Evaluating climate sensitivity in tree-ring and Riesling must sugar data from the Palatinate (Germany)

O. Konter[1], J. Traut[1], L. Schneider[1], U. Büntgen[2,3,4] & J. Esper[1]

[1]Department of Geography, Johannes Gutenberg University Mainz, Germany
[2]Swiss Federal Research Institute WSL, Birmensdorf, Switzerland
[3]Oeschger Centre for Climate Change Research, Bern, Switzerland
[4]Global Change Research Centre AS CR, Brno, Czech Republic
E-mail: o.konter@uni-mainz.de

Introduction

The Palatinate Forest, a low mountain range in southwest Germany, represents the largest contiguous forested area of the country. This region is characterized by pronounced dry conditions due to thes and stone bedrock and associated sandy soils. Its north-south orientation and associated lee-effects, due to predominating westerlies together with altitudinal differences of more than 300 m, lead to high temperature means and low precipitation totals. Here, the forest comprises a proportion of up to 80 % of pine trees, a result of historical management activities (personal communication with the forester of the area). The vegetation outside the forested areas in the plain is characterized as agricultural croplands with vineyards, representing one of the largest wine-growing regions in Germany.

Although viticultural data, i.e. grape harvest dates and grapevine yields, can serve as temperature proxies (Pfister 1981, Chuine et al. 2004, Duchêne et al. 2010, Urhausen et al. 2011b, Urhausen et al. 2011a) this relationship has not been assessed in this specific region. In the low mountain ranges, ring width increment from conifers is typically not solely controlled by one single climate parameter(Hartl-Meier et al. 2014). Analyzing must (grape juice) sugar content data might elucidate our understanding of longer-term climate variability in the Palatinate region, since temperature-sensitive must sugar content data has been reported from other regions in Germany (Urhausen et al. 2011b, Bock et al. 2013).

Here, we present tree-ring width of 487 *Pinus sylvestris* core samples and correlate these against regional meteorological station (1950-2012) and gridded data (1891-2010/12). In addition, we utilize a dataset of 30 consecutive years (1984-2003) of Riesling must sugar content from three vineyards adjoining the forested area into the plain.

Material and methods

Sampling sites and data treatment

For tree-ring width (TRW) measurements, we selected seven sites at the eastern ridge of the Palatinate Forest and sampled503 cores of *Pinus sylvestris* trees at ~500-600 m asl (mostly two cores per tree), ranging between 43 to 148 cores per site and spanning the period 1841-2012 at a minimum replication of 10 cores (Fig. 1).TRW was measured, absolutely dated and verified using a LinTab/TSAP device (Rinn 2007) and the COFECHA program (Holmes 1983). Several detrending techniques were applied using the ARSTAN software to remove non-climatic trends linked to juvenile growth fluctuations (Fritts 1976, Cook 1985). We applied 10-year cubic smoothing splines ($TRW_{10spline}$)(Cook & Peters 1981), negative exponential functions (Fritts 1976), and Regional Curve Standardization (TRW_{RCS})(Esper et al. 2003) to compute dimensionless indices highlighting climatic information in varying frequency domains. All data were power-transformed prior to detrending(Cook & Peters 1997). Index chronologies were calculated using robust bi-weight means, while variance was stabilized pondering varying replication and interseries correlations (rbar) (Frank et al. 2007). Rbar and Expressed Population Signal (EPS) were calculated using 31-year moving windows with 30-year overlap (Wigley et al. 1984) (Fig. 2). Specific site characteristics

Scientific Technical Report STR 16/04. GFZ German Research Centre for Geosciences.
http://doi.org/10.2312/GFZ.b103-16042

enabled re-organisation of the dataset into samples originating from trees growing in more steep (slope) and flat (plateau) situations spanning the period 1841-2012 and 1869-2012, respectively.
Must sugar is usually measured in degrees Oechsle (°Oe), which relates the density of must to pure water. We calculated a mean chronology using data originating from three nearby Riesling vineyards adjoining the forested area in the plain (Fig. 1). The data were provided by a local winegrower and span the period 1983-2013 at annual resolution (Fig. 5).

