Contribution of oak tree-ring width and stable isotopes to reconstruct hydroclimate variability in central France over the last millennium

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Context and objectives

To better understand current global warming, it is crucial to document natural climate variability during the pre-industrial period. This helps to characterize the patterns of variability and identify the forcings driving it, assess the accuracy of the variability simulated by climate models, and determine the role of anthropogenic effects (IPCC 2021).

In Europe, tree-ring width (TRW) and maximum latewood density (MXD) series have been widely used to reconstruct temperature variations over the past millennium, particularly in high-altitude or high-latitude regions (e.g. Briffa et al 1992; Corona et al 2010). At lower altitudes, tree growth is more controlled by drought and precipitation, making these records valuable for characterizing hydroclimate variability (e.g. Büntgen et al 2011, Cook et al 2016, Cooper et al 2013). However, these tree-ring series are affected by age-related effects and stand dynamics trends, requiring standardization procedures that can impact the low-frequency component of the signal (see Helama et al 2017, for a review). The dendroisotopic approach, which is based on the determination of the oxygen and carbon isotopic composition (δ18O and δ13C) in tree-ring cellulose, partly overcomes the issues associated with conventional tree-ring measurements. These isotopic proxies are highly sensitive to water stress, yet they are less affected, or even unaffected, by age-related growth effects. However, although numerous multi-century reconstructions exist across Europe (e.g. Büntgen et al 2021, Treydte et al 2024) and specifically in France (Etien et al 2008, Labuhn et al 2016), there are no millennial reconstructions based on stable isotopes or tree-ring widths at low altitudes in France. This is notable given that these areas have long been inhabited by human societies for centuries.

Our goal is to deepen the understanding of past climate variability at the regional scale, where changes are more pronounced, by producing the first millennial scale tree-ring width chronology for central France. In parallel, we aim to construct a cellulose $\delta^{18}O$ chronology covering the period 1200-1400 CE, which will help define the climatic transition between the relative warming of the Medieval Climate Anomaly (MCA; ~950-1250 CE) and the cooling of the Little Ice Age (LIA; 1350-1850 CE).

Material and methods

Tree-ring width data

Thirty-three tree-ring width chronologies from living oaks, spanning a large area of central France (46-48.5°N, -1.5-7.5°E), were selected from both published (e.g. Lebourgeois et al 2004, 2015, Mérian et al 2011, Pilcher 1996) and unpublished sources (Fig. 1). In addition, three new chronologies were developed. Samples preparation, measurement and dating were conducted at LGP using CooRecorder and CDendro (Larsson 2005).

