# USING KÖPPEN CLIMATE CLASSIFICATION AS A DIAGNOSTIC TOOL TO QUANTIFY CLIMATE VARIATION IN SOUTHWEST BULGARIA

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**Abstract:** Köppen climate classification add a new dimension to the description of climate variations. Over the recent years, there has been an increasing interest in using the classification to identify changes in climate and potential changes in vegetation over time. These successful applications point to the potential of using the Köppen classification as diagnostic tool to monitor changes in the climatic condition over various time scales. This article used the Köppen classification to define Annual Climate Types (ACT) for a set of 6 stations, representative for the climatic conditions of Mesta and Struma Valleys (Southwest Bulgaria). In the last years some research using Köppen classification concluded that the most significant change over 1901–2010 is a distinct areal increase of the dry climate (B). The area of Mesta and Struma Valleys is in risk of drought according some future climate scenarios and results present in this paper proves that.

**Keywords**: Annual Climate Types (ACT), Köppen climate classification, Southwest Bulgaria, Mesta Valley, Struma Valley

**Résumé :** La classification climatique de Köppen ajoute une nouvelle dimension à la description des variations climatiques. Au cours des dernières années, un intérêt croissant a été porté à l'utilisation de la classification pour identifier les changements de climat et les changements potentiels de la végétation dans le temps. Ces applications réussies indiquent le potentiel de la classification de Köppen en tant qu'outil de diagnostic pour surveiller les modifications du climat sur diverses échelles de temps. Cet article utilise la classification de Köppen pour définir les types de climat annuels (ACT) pour un ensemble de 6 stations représentatives des climats des vallées de Mesta et Struma (Sud-Ouest de la Bulgarie). Au cours des dernières années, les recherches utilisant la classification de Köppen ont conclu que le changement le plus important entre 1901 et 2010 est une extension spatiale du climat sec (B). La région des vallées de Mesta et Struma présente un risque de sécheresse dans plusieurs scénarios climatiques futurs, ce que démontrent les résultats de cet article.

**Mots-clés** : Types de climats annuels (ACT), Classification climatique de Köppen, Sud-Ouest de la Bulgarie, Vallées de Mesta et Struma

## Introduction

Climate change and its impact on people's lives and activities are the reason for the need for most research related to this topic. Köppen's climate classification based on the requirements of different types of vegetation for heat and moisture and defining empirical boundaries between different types of climate is still relevant today. First presented in 1884, reworked over the years 1900, 1918, 1936, and used for global and regional research in recent days (Kottek et al. 2006, Rubel & Kottek 2010, Chen & Chen 2013), it continues to be an important tool in climate research.

The expression "Annual Climate Type" (ACT) has thus been used to define the climatic atmosphere of a given year (Brisse et al. 1982). The classification of W. Köppen has thus already been applied by some authors to define these ACT in Argentina (Planchon & Rosier, 2005), in France (Quénol et al. 2008, Eveno et al. 2016) and Brazil (Dubreuil et al. 2017).

Kirov (1929) used Köppen classification together with other classifications to describe the climate in Bulgaria. Topliyski (2006) used Köppen classification for the period 1931-1970. Popov (2018) studied climate

changes in Struma valley using Köppen climate types and calculated 30 years moving averages for the period 1931-2012.

Struma and Mesta Valleys are located meridionally (North-South), in the central part of the Balkan Peninsula, in Southeastern Europe. These valleys are surrounded by Rila, Pirin and Rodopi, which are the highest mountains of the Peninsula (figure 1). According to Köppen climate classification there are many different types in close range in this region. The main objective of this research is to represent climate in the area using the method of Annual Climate Type (ACT).

## 1. Data and Methods

This article uses average monthly temperatures and monthly precipitation data from six stations located in the Struma and Mesta valleys. Four of the stations (Kustendil, Rila, Blagoevgrad and Sandanski) are located in the Struma Valley, and two stations (Bansko and Gotze Delchev) in Mesta Valley. The data on the Struma Valley are for the period 1931- 2017. The data from the stations in the Mesta Valley are for the period 1931-1990.

The original Köppen classification was used (table 1), in which the boundary between temperate climates «C» and cold continental snow climates «D» is -3 °C. For years with dry winter (w) it is accepted that the precipitation of the driest month in winter is at least 10 times less than the most wet month in summer. For dry summer years (s) there are two conditions - the driest month of summer is with less than 40 mm of rainfall, and the same precipitation are three times less than the rainiest month of winter. If it does not meet the conditions for dry winter or dry summer, then we assume that the precipitation is evenly distributed and the second index is "f". The third letter in the index is determined by the temperature of the hottest month of the year. If the temperature is at least 22 degrees, then the index is "a" – hot summer. If the temperature of the warmest month is between 19 and 21.9 degrees, then the index is "b" – warm summer. If the temperature of the warmest month is below 19 degrees then the index "c" – cold summer. Following these criterias, Köppen climate types were defined at each station. The Annual Climate Type (ACT) method was used, which is based on defining the classification index for every single year of the study period.

