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Evaluation of thermal continentality within southern Romania and northern Bulgaria (1961–2015)

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The assessment of continentality and oceanity of the climate at a global level or within particular regions has lately gained in importance on the background of global warming and its impact on food and water resources. Aiming at understanding these influences, there were analysed the spatial distribution (based on the data from 27 meteorological stations) and temporal variability of four indices (for 19 meteorological stations with complete data series covering the interval 1961–2015). In specialized literature, there are used different continentality and oceanity indices. We studied four of them, but the results indicate that three of these are redundant, as they deliver almost the same information. Consequently, only the results based on Gorczyński Continentality Index (*GCI*) and Kerner Oceanity Index (*KOI*) are presented and discussed in greater detail. These indices emphasize the continental character of the climate in the region, except for a narrow strip along the Black Sea Coast, which displays a maritime climate. There did not emerge a clear intensification of continentality (the trends were not statistically significant), in spite of the increase of air temperature in the region during the last two decades. However, a good correlation was obtained between three of the analysed indices (*GCI*, *II* and *KOI*) and North Atlantic Oscillation Index (*NAOI*).

Keywords: thermal continentality, Johansson Continentality Index (*JCI*), Ivanov Index of Thermic Continentality (*II*), Kerner Oceanity Index (*KOI*), Marsz Oceanity Index (*MOI*), Romania, Bulgaria

1. Introduction

The continental or oceanic features of a climate are mainly induced by different thermal and moisture characteristics specific to oceans and land surfaces. *Continentality* is a 'qualitative climatic condition determined by the low specific heat and poor conductivity of land vis-a-vis water' (Duckson Jr., 1987) and it renders the measure of the difference between continental and marine climates, being mainly characterized by increased annual temperature range (*www.britan-*

nica.com/science/continentality). *Oceanity* is considered a measure of the degree to which the climate of a region is influenced in all respects by the oceans (Andrade and Corte-Real, 2017). Consequently, continentality and oceanity highly depend on the distance to the nearest significant waterbody (either sea or ocean); however, latitude, hypsometry and position of main landforms to the main air masses are also key factors to be taken into consideration (Ciaranek, 2014).

Thus, most of the indices rendering both continentality and oceanity are based on temperature (annual temperature range, difference between mean temperature values of autumn and spring or of particular months, such as October and April) and latitude. Over time, the initial formula of an index was modified as there were discovered certain limitations. For example, Conrad and Pollak (1950) modified the formula of the continentality index elaborated by Gorczynsky in 1922, to better highlight the continentality of particular regions. Based on the same parameters, there were also elaborated new approaches (Marsz and Rakusa-Suszczewskis, 1987; Marsz, 1995 apud. Andrade and Corte-Real, 2017; Driscoll and Fong, 1992; Mikolaskova, 2009).

So far, continentality and oceanity indices were applied for different regions – Europe (Apostol and Sîrghea, 2015, Szabó-Takács et al., 2015), central Europe (Ciaranek, 2014), Pakistan (Gadiwala et al., 2013), Middle East and North Africa (El Kenawy et al., 2016), northern Greece (Baltas, 2007), Czeck Republic

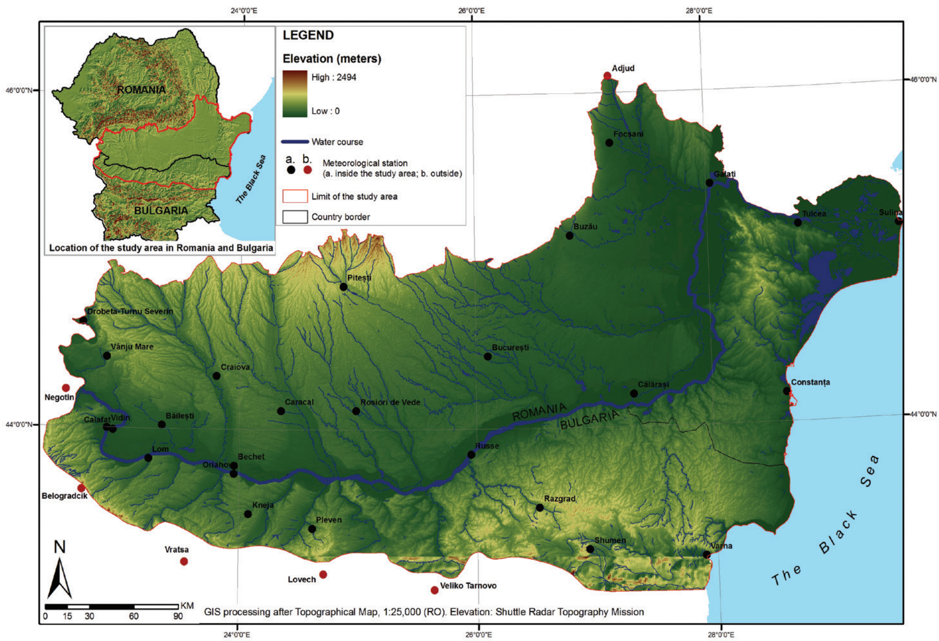

Figure 1. Study area and location of the meteorological stations.

