
y_1 – value of the phenomenon in the study period,
y_0 – value of the phenomenon in the year assumed as the basis.

Chain indices were used to calculate the average rate of changes:

$$\bar{T} = (\bar{y}_g - 100) \quad (6)$$

where: $\bar{T}$ – average rate of changes,
$\bar{y}_g$ – geometrical mean.

In the second phase, principal component analysis (PCA) was used. PCA includes the total variance of variables and explains maximum variation in the dataset. Moreover, principal components are a function of the primary variable and are always independent. The number of principal components included in further analysis was determined using the Kaiser criterion according to which components the eigenvalues of which is higher than 1 are analysed (Morrison 1990, Stanisz 2009). Next, the cluster analysis was applied to group the studied years according to the number of days characterised by a given weather type in winter. The grouping was performed following the method by Ward and using the Euclidean distance. In order to determine the cut-off point of the dendrogram, the Mojena rule was used (Stanisz 2007).

ANALYSIS OF RESULTS

In 2000–2016, the thermal winter in the Siedlce area lasted 66 day, on average (Table 1). It began on 5th December and ended on 6th March, on average. The average air temperature of the thermal winter was -2.1°C, and the number of days with snow cover per year was 37 days on average. The earliest beginning of the analysed season was on

Table 1. Average, minimum and maximum dates as well as the standard deviation of the dates of the beginning and end of thermal winter, number of days, average air temperature and number of days with snow cover of thermal winter in the Siedlce area

Parameter	The begining date	The end date	Number of days	Average air temp. of thermal winter (°C)	Number of days with snow cover
Average	5 Dec.	06 Mar.	66	-2.1	37
Min.	26 Nov.	22 Jan.	24	-6.0	8
Max.	31 Jan.	08 Apr.	96	0.0	68
Standard deviation	17 Apr.	5 Jan.	20	1.9	17

26th November, and the latest one on 31st January. The earliest recorded date of the end of winter was 22nd January and the latest one was 8th April.

Table 2 presents a comparison of the number of days characterised by a given type of weather in winter to the period directly preceding the study period. In 2006–2009, the number of days with the weather typical of mild winter did not vary. An increase in the number of days with such weather type compared with the preceding year was observed in 2002 (by 300%), 2004 (by 100%), 2010 (by 400%) as well as 2013 and 2014. From year to year, the number of days when the weather was typical of mild winter increased by 9.7%, on average. A fluctuation in the number of days with the remaining weather types was observed in the study period. In the long-term period, there was a decline in the number of the days with the weather typical of severe winter, on average, by 23.77% every year, whereas for the days with moderately severe weather, the decline was 18.18%, for the days with unusually severe weather by almost 7%. In contrast, an increase in the number of days with the weather typical of severe, very severe and extremely severe weather was observed, which amounted to 5.16, 4.48 and 7.85%, respectively. The year 2013 was of particular interest as the number of days with weather typical of extremely severe winter increased by 900% compared with 2012.

Table 3 contains the number of days with a given weather type in winter compared with 2000 (the base year). From 2013 to 2016, there was an increase in the number of days with weather typical of mild winter. An increase in the number of days with weather typical of slightly severe winter

Table 2. Analysis of dynamics of changes in the number of days with a given weather type during winter compared with the period directly preceding the study period

Years	Mild	Slightly severe	Moderately severe	Severe	Very severe	Unusually severe	Extremely severe
2000							
2001	100	44	78	111	115	208	133
2002	400	182	107	95	87	67	100
2003	25	105	117	76	140	72	75
2004	200	71	55	145	129	177	100
2005	50	80	103	107	125	91	133
2006	100	150	147	82	64	76	75
2007	100	83	104	70	72	81	200
2008	100	87	104	181	119	69	100
2009	100	123	118	81	80	133	67
2010	500	294	57	82	75	100	125
2011	20	28	156	158	160	67	40
2012	100	185	89	82	71	275	50
2013	300	58	104	110	147	68	100
2014	200	236	104	84	32	33	1000
2015	67	100	133	84	125	80	10
2016	125	88	81	129	170	125	600
Average rate of changes	9.7	-23.77	-18.18	5.16	4.48	-6.89	7.85

Table. 3. Analysis of the dynamics of changes in the number of days with a given weather type during winter compared with 2000

Years	Mild	Slightly severe	Moderately severe	Severe	Very severe	Unusually severe	Extremely severe
2000							
2001	100	44	78	111	115	208	133
2002	400	80	83	106	100	138	133
2003	100	84	97	81	140	100	100
2004	200	60	53	117	180	177	100
2005	100	48	55	125	225	162	133
2006	100	72	81	103	145	123	100
2007	100	60	84	72	105	100	200
2008	100	52	88	131	125	69	200
2009	100	64	103	106	100	92	133
2010	500	188	59	86	75	92	167
2011	100	52	91	136	120	62	67
2012	100	96	81	111	85	169	33
2013	300	56	84	122	125	115	33
2014	600	132	88	103	40	38	333
2015	400	132	117	86	50	31	33
2016	500	116	95	111	85	38	200

was recorded in 2010 and 2014–2016. Compared with 2000, the number of days with weather typical of moderately severe winter increased by 3% and 17% in 2009 and 2015, respectively. In general (during 15 years), there was an increase in the number of days with weather typical of severe, very severe and extremely severe winter. The fact that the number of days with weather typical of very severe and unusually severe winter declined in the last three years is of interest.

