**Climate
of the Past
Discussions**

An open-database of Grape Harvest dates for climate research: data description and quality assessment

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Abstract

We present a dataset of grape harvest dates (GHD) series that has been compiled from international and non-translated French and Spanish literature and from unpublished documentary sources from public organizations and from wine-growers. As of June 2011, this GHD dataset comprises 378 series mainly from France (93 % of the data) as well as series from Switzerland, Italy, Spain and Luxembourg. The series have variable length and contain gaps of variable sizes. The longest and most complete ones are from Burgundy, Switzerland, Southern Rhône valley, Jura and Ile-de-France.

The GHD series were grouped into 27 regions according to their location, to geo-morphological and geological criteria, and to past and present grape varieties. The GHD regional composite series (GHD-RCS) were calculated and compared pairwise to assess the quality of the series. Significant (p-value < 0.001) and strong correlations exist between most of them. As expected, the correlations tended to be higher when the vineyards are closer, the highest correlation ($R = 0.91$) being obtained between the High Loire Valley and the Ile-de-France GHD-RCS.

The strong dependence of vine cycle on temperature and, therefore, the strong link between GHD and the temperature of the growing season was also used to test the quality of the GHD series. The strongest correlations are obtained between the GHD-RCS and the temperature series of the nearest weather stations. Moreover, the GHD-RCS/temperature correlation maps show spatial patterns similar to temperature correlation maps. The stability of the correlations over time is explored. The most striking feature is their generalized deterioration at the late 19th–early 20th turning point. The possible effects on the GHD of the phylloxera crisis, which took place at this time, are discussed.

The median of the standardized GHD-RCS was calculated. The distribution of the extreme years of this general synthetic series is not homogenous. Extremely late years all occur during a two-century long time-window from the early 17th to the early 19th
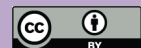
century, while extremely early years are frequent during the 16th and since the mid-19th century.

The dataset is made accessible for climate research through the Internet. It should allow a variety of climate studies, including reconstructions of atmospheric circulation over Western Europe.

1 Introduction

Grapevine (*Vitis vinifera* L.) harvest date (GDH hereafter) has been identified as an accurate documentary proxy to study past climate evolution in Europe (Brazdil et al., 2005; Jones et al., 2009). The analysis of the dependence of GHD on climate was first undertaken by Dufour (1870) who constructed a stacked series of GHD in Switzerland extending back to the 15th century. Then Angot (1883) built a comprehensive dataset of French and Swiss GHD series and performed analyses of the variability of GHD through space and time. The earliest date of the series he compiled belongs to the 14th century. Several decades later Garnier (1955), Le Roy Ladurie (1967) and Legrand (1978) highlighted the potential of GHD as climate proxies, and revived the scientific community's interest in GHD data. Le Roy Ladurie (1967) collected more than a hundred GHD series from southern France, with a few ones also going back to the 14th century. The GHD from Burgundy compiled by Angot (1883) have been completed, extended and stacked to produce a six-century long, almost continuous, GHD series (Chuine et al., 2004), and used to produce several climate reconstructions (Chuine et al., 2004; Etien et al., 2008; Guiot et al., 2005, 2010; Le Roy Ladurie, 1967, 2005; Le Roy Ladurie et al., 2006; Luterbacher et al., 2004; Menzel, 2005; Pfister, 1992; Schleip et al., 2008; Souriau and Yiou, 2001; Xoplaki et al., 2005). Recently, Labbé et al. (2011) revisited the archives of Dijon city and produced an up-dated corrected series for this Burgundy vineyard.

There are at least two main reasons to consider GHD as an interesting tool for past temperature reconstruction:

1. GHD are strongly linked to the phenological stages of the grapevine which, themselves, depend on the temperature of the growing season (Jones, 2003).

2. The harvest dates have been set and recorded by local authorities since the Middle Ages and, as a result, long yearly records of this event are available (Le Roy Ladurie, 1967).

Grapevine (*Vitis vinifera* L.) is a perennial long-lived plant adapted to warm and dry environments. Currently, it develops in areas where the mean temperature of the growing season (April–October in Northern Hemisphere) ranges between 13 °C and 20 °C, which corresponds approximately to the 33.25–49.75° latitude belts (Jones et al., 2005). However, because of these thermal needs, the area where grape is planted has changed through time. For instance, the vineyards planted in Southern England from the 10th to the 13th century, which disappeared from the British landscape during the cooling of the Little Ice Age (Gladstones, 1992; Jones et al., 2005), were reintroduced there after World War II, and have expanded since then. The development of grapevine is mainly driven by temperature (Jones, 2003). The key developmental stages are budbreak, flowering and veraison (time when grapes change their colour) (Jones, 2003). Budbreak requires firstly a chilling period to break winter dormancy followed by a prolonged exposure to higher temperatures which promote cell elongation (Lavee and May, 1997). Grapevine typically breaks bud in April–May, flowers occur in June, and veraison at the end of July or during August. The ripening phase initiates at veraison and finishes when grapes have reached a certain level of maturity. Currently, in France, grape harvest is most often scheduled between 10 September and 10 October (Van Leeuwen et al., 2008), i.e., 30 to 40 days after veraison (Chuine et al., 2004). The delay between the veraison and the grape harvest is quite constant in a vineyard. For example, its standard deviation is of 0.74 days for 26 series in the Alsace vineyard (Chuine et al., 2004). Furthermore, the correlations between flowering and veraison dates with GHD are very high in each vineyard (i.e., in Alsace vineyard, $r = 0.90$, $p < 0.0001$ and $r = 0.92$, $p < 0.0001$, respectively; Chuine et al., 2004).

Prior to the French revolution, in most areas, wine owners were not free to harvest at their convenience. They had to wait for a public order to harvest ("ban des vendanges") (de la Poix de Fremenville, 1758; Pocquet de Livonnière, 1733; Rageau and De Laurière, 1704; Salvaing de Boissière, 1664). The harvest date was an enlightened seigniorial or municipal decision (Garnier et al., 2011). In practice, the scheduling of the grape harvest was incumbent on several wine-growers and/or qualified persons who visited the vineyards to assess the maturity level of the grapes (de la Poix de Fremenville, 1758). Some anthropogenic factors (military threats, pest outbreaks, etc.) were likely to interfere with the harvest scheduling (Garnier et al., 2011). After the revolution, vine-growers were theoretically free to begin the harvest when they wanted to (law of 4 August 1789). In practice, most parishes maintained a compulsory minimum date for grape harvest in order to preserve law and order (Le Roy Ladurie and Daux, 2008). After 1791, the date was set by the mayor, on the vine growers' advice (Law of 6 October 1791). When several varieties were grown in the same area, the official date corresponded to the earliest and/or to the most important variety. The law of 9 July 1889 entitled the municipalities to keep or give up the "ban des vendanges" practice, which led to its disappearance in almost all of France. At the same time, different new diseases, downy mildew, powdery mildew and especially phylloxera, appeared and ravaged the vineyards.

