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OCCURRENCE OF HOT DAYS IN NORTH-WESTERN POLAND IN THE YEARS 1986-2015

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Abstract: The article discusses annual, multi-seasonal and spatial variability of the occurrence of hot days ($t_{max} \geq 30^{o}C$) in north-western Poland. The study used meteorological data gathered at ten gauging stations in the years 1986–2015. Calculations were conducted regarding the number of hot days in individual years, which allowed for determining trends of changes. Annual distribution of hot days is presented against months divided into decades. Furthermore, the analysis accounts for the intensity of temperatures at individual stations, as well as length of undisrupted sequences of hot days. The author also took upon himself to indicate air masses that contribute to the occurrence of such days.
Key words: hot days, multi-seasonal variability, annual and spatial distribution, air masses, north-western Poland

Introduction

One of the most significant problems currently tackled in climatology involves analysing tendencies related to changes in various elements of climate, and extreme weather occurrences in particular. Days are considered hot when the maximum recorded temperature is equal to or exceeds 30 ^{o}C. Hot days are particularly burdening for a human body, resulting in increased heart rate, lower blood pressure, increased respiratory rate and profuse sweating. This adversely affects one's wellbeing, as well as physical and mental fitness. (Kozłowska-Szczęsna, Krawczyk and Kuchcik, 2004). Also, hot days, and extended periods of hot weather

in particular, tend to have negative impact on the economy – they result in an increased demand for electric energy and water, limit the capacity to perform outdoor works at noon, affect transport and may cause damage in agriculture and forestry. Therefore, the subject has been tackled by numerous authors (Kuchcik, 2006; Kossowska-Cezak, 2010; Kossowska-Cezak and Skrzypczuk, 2011; Koźmiński and Michalska, 2010; Więcław, 2013). The paper aims at assessing multi-seasonal, annual and spatial distribution of hot days ($t_{max} \geq 30^{o}C$) in north-western Poland, as well as analysing the impact of air masses on their occurrence.

Material and methods

The study covers a period of thirty years, i.e. from 1986 to 2015. The selected study area extends from Pojezierze Wielkopolskie and Pojezierze Lubuskie in the south to Pobrzeże Południowobałtyckie in the north. In order to identify hot days, the author used data on maximum air temperatures recorded at ten meteorological stations owned by the Institute of Meteorology and Water Management at National Research Institute (IMGW-PiB). Their locations are marked in figure 1.