(Brázdil et al., 2008a, b), Turkey (Toros et al., 2008; Deniz et al., 2011), Romania (Strat, 2014), Italy (Nistor, 2016), the Iberian Peninsula (Andrade and Corte Real, 2016, 2017), Slovakia (Vilček et al., 2016), Bulgaria (Vekliska, 1975; Topliiski, 2002a, 2002b).

The main objective of the present study is the identification of any patterns in terms of spatial and temporal variability of thermal continentality indices in southern Romania and northern Bulgaria during the period 1961–2015. Moreover, the importance of the practical approach is underlined by the fact that climatic variability has major impact on agriculture and water resources and the analysed region represents the main agricultural area of both countries.

2. Materials and methods

Mean monthly air temperature data were used for 27 meteorological stations located within the region of interest (Fig. 1, Tab. 1), mainly for the period 1961–

Table 1. Geographical coordinates of the considered meteorological stations (from West to East of the study area).

No.	Station	Altitude (m)	Latitude	Longitude
1	D. T. Severin	77	44° 37' N	22° 37' E
2	Vidin	31	43° 59' N	22° 51' E
3	Vânju Mare	86	44° 26' N	22° 51' E
4	Calafat	61	43° 59' N	22° 57' E
5	Lom	32	43° 49' N	23° 13' E
6	Băileşti	57	44° 01' N	23° 20' E
7	Bechet	36	43° 47' N	23° 57' E
8	Craiova	192	44° 13' N	23° 52' E
9	Oriahovo	29	43° 43' N	23° 58' E
10	Kneja	117	43° 30' N	24° 05' E
11	Caracal	106	44° 06' N	24° 22' E
12	Pleven	160	43° 24' N	24° 37' E
13	Piteti	316	44° 50' N	24° 51' E
14	Roşiorii de Vede	102	44° 06' N	24° 58' E
15	Veliko Tarnovo	195	43° 05' N	25° 39' E
16	Russe	36	43° 51' N	25° 57' E
17	Bucureşti Băneasa	90	44° 31' N	26° 04' E
18	Razgrad	346	43° 33' N	26° 30' E
19	Buzău	19	45° 07' N	26° 51' E
20	Shumen	218	43° 16' N	26° 11' E
21	Focani	57	45° 41' N	27° 56' E
22	Călăraşi	90	44° 12' N	27° 19' E
23	Varna	39	43° 12' N	27° 57' E
24	Galați	71	45° 30' N	28° 01' E
25	Constanța	13	44° 13' N	28° 37' E
26	Tulcea	4	45° 10' N	28° 49' E
27	Sulina	3	45° 10' N	29° 43' E

2015. In order to elaborate the maps rendering the spatial distribution of the indices, there were also taken into account certain stations situated in the immediate proximity of the plain region (Adjud for Romania; Belogradchik, Vratsa, Lovech, Veliko Tarnovo for Bulgaria; Nis, Bor, Negotin for Serbia). Air temperature data for the Romanian territory come from the following sources – Klein Tank et al. (2002), except Bechet, Calafat, Băileşti, Caracal, Vânju Mare for which data were partly provided by the National Administration of Meteorology (NAM) or taken from the annual reports elaborated by the Environmental Protection Agencies (EPAs) and Piteşti, Focşani and Adjud – *https://en.climate-data.org*. Taking into account that there is a different reference period and there was no possibility to verify the reliability of the data, the values obtained for these last three stations were used only for the elaboration of the maps.

The air temperature data for the Bulgarian territory are taken from the Annual year books and Bulletins of National Institute of Meteorology and Hydrology, as well as from the Statistical Yearbook of the National Statistical Institute, Bulgaria. The missing data in the investigated time-series are completed with information from the specialized websites (*i.e. http://www.ecad.eu* and *http://www.tutiempo.net*).

In order to assess the climate of the low region located in the south of Romania (the Romanian Plain, Dobrogea Plateau and the Danube Delta) and north of Bulgaria (the Danube plain and the northern slopes of the Fore-Balkan foothills), we focussed on rendering the spatial distribution and different patterns of evolution of four thermal climatic indices, namely Gorczyński Continentality Index (*GCI*), Ivanov Index of Thermic Continentality (*II*), Kerner Oceanity Index (*KOI*) and Marsz Oceanity Index (*MOI*). Three of the indices fall into the continental-oceanic category, being exclusively based on air temperature values and latitude. Consequently, the results might be quite similar, especially in case of *GCI* and *II*, while additional information is brought by *KOI*, which, besides air temperature range, takes into account the temperature difference between April and October.

