Thermal continentality and its changes in Slovakia in the period 1961 – 2013

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Abstract

Thermal continentality plays an important role not only in the basic characterisation of the climate in particular regions but also in phytogeographic distribution of plants and ecosystem formation. Due to the ongoing climate change, the question about the changes of thermal continentality is very relevant. Therefore, we investigated the characteristics of the thermal continentality and its changes in the Slovak Republic between the years 1961 – 2013. Our results showed that the continentality of Slovakia increased in the period 1961 – 2013. However this trend was not significant. Nevertheless, it is necessary to be aware of this signal, especially because these changes could cause the changes in ecosystem formation in future.

1 Introduction

Continentality of climate belongs to basic climatic characteristics of an area. It specifies the influence of a continent on climate formation. According to the meteorological dictionary (Sobíšek et al. 1993), the most distinctive feature of continentality is the large amplitude of air temperatures, which is the main characteristic of thermic continentality (Hirschi et al. 2007).

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 thermal continentality or 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 of vegetation (species spreading in the Boreal or Atlantic periods) Shidei (1974), Klötzli (1976), Ellenberg (1988), Plesník (2004).

In the conditions of Slovakia, continentality or oceanity was examined by several authors. Hrudička (1933) dealt with thermic and ombric continentality. Kveták (1983) elaborated continentality of Slovakia in the most complex way using several indices. Melo (2002) addressed continentality in Hurbanovo (meteo-station in the South-west of Slovakia). Brázdil (2009) examined thermal continentality for the period 1961 – 2005 in the Czech Republic (west of Slovakia). Wypych (2010) and Ciaranek (2014) dealt with thermal continentality of Poland (north of Slovakia) in a wider European context.

Due to the ongoing climate change, significant increase of air temperature has been recorded and is projected for the next century (Spinoni et al., 2015). The most intense changes of air temperature are recorded in terms of summer and winter extremes (Hirschi et al., 2007; IPCC, 2013; Damborská et al., 2015). Since these parameters form the basis of air temperature amplitude, the question about the changes of thermal continentality is very relevant.

Hirschi et al. (2007) indicated the increase of thermal continentaliy in Eastern and South-eastern Europe in the period 1995 – 2005 in comparison to the period 1948 - 2005. These results are based on NCEP/NCAR surface temperature dataset analyses. A similar statement was presented by Apostol and Sîrghea (2015) dealing with thermal continentality in Europe. Nevertheless, Hirschi et al. (2007) comment that using ERA-40 reanalysis datasets, this change of thermal continentality pattern in Eastern and South-eastern Europe could not be seen. This result (no change of thermal continentality) was also confirmed by Brázdil et al. (2009) dealing with thermal continentality in the Czech Republic. Due to these inconsistencies in the results, it is necessary to analyse the changes on a smaller scale using station based data.

Therefore, we decided to analyse the changes of thermal continentality on selected meteorological stations in the Slovak Republic between the years 1961 – 2013.

2 Material and methods

2.1 Temperature data

The analyses presented in this paper are based on monthly mean temperature data of six selected stations of the Slovak Hydrometeorological Institute (SHMI) between the years 1961 - 2013. Data homogenisation procedures are standardly applied by the SHMI (SHMI 2008).

2.2 Characteristics of the selected meteorological stations

The meteorological stations were selected in order to generalise geographical and geomorphological characteristics of Slovakia (Figure 1). Table 1 presents the basic climatological and geographic characteristics of the selected stations. Warmest station with annual mean air temperature of 10.4°C is Hurbanovo (situated in the Podunajská nížina Lowland) followed by station Michalovce (Východoslovenská nížina Lowland) with annual mean air temperature of 9.4°C. On the contrary the coldest station is Skalnaté Pleso (situated in Tatra Mountains – elevation 1788 m a.s.l.) with annual mean temperature of 2.1°C followed by Oravská Lesná (situated in Oravské Beskydy Mountains – elevation 780 m a.s.l.) with annual mean temperature of 5.0°C. Stations Sliač and Rožňava which represent climate of intra-Carphatian valleys reach annual mean air temperature of 8.3°C and 8.7°C respectively. The annual temperature cycle of these stations is depicted in Figure 2. January is the coldest month at all stations except for the mountain station at Skalnaté Pleso, and July is the warmest month at all stations.