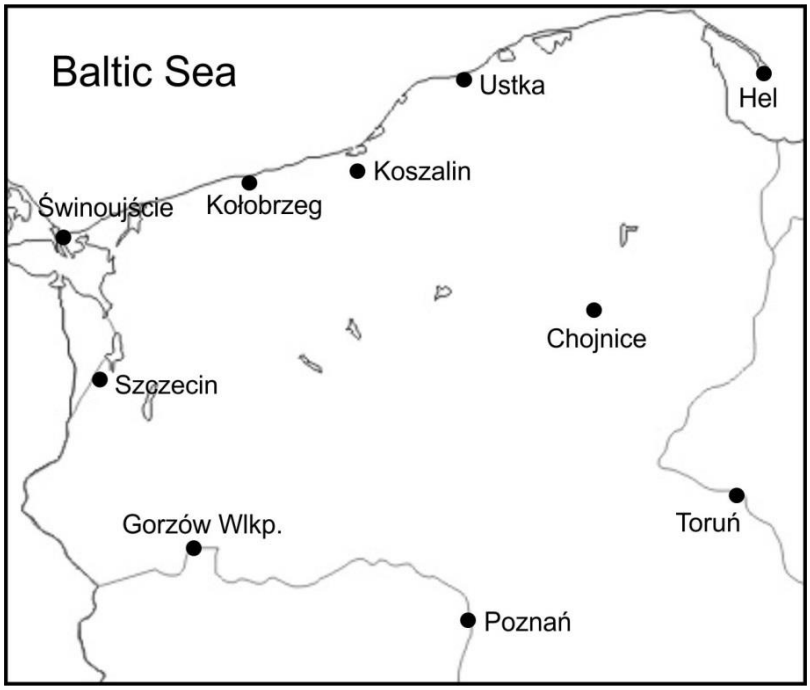

Fig. 1. Locations of meteorological stations

The day was considered hot if the temperature exceeded or was equal to 30 ^{o}C. Such a criterion (or $t_{max} > 30^{o}C$) has been widely accepted in climate studies performer in Poland (Błażejczyk, 2004; Lorenc, 2005; Grabowska, Panfil and Olba-Zięty, 2007; Koźmiński and

Michalska, 2010; Kossowska-Cezak and Skrzypczuk, 2011). The number of hot days was calculated for subsequent years, dividing them into months, and the latter into decades. The annual data served as a basis for identifying changes in the number of such days over the study period and analysing their statistical significance by means of applying the Student's *t*-test. Dividing months into decades allowed the author to precisely identify the season of hot days occurrence. Calculations were performer to determine the number of very hot days with $t_{max} \geq 35^{o}C$ and indicate peak temperatures.

The length and number of continuous sequences of hot days was determined not only in relations to the entire season of hot days occurrence, but also for individual months. If a given sequence ended in a month other than when it started, it was regarded as part of the month which represented a greater portion of the sequence. If the number of days in a sequence was equal in the beginning and closing month, it was attributed to the month of its commence. The types of air masses during hot days were determined on the basis of manual analysis of the surface weather maps of Europe published by IMGW-PiB in *Codzienny Biuletyn Meteorologiczny* [Daily Meteorological Bulletin] (1986-2009), and the available online weather service of IMGW-PiB (www.pogodynka.pl, years 2010–2015). The study included the geographic classification of air masses, which accounts for the location of the source area of a given mass. In the case of less frequently occurring tropical and arctic air masses, the author refrained from dividing them into continental and maritime, however, it was deemed justified to determine the degree of transformation of polar maritime masses and thus distinguish their two variations: fresh and old. In consequence, air masses occurring in Poland were divided into: arctic (A), polar maritime fresh (mPf), polar maritime warm (mPw), polar maritime old (mPo), polar continental (cP) and tropical (T).

Results

The area under analysis is characterised by considerable variety of geographical environment, therefore the average annual number of hot days ranges from nearly 10 in Pojezierze Wielkopolskie to 2–3 at the coast of the Baltic Sea (figure 2). The latter shows a decrease in the number of hot days moving from Zatoka Pomorska towards the open bay of the central and eastern part of the coast (Świnoujście 3,07; Kołobrzeg 2,50; Ustka 2,43). In Hel, the number of days in this category amounts to even less than 1 due to the fact that the meteorological station is located at a peninsula which extends into the sea. On the other hand, the greater the distance between a station and the sea, the higher the temperatures. This is evident when comparing data from Kołobrzeg and Koszalin. The number of days featuring

temperatures of ≥30°C at the elevated area of Pojezierze Pomorskie is only slightly higher than at the coast, and in Chojnice it amounts to 4.

