Minimal change of thermal continentality in Slovakia within 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 the phytogeographic distribution of plants and ecosystem formation. Due to ongoing climate change, questions surrounding the changes of thermal continentality are very relevant. Therefore, the aim of this study is to investigate the characteristics of thermal continentality and its temporal changes in the Slovak Republic between the years of 1961 and 2013. The study was carried out on several meteorological stations selected in respect to the geographical and geomorphological heterogeneity of Slovakia. Our results show that the continentality of Slovakia increased in the period 1961 to 2013; however, this trend is not significant. These non-significant trends are confirmed at all the stations. Nevertheless, it is necessary to be aware of this signal, especially because these changes could cause changes in ecosystem formation in future.

1 Introduction

Continentality of climate is a basic climatic characteristic 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 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 Slovakia, several authors have examined the influences of continentality or oceanity. Hrudička (1933) dealt with thermic and ombric continentality. Kveták (1983) explained continentality of Slovakia using several indices. His results (isoline maps of thermal continentality indices over the Slovakia) permitted spatial interpretation of thermal continentality over Slovakia. Melo (2002) addressed continentality in Hurbanovo (meteo-station in the south-west of Slovakia). Brázdil et al. (2009) examined thermal continentality for the period 1961 to 2005 in the Czech Republic (west of Slovakia) and Wypych (2010) and Ciaranek (2014) dealt with the thermal continentality of Poland (north of Slovakia) in a wider European context.

Due to ongoing climate change, a significant increase in air temperature has been recorded and further warming 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, questions regarding the changes of thermal continentality are very relevant.

Hirschi et al. (2007) indicated the greater increase of thermal continentality in eastern and south-eastern Europe during the period 1995 to 2005 in comparison to the period 1948 to 2005. These results were based on NCEP/NCAR surface temperature dataset analyses. Apostol and Sîrghea (2015) presented similar results when dealing with thermal continentality in Europe. Nevertheless, Hirschi et al. (2007) commented that when using ERA-40 reanalysis datasets, the change of thermal continentality patterns in eastern and south-eastern Europe were not observed. Brázdil et al. (2009) corroborated this result (no change of thermal continentality) when dealing with thermal continentality in the Czech Republic. The same results as Brazdil et al. (2009) were indicated by Mello (2002) when dealing with potential changes in thermal continentality based on a dataset from Hurbanovo meteorological station (south-west Slovakia). Due to these inconsistencies in reported results, it is necessary to analyse the changes on a smaller scale using station-based data, in respect to specific geographical and geomorphological characteristics of Slovakia.

Therefore, we decided to analyse the changes of thermal continentality on selected meteorological stations in the Slovak Republic between the years of 1961 and 2013 to determine whether thermal continentality increases or decreases during this period.

2 Material and methods

2.1 Temperature data

The analyses presented in this paper are based on monthly mean temperature data from six selected stations of the Slovak Hydrometeorological Institute (SHMI) between the years of 1961 and 2013. Data homogenisation procedures are applied as standard 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. The warmest station with annual mean air temperature of 10.4°C is Hurbanovo (situated in the Podunajská nížina Lowland) followed by the station at 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 at an elevation of 1788 m a.s.l.) with annual mean temperature of 2.1°C followed by Oravská Lesná (situated in Oravské Beskydy Mountains at an elevation of 780 m a.s.l.) with an annual mean temperature of 5.0°C. Stations Sliač and Rožňava, which represent the climate of the intra-Carphatian valleys, have annual mean air temperatures of 8.3 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 a geomorphological point of view the stations can be divided into three groups:

- Lowlands (Michalovce, Hubanovo)
- Valleys (Rožňava, Sliač)
- Mountains (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 the 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) and Hesse (1966) used the following values of annual temperature amplitude *Ic* in order to characterise climate continentality: < 2.5°C equatorial, 2.5–10°C oceanic, 10–25°C maritime transition zone, 25–40°C continental, > 40°C extremely continental.

2. Gorczynski index (K_G), proposed by Gorczynski (1920) is the most frequently used index in Europe. 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 of 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 in percent (Minetti 1989), *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 following categories for climatic characterisation (in %): K_C from −20 to 20 is hyper-oceanic, 20 to 50 oceanic/maritime, 50 to 60 is sub-continental, 60 to 80 is continental, 80 to 120 is extreme/hyper-continental climate.

