VARIABILITY OF THE THERMAL CONTINENTALITY INDEX IN CENTRAL EUROPE

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ABSTRACT. Variability of the thermal continentality index in Central Europe. The paper presents the spatial and temporal variability of thermal continentality in Central Europe. Gorczyński's and Johansson-Ringleb's formulae were used to derive the continentality index. The study also looked at the annual patterns of air temperature amplitude (A), a component of both of these formulae, and D; the difference between the average temperatures of autumn (Sep.-Nov.) and spring (Mar.-May). Records of six weather stations representing the climate of Central Europe were included in the study covering the period 1775-2012 (Potsdam, Drezden, Prague, Vienna, Krakow, Debrecen). The highest continentality index was found in Debrecen and the lowest in Potsdam. The continentality index fluctuated with time with two pronounced dips at the turn of the 19th century and in the second half of the 20th century. The highest continentality index values were recorded during the 1930s and 1940s.

Keywords: continentality index, air temperature amplitude, Central Europe

1. INTRODUCTION

One of the main properties of the Central European climate is transitionality, or the coexistence of both maritime and continental features (Gavilan 2005, Baltas 2007, Wypych 2010, Brázdil et al. 2009). Continentality is a measure of the degree, to which the region's climate is influenced by the advection of air masses from the Atlantic Ocean and from Eurasia (Kożuchowski, Marciniak 1986, 1991, 2002). It depends primarily on the region's distance from the surrounding seas and the ocean, but also from its hypsometry and landform. The degree of maritime influence on such transitional areas is regarded as a sensitive indicator of climate (Baryson 1974). The continentality index is expressed as a percentage and is calculated using a range of available formulae. Most of them involve the annual amplitude of air temperature and the area's latitude; others also include the difference between the average temperatures of autumn and spring (Table 1); some others still look at the average temperatures of July and January and at the total solar irradiance in these months (Spitaler 1922).

European climatologists have been researching climate continentality for a long time and the earliest studies were published in the first half of the 20th century. In Poland, Gorczyński (1918), Romer (1947), Ewert (1963,1972) and Szreffel (1961) wrote about determining the continentality of a given place using the

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amplitude of air temperature and the latitude. Wypych (2010), Baltas (2007), Gavilan (2005) also devoted a study to thermal and precipitation-determined continentality Kożuchowski (2003) and Brázdil et al. (2009) published many studies linking circulation with the degree of continentality. In his research on the variability of continentality Degórski (1984) examined the usefulness of Ellenberg's phytoindicative method that involved ranking the extents of occurrence of plant species characteristic of various climatic-vegetation zones. Huculak (1983) in turn, devised a method that pinned continentality on the time in spring and autumn when the air temperature crosses the annual average. Deniz et al.(2011) used four indicators that expressed continentality, maritime influence and climate aridity. This topic was also included in ecological studies on the adaptation of biological diversity depending on the gradient of climatic continentality in a given area (Kleinebecker et al. 2007, Ovaska et al. 2005). Hirschi et al. (2007) looked at the variability of continentality by analysing differences between the warmest and coldest months in the Arctic and Antarctic using NCEP/NCAR reanalysis.

The objective of this study is to identify the spatial and temporal variability of thermal continentality indices in Central Europe during the period 1775-2012.

2. DATA AND METHODS

The average monthly air temperature records used in this study came from six weather stations located in the middle latitudes of Central Europe between 47° N and 52° N. The data were obtained from the Hungarian Meteorological Service, Jagiellonian University's Climatology Department (Poland), Deutscher Wetterdienst (Germany) and online *European Climate Assessment* database (ECA&D), OGIMET (Table 1). All of these records were validated as homogenous. The three longest ones, from the historic weather stations of Vienna and Prague (both starting in 1775) and Krakow (starting in 1792), provide a good account of the change in the climate of Central Europe since the late 18th century.

The first analytical step involved the examination of four elements: the annual amplitude of air temperature (A), the difference between the average temperature in autumn and spring (D) and two continentality indices derived using selected formulae (Table 2).

One of the methods for deriving the continentality index was the one proposed by Gorczyński (1918). This particular formula is only applicable to areas between the latitudes 30° N and 60° N, i.e. in areas dominated by land, while in oceanic areas the index produces negative values (Brázdil et al. 2009). Gorczyński also tailored his formula to the southern hemisphere, which is dominated by oceans, and the index is known as the climate oceanity index (Szreffel 1961). The other formula selected for this study, the Johansson-Ringleb's, adds the difference between the average temperature of autumn (Sep.-Nov.) and spring (Mar.-May) to the amplitude of the annual air temperature (Table 2).

