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ORIGINAL ARTICLE

Climate-growth analysis using long-term daily-resolved station records with focus on the effect of heavy precipitation events

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ABSTRACT

Oak tree-ring series contain detailed information regarding climate variability for centuries to millennia. Such reconstructions are compiled with the use of climate response functions that are typically based on monthly precipitation or temperature data sets. We present an approach using a MATLAB® script and long-term daily precipitation and daily mean temperature records to evaluate intervals with daily resolution of radial growth sensitivity and to determine the effect of heavy precipitation events in the Mainfranken region (southern Germany). This allows improved insights into tree-ring response for local climate reconstructions. Annual radial stem growth is highly sensitive to total cumulative precipitation during the current year spring-summer period, but less sensitive to daily mean temperature. Response analysis reveals better results to precipitation records, when (very) heavy precipitation events are omitted (April 14–July 18, $R^2 = 0.31$, $p < 0.01$). Temporal sensitivity analysis of total ring width (TRW) to precipitation response within nine sub-periods revealed that the length of the sensitive intervals stretch between 41 to 141 days, depending on the period investigated. Our study shows that annual radial growth of oak trees is mainly affected by daily precipitation sums (DPS) of less than 10 mm. In contrast, heavy rainfall events do not influence radial increment significantly, but may substantially increase the total precipitation sum of the growing season. We propose that oaks in the Mainfranken region contain low to moderate information in their tree rings regarding heavy precipitation events. Furthermore, we conclude that a disordered sensitivity of TRW to precipitation during the past three to four decades is caused by drought climatologies, increased sulfur dioxide emission in the study area as well as by changes in diurnal temperature range. Thus, climate response functions for hydroclimatic reconstructions may only be developed until the 1970s.

1. Introduction

In Europe an extensive wide tree-ring data network exists often reflecting summer conditions (St. George, 2014). Tree-ring records provide information about past climate conditions and may increase our knowledge of seasonal- to decadal droughts and wet periods. A significant number of multi-century length climate reconstructions developed from living, historical and subfossil tree-ring series have been published in recent years (e.g. Wilson et al., 2005; Büntgen et al., 2011; Cooper et al., 2013; Levanič et al., 2013; Wilson et al., 2013; Cook et al., 2015; Land et al., 2015; Santos et al., 2015; Schönbein et al., 2015; Seftigen et al., 2015; Young et al., 2015). E.g. these reconstructions contain different hydroclimatic signals depending on various factors as the area under investigation, local hydroclimatic behaviour or the duration of trees sensitivity to rainfall within the vegetation period.

Climate-growth response analysis had mainly been conducted applying meteorological records with monthly resolution. These monthly records can be handled easily via the calibration process and such long-term instrumental records are often available as single or gridded station data. In contrast, consistent long-term daily instrumental records lasting for a century or longer are very rare in Europe. Although appropriate software (Schönbein, 2011; Beck et al., 2013) is published and available for free, very few studies have attempted to calibrate tree-ring growth using daily precipitation data (e.g. Pritzkow et al., 2014; Sanders et al., 2014; Castagneri et al., 2015) or reconstruct past hydroclimatic conditions with this technique (Land et al., 2015; Schönbein et al., 2015; Pritzkow et al., 2016). In southern Germany, several century-length daily meteorological records exist (e.g. Bamberg,

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Frankfurt a.M., Karlsruhe, Munich, Stuttgart) and are available via https://climexp.knmi.nl. These records are suitable for studying the correlations between seasonal tree growth and daily instrumental data on a local scale.

However, forest cover, vegetation surface, soil type, soil water-holding capacity as well as canopy water storage capacity and rainfall interception strongly affect the water availability for trees (e.g. Phillips and Ehleringer, 1995; Dohnal et al., 2014) and increase the complexity of the correlation analysis. Water availability for individual trees and the precipitation amount may differ greatly. For example surface runoff and soil water-holding capacity in response to a heavy rainfall event must be considered when analyzing radial growth. Taking into account that rainfall events exceeding 20–30 mm per day may occur several times per month, tree-ring calibration using only monthly station data with rainfall sums may lead to inaccurate interpretations of climate-growth responses. In our study, we aim to determine the effect of heavy daily precipitation events and the sensitivity of oak tree rings using long-term daily hydroclimatic records from Mainfranken (southern Germany).

2. Materials and methods

2.1. Tree-ring series of living oak trees

The tree-ring data archive of the University of Hohenheim (Holocene oak chronology, HOC and Preboreal pine chronology, PPC, Friedrich et al., 2004) contains more than 4000 subfossil, 6000 historical and 700 oak samples from living trees from southern Germany, spanning the Holocene and ranging from 8,480 BCE to the present day. The HOC serves to investigate past hydroclimatic variability on a seasonal to decadal scale (e.g. Land, 2014; Land et al., 2015; Schönbein et al., 2015).

