Global and Planetary Change 141 (2016) 39–53

Contents lists available at ScienceDirect

Global and Planetary Change

journal homepage: www.elsevier.com/locate/gloplacha

# Grape harvest dates as indicator of spring-summer mean maxima temperature variations in the Minho region (NW of Portugal) since the 19th century

J. Moreno [a,b,*], F. Fatela [a,b], F. Moreno [c], E. Leorri [d], R. Taborda [a,b], R. Trigo [e]

[a] IDL — Instituto Dom Luiz, Universidade de Lisboa, Campo Grande, 1749-016, Lisboa, Portugal
[b] Departamento de Geologia da Faculdade de Ciências da Universidade de Lisboa, Campo Grande, 1749-016, Lisboa, Portugal
[c] Independent researcher, Caminho da Portela, 4940-061 Bico PCR, Portugal
[d] East Carolina University, Department of Geological Sciences, Greenville, NC 27858-4353, USA
[e] DEGGE — Departamento de Engenharia Geográfica, Geofísica e Energia da Faculdade de Ciências da Universidade de Lisboa, Campo Grande, 1749-016 Lisboa, Portugal

ARTICLE INFO

*Article history:*
Received 17 July 2015
Received in revised form 26 February 2016
Accepted 4 April 2016
Available online 16 April 2016

*Keywords:*
Newspapers
Grape harvest dates
Growing season
Maxima temperatures
Teleconnection modes
TSI

ABSTRACT

This paper reports a climatic reconstruction approach for the Minho region (NW of Portugal) using grape harvest dates (GHD) as proxy of surface air temperature. This new GHD series was built based on the records from a set of local and regional newspapers (1854–1978) and the annuals of a Wine Producers Cooperative (1978–2010). The strong inverse correlation between Minho GHD and the mean maxima temperatures of the preceding March to August months (GSTmax), registered at the Braga weather station for the overlap period 1941–2009, allowed a reconstruction, with associated statistical uncertainties, of the regional GSTmax back to 1856. These were then used to characterize the main climatic episodes in the region during the last 154 years. The most noticeable feature that emerges from the comparison of the Minho GSTmax with the global annual average temperatures of Jones et al. (2013) is that these regional temperatures, in clear contrast with the global warming observed from around 1990 onwards, show no noteworthy increasing trend. The influence of climatic variability was examined also in terms of the relations between GSTmax (1950–2009) and the main meteorological teleconnection patterns affecting the North Atlantic European sector where the Minho region is included. Data support the hypothesis that persistent positive modes of spring-summer Scandinavian (SCA) and summer East Atlantic/Western Russia patterns triggered lower GSTmax, especially in the 60s–80s. The search for solar imprints in the Minho region climate identified the SCA mode as a promising connection between the two, since it is significantly inversely correlated with both, the TSI and the GSTmax.

Like in other traditional European viticultural regions, the Minho GHD have shown to be a valuable tool for understanding the interactions between large-scale circulation modes and regional/local climatic conditions. Besides it will deliver a reliable assessment of climatic proxies from geological record, like tidal marsh benthic foraminifera assemblages.



## 1. Introduction

The interest in past climate variability under the present scenario of climate change has led to various efforts to extend temperature reconstructions further back in time, particularly in Europe where archives and documentary sources abound. These reconstructions usually rely on a combination of instrumental data (only available for the last ca. 150 years), several kinds of historical records, archaeological evidence and inferences from environmental proxies (e.g., Jones and Mann, 2004).

