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A typology of winter thermal conditions

Typologia warunków termicznych zim

INTRODUCTION

Literature on climatology abounds in characteristics, classifications and typologies of the winter season based on air temperature (Wiszniewski 1948; Kosiba 1954, 1956; Mitosek 1961; Paczos 1982). A particularly valuable summary of such approach is provided in the work by Paczos (1985), reviewing, from various angles, the most significant international and Polish volumes devoted to winter conditions.

The huge variation in winter thermal conditions found in Central Europe renders any attempt at classification or typology a complex task. A single criterion is not sufficient to classify this season, nor even a statistical sequence of winter seasons is always conclusive as to the severity of winters (Piotrowicz 1996). A mare plausible approach seems to be an analysis of several characteristics and not just evaluated in parallel, but also simultaneously. Hence, a new and unique typology has been developed, which allows an analysis of winter conditions for other than just the thermal criteria. This typology employs five criteria, such as the beginning and end date, duration, compactness (ratio of winter-days to winter duration) and four thermal criteria: number of winter days ($t_{mean} < 0^{\circ}C$), freezing ($t_{max} < 0^{\circ}C$), extremely freezing ($t_{max} < -10^{\circ}C$)

and the sum of the cold ($Llm_{ean} < 0^{\circ}C$). Cracow and Prague in the period 1775/76-1995/96 were chosen for this paper as a representation of Central European climatic conditions subject to both natural and human-related influence.

Tab. 1. Winter classification - mean temperature and standard deviation (Lorenc, Suwalska-Bogucka 1995)
Klasyfikacja zim na podstawie średniej temperatury i wartości odchylenia standardowego (Lorenc, Suwalska-Bogucka 1995)

Class	Character of winter	Range of temperature
1	extremely warm	t. > $t_{ś}$, + 2.5 σ
2	anomalously warm	$t_{ś}$, + 2.0 σ < t. 5 $t_{ś}$, + 2.5 σ
3	very warm	$t_{ś}$, + 1.5 σ < t,:5 $t_{ś}$, + 2.0 σ
4	warm	$t_{ś}$, + 1.0 σ < t. 5 $t_{ś}$, + 1.5 σ
5	slightly warm	$t_{ś}$, + 0.5 σ < t. 5 tśr + 1.0 σ
6	norrnal	$t_{ś}$, - 0.5 σ 5 t. 5 $t_{ś}$, + 0.5 σ
7	slightly cold	$_{r}$ - 1.0 σ $ lz $ $t_{ś}$r - 0.5 (J
8	cold	$t_{ś}$, - 1.5 σ 5 t. 5 $t_{ś}$, - 1.0 σ
9	very cold	$_{r}$ - 2.0 (J 5 lz $ $t_{ś}$r - 1.5 (J
10	anomalously cold	$_{r}$ - 2.5 σ $ lz $ $t_{śr}$ - 2.0 σ
11	extremely cold	t. < $t_{ś}$, - 2.5 σ

The most difficult phase of the work was the selection of winter types, as this was going to influence the end result. Detailed literature research carried out by the author (Piotrowicz 2000) led to the conclusion that good results could be obtained with the average values and their standard deviation (o'). The 11-degree scale proposed by Lorenc and Suwalska-Bogucka (1995), with 0,5 σ increments (tab. 1), was selected after a modification replacing the average winter temperature (Dec.-Feb.) used originally with the long-term average values of each characteristic mentioned above (tab. 2, 3, 4). Other measures of dispersion, such as quartiles and decyles were eliminated as they would limit the versatility of the typology; values of these dispersion measures are moresusceptible to change with the extension of the observation series. Additionally, standard deviation allows separate typologies for each station taking into account their natural variability. The average long-term values in Cracow and Prague are different and so the „typical" and „extreme" winters will also be different in those cities.

