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"Changes" of the thermal continentality in Central Europe between the years 1951 and 2013: case study – Slovak Republic

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Abstract

The influence of continents and oceans plays conceptually the key role in the climate conditions of Europeans regions. Continentality is also an important phytogeographic factor of vegetation distribution in Slovakia. This study analysed continentality development at six meteorological stations in Slovakia during the periods 1951–2013, or 1961–2013. Rising trend of the maximal and minimal temperature has been observed at all meteorological stations (lowland as well as mountainous stations) in this periods. However the results showed non-significant increase of continentality index during the monitored period of 63 (53) years. Based on the results of CCM 2000 climate model we cannot expect significant changes of continentality by the end of the 21st century, but the climate change will be significantly manifested by the increase of maximum and minimum air temperatures.

1 Introduction

Continentality of climate belongs to basic climatic characteristics of an area. It specifies the influence of the continent on climate formation. The opposite of continentality is called oceanity (maritimity), which is a set of climatic features influenced by ocean. According to the meteorological dictionary (Bednář et al., 1993), the most distinctive feature of continentality is large amplitude of air temperatures, which is the main characteristic of thermic continentality (Hirschi et al., 2007). On the base of other climatic elements we distinguish ombric and baric continentality.

From the point of bioclimatology, geography and ecology, continentality is an important characteristic of environmental parameters. For example, it assists us in understanding complex relationships between the plant distribution and geographic position. With the help of continentality or oceanity indices, phytogeography explains the changes in vegetation conditions from oceans to the interior of continents, gradual transition from forests to steppes and semi-deserts, as well as postglacial development

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of vegetation (species spreading in the Boreal, or Atlantic period) Ellenberg (1988). Klötzli (1976), Shidei (1974) and Plesník (2004) present that in comparison with ocean, land is characterised by basic humidity conditions and temperature differences caused by the distance from ocean (normal continentality), as well as by the elevation and the robustness of a mountain range (alpine continentality). Ocean air masses change from the edge to the interior of mountains. This increases continentality and its impact on vegetation to such an extent that horizontal zones are formed within mountain ranges, which is called as intra-mountain zonality (Zhao et al., 2014). Forest altitudinal distribution is significantly higher on continental mountains in compare to oceanic peaks. For example the timberlines of isolated peaks at oceanic island are lower than on continental mountains at the same latitude (Leuschner, 1996). The Alps are a typical example (Ellenberg, 1988). From the edge of the mountains the vertical structures change from mesophilous atlantic plant communities up to extremely continental communities. Due to the alpine continentality, in the Alps we can see the ecological phenomena in a range of several tens of kilometres comparable to several thousand kilometres from the Atlantic coast up to the interior of Siberia. The impact of alpine continentality and subsequently also the intra-mountain zonality can also be observed in the Tatras of the Western Carpathians (Plesník, 2004). This phenomenon is more thoroughly described in forestry and plant community literature, e.g.: Fleischer (1994), Pagan (1992).

In the conditions of Czecho-Slovakia, continentality or oceanity was examined by several authors. Hrudička (1933) dealt with thermic and ombric continentality. Kveták (1974) elaborated continentality of Slovakia in a complex way using several indices. Brázdil et al. (2009) dealt with thermic continentality linked with atmospheric circulation patterns in the Czech Republic. Melo (2002) in Hurbanov addressed continentality in connection with climate change. He simulated future changes of continentality using CCCM 2000 and GISS 1998 climate models. Recently, some other studies, dealing with modelling of the climatic change, used the same characteristic to describe changes in continentality of climate in the twenty first century (Melo et al., 2013). The aim of the

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presented paper is to examine to development of continentality on stations situated at different elevations during the years 1951 (1961)–2013. The partial goal was to evaluate (un)suitability of continentality as an indicator of the ongoing climate change.

2 Materials and methods

The work is based on the data from the Slovak Hydrometeorological Institute (SHMI). Table 1 presents the stations included in the analysis and their geographic characteristics. From the point of terrain we can divide the stations into three groups as follows:

- Lowlands (Michalovce, Hurbanovo).
- Valleys (Rožňava, Sliač).
- Highlands (Oravská Lesná, Skalnaté Pleso).