In France, since 1979 (decree 79-868), the harvest date has been determined by the Prefect's service on a proposal of the National Institute of Origin and Quality (INAO), after the notice of the agency defined for each vineyard (i.e., Interprofessional Committee for Champagne Wine, Interprofessional Board of Burgundy Wines, Interprofessional Council for Bordeaux wines, etc.), taking into account the planting and the status of vineyards. In some cases, different official dates were proposed, according to the types of wine and the varieties (Garcia de Cortazar-Atauri et al., 2010). In the other countries represented in the database (Germany, Italy, Spain and Switzerland), the system is similar to the French one, with still some national particularities.

The present paper describes a GHD database, made accessible through the Internet, which includes datasets mentioned above as well as many unpublished series. It gathers 378 GHD series of variable length from all the French vineyards and from some Spanish, Swiss, Italian and German ones. Over the description of the structure of the database, our aim is to propose a grouping of the series into 27 composite series according to geological, geomorphological, historical and viticultural criteria in order to produce series representative of a region. While our aim is neither to discuss the reliability of GHD as climate proxies, nor to interpret the GHD-RCS in terms of climate dynamics, we assess the quality of the series by pairwise correlations. The former point has been already debated in two papers of the same research team (Garcia de Cortazar-Atauri et al., 2010; Garnier et al., 2011), and some aspects of the latter are addressed in a companion paper (Yiou et al., 2011).

2 Material and methods

2.1 Grape harvest dates collection

The database is composed of 378 individual GHD series which are 93 % from French vineyards and the 7 % left being from neighbouring countries (Germany, Switzerland, Spain and Italy) (Fig. 1a). The various origins of the series can be categorised as follows:

- Series published in easily accessible recent literature (e.g., GHD from Besançon published in Garnier et al., 2011).

- Series published in non-translated French books (e.g., a hundred series from Southern France in Le Roy Ladurie, 1967).

- Series published in French-language journals in volumes which exist only as paper versions (e.g., 60 series from different French vineyards in Angot, 1883 and Legrand, 1978).

– Unpublished series collected from public organizations and services (Towns Archives, Chambers of Agriculture, Direction Départementale de l'Agriculture et de la Forêt, MétéoFrance, etc.).

– Unpublished series collected from private wine-growers.

The information and date copying was carried out with care by the authors of the present publication and the series were controlled for typing errors. Most of the original documents were photographed or digitalised and can be consulted.

The series published in (Angot, 1883), which make up an important part of the database, were collected in 1881 by the Central Meteorological Office ("Bureau Météorologique Central") who enjoined local committees ("Commissions départementales") to take inventory of GHD information. As numerous civil servants were involved in the inventory process, the quality of the data reporting may have been very variable. For instance, the Dijon GHD series was re-compiled recently from the municipal archives and about 25 % of the dates in the new compilation (Labbé et al., 2011) were different from the ones published in Angot (1883). Some original documents (Chobaut's collection in the multimedia library of Avignon) used in Le Roy Ladurie (1967) were also revisited in order to complete some gaps, and obtain information (about varieties, wine quality, production levels ...) which were not reported in the original paper.

2.2 Regional classification

The 378 GHD series were grouped into 27 regions (Table 1; Fig. 1b) according to several criteria. The first one is based on the geographical location of the series and the relation it can have with the other ones around. We observed that most of the series of the database come from areas which have produced wine for a long time. Based on Guyot (1868a,b,c), who describes the grape varieties and the production practices adopted in each French department, we evaluated which series were similar enough to be classified in the same region (see below). We also identified to which current

vineyard the series are related to using the Protected Designation of Origin database of French communes (http://www.inao.gouv.fr). When available, other documents were also consulted to find supplementary information about varieties (Odart, 1845; Rendu, 1857) or about vineyards (Beaumont, 1899; Chaptal et al., 1801; Clémençot, 1897; Duval, 1900; Galet, 2004; Galet, 2006; Godinot, 1718; Holdsworth, 1842; Louis-Perrier, 1886; Saporta, 1894).

Geomorphological and/or geological variations, which may induce different micro and meso-climatic conditions, inside a vineyard or between two nearby vineyards, can affect grapevine growth and development (Tardaguila et al., 2011). To improve the accuracy of the classification, we also took into account these variations. Thus, for instance, the Burgundy series were separated from the "Jura" ones because (1) the two vineyards are separated by a plain, (2) the Burgundy vineyard has a very specific position on the eastern side of the Beaune hill, while the Jura vineyard grows on hills at various altitudes and expositions. Auxerre-Avalon and Beaujolais-Mâconnais vineyards currently belongs to the Burgundy vineyard, but the distance, the varieties and the geological differences between the areas have also allowed their separation into different series. A similar situation is also observed with the series of Champagne – Epernay and Reims (Champagne 1 hereafter) and Champagne – Côtes des Bar (Champagne 2). These two regions belong to the Champagne vineyard, but they have different substratums (Epernay and Reims are mostly chalky while Côtes des Bar, are mostly marl), and are separated by a plain more than 70 km wide, which may induce differences in local climates. In south-eastern France, the wine-producing area has also been divided into several regions: the area most subjected to the Mediterranean influence was labelled Languedoc region, the more continental one, north of the Alpilles Mountains (mainly Vaucluse and eastern Gard departments), was labelled "Southern Rhone Valley" region and the series which cannot be unequivocally related to a vineyard, were gathered together in a Various South East category.

2.3 Database structure

The main information concerning each GHD series is presented in Table S1 in the Supplement. For each series, the following is provided:

- – its name (in many cases the name of the closest town or village),

₅ – the time-period covered,

- – the source of the data (with the reference of the document if it is available),

- – the current name of the vineyard,

- – the coordinates (latitude, longitude and altitude),

- – the number of observations,

₁₀ – some additional information when possible (name of the variety, uncertainty of the sources ...).

The original GHD series grouped by region will be added to the phenological database developed in the GDR-project "Phenologic Information System for Management and Study of Climate Change" (http://www.gdr2968.cnrs.fr/spip.php?rubrique29/). Follow-
₁₅ ing the nomenclature adopted by the pioneers (Angot, 1883), the dates are expressed as the number of days after 31 August (1 September is 1, 1 October is 31, 29 August is –2, etc.). Missing values may correspond to a lack of grape harvest (which may or may not be connected to weather) or to sketchy sources. The dates before 1583 were corrected for calendar changes from Julian to Gregorian calendar (Gregory XIII papal
₂₀ bull "*Inter gravissimas* ..." of 1582). To do so, GHD were added by 10 days for the 16th century, 9 days for the 15th century and 8 days for the 14th century.

2.4 Reference series

For each region a reference series was chosen. The selection criteria were its length (the longest one is generally chosen) and the quality of the correlation with the other series of the region. When the regional datasets presented many incomplete series, more than one reference series was defined (i.e., Southern Rhone valley, Alsace) (Table 1). Following Chuine et al. (2004), the various series of a region were then adjusted by calculation of an adjustment factor as the difference between the mean value of the candidate series and the mean value of the reference one over their common period of record. Then, for each region, a mean composite series (hereafter grape harvest dates regional composite series, GHD-RCS; Table S2 in the Supplement; Fig. 2) was calculated as the median of the individual adjusted series of the region. Some series were not used for the calculation of the composite series of their region because they correspond to special conditions (for instance higher elevation than the other series of the region) which could introduce some noise in the GHD-RCS (Garcia de Cortazar-Atauri et al., 2010). The discarded series are identified in Table S1 in the Supplement. The availability of GHD decreases back in time. So, there are 25 GHD-RCS series in the 19th century, but only 7, fraught with gaps, before 1499.

