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BACCHUS grape harvest days and temperature reconstruction for Vienna from the 16th to the 18th century

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Abstract: We developed a grape harvest date (GHD) time series for the period 1523-2007 for the area of and around Vienna / Austria (48°15' north, 16°21' east, mean altitude of vineyards 200m to 300m). This region is one of the most north-eastern regions in Europe where vines are grown professionally and there is a long tradition as the Romans started here at about 200 AC. To avoid frost damage and to yield higher insolation vineyards are only situated on southern orientated slopes, the region is famous for white vine varieties. The climatological mean values (1961 to 1990) for this region are: annual temperature 9.7°C, main vegetation period April to September 16.0°C and for May to July 17.4°C; the annual sum of sunshine duration reaches 1919 hours, in the main vegetation period 1353 hours are registered. Annual precipitation sums up to 607 mm, in the period from April to September 352 mm rain are recorded. The absolute minimum temperature in 1961 to 1990 dropped to -19.6°C, the mean annual minimum temperature is as low as -12.6°C (all climate data are from the Viennese observatory at Hohe Warte, situated on a flat terrace with an outlook over the Northeast of Vienna).

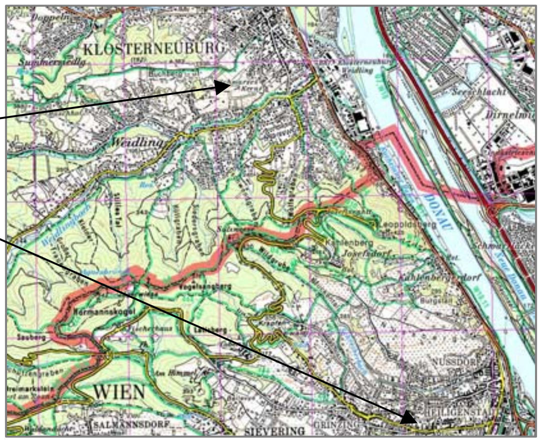

Figure 1: Maps showing the location of Klosterneuburg - monastery and Vienna – Hohe Warte

vineyards

As we aimed at using only original sources we went to the archives of the monastery in Klosterneuburg, some Kilometres north of Vienna, where we could retrieve the original historical manuscripts thus avoiding mistakes arising from later transcriptions and editions. Since grape harvest dates are strongly influenced by spring to (early) summer temperatures especially in a climatic border region for wine growing, we found highly significant correlation coefficients between the homogenized single to multi monthly mean temperatures at Vienna and GHD. This made it possible to reconstruct May to July mean temperatures starting in 1523. We found warm decades in the beginning of our series in the 16th century being as warm as the 1990ies. Afterwards temperatures started to sink, the coldest decades of the record were from 1771 to 1780 and from 1911 to 1920 (here already observed temperatures). The more than 30 years lasting continuous temperature increase since the 1970s seems to be unprecedented in the last 470 years.

Keywords: *Grape harvest phenology, temperature reconstruction, original historical sources, changing practices in viniculture*

1. INTRODUCTION

Climate Change has triggered many studies to extend temperature series into the pre-instrumental period. Especially high resolution paleoclimatology of the last millennium is in the focus of many studies using different proxies as tree rings, corals, ice cores, documentary evidence and phenological data. Many attempts have already been made to gain information about temperature conditions in Europe during past centuries. (for instance *Pfister et al., 2001; Briffa et al., 2002; Shabalova et al. 2003; Chuine et al., 2004; Luterbacher et al., 2004, 2007; Xoplaki et al., 2005; Guiot et al., 2005; Brázdil et al., 2005; Büntgen et al., 2006; Meier et al., 2007; Casty et al., 2005, Moberg et al., 2005 and Etien at al., 2008*). Their main target is to check the significance of variability simulated by climate models and to detect and quantify anthropogenic effects (*IPPC, 2007*). Paraphenological, phenological and oenological data can be useful in establishing temperature reconstructions with an annual resolution, if the data continuously span a long-term period including the instrumental era *(Pfister, 1985)*. Phenological and paraphenological data are more reliable than historical documents as diaries, annuals etc. This kind of information can only provide relative values based on the author's memory whilst phenological are absolute values giving a day of the year.
We built up a grape harvest date (GHD) time series for the area of (and around) Vienna for the period 1523-2007; and drew on original (manuscript) sources rather than using materials already published *(Maurer et al., 2009)*. We focused on temperature having the most significant impact on vegetation in temperate and cold climates *(Ruthishauser et al., 2007)*, especially if the considered genus, such as grape-vine, grows at the border of its distribution area *(Landsteiner, 1999)*. The correlation of GHD with (an ensemble of) mean temperatures of the preceding months was successfully used already for instance by *Meier et al (2007)* and *Chuine et al.* (2004) who studied the GHD series of France and the Swiss plateau respectively. GHD are assumed to be predominantly influenced by spring to (early) summer temperatures (*Lauscher, 1983; Pfister, 1985 and Meier, 2007).*