Continentality was calculated as a simple index of continentality (Ic) following the original definition of Supan applied by Rivas-Martinez et al. (2011):

$$Ic = (Tmax - Tmin) \quad (1)$$

where Ic is the continentality index, Tmax is the mean temperature (°C) of the warmest month, and Tmin is the mean temperature (°C) of the coldest month.

In the Czech and Slovak meteorological literature, continentality index is described as annual amplitude of temperature, or as an annual range of monthly mean air temperatures in °C, (difference between the maximum and minimum monthly mean air temperatures). Continentality index was also calculated for the future climate represented by GCMs scenario of CCCM 2000 (Canadian Climate Centre Model) following the works of Lapin et al. (2009), Melo (2002), Melo et al. (2013).

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3 Results and discussion

Since our goal was to evaluate the continentality over the whole varied terrain of Slovakia, we selected six meteorological stations from the network of SHMI. The elevations of stations vary from 112 to 1778 m a.s.l. Table 1 gives detailed information about temperature conditions of the examined stations. As we see, Hurbanovo situated in Podunajská nížina (lowland) is the warmest station, while Skalnaté Pleso in the Tatras, the highest mountains of Slovakia, is the coldest station. The amplitude of air temperature is the most important characteristic of thermic continentality calculated as the difference between the monthly mean temperatures of the warmest and the coldest months in the particular year. Mean amplitudes were evaluated for the period from 1951 to 2013, or 1961 to 2013, depending on the length of observations at a particular station (Table 1). The highest amplitude of air temperature was found for Michalovce (24.2 °C), which is the lowland station situated in the Eastern Slovakia. The difference between the temperature amplitudes in Podunajská nížina (lowland) and Východoslovenská nížina (lowland) is 1 °C. An interesting finding was that the amplitude of air temperature of the stations situated in valleys was also high: Rožňava (23.7 °C) and Sliač (23.6 °C). This is probably the result of their inversion positions with relatively low air temperatures in winter half-years, and high summer air temperatures. Skalnaté Pleso situated in the mountains has the lowest amplitude (18.0 °C). From the statistical point of view, the amplitude is a rather conservative parameter. The value of its standard deviation is almost equal for all stations (2.2–2.6). We can state that our results confirmed the opinion of Gorczynský ex Kveták (1983), etc., that continentality decreases with increasing elevation, and that from the point of thermic continentality the area of Slovakia still belongs to 3rd maritime transition zone (Ic = 10.1–25.0 °C)

Table 2 evaluates the developmental trend of temperature characteristics (mean, minimum, maximum air temperature) and of temperature amplitude, i.e. continentality index. Figures 1a–d and 2a–d present the developmental trends of temperature characteristics from 1951 (1961) to 2013 for the lowland station of Hurbanovo

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(115 m a.s.l.) and the highland station of Skalnaté Pleso (1778 m a.s.l.). Other stations are characterised in Table 2. All analysed characteristics of air temperature and thermic continentality have an increasing trend. Table 2 presents the results of the Student's *t* test of significance concerning the correlation coefficients of the mean annual temperature, maximum monthly temperature, minimum monthly temperature and continentality index Ic for the period 1951–2013 and the trend of linear regression as well. The highest rate of mean annual temperature increase equal to 0.0305 °C year^{-1} was observed in Hurbanovo. It means that over the whole period of 63 years, mean annual temperature increased by 1.62 °C. The slowest rate of temperature increase (0.0305 °C year^{-1}) was found in Oravská Lesná, where the temperature increased by 1.32 °C over the last 53 years. The increasing trend of mean annual temperature was significant for all stations at 99.9 %. Minimum monthly temperature also increased, but the increase was less significant and had higher variability. Maximum monthly temperature significantly increased on all stations, mostly in Rožňava (2.52 °C in 53 years).