In this context, a number of studies have used dates of vine harvests as indicators of climate variability (e.g., Guerreau, 1995 and references therein). Following the pioneer works of Dufour (1870), Angot (1883) and, later on, Garnier (1955) or Le Roy Ladurie (1967), connecting climate and viticulture, grape harvest dates (GHD) have been gathered to generate temperature reconstructions for the past 400 to 500 years from the traditional European viticultural regions of France, Italy, Spain, Switzerland and Germany (e.g., Le Roy Ladurie and Baulant, 1980; Pfister, 1992; Chuine et al., 2004; Brázdil et al., 2005, 2008; Meier et al., 2007; Jones et al., 2009; Mariani et al., 2009; Kiss et al., 2011; Krieger et al., 2011; Maurer et al., 2011). However, similar quantitative reconstructions are lacking from Portugal, despite the long history of this Iberian country in winemaking and the fact that it is the current 11th wine-producer worldwide (OIV, 2015). This Portuguese viticultural heritage is reflected by >250 native grape varieties as well as by the close link between this agricultural product (wine) and the historic expression of some local and regional cultural traditions. As stated

* Corresponding author.
*E-mail address:* jcmoreno@fc.ul.pt (J. Moreno).

http://dx.doi.org/10.1016/j.gloplacha.2016.04.003
0921-8181/

by Stanislawski (1970), these ones are deeply embedded in the rural landscape, remaining at present much alive in the geographical identity of the country (e.g., Hooson, 1998; Correia, 2011).

It has been recognized that the onset and duration of all major grapevine phenological growth stages are interconnected and strongly dependent on climate conditions (e.g., Jones and Davis, 2000), because wine production is largely controlled by atmospheric forcing, mainly during the growing season (GS), i.e., from budburst to harvest, when temperature is a major controlling factor. Indeed, temperature was used in the development of a number of climate indices linked to wine grape quality, such as the Latitude-Temperature Index (Kenny and Shao, 1992) and the Average Growing Season Temperature Index (Jones, 2006). Furthermore, on a global scale, it has long been considered that the optimal zones for viticulture are between either the mean annual 10–20 °C isotherms (e.g., de Blij, 1983) or the growing season 12–22 °C isotherms (Gladstones, 2004; Jones, 2006). In addition to temperature, annual precipitation and its seasonality is also a critical factor, affecting pest and disease pressure, fruit quality, vine balance and yield (Fraga et al., 2014; Keller, 2015). Excessive rainfall during the early GS has a negative effect by delaying growth, and precipitation during the late GS (particularly during the ripening period) may have a negative influence, diluting the grapes and producing lower relative sugar levels, thus lowering the alcohol content (e.g., Jones and Storchmann, 2001). In this sense, some modelling studies of Portuguese viticulture have included climatic variables to predict wine production (Gouveia et al., 2011) and yield (Santos et al., 2010a) in the famous Douro Port Wine Region. Likewise, extreme weather events, like hail, frost and heat waves during the GS, can have harmful impacts on vineyards, thus contributing to significant fluctuations in yield, wine quality and in the dates of harvest. Consequently, the overall grapevine growth cycle (including vegetative and reproductive cycles) is triggered by a combination of parameters such as surface air temperature, precipitation and solar radiation (e.g., Jones et al., 2005; Keller, 2015). In addition to this direct influence, other factors, as weather regimes or teleconnection climatic modes of oscillation (Wallace and Gutzler, 1981; Barnston and Livezey, 1987), may explain grape production and wine quality as they incorporate several components of climate in their typical atmospheric conditions. In Iberian Peninsula, such climatic stimuli and their effects have been studied before by Lorenzo et al. (2012) in Rías Baixas (NW of Spain) and by Fraga et al. (2014) in the northern Portuguese Minho Wine Region (MWR).

Amongst the vine-related biophysical indicators, GHD have attracted the attention of historical climatologists mainly due to the existence of these data in Europe since the “Middle Ages”. This (para) phenological information has resulted in long archives of dates, which, in general, correspond to the stage of full maturation of grapes. Owing to the strong control of temperature on grape ripening, these archived dates furnish a very concise record of growing season temperatures (GST; mean or maximum temperature averaged normally over April–August; Menzel, 2005). In fact, GST and GHD series present statistically significant correlations (e.g., Menzel, 2005; Daux et al., 2007; Meier et al., 2007; Maurer et al., 2011). Considering the whole body of evidence about the relationships between GHD and temperatures, the starting dates for grape harvests are currently held as a consistent proxy for this meteorological variable and a source of climatological knowledge in the reconstruction of past climates (Brázdil et al., 2008).

