Temperature variations in Central Italy (Marche region) and effects on wine grape production

Matteo Gentilucci, Marco Materazzi, Gilberto Pambianchi, Peter Burt & Giulia Guerriero

ONLINE FIRST

Theoretical and Applied Climatology

ISSN 0177-798X

Theor Appl Climatol
DOI 10.1007/s00704-020-03089-4

Springer

Theoretical and Applied Climatology
https://doi.org/10.1007/s00704-020-03089-4

ORIGINAL PAPER

Temperature variations in Central Italy (Marche region) and effects on wine grape production

Matteo Gentilucci[1] · Marco Materazzi[1] · Gilberto Pambianchi[1] · Peter Burt[2] · Giulia Guerriero[3,4]

Received: 19 November 2018 / Accepted: 2 January 2020

Abstract

The analysis of temperatures in this historical moment characterized by human-induced climate changes is becoming increasingly important. This study aims to accurately assess the change in temperatures over the past 50 years through the evaluation of 3 climatological standard normals. The pilot project was developed on the Marche region, an area on the Adriatic coast of Central Italy, and analyses climate change from a spatial point of view making extensive use of GIS software. The second purpose of this research is the evaluation of the relationship between the variation in the production quantities of wine grapes, a crop of value for the economy of this region, and the changes in average temperature. Obviously this study aims to provide a starting point for research that can also be applied to other territories, depending on the valuable crops possessed. The analysis showed a rise in temperatures from the past to the present; in fact comparing the period 1971–1990 with 2001–2020, there has been an increase of more than 0.5 °C on average although comparing the years 1981–1990 and 2011–2020, it has very weakened with a growth of only 0.1 °C. In this context, the influence that temperature can exert on *Vitis vinifera* has been evaluated with an inverse correlation. In fact, a higher temperature leads especially in all months except September to a decrease in production. This study could in the future calculate the optimal development temperatures for the different *Vitis vinifera* cultivars, not through the study of phenological phases but through production data. This analysis makes it increasingly clear how climate change can have enormous effects on the economy and on human life.

1 Introduction

1.1 Aim of the study and state of the art

Climate change is a global phenomenon which has become clear from the many studies which have been carried out over the last few years. The interest of the international community is mainly focused on future projections of climate change both at global (Meehl et al. 2007), Mediterranean (Giorgi and Lionello 2008), or European level (Déqué et al. 2005). However, the starting point is even important, as it is more appropriate to identify with certainty the climate changes that have occurred previously in order to assess possible future changes (Salinger 2005). There are several studies that address the analysis of past and present climate change. Climate studies tend to analyze very large areas, which do not match the variability typical of local atmospheric dynamics. In fact, there are many studies on Europe (Piani et al. 2010) and on the Mediterranean basin (Lionello et al. 2006) but few on smaller areas in order to provide a reliable report also necessary for application purposes. When the purpose of climate research is applicative, it is necessary to have the maximum precision in the collection of the initial parameters. There are some studies of a local nature such as those dealing with urban heat islands (Giannaros and Melas 2012; Akbari et al. 2016) or even few studies that analyze the climate in small extension areas (Gentilucci et al. 2018a, d). In this context, in order to be able to compare the analyses carried out in different parts of the world, it is necessary to divide the periods (climatological standard normal) according to the prescriptions of the World

✉ Matteo Gentilucci
matteo.gentilucci@unicam.it

1 School of Science and Technologies, University of Camerino, 62032 Camerino, Italy

2 Natural Resources Institute, University of Greenwich at Medway, Chatham, Kent ME4 4TB, UK

3 Department of Biology, University of Naples Federico II, Complesso Universitario di Monte S. Angelo, Via Cintia 26, I-80126 Naples, Italy

4 Interdepartmental Research Center for Environment (I.R.C.Env.), University of Naples Federico II, Via Mezzocannone 16, I-80134 Naples, Italy

Published online: 13 January 2020

Meteorological Organization (WMO 2017). Only few studies use climatological standard normal periods (Tadić 2010; Arguez et al. 2012); even fewer compare variations between them (Walsh 2012; Labudová et al. 2015). On the other hand, there are numerous studies in the literature that deal with climate trends for various regions (Moberg and Jones 2005; Kürbis et al. 2009). A further innovation that is present in this study but that at an international level has not been very thorough is that referred to the spatial variability analyzed by software type GIS. The GIS software applied to climate analysis can also provide graphical estimates of climate change (Rathod and Aruchamy 2010). In addition, this type of detailed analysis is extremely important to assess the local atmospheric dynamics (Wang 2014). Focusing on the study area (Marche region, Central Italy), there are a climate report for temperature from 1950 to 2000 (Spina et al. 2002). The climate issue was also dealt in a multidisciplinary way, in this area, highlighting some problems related to temperature increase (Appiotti et al. 2014). Therefore, the present study aims to provide a working method for a detailed analysis of climate trends and climate change, also from a spatial point of view, using geostatistics and GIS software. The other purpose, no less important, is to evaluate the influence that temperature has had on the production of valuable crops in recent years, in particular for *Vitis vinifera*. In literature, there are numerous studies dealing with viticultural zoning; however, very often they have a global character with few weather stations and large areas to be interpolated (Malheiro et al. 2010; Fraga et al. 2013). Moreover, the calculation of the optimal temperatures for the single cultivar of *Vitis vinifera* always involves the analysis of the phenological phases (Nendel 2010), which are not always available or are available for a few years. This study aims to establish whether the temperature variation has brought advantage or disadvantage to the production of wine grapes. Furthermore, it could be the starting point in the future for the calculation of optimal temperatures for wine grapes, based on annual production data.