Although the developmental trend of continentality was also increasing, the increase was slight and non-significant (in the case of Sliač station it was significant at 90.0 %). The increasing trend fluctuated from 0.0005 to 0.0305 °C year^{-1}.

Table 3 presents the trend of continentality until the year of 2075 according to the scenario of CCCM. It is expected that the continentality of all stations will slightly decrease. The amplitudes will decrease by 0.4 °C by the year 2075. Melo (2002) presented a similar results. Results of Wypych et al. (2010) dealing with large-scale changes of continenatlity in Central and Eastern Europe (ranging from Cracow – Poland to Lugansk – Ukraine) did not also exhibit a significant change.

Many naturalists ask themselves a question: "why do we not observe an increase of thermic continentality during the last period of the ongoing climate change?" The main cause is the increase of both maximum and minimum monthly temperatures. Since the amplitude is the difference between them, it remains without significant changes. Faster rate of maximum monthly temperature increase stimulates the increasing trend.

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However, it is only slight because minimum temperatures grow more slowly. Another explanation comes from the geographic definition of continentality: "continental climate is a type of climate inside the land of every continental zone affected by land features" (Činčura et al., 1985). According to this definition, the fact that the thermic continentality does not change is logical, because so far the climate change does not change the geographic distance from the ocean. Mindas et al. (1996) and other works presented the ongoing changes in bio-climatological zonation. For example, in the southern lowlands of Slovakia, bio-climatic conditions suitable for a new community of a xeric forest of a warm temperate zone are gradually being formed. Similarly, the bio-climatic conditions of highlands also change. The modelled scenario of CCCM for the year 2075 assumes a complete extinction of alpine communities, and their replacement by a sub-alpine very moist forest (Mindas et al., 1996). It follows that the thermic continentality remains more or less constant even under the conditions of changing climate. It is the bio-climatic conditions of the vegetation zone that changes. If in the future we want to include continentality in the studies dealing with climate change or the changes of bio-climatic conditions, continentality needs to be linked to a climatic zone, vegetation zone, etc. For example, the change from a warm temperate moist forest (continentality index Ic = 23) to a warm temperate dry forest (Ic = 23) following the change of humidity conditions, or the change from a warm temperate moist forest (Ic = 23) to a cool temperate moist forest (Ic = 23) following the change in temperature according to bio-climatological classification of Holdridge (1947).

4 Conclusions

Continentality as well as oceanity represent an important climate characteristic of a particular area. At the same time, they are also an important factor of natural vegetation distribution, not only in the postglacial period of Holocene. Thus, it is logical that a number of climatologists, geographers, geo-botanists and foresters have dealt with continentality in Slovakia. We evaluated continentality using a simple

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index of continentality expressed by the amplitude of air temperature defined as the difference between the monthly mean air temperatures of the warmest and the coldest months in the year. We analysed the development of continentality during the years 1951 (1961)–2013 at six meteorological stations. We selected the stations so that they represented lowlands (Michalovce, Hurbanovo), valleys (Rožňava, Sliač) and highlands (Oravská Lesná, Skalnaté Pleso). We found only a slight non-significant increase of continentality. While the temperature of the warmest month increased by 1.74 to 2.52 °C at all stations during 63 (53) years, the temperature of the coldest month increased by 0.55 to 2.14 °C. The continentality of the year 2075 was calculated using GCMs model of CCCM 2000 following the work of Lapin et al. (2000). The results of the climatic scenario indicate that by the end of 21st century we cannot expect significant changes in continentality, although the climate change will be closely coupled with the increase of maximum and minimum air temperatures.

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Table 1. Main characteristic of meteorological stations, theirs temperature variables (monthly mean, minimum, maximum air temperatures) and annual amplitude of temperatures as continentality index (Ic).

