Setting the tree-ring record straight

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Introduction

- Tree-ring chronologies are the main source for annually resolved and absolutely dated temperature reconstructions of the last millennia and thus for studying climate impacts. However, the reliability of their low-frequency variability is debated.
- Do the large temperature variations (see, Fig1. a) reflect historical reality?
- We focus on central Europe and compare the tree-ring based reconstruction (TRBR) with reconstructions based on harvest dates, observational data and model data. We find a much higher long-term persistence in the TRBR compared to the other datasets.
- Can the TRBR be corrected to obtain a more realistic reconstruction?

Long-term persistence of temperature records

- It is well known that temperature data are long-term persistent [1-3].
- In long-term persistent records, the autocorrelation function $C(s) \propto (1-\gamma)s^{-\gamma}$ and the power spectral density $S(f) \sim f^{-(1-\gamma)}$ decay by power laws.
- Since both $S(f)$ and $C(s)$ exhibit large finite-size effects and are affected by external trends we use wavelet (WT2) and detrended fluctuation analysis (DFA2)[4]. The corresponding fluctuation functions $G(s)$ and $F(s)$ show for long-term persistent data also a power law behaviour $\sim s^h$, $h = (2-\gamma)/2$.
- The deviation of the (Hurst) exponent h from $1/2$ (white noise) quantifies the strength of the long-term persistence.

Tree-ring based temperature reconstruction

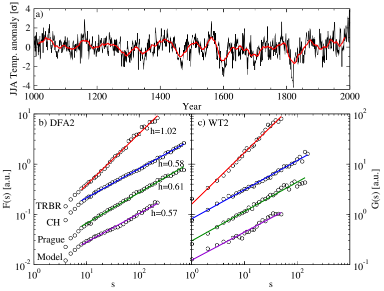

Fig1. (a) shows the tree-ring based reconstructed temperatures [5] in units of the records standard deviation. The red line depicts the 30y moving average. (b, c) show the DFA2 and WT2 fluctuation functions for the TRBR, the monthly observational data (Swiss temperatures from Berkeley Earth, station data from Prague) and the MPI-ESM-P-past1000 model output for central European summer temperatures. In the double logarithmic presentation, the asymptotic slopes represent the Hurst exponents h.

The tree-ring data ($h \cong 1$) and the observational and model data ($h \cong 0.6$) differ strongly in their long-term persistence.

Was the long-term persistence in the past higher?

Harvest date based temperature reconstructions

Harvest dates offer an independent point of view on the last centuries.

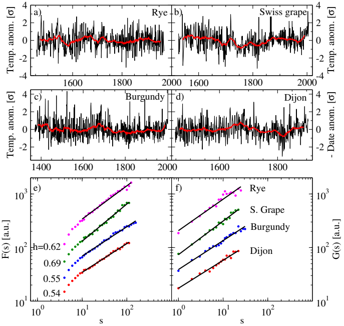

Fig2. Temperature anomalies based on (a) rye harvest dates from northern Switzerland and southwestern Germany (1454 - 1970) [6], (b) grape harvest dates in Switzerland (1480 - 2006) [7] and (c) grape harvest dates in Burgundy (1370 - 2003) [8]. (d) shows the inverted harvest date anomalies in Dijon (1385 - 1906) [9]. All anomalies are shown in units of their standard deviation from the mean. (e, f) show the corresponding DFA2 and WT2 fluctuation functions. The WT2 Hurst exponents are $h = 0.59, 0.63, 0.54$ and 0.52 from top to bottom.

⇒ The long-term persistence of the harvest date based temperature reconstructions is in line with the observational and model data.

Climate variability since 1753

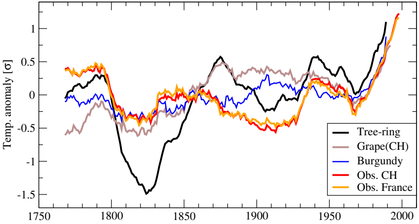

Fig3. 30-year moving averages of the observational temperatures (Berkeley Earth) of Switzerland (red), France (orange) and the temperature reconstructions based on tree rings (black), Swiss grape harvest dates (brown) and Burgundy harvest dates (blue) in units of their standard deviation.

The TRBR describes the appearance of the warm and cold periods properly, however, due to its considerably enhanced long-term persistence, overestimates the strength of the warm and cold periods considerably.