1.2 Geography of the area

The Marche region is an area of 9.401 km^2 (Fig. 1) in Central Italy, overlooking the Adriatic Sea with about 173 km of coastline. The territory is mostly hilly 69%, although there is to the west a wide mountain belt corresponding to the Central Apennines. The highest peak in the region is the Mount Vettore (2476 m a.s.l.), while from a hydrographic point of view, the rivers flow from west to east and the Metauro is the longest river (121 km). In the southwestern part of the region, there is the only river that flows in Tyrrhenian Sea (E-W), the river Nera, which is a tributary of Tevere River. As far as the climate is concerned, the Marche region has a marked variability that reflects its own territory. In fact, considering the classification of Koppen-Geiger, we can identify 5 different

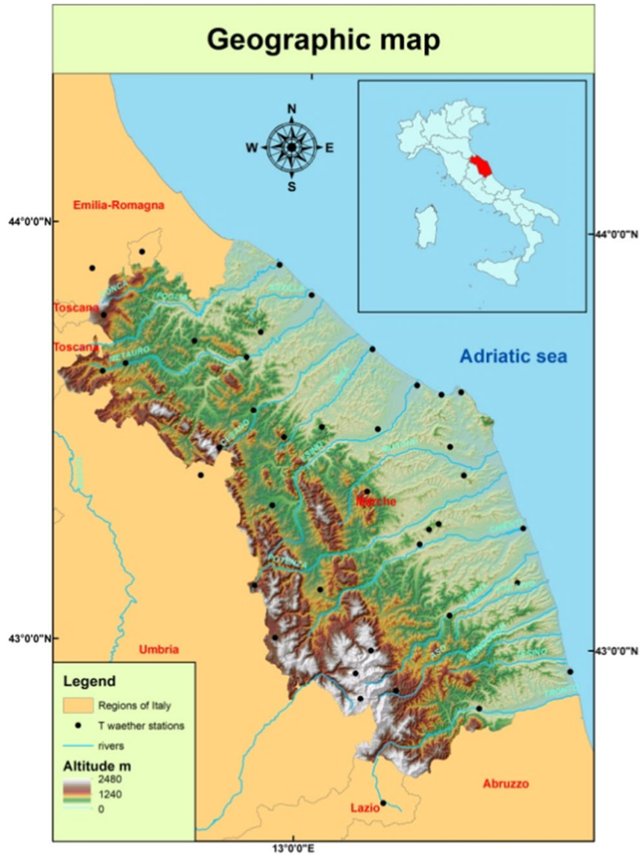


Fig. 1 Geography of the area

types of climate (Fratianni and Acquaotta 2017): "E" on the highest peak of Appennines, "Ds" on all the mountains of Appennines, "Cfc" on the Appennine foot, "Cfb" on the hills of Marche region, "Cfa" on the central-northern coast and in the territories behind the coast to the south, and "Csa" the typical Mediterranean climate in a small part of the southern coast.

2 Methods

Temperature data from 24 complete weather stations for temperature were collected. The institutions that provided the climate data were the following: the Experimental Geophysical Observatory of Macerata, former National Hydrographic Service (SIMN), Multiple-Risk Functional Center of the Civil Protection, Italian Air Force, Service Agency for the Agrifood Sector of the Marche Region (ASSAM), and the Functional Center of Umbria. The data were grouped into 3 climatological standard normals: 1971–2000, 1981–2010, and 1991–2020. The data were then subjected to a process of validation. The validation composed of quality control and homogenization has made it possible to increase the reliability of the data. The quality control was divided in gross error check (removal of impossible values), internal consistency (maximum value lower than a minimum one for temperature or a negative value for precipitation), tolerance test (each weather station is checked on the basis of its historical time series), temporal consistency (analysis of the values of contiguous days), and spatial consistency (analysis of the neighboring weather station to identify possible errors) (Gentilucci et al. 2018b). Instead the homogenization was performed using the standard normal homogeneity test (Alexandersson 1986). The starting point for the research was the creation of annual temperature maps from the weather stations' data. For data interpolation, the geostatistical co-kriging method was chosen, which was the best from previous surveys (Gentilucci et al. 2018b). Co-kriging is composed of a dependent variable that is temperature (in this study) and an independent one. The independent variable has been identified to be the altitude, because it has the strongest relationship with temperatures, among various other topographic variables investigated (distance from the sea, distance from the river, latitude, local relief) (Gentilucci et al. 2018a). There are many types of co-kriging; however, in this research, will be used only the ordinary one (Johnston et al. 2003).

$$Z_{OCK}(u) = \sum_{\alpha_1=1}^{n_1(u)} \lambda_{\alpha_1}^{OCK}(u) Z_1(u_{\alpha_1}) + \sum_{\alpha_2=1}^{n_2(u)} \lambda_{\alpha_2}^{OCK}(u) Z_1(u_{\alpha_2}) \quad \lambda_{\alpha_2}^{OCK}(u) \quad (1)$$

$\lambda_{\alpha_1}^{OCK}(u)$ and

$=$ weights of the data $Z_1(u_{\alpha_1})$ and $Z_1(u_{\alpha_2})$

$=$ primary and secondary data

Ordinary co-kriging has the advantage of calculating the average on the basis of the neighboring weather stations and of not considering the average constant over the whole domain, for example, in the case of simple co-kriging (Schabenberger and Gotway 2017). This allows an optimal interpolation in the case of such a varied territory and with many different types of climate, such as that of the Marche region. Obviously, in addition to a theoretical justification, the improvement of spatialization was also calculated iteratively with the Geostatistical Analyst tool of the software ESRI ArcGIS (Goovaerts 1998). The goodness of the interpolation was assessed by comparing the cross-validation of the different co-kriging methods after the semivariogram analysis (Oliver and Webster 2015). Cross-validation is composed by four statistical indices: root mean square error (RMSE), average standard error (ASE), mean standardized error (MSE), and root mean square error standardized (RMSSE).

