High resolution climate spatial analysis of European winegrowing regions
Analyse spatiale haute résolution du climat des régions viticoles européennes

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ABSTRACT

Climate strongly affects the geographical distribution of grape varieties, grapevine cultivation techniques and wine organoleptic properties. The current study aims at comparing the climatic features of European winegrowing regions. A geodatabase of 260 wine producing areas within 18 countries of the European Community was first established by means of maps collected from various sources (e.g. atlases and national wine and vine services). Within the 247 of the 260 initially delimited regions, areas actually planted with vine were identified by means of the Corine Land Cover database, for a total of 6 million of hectares. Each of the 1 km resolution pixels of the WorldClim 1950-2000 monthly climatic database located within these planted areas were used to calculate agroclimatic indices. The Huglin index, the Cool night index and the Dryness index, as described by the Multicriteria Climatic Classification system, as well as a winter freeze risk index, a spring frost risk index and a heat stress index were calculated. The use of a clustering algorithm (CLARA) with each of these 1 km resolution gridded indices resulted in the identification of six climate types: (1) sub-humid temperate, (2) sub-humid cool with very cool nights and high spring frost risk, (3) moderately dry and temperate with cool nights, (4) dry and temperate warm with temperate nights, (5) sub-humid temperate with strong frost risks, and (6) very dry and hot, with cool nights climates. Each of the 247 winegrowing regions was classified according to the type of climate that covers the largest part of its territory. Despite the clustering, the type 4 climate still exhibits a large diversity of climatic characteristics. It is located mainly within winegrowing regions located close to the Mediterranean Sea. To our knowledge the current work is the largest spatial climate analysis of winegrowing regions that have been performed so far.

Keywords: Climate,* Vitis vinifera*, European viticulture, WorldClim, agroclimatic indices.
Mots-clés : Climat,* Vitis vinifera*, viticulture européenne, WorldClim, Indices agroclimatiques.

1 INTRODUCTION

Thanks to the continuous and rapid growth of both communication and computer sciences, climate analyses and zoning of winegrowing regions are performed with an increasingly high spatial resolution. These analyses are mostly based upon gridded climate data interpolated from weather station records, rather than point data [1],[2]. Such approaches allow one to consider grape growing areas not only on the basis of their average climate characteristics, but also by taking into account the variability of the climatic structure within each region.

However, to depict and understand climate characteristics in winegrowing regions using gridded climate data requires an accurate delimitation of the studied area. For example, for relatively new winegrowing regions, where vineyard development is still occurring, gridded climate data summarized over the region can help depict it's potential suitability [1],[2]. On the other hand, if the goal is to study the climate characteristics of existing vineyard areas within regions, having precise vineyard land cover is important so as to capture the true climate structure. Corine Land Cover, a spatial database developed by the European Environment Agency, makes relatively precise identification of vineyards possible (CLC2000; polygons of approximately 25 ha resolution [3]) limiting the influence of non-vineyard lands that could be due to a specific land cover (e.g., urban areas) or terrain limitations to vineyard development (i.e., atypical slopes, elevations or aspects). The CLC2000 was previously used to assess the climate characteristics of 16 European winegrowing regions [4], and this research represents an update of that work to 260 European winegrowing regions from 20 European countries

2 MATERIAL AND METHODS

2.1 Agroclimatic indices

The climate analysis of European winegrowing regions was performed using the WorldClim 1950-2000 monthly gridded (interpolated) climate database [5]. Monthly rainfall, minimum and maximum temperature at 30 arc-seconds (~1 km) spatial resolution were used to calculate six agroclimatic indices:

- The Huglin index (HI) a heat summation from April to September modulated by a daylength factor estimated from the site's latitude;

- The Cool Night index (CI), the minimum temperature of the month of September;
- The Dryness index (DI), which is the result of a water balance calculated each month from April to September, as defined by the Multicriteria Climatic Classification system (MCC) for grapegrowing regions worldwide [6]. To calculate DI, evapotranspiration was estimated from monthly temperature data using Hargreave's formula [7];
- An extreme heat stress index (HSI), defined as the maximum temperature of the hottest month of the year;
- A winter freeze risk index (WFR), defined as the minimum monthly temperature of the coldest month from November to March;
- A spring frost risk index (SFR), defined as the minimum monthly temperature of the coldest month during April and May.