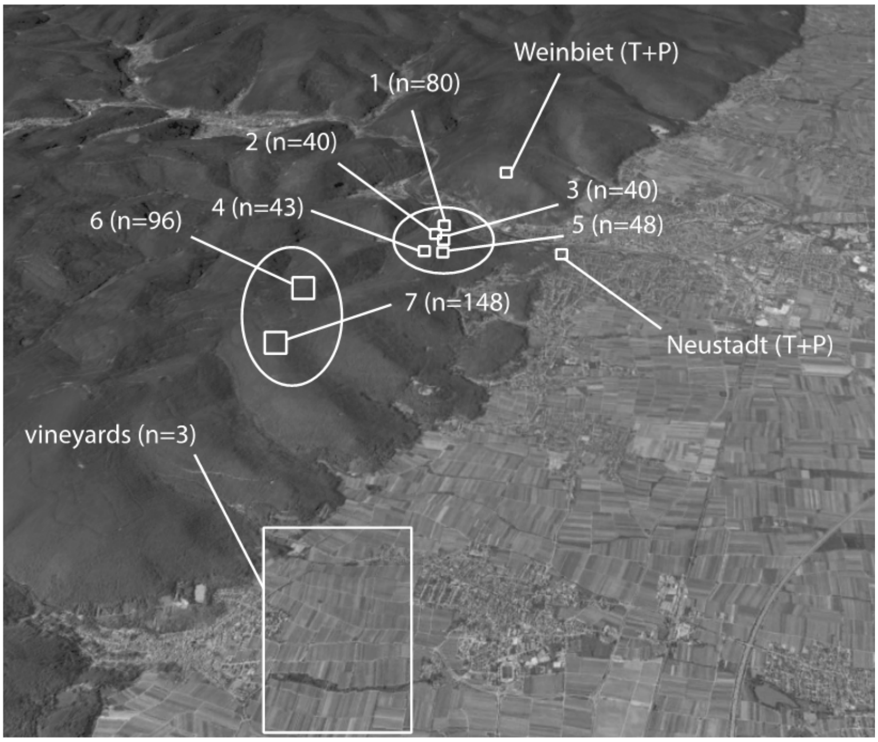

Figure 1: TRW sampling sites (1-7, n=number of individual cores), vineyards(n=number of datasets) and meteorological stations in Weinbiet and Neustadt (T=temperature, P=precipitation).

Meteorological data and calibration efforts

Temperature and precipitation measurements from two nearby meteorological stations, Weinbiet (49.38N, 8.12E; 553 m asl, 1953-2012) and Neustadt (49.35N, 8.14E; 146 m asl, 1950-1982), were used for calibration (Fig. 1). Due to the fragmented structure of both datasets (Weinbiet: seven years missing; Neustadt: eleven years missing), we calculated anomalies with respect to the longest consecutive period in both datasets (1954-1974) and filled the gaps of the Weinbiet-datasets with anomalies from the Neustadt station. In addition, gridded data were used to verify the combined datasets and to assess the influence of two versions of the self-calibrating Palmer Drought Severity Index (scPDSI): (1) UCAR scPDSI (University Corporation for Atmospheric Research: Dai et al. 2004, Dai 2011) and (2) CRU scPDSI (Climate Research Unit: van der Schrier et al. 2006). Data were collected from the nearest grid-points at 48.75N/49.25N and 8.75E/8.25E, respectively.
Both the TRW and must sugar data were correlated against monthly instrumental data over the 1950-2012 period, while gridded data enabled the application of longer calibration periods from 1891-2010/12, thereby supporting an assessment of the temporal robustness using split calibration approaches. By high- and low-pass filtering all data, using 15- and 31-year cubic splines and residuals thereof, the frequency-dependent coherency between the proxy- and target data was estimated (Fig. 5). We used the KNMI Climate Explorer for spatial correlations of must sugar data against gridded April-August temperatures over the 1950-2012 period, using the E-OBS dataset

(EU-FP6 project ENSEMBLES and ECA&D project: Haylock et al. 2008), due to a higher spatial resolution.

Results and discussion

TRW data and growth-climate relationships

Our newly produced TRW dataset from the Palatinate Forest spans the period 1832-2012 and with good replication (≥10 radii) back to 1841 (Fig. 2).Although growth of *Pinus sylvestris* trees in low mountain ranges is often weakly related to a single climatic factor, interseries correlation ($rbar_{mean}$=0.57) and EPS values denote a high and temporally robust coherency among the samples (see bottom panel in Fig. 2).