2. DATA

Different sources were investigated to create "wine" time series for Vienna and the neighbouring Klosterneuburg (Lower Austria). Relevant manuscript sources were studied in the archives of the Klosterneuburg monastery; the bulk of information used for reconstructing temperature came from Manuscript 121: Gedenkbuch und Weinchronik written by Josef Bittmann, Klosterneuburg, in 1880. Bittmann used his own records and older records of different writers to compile his "winechronicle". It contains highly detailed information about wine growing from 1540 to 1879. For the Vienna series a comprehensive reliable secondary source *(Pribram, 1938)* was used for the period 1523-1749 (Vienna/Buergerspital). Pribram evaluated primary sources. Data for the so called modern period of 1970 to 2007 were compiled at Lehr- und Forschungszentrum für Wein- und Obstbau Klosterneuburg *(Sommer, 2008)* from the original material *(Schmuckenschlager, 1970-2007)*.

Instrumental temperature (monthly means) are derived from the HISTALP data collection (Auer et al., 2007) in the bias corrected version 2008 (Böhm et al., The early instrumental warm bias a solution for long 148 central European temperature series 1760-2007. Climatic Change, submitted 2008).

3. METHODS

The GHD Vienna / Klosterneuburg and the instrumental temperature measurements in Vienna overlap between 1775 and 1879. We calibrated the linear regression model for temperature with GHD from 1775 to 1850, verified the results with the period 1851 to 1879 and reconstructed May to July mean temperatures for the period 1523 to 1774. The reconstruction criteria suggested by *Pfister(1999)* concerning the length of the overlapping period and the distance between the point of observation and the meteorological station are met. To prove the stability of the correlation between temperature and GHD we calculated 10 years running correlation coefficients for the period where both the GHD and instrumental data were available.
Finally, we compared our reconstructed May to July mean temperature values with the data from *Casty et al. (2005)* Till the decade 1651-1660 only winter, spring, summer and autumn mean temperatures were given, from the decade 1661-1670 to the decade 1871-1880 May to July mean temperatures can be calculated with the help of monthly values. *Casty et al.* used a combination of long instrumental station data and documentary proxy evidence to reconstruct seasonal (before 1659) and monthly (until 1900) mean values of temperature and precipitation back to 1500. From 1901 up to 2000 *Casty et al.* data is equivalent to the CRU TS 2.0 dataset.

4. RESULTS AND DISCUSSION

Table 1 shows some important linear correlation coefficients together with their levels of significance. Mean monthly and mean seasonal surface temperatures constantly exhibit negative correlations to all phenological data expressed in days of the year DOY (1st January is DOY 1, 1st February is DOY 32,…), a fact well known in literature. Harvest and flowering dates are even negatively correlated to mean annual temperatures (*Lauscher, 1983)*. However, different information can be found with regard to the month(s) having the greatest impact on the respective parameter. In general, combining two or three months yields the best results.

Table 1: Parameters to be correlated, value of correlation together with its level of significance and R^2. Correlations above an absolute value of 0.60 and their corresponding R^2 values are bold. If no location is mentioned, the values refer to Klosterneuburg.