Gorczyński Continentality Index (*GCI*) is used to assess the continentality of a climate based on the annual range of air temperature, but taking into account the geographic latitude of the stations as well. This is one of the most widely used indices to render continentality of a climate and it was introduced by Gorczyński (1920, 1922). It was applied by numerous researchers (Ciaranek, 2014; Brázdil et al., 2008b; Szabó-Takács et al., 2015; Vilček et al., 2016) as *GCI*, while others used the same formula, but the index was called Johansson Continentality Index (Andrade and Corte Real, 2017; Baltas, 2007; Deniz et al., 2011). It was calculated according to the following formula:

$$GCI = \frac{1.7A}{sin\phi} - 20.4 \quad (1)$$

where A represents the annual air temperature range (°C) and ϕ is the geographical latitude of the considered meteorological station.

The index is based on the principle that a purely oceanic climate presents a value of the index equal to 0, while an extremely continental climate would have a value of 100. The extreme station used to obtain the constants of the equations is Verkhoyansk (Siberia), which stands for extreme continentality (Gorczyński, 1920).

Thus, according to the same author, continentality is characterized by three degrees:

1. Transitional maritime, $k = 0$ to 33
2. Continental, $k = 34$ to 66
3. Extremely continental, $k = 67$ to 100

The same scale is also used for Johansson Continentality Index (Andrade and Corte Real, 2017).

Ivanov Index of thermal continentality (*II*) is an index proposed by Ivanov (1959) and then used by different researchers (most recently, Vilček et al., 2016). The formula is:

$$II = 100 \frac{A}{0.33 \cdot \theta} \tag{2}$$

where A is the annual air temperature range (°C) and θ is the geographical latitude of the considered meteorological station. According to Ivanov, there are ten categories of continentality (Tab. 2).

Kerner Oceanity Index (*KOI*) was calculated according to the following formula:

$$KOI = \frac{100(To - Ta)}{A} \tag{3}$$

where To is the mean air temperature value of October, Ta is the mean air temperature value for April and A is the annual air temperature range (difference between the highest and lowest mean monthly air temperatures), all values being expressed in °C. According to Baltas (2007), who quotes Zambakas (1992),

Table 2. Continentality categories according to Ivanov Index.

II values	Category of continentality	*II* values	Category of continentality
<47	extremely oceanic	101–121	slightly continental
48–56	oceanic	122–146	moderately continental
57–68	moderately oceanic	147–177	continental
69–82	maritime	178–214	strongly continental
83–100	slightly maritime	>214	extremely continental

Source: Ivanov (1959) apud. Vilček et al. (2016).

Table 3. Climate categories according to Marsz Oceanity Index (MOI).

MOI values	Climate
< 2	continental
2–3	sub-oceanic
> 3	oceanic

Source: Rachlewicz (2009) apud. Andrade and Corte Real (2017).

KOI values below 10 indicate a continental climate, while values above this threshold indicate a climate characterized as oceanic.

Marsz Oceanity Index (*MOI*), introduced by Marsz and Rakusa-Suszczewskis (1987), was calculated based on the following formula, according to Andrade and Corte Real (2017):

$$MOI = \frac{0.731\phi + 1.767}{A} \quad (4)$$

where φ represents the latitude and A is the annual air temperature range (°C). The significance of *MOI* values is rendered in Tab. 3.

As multiannual variability of continentality indices is highly important, the values registered at the reference meteorological stations were analysed. Linear regression was applied and the statistical significance of the trend was determined by AnClim free software available on-line *at www.climahom.eu/software-solution/anclim*, more specifically *t*-test. The *t*-test (one sample) is used to test hypotheses about µ (mean value, in this case the mean value of the analysed indices), when standard deviation of a particular population is not known.

The variability of continentality was also investigated in relation to the North Atlantic Oscillations (NAO). For that purpose, Hurrell station-based annual NAO indices (*NAOI*) were used (Hurrell et al., 2003). *NAOI* data were provided by the Climate Analysis Section, NCAR (*https://climatedataguide.ucar.edu/climate-data/hurrell-north-atlantic-oscillation-nao-index-station-based*, accessed on March 6, 2017). The annual values of *NAOI* were calculated as a normalized difference of sea level pressure between Reykjavik and Ponta Delgada. We studied the correlation between the annual *NAOI* and the four continentality/oceanity indices, namely Gorczyński Continentality Index (*GCI*), Ivanov index of thermic continentality (*II*), Kerner Oceanity Index (*KOI*), and Marsz Oceanity Index (*MOI*) for the period 1961–2015.

In order to study spatial distribution and to extrapolate the parameters of interest, firstly a geodatabase was created comprising the spatial location of the considered meteorological stations, as well as their characteristic values for the analysed indices (*GCI*, *II*, and *KOI*), averaged for the period 1961–2015. Secondly, among the several spatial interpolation methods available, in the present study, the spatialisation of the mean values was conducted through the Spline Tension Method, readily integrated in the ArcGIS *Spatial Analyst Tools*. The auxiliary geographical information concerning altitude has been integrated in GIS by using the digital elevation model (Shuttle Radar Topography Mission/ SRTM data).