- $RMSE: \quad \sqrt{\sum_{i=1}^{n}\left[\frac{\left[\hat{Z}(s_i) - z(s_i)\right]^2}{n}\right.}$ (2)
- $ASE: \quad \sqrt{\frac{\sum_{i=1}^{n}\hat{\sigma}^2(s_i)}{n}}$ (3)
- $MSE: \quad \sum_{i=1}^{n}\left[\frac{\hat{Z}(s_i) - z(s_i)\left]/\hat{\sigma}(s_i)\right.}{n}\right.$ (4)
- $RMSSE: \quad \sqrt{\sum_{i=1}^{n}\left[\frac{\left[\hat{Z}(s_i) - z(s_i)/\hat{\sigma}(s_i)\right]^2}{n}\right.}$ (5)

The analysis of cross-validation is very important to ensure comparison and assess the significance of the study carried out. The values obtained are indisputably very good, and it follows that the interpolation is free of significant errors (Table 1). It is possible to observe that the value of the statistical indices is very close to the best possible value; in fact, the RMSSE is close to 1, RMSE is very similar to ASE, and the MSE is close to 0 (Johnston et al. 2001).

In this way, numerous interpolation maps have been created, one annual and one for each month of each climatological standard normals (1971–2000; 1981–2010; 1991–2020). Subsequently, these interpolation maps were compared with each other using the GIS tool "Raster math," which allows mathematical calculations between rasters. The following period was subtracted from the following period. The previous period was subtracted from the next period (i.e., 1991/2020–1981/2010; 1991/2020–1971/2000; 1981/2010–1971/2000). Subsequently, the maps of the variations were analyzed with descriptive statistics and, graphically, in order to obtain a complete report of variations. Subsequently, for the analysis of the effects of the change in temperature on wine grapes, territories with altitudes of more than 600 m were excluded from interpolation. An average was obtained for both the 30-year period and the individual months and years. An average was obtained for both the 30-year period and the individual months and years, while at the same time, data on the production of wine grapes from 1971 to 2018 were collected from the yearbooks of agricultural statistics of the ISTAT (National Institute of Statistics, Italy). Two data of interest have been identified: the area of cultivation of the vine in hectares and the production of wine grapes in tonnes. Finally, the thermometric and agricultural data have been correlated in order to evaluate the existence of some relationship.

3 Results

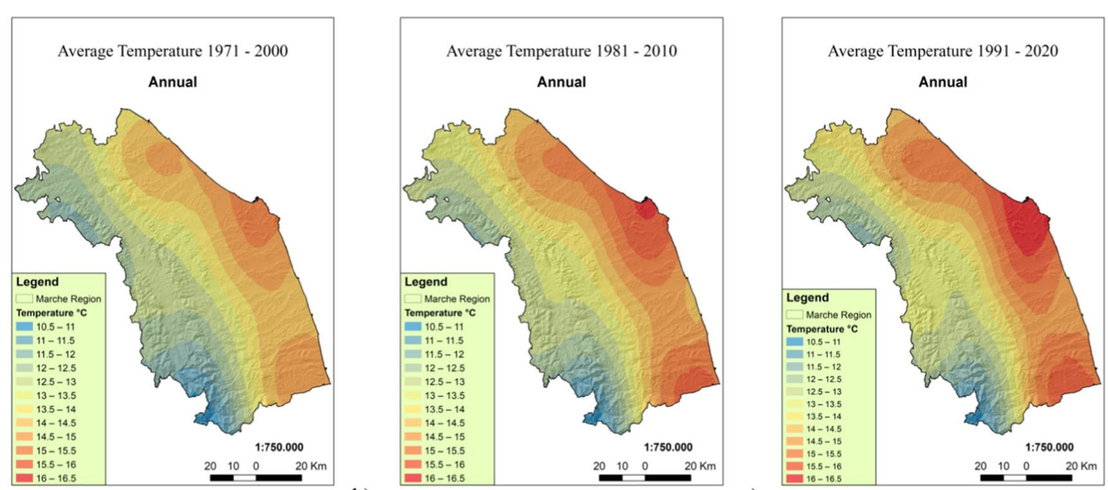
3.1 Interpolation of temperatures and precipitation

Interpolation is the basis for understanding the distribution of a climatic variable over a territory. The temperatures of the periods investigated (1971–2000; 1981–2010; 1991–2020) were analyzed from an annual, monthly, and seasonal point

Table 1 Value of statistical indices in the context of cross-validation for the interpolation of average temperature data in (to the left): 1971–2000 T; 1981–2010 T; 1991–2020 T