4. Ivanov index of thermic continentality was 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 Ivanov 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 the ten categories of continentality (in %): < 47 is extremely oceanic, 48–56 is oceanic, 57–68 is moderately oceanic, 69–82 is maritime, 83–100 is slightly maritime, 101–121 is slightly continental, 122–146 is moderately continental, 147–177 is continental, 178–214 is strongly continental and > 214 is extremely continental.

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

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

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 show 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., the contribution of land to continentality). Hence, the influence of continents in the Southern Pacific area is < 10%, in the North Atlantic area is > 25%, on the Western European coast is 50–75% and in Central and Northeast Asia is > 90%. Thus, according to the annual temperature amplitude, even the most maritime climate in the continent is still more influenced by the continent than the ocean. Based on this feature, the continentality of Central Europe has relatively high values of 80% (Kveták 1983).

These indices were selected due to their wide use in the literature (Kveták 1983, Khromov and Petrosyan 2001, Melo 2002, Hirschi et al. 2007, Brazdil et al. 2009, Wypych 2010, Ciaranek 2014) and because the most distinctive feature of continentality is the large amplitude of air temperatures, which is the main characteristic of thermic continentality (Sobíšek et al. 1993, Hirschi et al. 2007). Although these indices are based on the air temperature amplitude, their sensitivity to regional climatological patterns is different. This permits confirmation of whether different indices provide varying results.

2.4 Trend analyses

Time series of air temperature as well as time series of the applied continentality indices were fitted by linear regression. These linear trends were tested for significance using the Student *t*-test.

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 study period at all the meteorological stations described in Section 2.2. In this case, temporal trends of annual mean temperature and monthly temperature means of the coldest and the warmest months were analysed by linear regression (Figure 3). The main result was a 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, including 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 also showed 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 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 Section 2.3, thermal continentality of the analysed stations was characterised by mean values of the applied indices for the period 1961 to 2013. A complete overview of the thermal continentality indices is provided in Table 3.

The basic index I_C showed that the highest annual amplitude of air temperature was found for Michalovce (24.2°C), which is the lowland station situated in eastern Slovakia. The difference between I_C for Michalovce and Hurbanovo (lowland station situated in western 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 (18.0°C) followed by another mountain station of Oravská Lesná (21.6°C). From a 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). Our results confirm the opinion of Kveták (1983) that continentality decreases with increasing elevation and that from the point of thermic continentality the area of Slovakia still belongs to the 3rd maritime transition zone (Ic = 10.1–25.0 °C).

Based on the values of Gorczynski index, all stations except Michalovce (eastern 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). We assume that this area is more influenced by the climate of the Sarmatic plain than by the climate of the Panonnian Basin because K_G for other stations was not higher than 34%. This result corresponds with the findings of Ciaranek (2014) regarding decline of the maritime influence on the climate from the west towards the east of the European continent. The comparison of I_C with K_G showed that the second index is more sensitive to large-scale (continental and sub-continental scale) influences 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 index values, 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 our study revealed relatively low differences in K_C between particular stations (except for mountain stations), we included 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 rang 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 a decrease of thermal continentality with 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 still be seen (West: Hurbanovo K_I = 148.5% and East: Michalovce K_I = 151.1%).

The 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 to 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%, western Slovakia; Michalovce: K_{Kh} = 83.0%, eastern Slovakia). We argue that this index is less suitable for characterisation of continentality compared with the Gorczynski index due to its low sensitivity at a meso-climatic scale. This finding corresponds with those of Kveták (1983) who analysed use of the Khromov index in Slovakia.

Based on the analysis of five thermal continentality indices we conclude that: (1) the climate in southern parts of Slovakia is more continental in comparison to northern Slovakia, which are mostly mountainous areas and a typical example of Alpine continentality (Plesník 2004); (2) thermal continentality increases from west to east in Slovakia, implying a greater influence of the Eastern European plain (Sarmatic plain) in eastern Slovakia compared with the West; (3) high values of continentality indices were also found in the valleys (stations Sliač and Rožňava), which is probably caused by their temperature inversion positions with relatively low air temperatures in winter half-year, and high summer air temperatures and (4) 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.