3. Results and discussion

The climate of southern Romania and northern Bulgaria is moderately continental. However, this general feature of the climate is modified by the local peculiarities of the relief – exposure, altitude (there is an altitudinal range of about 300 m between the Danube Valley – the shore of the Black Sea and the pre-Balkan foothills – the northern extremity of the Romanian Plain) and atmospheric circulation. The study area is composed mainly by plains, lowlands and hills. The climate is determined by the transformed oceanic air masses from West and North-West and by the continental air masses of temperate or arctic latitudes penetrating the region from North-East. The warmest month is July, with the monthly mean air temperature in most of the investigated stations between 22 and 23 °C; the coldest month is January with the lowest monthly mean air temperature around –2 °C (meteorological stations Kneja and Roşiorii de Vede, situated in the central sector of the studied area) (Fig. 2). The air temperature in January is positive only at the stations located on the Black Sea coast (the monthly values reach a maximum of 2.2 °C at Varna, followed by Constanța with

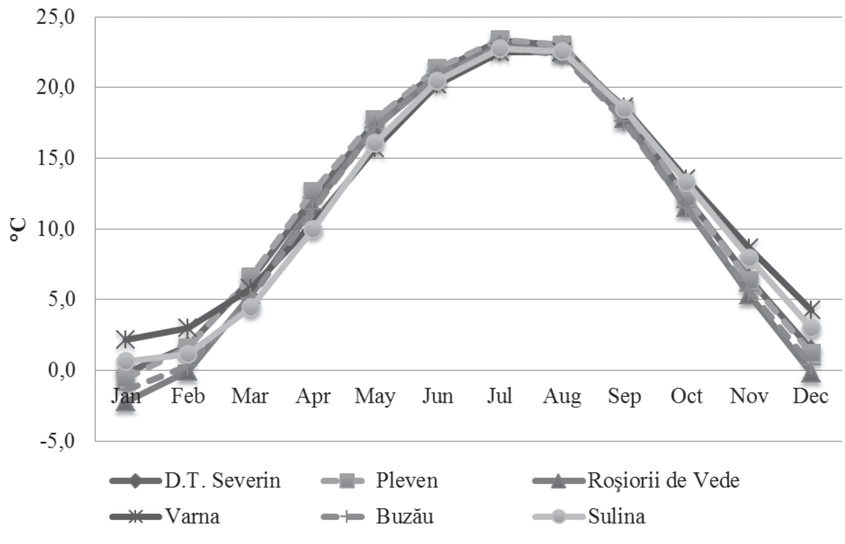

Figure 2. Annual cycle of air temperature (°C) in the selected meteorological stations.

1 °C and Sulina with 0.6 °C). The annual air temperature range is between 20.0 and 24.9 °C and a slight decrease of the values can be observed in the eastern part due to the moderating influence exerted by the Black Sea. Thus, the greatest air temperature differences between stations are registered during the cold season, mainly in December and January (maximum of 4.4 °C), while in summer they are lower (a maximum of 2.6 °C).

3.1. Spatial characteristics

The results of the spatial analysis of the indices confirm the zero hypothesis that the climate in the investigated territory is continental and the continentality decreases in the eastern part under the influence of the Black Sea. However, in the western part of the region, this general feature of the climate of the south of Romania and the north of Bulgaria is modified by the local peculiarities of the relief and atmospheric circulation and the continentality of the climate is not clearly manifested.

The values of the *Gorczyński Continentality Index* (*GCI*) calculated on the basis of average monthly values, for the period 1961–2015, emphasize the continental character of the climate in most of the investigated area (Fig. 3). In spite of the fact that continentality is considered to increase eastwards based on the more frequent penetration of dry continental polar and arctic air masses (this

