

AS WE SEE IT

# Assessing the spatial signature of European climate reconstructions

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**ABSTRACT:** Much progress has recently been made in reconstructing European temperature variability over centuries to millennia. In contrast, there are only a few attempts at long-term precipitation and/or drought reconstruction, which are spatially less significant. Here we discuss the possibility of using climate reconstructions from tree-ring density and width to make spatially explicit estimates of European temperature and drought variability, respectively. Four experiments were performed to assess spatial field correlations of (1) parameter-specific mean reconstructions, (2) individual site reconstructions, (3) instrumental stations, and (4) model analogues. The simple mean of 4 temperature reconstructions from northern Scandinavia and high-elevation sites in the Tatra, Alps, and Pyrenees revealed a significant positive correlation ( $r > 0.4$ ) with the gridded Central European summer temperature south of 55° N and west of 25° E. In contrast, the mean of 11 hydro-climatic reconstructions located between Sweden and Turkey had a significant positive correlation with only a handful of small patches scattered along an east-west corridor from the British Isles over Germany to the Baltic. The significant positive correlation increased to 71 % of the European landmass between 35–70° N and 10° W–40° E when using the individual 4 temperature reconstructions instead. The 11 individual hydro-climatic reconstructions had a significant positive correlation with summer drought over only 16 % of the area. The proxy-based correlation fields are greatly supported by the spatial significance of instrumental station measurements and model analogues corresponding to the initial tree-ring site locations.

**KEY WORDS:** Climate reconstruction · Dendroclimatology · Hydroclimatology · Tree rings · Temperature · Precipitation · Drought · Europe

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## 1. INTRODUCTION

For the European/North Atlantic sector, much progress has recently been made in understanding climatic variations through studies of instrumental measurements, gridded indices, historical documents, tree-ring chronologies, phenological observations, multi-proxy compilations, and model simulations (see Jones et al. 2009 for a review). Long-term reconstructions of annually resolved temperature that use tree-

ring maximum latewood density measurements are restricted to Northern Scandinavia (Grudd 2008), the Alps (Büntgen et al. 2006), Tatra (Büntgen et al. 2007), and Pyrenees (Büntgen et al. 2008). In contrast, ring width-based reconstructions of hydro-climatic fluctuations are mainly limited to lower latitudes (e.g. Akkemik & Aras 2005), with exceptions in southern Scandinavia (Linderholm & Molin 2005, Helama et al. 2009), and central-eastern Europe (Brázdil et al. 2002, Wilson et al. 2005, Büntgen et al. 2010). The ideal tree-ring

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proxy number and their locations necessary to capture spatially explicit patterns of European-scale climate variability are largely unknown. This picture becomes even more complicated when using traditional reconstruction methods that use a combination of individual records, and thus likely diminish their maximum spatial significance.

Here we assessed the ability of existing tree-ring density- and width-based climate reconstructions situated between northern Scandinavia and the Mediterranean to mimic European growing season temperature and drought variability. Our interest stems from a practical rather than a theoretical perspective, as we analyzed the temperature and precipitation co-variability of existing mean and individual climate reconstructions, complemented by the assessment of the spatial extension of temperature and precipitation relationships within instrumental measurements, as well as climate model simulations. A suite of experiments (Expts 1 to 4) was performed. The simple mean of 4 (11) available temperature (hydro-climatic) reconstructions was correlated against gridded European temperature (drought) indices (Expt 1); the 15 individual reconstructions were correlated against climate grids (Expt 2), while instrumental station measurements near to the proxy locations (Expt 3) and model analogues most similar to the temperature/precipitation reconstruction arrays (Expt 4) were both considered for verification of the spatial domains for which temperature and precipitation reconstructions provide useful information.