HSI, WFR and SFR were developed from a preliminary climate analysis using ECA&D daily temperature data of 24 sites from Sweden (Nordby) to Algeria (Algeria). Heat stress (daily max. temperature over 35°C) and frost/freeze (daily min. temperature under -1°C for April / May and -17°C during winter) frequencies were calculated for each station. These values were compared to the monthly temperature data. A strong relationship (R^2 from 0.70 to 0.92) was observed between station extreme events frequency and gridded monthly min. and max. temperature data.
These six agroclimtic indices were then calculated for each 30 arc-second pixel (~1 km resolution over the study area) located were grapevines are actually planted.

2.2 European winegrowing regions geodatabase
The climate analysis was performed for the European vineyards identified from class 221 of the Corine Land Cover 2000 GIS vector layer (CLC2000, [3]). As this database does not provide information concerning the name of the winegrowing region, we developed a geodatabase (GIS vector layer) of European winegrowing regions.
European winegrowing regions were identified using several sources: the World Atlas of Wine, 5th edition [8], a European vineyards map edited by Benoît France [9] and a map of Portuguese IGP collected from the Portuguese Institute of Vine and Wine [10].
Each of the maps collected from these sources were georeferenced, and bulk limits of 260 winegrowing regions were digitized using QGIS software [11]. From this process it was possible for a given winegrowing region to encompass other smaller appellations. For example, Piemonte (Italy) was considered as a single region, rather than a collection of appellations such as (Asti, Roero, Barolo, Barbaresco, etc.). The winegrowing region geodatabase was overlayed on the CLC2000 vineyard layer to assign each vineyard polygon to a winegrowing region. Overall 59346 WorldClim pixels (about 6 million hectares) located within CLC2000 vineyards polygons (Figure 1) were used to perform the analysis of European winegrowing region climatic features. Thirteen delineated regions contained no WorldClim pixels (due to size or spatial configuration), reducing the number to 247 winegrowing regions that were analysed.

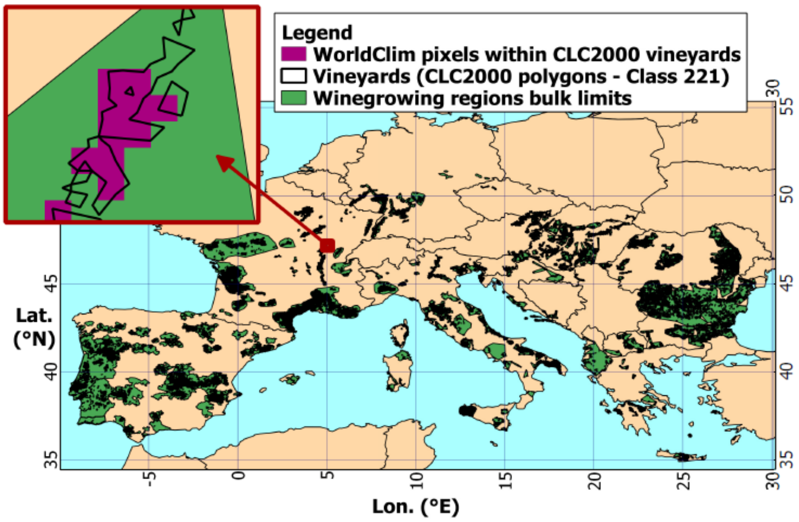

Figure 1. The winegrowing regions geodatabase and the CLC2000 vineyard gridded at to match WorldClim data.

2.3 Statistical analysis
The six agroclimatic indices were used to perform a clustering of the collection of vineyard pixels. Given the considerable quantity of pixels to analyse, CLARA (Clustering Large Application), a clustering method using sub-sampling to address large datasets, was used [12]. This k-medoids clustering method is similar to k-means, but proven to provide more relevant partitioning [13]. As the final number of clusters has to be set by the user, CLARA was performed 19 times to produce from 2 to 20 final clusters. The iteration providing the largest average dissimilarity between each cluster was selected (using the silhouette index [14]).