**Table 1**. Köppen climate classification scheme symbols description table. 1st – main climate type, 2nd – subtype for B (arid) climate or precipitation regime type for C (temperate) climate and D (continental) climate, 3rd – subtype based on the temperature regime.

| 1st | 2nd | 3rd | Subtypes found in Bulgaria |
|---|---|---|---|
| **B (Arid)** | S (Steppe) | k (Cold) | BSk – Cold steppe climate |
| **C (Temperate)** | w (Dry winter) | a (Hot summer) | Cwa - Dry-winter humid subtropical climate |
| | | | Cwb - Dry-winter subtropical highland climate |
| | f (No dry season) | | Cfa – Subtropical humid |
| | | b (Warm summer) | Cfb – Subtropical highland climate with warm summer |
| | | | Cfc – Subtropical highland climate with cold summer |
| | s (Dry summer) | | Csa – Mediterranean with hot summer |
| | | | Csb - Mediterranean with warm summer |
| | | c (Cold summer) | Csc - Mediterranean with cold summer |
| **D (Continental)** | w (Dry winter) | a (Hot summer) | Dwa - Hot summer continental climates |
| | | | Dwb - Warm summer continental or hemiboreal climates |
| | f (No dry season) | | Dfa - Hot-summer humid continental climate |
| | | b (Warm summer) | Dfb – Warm humid continental climates |
| | s (Dry summer) | | Dsa - Hot and dry summer continental climates |
| | | | Dsb - Warm and dry summer continental climates |
| | | c (Cold summer) | Dwc -Dsc – Dfc – Boreal climates |