Period 1971–2000 T	RMSE	MSE	RMSSE	ASE	Period 1981–2010 T				
Annual av.	0.98	0.01	1.01	0.88	Annual av.	1.01	0.00	1.04	0.82
Av. January	0.84	0.03	1.03	0.75	Av. January	0.85	0.02	1.01	0.72
Av. February	0.97	0.02	1.02	0.86	Av. February	0.95	0.02	1.01	0.80
Av. March	1.02	0.00	1.00	0.96	Av. March	0.98	0.02	1.01	0.85
Av. April	1.08	−0.01	1.02	1.00	Av. April	1.01	0.00	1.03	0.90
Av. May	1.03	0.00	1.02	0.94	Av. May	1.02	0.00	0.97	0.92
Av. June	1.17	−0.01	1.03	1.03	Av. June	1.23	−0.01	1.09	0.97
Av. July	1.23	0.00	1.07	1.04	Av. July	1.23	0.00	0.95	1.13
Av. August	1.12	0.01	0.98	1.05	Av. August	1.14	0.01	0.98	1.01
Av. September	1.12	0.00	0.98	1.05	Av. September	1.14	−0.01	0.98	1.03
Av. October	1.05	0.00	0.98	1.00	Av. October	1.03	0.00	0.95	0.95
Av. November	0.90	−0.01	1.02	0.81	Av. November	0.92	−0.01	1.00	0.78
Av. December	0.83	0.03	1.03	0.74	Av. December	0.82	0.03	1.06	0.64
Period 1991–2020 T									
Annual av.	2,32	−0,22	1,19	2,22					
Av. January	0.71	0.01	0.90	0.68					
Av. February	0.84	−0.01	0.94	0.79					
Av. March	0.84	−0.02	0.94	0.78					
Av. April	0.92	0.00	0.99	0.85					
Av. May	0.91	0.01	0.89	0.87					
Av. June	1.02	0.01	0.89	0.95					
Av. July	1.14	0.01	0.95	1.01					
Av. August	1.00	0.01	0.90	0.90					
Av. September	1.01	−0.01	0.95	0.92					
Av. October	0.82	0.03	0.83	0.80					
Av. November	0.79	0.01	0.92	0.71					
Av. December	0.73	0.01	0.98	0.64					

of view. The data for the years of the months and seasons have been interpolated; however, for synthesis of exposure, the most significant maps are provided, relating to the average annual temperature of the period (Fig. 2). The annual maps show a thermometric variability that divides the region into bands parallel to the coastline and to the mountains. In fact, as



a) b) c)

Fig. 2 Three maps of average annual temperatures, for each standard period considered (**a** 1971–2000; **b** 1981–2010; **c** 1991–2020)

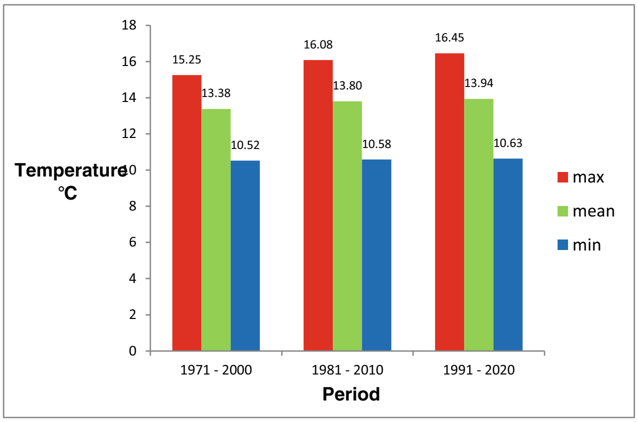


Fig. 3 Annual maximum, average, and minimum temperature in the study area for the considered periods (1971–2000; 1981–2010; 1991–2020)

explained above, the altimetric trend of the territory is decisive for the distribution of temperatures. The maps show (Fig. 2) that there is a warmer area on and around the coast, especially in the central and southern part of the Marche region. Going westward with the rise of the altitude, there is a gradual decrease in the average temperature until reaching the Apennine mountains, with the maximum cold concentrated in the southern part (Sibillini massif). In addition, it is visible a certain increase in temperature from the past (1971–2000) to the present (1991–2020) (Fig. 2).

The situation summarized through the histogram (Fig. 3) becomes immediately much clearer also from the point of view of the thermometric variations between the standard periods. There is a consistent growth of the average temperature especially since 1981; in fact the last two climatological standard normals, compared to the period 1971–2000, show an increase of about 0.5 °C. Assessing the variation between periods, it is possible to notice that compared to the average temperature, the maximum temperature has higher variations in percentage (about 0.8 °C between 1971 and 2000 and 1991–2020), while the minimum temperature shows an almost negligible increase (Fig. 3).

Therefore, comparing the period 1971–1990 and 2001–2020, it can be stated that there has been a significant increase in the average annual temperature of 0.56 °C. In the same period of time, the average maximum temperature rises by 1.2 °C, a sign of an increase in extreme temperatures, the most dangerous for crops. Instead, comparing the two non-overlapping decades of the last two periods (1981–2010; 1991–2020) we can see a slight increase in average temperatures (0.14 °C), although the increase in maximum temperatures is more substantial (0.37 °C). Minimum temperatures are not subject to significant increases.

3.2 Climate changes areal analysis

After a preliminary overview of the temperature situation of the Marche region, the thermometric variations can be analyzed in more detail. The tool to perform this through the software GIS ArcGis 10.5 is the mathematics between rasters. The rasters of the interpolations of the climatological standard normals have been used, subtracting from the more recent periods the less recent ones, allowing to obtain maps of the variations. These maps have been obtained for individual months for years and seasons, so as to have a complete overview of any thermometric changes affecting the Marche region between different standard periods (1971–2000; 1981–2010; 1991–2020). The following is the spatial evaluation of the annual thermometric variation (Fig. 4). From the maps, it can be seen that there is a clustering of areas that show a lower increase in temperature or in some cases a decrease in it and some with an higher increase in temperature.