Tab. 2. Winter types - beginning and end dates and frequency (%) in Cracow (1792/93-1995/96) and Prague (1775/76-1995/96)
Typy zim ze względu na daty początku i końca oraz ich częstość (%) w Krakowie (1792/93-1995/96) i Pradze (1775/76-1995/96)

No	Types of winter	Cracow		Prague	
		ranges	frequency (%)	ranges	frequency (%)
The dates of winters beginning					
1	extremely early beginning	before 13 X	-	before 13 X	-
2	anomalously early beginning	13 X-19 X	0.5	13 X-20 X	-
3	very early beginning	20 X-26 X	5.9	21 X-28 X	2.7
4	early beginning	27 X-1 XI	10.8	29 X-5 XI	9.9
5	slightly early beginning	2 XI-8 XI	9.7	6 XI-13 XI	14.1
6	average beginning	9 XI-21 XI	44.6	14 XI-30 XI	46.2
7	slightly late beginning	22 XI-28 XI	12.4	1 XII-8 XII	9.9
8	late beginning	29 XI-5 XII	7.5	9 XII-16 XII	7.7
9	very late beginning	6 XII-12 XII	4.8	17 XII-24 XII	6.3
10	anomalously late beginning	13 XII-19 XII	3.8	25 XII-1 I	1.4
11	extremely late beginning	after 19 XII	-	after 1 I	1.8
The dates of winters ending					
1	extremely early ending	before 9 II	1.1	before 21 I	1.4
2	anomalously early ending	911-1611	0.5	21 1-30 I	2.3
3	very early ending	17 11-24 II	6.9	31 1-9 II	3.2
4	early ending	25 11-4 III	6.4	1011-1911	9.0
5	slightly early ending	5 III-12 III	9.0	20 11-29 II	11.3
6	average ending	13 III-28 III	40.7	1 III-20 III	36.6
7	slightly late ending	29 III-5 IV	21.2	21 III-30 III	23.1
8	late ending	6 IV-13 IV	10.6	31 III-9 IV	9.5
9	very late ending	14 IV-21 IV	2.6	10 IV-19 IV	3.2
10	anomalously late ending	22 IV-29 IV	1.1	20 IV-29 IV	0.4
11	extremely late ending	after 29 IV	-	after 29 IV	-

WINTER TYPES BROKEN DOWN BY BEGINNING AND END OATES, DURATION AND COMPACTNESS

In ma.king a detailed characteristic of Central European winter seasons the start and end dates in each individual season must be determined. Indeed, in the moderate climate, a winter can start as early as at the end of October or as late as in December or even in January; on the other hand the season may end any-

time between January and April (Tab. 2). A number of methods are useful for this task including one proposed by Kosiba (1956), Mitosek (1961), Makowiec (1983), Piotrowicz (1996, 2000). The typology proposed here allows for a parallel analysis of winter types determined on the basis of those two characteristics. In Cracow, for example, among the extremely (1988/89, 1989/90) and anomalously (1896/97) early-ending winters, the first started early (type 4) and the other two were average (type 6) as far as the end dates were concerned.

Tab. 3. Winter types based on their duration and frequency (%) in Cracow (1792/93-1995/96) and Prague (1775/76-1995/96)
Typy zim ze względu na długość oraz ich częstość(%) w Krakowie (1792/93-1995/96) i Pradze (1775/76-1995/96)

No	Types of winter	Cracow		Prague	
		ranges	frequency (%)	ranges	frequency (%)
1	extremely short	< 71 days	0.5	< 43 days	2.3
2	anomalously short	71-81	3.2	43-55	1.4
3	very short	82-92	5.4	56-68	4.1
4	short	93-103	5.9	69-81	7.7
5	slightly short	104-114	13.0	82-94	12.2
6	average duration	115-137	41.4	95-121	39.8
7	slightly long	138-148	15.0	122-134	20.8
8	long	149-159	9.1	135-147	9.0
9	very long	160-170	6.5	148-160	2.3
10	anomalously long	171-181	-	161-173	0.4
11	extremely short	> 181 days	-	> 173 days	-

Tab. 4. Winter types based on their compactness and frequency (%) in Cracow (1792/93-1995/96) and Prague (1775/76-1995/96)
Typy zim ze względu na zwartość oraz ich częstość(%) w Krakowie (1792/93-1995/96) i Pradze (1775/76-1995/96)

