ГЛАСНИК Српског географског друштва 98(1) 79-90
BULLETIN OF THE SERBIAN GEOGRAPHICAL SOCIETY 2018

Original scientific paper
UDC 551.585 (282) (292.464)
https://doi.org/10.2298/GSGD180428005P

Received: April 28, 2018
Corrected: May 15, 2018
Accepted: May 22, 2018

Hristo Popov[1*]

[*] *Sofia University, Faculty of Geology and Geography, Department of Climatology, Hydrology and Geomorphology, Sofia, Bulgaria*

LOCAL CLIMATES OF VARDAR, STRUMA AND MESTA VALLEYS (BALKAN PENINSULA) ACCORDING TO THE MODIFIED KÖPPEN CLIMATE CLASSIFICATION

Abstract: The Köppen classification is commonly used and helpful for characteristics of different climate types and their changes. Available maps based on this classification are dealing with continental and worldwide zones. This is the reason mountainous territory of the Balkans to be defined as zones with cold or high mountain climate without further details. The main aim of the study is detail classification of the territory of Vardar, Struma and Mesta in the view of the Köppen system and establishing the inner zones variability trough time. In order to achieve this goal we use the SAT (surface air temperature) and precipitation data from meteorological stations located in key areas of the valleys. We build 30 year moving average to present climate fluctuations in these areas according to the modified Köppen classification. Results show that index changing is variable through the different periods but there has a tendency for general reduction of the annual precipitation in the whole period of observation.

Key words: climate change, the modified Köppen classification, Vardar, Struma and Mesta valleys, temperature, precipitation

[1] hpopov@gea.uni-sofia.bg (corresponding author)

Introduction

The climate classification, based on the work of Wladimir Köppen from 1900, continues to be the most widely used climate scheme over a century later. For instance, Essenwanger (2001) has provided a comprehensive review of the classification of climate from prior to Köppen through to the present. Köppen's inspiration for developing a world map of climate classification in 1900 owed much to the global vegetation map of Grisebach published in 1866 (Wilcock, 1968) and Köppen's own background in plant sciences (Peel et al., 2007).

The use of Köppen's classification is not confined to teaching. Many researchers routinely use it for their own particular research purposes. Lohmann et al. (1993) have applied the Köppen classification to the output from both atmosphere general circulation models, coupled atmosphere-ocean circulation models, and compared these to maps of the Köppen classification using modern data sets and to Köppen's 1923 map. They modelled both present conditions, enhanced greenhouse scenarios and concluded: "However, the Köppen classification is easier to apply and is still a useful tool for estimating the ability of climate models to reproduce the present climate as well as indicate the impact of climate changes on the biosphere" (Peel et al.,2007).

In a similar study to that of Lohmann et al. (1993), Kalvova et al. (2003) compared global climate model outputs to maps of Köppen's classification drawn from gridded observed data and to Köppen's 1923 map. They were attracted to the Köppen system because of its known links to natural vegetation patterns as they have attempted to assess the impact of global warming on major biomes. They also compare the map they produced of Köppen's climate zones based on modern data with his 1923 map and show that the differences are only around 0.5% of the area distribution (Peel et al., 2007).

A more critical approach to the Köppen classification has been taken by Triantafyllou & Tsonis (1994) who claim to be the first to evaluate the Köppen classification using modern temperature and precipitation data (for the northern hemisphere). They classified climate stations on a year by year basis and then analysed the frequency with which they shifted between the major Köppen climate types (e.g. A to B) in order to assess the adequacy of the Köppen system. In North American and North Africa, they found low variability within a climate type and narrow regions of high variability between climate types, indicating the Köppen system performed adequately. For Europe and Asia they found the pattern of variability less defined, indicating either high within climate type variability or wide regions between climate types resulting in an inadequate performance of the Köppen system. It is the case however that the Köppen classification was intended to represent long term mean climate conditions and not year-to year variability though it can be put to good use as the basis for assessing climate variability on a year-to-year (Dick, 1964) or multi-decadal basis (Gentilli, 1971). Triantafyllou and Tsonis (1994) conclude, with Sanderson (1999), that there is a need for a new scheme to represent the world's climates (Peel et al., 2007).