The variations observed have been reported in graphs whose lines underlie the area of variations between the

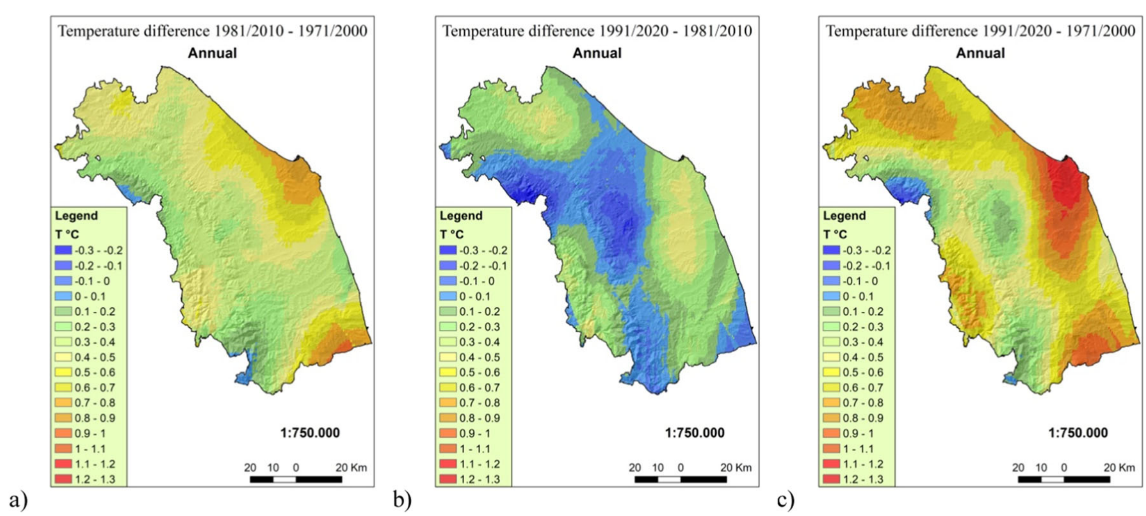


Fig. 4 Mean average temperature difference between the three standard periods: **a** difference between 1971–2000 and 1961–1990; **b** difference between 1981–2010 and 1971–2000; **c** difference between 1981–2010 and 1961–1990

Table 2 Descriptive statistic of annual average temperatures for areal variations between standard period

Annual average temperatures	1991/2020–1981/2010	1981/2010–1971/2000	1991/2020–1971/2000
Weighted average	0.10 °C	0.33 °C	0.51 °C
Most represented frequency	From 0.1 to 0.2 °C	From 0.2 to 0.3 °C	From 0.5 to 0.6 °C
Area of the most represented frequency	2080.85 km^2	3112.81 km^2	1592.24 km^2
Kurtosis	−1.77	−1.11	0.92
Skewness	0.04	0.59	1.39

climatological standard normals (**Errore. L'origine riferimento non è stata trovata.**). It is interesting to evaluate both the shape of distribution and the parameters in order to understand if the variations are homogeneously distributed over the territory or if there is a dominant frequency, etc. In order to obtain this result, descriptive statistics were used which allowed the numerical definition of the distribution (Table 2).

In this case, only the descriptive statistics of the annual variations for the 3 periods considered are reported; however, the considerations are very interesting. All the distributions move away from normal distributions; in fact, kurtosis which measure the flatness of a distribution show that 1991/2020–1981/2010 and 1981/2010–1971/2000 are platykurtic, while 1991/2020–1971/2000 is leptokurtic (Fig. 5). Instead the skewness of distribution is equal to 0 for the 1991/2020–1981/2010 and gradually further away from symmetry for the periods 1981/2010–1971/2000 and 1991/2020–1971/2000.

In this in-depth analysis, both the trend of seasonal variations between periods and the trend of monthly variations are fundamental. The seasonal variation graph shows little variation in the winter season and large variations aimed at a marked warming of the climate in both the spring and summer seasons (Fig. 6). Surprisingly, the autumn season shows a slight average decrease in temperature in the period 1991/2020–1981/2010 (Fig. 6).

As for seasonal averages, also for monthly and annual averages, the variations have been reported in a histogram (Fig. 7). In almost every month from the period before to the following one, there is a certain increase in temperature, which is highest in the summer months, in spring and in November, with some significant exceptions. In fact, there is the case of December where temperatures have always decreased from the first 30 years to the last. Furthermore there was also a decrease of the average temperature from 1971–2000 to 1981–2010 in February. Finally, there was a decrease between 1981–2010 and 1991–2020 for the months of September and October.

All the altimetric bands are growing, although we can see a weakening of the growing trend with the increase of the elevation. This trend is largely due to the difference in temperature values, which are lower in the mountains and higher near the coast (Table 3).

3.3 Grape production and relationship with temperature

In order to analyze the real influence of temperatures on the production of wine grapes, production data from 1971 to the present day have been collected for the Marche region. The production data were related both at the level of climatological standard normals (1971–2000; 1981–2010; 1991–2020) and at the annual level, assessing the possible causes in the months from budding BBCH01 to ripening BBCH89. The data of the wine grapes produced have been subdivided by area of

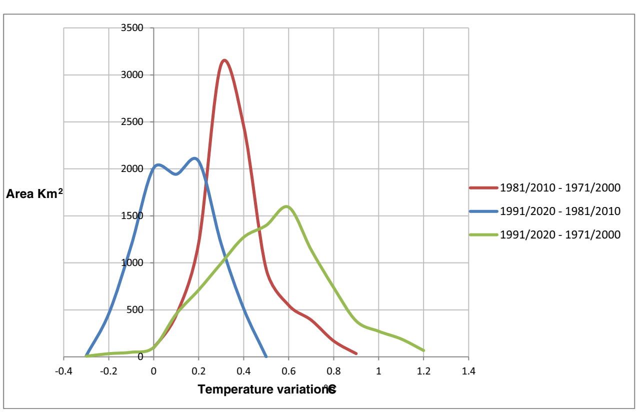


Fig. 5 Graph of the thermometric variations between climatological standard normal periods in relation to their area