No	Types of winter	Cracow		Prague	
		ranges	frequency (%)	ranges	frequency (%)
1	extremely little compact	< 19%	-	<5 %	-
2	anomalously little compact	19-25	0.5	5-11	1.8
3	very little compact	26-31	5.9	12-19	2.7
4	little compact	32-38	12.4	20-27	10.4
5	poorly compact	39-44	15.0	28-35	19.5
6	average compact	45-58	38.7	36-51	34.4
7	slightly compact	59-65	12.4	52-59	16.3
8	compact	66-71	7.5	60-67	9.0
9	very compact	72-78	5.4	68-75	3.6
10	anomalously compact	79-84	2.2	76-82	0.9
11	extremely compact	> 84%	-	> 82%	1.4

The Central European winter features multiple changes of air temperature from negative into positive and back, causing the so-called „cold and warm waves". For a more in-depth analysis of winter thermal conditions, they can be broken down by the duration (Tab. 3) and compactness (Tab. 4). This was done as above with compactness expressed by the percentage calculated as a ratio of the number of winter-days to winter duration. This is a very useful characteristic, particularly if we define the beginning of winter as the first day with the average temperature lower than the freezing point ($t_{mean} < 0^{\circ}C$), the last such day marking the end of winter.

When the results were compared it became elear that the duration of Central European winter seasons depended primarily on their end date. In most cases short winter seasons also ended early. With the use of the typology it is very easy to answer questions such as: Are short winter seasons always very compact? Are early-starting winters compact or not?

Since eleven winter types have been deterrnined for either of the cities, making drawing conclusions a somewhat complex task, the types can be grouped into five (1-2, 3-4, 5-7, 8-9, 10-11) or, in extreme cases, three classes (1-5, 6, 7-11).

WINTER TYPES BY THERMAL CONDITIONS

In describing a winter season one must select the right criteria. They should complement each other taking into account the variability of Central European winter thermal conditions and render the quantity of negative temperatures in a number of ways. Hence, the four criteria mentioned at the beginning were selected as meeting the requirements and as sufficient for the deterrnination of winter severity.

The winter thermal typology was constructed in the following manner: first, winter thermal conditions were comprehensively defined with the use of the criteria mentioned above - all at the same time and not just in parallel. Hence, the values of each criterion for each winter were classified in the appropriate ranges with a score from O to 12 for the number of cold and very cold winter-days, as well as for the sum of the cold (Tab. 5).

The ranges and the allocated scores were defined subjectively and so are certainly arguable. Nevertheless, this classification can in no way be regarded as limited and should be useful with the extended data series. Detailed investigation led to conclusion that 10-day and $100^{\circ}C$-ranges were accurate enough to differentiate winter seasons from the point of view of thermal conditions. In order to make the ranges equal in duration and to indicate winters without any winter-days, freezing and extremely freezing days and during which the sum of cold was equal to zero it was decided not to assign any score to them.

Tab. 5. The scores for the nwnber winter days, freezing days, extremely freezing days and the swn of the cold
Punktacja dla wartości liczby dni zimowych, mroźnych, bardzo mroźnych oraz swny zimna

Nwnber of points	Ranges of values for the nwnber of davs	Ranges of values for the swn of the cold
0	0	0
1	1-10	from -1 to -100
2	11-20	from -101 to -200
3	21-30	from -201 to -300
4	31-40	from -301 to -400
5	41-50	from -401 to -500
6	51-60	from -501 to -600
7	61-70	from -601 to -700
8	71-80	from -701 to -800
9	81-90	from -801 to -900
10	91-100	from -901 to -1000
11	101-110	from -1001 to -1100
12	111-120	from -1101 to -1200

The scores allocated to each winter were added together yielding the range of difference in thennal severity of Central European winters from 3 to 37 points with the highest scores for the most severe winters. Eight winter types were defined on the basis of such score with five points per type (Tab. 6).

Tab. 6. Thennal winter types and their frequency (%) in Cracow (1792/93-1995/96) and Prague (1775/76-1995/96)
Typy zim pod względem warunków tennicznych oraz ich częstość (%) w Krakowie (1792/93-1995/96) i Pradze (1775/76-1995/96)

No	Nwnber of points	Types of winters	Cracow			Prague			
			%	Types of winters	%	No	No	%	%
1	1-5	very mild	11	mild	20.1	1	1-2	10.9	50.2
2	6-10	mild	19.0			2		39.3	
3	11-15	temperate mild	4.9	temperate	57.7	3	3-4	30.8	43.0
4	16-20	temperate frosty	22.8			4		12.2	
5	21-25	frosty	16.9	frosty	21.7	5	5-6	5.9	6.8
6	26-30	very frosty	4.8			6		0.9	
7	31-35	anomalously frosty	-	anomalously frosty	0.5	7	7-8	-	-
8	36-40	extremely frosty	0.5			8		-	