Recently, four Köppen world maps based on gridded data have been produced for various resolutions, periods and levels of complexity. Kalvova et al. (2003) using Climate Research Unit (CRU, the University of East Anglia) gridded data for the period 1961–1990 presented a map of the 5 major Köppen climate types (with E divided into 2 types) at a resolution of 2.5° latitude by 2.5° longitude. Gnanadesikan and Stouffer (2006)

presented a Köppen map of 14 climate types based on the same CRU data and period as Kalvova et al. (2003), but at a resolution of 0.5° latitude by 0.5° longitude. Fraedrich et al. (2001) using CRU data for the period 1901–1995 presented a Köppen map of 16 climate types at a resolution of 0.5° latitude by 0.5° longitude and investigated the change in climate types over the period 1981–1995 relative to the complete period of record. The most comprehensive Köppen world map drawn from gridded data to date is that of Kottek et al. (2006) who presented a map with 31 climate types at a resolution of 0.5° latitude by 0.5° longitude based on both the CRU and Global Precipitation Climatology Centre (GPCC) VASClimO v1.1 data sets for the period 1951–2000 (Peel et al., 2007).

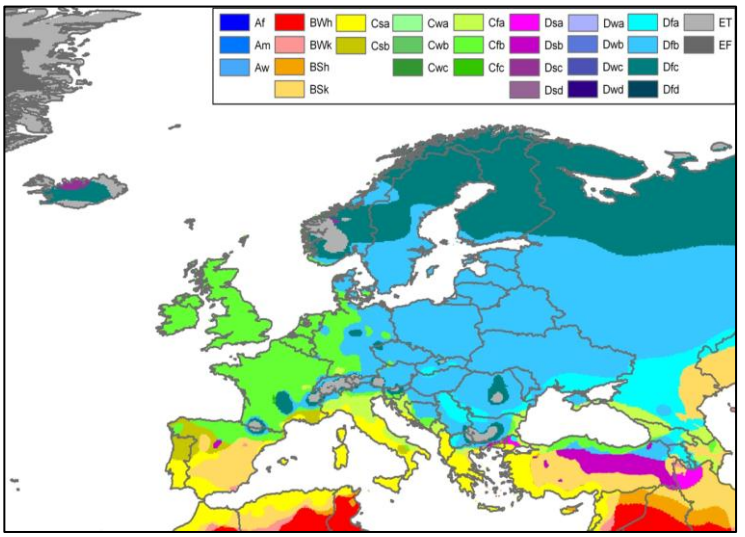

Fig. 1. Köppen-Geiger climate classification for the territory of Europe (after Peel et al., 2007)

In mountainous areas, such is the most of the Balkan's territory, the variety of climatic factors is an obstacle in giving a general characterization for the entire zone (Bouma, 2005). The valleys of Struma, Mesta and Vardar Rivers are located in mountainous territories of the Macedonian and Rila-Rhodopean Massifs but because of their openness to the Mediterranean basin, a southern influence penetrates deeply into the Balkan Peninsula. This is the reason that they are typical example of the Köppen classification insufficient character for little territories with uneven structure. Some authors, like Russel (1931), made some changes in borders between main climate types. Others, like Ristevski (2012), input some sub-indexes to present more details in climate variability.

In this study Köppen classification is used as basis for climate zonation along the three river valleys in the central part of the Balkan Peninsula. In order to obtain more detailed picture in such little territory sub-indices are used.

Materials and methods

We used data from 9 stations in three river valleys - Vardar, Struma and Mesta, in the middle of the Balkan Peninsula. On Fig. 1, all of them belong to "D" – cold or "ET" – tundra climates. Three stations are in the Vardar's valley, four stations are in the Struma's valley and two in the Mesta's valley. The monthly temperatures and precipitations from every year are used to build 30 years moving average (the standard 30-years climatologic period). They allow us to observe the climate variability in the valleys and to define the periods with fluctuations. Some of the stations differ in period of observations. (Tab. 1)

Tab. 1. List of meteorological stations used in the paper

Studied territory	Station	°φ	°λ	Altitude	Observation period
Vardar valley	Gevgelia	41° 09' N	22° 30' E	57 m	1951/2012
	Demir Kapia	41° 14' N	22° 08' E	125 m	1967/2012
	Skopie	42° 00' N	21° 25' E	234 m	1951/2012
Struma valley	Kustendil	42°16′ N	22°46′ E	521 m	1925/2012
	Sandanski	41°33′ N	23°16′ E	191 m	1931/2012
	Rila	42°06′ N	23°07′ E	418 m	1925/2012
	Blagoevgrad	42°01′ N	23°06′ E	410 m	1925/2012
Mesta valley	Bansko	41°51′ N	23°30′ E	918 m	1933/1991
	Gotze Delchev	41°34′ N	23°44′ E	508 m	1925/1992

The common period for all stations is 1951-1990. For the stations on Struma and Mesta valleys the common period is longer - 1931-1990. Stations along the Struma Valley are with longer period with meteorological observations. We found strong correlation (85-95%) in monthly temperatures between some stations in these two valleys and thus we tried to recover data for the period after 1990 in the Mesta valley. For the Vardar and Struma valleys, the common period is 1951-2012. Station Demir Kapia is with shortest period of observations - 1967-2012. The longest period of observation has station Rila – 1925-2012 (Fig. 2).