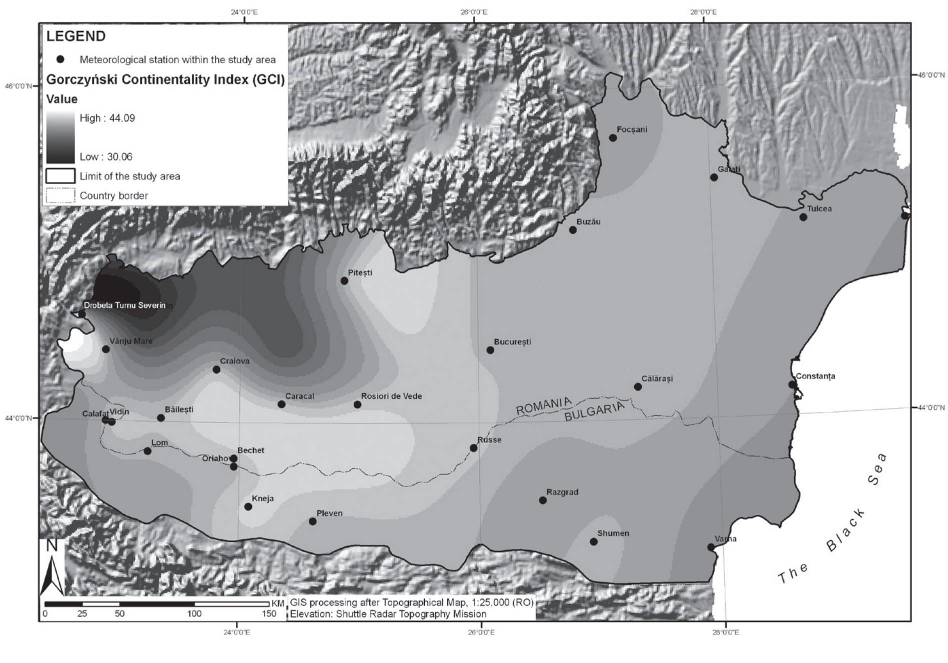

Figure 3. Gorczyński Continentality Index (JCI) within the studied area.

being valid if we consider rainfall amounts when assessing continentality), the obtained values indicate a more intense continentality in the western and central sectors of the analysed region, especially along the Danube Valley (*GCI* above 40). The frequency of dry tropical continental air masses, penetrating mainly from Northern Africa, is the key factor in the analysed region. This situation appears when central or northern and northwestern Europe is under the influence of a depression, while northern Africa and the Mediterranean Sea have high pressure values. These dry tropical continental air masses affect the western part of the region both in summer triggering heat waves, and in winter, when they provoke warm spells. Thus, greater temperature differences are registered in the western part of the region compared to the eastern part (Dobrogea, the Danube Delta and the Black Sea coast), where cold continental air generates low temperatures in winter, but the influence of the vast water surface makes summer temperature lower than in the western part. Maritime climate is characteristic only on the coast of the Black Sea (stations Varna, Sulina; we may consider even Constanța, where the value is very close to the 33 threshold, respectively 33.08). The other area displaying a transitional maritime climate is the northwestern extremity, at the contact with the mountains and Mehedinți Plateau, due to lower air temperature values registered here as altitude increases. For some of the years during the period 1961–2015, *GCI* shows a character of transitional maritime climate in various parts of the studied area, but the number of years with continental character is highly predominant. Thus, in the western and eastern extremities, there are generally below 10% years displaying a character of transitional maritime climate (1975 for most of the stations; 2014 only in the western part; 1971 and 1989, one case each in the east in Romania and 1989 also in the western part of Bulgaria). In the central part of the region and in most of stations from the western part, the climate was continental in more than 90% of the years during the investigated period (Tab. 4). There was registered only one case of extreme continental Călărași climate, at Romania, in 1963. This year registered one of the highest *GCI* values – above 60 in the western and eastern sectors of the analysed region, and above 50 within the rest of the region, including the shore area. The decrease of the number of years with continental character during the period 1961–2015 was registered in the east and on the Black Sea coast (station Varna), where the climate was continental in 43% of the years during the investigated period.

According to *Ivanov Index* (*II*), calculated on the basis of monthly average for the period 1961–2015, with two exceptions, all the stations belong to the same category, namely continental climate. Thus, Varna station registered a moderate continental climate (*II* – 142.86) and Kneja displayed a strongly continental climate (*II* – 181.9). Varna is located on the coast of the Black Sea and Kneja in the middle part of the Bulgarian Danube Plain. However, according to the annual values, there is greater variability. Besides the years with continental or strongly continental character of the climate, there are some cases of extremely