2.5 Reliability of the sources and statistical methods

In order to assess the quality of the database and its potential for past climate reconstructions, preliminary analyses of the two-by-two GHD-RCS correlations were conducted. Pearson correlation coefficients (PCC) were calculated over the entire series and over 15-year running windows. Data before 1400 were aggregated to the 15th century, and those after 2000, to the 20th.

The strong dependence of the vine cycle on temperature and, therefore, the strong link between GHD and the temperature of the growing season (i.e., Chuine et al., 2004; Daux, 2010; Etien et al., 2009; Meier et al., 2007), provides a mean for testing the quality of GHD dataset. Even if the analysis of the relation between GHD and temperature

is more efficiently conducted with a process-based model, it can be achieved by simple correlation analyses (Garcia de Cortazar-Atauri et al., 2010). We have, therefore, calculated the correlation coefficients between the GHD-RCS and the growing season temperature (monthly maximum temperature averaged over April to September: $T_{\max}^{(\mathrm{AMJJAS})}$) recorded at 85 stations of the Météo-France meteorological network, at Milan (Italy) (Maugeri et al., 2002a,b), at Karlsruhe and Stuttgart (Germany), at Geneva (Switzerland), at Navacerrada and Salamanca (Spain) and at Luxembourg (Klein Tank et al., 2002) (Table S4 in the Supplement). The start of the instrumental temperature series ranges from 1865 to 1936. The correlation coefficients between the GHD-RCS and the Central England temperature record and De Bilt (Netherlands) record were also calculated. The CE temperature record starts in 1659 (Manley, 1974), and was updated by Parker and Horton (2005). De Bilt record starts in 1706 (van Engelen and Geurts, 1983–1992; van Engelen and Nellestijn, 1996) and was updated by the EC EMULATE project (http://www.cru.uea.ac.uk/projects/emulate/).

3 Results and discussion

For some twenty years, various studies have introduced a note of caution to the use of GHD as a climate proxy. Guerreau (1995), thus, considered GHD to be more a social than a temperature-dependent phenological data. Pfister (1984, 1999) was less categorical, but also pointed out the influence of anthropogenic factors on GHD. More recently, Rutishauser et al. (2007) and Meier et al. (2007) came back over this issue and questioned the effect of the context on the stability of the GHD-temperature relation through time.

In this study, it is beyond our goal to fully discuss this matter. It has been extensively done in two contributions of the same authors (Garcia de Cortazar-Atauri et al., 2010; Garnier et al., 2011) who identified and discussed four major possible causes of flaws in GHD-based temperature reconstructions: (1) uncertainties in the model used to relate temperature to GHD, and change through time of (2) grape varieties (3) type of

wine, and (4) viticultural practices. They conclude to the need for contextualizing GHD series to disentangle manmade from climate related effects prior to using GHD. This step, which is indispensable to any GHD-based climate study, calls for interdisciplinary investigations.

5   The quality of 8 out of the 27 GHD-RCS (SRv, Bur, Jur, Swi, Als, IdF, LLV and Bord) of this study were analysed thoroughly (investigations on varieties, viticultural practices, type and quality of wine produced over time) in order to use them for past climate reconstructions. The method and the data can be found in Garcia de Cortazar-Atauri et al. (2010) and Yiou et al. (2011). The other GHD-RCS of the database were not

10   analysed in such detail. In the following sections, we present some clues based on the pairwise GHD-RCS relations and on the relations between GHD-RCS and temperature series to assess their quality. However, we strongly recommend their contextualization (information can be found in various documents, e.g., de Serres, 1600; Bidet, 1759a,b; Odart, 1845; Rendu, 1857; Guyot, 1868a,b,c; Jullien and Jullien, 1866; Galet, 2004,

15   2006) and the critical analysis of the variation through time of man-related effects on the harvest dates before interpreting them in terms of climate change.

3.1 Two-by-two correlations in the GHD-RCS dataset

The results of the pairwise correlations of the GHD-RCS are presented in Fig. 3, Table 2 and Table S3 in the Supplement. As the GHD-RCS have variable lengths and contain

20   gaps of variable size, the number of data used to calculate the correlation coefficients vary from one to another pairwise correlation. So, the correlation coefficients are not comparable to one another. However, taking into account the level of significance (p-value) of the correlations some general comments can be made.

   Significant (p-value < 0.001) and strong two-by-two correlations exist between most

25   of the GHD-RCS. As expected, the correlations tend to be higher when the vineyards are closer (see some examples in Fig. 3). The highest correlation ($R = 0.91$) was obtained between the High Loire Valley and the Ile-de-France GHD-RCS (which have almost three hundred years in common). The GHD-RCS from Italy and Germany show
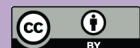
significant correlations with most of the French series. Some correlations show very low values: the lowest are those involving the GHD-RCS from Spain, Languedoc, Southern Rhône valley, Luxemburg and Various South-East.

The stability through time of the correlations was tested by calculating the 15-year running Pearson correlation coefficients for the pairwise correlations between the longest GHD-RCS (i.e., Burgundy, Switzerland, Southern Rhône valley, Jura and Ile-de-France). The correlations with Champagne 2 and Bordeaux GHD-RCS (which are shorter) are also discussed hereafter because these series cover well (with very few missing dates) the transition between the 19th and the 20th century which is a criti-cal period regarding the possible effects of phylloxera outbreak on GHD. The results (Fig. 4) can be summarized as follows:

- Pairwise correlations with the Burgundy GHD-RCS: they are high (PCC > 0.7) almost all over the 500-year time period, but deteriorated in the 1570–1580 and 1690–1700 intervals. With Southern Rhône valley GHD-RCS, the PCC correlation curve plunges by the end of the 19th century and recovers from 1950 onwards. The other PCC curves decrease at the turn of the 20th century, with a minimum around 1920, and then increase (back to ≈0.7–0.8 values) from ca. 1940 onwards.

- Pairwise correlations with Ile-de-France GHD-RCS: they also lessen in the 1570–1580 and 1690–1700 intervals. The correlation with SRv falls as soon as 1840; those with the other GHD-RCS show the same patterns as with the burgundian one.

- Pairwise correlations with Switzerland GHD-RCS: they are all high most time, but weakened during the 16th and the 18th centuries (around 1750) and at the junction between the 19th and the 20th centuries, earlier with SRv GHD-RCS than with the other series. They show a negative peak in the 1990–1995 time window.

- Pairwise correlations with SRv GHD-RCS: they are rather stable from the 16th century to 1850 apart for a drop around 1750. They deteriorate from 1850

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onwards and are restored by the second half of the 20th century (maybe earlier, but there is a gap in the SRv series between 1920 and 1950).

– Correlations with Jura GHD-RCS: there is no pattern common to all the correlations apart from a drop of the PCC during the 1960-1970 interval. As there are many missing data between 1870 and 1920 in the Jura GHD-RCS no tendency can be drawn for this period.