Historic Data		**Modern Data**
Correlation	*Value (Level of Significance)*	*Value (Level of Significance)*
Quality Index- Harvest Date	-0.55 (99%)	
Quality Index- Flowering Date	-0.46 (99%)	
Quality Index- Mellowness Date	**-0.66 (99%)**	
Quantity Index- Harvest Date	-0.28 (99%)	
Quantity Index- Flowering Date	-0.28 (99%)	
Quantity Index- Mellowness Date	-0.31 (99%)	
Price- Mellowness Date (1834-1879)	-0.40 (99%)	
Quality Index- Harvest Date/Buergerspital	**-0.60 (99%)**	
Quantity- Harvest Date/Buergerspital	-0.41 (99%)	
Rain/Shower- Harvest Date	0.29 (99%)	
Rain/Shower- Flowering Date	0.34 (99%)	
Annual Mean Temperature- Harvest Date	**-0.63 (99%)**	**-0.69(99%)**
		-0.39 (95%), Vienna
Mean Temperature of May- Harvest Date	-0.50 (99%)	**-0.72 (99%)**
		-0.57 (99%), Vienna
Mean Temperature of June- Harvest Date	-0.55 (99%)	-0.59 (99%)
		-0.36 (95%), Vienna
Mean Temperature of July- Harvest Date	**-0.63 (99%)**	-0.58 (99%)
		not significant, Vienna
Mean Temperatur of April to July- Harvest Date	**-0.76 (99%)**	**-0.89 (99%)**
		-0.58 (99%), Vienna
Mean Temperature of May to June- Harvest Date	**-0.70 (99%)**	**-0.76 (99%)**
		-0.61 (99%), Vienna
Mean temperature of May to July- Harvest Date	**-0.79 (99%)**	**-0.87 (99%)**
		-0.59 (99%), Vienna
Annual Mean Temperature- Flowering Date	-0.56 (99%)	
Mean Temperature of May- Flowering Date	**-0.66 (99%)**	
Mean Temperature of March to May- Flowering Date	**-0.69 (99%)**	
Mean Temperature of June- Mellowness Date	-0.46 (99%)	
Mean Temperature of July- Mellowness Date	-0.47 (99%)	
Mean Temperature of June to July- Mellowness Date	-0.59 (99%)	

Considering the "modern" Klosterneuburg period one recognizes the outstanding feature, namely, that seven out of eight correlation coefficients show a higher absolute value than the ones in the "historic" period, whereas with the "modern" Vienna data circumstances are the other way round. We attributed this mainly to the non-mixed/mixed data concerning the different vine varieties. But, over centuries, the change of vine varieties in a certain wine-growing area must be seen as an unavoidable fact, independent from the accuracy of the observer. Since an advance of the (para-) phenological stages is accompanied by a high quality index on the one hand and by positive spring to early summer temperature anomalies on the other, a positive correlation coefficient between quality and temperature can be expected. This was verified by two examples concerning the correlation between mean seasonal temperature from June to July (following the information given by *Pfister (1985)* and the quality (r=0.65) index. Difficulties concerning the quality index stem from changed demands (which particularly complicates the indexing of "normal" or "medium" qualities *(Bauer, 2008)*) in the course of decades and from modifications in viticulture (e.g. premature harvest or the cultivation of sour, but profit-yielding varieties in earlier times *(Pfister, 1985).*

As this fact points out to changing practices in viniculture in the region of Vienna we compared 30 year means of temperature and GHD between the "historic" and the "modern" period. As for the Buergerspital/Vienna, the mean harvest date of 1686-1715 (DOY 279.9) proves to be significantly different to the 1969-1999 mean (DOY 285.8, 1987 is missing) on the 99% level. Similarly, the mean harvest date of 1831-1860 at Klosterneuburg (285.8) differs on a 92% significance-level from the one of 1970-1999 (DOY 289.6). Temperature means of the two periods at Klosterneuburg are actually different on the 99.5% level. But the means of temperature and wine harvest develop in the same directions! So we have to assume that practices in viniculture have altered. Nevertheless, a clear trend towards earlier harvest dates during the modern periods is evident and amounts to about 5 days advance per 10 years in Klosterneuburg and to about 3 days advance per 10 years in Vienna – similar to the findings of *Menzel et al., 2006*.

Finally we reconstructed the mean decadal May to July surface temperature at Hohe Warte, Vienna, with the help of the Buergerspital and Klosterneuburg GHD. This special seasonal temperature was chosen because it shows the highest correlation (r=-0.79) with GHD. The stability of this relation was tested calculating a running correlation with moving correlation windows of 10 years (figure 2).