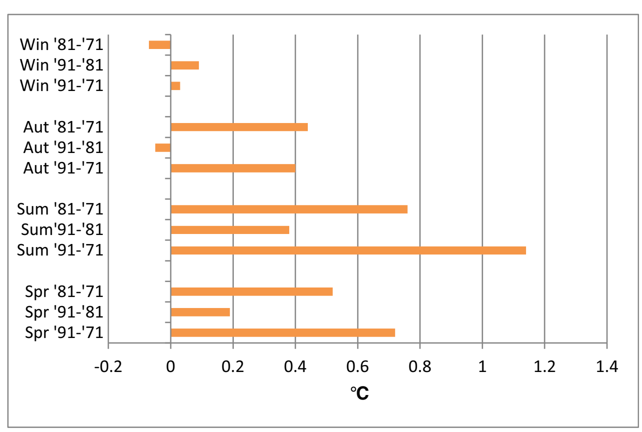


Fig. 6 Mean seasonal temperature variations between climatological standard normal periods (1981/2010–1971/2000; 1991/2020–1981/2010; 1991/2020–1971/2000)

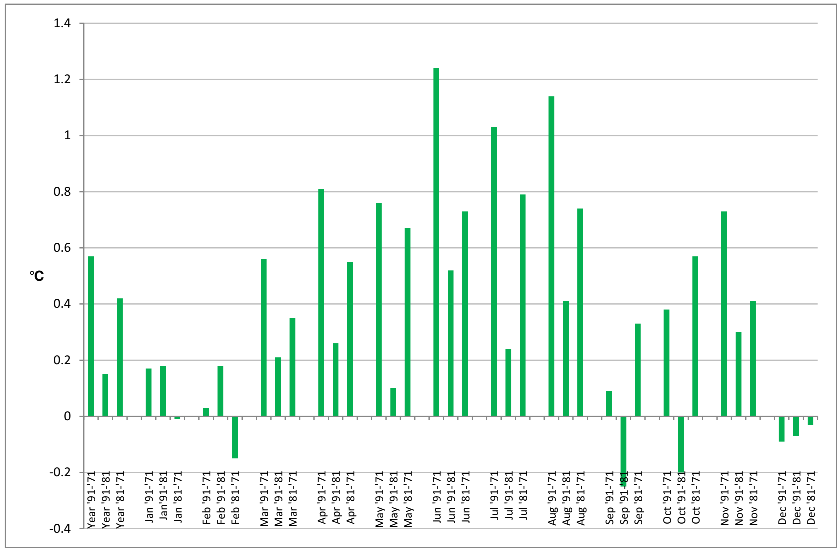


Fig. 7 Mean temperature variations for standard periods

production, in order to obtain the ton (t) per hectare (ha) produced for each 30-year period (Table 4).

These data were related to the temperature both annually and for the months affected by the phenological phases from budding to ripening.

The correlation between production and temperatures seems to be inverse, i.e., as temperatures rise, the production of grapes decreases (Table 5). This correlation is good annually and in August, while it is excellent in April, June, and July. During the month of April, the phenological phases

Table 3 Average temperature variation for altimetric bands

Altitude	1981/2010–1971/2000	1991/2020–1971/2000	1991/2020–1981/2010
0–100	0,54	0,75	0,2
100–200	0,5	0,71	0,2
200–300	0,44	0,62	0,17
300–400	0,38	0,51	0,11
400–500	0,35	0,45	0,09
500–600	0,33	0,43	0,1
600–700	0,32	0,43	0,1
700–800	0,32	0,43	0,11
800–900	0,32	0,44	0,12
900–1000	0,32	0,45	0,13
1000–1100	0,31	0,45	0,13
1100–1200	0,29	0,43	0,14
1200–1300	0,26	0,38	0,13
1300–1400	0,23	0,34	0,12
1400–1500	0,19	0,28	0,09
1500–1600	0,17	0,24	0,09
1600–1700	0,16	0,24	0,06
1700–1800	0,16	0,24	0,06
1800–1900	0,15	0,23	0,06
1900–2000	0,14	0,22	0,06
2000–2100	0,13	0,19	0,05
2100–2200	0,12	0,17	0,04
2200–2300	0,1	0,11	0,03
2300–2400	0,08	0,12	0,05

Table 4 Data of wine grape production in t/ha

Period	1971–2000	1981–2010	1991–2020
t/ha	10.23	9.84	9.21

Table 6 Correlation between production in ton per hectare and temperatures year by year from 1971 to 2018, with only the weather stations above 600 m

Period	R^2 year by year
Ann	−0.33
Mar	−0.17
Apr	−0.47
May	−0.36
Jun	−0.28
Jul	−0.18
Aug	−0.13
Sep	0.42
Oct	0.08

change on average from BBCH 005 to BBCH 55, i.e., from the "wool stage" to the beginning of flowering. Instead in June and July, in the Marche region, the vine develops from "Fruit set" BBCH71 to the "Beginning of ripening" BBCH81. In addition, the monthly correlation from 1971 to 2018, year by year, was investigated, excluding from the interpolation of those weather stations outside the territory suitable for the cultivation of the vine (above 600 m). A correlation of this type using monthly data, considering the variables involved in the growth of the vine (precipitation, cold nights, aridity, etc.), should not provide significant results; however, from the table (Table 6), we can see a weak inverse correlation in April and a weak direct correlation with the month of September.