From these correlations we can conclude that the data from the 16th centuries may not be very reliable as the pairwise correlations are systematically low. At the end of the 17th century, both Burgundy and Ile-de-France show decreased correlations with the other series and with one another. This cannot reflect a common climate effect (which would have not affected the other vineyards) as a common cause would have very likely produced similar responses and, therefore, a high correlation between Burgundy and Ile-de-France signals. Thus, we have to consider that some data in the Burgundy and Ile-de-France series can be faulty in the 1690–1700 interval: the harvest may not have been conducted at the time of grape maturity (for unknown reasons) or transcription errors may have occurred. Similarly, some data may be bad in the Southern Rhône valley and Switzerland GHD-RCS around 1750. The main deterioration of the pairwise correlations takes place during an approximately 50-year long window at the junction between the 19th and 20th centuries. This interval is also characterised by many missing dates in the series. The correlation involving the GHD-RCS from the Southern Rhône valley weaken at earlier dates. The deterioration of the correlations coincides with the phylloxera outbreak which affected Southern France as early as 1863 (precisely in the Southern Rhône valley) and spread all over France (and even Europe) onwards. This parasitic attack devastated French vineyards mainly between 1863 and 1900. Production decreased importantly between 1879 and 1900 (Branas, 1974) and hybrid and high production varieties were selected. With the high demand for wine in France, replanting was hasty, but the wine production remained disorganized for years (Spahni, 1988), at least until the 1907 laws of regulation (29 June and 15 July laws,

and September 3rd decree). New viticultural technics, in particular the use of American rootstocks upon which to cultivate the European varieties, also affected production. Rootstocks influence scions, particularly with regard to water uptake, the ability of the grafted combination to increase or decrease uptake and translocation of nutrients and vigour (Coombe and Dry, 1988; Steigler and Howell, 1991; McCarty et al., 1997; Walker et al., 2000; Keller, 2001). However, there is no evidence in the literature that rootstocks affect the phenology of the plant which depends on the grafted variety (Calo et al. 1979; Eger and Grasselli, 1993) and most of the varieties used after the crisis as scions were identical to those planted before it (Galet, 2004; Odart, 1845; Rendu, 1857). Thus, if the GHD-RCS in the 'phylloxera' interval appear less reliable, the deterioration of the quality of the series is not due to phenological changes induced by the adjustment of the viticultural practices, but it may be due to the disruption of certain vineyards and to the a huge decrease of the number of available data.

3.2 Correlations between GHD-RCS and the temperature of the growing season $\left(T_{\max}^{(\text{AMJJAS})}\right)$ over the instrumental time period

We computed the PCC between the reconstructed (GDH-RCS) and instrumental temperatures $\left(T_{\max}^{(\text{AMJJAS})}\right)$ for comparison purposes (Table S4 in the Supplement) and to check the general consistency of the reconstructions. GHD-RCS which do not have many or even any years in common with temperature series are excluded de facto. Therefore, the correlations with Auv, Aux, Cha1, Gai, Ger, HLV, Mar, Nit, NLo, Slo, Sav, and VPC series could not be investigated.

The correlations between GHD-RCS and $T_{\max}^{(\text{AMJJAS})}$ are negative (the hotter the summer, the earlier the grape harvest). Most are significant (p-value < 0.001). As expected, the strongest correlations are obtained between the GHD-RCS and the weather series of the nearest stations. The best correlations are those which bring into play: Bur, IdF, LLV, NRv, Cha2 and Swi (mean $R \le -0.67$). The poorest are those with: VSE, Lux, SRv and Lan (mean $R \ge -0.44$). Als, Bea, Bor, Jur, Spa series obtain intermediate scores
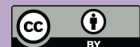
($-0.67 < $ mean $R \leq -0.58$). The Pearson correlation coefficients of the correlations of GHD-RCS with the long $T_{max}^{(AMJJAS)}$ series of Central England and De Bilt (Netherland) also reflect the geographical distribution of the sites, with the highest one obtained for the north-western GHD-RCS (top-five PCC with: VPC, LLV, HLV, Cha1 and IDF).

5   The quality of the GHD series (on the instrumental time period) can be evaluated by comparing the GHD-RCS/$T_{max}^{(AMJJAS)}$ correlations to the correlations between the $T_{max}^{(AMJJAS)}$ of a meteorological station close to the vineyard and the $T_{max}^{(AMJJAS)}$ of other meteorological stations (Table S5 in the Supplement; Fig. 3). Though the correlations involving GHD-RCS are lower than those involving only temperature series, the gen-
10   eral spatial patterns present similarities. For instance, the distribution of the Pearson correlation coefficients for:

   – The Burgundy GHD-RCS versus $T_{max}^{(AMJJAS)}$ series show a North-eastern–South-western gradient which mimics the distribution of the correlation coefficient between Dijon $T_{max}^{(AMJJAS)}$ and the other meteorological stations temperature.

15   – Ile-de-France GHD-RCS and $T_{max}^{(AMJJAS)}$ series display a North–South distribution similar to the temperature correlation with the Paris meteorological station.

The stability of the temperature – GHD-RCS correlations through time was tested by calculating the 15-year running PCC between GHD-RCS and the $T_{max}^{(AMJJAS)}$ series of the closest weather station. These tests, of course, could be performed only for the
20   GHD-RCS which contain data in the instrumental time (i.e., Als, Cha2, Bur, LLV, Swi, Bor, SRv; Fig. 5). For unknown reasons, several GHD-RCS (Cha2, Als, Bur, Swi) show weaker correlations, very likely revealing lower reliability of the data, in the 1990s. The decrease of these PCC in the 1990–1995 window echoes the degradation of some GHD-RCS pairwise correlations (between the GHD-RCS from Swiss, Burgundy and
25   SRv) described in Sect. 3.1. The correlations with temperature series involving Burgundy, Bordeaux, Southern Rhône valley and Low Loire valley are degraded around 1900 and in the 1918–1930 time window. This result, consistent with those of the

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GHD-RCS pairwise correlations, may reflect combined and detrimental effects of phylloxera (and maybe other pests) and World War I on vineyards management and grape harvest scheduling.

3.3 Extreme years and mean levels

To identify extreme years, we first calculated a "general" z-score series as the median of the z-scores of the GHD-RCS (Fig. 6). Then extreme years (i.e., years with an extremely late/early grape harvest, corresponding to an extremely cool/hot growing season), were defined as years with values superior/inferior to the average value of the general z-score series plus/minus 1.65 × the standard deviation (which allows extracting 10 % of the data). We arbitrarily excluded years for which the number of available GHD-RCS was inferior to 5. This led us to discard the years before 1550.

According to this procedure, the years with an extremely hot growing season (April–September) are, by increasing order of GHD earliness: 1952, 1599, 1571, 1976, 1559, 1718, 1616, 1945, 1637, 1865, 1893, 1556, 1822 and 2003. Those with an extremely cool growing season are, by decreasing order of GHD earliness: 1621, 1770, 1805, 1725, 1740, 1698, 1675 and 1816. Most of the extremely early/late years correspond to high/low values of the average T_{mean} at De Bilt and in Central England (T_{mean} rather than T_{max} was chosen here for the comparison with our data because the records are longer). The exceptions are 1698, which is not cold while the grape harvests are late, and 1945 and 1952 which are not particularly hot while the harvest are early.