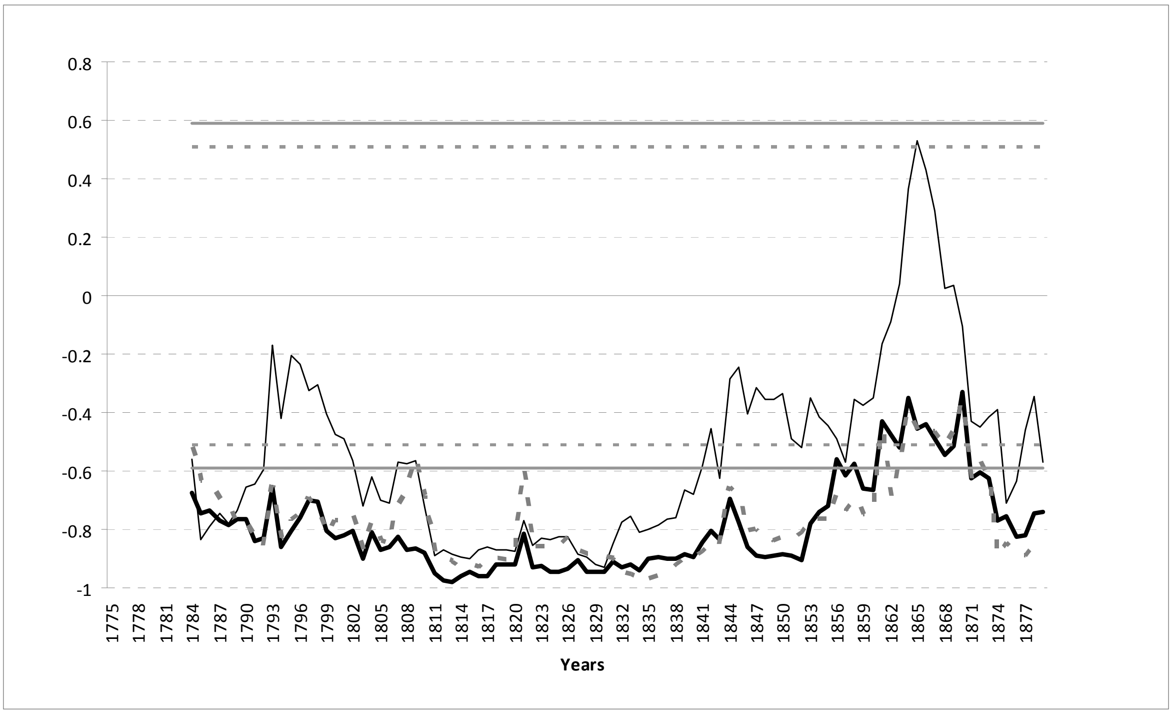

Figure 2: Running correlation between different mean temperatures and harvest dates for the period 1785-1879 using a moving 10-year-window; black thick line: running correlation with May to July mean temperature, black thin line: running correlation with mean June temperature, grey thick dashed line: running correlation with April to July mean temperature, horizontal grey solid and horizontal grey dashed lines: 95% and 90% significance level.

The correlation coefficients between grape harvest dates and May to July mean temperature vary between nearly -1 around 1810 and about -0.4 between 1860 and 1870, thereby dropping below the 95% and even the 90% significance level. The correlation between April to July temperatures and grape harvest shows a very similar run, although with slightly more outliers. The reason why the reconstruction of monthly mean temperatures must fail is best demonstrated by the running correlation between the mean monthly temperature of June and harvest dates. Correlation coefficients vary extremely, ranging from about -0.9 around 1830 to + (!) 0.5 around 1865.

The use of a simple linear regression for reconstructing temperature is justified, since the correlation turns out to be really linear. No other type of regression yields a greater R^2. The course of decadal temperatures can be seen in Figure 3. The calculation of the reduction of error (RE) gives values of 0.7 in the calibration period (1775-1850) and of 0.32 in the verification period (1851-1879), thereby surpassing the quality of the estimation given by the simple climatologic mean. The fact that the absolute minimum can be found in the decade 1771-1780 as also in *Etien et al., (2008*), which is known for being rather cold (Maunder Minimum) confirms a successful reconstruction.