The present work aims to take a step further towards a more comprehensive understanding of the climatic patterns in the MWR, derived from the compiled information about the beginning of the grape harvests. We do this by i) introducing a 154-year series of grape harvest dates for this region, ii) evaluating the potential of these data for temperatures reconstruction in the MWR by means of a linear product-moment Pearson correlation methodology, iii) examining how the mean maxima temperatures of the GS (reconstructed from the Minho GHD series) have changed over the documented period (1856–2009), and iv) relating the main North Atlantic teleconnection modes and the oscillations in the total solar irradiance (TSI) with GSTmax changes.

## 2. Study area

The Minho region is a historical province, located in the NW of Portugal, that includes the Braga and Viana do Castelo districts. This region borders Galicia (Spain) in the north and the Atlantic Ocean in the west and covers 4700 $km^2$. The MWR, demarcated in 1908, is one of the oldest in the country land covering about 8800 $km^2$ and geographically coinciding with the “Vinho Verde” denomination of origin (Fig. 1A and B). It is the Atlantic wet climate, with relatively high exposure to maritime winds, high annual precipitation (1200–2400 mm), mild summers (summer mean temperatures from 18 to 22 °C) and relatively low annual insolation (<2500 h), that explains the MWR uniqueness and discrimination from other Portuguese wine regions (Fraga et al., 2014). The MWR possesses an irregular topography, ranging from 0 m to ca. 1500 m altitude, characterized by a compact valley system (Magalhães, 2008), in a geological setting of igneous and metamorphic rocks, including granites, quartz-diorites, greywackes and schists (IGME, 1986; Pereira et al., 1989). Benefiting from these local/regional climatic and geomorphological features, some traditional vine training systems (pergola, stakes, trellised vines and tall growing vines) have survived to modern times. These systems are a response to the high vegetative growth of vines and the need to isolate grapes from the ground to facilitate ripening and to diminish the risk of fungal diseases.

## 3. Materials and methods

### 3.1. Grape harvest dates and weather information from documentary sources

The time series of grape harvest dates for the Minho region was compiled from two documentary sources: 41 local and regional newspapers, from 1854 to 1978, and the annual records (unpublished) from the Ponte de Lima Wine Producers Cooperative (1978–2012), located in the Viana do Castelo district. As a result, the series was constructed from an ensemble of harvest dates chronicled at 16 municipalities from a total of 24 belonging to the Viana do Castelo and Braga districts (Fig. 1B). Just the newspapers from 1854 to 55, 1860, 1883, 1933, 1946, 1951, and 1955 did not contain any reference to grapevine harvests, i.e., only about reducing the information gaps to ca. 5% of the total period considered. For a given year, we have stipulated the harvest starting date as the first news published about grape harvesting. Simultaneous to the GHD research, the newspapers were methodically reviewed for supplementary descriptive data as regards to meteorological events with potential meaningful impacts on those dates (e.g., floods, droughts, storms, snowfall, hail, etc.).

In Catholic countries like Portugal, the use of religious ceremonies constitutes an important source of information that can support historical climate reconstructions. The potential use of these rogations (i.e., “prayer, plea, request”) as a climate proxy was recognized by Giralt (1958), and since then systematic records of these religious expressions, with traditional rituals appealing for the end of drought periods – *pro-pluvia* rogations/processions – or long wet/stormy spells – *pro-serenitate* rogations/processions, have often been used in historical climatology (e.g., Alcoforado et al., 2000; Domínguez-Castro et al., 2008). Rogations were indeed an institutional mechanism related to climate stress situations (e.g., Martín-Vide and Barriendos, 1995; Barriendos, 2005). They were ordered by ecclesiastical and municipal authorities when the harvests seemed to be threatened by drought or excessive rainfall. Thus, the occurrence of *pro-pluvia* and *pro-serenitate* ceremonies was also compiled.

In order to avoid redundancy, when the same meteorological or religious event was reported by several newspapers, it was included in the