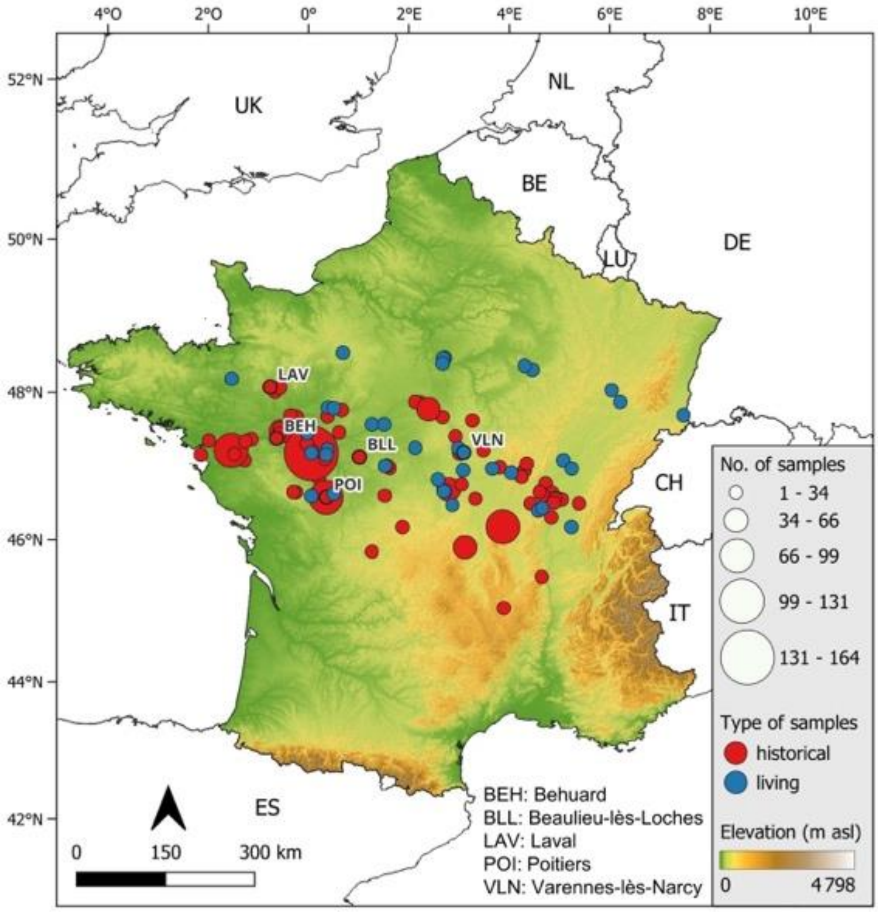

Fig. 1: Tree-ring width (TRW) and stable isotope (TRSI) series studied.TRSI series sites are indicated by labels. The dataset consists of 1,523 series grouped in 141 site chronologies.

To cover the last millennium, we leveraged a vast corpus of wood (> 3,000 series) from historic buildings as well as archaeological remains including ancient bridges, mills, fisheries, etc. excavated from the Loire River bed (e.g. Dumont et al 2014). Here, we present the temporal distribution of the initial data, comprising more than 1,400 individual tree-ring width series that already cover the defined spatiotemporal framework (Fig. 2). These data have been generously provided by French dendroarchaeologists.

Tree-ring stable isotope data

Among the living trees cored at the VLN site (Fig. 1), the tree-ring latewood from 9 cores was cut with a scalpel over the period 1910-2023. The tree rings were then pooled by year, and α-cellulose from each year was chemically extracted. The isotopic analyses were conducted at LSCE. $\delta^{18}O$ and $\delta^{13}C$ of α-cellulose was measured by pyrolysis with a high-temperature conversion elemental analyzer (vario PYRO cube) coupled to a mass spectrometer (IRMS, isoprime precisION). Each cellulose sample was measured at least twice. A cellulose reference material (Whatmann CC31) was included in the analysis sequences to correct for analytical drift and normalize the data to internationally accepted standards. The long-term analytical precision based on repeated measurements of CC31 cellulose was within 0.2‰ for $\delta^{18}O$ and 0.1‰ for $\delta^{13}C$. For the period 1200-1400 CE, the same protocol was followed. Five cores from 4 sites (BLL, BEH, LAV and POI; Fig. 1) with at least 30y-overlap periods, were included in the isotopic chronology.