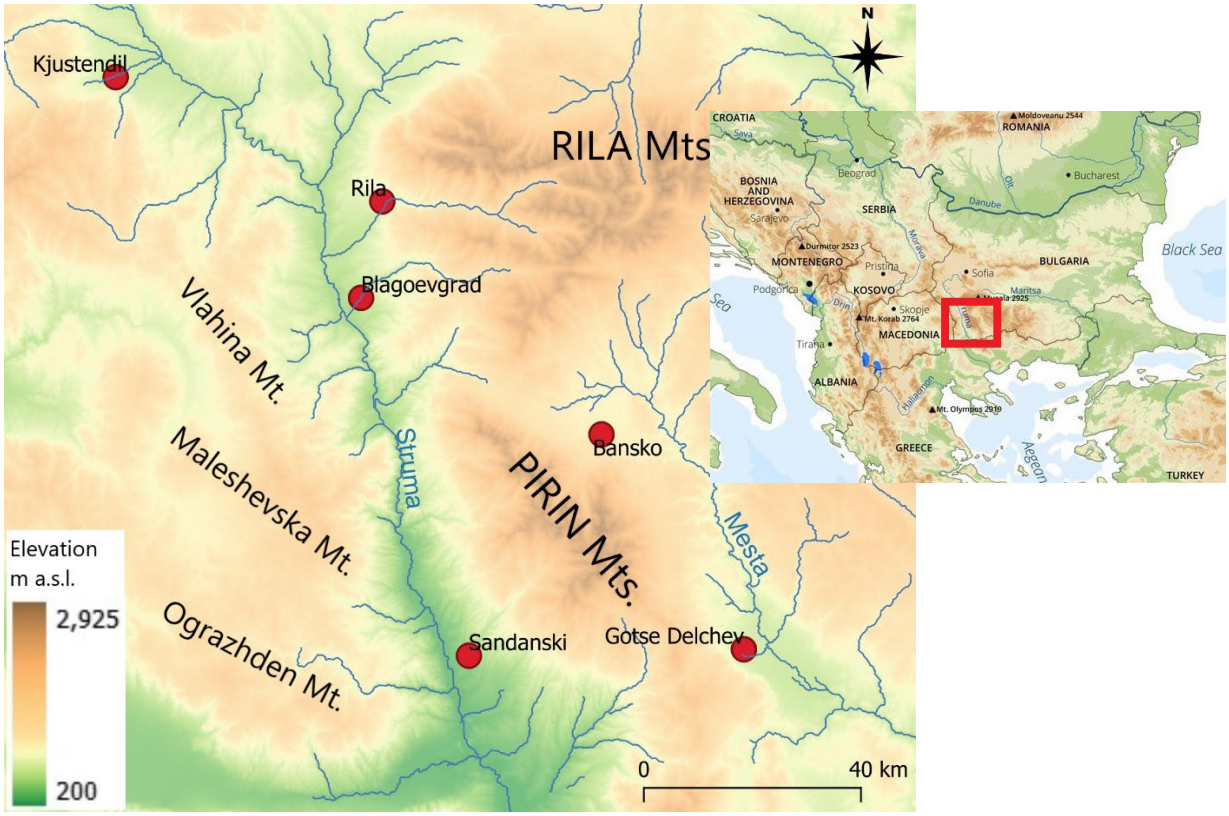


**figure 1.** Map of study area.

## 2. Results

With regard to the dry climate (BSk), the Struma Valley reveals a tendency to increase its influence from North to South. According to the annual climate index, the Kyustendil area belongs to the steppe climate for only 3,5 % of study period. In the south its influence increases as for the region of the Blagoevgrad valley it reaches 10% of the years in the studied period. The southernmost parts of the Struma Valley dry climate cover more than 20% of the years. For the Mesta Valley, according to the annual climate index, only one of these sixty years has a dry climate in the region of the Gotse Delchev valley.

The Mediterranean climate influence is characterized by the indices Csa, Csb and the mountain variant Csc. For the Struma Valley this type of climate indices dominates as for the Kyustendil field. The Mediterranean climate with warm summer Csb prevails - 25%, before the Mediterranean climate with hot summer Csa - 20%. In the southern direction, the Mediterranean influence is increasing, with the dominant index being that of the Mediterranean type with hot summers - Csa. For the region of Rila this index covers one third of the years, and for the region of Blagoevgrad valley it reaches 43%. For the Struma valley south of the Kyustendil field, the Mediterranean climate types according to the annual indices cover between 45 and 50% of the years in the studied period. South of the Kresna Gorge, the Mediterranean influence accounts for 50% of the years studied. The Mediterranean influence is well manifested in the Mesta valley. For the Gotse Delchev valley, the annual climatic types for hot summer and warm summer cover the same number of years of the studied period. In total, the two types determine about two thirds of the years in the study period. For the region of Bansko due to the higher altitude we register the mountain variant of the Mediterranean climate – Csb and Csc. Both types cover a total of 40 percent of the study period and cover equal number of years.

To the types with Mediterranean precipitation distribution we add also those with cold winter or more continental (D), where the temperature of the coldest month is below - 3 °C. For the Struma Valley, the years with such indices cover between 5 and 15%. From the north to the south the continental influence decreases and south of the Kresna gorge annual climate types with cold winters are not registered.

Because the high altitude for the Bansko region, the continental climate types with a Mediterranean precipitation regime cover one third of the years in the study period. For the Gotse Delchev valley the years with cold winters and the Mediterranean precipitation regime covers a little over 6%.

Annual climatic types characterized by dry winters (Cw ... and Dw ...) cover single years and are not typical of the region studied in this article. They cover individual years and their share varies between 1 and 5%. ACT for dry winter is most common for Kyustendil valley where these climate types describe 9% of the years in the study period.

Annual climatic types with an even distribution of precipitation (Cfa, Cfb, Cfc) cover between 10 and 33% of the studied period. For the Mesta Valley, these indices are poorly represented. For the region of Bansko the three types (Cfa, Cfb, Cfc) cover a total of 10%. The most representative is the mountain variety Cfc - 6%. For the region of Gotse Delchev Temperate climate types without dry season cover 20% of the studied years. Cfb 15% is best represented.

About the Struma Valley Temperate climate types without dry period (Cfa+Cfb) cover between 24 and 33% of the study period. For the Sandanski region these types of climate are represented only by the variant with hot summer Cfa - 24%. In north direction the Mediterranean influence (Csa) recedes and subritropical humid climate (Cfa) increases slightly in frequency. For the region of Blagoevgrad this climate type (Cfa) is 26% of the studied period. For the Rila station area Cfa - 16% . For the region of Kyustendil Cfa is 9%.

North of the Kresna Gorge, the data show warm summers (Cfb) during part of the study period, and their share logically increases with increasing latitude instead of hot summer years (Cfa). For the region of Blagoevgrad ACT of Cfb is 7%. For the Rila station area Cfb is 12%. For the region of Kyustendil Cfb climate type is 15%.