The distribution of early and late years is not homogenous in the series: extremely late harvest occurred from 1621 to 1816, while the extremely early ones, except 1718, occurred before 1637 or after 1822. Extremely late years all occur during the Little Ice Age, while extremely early years are also frequent at the beginning of the Little Ice Age. The periods of late harvest at the end of the 17th century and in the early 19th century are consistent with the Late Maunder (1675–1715) and Dalton minimum (1800–1820). The tendency towards earlier and earlier GHD, since 1970, is in agreement with the 20th century warming trend.

4   Conclusions

The current database includes 16 921 grape harvest dates from 378 series, classified in 27 regions. It will be freely available for download for scientific or teaching purposes. It will be updated, corrected and expanded as original series or revisions of already included series will become available.

The quality of 8 out of the 27 GHD of this study were analysed thoroughly (investigations on varieties, viticultural practices, type and quality of wine produced over time) in order to use them for past climate reconstructions. The other GHD-RCS of the database were not analysed in such detail. In this paper, we have restricted ourselves to a very general quality assessment of the GHD-RCS by performing pairwise correlations, by comparing them to Météo-France and ECA temperature series (Klein Tank et al., 2002) and by testing the stability through time of these GHD-RCS pairwise correlations and of GHD-RCS-temperature correlations. We strongly recommend the contextualization of the series before interpreting them in terms of climate change.

We accomplished an initial step towards the development of a European dataset which would be very valuable for the analysis of temperature change, weather regimes or atmospheric circulation patterns over the last centuries. The potential of the database is demonstrated in a companion paper, which presents a GHD-based reconstruction of the atmospheric circulation over Europe during the Little Ice Age (Yiou et al., 2011).

Supplementary material related to this article is available online at:
http://www.clim-past-discuss.net/7/3823/2011/cpd-7-3823-2011-supplement.zip.

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Table 1. Regional composite series description.

Name	Abb.[1]	Numb.[2]	Start	End	Length	Gaps	Reference Series	Mean Lat.	Mean Long.
Alsace	Als	16	1700	2005	306	44	Ribeauvillé; Riquewihr	48.17	7.28
Auvergne	Auv	15	1799	1879	80	1	Chadeleuf	45.58	3.17
Auxerre-Avalon	Aux	2	1751	1879	129	1	–	47.78	3.57
Beaujolais and Maconnais	Bea	4	1892	1976	85	12	Beaujolais	46.24	4.58
Bordeaux	Bor	14	1449	2006	558	231	Pichon-Longueville	45.18	−0.75
Burgundy	Bur	20	1354	2006	652	39	Dijon	47.32	5.04
Champagne 1	Cha1	28	1806	2006	201	17	C1; C2; Sézanne; Aÿ 1	49.04	3.97
Champagne 2	Cha2	6	1799	1879	81	0	Les Riceys	47.98	4.28
Gaillac-South-West	Gai	5	1483	1789	307	234	–	43.9	1.9
Germany	Ger	2	1611	1830	220	22	–	48.77	9.17
High Loire Valley	HLV	3	1600	1879	280	170	–	47.07	2
Ile de France	IdF	16	1478	1977	500	81	Argenteuil	48.93	2.23
Jura	Jur	16	1449	1976	528	86	Salins	46.93	5.88
Languedoc	Lan	36	1524	2007	484	150	Montpellier	43.6	3.87
Low Loire Valley	LLV	6	1801	2006	206	3	Chinon	47.15	0.22
Luxembourg	Lux	1	1840	1949	110	3	Grand Duché	49.67	6.13
Maritime alps	Mar	3	1500	1796	297	74	–	43.5	6
Northern Italy	NIt	1	1623	1884	262	99	Tirano	46.22	10.17
Northern Lorraine	NLo	8	1752	1884	133	6	Toul	48.68	5.88
Northern Rhone valley	NRv	3	1537	2006	470	342	–	45.48	4.83
Savoie	Sav	3	1713	1879	167	44	–	45.6	6
Spain	Spa	4	1499	2007	509	161	–	42.34	−3.3
Southern Lorraine	SLo	3	1760	1879	120	11	Châtillon-sur-Saône	47.98	5.88
Southern Rhone valley	SRv	51	1433	2006	574	123	Pernes-les-Fontaines; Couvent des Pernes	43.98	5.05
Switzerland (Leman Lake)	Swi	15	1480	2007	528	38	Lausanne	46.57	6.52
Various South-East	VSE	33	1543	1933	391	274	–	43.74	3.47
Vendée – Poitou Charente	VPC	6	1600	1877	278	172	Saint-Hilaire-de-Talmont	46.45	−1.5

[1] Abb. = abbreviation; [2] Numb. = number of series included in the composite series.

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Table 2. Pearson correlation coefficients of the two-by-two correlations between GHD-RCS over the whole length of the records. Codes of significance test: black: p-value < 0.001, red: p-value < 0.01, green: p-value < 0.05, blue: p-value > 0.05. Abbreviations as in Table 1.

|	Als	Auv	Aux	Bea	Bor	Bur	Cha2	Cha1	Gai	Ger	HLV	IdF	Jur	Lan	LLV	Lux	Mar	Nlt	NLo	NRv	Sav	Spa	SLo	SRv	Swi	VSE
Auv	0.67																									
Aux	0.67	0.83																								
Bea	0.79																									
Bor	0.62	0.79	0.70	0.68																						
Bur	0.60	0.85	0.77	0.85	0.66																					
Cha2	0.71	0.88	0.89		0.80	0.90																				
Cha1	0.68	0.83	0.89	0.83	0.72	0.83	0.86																			
Gai	0.70		0.75		0.81	0.40																				
Ger	0.58	0.78	0.65		0.28	0.64	0.76	0.82	0.53																	
HLV	0.65	0.84	0.88		0.85	0.76	0.88	0.82	0.72	0.59																
IdF	0.61	0.80	0.82	0.76	0.70	0.72	0.89	0.82	0.47	0.52	0.91															
Jur	0.54	0.82	0.70	0.65	0.64	0.77	0.86	0.70	0.57	0.61	0.81	0.73														
Lan	0.50	0.30	0.28	0.59	0.43	0.30	0.12	0.45	0.35	0.24	0.32	0.30	0.25													
LLV	0.52	0.78	0.82	0.67	0.76	0.81	0.85	0.73			0.81	0.87	0.80	0.74	0.00											
Lux	0.58	0.42	0.59	0.37	0.29	0.39	0.62	0.36		0.49	0.47	0.56		−0.30	0.41											
Mar	0.49		0.30		0.40	0.43			0.58	0.34	0.62	0.50	0.52	0.58												
Nit	0.62	0.76	0.58		0.49	0.49	0.68	0.63	0.39	0.47	0.61	0.48	0.47	0.41	0.57	0.24	0.43									
NLo	0.68	0.80	0.78		0.64	0.81	0.88	0.84	0.73	0.73	0.79	0.82	0.80	0.25	0.73	0.63	0.38	0.59								
NRv	0.67	0.81	0.80	0.54	0.69	0.73	0.79	0.72		0.54	0.80	0.72	0.52	0.50	0.64	0.45		0.68	0.75							
Sav	0.71	0.73	0.70		0.70	0.68	0.83	0.79	0.61	0.59	0.78	0.63	0.62	0.53	0.76	0.39	0.58	0.64	0.71	0.76						
Spa	0.38		0.14	0.42	0.38	0.44			0.55	0.19	0.18	0.42	0.26	0.28	0.45	0.53	−0.01	0.20	0.35	0.40	0.68					
SLo	0.66	0.80	0.80		0.79	0.78	0.87	0.83	0.60	0.55	0.83	0.85	0.80	0.25	0.80	0.57	0.65	0.64	0.81	0.77	0.80	0.45				
SRv	0.44	0.75	0.58	0.23	0.27	0.50	0.66	0.37	0.43	0.40	0.44	0.34	0.31	0.56	0.49	0.26	0.66	0.46	0.53	0.62	0.59	0.34	0.58			
Swi	0.63	0.85	0.72	0.69	0.61	0.58	0.86	0.60	0.60	0.43	0.74	0.54	0.68	0.57	0.72	0.59	0.60	0.60	0.79	0.56	0.77	0.30	0.86	0.52		
VSE	0.30	0.42	0.44	0.25	0.43	0.40	0.30	0.20	0.72	0.38	0.27	0.28	0.51	0.37	0.21	0.16	0.69	0.33	0.33	0.44	0.45	0.30	0.30	0.15	0.58	
VPC	0.49	0.77	0.80		0.47	0.59	0.78	0.77		0.46	0.64	0.74	0.47	−0.13	0.83	0.41	−0.06	0.45	0.69	0.74	0.76	−0.18	0.80	0.53	0.55	0.18

