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Grape harvest dates for checking NAO paleoreconstructions

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Abstract. Dates of the grape harvests in northeastern France and Switzerland exhibit significant correlations with the North Atlantic Oscillation (NAO), a large-scale mode of climate variability over North Atlantic. These correlations, established for the monthly values of the NAO index over the last 175 years, reveal characteristic signatures as a function of frequency. Conversely, these signatures may be used to test the robustness of existing NAO paleoreconstructions, thanks to the availability of harvest dates for northwestern Europe since the end of the fifteenth century. Climatic signal appears prevailing over possible human factors in these series. The results demonstrate the importance of including old instrumental data and of providing monthly values rather than annual means in the NAO reconstructions. They suggest that the available long harvest dates series could constitute an interesting proxy to constrain such reconstructions.

Introduction

A major source of variability in atmospheric circulation is the North Atlantic Oscillation (NAO), which controls some of the decadal variations of climate over the North Atlantic, Western Europe and the Middle-East [Rogers, 1984; Hurrell, 1995]. The NAO corresponds to a dipolar mode of Atlantic circulation with high pressure at latitudes 35–40°N and low pressure at northern latitudes. Its variability is represented by an index, available for the last 175 years, which is defined as the difference in normalized sea level pressures at two fixed locations, one to the South (Azores [Rogers, 1984], Lisbon [Hurrell, 1995], or Gibraltar [Jones *et al.*, 1997; Osborn *et al.*, 1999]), one in Iceland. Pressure anomalies have their most important effects during the winter months [Hurrell, 1995]. Positive values of the NAO index correspond to stronger than normal westerlies onto Europe, inducing mild and humid weather over northern Europe and parts of France, whereas Mediterranean regions may be subject to drought [Hurrell, 1995].

Because of its influence on climate, the NAO has a strong signature on many biological processes, in particular on vine, which is sensitive to temperature and precipitation at specific periods of its vegetative cycle. This cycle spreads over two years [Rosini, 1984]: in April rudimentary shoots appear. A dormant stage from August to November is followed by an active hibernation from December to February. The active

growth starts in April of the next year, the blossoming period is in June, and the harvest is in September–October. Thus, grape harvest dates certainly contain integrated information on local climatic conditions.

Here we analyze the relationships between harvest dates and the NAO, and check whether it could be a useful proxy of long-term climatic variations. This is important because of the non-stationarity of NAO [Appenzeller *et al.*, 1998], which makes inefficient any reconstruction based on harmonic analyses. The main advantage of the vine, in addition to its climatic sensitivity, is its broad geographic extension in the whole western Europe, and the availability of a great number of harvest dates records for at least five centuries.

In what follows, we first analyse the correlations between an experimental NAO series and the grape harvest dates. Then we use some of these correlations to test three published NAO paleoreconstructions.

Instrumental NAO data and grape harvest dates

Several complete experimental series of normalized monthly NAO values are available [Rogers, 1984; Hurrell, 1995; Jones *et al.*, 1997]. They exhibit a rather good consistency, mostly for the winter months, which include the most important part of the coherent NAO variability. The summer indices are often considered as less climatically significant. We used the time series of Jones *et al.* [1997], which is the longest one, going back to 1825. Fig. 1a shows the mean annual NAO indices defined either over 12 months (from April to March of the next year), or over the winter months (December to February). As noted by previous studies [Rogers, 1984; Mann and Park, 1996], the dominant frequencies vary with time. For the last 170 years, the spectra of the annual and winter means (Fig. 1b) confirm the important decadal variability. For the winter mean index, the main peaks of energy are observed at periods of about 2.4, 4.9 and 8 years, but the variability is large from one month to the other. For spring (April), a strong energy is present at 3 years and at a long period ($T > 10$ years).

We used a synthetic grape harvest date series obtained by Le Roy Ladurie [1983] for the period 1484–1977. It corresponds to the merging of five series from northeastern France and two from French Switzerland. These regions experience nearly the same climatic variations with respect to the NAO. The mean values of the different series have been aligned to the mean of a reference series (Volnay, in Burgundy) before merging. Hence we do not have to consider the regional fluctuations of maturation, due to both local climatic influences and variations in vine phenology. A difficulty may come from the human influence on harvest