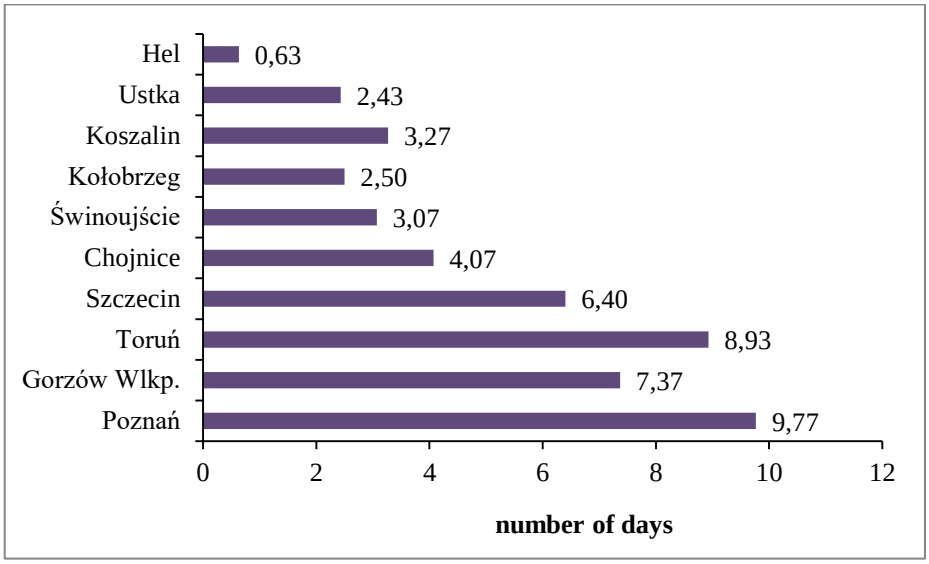

Fig. 2. Average annual number of hot days (t_{max}≥30°C) at the meteorological stations of north-western Poland. The data represent the period of 1986–2015

The conducted research on multi-seasonal variability of the number of hot days indicated a trend of increase across nearly all the meteorological stations with the exception of Hel (figure 3). These trends were found to be statistically significant (at 0,05) for the towns located in the southern part of the study area: Gorzów Wielkopolski, Poznań and Toruń. The data from the stations in question showed that years 2006, 2015 and 1994 featured the highest number of hot days, exceeding or oscillating around 20. At the coast of the Baltic sea, hot days occurred relatively frequently at the beginning of the 90s (1994 and 1992) and in the year 2010, albeit even in these years the number did not exceed ten.