We used the idea from Ristevski (2012) who adopted the Köppen classification to produce the Macedonian climate map. He expands the temperate climate "C" to three separate parts with sub-indexes – C1, C2, C3. "C3" temperate climates are in territories where the temperature of the coldest month is 3°C or above, which means mild winter. "C2" temperate climates are in territory where the temperatures of coldest month are between 0 and 3°C. "C1" temperate climates are in territory where the temperatures of coldest month are between 0 and -3°C. Russell (1931), in his study about dry climates of the United States, accept such areas as cold climates type "D" putting the 0°C isotherm of the coldest month as the boundary between cold and temperate climates. In our research, we accept "C1" as temperate climates – a "border zone" between "C" and "D" climates, with cold winter. Some stations in our study area are in this border zone for the whole period or for some parts of it.

The second letter is an index for precipitation regime and indicates the drier period. For example, drier summer (AMJJAS) is indicated with "s", drier winter (ONDJFM) – with "w" and if there isn't drier period -"f".

Fig. 2. Study area with meteorological stations used in this paper

Ristevski (2012) also used some sub-indexes in the third letter in the modified Köppen classification. He uses (a') for climates with temperature 25°C or above in the hottest month, which we indicate as very hot summer. When this temperature is 19°C or bellow, he uses (b'), which we call mild summer. We are using these sub-indexes for more detailed characteristics for climate variations in the three valleys. For the hottest month with temperature between 22 and 25°C we use normal Köppen index "a" (hot summer), and "b" for temperature between 19 and 22°C (warm summer).

In more details, the usage of indices gives us an idea of the changes in temperature as the coldest and the hottest months. This in turn corresponds well with the temperature sums accumulate during the growing season of plants, which is an important agroclimatic indicator. For example C1...b' corresponds to approximately 2,600-2,700°C – areas with possible cultivation of crops, which are cold unpretentious to heat conditions. On the other, hand C2...a` corresponds to 4,400°C, conditions for growing thermophilic crops. C3...a` is a type of climate where the warm winter allows citrus crops being grown.

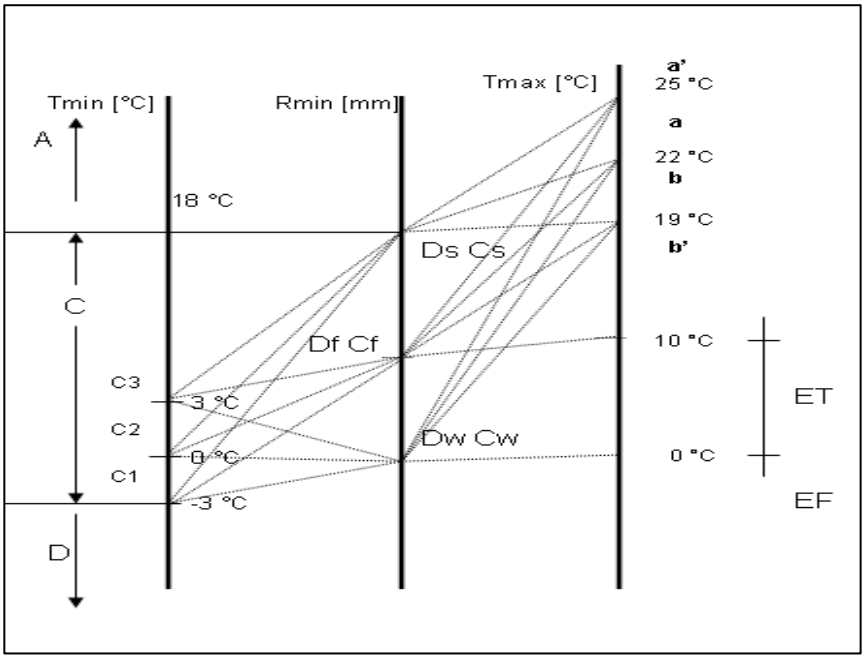

Fig. 3. Sub-indices in the modified Köppen classification (acc. to Ristevski, 2012)

Results and discussion

If we follow the three valleys from north to south, we begin with the "border zone" area, where the stations Skopie, Kustendil and Bansko are located. From these three stations, which are representative for the upper part of the valleys, Kustendil has the longest data period (1925-2012). This station is the northernmost point in the territory and is placed between Osogovo and Konyavska Mountains. For the whole period, this area belongs to the temperate climate "C1" and there is not dry period "f". From 1925-1954 to 1938-1967 periods this area belongs to the temperate climate without dry season and hot summer (C1fa), or cold climate without dry season and hot summer (Dfa) if we use Russel's (1931) and Peel's (2007) version of Köppen classification. After that from 1939-1968 to 1983-2012 this area belongs to C1fb climate (temperate climate without dry season and warm summer).