Station		Michalovce	Hurbanovo	Rožňava	Sliač	Oravská Lesná	Skalnaté Pleso
Geographic factors							
Altitude (m)		112	115	289	313	780	1778
Latitude		48°45′	47°52′	48°39′	48°39′	49°22′	49°11′
Longitude		21°57′	18°12′	20°32′	19°08′	19°11′	20°14′
Landform		Lowland		Valley		Mountain	
Climatic variables							
Observed period (years)		1961–2013	1951–2013	1961–2013	1951–2013	1951–2013	1961–2013
Mean annual temperature (°C)	Mean	9.4	10.53	8.7	8.2	4.9	2.1
	σ	(0.75)	(0.8)	(0.8)	(0.7)	(0.7)	(0.8)
Minimum monthly mean temperature (°C)	Mean	−3.5	−1.9	−3.9	−4.4	−6.4	−7.2
	σ	(2.1)	(2.2)	(1.8)	(2.2)	(2.4)	(2.1)
Maximum monthly mean temperature (°C)	Mean	20.7	21.3	19.8	19.2	15.2	10.8
	σ	(1.4)	(1.3)	(1.4)	(1.4)	(1.2)	(1.3)
Continentality Index Ic – annual amplitude of temperature (°C)*	Mean	24.2	23.2	23.7	23.6	21.6	18.0
	σ	(2.5)	(2.3)	(2.2)	(2.4)	(2.6)	(2.35)

* Ic (continentality index) is the annual range of monthly mean air temperatures in °C, (difference between the maximum and minimum monthly mean air temperatures), σ – standard deviation.

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Table 2. The linear trend values (°C year^{-1}; (°C) (observed period)$^{-1}$) and their statistical significance levels of temperatures (monthly mean, minimum, maximum air temperatures and annual amplitude of temperatures as continentality index – Ic) for the 6 meteorological stations in Slovakia.

Station		Michalovce	Hurbanovo	Rožňava	Sliač	Oravská Lesná	Skalnaté Pleso
Observed period (years)		1961–2013	1951–2013	1961–2013	1951–2013	1951–2013	1961–2013
Mean annual temperature	°C year^{-1}	0.0305	0.0244	0.03	0.0227	0.021	0.0284
	(°C) (observed period)$^{-1}$	1.6165	1.5372	1.59	1.4301	1.323	1.5052
	Significance	****	****	****	****	****	****
Minimum monthly mean temperature	°C year^{-1}	0.0403	0.0248	0.0366	0.0088	0.0281	0.0324
	(°C) (observed period)$^{-1}$	2.1359	1.5624	1.9398	0.5544	1.7703	1.7172
	Significance	**	NS	**	NS	*	*
Maximum monthly mean temperature	°C year^{-1}	0.0451	0.0373	0.0477	0.0393	0.0276	0.0453
	(°C) (observed period)$^{-1}$	2.3903	2.3499	2.5281	2.4759	1.7388	2.4009
	Significance	****	****	****	****	***	****
Continentality Index – Ic (annual amplitude of temperature)	°C year^{-1}	0.0049	0.0125	0.0011	0.0305	0.0005	0.0128
	(°C) (observed period)$^{-1}$	0.2597	0.7875	0.0583	1.9215	0.0315	0.6784
	Significance	NS	NS	NS	*	NS	NS

Significance: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$, **** $p < 0.001$; NS – not significant.

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Table 3. Annual amplitude of temperature as continentality index (Ic) for reference period and for climatic scenario CCCM in 2030 and 2075.

Years/Scenario	Hurbanovo	Michalovce	Rožňava	Sliač	Oravská Lesná	Skalnaté Pleso
1951–1980	21.6	22.8	22.3	22.1	19.8	15.5
2030*	21.4	22.6	22.1	21.9	19.6	15.3
2075*	21.2	22.4	21.9	21.7	19.4	15.1

* Scenario CCCM.