## 2. EXPERIMENTS

**Expt 1.** The simple mean of 4 density-based temperature reconstructions from thermal treeline sites was used for comparison to gridded temperature data, and the mean of 11 ring width-based hydro-climatic reconstructions from temperate forest sites was used for comparison to gridded drought metrics. Note that only final reconstructions are considered here, whereas simple chronologies were disregarded. Table 1 shows a summary of the selected data pool; note that minor differences between the originally published results on climate sensitivity and those reported here are most likely caused by deviations in the seasonal response windows, lagged climate variables, and calibration periods used. The mean temperature and drought reconstructions (using density and ring width, respectively) were correlated against gridded ( $0.5 \times 0.5^\circ$ ) growing season (A–S: April to September) temperature and the self-calibrated Palmer Drought Severity Index (scPDSI) over the 1901 to 1993 common period and the  $35$  to  $70^\circ$  N and  $10^\circ$  W to  $40^\circ$  E region (Climate

Research Unit TS3; Mitchell & Jones 2005, van der Schrier et al. 2006). Spatial field correlation of the mean density record is  $>0.4$  over Central Europe south of  $55^\circ$  N and west of  $25^\circ$  E (Fig. 1A). In contrast, spatial field correlation of the mean ring width record is  $>0.4$  for only a few patches scattered along an east-west corridor from the British Isles, over Germany, to the Baltic (Fig. 1B).

**Expt 2.** The 4 temperature and 11 drought reconstructions (using density and ring width, respectively) were individually correlated against gridded A–S temperature and the scPDSI (1901 to 1993). Spatial field correlations of the density records against gridded A–S temperature are  $>0.4$  for 71% of the European land-mass (Fig. 1C). Correlations  $>0.6$  are found over Northern Scandinavia ( $>60^\circ$  N) and Central Europe ( $<50^\circ$  N). Less variance is explained along a west-east corridor ( $\sim 50$  to  $55^\circ$  N) from the British Isles to Eastern Europe ( $>35^\circ$  E) and from the Kola Peninsula to the Near East. In contrast, correlations  $>0.4$  of the ring width records against gridded A–S scPDSI are limited to areas around the proxy sites, summing up to only 16% of the continent (Fig. 1D). This poor picture becomes even more pronounced when considering field correlations between 0.5 and 0.6. Correlations  $>0.6$  are not reached in any region.

**Expt 3.** Spatial correlation fields based on instrumental measurements near the proxy locations (Table 1) confirm the proxy-based observations as obtained from Expt 2: 2 large fields of positive correlations with temperature are revealed over Central and Northern Europe, whereas much smaller clusters of generally lower correlations are revealed with precipitation (Fig. 1E,F). Spatial field correlations against gridded A–S temperature are  $>0.6$  for most of Scandinavia and continental Europe, whereas correlations against precipitation are  $>0.6$  for a limited region north of the Alpine arc. Non-significant correlations with precipitation dominate the high northern latitudes ( $>60^\circ$  N), the Mediterranean region ( $<45^\circ$  N), and most of Eastern Europe ( $>20^\circ$  E). Empirical Orthogonal Function (EOF) analysis additionally confirms these patterns: the first 4 EOFs explain  $\sim 80\%$  of European summer temperature variability, but the cumulative sum of the first 10 EOFs only explains  $\sim 60$  and  $55\%$  of corresponding precipitation and scPDSI variability, respectively (not shown).

**Expt 4.** Reanalysis data (ERA-40; Uppala et al. 2005) of the grid-cells covering the proxy locations serve as targets for the analogue search among a suite of model simulations: a control and 2 forced ECHO-G runs (González-Rouco et al. 2006), the forced HadCM3 run (Tett et al. 2007), a COSMOS control run, and the COSMOS Millennium ensemble runs 1 and 2 (J. Jungclaus pers. comm.). Reanalysis data are restricted to a spatial resolution of  $3.75 \times 3.75^\circ$  for the period 1958 to

Table 1. Summary information of the proxy reconstructions used. ‘Seasonal response’ indicates the originally described maximum climate sensitivity; ‘Climate response’ is expressed as Pearson’s correlation coefficients herein computed over the 1901 to 1993 period. PISY: *Pinus sylvestris*, PCAB: *Picea abies*, LADE: *Larix decidua*, PIUN: *Pinus uncinata*, QUSP: *Quercus sp.*, ABAL: *Abies alba*, ABAL: *Abies alba*, PINI: *Pinus nigra*. a.s.l.: above sea level