On almost the same latitude, western than Kustendil, in the Vardar Valley, between Crna Gora (1,650 m), Suva Gora (1,745 m) and Jacupica (2,540 m) mountains, is the Skopie intermountain lowland. In this territory, the winter is not so cold and we could observe some fluctuations in winter temperatures. In the periods between 1951-1980 and 1960-1989, these areas are part of C2fa (temperate climate without dry season and hot summer). From 1961-1990 to 1967-1996 period winters became colder and the area climate changed to C1fa (or Dfa). From 1968-1997 to 1972-2001 winters became warmer and climate changed again to C2fa. This situation was followed by new cold winter period 1973-2002 to 1976-2005 with C1fa climate, and temperate winter period with C2fa climate from 1977-2006 to 1983-2012.

On the same river valley, southern than Skopie, we used data from another two stations – Demir Kapia and Gevgelia. Demir Kapia station has the shortest period of observations in the studied area – 1967-2005. This is the reason that we have only several 30-years moving average periods. This area is part of temperate climate C2. From 1967-1996 to 1973-2002 the climate here is without dry season and with hot summer C2fa. The next 1974-2003 to 1975 -2004 is a period with dry summer and climate type became C2sa. The last period 1976-2005 is with temperate climate with dry and very hot summer C2sa'.

South from Demir Kapia is the Gevgelia intermountain lowland. Here is the southernmost point of the observed area. The climate here is temperate with warm winter C3. For the period 1951-1980 to 1952-1981 the climate in this part of Vardar Valley is with dry and very hot summer C3sa'. From 1953-1982 to 1961-1990 is a cool summer period with dry and hot summer C3sa. After this period there are some fluctuations: 1962-1991 is a period with C3fa' - without dry season and very hot summer; 1963-1992 and 1964-1993 are periods with C3fa - without dry season and hot summer; from 1965-1994 to 1976-2005 the summers became very hot and climate change to C3fa'; for 1977-2006 and 1978-2007 periods, climate changed again to temperate with warm winter and dry and very hot summer C3sa'.

Northeast from Gevgelia is the Sandanski intermountain lowland. Between these two basins is Belasitza Mountain (2,029 m). Sandanski is a station with the longest period of observation – from 1931 to 2012. This territory is defined according meteorological data as the hottest place in Bulgaria. According to the modified Köppen's detail classification the climate here is temperate C2. There are some fluctuations in precipitation regime and the temperature of the hottest month: for the period 1931-1960 the climate here is temperate with very hot summer and without dry season C2fa'; 1932-1961 is a period with temperate with hot summer and without dry season C2fa; the next period 1933-1962 to 1949-1978 was with typical Mediterranean climate with dry and hot summer C2sa; only for the period 1934-1963 there is very hot summer C2sa'; from 1950-1979 to 1975-2004 the climate in Sandasnki Lowland is temperate with hot summer and without dry season C2fa; in the end of this period the climate became warmer and the modified Köppen index changed to C2fa' for the last period from 1976-2005 to 1983-2012, like in the beginning of the observations. This warming has been observed also for the winter months, so the modified Köppen index changed to C3fa' just for the period 1982-2011. Based on these results we can make a conclusion that 1982-2011 is the period with hottest climate for the whole period of observations in Sandanski Lowland. If this tendency of warming continues, the index C3fa' will become typical for the area.

Between Sandanski & Kustendil we observe another two stations – Blagoevgrad and Rila. In Blagoevgrad intermountain lowland, the climate does not have many fluctuations with respect to the Köppen index. In the most period of observations, this area belongs to temperate climate without dry season and hot summer C2fa. There are some fluctuations in temperatures of hottest month for the period from 1953-1982 to 1960-1989, when the climate here was changed to temperate climate without dry season and warm summer C2fb. After that from 1961-1990 summers here are hot again and index changed to C2fa.

Rila station is located on the west slope of the Rila Mountains (2,925 m), which are the highest on the Balkan Peninsula. This station is placed north of Blagoevgrad and its position on the mountain slope is the reason for more fluctuations. The climate here is without dry season for the whole period, so we will not comment the precipitation regime,

but in winter and summer, temperatures have many fluctuations. In the beginning 1925-1954 the climate here was temperate with cold winter and hot summer C1fa. Maybe this is the end of cold winter period because from 1926-1955 to 1936-1965 is a period with C2fa climate. Then a new period began with cold winter from 1937-1966 to 1942-1971 when the climate got back to the previews type C1fa. From the period 1943-1972 winter became warmer and unchangeable until the end of data C2. However, in these data we still see some fluctuations in temperatures of the hottest month. The period 1943-1972 is with hot summer C2fa. After that from 1944-1973 to 1975-2004 is a period with warm summer C2fb. From the period, 1976-2005 to end of the observation period became warmer that caused a change in the Köppen index to C2fa.