Although we identified Gorczynski index as the most suitable, temporal development of all the 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 questions as to how and to what extent thermal continentality has changed in Slovakia. This was examined via linear analysis of the temporal trend of indices described in Section 2.3: the 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 by all indices. The result could due to the afore-mentioned temperature inversion characteristics of the valley. On the contrary, the smallest change of thermal continentality was recorded in Michalovce, in eastern Slovakia (except for K_{Kh}). To facilitate comprehension all results are depicted in Figure 4. Almost no trends were recorded in our analyses because of increasing temperatures of both the warmest and coldest months, as described in Section 3.1.

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

4 Conclusions

Due to ongoing climate change, possible changes of thermal continentality are widely discussed in literature. Some signals referring to potential changes in thermal continentality are directly linked to areas of east and south-east Europe we decided to analyse thermal continentality and its changes at six selected stations in Slovakia between the years of 1961 and 2013.

The meteorological stations used in this paper were selected in order to represent typical geographic and geomorphological landforms of Slovakia (i.e., lowlands, valleys and mountains). In addition, these stations were selected with respect to the elongated shape of the country from west to 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 also has 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 to 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 over time, based on the employed thermal continentality indices. The reason for this is because although the temperature of the warmest month increased by 2.39 to 3.13 °C at the stations during the observed period, the temperature of the coldest month increased by 0.73 to 2.14 °C. Disparity of these trends are reflected in rising but non-significant trends toward higher thermal continentality. 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 characteristics of the climate in this valley. Although we did not reveal any significant changes of thermal continentality during the studied period, researchers should be aware of these changes, even from the insignificant trends, especially because these changes could cause the changes in ecosystem formation in future. Therefore, the study of the projected changes in temperature variability related to the changes in thermal continentality will be carried out in future.

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References

Andrade, C. and Corte-Real, J. 2016. Assessment of the spatial distribution of continental-oceanic climate indices in the Iberian Peninsula. Int. J. Climatol., doi: 10.1002/joc.4685.

Apostol, L. and Sîrghea, L. 2015. Thermal continentalism in Europe. Aerul si Apa. Componente ale Mediului, 2015: 49–55, doi: 10.17378/AWC2015_07.

Brázdil, R., Chromá, K., Dobrovolný, P., and Tolasz, R. 2009. Climate fluctuations in the Czech Republic during the period 1961–2005, Int. J. Climatol., 29(2): 223–242, doi: 10.1002/joc.1718.

Ciaranek. D. 2014. Variability of the thermal continentality index in Central Europe. Aerul si Apa. Componente ale Mediului, 2014, 307–313.

Damborská, I., Gera, M., Melo, M., Lapin, M. and Nejedlík, P. 2015. Changes in the daily range of the air temperature in the mountainous part of Slovakia within the possible context of global warming, Meteorol. Z., 25(1): 17–35, doi: 10.1127/metz/2015/0569, 2015.

Ellenberg, H. 1988 Vegetation ecology of central Europe, Cambridge University Press, Cambridge-New York-New Rochelle-Melbourne-Sydney.

Gorczynski, W. 1920. Sur le calcul du degré de continentalisme et son application dans la climatologie [For calculation of Continentalism Degree and Its Application in Climatology], Geografiska Annaler, 2: 324–331.

Hesse, W. 1966. Grundlagen der Meteorologie für Landwirtschaft, Gartenbau und Forstwirtschaft. Leipzig: Akademische Verlagsgesellschaft Geest & Portig, 568 pp.

Hirschi, J. J. M., Sinha, B. and Josey, S. A. 2007. Global warming and changes of continentality since