Site (Corresponding station)	Location	Latitude	Longitude	Elevation (m a.s.l.)	Period	Seasonal response	Species	Climate response			Source	
								Temp.	Precip.	Drought		
Density-based temperature reconstructions												
<b>1</b>	(Haparanda) Northern Sweden	68° 20' 55" N	18° 50' 19" E	550	501–2004	AMJJAS	PISY	0.74	-0.11	0.05	Grudd (2008)	
<b>2</b>	(Budapest) Tatra	49° 15' 26" N	20° 00' 15" E	1450	1709–2004	AMJJAS	PCAB/LADE	0.54	-0.39	-0.22	Büntgen et al. (2007)	
<b>3</b>	(St. Bernard) Swiss Alps	46° 25' 10" N	7° 49' 46" E	1800	755–2004	JJAS	LADE	0.72	-0.45	-0.34	Büntgen et al. (2006)	
<b>4</b>	(Valencia) Central Pyrenees	42° 41' 00" N	0° 47' 50" E	2400	1260–2005	MAMJJAS	PIUN	0.64	-0.42	-0.40	Büntgen et al. (2008)	
Ring width-based hydro-climatic reconstructions												
<b>1</b>	(St. Petersburg) Southern Finland	61° 30' 00" N	28° 30' 00" E	75	660–1993	MJ	PISY	0.13	0.37	0.46	Helama et al. (2009)	
<b>2</b>	(Uppsala) Central-east Sweden	59° 11' 00" N	18° 16' 00" E	30	1750–1999	JJA	PYSI	-0.05	0.39	0.26	Linderholm & Molin (2005)	
<b>3</b>	(Oxford) South-central England	51° 45' 08" N	1° 15' 20" W	85	827–2008	JJA	QUSP	-0.06	0.29	0.48	Wilson (2009)	
<b>4</b>	(Frankfurt) Central Germany	51° 11' 63" N	9° 12' 16" E	250	996–2005	JJAS	QUSP	-0.22	0.38	0.37	Büntgen et al. (2010)	
<b>5</b>	(Regensburg) Bavaria	49° 02' 02" N	12° 43' 10" E	600	1480–2001	MAMJJA	PCAB	-0.18	0.37	0.50	Wilson et al. (2005)	
<b>6</b>	(Uzhgorod) Tatra	48° 55' 54" N	20° 16' 54" E	800	1734–2006	JJA	PISY	-0.31	0.45	0.55	Büntgen et al. (2009)	
<b>7</b>	(Kremsmuenster) Southern Moravia	48° 54' 16" N	16° 09' 05" E	250	1376–1996	MAMJJA	ABAL	-0.11	0.34	0.20	Brazdil et al. (2002)	
<b>8</b>	(Vienna) Vienna Basin	48° 12' 32" N	16° 22' 00" E	210	1320–1996	JJA	PINI	-0.29	0.61	0.38	Wimmer pers. comm.	
<b>9</b>	(Innsbruck) Tyrol, Austria	46° 58' 40" N	10° 33' 13" E	900	1724–1997	AMJ	PISY	-0.13	0.18	0.09	Oberhuber & Kofler (2002)	
<b>10</b>	(Geneva) Vallis, Switzerland	46° 18' 21" N	7° 35' 06" E	550	1902–2001	June	PISY	-0.28	0.14	0.37	Affolter et al. (2010)	
<b>11</b>	(Yalta) Northwest Turkey	41° 30' 00" N	33° 00' 00" E	1000	1635–2000	MAMJ	PINI	-0.17	0.38	0.28	Akkemik & Aras (2005)	

2002. The spatial field reconstructions of temperature and precipitation variability are obtained by the Proxy Surrogate Reconstruction method (PSR; Graham et al. 2007), which combines the advantages of climate models in simulating physically-consistent climate fields with the strength of proxy data (here time-series extracted from the ERA-40 dataset) that target the real climate trajectory (see also Goosse et al. 2006, Trouet et al. 2009). This combination is achieved by selecting the model states (analogues) that are most similar with proxy/instrumental data available at specific places and specific moments of time. Composites of the 10 closest model analogues for A–S temperature and precipitation are used. Spatial fields of explained A–S temperature and precipitation variability, as derived from the shuffled model analogues of the PSR method, are in general agreement with the spatial correlation patterns of the proxy and instrumental records (Fig. 1G,H). The relatively coarse model resolution tends to amplify the area of explained variability, but does not change the main conclusion, i.e. precipitation is characterized by much higher local variability than temperature, and many more sites are required for reliable spatial precipitation reconstructions, whereas relatively robust spatial temperature estimates can be generated from only a couple of well-located proxy records.