From the geomorphological point of view the stations can be divided into three groups:

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

2.3 Thermal continentality indices

Thermal continentality was assessed using five indices:

1. A simple index of continentality (Ic) following the original definition of Supan applied by Rivas-Martinez et al. (2011):

$$I_C = (T_{max} - T_{min}) \quad (1)$$

where: *Ic* is Continentality Index, *Tmax* represents monthly mean temperature (°C) of the warmest month, and *Tmin* is monthly mean temperature (°C) of the coldest month. Knoch and Schulze (1952) as well as Hesse (1966) used the following values of annual temperature amplitude *Ic* in order to characterise climate continentality: < 2.5 equatorial, 2.5 – 10 oceanic, 10-25 maritime transition zone, 25-40 continental, > 40 °C extremely continental.

2. Gorczynski index (K_G), the most frequently used index in Europe was proposed by Gorczynski (1920). It is computed using the equation:

$$K_G = 1.7(A/sin\theta) - 20.4 \quad (2)$$

where: K_G is the index of continentality in percent, A is the annual amplitude of temperature in °C and θ represents the latitude in degrees. According to this equation, Gorczynski suggests three levels of continentality: transitional maritime (K_G = 0 to 33 %), continental (K_G = 34 to 66 %) and extremely continental (K_G = 67 to 100 %) climate (Mikolášková, 2009). However Ciaranek (2014) argues that this formula is only applicable to areas between the latitudes 30° N and 60° N, i.e. in the areas dominated by land, while in oceanic areas the index gives negative values.

3. Conrad's index (K_C) is a reliable widely accepted formula, which is expressed as:

$$K_C = 1.7[A/(sin\theta + 10)] - 14 \quad (3)$$

where: K_C represents continentality index, A is the annual amplitude of mean temperature of the warmest and coldest month in °C, and θ is the station latitude in degrees (Snow 2005). Andrade and Corte-Real (2016) created the the following categories for climatic characterisation: K_C from -20 to 20 means hyper-oceanic, 20 to 50 oceanic/maritime, 50-60 sub-continental, 60 to 80 continental, 80 to 120 extreme/hyper-continental climate.

4. Ivanov index of thermic continentality. Originally proposed by Ivanov (1959) and used by Kveták (1983). The index is expressed as:

$$K_I = 100\ (A/0.33\theta) \quad (4)$$

where: K_I represents the index, A is the annual amplitude of mean temperature of the warmest and coldest month in °C, and θ is the station latitude in degrees. Ivanov (1959) presents these 10 categories of continentality (in %): < 47 extremely oceanic, 48-56 oceanic, 57-68 moderately oceanic, 69-82 maritime, 83-100 slightly maritime, 101-121 slightly continental, 122-146 moderately continental, 147-177 continental, 178-214 strongly continental and > 214 extremely continental.

5. Khromov continentality index (K_{Kh}) calculated by the equation (Khromov, 1957):

$$K_{Kh} = 100[(A - 5.4sin\theta)/A] \quad (5)$$

where: K_{Kh} is the index of continentality in %, A is the annual amplitude of temperature in °C, θ is latitude in degrees. Khromov and Petrosyan (2001) argue that the K_{Kh} index shows how much (in %) of the annual air temperature amplitude at a given point is caused by the presence of land around the globe, i.e. what is contribution of land to continentality. Hence, the influence of continents in Southern Pacific area is <10%, in Northern Atlantic area >25%, at Western European coast 50-75%, in Central and North-eastern Asia >90%. Thus, according to the annual temperature amplitude, even the most maritime climate at the continent is still more influenced by the continent than the ocean. Based on this feature, the continentatliy of Central Europe explained by Khromov index K_{Kh} has relatively high values – 80% (Kveták1983).