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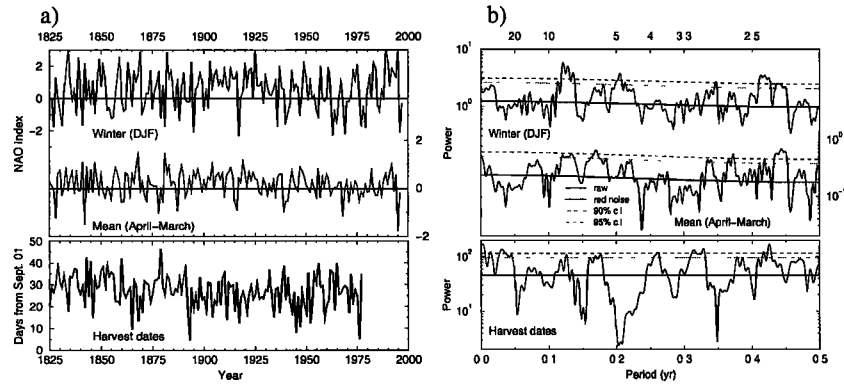


Figure 1. a) From top to bottom: NAO index averages from Jones *et al.* [1997] for winter months (December to February) and for the whole year from April to March; grape harvests dates in northeastern France, in days from September 1st [Le Roy Ladurie, 1983]; b) Power spectra of the same series; thick, dotted and dashed lines represent respectively the red noise background, 90% and 95% confidence level above this red noise. Note that energy is distributed in the whole spectrum and that only a few peaks rise above the 95% confidence level.

dates, which is superimposed to the climatic influence. Economic (e.g., improvement of quality), and cultural reasons influence harvest dates [e.g. Le Roy Ladurie, 1983; Lachiver, 1988; Pfister *et al.*, 1999]. We checked this factor by comparing the northeastern France series with a similar series for southern France. They correspond to different plant species, but also to regions with very different traditions. The correlation coefficient of the two series is close to 0.80 for the period where they overlap (17th and 18th centuries), a large value which shows that cultural factors must be marginal compared to the influence of climate variability. The most serious perturbation may come from the phylloxera, a disease which affected most of the European vines in 1860-70, and imposed drastic changes in the plants. Fig. 2 shows histograms of grape harvests for three periods of 100 years, the last two ones being separated by the phylloxera crisis. The maximum is unchanged during the three centuries. An important difference is the smallest number of late harvests during the last century. Although the effect of new vine grower practices cannot be dismissed, this trend more likely reflects the secular climatic trend whose effect is also observed on many other biological processes. Thus, although the direct human impact is probably not negligible, the climatic signal seems prevailing in the composite series we analyze.

Fig. 1a shows the harvest series used since 1825, together with the NAO indices. No obvious relationship may be observed between the different series. However, their spectra reveal energy in similar frequency bands (Fig. 1b), in particular for the winter mean at periods 2.4 and 8 years.

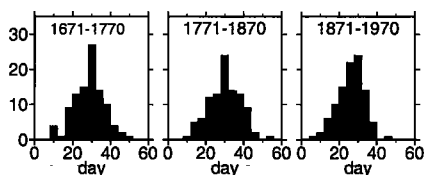


Figure 2. Histograms of the grape harvest dates in northeastern France for three periods: 1671-1770, 1771-1870, 1871-1970. Day from September 1st. Note the stability of the maximum (day 30), even after the phylloxera crisis (~1870), and the decrease of late harvests for the last century.

Correlations between NAO index and grape harvest dates

We analyzed the correlations between the harvest date series and the NAO series in specific spectral domains for indices corresponding to a specific month. Band-pass filters are applied to each series and the correlation coefficient r is computed for the common part of the two series. Moreover, in order to check the stability of r with time, correlation coefficients are computed for 50-year moving windows shifted by 10-year steps. Due to the window overlaps, the different correlation coefficients obtained for the successive windows are not independent. Consequently, the standard deviation of these successive values is not a confidence interval in a usual statistical approach. The error bar defined with this method gives however a useful estimate of the stability of the series through time.

Table 1 reports the most significant correlation coefficients between harvest dates and the NAO indices for the different months. Summer months have not been considered, because weather conditions are poorly related to the NAO index during these months. As reported in Table 1, a positive correlation is obtained with the December index at short periods: a cold beginning of winter related to a low NAO index accelerates the active hibernation of the stocks, leading to an early harvest. At intermediate and long periods, negative correlations are observed with some late winter or spring indices (e.g. May at period 3.1 yr), indicating that high NAO values, thus mild and humid springs, are followed by early harvests. At long time scales ($T \geq 10$ yr), the negative correlation obtained for winter and early spring months appears very stable. The highest (negative) correlation is obtained for April: it is of the order of -0.52 ± 0.06 for periods $T \geq 10$ yr, and reaches -0.70 ± 0.10 for $T \approx 20$ yr. A plot of the harvest dates superimposed onto the NAO April index (Fig. 3), filtered with the same low-pass filter, shows that the two series have very similar features and are in phase. The annual mean also gives a high negative correlation. These long period correlations are striking, in regard of the two year cycle of the vine. They possibly reflect the relative insensitivity of the vine to short term climatic fluctuations (in particular precipitation), because of the great depth of its roots (several meters), whereas it will react to long term