Bansko is the highest station in the studied territory. It is located in intermountain lowland in the upper part of the Mesta River. This coldest station (amongst the three studied valleys) is placed between three of the highest mountains on the Balkan Peninsula –Rila, Pirin and the Rhodops. Here the climate is temperate with cold winter for the whole period - C1. In the precipitation regime there is a tendency for transition from Mediterranean type with dry summer, for the periods from 1932-1961 to 1945-1974 - C1s, to climate without dry season C1f from 1946-1975 to the final period 1961-1990. For Bansko does not have precipitation data for years after 1990. Monthly average temperature is recovered after 1991, because there is strong correlation between Bansko and Blagoevgrad. Results from this recovery showed that there have no changes in climate and it remained type C1 with respect to the winter. When we analyzed the hottest month temperatures, we defined "b" index for the periods between 1932-1961 and 1939-1968. There is a tendency for cooling in the summer months and from 1940-1969 to 1973-2002 the third letter index changed to b'. We can assume that for the period 1940-1969 the climate in Bansko area changed from C1sb to C1sb'. The period with climate with Mediterranean precipitation regime continued to 1946-1975 when it changed to C1fb'. The climate type changed again for the period 1974-2003 when become C1...b.

We could not be sure, because most of the data is recovered (after 1991), but we suppose that with strong confident. We suppose the precipitation regime remained the same (without dry season) for this period until the end of data row, but also we could not sure about that.

Gotze Delchev station is in the southeastern part of the studied area. Gotze Delchev intermountain lowland is placed between the Pirin Mountains (2,914 m), Slavyanka (2,212 m) and the Rhodops Mountain Range. This position between high mountains and close to the Mediterranean Sea placed this area in the border zone of changing precipitation regime (from "s" to "f") according to the Köppen classification. The period of observation began in 1925 and we have data for temperature to 1992. Precipitation data are to 1990. Because we have found strong correlation ($r \geq 0.8$) in temperatures between Gotze Delchev and Sandanski we recovered the temperatures after 1992.