Correlation coefficients
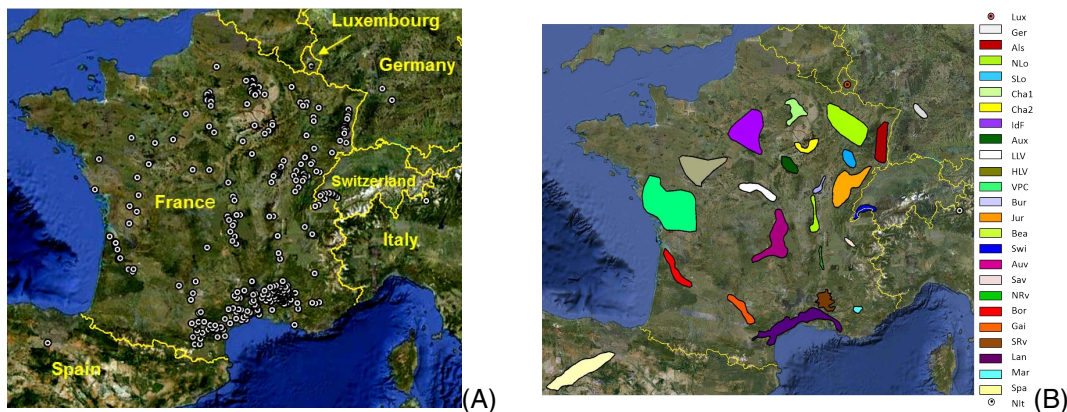
Fig. 1. (A) Location of the GHD sites and **(B)** of the regions defined in Table 1. "Various South East" field is not reported. It corresponds to the series in South-Eastern France which cannot be classified in Languedoc, in Maritime Alps or in Southern Rhône valley.
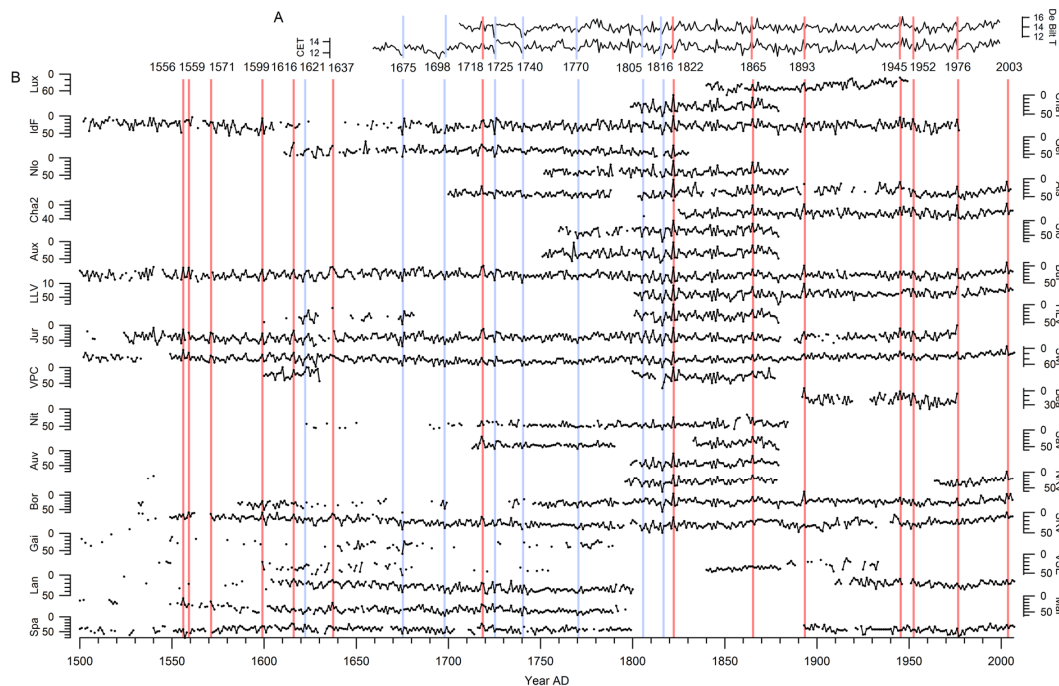
Fig. 2. GHD-RCS from 1500 to 2007. Regions abbreviated name are defined in Table 1. $T_{mean}^{(AMJJAS)}$ at De Bilt (Netherland) and Central England are depicted in the top panel for comparison. The vertical bars correspond to years with extremely warm (red) and cool (blue) summers as defined in Sect. 3.2.

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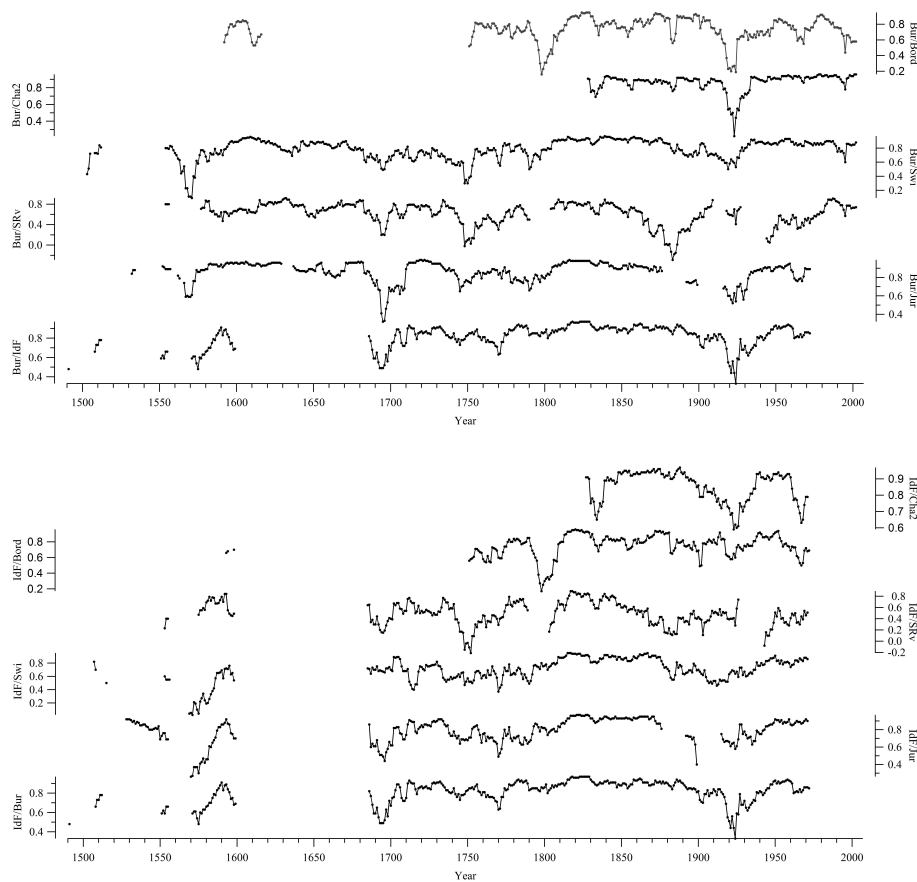Abstract   Introduction