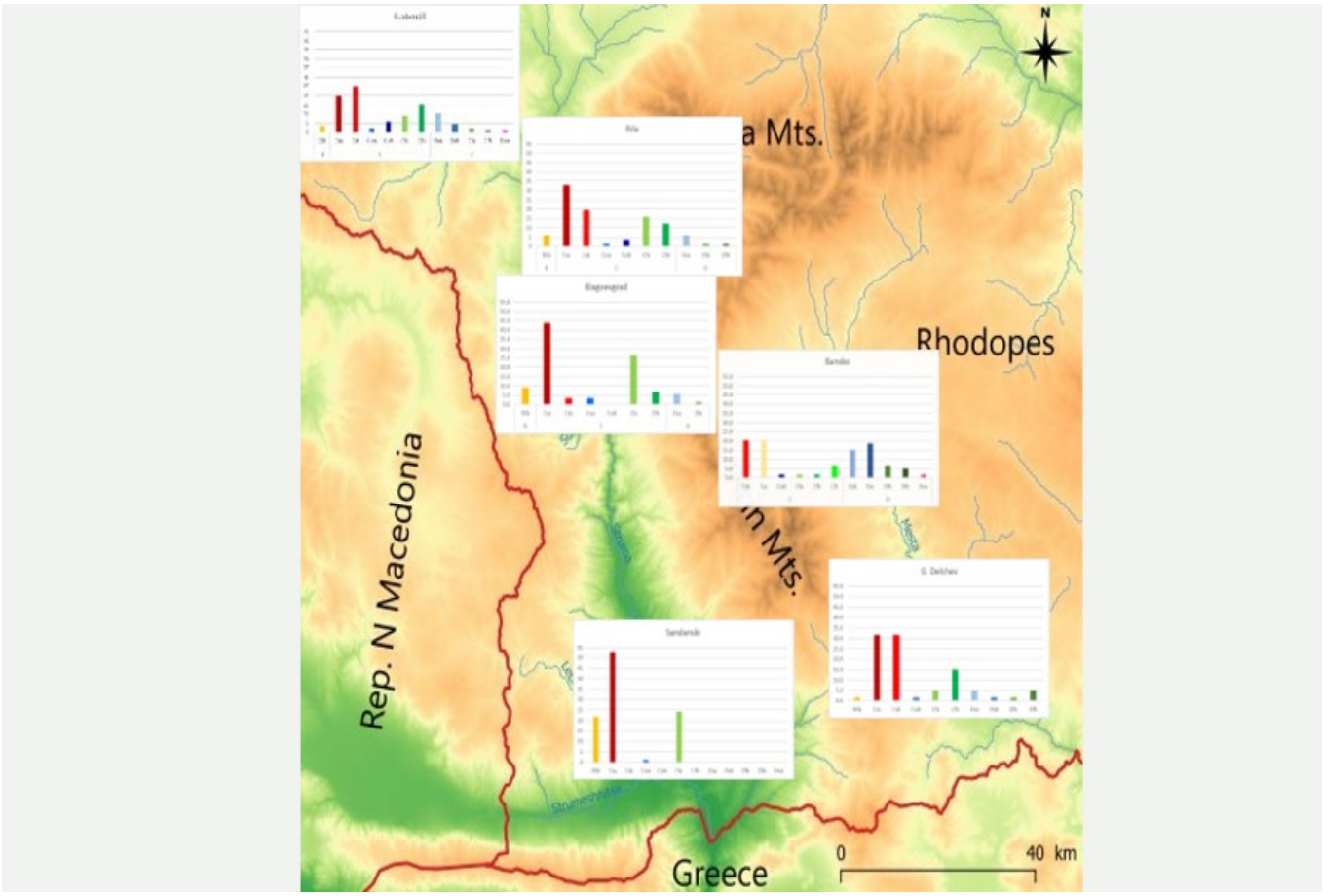


**figure 2.** Spatial distribution of detailed Annual Climate Type (ACT) in Struma and Mesta Valleys (Southwest Bulgaria) (key and zoom of charts in Fig. 3).