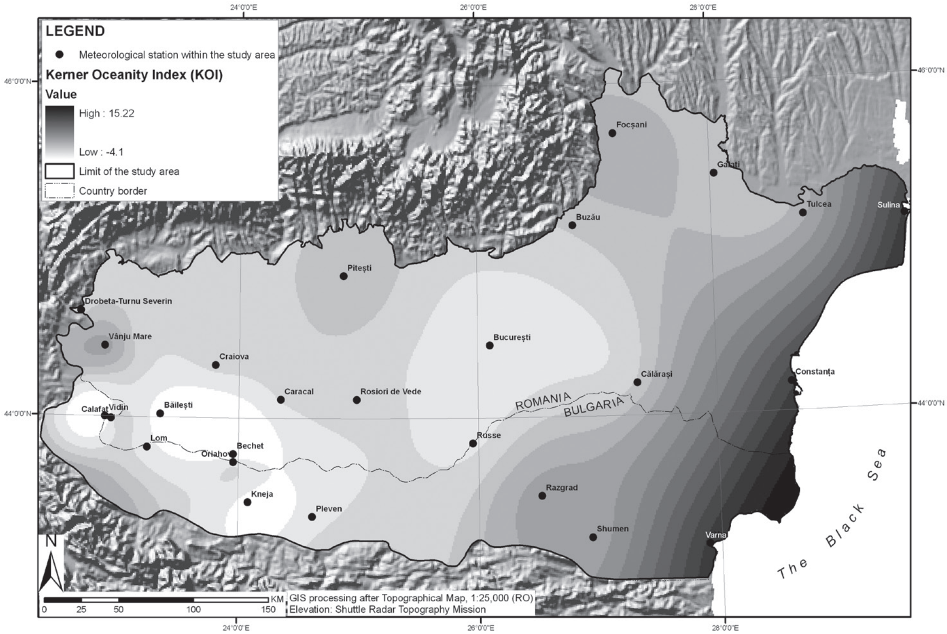

Figure 4. Kerner Oceanity Index (KOI) within the studied area.

continental years, *II* > 214. Thus, it is the case of 1963 (with very low monthly air temperatures for January), for the entire analysed region except for the coast of the Black Sea, and 2012 (with the high monthly air temperatures in July), in the central and eastern sectors of Romania and within the entire Bulgarian territory. Generally, in these years, *II* values exceeded 240. In terms of territorial distribution, the percentage of the years with moderately temperate climate increases eastwards, towards the Black Sea coast (Tab. 4). As temporal distribution, even if there does not emerge a clear pattern, the *II* values increased in the last 20 years, compared to the previous interval, highlighting a certain intensification of the continentality within the analysed region.

The average values of *Kerner Oceanity Index (KOI)* for the period 1961–2015 is negative in most of the investigated stations (Fig. 4), which indicate continental climate. It is not simply the inverse of continentality, as it also includes as input October–April temperature difference. Positive values are observed only east of 26° 30' E long. However, only the stations situated on the Black Sea coast, with *KOI* values above 14, can be considered stations with maritime / oceanic climate. The stations that present the highest *GCI* display some of the lowest values of *KOI*, thus, certifying the continental character of the climate.

On the other hand, the areas where *KOI* indicates oceanic climate, present *GCI* values very close to the limit between continental and maritime climate.

Table 4. Percentage of the years included in different categories (% of total number of the investigated years).

Meteo. station	*GCI* Extreme continental (> 66)	*GCI* Continental (34–66)	*GCI* Transitional maritime (0–33)	*II* Strongly continental (> 177)	*II* Continental (147–177)	*II* Moderately continental (122–146)	*KOI* Continental (<10)	*KOI* Oceanic (>10)
D. T. Severin	0	92.7	7.3	61.8	38.2	0	92.7	7.3
Vidin	0	94.5	5.5	40	58.2	1.8	98.2	1.8
Lom	0	92.6	7.4	40.7	55.6	3.7	96.3	3.7
Craiova	0	94.5	5.5	45.5	54.5	0	92.7	7.3
Oriahovo	0	94.4	5.6	50	48.1	1.9	92.6	7.4
Kneja	0	97.7	2.3	53.5	46.5	0	93	7
Pleven	0	100	0	49.1	50.9	0	90.9	9.1
R. de Vede	0	100	0	61.8	38.2	0	87.3	12.7
Russe	0	100	0	49.1	50.9	0	90.9	9.1
Buc. Băneasa	0	96.4	3.6	40	41.8	0	94.5	5.5
Razgrad	0	72.7	27.3	25.5	60	14.5	80	20
Buzău	0	92.7	7.3	36.4	60	3.6	90.9	9.1
Shumen	0	74	26	22	66	12	80	20
Călăraşi	3.6	96.4	0	43.6	54.5	1.8	90.9	9.1
Varna	0	43.6	56.4	9.1	50.9	40	30.9	69.1
Galați	0	94.5	5.5	38.2	58.2	3.6	87.3	12.7
Constanța	0	67.3	32.7	14.5	69.1	16.4	38.2	61.8
Tulcea	0	83.6	16.4	21.8	70.9	7.3	83.6	16.4
Sulina	0	67.3	32.7	14.5	69.1	16.4	29.1	70.9

Similar results are established for northern Greece by Baltas (2007). According to *KOI*, the percentage of the years with a continental climate during the period 1961–2015 is between 80 and 98%, but for the three stations located on the Black Sea coast, which have oceanic climate (Sulina, Constanța and Varna), only 29–39% of the years display a continental climate (Tab. 4). The percentage differences between *GCI* and *II* are mainly induced by the considered classes for each index – 10 classes for *II* and only 3 classes for *GCI*. Despite the different percentages in Tab. 4, for most part of the investigated area both Gorkinsky Index and Ivanov Index show a predominant number of the years with continental character of the climate during 1961–2015.

The spatial and temporal variability of *MOI* is very low. The annual values and the average for the investigated period are between 1.29 and 1.64; this situation shows a continental climate in case of all the investigated stations. The lowest values of *MOI* are characteristic for the central part of the investigated territory, while in the proximity of the Black Sea, *MOI* is higher than 1.5 due to the maritime influence. The low spatial variability of *MOI* is determined by reduced differences of the air temperature range and small difference in the values for geographical latitude.