1948, Weather, 62(8): 215–221, doi 10.1002/wea.88.
Hrudička, B. 1933. Doba polovičních srážek a periodická amplituda ročního srážkového průběhu v Československu [Term of half-time rainfall and periodic amplitude of the annual atmospheric precipitation course in Czechoslovakia], Spisy vydávané přirodovědeckou fakultou Masarykovy university, Brno, Czechoslovakia, 1–22.
IPCC. 2013. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.
Ivanov, N. N.1959. Poyasa kontinentalnosti Zemli [The belts of continentality on the Earth], Izvestiya Vsesoyuznogo Geographicheskogo obshchestva, 91: 410–423.
Khromov, S. P. 1957. K voprosu o kontinental'nosti klimata [To a problem of climate continentality], Izvestiya Vsesoyuznogo Geographicheskogo obshchestva, 89(3): 221–225.
Khromov, S. P. and Petrosyan, M. A. 2001. Meteorology and rudiments of climatology, Moscow University Press, Moscow, Russia, (in Russian).
Klötzli, F. 1976. Grenzen von Laubwäldern in Europa, Ber. Deut. Bot. Ges., 89: 371–380.
Knoch, K. and Schulze, A. 1952. Methoden der Klimaklassifikation: zweite Auflage, VEB Geographisch–Kartographische Anstalt Gotha.
Kveták, S. 1983. Príspevok ku kontinentalite podnebia na Slovensku [A paper about continentality of climate on the territory of Slovakia], in: Zborník prác SHMÚ, 22, Alfa, Bratislava, Czechoslovakia, 95–218.
Lapin, M., Gera, M., Hrvoľ, J., Melo, M. and Tomlain, J.: Possible impacts of climate change on hydrologic cycle in Slovakia and results of observations in 1951–2007, Biologia, 64(3): 454–459, doi:10.2478/s11756-009-0097-4.
Melo, M. 2002. Očakávané zmeny kontinentality podnebia v 21. storočí pre hurbanovo na základe výstupov dvoch klimatických modelov [Expected change of climate continentality for Hurbanovo in 21st century on the base two climate models outputs], in: XIV. Česko-slovenská bioklimatologická konference, Rožňovský, J. and Litschmann, T. (Eds.): Lednice na Moravě, Czech Republic, 2–4 September, 312–323.
Mikolášková, K. 2009. A regression evaluation of thermal continentality. Geografie-Sborník české geografické společnosti, 114(4): 350–362.
Minďáš, J., Lapin, M., and Škvarenina, J. 1996. Climate change and forests in Slovakia, in: National climate program of the Slovak Republic, 5: 1–96, Ministry of the Environment of the Slovak Republic, Bratislava.
Minetti, J. L. 1989 Kontinentalitätsindizes: Methodologische Revisionen und Vorschläge [Continentality Indices Methodological Revision and Proposition], Erdkunde, 51–58.
Oliver, J. E. (Ed.) 2005. Encyclopedia of World Climatology (Encyclopedia of Earth Sciences Series), Springer, Dordrecht, 854.

Plesník, P. 2004. General biogeography, Comenius University, Bratislava, Slovak Republic.

Rivas-Martinez, S., Rivas-Saenz, S., and Penas, A. 2001. Worldwide bioclimatic classification system, Global Geobotany, 1: 1–634, doi: 10.5616/gg 110001.

Shidei, T. 1974. Forest vegetation zones, in: The flora and vegetation of Japan, Numata, M. (Ed.), Kodansha, Tokyo, Japan, 87–124.

SHMI. 2008. Slovak Republic - Report containing additional information with respect to the implementation of the GCOS plan, Following the established reporting guidelines FCCC/SBSTA/2007/L.14, Ministry of the Environment of the Slovak Republic, Bratislava.

Sobíšek, B., et al. 1993. Meteorologický slovník & výkladový terminologický, S cizojazyčnými názvy hesel ve slovenštině, angličtině, němčine, francouzštine a ruštině [Meteorological vocabulary & explanatory terminological, Includes indexes of terms in Slovakian, English, French, German and Russian], Academia, Praha, 594 pp.

Snow, R. 2005. Continental climate and continentality, in: Encyclopedia of World Climatology. Springer Netherlands, 303–305.

Spinoni, J., et al. 2015. Nabyvanets, Y., Skrynyk, O., Krakovska, S., Gnatiuk, N., Tolasz, R., Antofie, T. and Vogt, J.: Climate of the Carpathian Region in the period 1961-2010: Climatologies and trends of 10 variables, Int. J. Climatol., 35: 1322–1341.

Wypych, A. 2010 Variability of the European Climate on the Basis of Differentiation of Indicators of Continentalism, in: The Polish Climate in the European Context: An Historical Overview, Przybylak, R., Majorowicz, J., Brazdil, R., Kejan, M. (Eds.), Springer Netherlands, 473–484.