Correction of the long-term persistence

To correct the enhanced long-term persistence in the TRBR, we are interested in a mathematical transformation of the data, which lowers the natural long-term persistence while leaving the gross features of the record, the positions of the warm and cold periods, unchanged.

To reduce the Hurst exponent from $h_0 \cong 1$ to $h_1 \cong 0.6$, we transform the TRBR data $y_0(i)$ to Fourier space and multiply the resulting Fourier transform $y_0(f)$ by $f^{(h_0-h_1)}$. Then we transform the product $y_1(f) = y_0(f)f^{(h_0-h_1)}$ back to time space. The resulting record $y_1(i)$ is long-term persistent with Hurst exponent h_1, since its power spectral density scales as $S_1(f) \equiv |y_1(f)|^2 \sim f^{-(2h_1-1)}$.

Original and transformed tree-ring temperature record

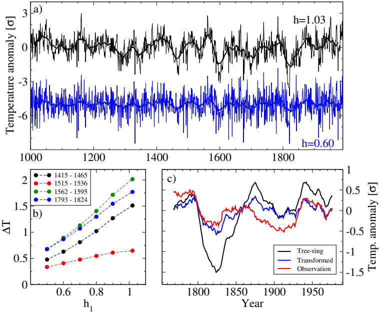

Fig4. (a) The original TRBR record for the period 1000-1990, where the Hurst exponent h is 1.03 (black) and the transformed TRBR record, where $h \equiv h_1 = 0.6$ (blue, for better visibility shifted downward by 5 units of its standard deviation). (b) shows how the magnitudes of the cold periods in the transformed TRBR record decrease with decreasing Hurst exponent h_1. The magnitudes are quantified by the differences of the 30y moving averages between the beginning and the end of the respective periods. (c) compares the 30y moving averages of the original, the transformed TRBR record ($h = 0.6$) and the observational temperatures from Switzerland.

The transformed TRBR record fits quite nicely with the observational data.

Summary

- The long-term persistences of temperatures from harvest date based reconstructions, observational and model data are in line, while the tree-ring based reconstruction shows a considerably higher long-term persistence.
- We showed how to correct the tree-ring based reconstruction by a mathematical transformation that adjusts the persistence and leads to reduced amplitudes of the warm and cold periods.
- The analysis and, if necessary, the adjustment of a record's long-term persistence is generally applicable to other high-resolution climate proxy archives, to obtain a more realistic reconstruction of the record's low-frequency part.

References

[1] Pelletier JD, Turcotte DL (1997) Long-range persistence in climatological and hydrological time series: Analysis, modeling and application to drought hazard assessment. *J Hydrol* **203**, 198–208

[2] Koscielny-Bunde E, Bunde A, Havlin S, Roman E, Goldreich Y, Schellnhuber HJ (1998) Indication of a universal persistence law governing atmospheric variability. *Phys. Rev. Lett.* **81**, 729-732

[3] Eichner J, Koscielny-Bunde E, Bunde A, Havlin S, Schellnhuber HJ (2003) Power-law persistence and trends in the atmosphere: A detailed study of long temperature records. *Phys. Rev. E* **68**, 046133

[4] Kantelhardt JW, Koscielny-Bunde E, Rego HHA, Havlin S, Bunde A (2001) Detecting long-range correlations with detrended fluctuation analysis. *Physica A* **295**, 441-454

[5] Büntgen U, Tegel W, Nicolussi K, McCormick M, Frank D, Trouet V, Kaplan JO, Herzig F, Heussner K, Wanner H, Luterbacher J, Esper J (2011) 2500 years of European climate variability and human susceptibility. *Science* **331**, 578-582

[6] Wetter O, Pfister C (2011) Spring-summer temperatures reconstructed for northern Switzerland and southwestern Germany form the winter rye harvest dates 1454-1970. *Clim. Past* **7**, 1307-1326

[7] Meier N, Rutishauser T, Pfister C, Wanner H, Luterbacher J (2007) Grape harvest dates as a proxy for Swiss April to August temperature reconstructions back to AD 1480. *Geophys. Res. Lett.* **34**, L20705

[8] Chuine I, Yiou P, Viovy N, Seguin B, Daux B, Le Roy Ladurie E (2004) Grape ripening as a past climate indicator. *Nature* **432**, 289-290

[9] Labbe T, Gaveau F (2011) The dates of bann harvest in Dijon: Critical establishment and archive revision of an old series. *Revue Historique* **657**, 19-51