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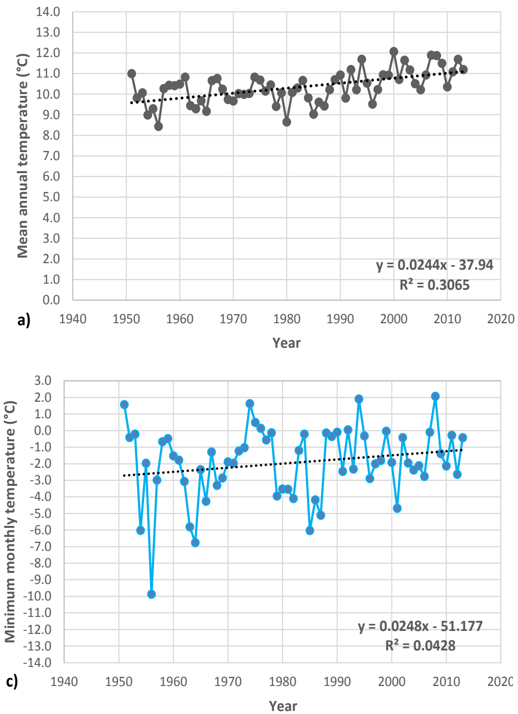

Figure 1. Lowland station Hurbanovo (115 m a.s.l.) – yearly variation, temperature pattern and trend line of the mean annual temperature **(a)**, maximum monthly temperature **(b)**, minimum monthly temperature **(c)** and continentality index Ic – annual amplitude of temperature **(d)** for the period 1951–2013.

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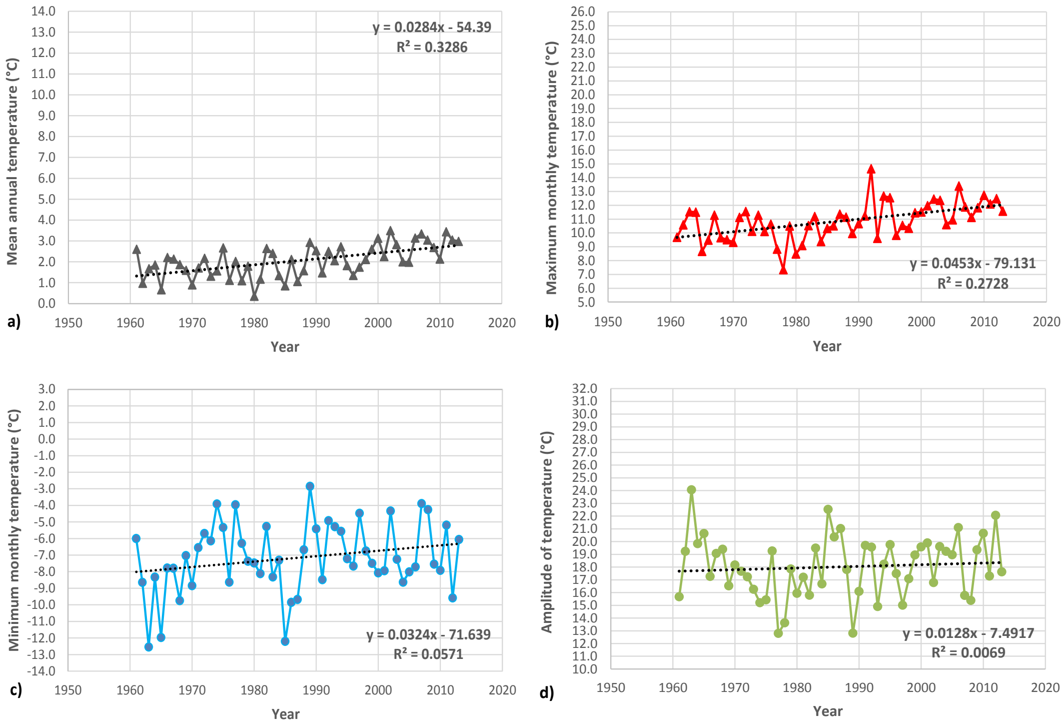

Figure 2. Mountain station Skalnaté Pleso (1778 m a.s.l.) – yearly variation, temperature pattern and trend line of the mean annual temperature **(a)**, maximum monthly temperature **(b)**, minimum monthly temperature **(c)** and continentality index Ic – annual amplitude of temperature **(d)** for the period 1961–2013.

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