3 Results and discussion

3.1 Changes of the temperature conditions in the period 1961 – 2013

In order to explain the characteristics of thermal continentality, it is necessary to consider the temporal development of the mean, minimum and maximum temperature over the particular years within the studied period. In this case, temporal trends of annual mean temperature, monthly temperature means of the coldest and the warmest months were analysed by linear regressions (Figure 3). The main result of the above mentioned analyses was the significant increase of the annual mean temperature at all stations (Table 2). Interestingly, air temperature trends were recorded with the same significance level ($p < 0.001$) at all stations, without the exception of the mountain stations. Temporal trends of the mean temperature of the warmest months experienced significant increase at all stations ($p < 0.001$).

The temporal development of the mean temperature of the coldest months showed also an increasing trend. However, these trends were less significant in comparison to the mean temperature of the warmest months. In addition, these trends were non-significant at two stations (Hurbanovo and Sliač). Trends significant at $p < 0.05$ were observed only at two stations (Michalovce and Rožňava). This finding of the overall temperature increase corresponds with Damborská et al. (2015) and Lapin et al. (2009).

3.2 Characteristics of the thermal continentality in the period 1961 – 2013

Based on the indices described in methodology, thermal continentality of the analysed stations was characterised by mean values of the applied indices in the period 1961 – 2013. A complete overview of particular thermal continentality indices is in Table 3.

The basic index I_C showed that the highest annual amplitude of air temperature was found for Michalovce (24°C), which is the lowland station situated in the Eastern Slovakia. The difference between I_C for Michalovce and Hurbanovo (lowland station situated in the West of Slovakia) is 1°C. An interesting finding was that the annual 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 caused by their temperature inversion positions with relatively low air temperatures in winter half-years, and high summer air temperatures. The lowest value of I_C was found at the mountain station of Skalnaté Pleso (18°C) followed by another mountain station of Oravská Lesná (21.6°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 Kveták (1983), etc., that continentality decreases with the 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).

Based on the values of Gorczynski index, all stations except Michalovce (Eastern of Slovakia) belong to the transitional maritime climate (K_G < 34 %). Michalovce station belongs to the continental climate (K_G = 34.2 %). However, the index value for this station exceeded the limit by only 0.2%. Based on the results we can conclude that Eastern Slovakia is a border of climatic influence of the Eastern European plain (Sarmatic plain). The reason why we assume that this area is more influenced by the climate of the Sarmatic plain than by the climate of the Panonnian Basin is that K_G for other stations was not higher than 34%. The comparison of I_C with K_G showed that the second index is more sensitive to large-scale (continental and sub-continental scale) influence of huge geomorphological units on climate formation in specific areas. These findings correspond with the results of Kveták (1983) about the temperature continentality border between the maritime and continental climate in Eastern Slovakia.

According to Conrad's index all analysed stations in Slovakia belong to the oceanic/maritime zone (K_C ranged from 20 to 50). Relatively high values of the index indicating continentality were found for the stations: Michalovce (K_C =34), Hurbanovo (K_C =32.8), Rožňava (K_C =33.2) and Sliač (K_C =33.1), in comparison to mountain stations of Skalnaté Pleso (K_C =21.7) and Oravská Lesná (K_C =28.6). Although in our study relatively low differences in K_C between particular stations (except for mountain stations) were revealed, we use this index because it is most frequently used index of all continentality indices (Oliver 2005).

The values of the Ivanov thermal continentality index (K_I) divided the evaluated stations into three thermal continentality zones. The first zone is characterised by continental climate (values of K_I from 147% to 177%). Four stations belong to this climate: Michalovce (K_I =151.1%), Hurbanovo (K_I =148.5%), Rožňava (K_I =148.3%) and Sliač (K_I =148.3%). The second zone has moderately continental climate (values of K_I range between 122% and 146%), to which the mountain station of Oravská Lesná belongs (K_I =132.8%). Finally, the third zone is a zone of slightly continental climate (K_I range between 101% and 121%). From these results we can see the decrease of thermal continentality with the increasing elevation (mountain stations; Oravská Lesná with an elevation of 780 m a.s.l. and Skalnaté Pleso with an elevation of 1,778 m a.s.l.). Although all remaining stations (except mountain stations) belong to only one zone of moderately continental climate, the shift toward the more continental climate from west to east could be seen (West – Hurbanovo K_I =148.5% and East – Michalovce K_I =151.1%).