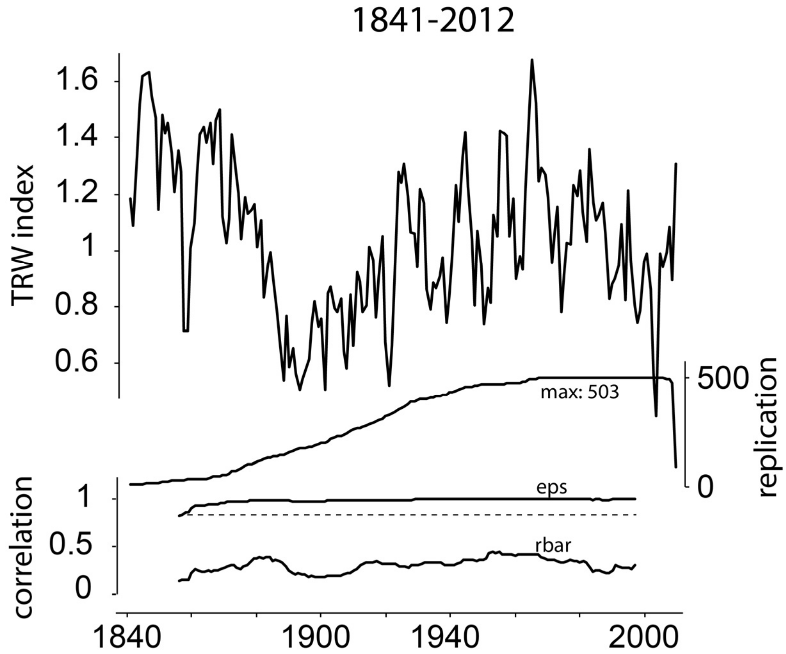

Figure 2: RCS detrended chronology, replication, and running rbar and EPS statistics.

Growth-climate response trials reveal mixed signals, including significant correlations with seasonal temperature, precipitation and drought indices (Fig. 3). TRW_{RCS} at the slope sites shows strongest negative relationships with April-June temperatures ($r_{1950\text{-}2012}$=-0.44, $p<0.01$), whereas$TRW_{10spline}$ from the plateau sites reveals highest correlations with June-July precipitation ($r_{1950\text{-}2012}$=0.31, $p<0.05$) (fig. 3, left panels).At the slope sites, tree growth is reduced with higher temperatures, likely because exposition increases the maximum angel of insolation, together with increased surface water run-off limiting trees' water availability. Using all TRW_{RCS} data, only a significant April-June temperature signal can be obtained ($r_{1950\text{-}2012}$=-0.33, $p<0.05$). A clearer pattern is found when correlating TRW_{RCS} data with scPDSI (Fig. 3, right panels). All monthly correlations are positive with the highest value obtained for TRW_{RCS} from the slope sites against the seasonal mean of April-August ($r_{UCAR1950\text{-}2010}$=0.50, $p<0.001$) or April-June ($r_{CRU1950\text{-}2012}$=0.47, $p<0.01$). Additionally, TRW_{RCS} from plateau sites exhibits significant correlations ($r_{UCAR1950\text{-}2010}$=0.41, $p<0.01$; $r_{CRU1950\text{-}2012}$=0.35, $p<0.05$).

To explain tree growth at all sites, using only temperature and precipitation data is not satisfying. The growth-climate relationship at the Palatinate Forest may be best estimated by drought-related indices, since these data integrate temperature, precipitation, and soil information. Due to the unique ecological setting in the area, soil information and water availability seem to be key to tree growth over the 1950-2010/12 period.