3.2. Temporal characteristics

In order to determine the tendencies of the multiannual variability of the continentality, there were calculated the linear regression equations for the time-series of three indices – *GCI*, *II* and *KOI* for the period 1961–2015. The results show positive tendencies for *GCI* and *II* and a negative trend for *KOI* (Tab. 5.) The positive trends of *GCI* and *II* increase from west to east. On the other hand, the negative trend of *KOI* registers the highest values in the west and the east, while in the central part of the studied area, the values of the trend are 0.

Despite the interannual variability and determined trends, we cannot conclude that there is a tendency of continentality increase in southern Romania and northern Bulgaria as the trend is not statistically significant. These results correspond to those for Central Europe obtained by Brázdil et al. (2008a), Melo (2002) and Vilček et al. (2016). On the basis of Gorczynski index, Topliiski (2002, 2002a) pointed out that the continentality in Bulgaria decreased in the period 1961–1990 versus the period 1931–1960. The results of the present investigations show minimal increase of the continentality during the recent years. Based on the data from three RCMs (RegCM3, ALADIN-Climate and PROMES at 25-

Table 5. The linear trend of continentality/oceanity indices for the period 1961–2015 (°C/10 years).

Meteorological stations	*JCI*	*II*	*KOI*
D. T. Severin	0.27	0.75	–0.61
Vidin	0.51	1.44	–0.39
Vratsa	0.05	0.15	–0.90
Craiova	0.00	–0.63	–0.45
Pleven	0.22	0.61	0.02
Roşiorii de Vede	0.61	2.43	–0.07
Russe	0.64	1.79	–0.18
Bucureşti Băneasa	0.14	1.34	–0.07
Razgrad	0.21	0.59	0.38
Buzău	0.83	4.05	–0.12
Călăraşi	0.69	3.47	0.07
Varna	0.39	1.11	–0.54
Galați	0.50	3.32	–0.34
Constanța	0.68	1.27	–1.04
Tulcea	0.41	1.73	–0.18
Sulina	0.60	2.94	–0.85

* Significance – Not significant

km spatial resolution), Cheval et al. (2017) calculate *JCI* and *KOI* and show that in the Southeast Europe the spatial pattern of continentality and oceanity is not changing significantly for the period 1961–2050.

3.3. Correlation with NAOI

The temporal variability of continentality can be partly related to the influence of North Atlantic Oscillation Index (*NAOI*). Generally, when *NAOI* is in a positive phase, the westerly winds are stronger and the weather in northern Europe is warmer and wetter than the average, while in southern Europe, including Bulgaria and Romania, it is colder and drier. When *NAOI* registers a negative phase, the westerly winds are weaker than normal and, in southern Europe, air temperatures are higher than normal (Hurrell et al., 2003).

Statistically significant correlation between *NAOI* and wintertime air temperature in the north of Bulgaria was found by Nikolova and Noda (2004) as well as by Nikolova and Tsenkov (2006). In Romania, the decrease in winter precipitation was at least partially related to the NAO positive phase (Tomozeiu et al., 2005; Cheval et al., 2014; Piticar and Ristoiu, 2014); warming in winter was also connected with positive NAO (Tomozeiu et al., 2002; Piticar and Ristoiu, 2014), while summer air temperature variability with *AMO* (Atlantic multi-decadal oscillation) (Ioniță et al., 2013). In the present study, we found rather low but statistically significant correlation between annual *NAOI* and those indices of

Table 6. Correlation coefficients between annual NAOI and continentality/oceanity indices.

Meteo. stations	*GCI*	*II*	*KOI*	*MOI*
D. T. Severin	–0.36	–0.36	0.01	0.36
Vidin	–0.36	–0.36	0.02	0.36
Vratsa	–0.31	–0.31	0.05	0.32
Craiova	–0.35	–0.35	–0.01	0.35
Pleven	–0.37	–0.37	0.05	0.37
Roşiorii de Vede	–0.33	–0.33	0.02	0.34
Russe	–0.34	–0.34	0.00	0.34
Bucureşti Băneasa	–0.32	–0.32	0.01	0.32
Razgrad	–0.37	–0.37	0.07	0.37
Buzău	–0.33	–0.33	0.01	0.31
Călăraşi	–0.37	–0.37	0.03	0.37
Varna	–0.38	–0.38	0.07	0.37
Galați	–0.36	–0.36	0.01	0.35
Constanța	–0.35	–0.35	0.05	0.32
Tulcea	–0.38	–0.38	0.02	0.37
Sulina	–0.31	–0.31	0.05	0.28

* Correlation coefficients in bold are statistically significant at $\alpha = 0.05$ (the significance is tested by t-test).

continentality/oceanity, which are calculated taking into account not only the air temperature (temperature range), but also the geographical latitude (*GCI*, *II* and *MOI*) (Tab. 6).