3 RESULTS AND DISCUSSION

The largest dissimilarity between each cluster was The largest dissimilarity between each cluster was reached with six clusters (Figure 2). Their average climatic features are shown in Table 1. According to the MCC classification [5], the clusters exhibit the following climate characteristics:

Cluster 1 the grape growing climate can be described as sub-humid temperate with cool nights and moderate spring frost risk.

Cluster 2 has similar average features as for cluster 1, but it nights are cooler in September, and the freeze risk is moderate during winter and spring frost risk is high during spring.

Cluster 3 has moderately dry and temperate warm agroclimatic mean characteristics, with cool nights, and moderate spring frost risk.

Cluster 4 is globally moderate. It's average characteristics are similar to cluster 3, but without any extreme climate event risks, and has temperate nights during September.

Cluster 5 average Dryness index is classified as moderately dry. Its thermal structure is temperate with cool nights. Freeze risks are medium during winter and frost risks high during spring.

Cluster 6 exhibits the most extreme climatic characteristics being very dry and warm, with temperate nights, moderate spring frost risk and heat stress during summer often occurs.

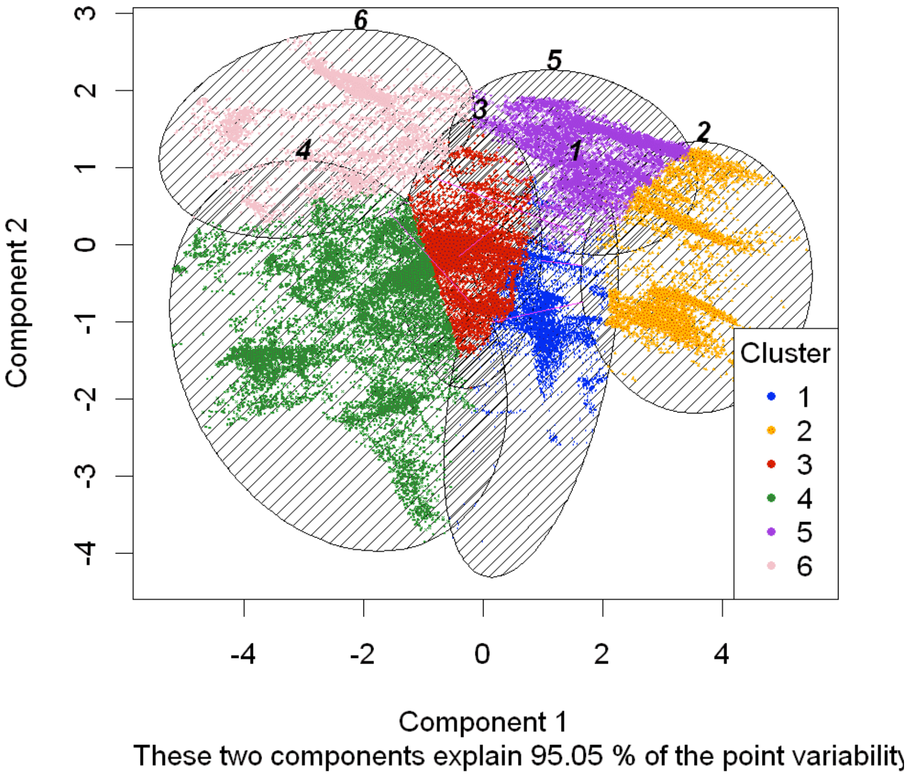

Figure 2. CLARA cluster group representations of the WorldCLim pixels located within winegrowing regions (Axes correspond to the two first principal components of a PCA performed on the agroclimatic indices).

Cluster 4 encompasses the largest area (about 1.4 million hectares, Table 1). It also exhibits the largest climatic diversity (Figure 2). The variance of each of the six indices used for this partitioning is always the highest for cluster 4. Cluster 3 shows little climatic distinctiveness and can be consider as an "average" group, has displayed by its central position on Figure 2. Within each region, the distribution of the total area (number of pixels) for each group was addressed. Some regions are fully classified in a given cluster (such as Charentes, France, within which 100 % of the pixels are associated with cluster 1). Other regions have greater diversity; such as Umbria (Italy), which has 46.1% of its area belonging to cluster 3 and 53.8% belonging to cluster 4.