Khromov index of continentality examines how much (in %) of the annual air temperature amplitude at a given point is caused by the presence of land around the globe. From this point of view the whole area (all analysed stations) of Slovakia is under significant dominance of continental climate (values of K_{Kh} range between 76.9 – 83 %). The lowest value of K_{Kh} was recorded for the mountain station of Skalnaté Pleso. When analysing K_{Kh} dependence on latitude, we see very slight decrease (0.3%) of the influence of the continent toward the Atlantic Ocean coast (from east to west) (Hurbanovo K_{Kh} =82.7% – West of Slovakia, Michalovce K_{Kh} =83.0% – East of Slovakia). We argue that this index is less suitable for characterisation of continentality in comparison to Gorczynski index due to its low sensitivity at a meso-climatic scale. This finding corresponds with Kveták (1983) analysing Khromov index in Slovakia.

Based on the analysis of five thermal continentality indices, we conclude that the Gorczynski index seems to be the most suitable for the analyses of thermal continentality in Slovakia due to its sensitivity to both longitude and elevation. Because the latitude range of Slovakia is less than 2°, this parameter is irrelevant in thermal continentality analyses.

Although we identified Gorczynski index as the most suitable, temporal development of all indices was also analysed.

3.3 Changes of the thermal continentality in Slovakia between the years 1961 – 2013

The recorded increase of air temperature as described above raised the question how and to what extent thermal continentality has changed in Slovakia. This was examined by the linear analysis of the temporal trend of indices described in the methodology part (i.e.: Simple index of thermal continentality (I_C), Gorczynski index (K_G), Conrad's index (K_C), Ivanov index (K_I) and Khromov index (K_{Kh}). Detailed outputs of linear trend analyses of particular indices for each station are described in Table 4. All studied indices showed insignificant trends toward higher continentality. The highest trend was recorded at the valley station of Sliač (R^2 = 0.0438) by all indices except for K_{Kh}. The reason of this result could be the already-mentioned temperature inversion character in the valley. On the contrary, the smallest change of thermal continentality was recorded in Michalovce – East of Slovakia (R^2 = 0.0009). The trends of other stations ranged between R^2 = 0.0016 and R^2 = 0.01. For better description, all results are also depicted in Figure 4.

Although we observed slightly increasing temporal trends toward higher continentality in all indices and at all stations, the test on significance of these trends showed that none of them was significant. This finding corresponds with Brázdil et al. (2009) who dealt with thermal continentality changes expressed by Gorczynski index. Nevertheless, although our study based on the data from the period 1961 – 2013 showed insignificant changes of thermal continentality, the signal of possible changes needs to be studied in terms of the projected future changes of temperature regime. Especially because this changes could cause the changes in ecosystem formation in future (Mindas et al. 1996)

4 Conclusions

Because of the ongoing climate change, possible changes of thermal continentality have been discussed in literature. Because some signals referring potential changes in thermal continentality have been directly linked to area of East and South-east Europe we decided to analyse thermal continentality and its changes on six selected stations of Slovakia between the years 1961 – 2013.

The meteorological stations used in this paper were selected in order to represent typical geographic and geomorphological land forms of Slovakia, i.e. lowlands, valleys and mountains. In addition, these stations were selected with respect to the elongated shape of the country from the west to the east. In order to obtain relevant results, we used five widely used thermal continentality indices. Based on the analyses we can conclude that the influence of land on thermal continentality increases with longitude toward the East. In addition, elevation has also a great influence on thermal continentality. We recorded decreasing thermal continentality with increasing elevation.

From the point of temporal development of thermal continentality during the period 1961 – 2013, changes in continentality were anticipated due to the recorded signals of the temperature increase. However, we found only a slight insignificant increase of continentality in time. Although the temperature of the warmest month increased by 2.4 °C to 3.13 °C at the stations during the observed period, the temperature of the coldest month increased only by 0.73 °C to 2.14 °C. The highest though insignificant trend toward continental climate was observed at the valley station of Sliač situated in Central Slovakia. We assume that this is because of the strong temperature inversion character of the climate in this valley. Although we did not reveal any significant changes of thermal continentality within the studied period, we need to be aware of the signal coming even from the insignificant trends. Especially because these changes could cause the changes in ecosystem formation in future. Therefore, the study on the projected changes in temperature variability related to the changes in thermal continentality will be carried out in future.