Table 1. Source material characteristic

Station	Latitude (φ)	Longitude (λ)	H m a.s.l	Data periods
Potsdam	52°38' N	13°07' E	100	1893-2012
Dresden	51°13' N	13°75' E	232	1917-2012
Prague	50°10' N	14°25' E	365	1775-2007
Vienna	48°25' N	16°37' E	209	1775-2008
Krakow	50°04' N	19°58' E	220	1792-2012
Debrecen	47°48' N	21°63' E	112	1901-2012

Table 2. Continentality indices

Author	Formula
Gorczyński (K_G)	$K_G = 1.7\frac{A}{sin\varphi} - 20.4$
Johansson-Ringleb (K_{JR})	$K_{JR} = 0.6\left(1.6\frac{A}{sin\varphi} - 14\right) - D + 36$
K- continentality index, φ – latitude, A-annual temperature amplitude, D-average temperature differences between autumn and spring	

3. RESULTS

The analysis has shown a centuries-long alternation between continental and maritime dominance of the Central European climate, which was observable at most of the stations included in the study.

The first decline in continental influence was recorded at the turn of the 19th century in Prague (1890-1924), Vienna (1891-1924) and Krakow (1895-1921) (Fig. 1). The second decline was observed at the turn of 1970 at all of the stations, even though it was the strongest in Debrecen in 1967-1979. The strongest thermal continentality index values (K_G) were observed during the first three decades of the 19th century in Krakow and in the third and fourth decade of the 20th century in Krakow, Vienna, Prague, Potsdam and Dresno (Fig. 1). In Debrecen, these fluctuations were weak and did not follow any particular trend.

In the next step, the maritime and continental phases identified in accordance with the K_G index were compared with those identified using annual temperature amplitude. The average temperature amplitudes (A) of the common timeframe (1917-2007) ranged from 20.8°C in Potsdam to 24.7°C in Debrecen (Table 3). However, across all individual records (A), including ones longer (Krakow, Prague, Vienna) than those common to all stations, the highest amplitude was recorded in the early 19th century in Krakow (33.5°C) (Table 3). An analysis of the standard deviations (σ) of all the elements included (A, D, K_G, K_{JR}) revealed that the lowest standard deviation of the average amplitude was also in Krakow (3.4) (Table 3). The indicator defining the difference between the average temperature in autumn and spring (D) clearly confirmed the strongest continental influence in central Hungary. Indeed, of all the stations, Debrecen has produced the lowest and negative values of the D index (-0.4°C) (Table 3).

Differences between the values obtained from the Gorczyński's and Johansson-Ringleb's formulae stem from their design and are not high. Because both of the formulae include the amplitude of air temperature it would be plausible to argue that this variable has a decisive influence on continentality.

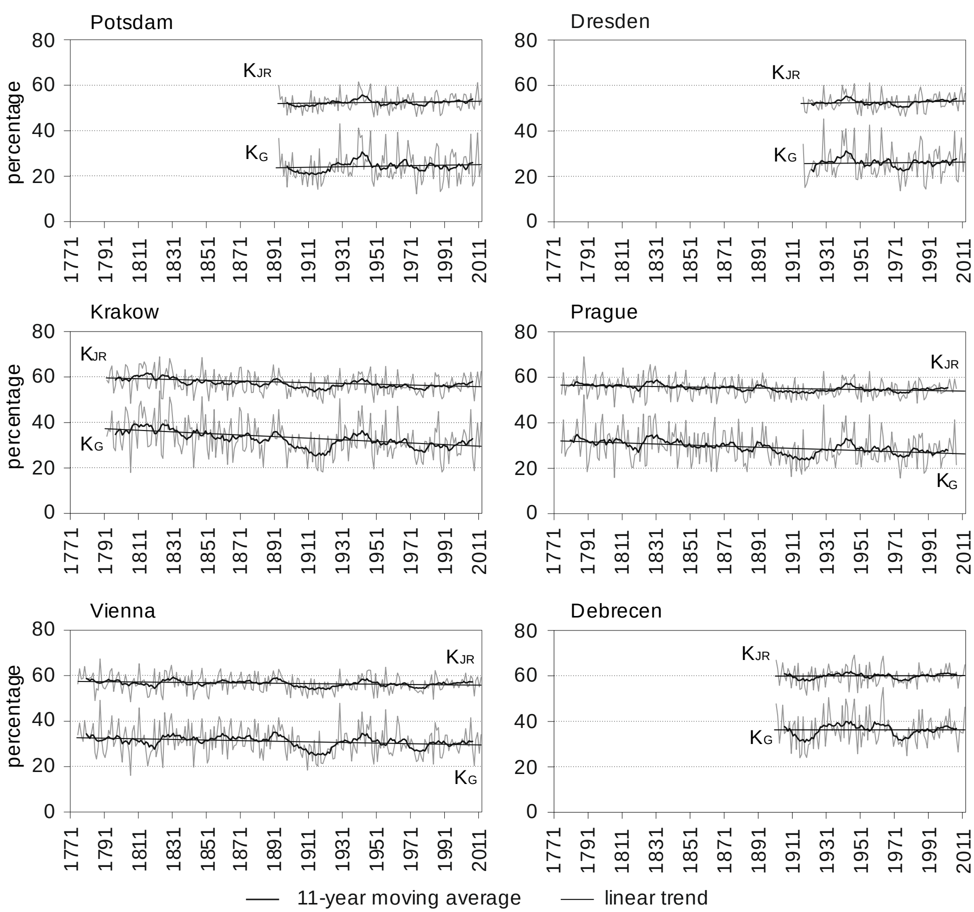

Fig. 1. Multi-annual courses of Gorczyński (K_G) and Johansson-Ringleb (K_{JR}) thermal index values (%) in selected European stations