European winegrowing regions were then classified according to the group which covered the largest area (Figure 3). The maps of group location reveal climatic proximity between regions that are sometimes spatially remote. For example, the Ribera del Duero (Spain) as well as Val de Loire (France) and Friuli/Venezia Giulia (Italy) are classified within cluster 1 (at least for the largest part of their area planted to vineyards). The thermal risks are indeed similar within these regions (data not shown). Yet some climate characteristics of theses regions remain different (HI of 1635°C.days for Val de Loire against 2154°C.days in Venezia), which underlines the limits of the choice of only six clusters to depict climate features of such a large area.

Table 1. European vineyard-climate index cluster average values. ***N = number of pixels (See section 2.1 for other acronym definitions).*** **Warm colors (i.e. yellow and orange) suggest either low DI, WFR, SFR or high HI, CI and HSI.**

	Multicriteria Climatic Classification			Extreme Events Risks			
Cluster	**DI**	**HI**	**CI**	**WFR**	**SFR**	**HSI**	**N**
1	78	1845	12.3	1.0	3.8	26.0	10051
2	117	1597	9.8	-3.2	0.6	24.6	7285
3	21	2101	13.5	1.0	4.4	28.3	9983
4	-11	2305	16.3	4.9	7.1	28.7	14122
5	38	2013	11.0	-4.8	0.5	27.4	9656
6	-117	2492	14.0	1.4	4.5	32.4	8249

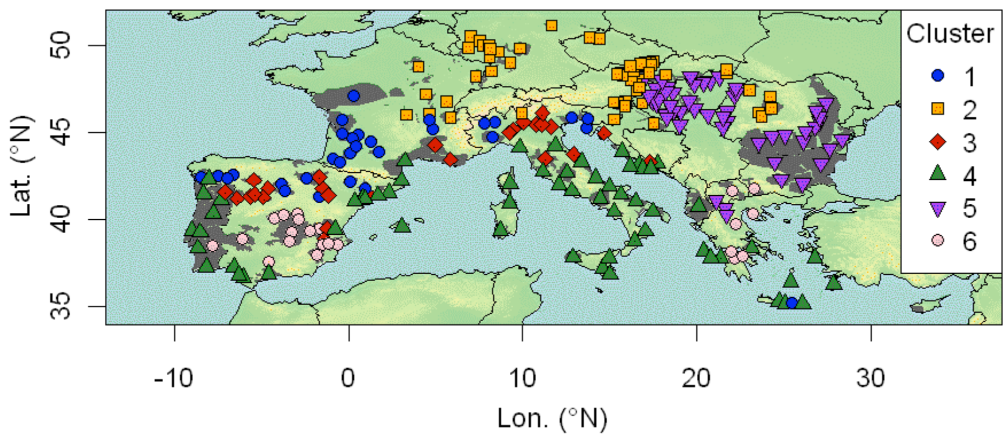

Figure 3. Cluster membership of the 247 winegrowing regions.

Most of the regions located on the Mediterranean coastal areas of Southern Europe are classified in cluster 4. These regions show a strong climatic diversity in some characteristics. For example, the Sicilian region of Eloro is marked by warm nights during September (average CI = 19.1°C) while the Northern Portugal Miñho region provides cool to temperature nights (average CI = 13.7°C). Though generally dry, sub-humid climates can also be found within this group, such as in Marche (Italy).

4 CONCLUSIONS

The present work describes an analysis of European winegrowing regions by means of the Multicriteria Climatic Classification and climate risk indices, applied to a high resolution gridded monthly climate data set. The development of a geodatabase locating the bulk limits of 260 grape growing regions combined with the vineyard area identified in the CLC2000 database allowed for a more precise analysis of actual planted areas. An objective clustering procedure resulted in the identification of six clusters which, though spatially remote, exhibited common climatic characteristics. We believe that further development of this work might be a useful contribution to better depict and understand terroir characteristics of winegrowing regions worldwide.

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