Classification of Serbian winegrowing regions based on climate-viticulture indices

Mirjana Ruml[1], Ana Vuković[1,3], Mirjam Vujadinović[1,3], Vladimir Djurdjević[2,3], Zorica Ranković-Vasić[1], Zoran Atanacković[1]
[1]*Faculty of Agriculture, University of Belgrade, Serbia (mruml@agrif.bg.ac.rs)*
[2]*Institute for Meteorology, Faculty of Physics, University of Belgrade, Serbia*
[3]*South East European Virtual Climate Change Center, Belgrade, Serbia*

Abstract
The aim of this work was to categorize wine region climates of Serbia using climate-viticulture suitability indices and compare the results to other winegrowing regions in Europe and worldwide. Meteorological observations for all available climatological stations located in the traditional viticultural regions of Serbia with complete data for the period 1961–1990 were used to determine five commonly used indices in viticulture zoning studies: growing season average temperature, the Winkler index, the heliothermal, dryness and cool night index as used in the Geoviticulture multicriteria climatic classification system.

Materials and methods
We considered precipitation and temperature observations for all available climatological stations located in the traditional viticultural regions with complete data for the period 1961–1990 (the reference time period for the present climate according to the World Meteorological Organization). Data were provided by the Republic Hydrometeorological Service of Serbia.
The climate-viticulture indices were calculated according to the equations given in Table 1 and evaluated on the basis of the maturity class levels listed in the same table.

Table 1. Climate-viticulture indices and ranking systems used in the study

Index/Reference	Equation	Period	Classes definition	
Average growing season temperature (Tgs) Jones (2006)	$1/N\ \Sigma((Tmax+Tmin)/2)$ Tmax – maximum daily temperature Tmin – minimum daily temperature N – number of days in the period	April - October	Too cool Cool Intermediate Warm Hot Very hot Too hot	< 13°C 13 to 15°C 15 to 17°C 17 to 19°C 19 to 21°C 21 to 24°C >24°C
Growing degree-days (GDD or WI) Winkler et al. (1974)	$\Sigma\ ((Tmax+Tmin)/2)-10°C)$	April - October	Region I Region II Region III Region IV Region V	< 1390 1391 to 1670 1671 to 1940 1941 to 2220 > 2220
Huglin index (HI) Huglin (1978)	$\Sigma\ ((Tavg - 10°C)+(Tmax -10°C)/2)*k$ Tavg – average daily temperature *k* latitude /daylength adjustment factor	April - September	Very cool (HI-3) Cool (HI-2) Temperate (HI-1) Temperate warm (HI+1) Warm (HI+2) Very warm (HI+3)	< 1500 1500 to 1800 1800 to 2100 2100 to 2400 2400 to 2700 > 2700
Dryness ndex (DI) Tonnieto and Carbonneau (2004)	$Wo - \Sigma\ (P- ET)$ Wo – initial soil moisture P - precipitation ET – evapotranspiration	April - September	Very dry (DI+2) Moderately dry (DI+1) Sub-humid (DI-1) Humid (DI-2)	< -100 -100 to 50 50 to 150 >150
Cool night index (CI) Tonnieto (1999)	$1/N\ \Sigma\ Tmin$	September	Very cool nights (CI+2) Cool nights (CI+1) Temperate nights (CI-1) Warm nights (CI-2)	< 12°C 12 to 14°C 14 to 18°C > 18°C

Results and discussion
The five climate-viticulture suitability indices were analyzed for each of 14 climatological stations individually (Figure 1), then averaged by region (Table 2) and compared to other viticultural regions worldwide.

According to classification based on Tgs, vineyard regions of Serbia belong to a warm category, which allows for a very large range of varieties to ripen (Jones, 2006). The Serbian viticultural regions, averaging around 1400-1500 GDD, fall into Winkler region II.

Table 2. Mean values of climate-viticulture indices of major Serbian winegrowing regions.
Tgs - average growing season temperature; WI -Winkler index; HI - Huglin index; CI - Cool night index; DI - Dryness index.
The unit DD stands for degree-days.