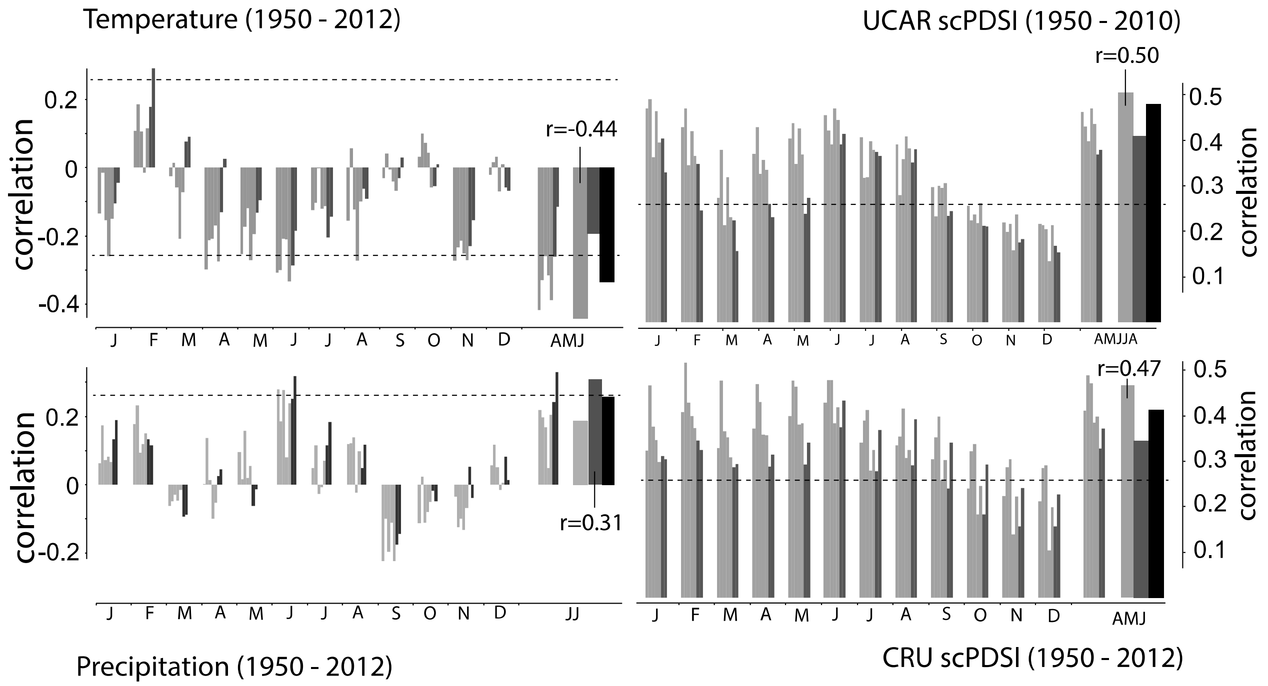

Figure 3: Growth-climate relationship expressed as correlations between TRW and instrumental climate data. Upper left: correlations with temperature data (TRW: RCS detrended); lower left: correlations with precipitation data (TRW: 10-year spline detrended); upper right: gridded UCAR scPDSIdata (TRW: RCS detrended); lower right: gridded CRU scPDSI data (TRW: RCS detrended).Dashed lines indicate significance levels (p<0.05). Lighter grey indicates the five slope-sites, dark grey the two plateau-sites, and black all data.

The significant relationship between TRW from the slope sites and April-August scPDSI over the 1950-2010 period is not restricted to more low-frequency trends (r_{LP}=0.88), but also found in the high-frequency year-to-year variations (r_{HP}=0.32) (Fig. 4).However, extending the calibration period over the full 20th century reveals a temporal shift of the growth-climate relationship. Comparison with UCAR scPDSI over the full period1891-2010 unfolds insignificant results ($r_{1891\text{-}2010}$=0.15), particularly in the early period 1891-1949 the drought signal appears to be absent (r=-0.05). This temporal shift either indicates that the climate control of tree growth varied over the 20th century, or that the early instrumental climate data are biased by larger uncertainties(Wijngaard et al. 2003).