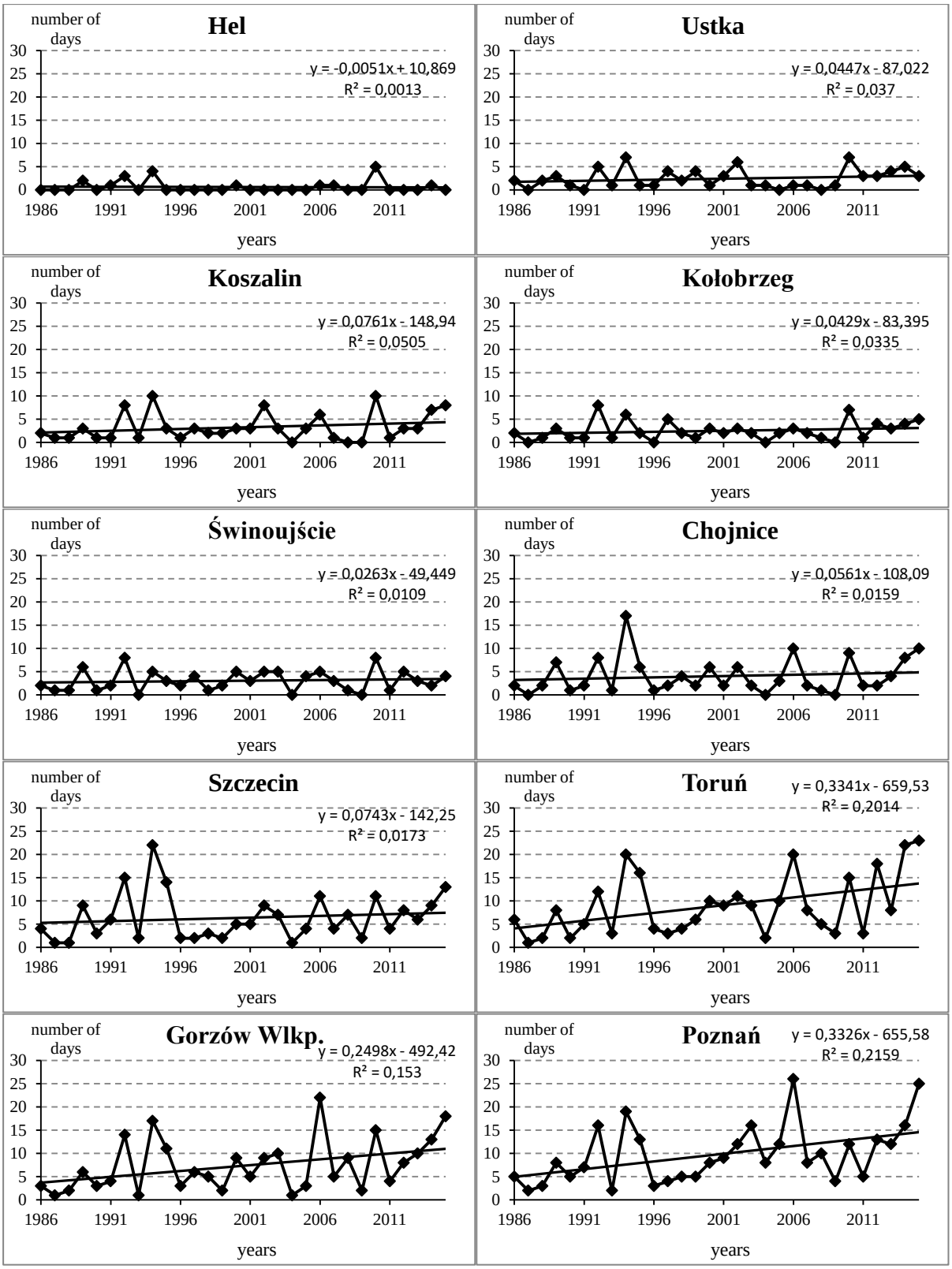

Fig. 3. Multi-seasonal variability of the number of hot days ($t_{max} \geq 30^{o}C$) at the meteorological stations of north-western Poland. The data represent the period of 1986–2015

Extreme peak temperatures in the analysed period recorded at eight stations ranged from 37.1 to 38. $0^{o}C$ (table 1). Only two gauging stations displayed lower values: $36.3^{o}C$ in Chojnice and up to $34^{o}C$ at the Hel Peninsula. In the case of most towns, the highest air

temperature was recorded at the end of the first decade of August 1992. Three stations recorded the absolute temperature maximum at the end of July and the beginning of August 1994, whereas in Poznań the highest temperature occurred on August 8th, 2015. Maximum air temperatures recorded at all the meteorological stations with the exception of Hel exceed 35 °C. Such days can be considered very hot (Kossowska-Cezak and Skrzypczuk, 2011). Over the entire 30-year-long study period, hot days featuring this high temperatures occurred 23 times in Toruń, whereas in Poznań, Gorzów Wielkopolski and Szczecin – between ten and twenty (table 2). Such days occurred relatively frequently in the year 1994 and 1992, as well as 2015, albeit in the most recent year they were not observed at the coast of the Baltic Sea. All very hot days coincided with the advection of tropical air over the study area.

Table 1. Absolute air temperature maximum at the meteorological stations of north-western Poland in the years 1986-2015

Stations	Temperature (°C)	Days
Hel	33,7	29.07.1994
Ustka	37,8	10.08.1992
Koszalin	37,1	10.08.1992
Kołobrzeg	38,0	10.08.1992
Świnoujście	37,4	01.08.1994
Chojnice	36,3	10.08.1992
Szczecin	37,8	01.08.1994
Toruń	37,5	10.08.1992
Gorzów Wlkp.	37,3	09.08.1992
Poznań	37,1	08.08.2015

Table 2. Number of days with maximum air temperature of ≥35°C at the meteorological stations of north-western Poland in the years 1986–2015