Comparing the winter types and at the same time detennining the types that occurred at each individual station seemed to be another particularly difficult phase of the project. However, the proposed typology made it an uncomplicated task; within each thennal winter type the seasons are broken down by the dates of the beginning and end, the duration and compactness. Here, one must remember that in the case of each winter type the number of cases is different having an impact on the calculated frequency. Table 7 shows just the last 15 winter seasons of the analysed period and the number of type according to the five criteria.

Tab. 7. Winter types based on their beginning and end dates, duration, compactness and thermal conditions in Cracow and Prague
Typy zim wydzielone ze względu na daty początku, końca, długość, zwartość i warunki termiczne w Krakowie i Pradze

Winters	Cracow					Prague				
	Beginning	End	Duration	Compact.	Thermal	Beginning	End	Duration	Compact.	Thermal
1981/82	6	4	5	6	3	8	5	4	8	3
1982/83	5	6	6	3	2	11	5	1	7	1
1983/84	6	6	6	5	5	5	6	7	4	2
1984/85	6	5	6	7	4	8	7	4	9	3
1985/86	6	8	7	6	4	6	9.	8	6	3
1986/87	8	6	5	8	4	6	6	6	6	3
1987/88	8	6	5	3	1	8	6	5	3	1
1988/89	4	1	3	4	2	4	3	5	4	1
1989/90	6	1	1	7	2	6	1	2	7	2
1990/91	8	3	2	6	3	7	4	4	6	2
1991/92	4	6	6	3	2	8	4	4	4	1
1992/93	10	5	3	6	3	9	6	4	7	2
1993/94	6	3	4	3	2	6	5	5	4	2
1994/95	6	6	6	2	2	9	2	1	7	1
1995/96	6	8	8	7	5	6	6	6	7	3

CONCLUSIONS

This paper presents a typology of winter seasons according to five characteristics which quantify winter severity. With this method, each winter season can be classified in one of the types taking into account the beginning and end date, duration, compactness and the thermal conditions: number of winter days

($t_{mean} < 0^{\circ}C$), freezing ($t_{max} < 0^{\circ}C$), extremely freezing ($t_{max} < -10^{\circ}C$) and the sum of the cold ($t_{mean} < 0^{\circ}C$). It also shows similarities and differences between winter thermal conditions in various regions of the country. A particular difficulty was posed by the need to name each type, finally solved by using climatological literature as the source of the most appropriate terminology. This may be very subjective and debatable but seems more suitable than plain letter symbols.

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STRESZCZENIE

Celem opracowania jest prezentacja oryginalnej typologii zim na podstawie wybranych kryteriów, które uzupełniają się nawzajem, uwzględniają zmienność warunków termicznych okresu zimowego w strefie umiarkowanej i w różny sposób określają ilościowe natężenie chłodu. Zdaniem autorki takich kryteriów nie powinno być zbyt wiele, ponieważ mogą utrudniać analizę i późniejszą syntezę. Również dokonywanie klasyfikacji zim w oparciu o jedno kryterium jest niewystarczające. Bardziej słuszne wydaje się wykorzystanie kilku charakterystyk i analizowanie ich nie tylko równolegle, ale jednocześnie. Dlatego też zdecydowano się wykorzystać: daty początku i końca zim, długość, zwartość (liczba dni zimowych do długości zim), liczbę dni zimowych ($t_{śr} < 0^{\circ}C$), mroźnych ($t_{max} < 0^{\circ}C$), bardzo mroźnych ($t_{max} < -10^{\circ}C$) i sumę zimna ($Lt_{śr} < 0^{\circ}C$), bazując na dobowych wartościach temperatury powietrza z Krakowa i Pragi z lat 1792/93-1995/96. Uwzględnienie natomiast wartości odchylenia standardowego (σ) umożliwiło sklasyfikowanie zim na każdej stacji oddzielnie, z uwzględnieniem naturalnej zmienności termiki zim.