Region	Tgs (°C)	WI (DD)	HI (DD)	DI (mm)	CI (°C)
Subotica – Horgoš	17.4	1454	2009	144	10.8
Banat	17.9	1564	2065	181	11.2
Srem	17.7	1511	2050	150	11.2
Šumadija - Great Morava	17.4	1459	2033	179	10.6
West Morava	17.5	1479	2029	217	10.6
Timok region	17.8	1432	2118	140	10.4
Nišava - South Morava	17.6	1503	2058	144	10.8

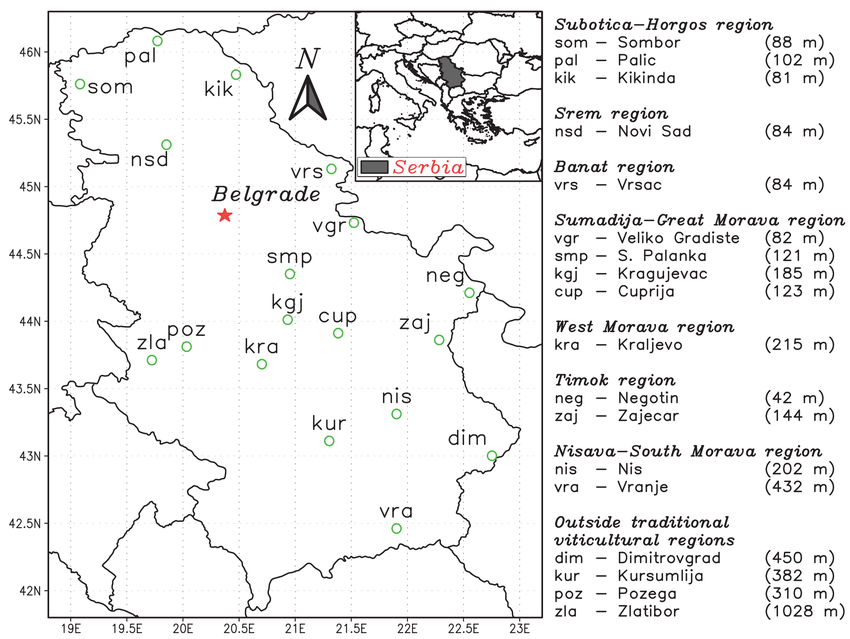

Figure 1. Viticultural regions in Serbia and stations with available observations for period 1961 - 1990

The three viticultural climates, defined in the Geoviticulture MCC system, are present in Serbia (Figure 1 and Figure 2):
▲ HI–1 DI–1 CI+2 temperate, sub-humid with very cool nights, regions: Subotica-Horgoš, Srem and Nišava-South Morava;
▲ HI–1 DI–2 CI+2 temperate, humid with very cool nights, regions: Banat, Šumadija-Great Morava and West Morava;
▲ HI+1 DI–1 CI+2 temperate warm, sub-humid with very cool nights, Timok region.

According to Tonietto and Carbonneau (2004), the theoretical characteristics of viticultural climate classes in Serbia, are:
HI–1 - the later varieties, such as Cabernet-Sauvignon, Ugni Blanc and Syrah can reach maturity;
HI+1 - Grenache, Mourvèdre, Carignan can ripen, meaning that there is practically no heliothermal constraint to ripen all cultivated varieties (besides some exceptions such as the seedless varieties);
DI–1 - characterizes "absence of dryness";
DI–2 - corresponds to "absence of dryness" with a high level of water availability, that may have a negative effect on grape and wine quality; commonly best quality is obtained in less humid years;
CI+2 - the positive effect of low night temperatures on colour, aroma and flavour characteristics, depends primarily on a heliothermal potential that ensures good grape ripening for a given variety.