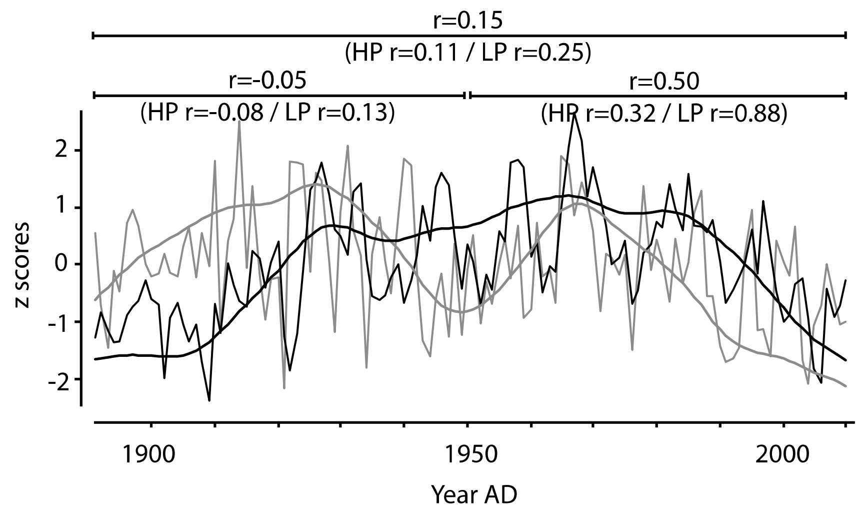

Figure 4: Slope sites TRW chronology (black) and Apr-Aug UCAR scPDSI (grey), original and smoothed (31-year cubic spline) data. r = correlation values, LP = low-pass filtered data using 31-year cubic smoothing splines, HP = high-pass filtered data using residuals from the splines.

Must sugar data and sugar-climate relationships

The must sugar and summer temperature data synchronize very well (Fig. 5). Monthly calibration results exhibit a distinct pattern of positive correlations throughout the vegetation period, except from October, the month of the grape harvest (Fig. 5, upper right panel). For the best responding season April-August, significant correlations can be observed ($r_{1983\text{-}2013}$=0.67) over the full 1983-2013 calibration period, while growth-climate relationships between TRW from the slope sites and April-August scPDSI appear weaker in comparison ($r_{1983\text{-}2010}$=0.39). High-pass filtering the data underlines the stronger coherency between the must sugar and temperature ($r_{1983\text{-}2013}$=0.49), thereby verifying a distinct association not only in the low-frequency domain but also in the year-to-year variations. Results of a split calibration approach with two equidistant periods indicate no temporal shift or signal losses in both, original and high-pass filtered data.