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

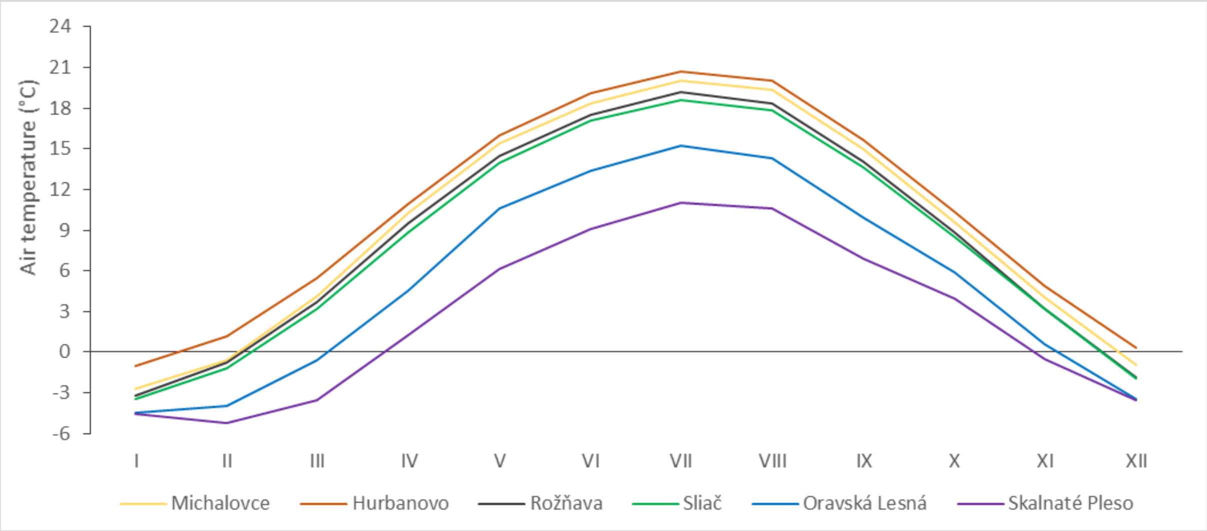

Figure 2. Annual cycle of the temperature at stations used in the study

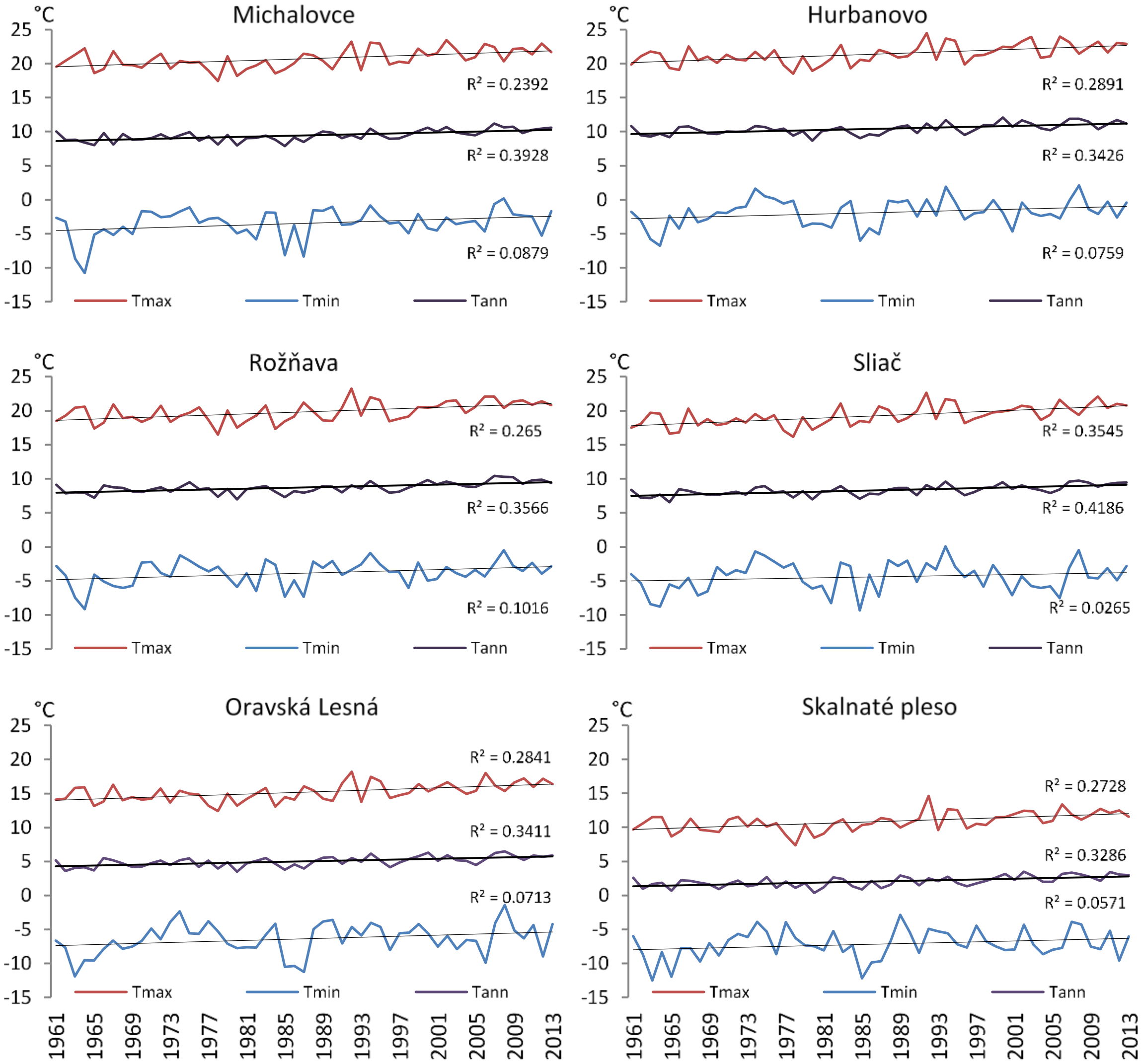

Figure 3. Linear trends of the annual mean temperature (T_{ann}), monthly mean temperatures of the coldest (T_{min}) and warmest month (T_{max}) at stations used in the study