Years	Stations									
	Hel	Ustka	Koszalin	Kołobrzeg	Świnoujście	Chojnice	Szczecin	Toruń	Gorzów Wlkp.	Poznań
1986	-	-	-	-	-	-	-	-	-	-
1987	-	-	-	-	-	-	-	-	-	-
1988	-	-	-	-	-	-	-	-	-	1
1989	-	-	-	-	-	-	-	-	-	1
1990	-	-	-	-	-	-	-	-	-	-
1991	-	-	-	-	-	-	-	-	-	-
1992	-	1	1	2	1	2	3	3	3	2
1993	-	-	-	-	-	-	-	-	-	-
1994	-	-	2	-	1	3	4	6	4	4
1995	-	-	-	-	-	-	-	-	-	-
1996	-	-	-	-	-	-	-	-	-	-
1997	-	-	-	-	-	-	-	-	-	-
1998	-	-	-	-	-	1	1	1	1	1
1999	-	-	-	-	-	-	-	-	-	-
2000	-	-	-	-	1	1	1	2	1	2
2001	-	-	-	-	-	-	-	-	-	-
2002	-	-	-	-	-	-	-	-	-	-
2003	-	-	-	-	-	-	-	-	-	1
2004	-	-	-	-	-	-	-	-	-	-
2005	-	-	-	-	-	-	-	-	-	-
2006	-	-	-	-	-	-	-	1	1	-
2007	-	-	1	-	1	-	1	2	2	1
2008	-	-	-	-	-	-	-	-	-	-
2009	-	-	-	-	-	-	-	-	-	-
2010	-	1	-	-	1	-	2	2	-	1
2011	-	-	-	-	-	-	-	-	-	-
2012	-	-	-	-	-	-	-	1	-	1
2013	-	-	-	-	-	-	-	1	-	-
2014	-	1	-	-	-	-	-	-	-	-
2015	-	-	-	-	-	1	1	4	3	2
Total	0	3	4	2	5	8	13	23	15	17

The study area is considerably varied in terms of the length of hot days occurrence season (table 3). In the south of the area and in Szczecin, such days may occur as early as in the last decade of April, and no later than by the end of August. The period in question

appears to be shorter at the coast, where majority of stations indicated its beginning in the second decade of May and closure at the end of August. It is particularly short at the Hel Peninsula, where hot days occur nearly exclusively in July and in the first two decades of August. Approximately 50% of hot days occur in July, and in most towns they are observed in the third decade of the month. Days with maximum temperatures ≥30^{o}C were also recorded in August.

Table 3. Total number of hot days (t_{max}≥30^{o}C) at the meteorological stations of north-western Poland in the years 1986–2015

Stations	April			May			June			July			August			September		
	Decade																	
	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III
Hel	-	-	-	-	-	-	-	1	-	4	6	4	3	1	-	-	-	-
Ustka	-	-	-	-	2	2	3	2	3	13	9	15	13	5	6	-	-	-
Koszalin	-	-	-	-	1	2	5	3	7	15	15	22	17	9	2	-	-	-
Kołobrzeg	-	-	-	-	1	2	2	3	5	12	8	16	15	6	5	-	-	-
Świnoujście	-	-	-	-	1	3	6	7	9	13	11	13	17	7	4	-	1	-
Chojnice	-	-	-	-	1	-	4	4	5	19	20	29	21	12	6	1	-	-
Szczecin	-	-	1	-	1	5	12	5	13	32	26	40	29	22	5	-	1	-
Toruń	-	-	3	2	2	8	12	10	14	43	38	54	37	29	11	2	2	1
Gorzów Wlkp.	-	-	2	-	2	4	13	9	15	29	30	51	33	22	10	1	-	-
Poznań	-	-	2	1	2	7	14	13	19	36	38	60	49	32	15	2	2	1

At the Baltic coast, hot days mostly occur individually, sporadically in three-, four- and five-day sequences (table 4). In the south of the study area and in Szczecin, the observed sequences were eleven and thirteen days long. Heat waves with length of at least four days occur almost exclusively in July, however, in August 2015 periods of heat lasting from six to seven days did occur in Toruń, Poznań and Gorzów Wielkopolski (table 5).