### 3. CONCLUSIONS

Independent methodological lines of tree-ring proxy, instrumental station, and model simulation evidence show a high degree of spatial temperature covariance in contrast to much more fragmented precipitation variability over the European/North Atlantic sector. Four temperature reconstructions based on density measurements from Scandinavia, the Alps, Tatra, and Pyrenees reveal correlations  $>0.4$  with summer temperature over 71% of the European landmass. In contrast, 11 ring width-based hydro-climatic reconstruc-

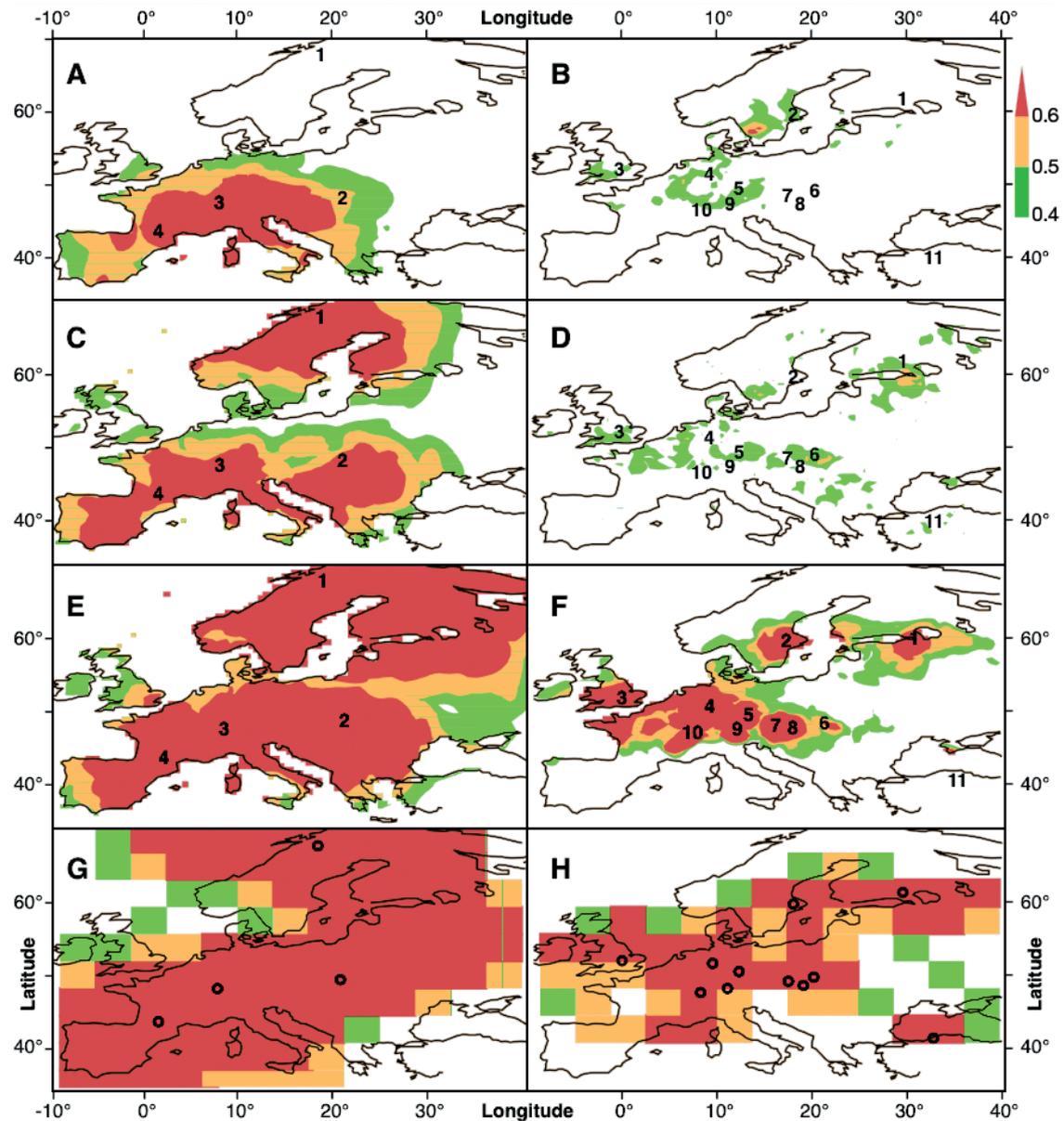


Fig. 1. Composite overlay maps of Pearson's correlation coefficients of the 4 experiments. Correlation fields computed from (A) the mean density and (B) ring width reconstruction (Expt 1), (C) the 4 individual density reconstructions, (D) the 11 ring width reconstructions (Expt 2), the instrumental (E) temperature and (F) precipitation measurements (Expt 3), and the model (G) temperature and (H) precipitation analogues (Expt 4). Circles/numbers correspond to tree-ring sites listed in Table 1

tions only correlate  $>0.4$  with summer drought over 16% of the European landmass. Even though our results have been partially highlighted by other authors at larger scales (Jones et al. 1997 and references therein), our experimental setting allows a new perspective to be drawn for the European region.

Besides the re-evaluation of the enormous pool of existing European tree-ring chronologies, we emphasize the importance of methodological refinements of the assessments of proxy climate sensitivity and trend preservation (Frank et al. 2008). Additional hugely im-

portant untapped paleoclimatic resources are the historical oak chronologies available for many different European regions (see Haneca et al. 2009 for a review), of which some have already been successfully utilized for climate reconstructions (Wilson 2009, Büntgen et al. 2010). Additional insights on past precipitation/drought variability might also be obtained from isotopic analyses (Treydte et al. 2007), with specific priority given to the Mediterranean region, where quality and quantity of hydro-climatic proxy and target data are still low (Xoplaki et al. 2004), but where future