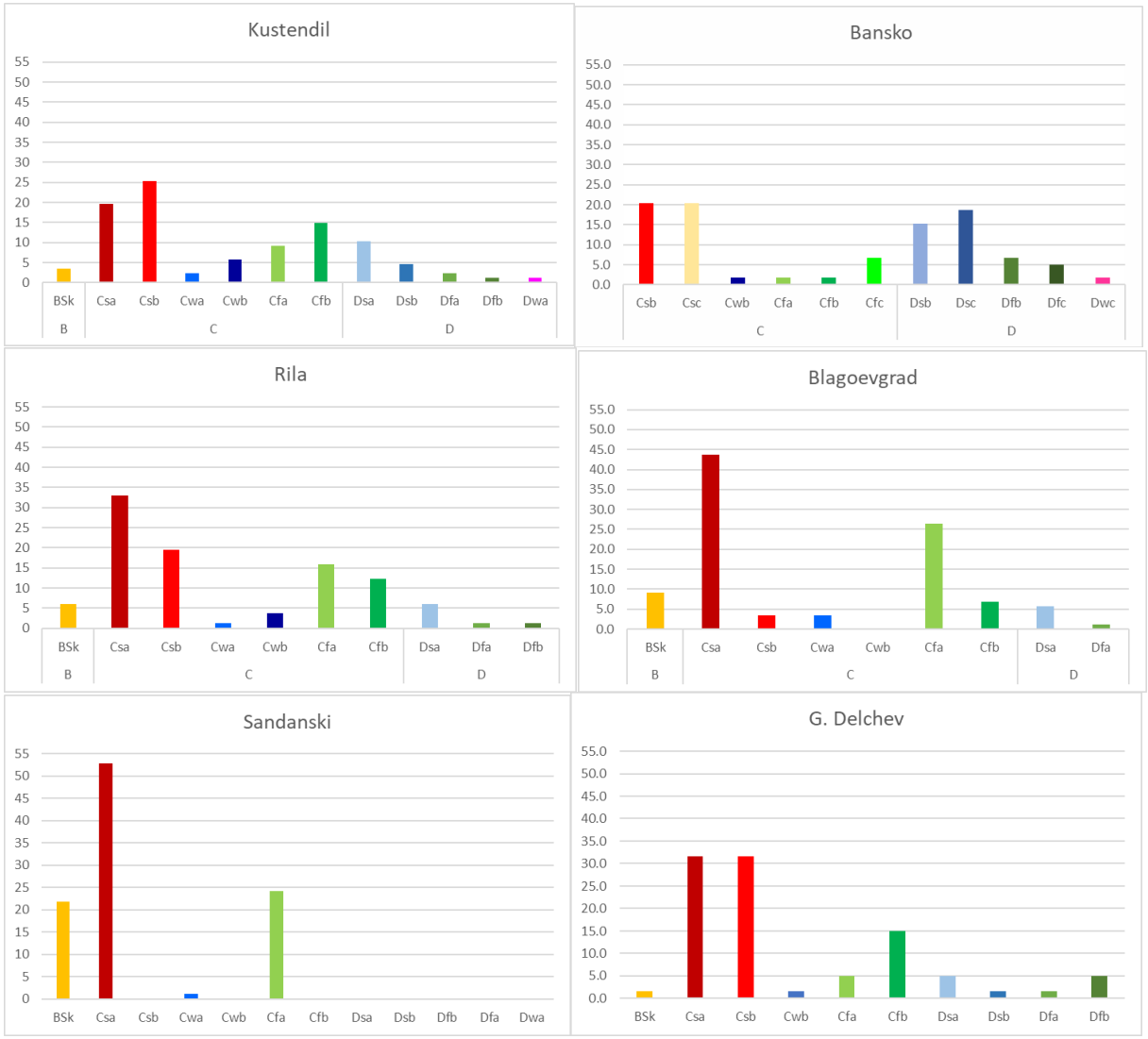


**figure 3.** Quantitative distribution of detailed Annual Climate Type (ACT) in Struma and Mesta valleys (Southwest Bulgaria). Climate types are shown along the x-axis (Orange – BSk, Dark red – Csa, Red – Csb, Blue – Cwa, Dark blue - Cwb, Green – Cfa, Dark green – Cfb, Sky blue – Dsa, Dark sky blue – Dsb, Forest green – Dfa, Dark forest green – Dfb, Pink – Dwa, Dark pink – Dwc, Very dark sky blue – Dsc, Very dark forest green – Dfc only for Bansko station) and percentage frequencies along the y-axis.

## Conclusion

The continental climates with cold winters - "D" cover 47% of the studied period. The rest of the study area has significantly less continental influence. For the region of the Gotse Delchev valley and the middle reaches of the Struma the share of the years with cold winters is about 7-8%. They are more often registered in the Kyustendil valley where their share is about 20%.

The Mediterranean influence in the region is registered by the indices defining dry summer. For the Valley of Mesta, the years with such indices are between 70 and 75%. For the Struma Valley, these indices cover between 53 and 60% of the study period.

Regarding the indices characterizing the years as dry climate (BSk), their share is the largest for the region of Sandanski-Petrich field, where they reach 20%. For the last 30 years, however, the share of dry climate years in this region is one third. Impressive are the years 2000 and 2011 during which all stations in the Struma Valley registered a dry climate index. Far away in past 1948 was also a year with a BSk ACT for Struma Valley and also the southern part of Mesta Valley.

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