Acknowledgements

This work was accomplished as a part of the projects VEGA No.: 1/0367/16, 1/0008/13, 1/0589/15, 1/0463/14, 2/0101/14 of the Ministry of Education, Science, Research and Sport of the Slovak Republic and the Slovak Academy of Science; and the projects of the Slovak Research and Development Agency No.: APVV-00480-12, APVV-0423-10, APVV-0131-11 and APVV-0303-11.

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Figure 1. Location of the meteorological stations used in the study.

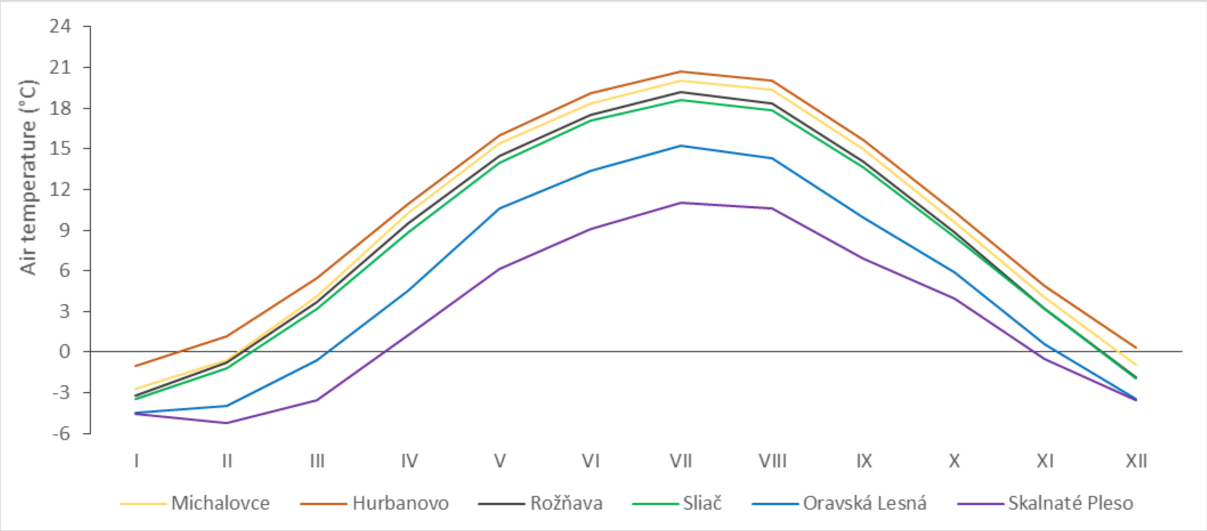

Figure 2. Annual cycle of the temperature on stations used in the study

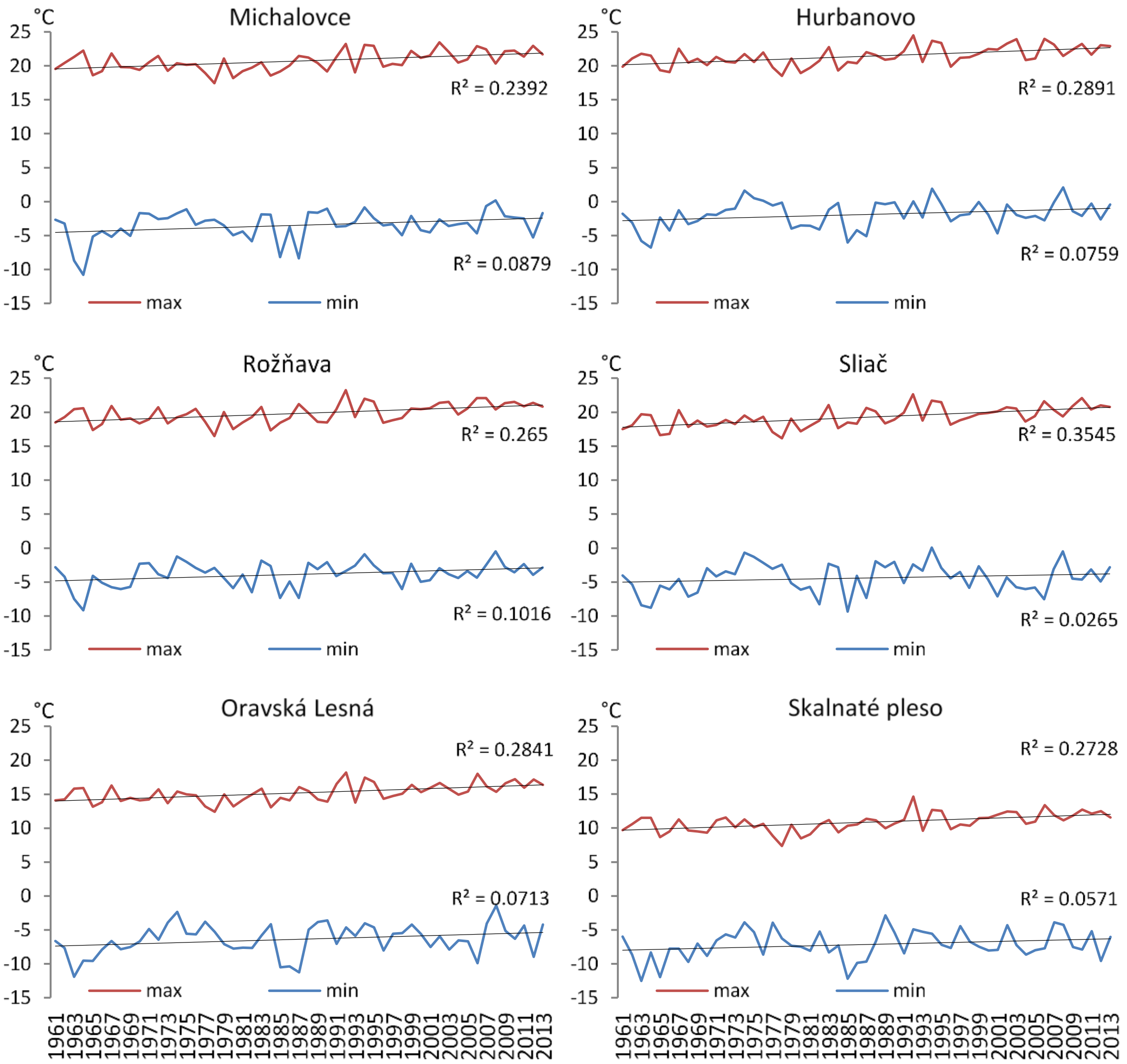

Figure 3. Linear trends of the coldest and warmest months on stations used in the study