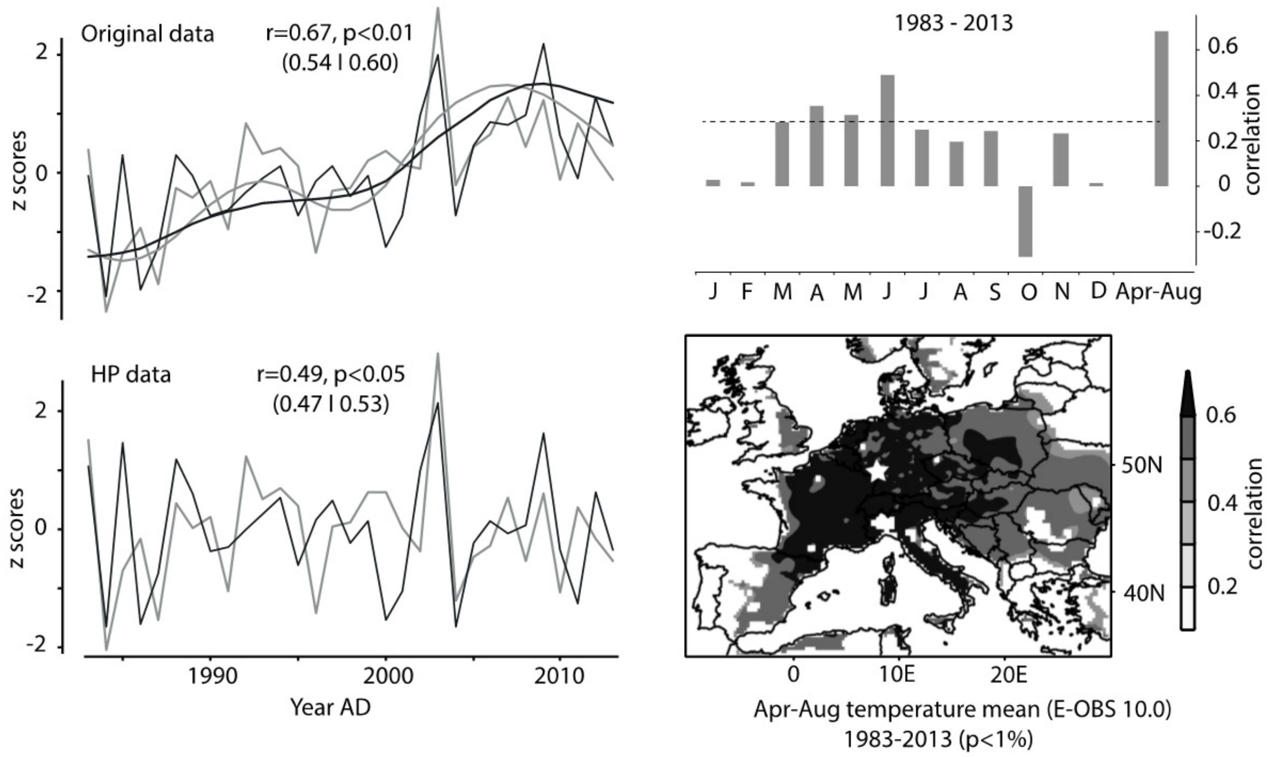

Figure 5: Climate sensitivity of must sugar data. Upper left: Original and smoothed (11-year cubic smoothing spline) must sugar data (black) and Apr-Aug temperature data (grey), with r = correlation values, p = significance level. Numbers in brackets indicate correlation values from split calibration. Lower left panel shows the 11-year high-pass filtered must sugar and temperature data. Upper right shows the monthly and seasonal sugar-climate correlations, with the dashed line indicating significance p<0.05. Lower right shows the European correlation field of the original must sugar data against gridded E-OBS data (p<0.01).

The analysis of sugar-climate relationships over space reveals a widespread representativeness of the data (Fig.5, lower right panel). Areas with correlation values of r>0.6 almost completely cover Central Europe, Italy and parts of Eastern Europe. The changing climate envelope as a function of time plays an important role in the assessment of climate-induced changes in plant phenology and ecology (Chuine et al. 2000), including trees and grape vines (Chuine et al. 2004, Jones et al. 2005, Hartl-Meier et al. 2014). Our findings indicate that must sugar data from the Palatinate could contribute to paleoclimatic research in Europe when developing datasets in centennial timescales. The relationship of sugar content in grapes and temperature is well known among wine growers (Pfister 1981, Urhausen et al. 2011a, Bock et al. 2013), but has not been used in a European paleoclimatic perspective. The impact of modified seed, genetic technology, and cultivation methods, particularly in the 20th century requires further assessments and research (Duchêne et al. 2010, Bock et al. 2013).

Conclusions

Although the low mountain range of the Palatinate Forest offers at its most eastern transition zone to the Upper Rhine Plain a unique climatological and ecological setting, a distinct growth-climate coherency in *Pinus sylvestris* trees is not detectable. Calibrating TRW data against regional temperature, precipitation and drought indices (scPDSI) reveals a mixed influence on growth, limiting TRW for paleoclimatic reconstruction purposes.

Must sugar data exhibit a clear coherency to temperature variations and may, therefore, contribute to potential summer temperature reconstructions for the Palatinate region in Germany. The temperature control in regional must sugar content is not limited to year-to-year variations, but seems also coherent in the lower frequency domain, though the 1983-2012 calibration period is too short to conclude on this issue. Extending the calibration period to cover the complete 20th century would be essential and improve the analysis of this relationship. Since TRW of conifers here and in other low mountain ranges in Central Europe is not fulfilling requirements for reliable paleoclimatic research, must sugar data may, in the long-term, contribute to the understanding of past climatic variations.

Acknowledgements

We thank the anonymous winegrower for providing the most sugar data and foresters Jens Bramenkamp and Klaus Burkhart for support and sampling permissions. In addition, we thank Sarah Adam, Lara Klippel, Joana Helms, and many other students for TRW measurement and sampling efforts.

References

Bock, A., Sparks, T. H., Estrelle, N. and Menzel, A. (2013): Climate-Induced Changes in Grapevine Yield and Must Sugar Content in Franconia (Germany) between 1805 and 2010. *PLoS ONE* 8, 7.

Chuine, I., Cambon, G. and Comtois, P. (2000): Scaling phenology from the local to the regional level: advances from species-specific phenological models. *Global Change Biology* 6: 943-952.