4 Discussion

This study highlights a clear and unequivocal warming of the climate; this climate change is greater when comparing the current period (1991–2020) with the earliest one 1971–2000 (0.56 °C), while it is weaker when comparing the periods 1981–2010 and 1991–2020 (0.14 °C of variation). This trend is fully confirmed by numerous other large-scale climate studies in the Mediterranean and in Europe (Domroes and El-Tantawi 2005; Sparks et al. 2009). However, it is necessary to pay attention to some periods in contrast to the trend. For example, the winter season does not show significant increases from the past to the present and even shows a decrease between 1971–2000 and 1981–2010 of about 0.1 °C. The lack of temperature increase in winter is confirmed by other previous studies in Italy (Colombo et al. 2007), which observe in some cases, especially for the mountain weather stations, a decrease in this season. Similarly, there are significant increases in temperature in spring and summer, while in autumn, there are contrasting trends in places. The most innovative part of this study is the spatial analysis of temperature changes obtained through mathematics between rasters. This tool has highlighted significant differences also between neighboring areas; in fact, although the dominant tendency is to increase the temperature, there are some areas in countertrend. There is a stationarity of temperatures in the central part of the Marche region and in the area to the south-west (Sibillini massif). In addition, there are also areas where temperatures have decreased, to the northwest on the Apennine belt and at the extreme tip to the south-west, in a small portion of the Sibillini Massif. A further analysis was carried out on the altimetric bands, which demonstrated what was clear from the beginning, namely, that the altitude is highly correlated with the temperature. Average temperature variations with altitude are almost constant (Table 3), although there may be differences in terms of maximums and minimums depending on local climatic conditions. A final important consideration on temperatures concerns area histograms that allow the synthesis of spatial climate changes. The greater difference between the periods (e.g., 1991–2020/1971/2000) determines a wider distribution of the values that graphically assume a platykurtic tendency (Fig. 5). As regards the relationship between wine grape production and temperatures, the results seem to be unequivocal. There is a good correspondence between the increase in temperatures from the preceding to the

Table 5 Correlation between production in ton per hectare and temperatures for all climatological standard normals

Period	T 1971–2000	T 1981–2010	T 1991–2020	R^2 between grape production and temperature
Ann	13.38	13.80	13.94	−0.92
Mar	8.30	8.74	8.95	−0.95
Apr	11.37	11.92	12.19	−0.95
May	16.01	16.68	16.78	−0.86
Jun	19.82	20.54	21.05	−0.97
Jul	22.20	23.49	23.74	−0.88
Aug	22.72	23.46	23.86	−0.96
Sep	18.97	19.33	19.08	−0.17
Oct	14.43	15.01	14.8	−0.52

following period and the decrease in wine grape production. This result is in agreement with many other studies that highlight the problems related to warm temperature, very often however linked to a factor of soil moisture (Duchêne and Schneider 2005). Finally, the relationship temperature/production was investigated not only in aggregate throughout the period but also year by year. In this case, the relationship has inevitably become weaker, although it has allowed the important consideration that the temperature is directly related to the production of wine grapes in September and inversely related in April.

5 Conclusions

This study is not only an in-depth report for the temperatures of the Marche region, but it is also the starting point for a spatial analysis of climate change. This study highlights the growth of temperatures in the region, not neglecting the spatial variation of the same. The decrease in temperatures in December and the anomalies in February, September, and October were highlighted. These climatic analyses are certainly preliminary to a more complete analysis of the local climatic dynamics, in order to assess the causes of these events. From an agroclimatic point of view, an excellent correlation was found between the increase in temperature and the decrease in the production of wine grapes in each climatological standard normal periods. Furthermore analyzing the months year by year, a weak direct correlation has been identified with temperatures for the month of September while the inverse with the month of April. This is a clear indication of the needs of the vine. In conclusion, it is very important to assess climate change on a local scale for any kind of application purpose. The proposed working methodology could be applicable to any type of woody crop and to any other area. This type of research should make us reflect on the seriousness of climate change. At the same time, understanding the phenomena makes it possible to reduce the effects of climate change on environment.

References

Akbari H, Cartalis C, Kolokotsa D, Muscio A, Pisello AL, Rossi F et al (2016) Local climate change and urban heat island mitigation techniques–the state of the art. J Civ Eng Manag 22(1):1–16. https://doi.org/10.3846/13923730.2015.1111934

Alexandersson H (1986) A homogeneity test applied to precipitation data. Int J Climatol 6(6):661–675. https://doi.org/10.1002/joc.3370060607

Appiotti F, Krželj M, Russo A, Ferretti M, Bastianini M, Marincioni F (2014) A multidisciplinary study on the effects of climate change in the northern Adriatic sea and the Marche region (Central Italy). Reg Environ Chang 14(5):2007–2024. https://doi.org/10.1007/s10113-013-0451-5

Arguez A, Durre I, Applequist S, Vose RS, Squires MF, Yin X et al (2012) NOAA's 1981–2010 US climate normals: an overview. Bull Am Meteorol Soc 93(11):1687–1697. https://doi.org/10.1175/BAMS-D-11-00197.1

Colombo T, Pelino V, Vergari S, Cristofanelli P, Bonasoni P (2007) Study of temperature and precipitation variations in Italy based on surface instrumental observations. Glob Planet Chang 57(3–4):308–318. https://doi.org/10.1016/j.gloplacha.2006.12.003

Déqué M, Jones RG, Wild M, Giorgi F, Christensen JH, Hassell DC et al (2005) Global high resolution versus limited area model climate change projections over Europe: quantifying confidence level from PRUDENCE results. Clim Dyn 25(6):653–670. https://doi.org/10.1007/s00382-005-0052-1

Domroes M, El-Tantawi A (2005) Recent temporal and spatial temperature changes in Egypt. Int J Climatol 25(1):51–63. https://doi.org/10.1002/joc.1114

Duchêne E, Schneider C (2005) Grapevine and climatic changes: a glance at the situation in Alsace. Agron Sustain Dev 25(1):93–99