Jones et al. (2009) have examined the spatial structure of six commonly used climate-viticulture indices in 16 European winegrowing regions and compared the results to other western United States and Australian regions. Comparison of indices between Serbian and viticultural regions given in Jones et al. (2009) reveals that vineyards of Serbia have pretty unique viticultural climates.
When hydric characteristics are considered, Serbian regions are similar to much cooler German regions.
On the other hand, regions with similar heliothermic conditions as Serbian ones, are much drier and with higher minimum temperatures in the ripening month (Côtes du Rhône Méridionales in France; Barolo, Chianti and Classico Vino Nobile di Montepulciano in Italy; Porto and Vinho Verde in Portugal), Figure 2 ●
In the work of Tonietto and Carbonneau (2004), the same viticultural climates as those in Serbia, according to MCC system, have been identified in Perugia, Italy and Bratislava, Slovakia (Figure 2 ▲), and in Macon, France (▲), but there are no matches for viticultural climate HI+1 DI–1 CI+2 (▲) in their database.
Also, same climatic groups as those in Serbia, have been found in Galicia (north west Spain) where the most present types are temperate (HI–1) or temperate warm (HI+1), sub-humid (DI–1) with very cool nights (CI+2), as reported by Queijeiro et al. (2006).

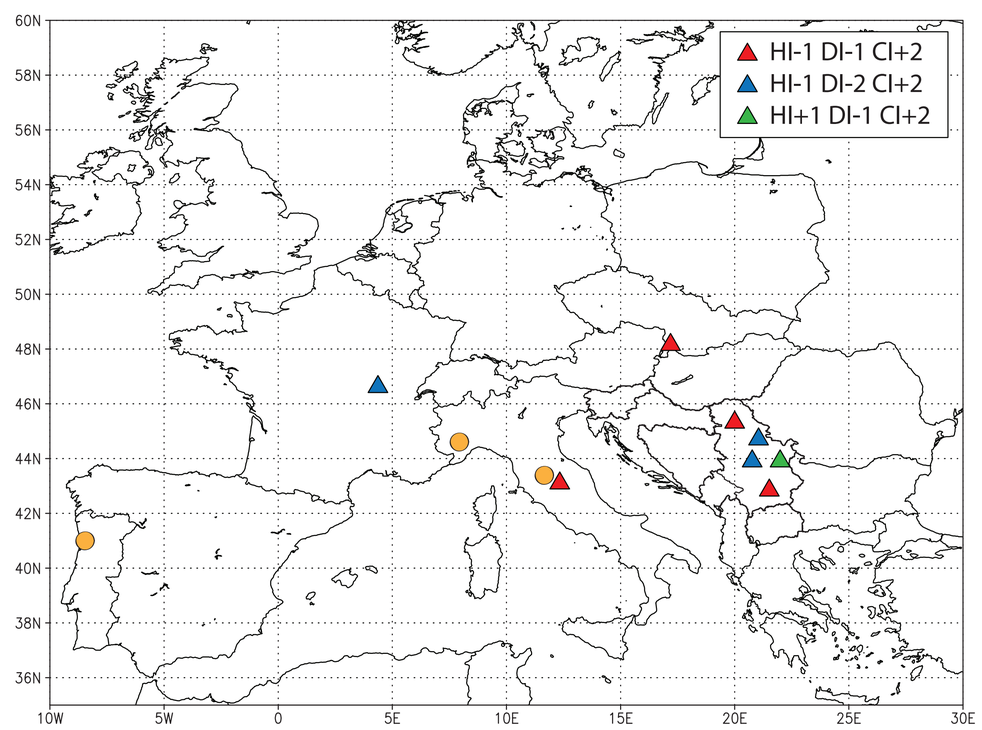

Figure 2. Examples of viticultural climates similar to those in Serbia, according to MCC system.

It is important to point out that belonging to the same climatic group indicates similar, not necessarily the same climatic characteristics of the regions. Due to the large climate variability worldwide, there could be significant climatic differences between regions within the same climatic group and even with the same HI, CI and DI values. To better depict the viticultural climate of a region, sometimes it is necessary to compare the evolution of the climatic indices throughout the vine cycle and relate it to the phenology.

Conclusion
This study provides a comprehensive and climatically appropriate zoning of viticultural potential in Serbia and compares it to other traditional viticultural regions in Europe and worldwide. Since the baseline climate has been determined, then, it is possible to further investigate the impact of climate variability and climate change on grape growing conditions in the studied region.

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