The present study focuses on the Mainfranken region in Northern Bavaria, Germany. Samples from living oak trees of *Quercus robur* L. and *Quercus petraea* (Matt.) Liebl. were collected (Fig. 1) which originate from locations with different site conditions: wet to dry soils as well as groundwater affected forests growing on steep slopes or flat ground (for site descriptions see Table S1). These locations represent a wide variety of site characteristics found in Mainfranken. Two cores per tree were taken at breast height using an increment borer (Suunto, Vantaa, Finland). The samples were attached to wooden supports and the cross-section surface was smoothed with a core-microtome. The cut surface was treated with chalk to enhance visual contrast of the cells for tree-ring measurements. Annual total ring width (TRW) was measured with a commercial software (TSAPWin, Version 4.69b, Rinntech, Heidelberg, Germany) with a resolution of 0.01 mm. A mean TRW series for each tree was built following a visual cross-check of the core measurements and the samples were then dated to a particular end year. A total of 144 TRW series from twelve sites were available for further dendroclimatological analysis with a minimum series length of 81 years and a maximum of 211 years.

2.2. Long-term daily precipitation and temperature records

To analyze the correlations between TRW chronologies and daily precipitation sum (DPS) as well as daily mean temperature (DMT), the data records of six long-term climate stations (Table S2) in the Mainfranken region were used (Fig. 1). The Bamberg station has a continuous record of daily precipitation and daily mean temperature (with missing data in 1882) from 1879 to present. The climate station with the shortest record (Schweinfurt) reveals at least a 63-year-long daily record. The stations were selected due to their proximities, their extensive durations and their long-lasting daily records. DPS and DMT data from the used meteorological stations were obtained from KNMI Climate Explorer http://climexp.knmi.nl (Klein Tank et al., 2002). All data sets were checked for missing data (see Table S2).

2.3. Standardization of TRW series and chronology construction

The standardization of oak TRW series was performed via ARSTAN (Cook and Krusic, 2005) using a 70% cubic smoothing spline with a 50% frequency response cut-off, to preserve high- to mid-frequency variability. After transformation, annual indices were calculated as ratios from the fitted growth curves and the TRW series. The variance was adjusted taking into account the changing replication through time in the TRW set. Site-chronologies were constructed using the bi-weight robust mean method. To assess the signal strength of the constructed chronologies, Expressed Population Signal (EPS) and inter-series correlation (RBAR) were calculated to ensure sufficient sample replication over time. A window length of 50 years with 25 years of overlap was applied. A threshold of EPS > 0.85 was accepted as a desirable level for a robust and hypothetical noise-free tree-ring chronology (Wigley et al., 1984). Additionally, a chronology was constructed using all TRW series from the Mainfranken region (hereafter referred to as Composite chronology) applying the same methodology as descripted above.

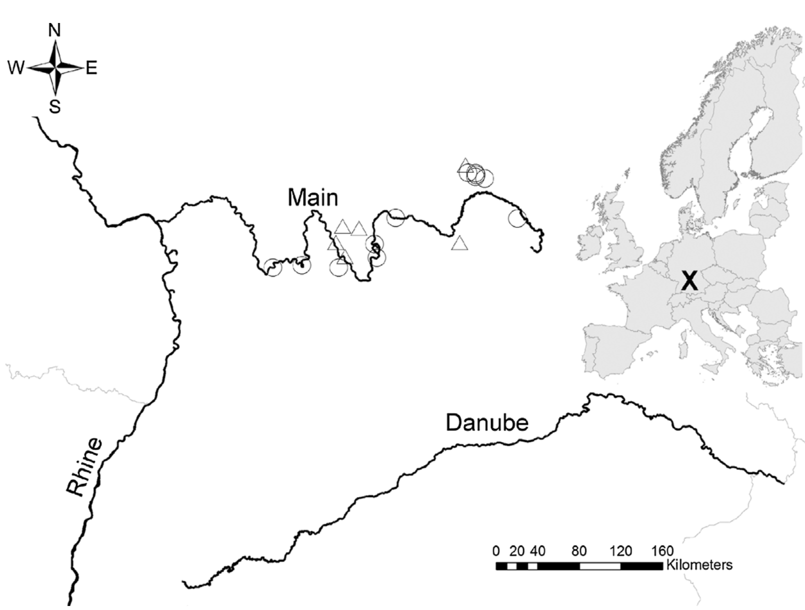

Fig. 1. Location map of climate stations (triangle) with long-term records of daily precipitation and daily mean temperature and tree-ring sites (circles) in the Mainfranken region (southern Germany).