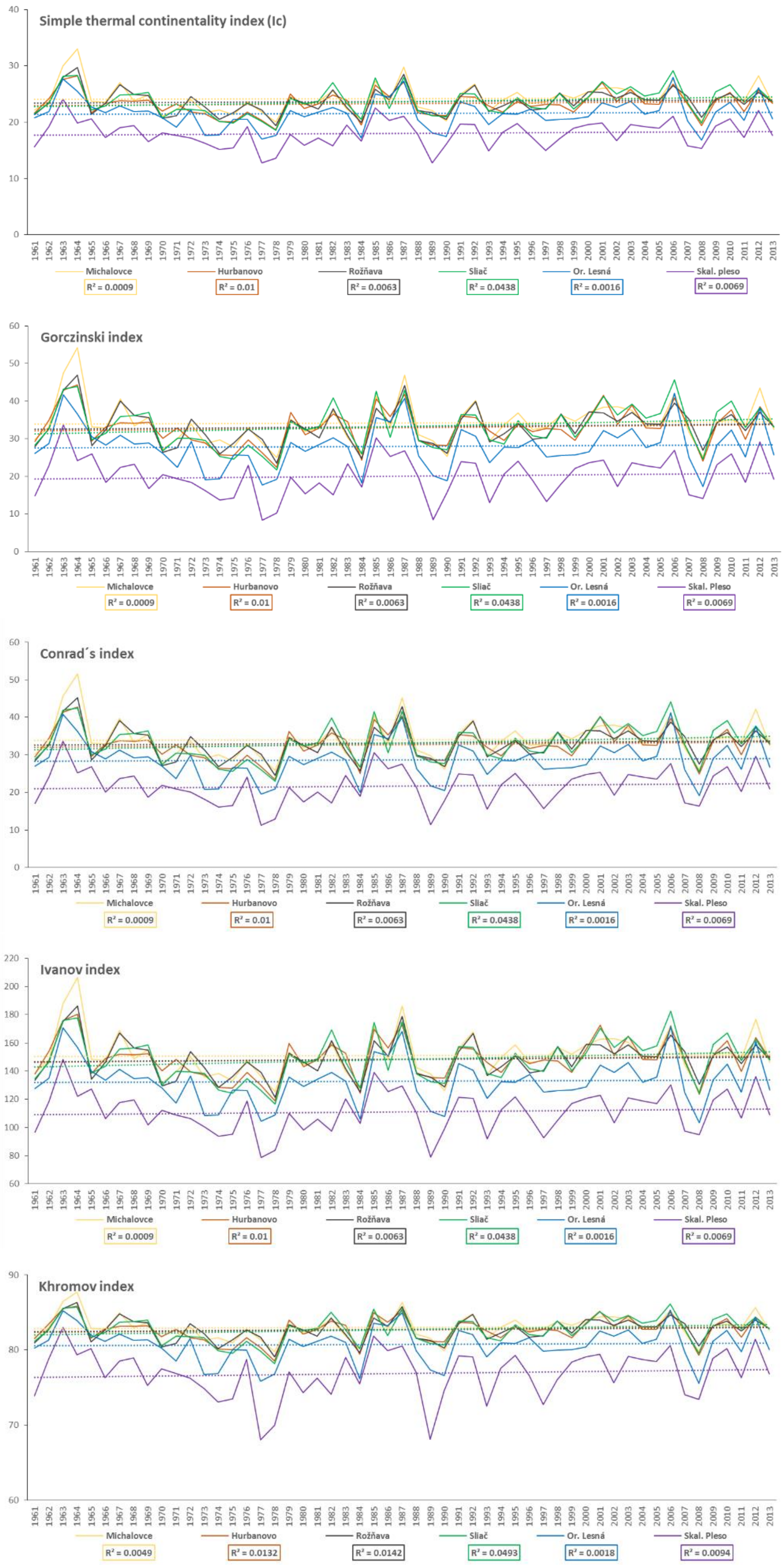

Figure 4. Linear trends of the continentality indices within the period 1961–2013

Table 1: Main characteristic of meteorological stations, theirs temperature variables: annual mean temperature (T_{ann}), monthly mean temperatures of the coldest (T_{max}) and warmest month (T_{min}) in degrees Celsius; σ is standard deviation

Station	Michalovce	Hurbanovo	Rožňava	Sliač	Oravská Lesná	Skalnaté Pleso
Geographic factors						
Altitude (m. a. s. l.)	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	
Observed period	1961-2013	1961-2013	1961-2013	1961-2013	1961-2013	1961-2013
Climatic variables						
T_{ann} (°C)	9.4	10.4	8.7	8.3	5.0	2.1
Mean *σ*	0.8	0.8	0.8	0.7	0.7	0.8
T_{min} (°C)	-3.5	-1.9	-3.9	-4.4	-6.4	-7.2
Mean *σ*	2.1	1.9	1.8	2.1	2.2	2.1
T_{max} (°C)	20.7	21.4	19.8	19.3	15.2	10.8
Mean *σ*	1.4	1.4	1.4	1.4	1.3	1.3

Table 2: The linear trend values ((°C)/year; (°C)/observed period) and their statistical significance levels of annual mean temperature, monthly mean temperatures of the coldest and warmest month, for the 6 meteorological stations