Chuine, I., Yiou, P., Viovy, N., Seguin, B., Daux, V. and Le Roy Ladurie, E. (2004): Grape ripening as a past climte indicator. *Nature* 42432: 289-290.

Cook, E. R. and Peters, K. (1981): The Smoothing Spline: A New Approach To Standardizing Forest Interior Tree-Ring Width Series For Dendroclimatic Studies. *Tree-Ring Bulletin* 41: 45-53.

Cook, E. R. (1985). A Time Series Analysis Approach To Tree Ring Standardization. Ph.D. Thesis, University of Arizona.

Cook, E. R. and Peters, K. (1997): Calculating unbiased tree-ring indices for the study of climatic and environmental change. *The Holocene* 7, 3: 361-370.

Dai, A., Trenberth, K. E. and Qian, T. (2004): A Global Dataset of Palmer Drought Severity Index for 1870-2002: Relationship with Soil Moisture and Effects of Surface Warming. *Journal of Hydrometeorology* 5: 1117-1130.

Dai, A. (2011): Characteristics and trends in various forms of the Palmer Drought Severity Index during 1900–2008. *Journal of Geophysical Research* 116, D12.

Duchêne, E., Huard, F., Dumas, V., Schneider, C. and Merdinoglu, D. (2010): The challenge of adapting grapevine varieties to climate change. *Climate Research* 41, 3: 193-204.

Esper, J., Cook, E. R., Krusic, P. J., Peters, K. and Schweingruber, F. H. (2003): Tests of the RCS method for preserving low-frequency variability in long tree-ring chronologies. *Tree-Ring Research* 59, 2: 81-98.

Frank, D., Esper, J. and Cook, E. R. (2007): Adjustment for proxy number and coherence in a large-scale temperature reconstruction. *Geophysical Research Letters* 34, 16: n/a-n/a.

Fritts, H. C. (1976): Tree Rings and Climate. Academic Press, 567.

Hartl-Meier, C., Dittmar, C., Zang, C. and Rothe, A. (2014): Mountain forest growth response to climate change in the Northern Limestone Alps. *Trees* 28, 3: 819-829.
Haylock, M. R., Hofstra, N., Klein Tank, A. M. G., Klok, E. J., Jones, P. D. and New, M. (2008): A European daily high-resolution gridded data set of surface temperature and precipitation for 1950–2006. *Journal of Geophysical Research* 113, D20.
Holmes, R. L. (1983): Computer-assisted quality control in tree ring dating and measurement. *Tree Ring Bulletin* 43: 69-78.
Jones, G. V., White, M. A., Cooper, O. R. and Storchmann, K. (2005): Climate Change and Global Wine Quality. *Climatic Change* 73, 3: 319-343.
Pfister, C. (1981): Die Fluktuationen der Weinmosterträge im schweizerischen Weinland vom 16. bis ins frühe 19. Jahrhundert. Klimatische Ursachen und sozioökonomische Bedeutung. *Schweizerische Zeitschrift für Geschichte* 31, 4: 445-491.
Rinn, F. (2007): TSAP Win Professional. Zeitreihenanalysen und Präsentation für Dendrochronologie und verwandte Anwendungen. Benutzerhandbuch. Rinntech, 91.
Urhausen, S., Brienen, S., Kapala, A. and Simmer, C. (2011a): Must quality estimation based on climate data in the Upper Moselle region. *Meteorologische Zeitschrift* 20, 5: 479-486.
Urhausen, S., Brienen, S., Kapala, A. and Simmer, C. (2011b): Climatic conditions and their impact on viticulture in the Upper Moselle region. *Climatic Change* 109, 3-4: 349-373.
van der Schrier, G., Briffa, K. R., Jones, P. D. and Osborne, T. J. (2006): Summer Moisture Variability across Europe. *Journal of Climate* 19: 2818-2834.
Wigley, T. M. L., Briffa, K. R. and Jones, P. D. (1984): On the Average Value of Correlated Time Series, with Applications in Dendroclimatology and Hydrometeorology. *Journal of Climate and Applied Meteorology* 23: 201-213.
Wijngaard, J. B., Klein Tank, A. M. G. and Können, G. P. (2003): Homogeneity of 20th century European daily temperature and precipitation series. *International Journal of Climatology* 23, 6: 679-692.