Tab.2. The modified Köppen index calculated from 30-years moving average

	Skopie	DemirKap	Gevgelia	Kustendil	Rila	Blagoevgr	Sandansk	Bansko	G.Delchev
1925-54				C1 f a	C1 f a	C2 f a			C1 s a
1926-55				C1 f a	C2 f a	C2 f a			C1 s a
1927-56				C1 f a	C2 f a	C2 f a			C1 s a
1928-57				C1 f a	C2 f a	C2 f a			C1 f a
1929-58				C1 f a	C2 f a	C2 f a			C1 f a
1930-59				C1 f a	C2 f a	C2 f a			C1 f a
1931-60				C1 f a	C2 f a	C2 f a	C2 f a'		C1 s b
1932-61				C1 f a	C2 f a	C2 f a	C2 f a	C1 s b	C1 s b
1933-62				C1 f a	C2 f a	C2 f a	C2 s a	C1 s b	C1 s b
1934-63				C1 f a	C2 f a	C2 f a	C2 s a'	C1 s b	C1 s b
1935-64				C1 f a	C2 f a	C2 f a	C2 s a	C1 s b	C1 s b
1936-65				C1 f a	C2 f a	C2 f a	C2 s a	C1 s b	C1 s b
1937-66				C1 f a	C1 f a	C2 f a	C2 s a	C1 s b	C1 s b
1938-67				C1 f a	C1 f a	C2 f a	C2 s a	C1 s b	C1 s b
1939-68				C1 f b	C1 f a	C2 f a	C2 s a	C1 s b	C1 s b
1940-69				C1 f b	C1 f a	C2 f a	C2 s a	C1 s b'	C1 s b
1941-70				C1 f b	C1 f a	C2 f a	C2 s a	C1 s b'	C1 s b
1942-71				C1 f b	C1 f a	C2 f a	C2 s a	C1 s b'	C1 s b
1943-72				C1 f b	C2 f a	C2 f a	C2 s a	C1 s b'	C1 s b
1944-73				C1 f b	C2 f b	C2 f a	C2 s a	C1 s b'	C2 s b
1945-74				C1 f b	C2 f b	C2 f a	C2 s a	C1 s b'	C2 s b
1946-75				C1 f b	C2 f b	C2 f a	C2 s a	C1 f b'	C2 s b
1947-76				C1 f b	C2 f b	C2 f a	C2 s a	C1 f b'	C2 f b
1948-77				C1 f b	C2 f b	C2 f a	C2 s a	C1 f b'	C2 f b
1949-78				C1 f b	C2 f b	C2 f a	C2 s a	C1 f b'	C2 f b
1950-79				C1 f b	C2 f b	C2 f a	C2 f a	C1 f b'	C2 f b
1951-80	C2 f a		C3 s a'	C1 f b	C2 f b	C2 f a	C2 f a	C1 f b'	C2 f b
1952-81	C2 f a		C3 s a'	C1 f b	C2 f b	C2 f a	C2 f a	C1 f b'	C2 f b
1953-82	C2 f a		C3 s a	C1 f b	C2 f b	C2 f b	C2 f a	C1 f b'	C1 f b
1954-83	C2 f a		C3 s a	C1 f b	C2 f b	C2 f b	C2 f a	C1 f b'	C1 f b
1955-84	C2 f a		C3 s a	C1 f b	C2 f b	C2 f b	C2 f a	C1 f b'	C2 f b
1956-85	C2 f a		C3 s a	C1 f b	C2 f b	C2 f b	C2 f a	C1 f b'	C2 f b
1957-86	C2 f a		C3 s a	C1 f b	C2 f b	C2 f b	C2 f a	C1 f b'	C2 f b
1958-87	C2 f a		C3 s a	C1 f b	C2 f b	C2 f b	C2 f a	C1 f b'	C2 f b
1959-88	C2 f a		C3 s a	C1 f b	C2 f b	C2 f b	C2 f a	C1 f b'	C2 f b
1960-89	C2 f a		C3 s a	C1 f b	C2 f b	C2 f b	C2 f a	C1 f b'	C1 f b
1961-90	C1 f a		C3 s a	C1 f b	C2 f b	C2 f a	C2 f a	C1 f b'	C1 f b
1962-91	C1 f a		C3 f a'	C1 f b	C2 f b	C2 f a	C2 f a	C1 b'	C1 b
1963-92	C1 f a		C3 f a	C1 f b	C2 f b	C2 f a	C2 f a	C1 b'	C1 b
1964-93	C1 f a		C3 f a	C1 f b	C2 f b	C2 f a	C2 f a	C1 b'	C1 b
1965-94	C1 f a		C3 f a'	C1 f b	C2 f b	C2 f a	C2 f a	C1 b'	C2 b
1966-95	C1 f a		C3 f a'	C1 f b	C2 f b	C2 f a	C2 f a	C1 b'	C2 b
1967-96	C1 f a	C2 f a	C3 f a'	C1 f b	C2 f b	C2 f a	C2 f a	C1 b'	C2 b
1968-97	C2 f a	C2 f a	C3 f a'	C1 f b	C2 f b	C2 f a	C2 f a	C1 b'	C2 b
1969-98	C2 f a	C2 f a	C3 f a'	C1 f b	C2 f b	C2 f a	C2 f a	C1 b'	C2 b
1970-99	C2 f a	C2 f a	C3 f a'	C1 f b	C2 f b	C2 f a	C2 f a	C1 b'	C2 b
1971-2000	C2 f a	C2 f a	C3 f a'	C1 f b	C2 f b	C2 f a	C2 f a	C1 b'	C2 b
1972-2001	C2 f a	C2 f a	C3 f a'	C1 f b	C2 f b	C2 f a	C2 f a	C1 b'	C2 b
1973-2002	C1 f a	C2 f a	C3 f a'	C1 f b	C2 f b	C2 f a	C2 f a	C1 b'	C2 b
1974-2003	C1 f a	C2 s a	C3 f a'	C1 f b	C2 f b	C2 f a	C2 f a	C1 b	C2 b
1975-2004	C1 f a	C2 s a	C3 f a'	C1 f b	C2 f b	C2 f a	C2 f a	C1 b	C2 b
1976-2005	C1 f a	C2 s a'	C3 f a'	C1 f b	C2 f a	C2 f a	C2 f a'	C1 b	C2 a
1977-2006	C2 f a	C2 f a'	C3 s a'	C1 f b	C2 f a	C2 f a	C2 f a'	C1 b	C2 a
1978-2007	C2 f a	C2 f a'	C3 s a'	C1 f b	C2 f a	C2 f a	C2 f a'	C1 b	C2 a
1979-2008	C2 f a	C2 f a'	C3 f a'	C1 f b	C2 f a	C2 f a	C2 f a'	C1 b	C2 a
1980-2009	C2 f a	C2 f a'	C3 f a'	C1 f b	C2 f a	C2 f a	C2 f a'	C1 b	C2 a
1981-2010	C2 f a	C2 f a'	C3 f a'	C1 f b	C2 f a	C2 f a	C2 f a'	C1 b	C2 a
1982-2011	C2 f a	C2 s a'	C3 s a'	C1 f b	C2 f a	C2 f a	C3 f a'	C1 b	C2 a
1983-2012	C2 f a	C2 s a'	C3 s a'	C1 f b	C2 f a	C2 f a	C2 f a'	C1 b	C2 a