Table 4. Total number of hot days sequences (t_{max}≥30°C) at the meteorological stations of north-western Poland in the years 1986–2015

Stations	Length of sequence (in days)												
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Hel	13	-	2	-	-	-	-	-	-	-	-	-	-
Ustka	49	7	2	1	-	-	-	-	-	-	-	-	-
Koszalin	58	8	5	1	1	-	-	-	-	-	-	-	-
Kołobrzeg	50	9	1	1	-	-	-	-	-	-	-	-	-
Świnoujście	64	10	1	-	1	-	-	-	-	-	-	-	-
Chojnice	43	19	5	4	1	-	-	-	-	1	-	-	-
Szczecin	73	24	13	2	1	1	-	-	-	-	-	-	1
Toruń	73	32	19	5	5	2	-	-	1	-	1	-	-
Gorzów Wlkp.	64	33	11	3	2	1	-	-	1	-	2	-	-
Poznań	82	38	20	3	3	-	1	-	2	-	2	-	-

Table 5. Total number of hot days sequences (t_{max}≥30°C) at the meteorological stations of north-western Poland. Data regarding months in the period of 1986–2015

	Months	Length of sequence (in days)										
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Hel	April											
	May											
	June	1										
	July	8		2								
	August	4										
	September											
	Months	Length of sequence (in days)										
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Ustka	April											
	May	4										
	June	8										
	July	20	6	1	1							
	August	17	1	1								
	September											
	Months	Length of sequence (in days)										
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Koszalin	April											
	May	3										
	June	10	3									
	July	25	4	3	1	1						
	August	20	1	2								
	September											
		Length of sequence (in days)										
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Kołobrzeg	April											
	May	3										
	June	7	2									
	July	18	7		1							
	August	22		1								
	September											

	Months	Length of sequence (in days)										
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Świnoujście	April											
	May	4										
	June	15	4									
	July	24	2	1		1						
	August	20	4									
	September	1										
Chojnice	Months											
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
	Kwiecień											
	Maj	1										
	Czerwiec	6	2	1								
	Lipiec	17	10	2	4						1	
	Sierpień	19	7	2								
	Wrzesień											
Szczecin	Months	Length of sequence (in days)										
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**13**
	April	1										
	May	6										
	June	15	5	2								
	July	28	8	8	2	1	1					1
	August	22	11	3								
	September	1										
Toruń	Months	Length of sequence (in days)										
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
	April			1								
	May	8	2									
	June	14	7	2	1							
	July	22	11	10	4	5	1			1		1
	August	25	12	6			1					
	September	4										
Gorzów Wlkp.	Months	Length of sequence (in days)										
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
	April		1									
	May	4	1									
	June	13	8	3								
	July	21	9	7	3	2				1		2
	August	26	14	1			1					
	September											
Poznań	Months	Length of sequence (in days)										
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
	April		1									
	May	5	2									
	June	15	10	4								
	July	22	13	7	3	3				2		2
	August	36	12	9				1				
	September	4										

The analysis of the surface weather maps of Europe showed that hot weather tends to form at the time of tropical air advection. The percentage share of tropical masses during hot days at the Baltic coast and in Chojnice amounted to 80% and is thus higher than in the southern part of the study area (table 6). Hot weather forms less frequently during the advection of polar continental air, whereas polar maritime old and warm air masses tend to

occur sporadically on hot days. Data gathered at the meteorological stations where hot days season is longest (Toruń, Poznań, Gorzów Wielkopolski) indicate that at the beginning and the end of that period hot weather forms exclusively under the influence of continental air. In July and August, however, there have been occurrences of hot weather coinciding with the advection of other air masses, particularly polar continental.