The principal component analysis demonstrated that the number of days with a given weather type in winter was in 77% affected by the study years. They were the most influenced by the number of days with the weather typical of very severe, slightly severe and extremely severe winter, as indicated by values of correlation coefficients pertaining to the first principal component (PC1) which were -0.888; 0.822 and -0.759, respectively. The second principal component carried the information on the number of days with weather typical of moderately severe and mild winter. The reciprocal multi-trait associations indicate that the years when there were more days with weather typical of slightly severe winter had less days with the weather typical of very severe and extremely severe winter. In turn, in years with more days characterised by the weather typical of moderately severe winter, there were less days with a mild weather type (table 4).

On the basis of the cluster analysis, three groups of years were formed, characterised by similar characteristics of winter severity. The first group included 11 years, the second group was made up of the years 2004 and 2005 and the third group consisted of 2010, 2014, 2015 and 2016 (Fig. 1). The years in group 3 had the highest average number of days with weather typical of mild,

Table 4. Factor loads, eigenvalues and proportion of the first two principal components in the total variance

Traits	PC1	PC2
X_1 – number of days with mild winter	0.735	-0.410
X_2 – number of days with slightly severe winter	0.822	-0.324
X_3 – number of days with moderately severe winter	0.528	0.809
X_4 – number of days with severe winter	-0.553	0.099
X_5 – number of days with very severe winter	-0.888	-0.126
X_6 – number of days with extremely severe winter	-0.759	-0.303
Eigenvalue principal components	3.2	1.4
Explainded proportion of total variance (%)	57.2	20.1
Comulative proportion of total variance (%)	57.2	77.3

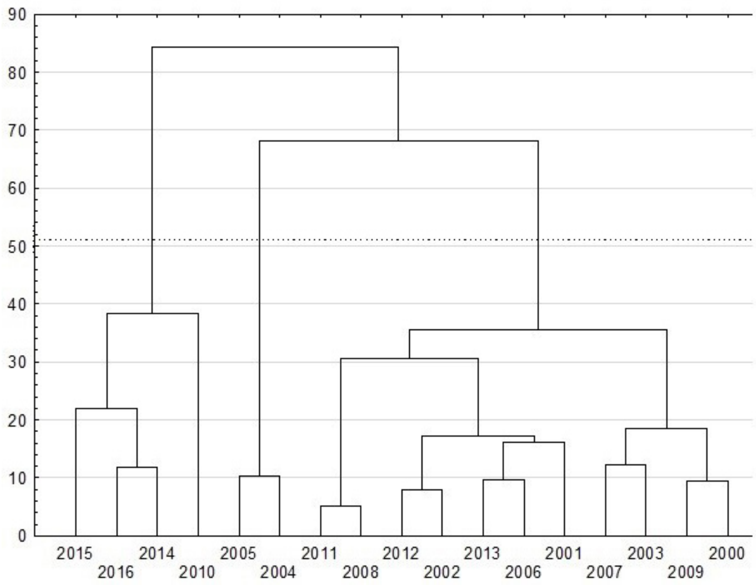

Fig. 1. Dendrogram of grouping of years in terms of according to weather types in winter

Table 5. Average numbers of days with a given weather type for groups formed by means of the cluster analysis

Group	Mild	Slightly severe	Moderately severe	Severe	Very severe	Unusually severe	Extremely severe
group 1	1.45	17.27	51.18	38.55	22.91	15.09	3.36
group 2	1.50	13.50	31.50	43.50	40.50	22.00	3.50
group 3	5.00	35.50	52.00	34.75	12.50	6.50	5.50

slightly severe, and moderately severe winter, and the lowest average number of days with weather typical of severe, very severe, unusually severe and extremely severe winter. The years 2004 and 2005, which formed the group 2, had the lowest average number of days with weather typical of slightly severe and moderately severe winter, and the highest average number of days with weather typical of severe, very severe, unusually severe and extremely severe winter (Table 5).

CONCLUSIONS

1. The thermal winter in the Siedlce area in 2000–2016 began on 5th December and ended on 6th March, on average. The winter was found to have lasted for 66 days. The average temperature of the thermal winter was -2.1°C. The number of days with snow cover through the year averaged 37 days.
2. The analysis of the dynamics of changes in the number of days with a given weather type in winter demonstrated that from year to year, there was an average increase in the number of days with mild weather (by 9.70%). The greatest decline was found for the days with weather typical of slightly severe and moderately severe winter (by 23.77% and 18.18%, respectively).
3. Compared to the base year 2000, there was an increase in the number of days with the weather typical of severe, very severe and extremely severe winter. It was found that the number of days with the weather typical of very severe and unusually severe winter declined during the period of the last 3 years.
4. The cluster analysis yielded three groups of years characterised by similar traits of winter severity. The first group included 11 years, the second group was composed of the year 2004 and 2005, and the third group was formed by 2010, 2014, 2015 and 2016. The last study years had the highest number of days with the weather typical of mild, slightly severe and moderately severe winter, and the lowest number of the days with the weather typical of severe, very severe, unusually severe and extremely severe winter.

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