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Fig. 3. See caption on next page.
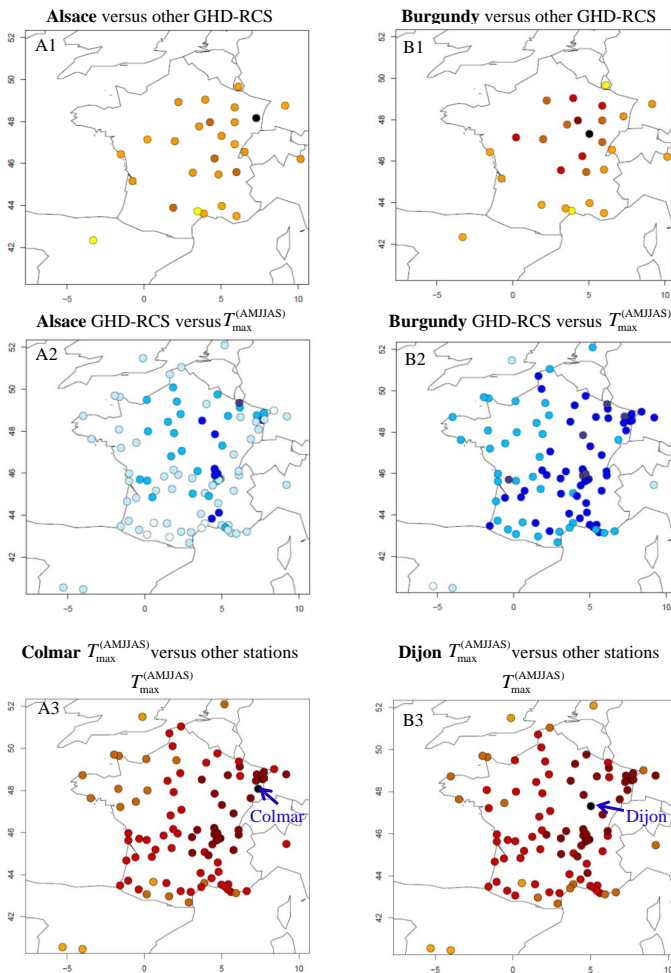
Fig. 3. See caption on next page.

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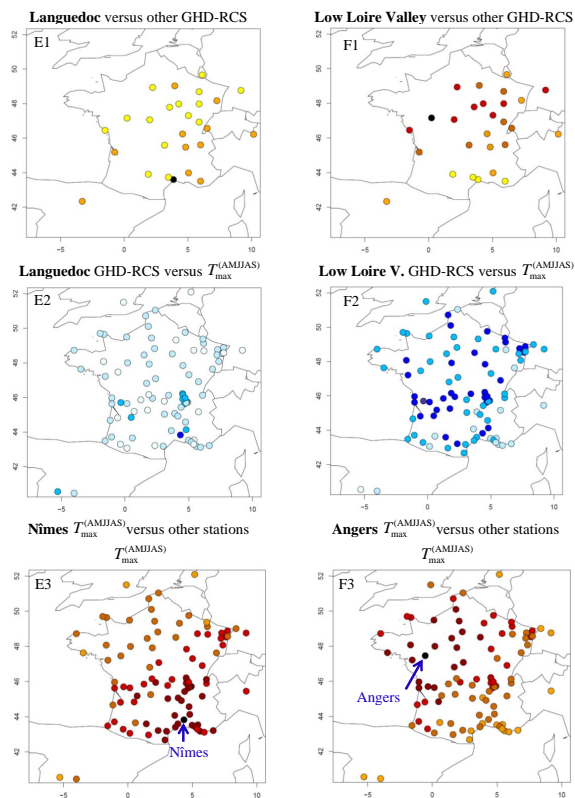
Fig. 3. Comparison of correlation maps. Top panels (1): two-by-two GHD-RCS correlations, intermediate panels (2): GHD-RCS versus $T_{max}^{(AMJJAS)}$ correlations, bottom panels (3): pairwise $T_{max}^{(AMJJAS)}$ correlations. Each point is centred on the location of the temperature series. Colour code for top and bottom panels: value of the correlation coefficients: $r = 1$: black; $1 > r \geq 0.9$: dark-red; $0.9 > r \geq 0.8$: red; $0.8 > r \geq 0.7$: dark orange; $0.7 > r \geq 0.6$: orange; $0.6 > r \geq 0.4$: light orange; $0.4 > r \geq 0$: yellow. Colour code for middle panels: $-1 \leq r \leq -0.9$: black; $-0.9 < r \leq -0.8$; dark blue; $-0.8 < r \leq -0.7$; blue: $-0.7 < r \leq -0.6$: sky blue; $-0.6 < r \leq -0.4$: pale blue; $-0.4 < r \leq 0$: bluish white.