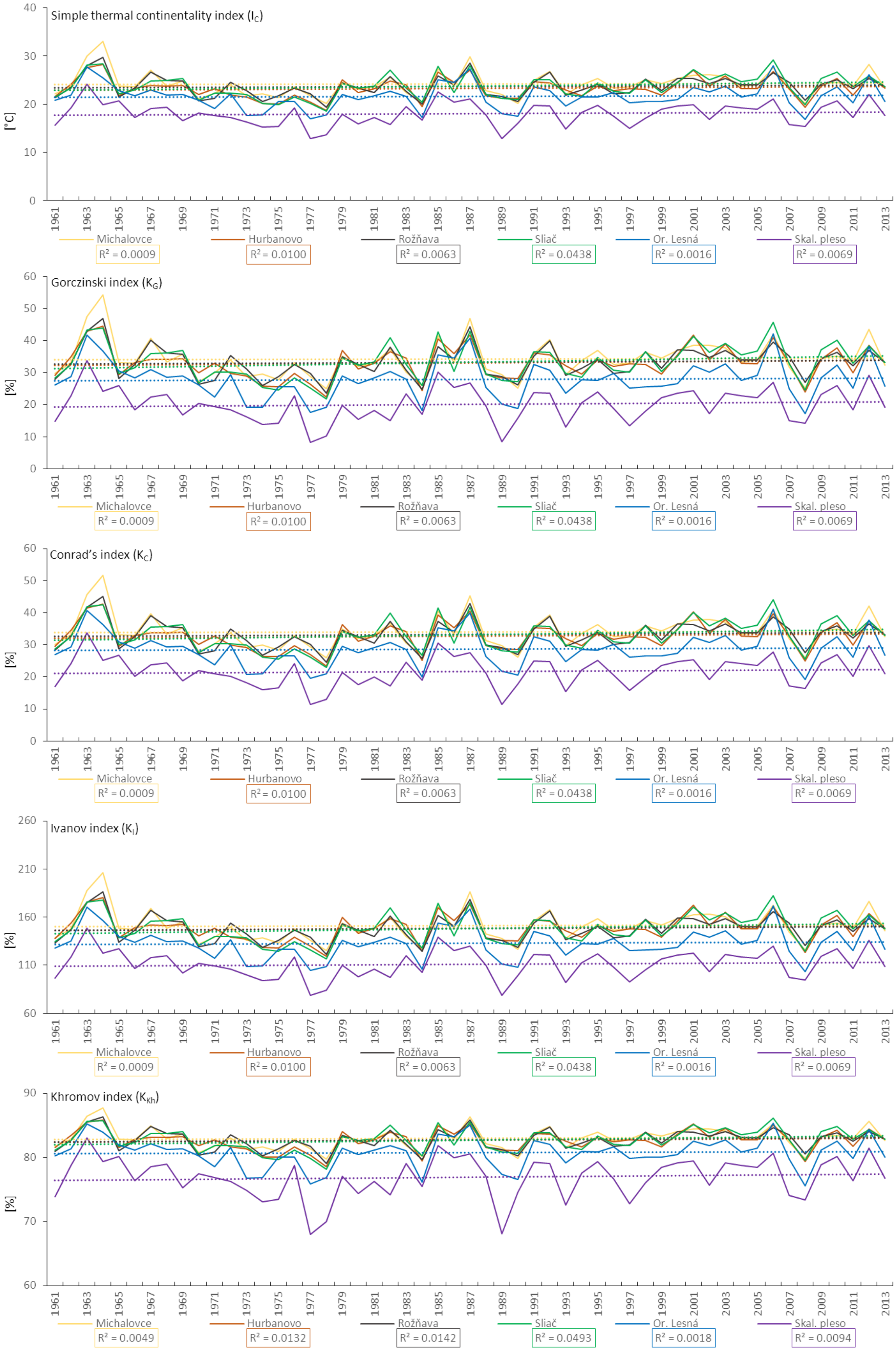

Figure 4. Linear trends of the thermal continentality indices within the period 1961 to 2013

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

Station	Michalovce	Hurbanovo	Rožňava	Sliač	Oravská Lesná	Skalnaté Pleso
Geographic factors						
Elevation (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 statistical significance levels of annual mean temperature, monthly mean temperatures of the coldest and warmest month, for the six meteorological stations

Station	Michalovce	Hurbanovo	Rožňava	Sliač	Oravská Lesná	Skalnaté Pleso
Elevation (m a.s.l.)	112	115	289	313	780	1778
Annual mean temperature						
(°C)/year	0.031	0.030	0.030	0.031	0.028	0.028
(°C)/observ. period	1.617	1.590	1.590	1.659	1.479	1.505
Significance*	***	***	***	***	***	***
Monthly mean temperatures of the coldest month						
(°C)/year	0.040	0.035	0.037	0.014	0.039	0.032
(°C)/observ. period	2.136	1.844	1.940	0.726	2.056	1.717
Significance*	*	NS	*	NS	+	+
Monthly mean temperatures of the warmest month						
(°C)/year	0.045	0.049	0.048	0.059	0.046	0.045
(°C)/observ. period	2.390	2.576	2.528	3.127	2.417	2.401
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 continentality indices: Continentality index (I_C), Gorczynski (K_G), Conrad (K_C), Ivanov (K_I) and Khromov (K_{Kh}) for the period 1961 to 2013

Station		Michalovce	Hurbanovo	Rožňava	Sliač	Oravská Lesná	Skalnaté Pleso