The only index that does not present statistically significant correlations is *KOI*, the formula of which does not have geographical latitude. Thus, according to the results, the correlation is negative for *GCI* and *II* and positive for *MOI*. That could be explained by the proportional or inversely proportional dependence of these indices on yearly temperature range.

The correlation is negative for *GCI* and *II* and it is positive for *MOI*. These could be explained by the opposite place of the temperature range in the formulas used for the calculation of *GCI* and *II*, on the one hand, and *MOI*, on the other.

4. Conclusions

The paper analyses the spatial distribution and temporal variability of thermal continentality in the lowlands from southern Romania and northern Bulgaria, which helps us clarify recent features of the climate in the investigated territory. On the basis of the analysis of thermal indices it was shown that climate is continental, except for the Black Sea coast, where three of the used indices (*GCI*, *II* and *KOI*) indicate a maritime climate. However, the influence of the Black Sea is quite reduced, being limited to a narrow strip along the coast.

This results from the analysis of each year values for different indices. For example, according to *GCI*, only at Varna it is a higher percent of years with transitional maritime climate (56.4%), while at Constanța and Sulina, the percent is 32.7. However, in the central part of the analysed region, there were registered only years with continental climate (Pleven, Roşiorii de Vede and Russe). The same situation is highlighted by *II* – the lowest percentage of the years with strongly continental climate being registered on the coast of the Black Sea and the lowest percentage of the years displaying a moderately continental climate in the western part of the analysed region (west of Bucureşti Băneasa). Based on *KOI*, there is the same pattern. The reduced influence of the Black Sea can be deduced from the values registered at the stations located not far from the shore, such as Tulcea and Călăraşi, where there is a clear predominance of the years characterized by different continentality degrees.

The multiannual variability of the continentality / oceanity indices for the period 1961–2015 emphasizes a slight increase of continentality and decrease of oceanity; however, the trends are not statistically significant. Thus, a clear signal of temporal evolution was not found, in spite of the fact that air temperature (minimum, mean and maximum) increased in the last two decades. The temporal variability of thermal indices correlates weakly but significantly with Annual *NAOI*. There is only one exception, namely *KOI* and *NAOI*, in case of which the correlation is not statistically significant.

The results of the present study allow us to point out that in order to receive the detailed information on the spatial distribution and temporal variability of thermal continentality, the analysis have to take into account not only air temperature, but also other important factors, such as geographical latitude and peculiarities of the surface. The results show that the most adequate indices to assess continentality and oceanity within the analysed region are *GCI* and *KOI*. However, considering the importance of the knowledge about climate variability and continental or oceanic character of the climate, the study will be extended in the future by the investigation on the basis of precipitation indices.

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SAŽETAK

Procjena toplinske kontinentalnosti u južnoj Rumunjskoj i sjevernoj Bugarskoj (1961.–2015.)

Alina Vlăduț, Nina Nikolova i Mihaela Licurici

Procjena kontinentalnosti i maritimnosti globalne i regionalne klime je u posljednje vrijeme postala važna u kontekstu globalnog zatopljenja i njegovog utjecaja na proizvodnju hrane i vodne resurse. S ciljem razumijevanja tih utjecaja, na temelju podataka s 27 meteoroloških postaja, analizirane su prostorna raspodjela i vremenska varijabilnost četiriju indeksa (za 19 meteoroloških postaja s potpunim vremenskim nizovima podataka koji pokrivaju intervalu 1961.–2015.). U stručnoj literaturi koriste se različiti indeksi kontinentalnosti i maritimnosti. U ovom radu proučavali smo smo četiri indeksa, ali rezultati ukazuju na to da su tri od njih suvišna, jer pružaju gotovo iste informacije. U skladu s tim, u radu smo prikazali i detaljnije raspravili vezene uz Gorczyńskijev indeks kontinentalnosti (*GCI*) i Kernerov indeks maritimnosti (*KOI*). Ovi indeksi ukazuju na kontinentalni karakter klime u regiji, osim uskog pojasa duž crnomorske obale, koja ima obilježja maritimne klime. Unatoč porastu temperature zraka u regiji tijekom posljednja dva desetljeća nije došlo do vidljivog intenziviranja kontinentalnosti (trendovi nisu bili statistički značajni). Međutim, dobivena je dobra korelacija između tri analizirana indeksa (*GCI*, *II* i *KOI*) i indeksa Sjevernoatlantske oscilacije (*NAOI*).

Ključne riječi: termalna kontinentalnost, Johanssonov indeks kontinentalnosti (*JCI*), Ivanovljev indeks termičke kontinentalnosti (*II*), Kernerov indeks maritimnosti (*KOI*), Marszov indeks maritimnosti (*MOI*), Rumunjska, Bugarska

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