rates of temperature increase and precipitation decrease are expected to be most rapid (see Luterbacher et al. 2006 for a review). Moreover, there remains a west–east corridor between ~50 and 60°N for which new reconstructions should be developed. Besides the limitations in capturing hydro-climatic variability, further caution is advised, as proxy noise generally increases for data further back in time, and thus the effective number of annual predictors necessary to estimate historical variations is greater than those needed to estimate contemporary conditions. In this regard, much more data from different regions and archives are necessary to capture past climate variability across the European/North Atlantic sector (Pauling et al. 2006). Documentary archives can contain exceptional information on the spatial characteristics of historical climate extremes, which could be used to address this issue (Dobrovlný et al. 2010). We advocate that multi-proxy compilations and their cross-validation become routine when reconstructing climate.

Due to the importance of tree-ring-based proxies to understand annual to centennial-long variations of past hydro-climatology, we recommend an emphasis on new sites and parameters that are primarily sensitive to moisture availability, well replicated, and processed to include high- to low-frequency information. Nevertheless, precipitation reconstructions across mountain regions will continue to be particularly difficult. Given the spatial character of existing temperature proxies, additional density composites spanning several centuries to millennia should be developed for Scotland and the Carpathian arc where potential has already been indicated (Popa & Kern 2009, Wilson 2009).

*Acknowledgements.* We thank the authors who published the original tree-ring data, and 4 anonymous reviewers who helped improve the manuscript. The Climate Research Unit (CRU), Royal Netherlands Meteorological Institute (KNMI), and European Centre for Medium-Range Weather Forecasts (ECMWF) kindly made their data available. This study was supported by the European Union project MILLENNIUM (no. 017008-GOCE) and the SNSF (NCCR-Climat).

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*Editorial responsibility: Geir Ottersen, Oslo, Norway*

*Submitted: September 21, 2009; Accepted: February 2, 2010  
Proofs received from author(s): March 13, 2010*