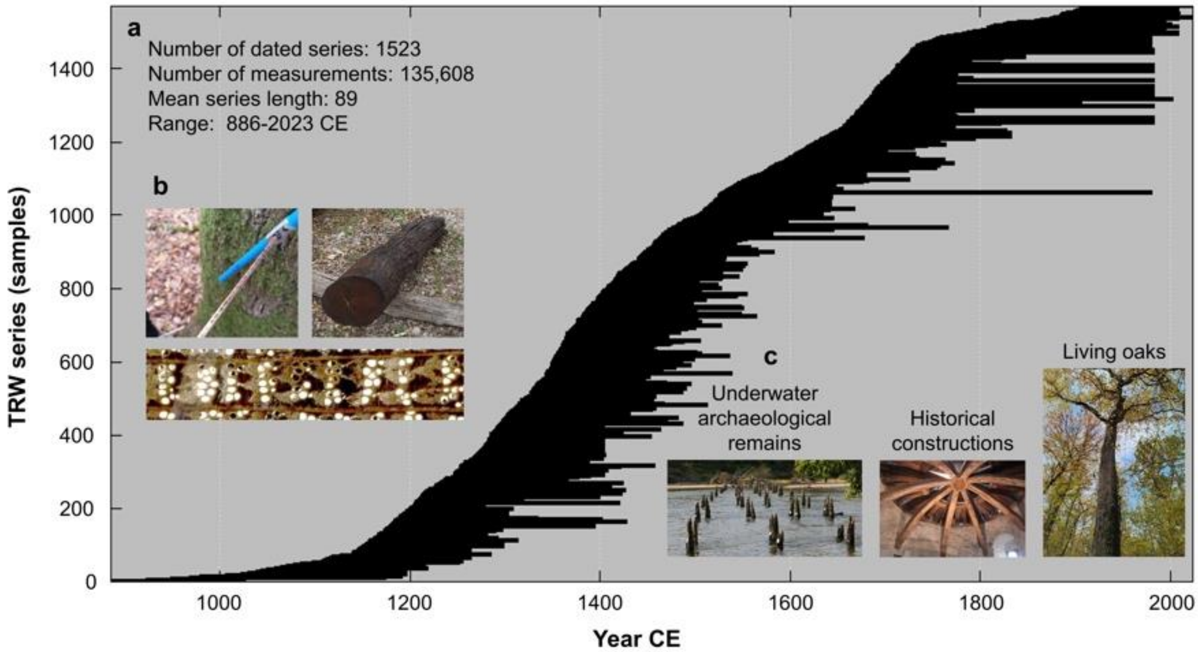

Fig. 2: Sample distribution of the central France dataset. a) Temporal coverage of 1,523 living, historical and archaeological oaks along with their dataset statistics. b) Coring of living trees, an example of a bridge pier extracted from the Loire River and a microscopic view of a sessile oak showing a sequence of annual tree rings. c) The various types of oak samples analyzed in this study.

Climate-growth relationships

Temperature (T, Tmax, Tmin) and precipitation (PRE) data from the CRU TS4.08 were extracted at the nearest grid point (0.5° resolution) for each chronology (crudata.uea.ac.uk/cru/data/hrg/cru_ts_4.08/). Standardized Precipitation-Evapotranspiration Indexes (SPEI) were also obtained (spei.csic.es/). The relationships between TRW and TRSI chronologies and monthly or seasonal instrumental data and SPEI were assessed using bootstrapped Pearson correlations for the period 1910-2023.

First results

We present here the methodological framework of this work along with the initial findings on growth-climate relationships during the instrumental period. The climate sensitivity of the 3 proxies (TRW, $\delta^{18}O$ and $\delta^{13}C$) has been evaluated. Notably, the strong correlation between the June-July SPEI and cellulose $\delta^{18}O$ ($r = -0.75$), combined with model verification, indicates that δ¹⁸O is the most reliable proxy for reconstructing past hydroclimatic variability (Fig. 3). In contrast, TRW seems to be controlled more by the March-July SPEI and precipitation (r = 0.61).

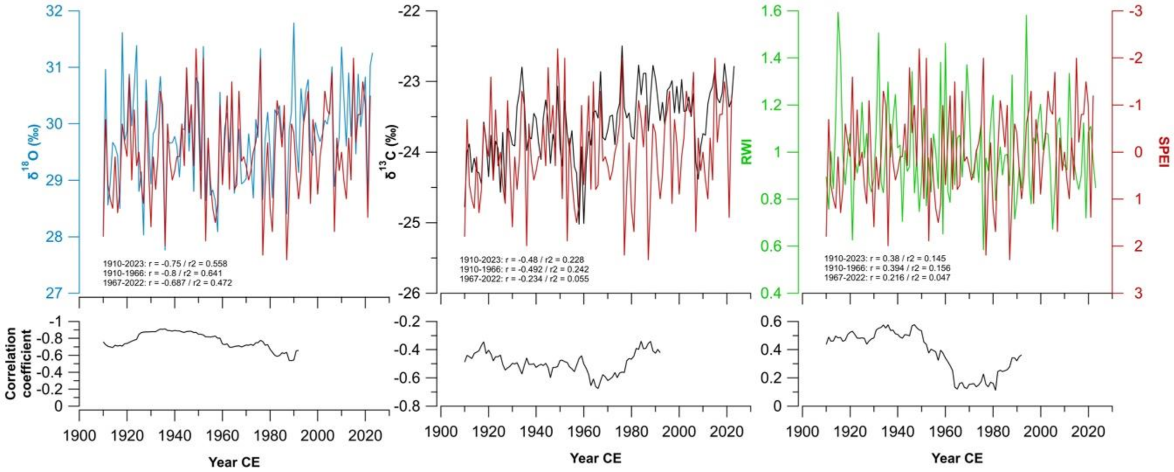

Fig. 3: Relationship between the, $\delta^{13}C$, ring width index (RWI) series and the June-July SPEI over the period 1910-2022. Thirty-one-year moving correlations have been calculated to assess the signal stability. Note that the SPEI axis is reversed, meaning that upward values indicate warm and dry years.

Conclusion and perspectives

The observed correlations between the proxies and instrumental data indicate the potential to reconstruct past hydroclimatic variability. Dry and wet periods can be reconstructed over the last millennium from TRW using the vast corpus of archaeological wood studied, as well as from cellulose $\delta^{18}O$ during the period 1200-1400 CE. This will provide new data on both climatic long-term variability and the MCA-LIA transition at low altitude in France.

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