In the first period 1925-1954 the climate in Gotze Delchev is temperate with cold winter and dry, hot summer C1sa. That Mediterranean precipitation regime ("s") continues to 1927-1956. Next period from 1928-1957 to 1930-1959 is without dry season - C1fa. In 1931-1960, a cooling period began with warm and dry summer C1sb. This situation continued to 1944-1973 when winters became warmer and the modified Köppen index changed to C2sb. The period with this index did not stayed for long and continued to 1946-1975. Some changes in precipitation regime changed the Köppen index to C2fb – without dry period. This temperate winter period was interrupted for a while (1953-1982 to 1954-1983) with cold winter period C1fb, but after that returned back and continued to 1959-1988. In 1960-1989, a new cold winter period C1fb began. It continued to 1964-1993. After this moment a warming period started. At first winters became warmer and index changed to C2…b to 1975-2004. After that, the index changed for the hottest month and the climate became temperate with hot summer (C2…a) for the period from 1976-2005 to 1983-2012. There are tendencies that Gotze Delchev lowland would return to the Mediterranean dry summer index "s" with regard to the precipitation regime.

Conclusion

The Köppen classification scheme has to be used carefully because of resolution issues. Because of them and due to average temperature values areas with high mountains in the southern parts of the temperate zone are defined as territories with cold climate (D) or tundra (ET) climate. In this way, we could miss the lowlands between mountains with different warmer climate. These areas are important because they are useful in agriculture and many infrastructure aspects. This is the main reason to start this research for the territories of Struma, Mesta and Vardar in the center of the Balkan Peninsula.

When we compare some averages, it is possible to miss some important fluctuations, which give us many details about the climate changes. If we use only usual periods as 1931-1960 and 1961-1990 to compare climate data, it is possible to have some fluctuations, which we could miss between these periods. Good example about that is Gotze Delchev lowland area and middle part of the Struma Valley (between Rila and Sandanski).

In other territories, like the north part of Struma and Mesta valleys, only few fluctuations are observed. The climate there is temperate with cold winter. Precipitation regime in Kustendil lowland is without dry season. The Köppen index is changing only in the third letter C1fa to C1fb, because summers became colder in after 1939-1968 period. In the north part of Mesta valley summers also became colder and the modified index changed from C1sb to C1sb' almost in the same time in the 1940-1969 period. Later precipitation regime is changed from dry summer C1sb' to without dry C1fb' season in 1946-1975.

In the north part of Vardar Valley, there are some fluctuations in winter temperatures, which define this area as a border zone between temperate climate C1 (with cold winter) and temperate climate C2.

Gevgelia precipitation regime here is changing from Mediterranean (s) to without dry season (f) in 1962-1991 and after that come back to previous regime in 1977-2006 period.

The data we have for the region start from 1951. In the first 30 moving average annual climate here has a very hot and dry summer C3sa'. We can assume that for at least 20 years before the climate also was belonged to this index.

We can conclude that the southern areas are located (in a place) where rainfall patterns is changing. The greater openness to the Mediterranean Sea near Gevgelija, as well as the southern position with reference to the Sandanski lowland, defines it with more expressed Mediterranean rainfall patterns. This regime could be linked to a more northerly path of the crossing the Mediterranean cyclones. When they shift north in the late spring and early summer, the southern parts of the observed territory remain beyond their reach, which brings dry summer in the area. Those located further north in their periphery obtain more rainfall and they remain without dry season (f precipitation index). That is why precipitation type in the region of Sandanski get to transitional type (f) earlier (than Gevgelia lowland) and remain on it for a longer time.

References

Bouma, E. (2005). Development of comparable agro-climatic zones for the international exchange of data on the efficacy and crop safety of plant protection products: OEPP/EPPO, *Bulletin OEPP/EPPO Bulletin* 35, 233–238.

Dick, R. S. (1964). Frequency patterns of arid, semi-arid and humid climates in Queensland, *Capricornia*, 1, 21–30.

Essenwanger, O. M. (2001). Classification of climates. In *World Survey of Climatology 1C*, General Climatology, Elsevier, Amsterdam, 102.

Fraedrich, K., Gerstengarbe, F. W. & Werner, P. C. (2001). Climate shifts during the last century, *Climatic Change*, 50, 405–417.

Gentilli, J. (Ed.) (1971). Climates of Australia and New Zealand, In *World Survey of Climatology*, 13. Elsevier, Amsterdam, 405.