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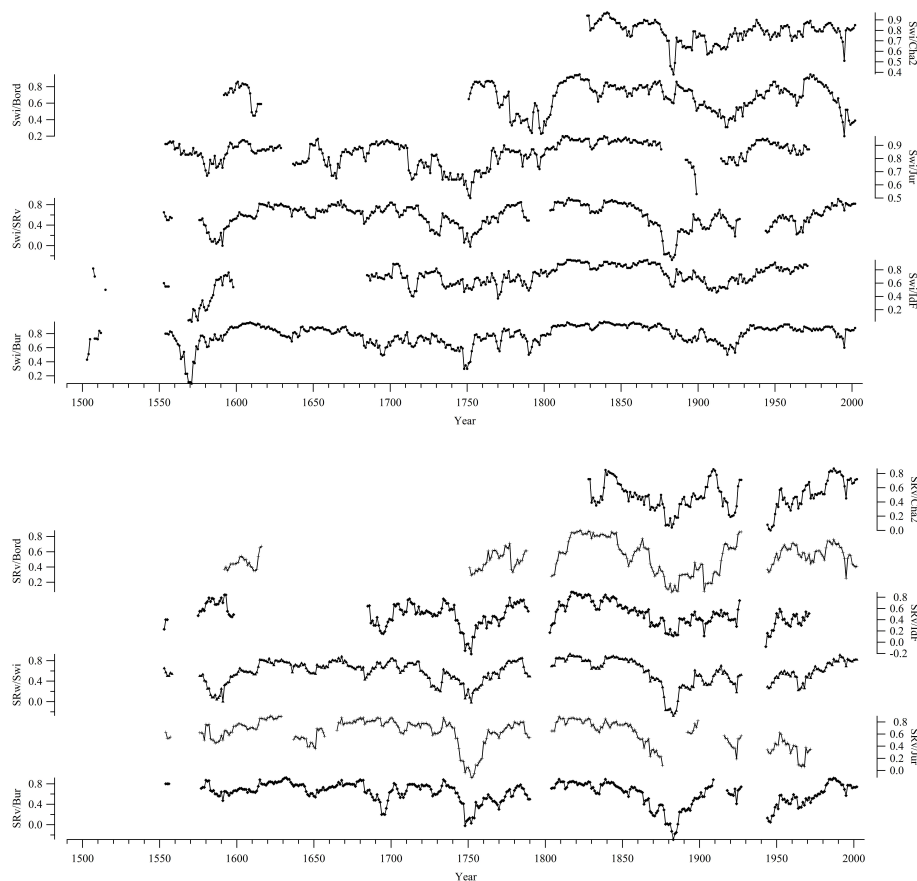Interactive Discussion

Fig. 4. See caption on next page.

Fig. 4. Variation of the 15-year running Pearson correlation coefficients of the GHD-RCS pairwise correlations. From bottom to top: correlations with Burgundy, Ile-de-France, Switzerland and Southern Rhône valley GHD-RCS.
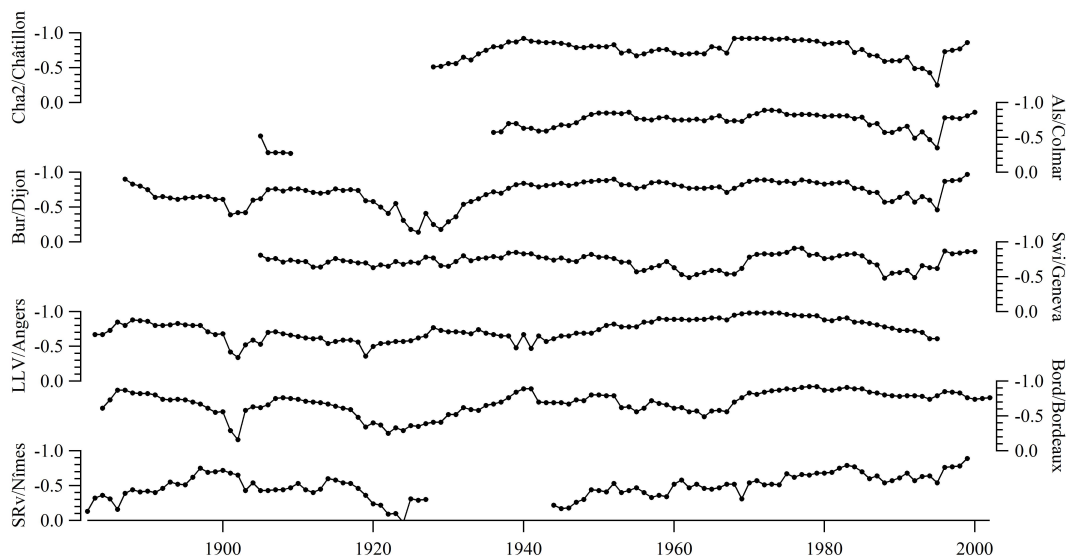
Fig. 5. From bottom to top, variation of the 15-year running Pearson correlation coefficients of GHD-RCS – $T_{max}^{(AMJJAS)}$ correlations: SRv versus Nîmes, Bord versus Bordeaux, LLV versus Angers, Swi versus Geneva, Bur versus Dijon, Als versus Colmar and Cha2 versus Châtillon-sur-Seine.
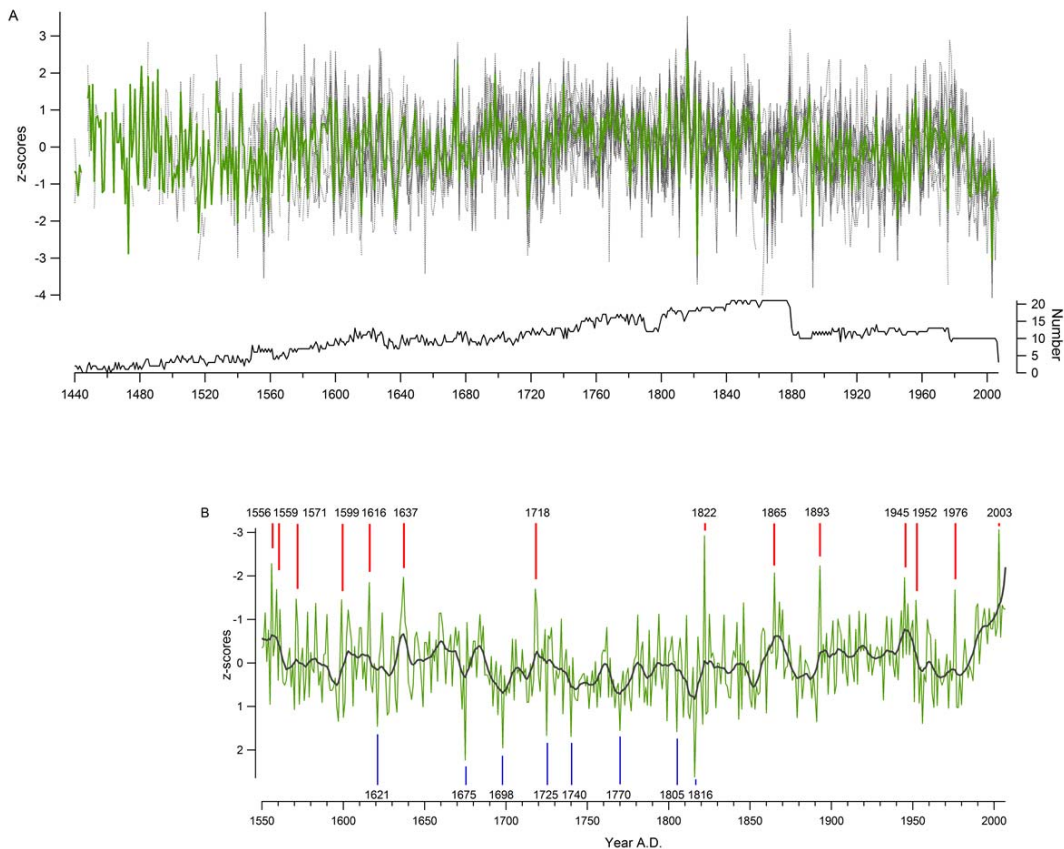
Fig. 6. z-scores of the GHD-RCS (grey lines). The median of the z-scores is in green. The black bold curve is a 11-year running mean. The red and blue vertical lines correspond, respectively, to the years of early and late harvests. The number of GHD-RCS available is reported in panel **(A)**.