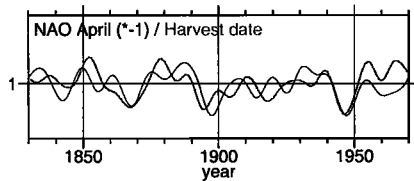


Figure 3. Decadal variations of *Jones et al.*'s [1977] NAO April index (reversed) superimposed to the harvest dates. Data low-pass filtered ($T > 10$ yr), normalized amplitudes.

fluctuations [Lachiver, 1988]. Late winter and early spring conditions are important for harvest dates, because they determine the blossoming time. A common observation is that the harvest occurs about 100 days after the blossoming time.

Correlations of harvest dates with temperatures (mean values interpolated from gridded data with $5^\circ \times 5^\circ$ mesh) and precipitation (values at two sites in the northeastern France) leads to poorly informative results. The NAO index has the advantage of integrating these two parameters in the complex biological processes governing vine growing.

Test of NAO paleoreconstructions

The correlations obtained in the previous section have revealed that grape harvest dates contain very rich information at various frequencies about the monthly variability of the NAO. They can thus constitute an interesting, new proxy to test the existing NAO paleoreconstructions. Three reconstructions will be considered here (Table 1 and Fig. 4).

The first reconstruction, by *Cook et al.* [1998], is based on tree-ring chronologies from North America and northwestern Europe. It extends back to 1701, and is calibrated on *Rogers* [1984] series of winter indices (December to February) for the 1874–1980 period. Considering the previous results, the

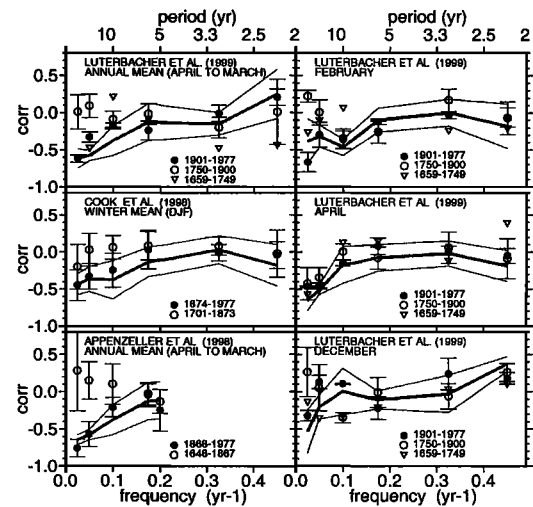


Figure 4. Correlation coefficient of harvest dates with NAO indices as a function of frequency. Left: annual means for the three reconstructions considered in this study (no short periods in *Appenzeller et al.*'s series); right: *Luterbacher et al.*'s [1999] monthly reconstruction for three months with very different signatures in frequency (February, April, and December). Filled circles: calibration period, open circles: precalibration period including instrumental data, with 1σ error bars. Triangles: early data (from *Luterbacher et al.* [2001]). Thick lines: experimental series by *Jones et al.* [1997], with 1σ -confidence domain (thin lines).

highest correlation of the mean winter NAO index with harvest dates was obtained at long period ($r = -0.37 \pm 0.17$ for $T \geq 10$ years). *Cook et al.*'s series, checked in the same conditions, leads to a similar value during the calibration

Table 1. Correlation coefficient $r \pm \delta r$ between grape harvest date and NAO (monthly indices or mean values defined over several months noted with their initial). Grape harvest dates by *Le Roy Ladurie* [1983] for the period 1484–1977, NAO instrumental series by *Jones et al.* [1997] from 1825 to 1997, reconstructed series: *Cook et al.* [1998] from 1701 to 1980 (with calibration period 1874–1980); *Appenzeller et al.* [1998] from 1648 to 1991 (with the last 130 years for the calibration period); and NAO1 series by *Luterbacher et al.* [1999] from 1750 to 1990 (calibration and verification period 1901–1990). For the reconstructed series, * corresponds to the calibration period, ^a to the period before calibration. Correlation coefficients apply to the time intervals common to the harvest series and each of the NAO series.