Table 6. Air masses on hot days ($t_{max} \geq 30^{o}C$) at the meteorological stations of north-western Poland. Mean percentage values regarding the years 1986–2015

Stations	Air masses						Total
	A	mPf	mPw	mPo	cP	T	
Hel	-	-	5,3	0,0	15,8	78,9	100,0
Ustka	-	-	2,7	2,7	17,8	76,7	100,0
Koszalin	-	-	4,2	1,1	14,6	80,1	100,0
Kołobrzeg	-	-	4,0	1,3	20,0	74,7	100,0
Świnoujście	-	-	3,3	2,2	18,5	76,1	100,0
Chojnice	-	-	1,6	1,6	17,2	79,5	100,0
Szczecin	-	-	5,2	5,7	22,9	66,1	100,0
Toruń	-	-	3,7	5,2	17,2	73,9	100,0
Gorzów Wlkp.	-	-	5,9	5,0	20,8	68,3	100,0
Poznań	-	-	6,2	6,8	21,2	65,8	100,0

Air masses: A - arctic, mPf - polar maritime fresh, mPw - polar maritime warm, mPo - polar maritime old, cP - polar continental, T – tropical.

Table 7. Air masses on hot days ($t_{max} \geq 30^{o}C$) at the meteorological stations of north-western Poland. Mean percentage values regarding individual months in the years 1986–2015

	Months	Air masses						Total
		A	mPf	mPw	mPo	cP	T	
Hel	April	-	-					100,0
	May	-	-					100,0
	June	-	-	0.0	0.0	0.0	100.0	100,0
	July	-	-	0.0	0.0	21.4	78.6	100,0
	August	-	-	25.0	0.0	0.0	75.0	100,0
	September	-	-					100,0
	Months	Air masses						Total
		A	mPf	mPw	mPo	cP	T	
Ustka	April	-	-					100,0
	May	-	-	0.0	0.0	25.0	75.0	100,0
	June	-	-	0.0	0.0	25.0	75.0	100,0
	July	-	-	0.0	2.7	10.8	86.5	100,0
	August	-	-	8.3	4.2	25.0	62.5	100,0
	September	-	-					100,0
	Months	Air masses						Total
		A	mPf	mPw	mPo	cP	T	
Koszalin	April	-	-					100,0
	May	-	-	0.0	0.0	33.3	66.7	100,0
	June	-	-	0.0	7.1	14.3	78.6	100,0
	July	-	-	2.0	0.0	16.0	82.0	100,0
	August	-	-	10.7	0.0	7.1	82.1	100,0