Elevation (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 values (units/year; units/observed period) and statistical significance levels of five continentality indices: Continentality index (I_C), Gorczynski (K_G), Conrad (K_C), Ivanov (K_I) and Khromov (K_{Kh}) for the period 1961 to 2013

Station	Michalovce	Hurbanovo	Rožňava	Sliač	Oravská Lesná	Skalnaté Pleso
Altitude (m. a. s. l.)	112	115	289	313	780	1778
Simple thermal continentality index (I_C)						
(°C)/year	0.0049	0.0138	0.0111	0.0336	0.0068	0.0128
(°C)/observ. period	0.2597	0.7314	0.5883	1.7808	0.3604	0.6784
Significance*	NS	NS	NS	NS	NS	NS
Gorczinski index (K_G)						
(%)/year	0.0110	0.0317	0.0252	0.0761	0.0152	0.0288
(%)/observ. period	0.5830	1.6801	1.3356	4.0333	0.8056	1.5264
Significance*	NS	NS	NS	NS	NS	NS
Conrad's index (K_C)						
(%)/year	0.0097	0.02778	0.0222	0.0669	0.0134	0.0254
(%)/observ. period	0.5141	1.47234	1.1766	3.5457	0.7102	1.3462
Significance*	NS	NS	NS	NS	NS	NS
Ivanov index (K_I)						
(%)/year	0.0306	0.0883	0.0698	0.2105	0.0418	0.0792
(%)/observ. period	1.6218	4.6799	3.6994	11.1565	2.2154	4.1976
Significance*	NS	NS	NS	NS	NS	NS
Khromov index (K_{Kh})						
(%)/year	0.0076	0.0119	0.0121	0.0260	0.0064	0.0202
(%)/observ. period	0.4028	0.6307	0.6413	1.3780	0.3392	1.0706
Significance*	NS	NS	NS	NS	NS	NS

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