Gnandesikan, A. & Stouffer, R. J. (2006). Diagnosing atmosphere-ocean general circulation model errors relevant to the terrestrial biosphere using the Koppen climate classification, *Geophys. Res. Lett.*, 33, L22701. DOI: 10.1029/2006GL028098.

Köppen, W. (1936). *Das geographisca System der Klimate, in: Handbuch der Klimatologie*, edited by: Köppen, W. & Geiger, G., 1. C. Gebr, Borntraeger, 1–44.

Kalvova, J., Halenka, T., Bezpalcova, K. & Nemesova, I. (2003). Köppen Climate types in observed and simulated climates, *Stud. Geophys. Geod.*, 47, 185–202.

Kottek, M., Grieser, J., Beck, C., Rudolf, B. & Rubel, F. (2006). World map of the Köppen-Geiger climate classification updated, *Meteorol. Zeitschr.*, 15(3), 259–263.

Lohmann, U., Sausen, R., Bengtsson, L., Cubasch, U., Perlwitz, J. & Roeckner, E. (1993). The Köppen climate classification as a diagnostic tool for general circulation models, *Clim.Res.*, 3, 177–193.

Russell, R. J. (1931). *Dry climates of the United States: I climatic map*, University of California, Publications in Geography, 5, 1–41.

Peel, M. C., Finlayson, B. L. & McMahon, T. A. (2007). Updated world map of the Köppen-Geiger climate classification, *Hydrology and Earth System Science*, 11, 1633–1644.

Ристевски, П. (2012). Климатът и агроклиматичните ресурси на Република Македония. *Автореферат*. БАН. София [Ristevski, P. (2012). Climate and agricultural resourses in Republic of Macedonia. Doctoral Disertation. BAN. Sofia]

Христо Попов*

* *Универзитет у Софији, Факултет за геологију и географију, Департман за климатологију, хидрологију и геоморфологију, Софија, Бугарска*

ЛОКАЛНЕ КЛИМЕ ДОЛИНА ВАРДАРА, СТРУМЕ И МЕСТЕ (БАЛКАНСКО ПОЛУОСТРВО) ПРЕМА МОДИФИКОВАНОЈ КЕПЕНОВОЈ КЛИМАТСКОЈ КЛАСИФИКАЦИЈИ

Резиме: У овом раду се користи модификована Кепенова класификација климата за проучавање централног дела Балканског полуострва. Предмет истраживања су долине река Месте, Струме и Вардара, које се налазе између највиших планина у региону. Када се користе модели са нижим резолуцијама, ове територије се класификују као подручја са хладном климом или тундром. Климатолошки подаци са станица у долинама не одговарају таквим закључцима.

У овом истраживању су коришћене месечне температуре ваздуха и месечне падавине за израчунавање модификованих Кепенових индекса. Климатолошки подаци се филтрирају кроз 30-годишње покретне просеке како би се открилe флуктуације Кепенових индекса у условима климатских промена. Основни период за све станице је 1951-1990. година.

Резултати показују да се у северном делу долине Вардара (Скопска котлина) флуктуације могу посматрати само у подиндексу о зимским температурама (C_1 до C_2). У области око Демир Капије постоје флуктуације режима падавина (друго слово) и подиндекси летњих температура (треће слово од (a) до (a')). Ђевђелија има сличне флуктуације, али са благим зимским (C_3) условима.

У северном делу долине Струме (Ћустендилска котлина) резултати показују промену Кепенових индекса због хлађења у летњим месецима (треће слово од (a) до (b)). У зимском подиндексу (C_1 до C_2) и летњем индексу (треће слово од (b) до (a)) у близини станице Рила постоје флуктуације. У Благоевградској равници исти топли летњи период завршио се раније крајем 80-их. У Санданској низији примећују се флуктуације режима падавина из Медитерана са сувим летом до таквог без сувог времена (друго слово од "s" до "f") и неке промене у под-индексу летњих температура (треће слово од (a) до (a')).

Долина Месте, заједно са Ћустендилском котлином су најхладнија у истраживаној области. Режим падавина у долини Месте био је са медитеранским карактером почетком седамдесетих, а после тога није забележена сува сезона. У Разлошкој котлини након 1975. године и до 2000. године лета су била хладнија. На станици Гоце Делчев могу се посматрати флуктуације зимског подиндекса, али после 1994. године зиме су релативно блаже.

Коппенова модификована класификација је веома погодна за мање територије и пружа поуздане резултате за детаљне карактеристике климатских промена. 30-годишњи покретни просеци су добар приступ за откривање флуктуација у подиндексима. Могу се користити у пракси и у различитим климатолошким студијама.