Station	Michalovce	Hurbanovo	Rožňava	Sliač	Oravská Lesná	Skalnaté Pleso
Observed period	1961-2013	1961-2013	1961-2013	1961-2013	1961-2013	1961-2013
Annual mean temperature						
(°C)/year	0.0305	0.03	0.03	0.0313	0.0279	0.0284
(°C)/observ. period	1.6165	1.59	1.59	1.6589	1.4787	1.5052
Significance[*]	***	***	***	***	***	***
Monthly mean temperatures of the coldest month						
(°C)/year	0.0403	0.0348	0.0366	0.0137	0.0388	0.0324
(°C)/observ. period	2.1359	1.8444	1.9398	0.7261	2.0564	1.7172
Significance[*]	*	NS	*	NS	+	+
Monthly mean temperatures of the warmest month						
(°C)/year	0.0451	0.0486	0.0477	0.059	0.0456	0.0453
(°C)/observ. period	2.3903	2.5758	2.5281	3.127	2.4168	2.4009
Significance[*]	***	***	***	***	**	***

[*]Significance: + $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; NS - not significant

Table 3: Mean, standard deviation (σ), and coefficient of variation (cv) of five continetality indices: Continentality index (I_C), Gorczynski (K_G), Conrad (K_C), Ivanov (K_I) and Khromov (K_{Kh}) for the period 1961 – 2013

Station		Michalovce	Hurbanovo	Rožňava	Sliač	Oravská Lesná	Skalnaté Pleso
Altitude (m. a. s. l.)		112	115	289	313	780	1778
I_C	Mean	24.2	23.3	23.7	23.7	21.6	18.0
	σ	2.5	2.1	2.2	2.5	2.6	2.4
	cv	10.4	9.1	9.1	10.4	12.0	13.1
K_G	Mean	34.2	33.0	33.2	33.2	27.9	20.1
	σ	5.7	4.9	4.9	5.6	5.8	5.3
	cv	16.7	14.7	14.7	16.7	20.7	26.4
K_C	Mean	34.0	32.8	33.2	33.1	28.6	21.7
	σ	5.0	4.3	4.3	4.9	5.1	4.7
	cv	14.7	13.0	12.9	14.8	17.8	21.5
K_I	Mean	151.1	148.5	148.3	148.3	132.8	111.2
	σ	15.8	13.5	13.5	15.4	15.9	14.5
	cv	10.4	9.1	9.1	10.4	12.0	13.1
K_{Kh}	Mean	83.0	82.7	82.7	82.7	80.7	76.9
	σ	1.7	1.6	1.6	1.8	2.3	3.2
	cv	2.0	1.9	1.9	2.2	2.9	4.1

Table 4: The linear trend and statistical significance levels of five continetality indices: Continentality index (I_C), Gorczynski (K_G), Conrad (K_C), Ivanov (K_I) and Khromov (K_{Kh}) for the period 1961 – 2013

Station		Michalovce	Hurbanovo	Rožňava	Sliač	Oravská Lesná	Skalnaté Pleso
Altitude (m a. s. l.)		112	115	289	313	780	1778
I_C	R^2	0.0009	0.01	0.0063	0.0438	0.0016	0.0069
	Significance*	NS	NS	NS	NS	NS	NS
K_G	R^2	0.0009	0.01	0.0063	0.0438	0.0016	0.0069
	Significance*	NS	NS	NS	NS	NS	NS
K_C	R^2	0.0009	0.01	0.0063	0.0438	0.0016	0.0069
	Significance*	NS	NS	NS	NS	NS	NS
K_I	R^2	0.0009	0.01	0.0063	0.0438	0.0016	0.0069
	Significance*	NS	NS	NS	NS	NS	NS
K_{Kh}	R^2	0.0049	0.0132	0.0142	0.0493	0.0018	0.0094
	Significance*	NS	NS	NS	NS	NS	NS

*Significance: + $p < 0.1$, ∗ $p < 0.05$, ∗∗ $p < 0.01$, ∗∗∗ $p < 0.001$; NS - not significant