Frequency (yr ⁻¹)	Mean Period (yr)	Month	Correlation coefficient $r \pm \delta r$				
			<i>Jones et al.</i>	<i>Cook et al.</i>	<i>Appenzeller et al.</i>	<i>Luterbacher et al.</i>	
0.4-0.5	2.2	Dec.	$+0.37 \pm 0.10$			$+0.18 \pm 0.08$ *	
						$+0.26 \pm 0.12$ ^a	
0.25-0.4	3.1	May	-0.47 ± 0.11			-0.34 ± 0.05 *	
						-0.27 ± 0.17 ^a	
0-0.1	≥ 10	Winter (DJF)	-0.37 ± 0.17			-0.28 ± 0.17 *	
					-0.33 ± 0.17 *		-0.01 ± 0.16 ^a
					$+0.03 \pm 0.22$ ^a		
0-0.25	> 4	April	-0.52 ± 0.06			-0.46 ± 0.04 *	
						-0.35 ± 0.14 ^a	
0-0.25	> 4	Annual mean (April to March)	-0.58 ± 0.07			-0.33 ± 0.07 *	
						$+0.09 \pm 0.17$ ^a	
0-0.25	> 4	Annual mean (April to March)	-0.32 ± 0.15			-0.34 ± 0.13 *	
						$+0.06 \pm 0.13$ ^a	

period ($r = -0.33 \pm 0.17$), but is unsuccessful before this period ($r = +0.03 \pm 0.22$), a result which possibly reflects the low sensitivity of tree-ring growth to winter conditions.

The second reconstruction, from Appenzeller *et al.* [1998], is based on Greenland ice cores and spans over the past 350 years. It corresponds to an annual mean average from spring to spring (April to March), a linear trend and the higher frequencies being removed. It has been calibrated with Hurrell's [1995] series for the last 130 years. The correlation coefficient r between Appenzeller *et al.*'s series and the grape harvest dates, low-pass filtered at 4 years, is -0.34 ± 0.13 for the calibration period, and reaches -0.57 ± 0.17 for $T > 10$ years, thus of the same order as those obtained with the instrumental series ($r = -0.32 \pm 0.15$ and $r = -0.58 \pm 0.07$, respectively) (Table 1). However, r is of opposite sign before the calibration period, suggesting a poor performance of the reconstruction before 1865.

The third reconstruction, by Luterbacher *et al.* [1999], combines old instrumental data and a large amount of proxy data, and proposes monthly values back to 1675. It proposes two series (NAO1 and NAO2) for which we obtain nearly similar results, only those with NAO1 are presented. The calibration period is 1901–1960, and the verification period spans 1961 to 1990. Results for annual mean are similar to those obtained for the previous series (Fig. 4). Owing to the availability of monthly values, it is possible to test extensively this reconstruction, during the calibration–verification period, and during two precalibration periods: one starting at the beginning of the series in 1675, the other one starting in 1750, i.e. when more instrumental data become available. This second period gives better performances, in particular at intermediate frequencies: For winter months, the correlation coefficients obtained with the reconstructed series are often of the same order as those obtained with the instrumental series (Table 1 and Fig. 4). The results at very long periods are generally poor, except for the April index, which is the most sensitive with respect to harvest date, and which gives good results at all periods. The lower performance at long period is possibly due to the short length of the calibration period (60 years) compared to the dominant period of the signal ($T \geq 10$ yr). A new series with monthly values back to 1659 [Luterbacher *et al.*, 2001] gives similar results, with particularly good results for April (Fig. 4).

Conclusion

The present study has demonstrated that, due to their different sensitivities to the NAO indices of the different months at different wavelengths, grape harvest dates are an interesting tool to check NAO paleoreconstructions. Some limitations may come however from the poor control of the human impact (changes in vine grower practices), even if the climatic impact appears prevailing. Among the series we considered, Luterbacher *et al.*'s [1999, 2001] series appear as the most informative, owing to the availability of monthly values. The introduction of instrumental data is probably an important aspect for the quality of this reconstruction [Schmutz *et al.*, 2000].

Instrumental data do not go back further than 1650, and are in limited number before the 19th century. Historical and experimental proxies [Mann *et al.*, 1998] are thus of major interest. Grape harvest dates, which are known since the

fifteenth century and have a large geographic extension, deserve further exploration as a possible proxy to extend or constrain the monthly NAO paleoreconstructions further back in time.

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