	September	-	-					100,0
Kołobrzeg	Months	Air masses						Total
		A	mPf	mPw	mPo	cP	T	
	April	-	-					100,0
	May	-	-	0.0	0.0	33.3	66.7	100,0
	June	-	-	0.0	0.0	30.0	70.0	100,0
	July	-	-	0.0	0.0	16.7	83.3	100,0
	August	-	-	11.5	3.8	19.2	65.4	100,0
	September	-	-					100,0
Świnoujście	Months	Air masses						Total
		A	mPf	mPw	mPo	cP	T	
	April	-	-					100,0
	May	-	-	0.0	0.0	25.0	75.0	100,0
	June	-	-	0.0	4.5	22.7	72.7	100,0
	July	-	-	0.0	0.0	18.9	81.1	100,0
	August	-	-	10.7	3.6	14.3	71.4	100,0
	September	-	-	0.0	0.0	0.0	100.0	100,0
Chojnice	Months	Air masses						Total
		A	mPf	mPw	mPo	cP	T	
	April	-	-					100,0
	May	-	-	0.0	0.0	100.0	0.0	100,0
	June	-	-	0.0	0.0	0.0	100.0	100,0
	July	-	-	0.0	1.5	25.0	73.5	100,0
	August	-	-	5.1	2.6	7.7	84.6	100,0
	September	-	-	0.0	0.0	0.0	100.0	100,0
Szczecin	Months	Air masses						Total
		A	mPf	mPw	mPo	cP	T	
	April	-	-	0.0	0.0	0.0	100.0	100,0
	May	-	-	0.0	16.7	16.7	66.7	100,0
	June	-	-	0.0	10.0	10.0	80.0	100,0
	July	-	-	6.1	4.1	32.7	57.1	100,0
	August	-	-	7.1	5.4	14.3	73.2	100,0
	September	-	-	0.0	0.0	0.0	100.0	100,0
Toruń	Months	Air masses						Total
		A	mPf	mPw	mPo	cP	T	
	April	-	-	0.0	0.0	0.0	100.0	100,0
	May	-	-	0.0	8.3	8.3	83.3	100,0
	June	-	-	2.8	2.8	5.6	88.9	100,0
	July	-	-	4.4	5.2	25.9	64.4	100,0
	August	-	-	3.9	6.5	10.4	79.2	100,0
	September	-	-	0.0	0.0	0.0	100.0	100,0
Gorzów Wlkp.	Months	Air masses						Total
		A	mPf	mPw	mPo	cP	T	
	April	-	-	0.0	0.0	0.0	100.0	100,0
	May	-	-	0.0	0.0	33.3	66.7	100,0
	June	-	-	0.0	10.8	8.1	81.1	100,0
	July	-	-	7.3	3.6	25.5	63.6	100,0
	August	-	-	7.7	4.6	20.0	67.7	100,0
	September	-	-	0.0	0.0	0.0	100.0	100,0
Poznań	Months	Air masses						Total
		A	mPf	mPw	mPo	cP	T	
	April	-	-	0.0	0.0	0.0	100.0	100,0
	May	-	-	0.0	11.1	33.3	55.6	100,0
	June	-	-	4.3	13.0	8.7	73.9	100,0
	July	-	-	6.7	6.0	26.9	60.4	100,0
	August	-	-	7.3	5.2	19.8	67.7	100,0
	September	-	-	0.0	0.0	0.0	100.0	100,0

Air masses: A - arctic, mPf - polar maritime fresh, mPw - polar maritime warm, mPo - polar maritime old, cP - polar continental, T – tropical.

Conclusions

Due to the impact of the Baltic sea, the number of hot days occurring along the coast and at the elevated areas of Pojezierze Pomorskie is markedly lower than in the southern part of the analysed area. Studies on multi-seasonal variability of hot days occurrence showed a statistical trend of increase in relation to Toruń, Poznań and Gorzów Wielkopolski. Considerable increase in the number of hot days can also be indicated in other regions of Poland (Matuszko and Piotrowicz, 2012). Meanwhile, in the north, along the coastline, the trends of changes are statistically insignificant, which has been confirmed by Koźmiński and Michalska (2010). Diversity of natural environment in the area under analysis determines marked differences in the length of hot days occurrence season. In Poznań and Toruń, such days may take place as early as in the last decade of April, and the last occur by the end of September. The season is shorter at the coast, particularly in its eastern part. Approximately half of the entirety of hot days occur in July – such days are particularly frequent in the third decade of the month. At the coast of the Baltic, hot days typically occur individually, and may sporadically extend into several-days-long heat waves. Longer periods of hot weather have been observed in the south of the study area and in Szczecin, lasting up to elven or thirteen days. Hot weather most frequently forms during the advection of tropical air. The impact of tropical air masses on hot weather formation increases at the beginning and the end of the season, where days feature temperatures of $t_{max} \geq 30^{o}C$. The percentage share of tropical air masses on hot days is highest at the coast of the Baltic sea and at the strip of elevated area of Pojezierze Pomorskie. In the south, hot weather may be shaped slightly more frequently by air masses that are potentially colder.

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