Table 3. Average long-term, minimum and maximum values of amplitude (A), difference between the average temperature in autumn and spring (D) and two continentality indeces in selected European stations

Station	Amplitude (A) [°C]				Autumn/Spring (D) [°C]			
	Mean	Max	Min	σ	Mean	Max	Min	σ
Potsdam	20.8	29.5 1929	15.2 1974	3.1	0.4	4.5 2006	-4.2 1920	1.5
Dresden	21.0	29.8 1929	15.4 1974	3.1	0.8	4.4 2006	-3.7 1920	1.6
Prague	22.5	32.9 1788	16.3 1974	3.1	0.4	5.6 1785	-3.8 2007	1.5
Vienna	22.7	30.7 1788	16.1 1806	2.7	0.1	4.8 1785	-4.7 1920	1.4
Krakow	23.9	33.5 1823	17.3 1806	3.4	0.3	4.3 1839	-5.4 1920	1.5
Debrecen	24.7	32.8 1964	19.3 1915	2.9	-0.4	3.2 1944	-5.8 1920	1.7
Station	K_G [%]				K_{JR} [%]			
	Mean	Max	Min	σ	Mean	Max	Min	σ
Potsdam	24.4	43.0 1929	12.3 1974	6.6	52.4	61.5 1940	46.0 1949	3.5
Dresden	26.0	45.3 1929	13.7 1974	6.8	52.6	61.1 1956	46.4 1977	3.5
Prague	29.3	52.3 1788	15.7 1974	6.9	55.3	69.0 1788	46.9 1806	3.9
Vienna	31.1	49.2 1788	16.1 1806	6.2	56.6	67.4 1788	48.5 1806	3.6
Krakow	32.7	53.9 1823	18.0 1806	7.6	57.2	68.9 1823	48.4 1806 1919	4.4
Debrecen	36.3	54.9 1964	24.0 1915	6.6	60.0	69.1 1947	51.5 1919	3.7

The last step in the research included an analysis of the differences between the long-term average K_G and its average values in each decade. It was found that the lowest negative values of the Gorczyński's index ranged from -2.9% in Prague to -4.6% in Krakow during the decade 1911-1920 (Fig. 2). The highest positive deviation from the long-term average occurred in 1941-1950 when it was recorded at all of the stations, but peaked in Debrecen (3.0%) and Prague (4.3%) (Fig. 2).

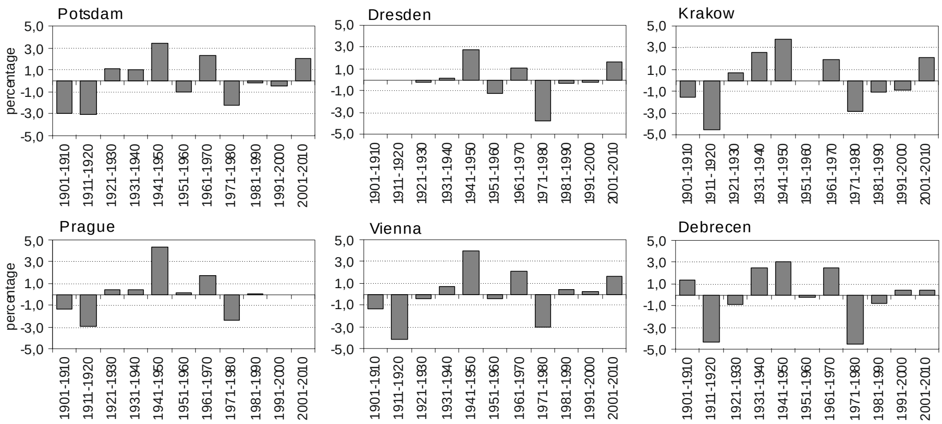

Fig. 3. Long-term average deviation of Gorczynski index (%) in the different decades in selected European stations

4. CONCLUSIONS

The amplitude of air temperature provides the simplest means to assess continental vs. oceanic influences on European climatic conditions. Characteristic features of a continental climate primarily include hot summers and severe winters, as well as higher spring than autumn temperatures (Martyn 1992). This is corroborated by this study. Indeed, the lowest and negative values of the D index among the stations were recorded in Debrecen. The average values of thermal continentality calculated at these stations clearly show a decline of the maritime influence on the climate from the west towards the east of the continent.

Fluctuations in continental and maritime dominance are observed not just in space, but also in time. The first wave of declining continental influence was noted at the turn of the 19^{th} century in Prague, Vienna and Krakow. The second such wave occurred at all of the stations in the 1970s and 1980s. The highest climatic continentality occurred during the 1930 and 1940s in Krakow, Vienna, Prague, Potsdam and Dresden.

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