When comparing different reconstructed temperature series (not shown here) one can recognize their limitations. They may diverge considerably, and it is difficult to judge which one is the most “correct”. In general, the quality of temperature reconstructions should increase with a growing number of predictors, like they were used by *Casty et al. (2005)* and *Etien et al. (2008).* But it is turned out that *Casty et al.* reconstruction does not fit well the corresponding temperatures at Hohe Warte, Vienna, until the decade 1851-1860 (r=0.65). Particularly the M-shape around the decade 1771-1780 is only rudimentarily pronounced. The excellent agreement (r=0.99) after 1900 is no surprise, since henceforward *Casty et al.* temperatures are identical with the CRU TS 2.0 dataset. On the other hand, the consistency between our reconstructed temperatures and those observed at Hohe Warte, Vienna, in the decades 1781-1850 is to be expected as it concerns the calibration period. All in all, before 1900, the three different temperature curves match only during the three decades between 1851 and 1880.

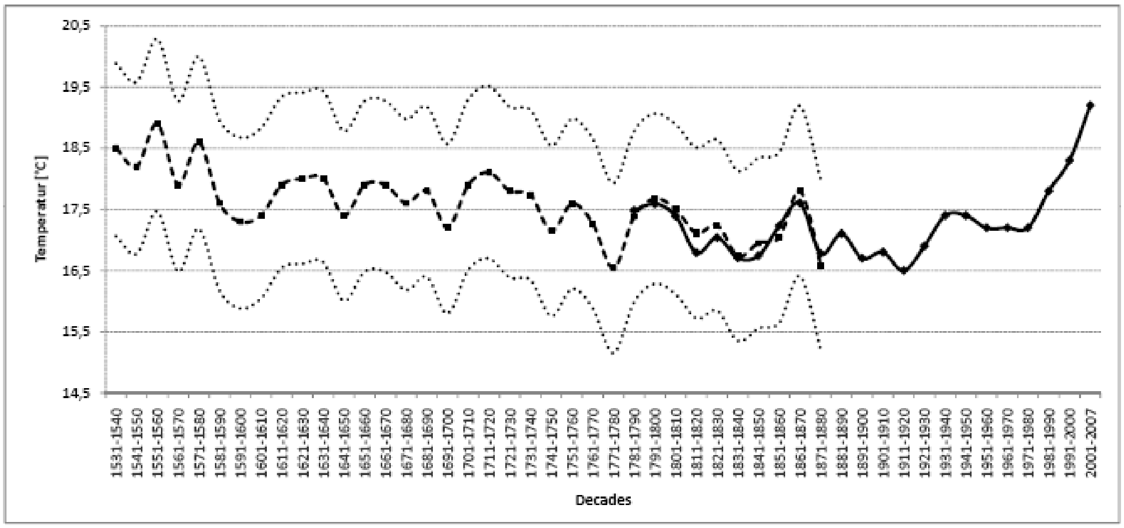

Figure 3: Observed (solid line, 1781-2007) and reconstructed (dashed line, 1531-1879) mean decadal May to July temperature at Hohe Warte, Vienna together with uncertainty (dotted lines, 1531-1879) given a 90%-confidence level

5. CONCLUSIONS

Firstly, our work intended to construct a grape harvest series as continuous as possible. In the course of this work the climatologic value of additional available parameters was assessed. We elongated the Klosterneuburg grape harvest series by the help of the Buergerspital data so that an uninterrupted series ranging from 1523 until 1879 for the region of Vienna can be generated. GHD dates before 1775 are valuable because of lacking temperature information at Vienna.

Using a linear regression model between GHD and the multi monthly mean temperatures May to July which months have the strongest correlation with GHD ($R = -0.79$, p 0 0.01), we found warm decades in the beginning of our series in the 16th century being as warm as the 1990ies. Afterwards temperatures started to sink, the coldest decades of the record were from 1771 to 1780 and from 1911 to 1920 (here already observed temperatures). The more than 30 years lasting continuous temperature increase since the 1970s seems to be unprecedented in the last 470 years.

Taking the quality index as an additional proxy, a bi-proxy temperature reconstruction back to 1523 seems possible. Other parameters such as quantity index or the price of wine must be regarded as less helpful, because they are influenced by local effects and economic trends, but they are interesting from the historical point of view.

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