Fraga H, Malheiro AC, Moutinho-Pereira J, Santos JA (2013) Future scenarios for viticultural zoning in Europe: ensemble projections and uncertainties. Int J Biometeorol 57(6):909–925. https://doi.org/10.1007/s00484-012-0617-8

Fratianni S, Acquaotta F (2017) The climate of Italy. In: Soldati M, Marchetti M (eds) Landscapes and landforms of Italy. World Geomorphological Landscapes. Springer, Cham. https://doi.org/10.1007/978-3-319-26194-2_4

Gentilucci M, Bisci C, Burt P, Fazzini M, Vaccaro C (2018a) Interpolation of rainfall through polynomial regression in the Marche region (Central Italy). In: Mansourian A, Pilesjö P, Harrie L, van Lammeren R (eds) Geospatial technologies for all, AGILE, vol 2018. Lecture Notes in Geoinformation and Cartography. Springer, Cham, pp 55–73. https://doi.org/10.1007/978-3-319-78208-9_3

Gentilucci M, Barbieri M, Burt P, D'Aprile F (2018b) Preliminary data validation and reconstruction of temperature and precipitation in Central Italy. Geosciences 8(6):202. https://doi.org/10.3390/geosciences8060202

Gentilucci M, Barbieri M, Burt P (2018d) Climatic variations in Macerata Province (Central Italy). Water 10(8):1104. https://doi.org/10.3390/w10081104

Giannaros TM, Melas D (2012) Study of the urban heat island in a coastal Mediterranean City: the case study of Thessaloniki, Greece. Atmos Res 118:103–120. https://doi.org/10.1016/j.atmosres.2012.06.006

Giorgi F, Lionello P (2008) Climate change projections for the Mediterranean region. Glob Planet Chang 63(2–3):90–104. https://doi.org/10.1016/j.gloplacha.2007.09.005

Goovaerts P (1998) Ordinary cokriging revisited. Math Geol 30(1)

Johnston K, Ver Hoef JM, Krivoruchko K, Lucas N (2001) Using ArcGIS geostatistical analyst, vol 380. Esri, Redlands

Johnston K, Ver Hoef JM, Krivoruchko K, Lucas N (2003) ArcGis 9. Using ArcGis Geostatistical Analyst, Environmental Systems Research Institute, Redlands, CA

Kürbis K, Mudelsee M, Tetzlaff G, Brázdil R (2009) Trends in extremes of temperature, dew point, and precipitation from long instrumental series from Central Europe. Theor Appl Climatol 98(1–2):187–195. https://doi.org/10.1007/s00704-008-0094-5

Labudová L, Faško P, Ivaňáková G (2015) Changes in climate and changing climate regions in Slovakia. Moravian Geographical Reports 23(3):71–82. https://doi.org/10.1515/mgr-2015-0019

Lionello P, Malanotte-Rizzoli P, Boscolo R (eds) (2006) Mediterranean climate variability (Vol. 4). Elsevier

Malheiro AC, Santos JA, Fraga H, Pinto JG (2010) Climate change scenarios applied to viticultural zoning in Europe. Clim Res 43(3):163–177. https://doi.org/10.3354/cr00918

Meehl GA, Stocker TF, Collins WD, Friedlingstein P, Gaye T, Gregory JM, Kitoh A, Knutti R, Murphy JM, Noda A, Raper SCB, Watterson IG, Weaver AJ, Zhao ZC (2007) Global climate projections. In: Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL (eds) IPCC, 2007: climate change 2007: the physical science basis. Contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge

Moberg A, Jones PD (2005) Trends in indices for extremes in daily temperature and precipitation in central and western Europe, 1901–99. Int J Climatol 25(9):1149–1171. https://doi.org/10.1002/joc.1163

Nendel C (2010) Grapevine bud break prediction for cool winter climates. Int J Biometeorol 54(3):231–241

Oliver MA, Webster R (2015) Basic steps in geostatistics: the variogram and kriging, vol 106. Springer, New York

Piani C, Haerter JO, Coppola E (2010) Statistical bias correction for daily precipitation in regional climate models over Europe. Theor Appl Climatol 99(1–2):187–192. https://doi.org/10.1007/s00704-009-0134-9

Rathod IM, Aruchamy S (2010) Spatial analysis of rainfall variation in Coimbatore district Tamil Nadu using GIS. Int J Geomatics Geosci 1(2):106

Salinger MJ (2005) Climate variability and change: past, present and future—an overview. In: Increasing climate variability and change. Springer, Dordrecht, pp 9–29

Schabenberger O, Gotway CA (2017) Statistical methods for spatial data analysis. CRC Press

Sparks TH, Aasa A, Huber K, Wadsworth R (2009) Changes and patterns in biologically relevant temperatures in Europe 1941–2000. Clim Res 39(3):191–207. https://doi.org/10.3354/cr00814

Spina R, Stortini S, Fusari R, Scuterini C, Di Marino M (2002) Caratterizzazione climatologica delle Marche: campo medio della temperatura per il periodo 1950–200. Centro di Ecologia e Climatologia - Osservatorio Geofisico Sperimentale, Macerata

Tadić MP (2010) Gridded Croatian climatology for 1961–1990. Theor Appl Climatol 102(1–2):87–103. https://doi.org/10.1007/s00704-009-0237-3

Walsh S (2012) A summary of climate averages for Ireland. Met Eireann, Dublin

Wang YQ (2014) MeteoInfo: GIS software for meteorological data visualization and analysis. Meteorol Appl 21(2):360–368. https://doi.org/10.1002/met.1345

WMO (2017) WMO Guidelines on the Calculation of Climate Normals, WMO-No.1203, Geneva 2, Switzerland