# The Feasibility of Reconstructing Hydroclimate over West Africa using Tree-Ring Chronologies in the Mediterranean Region

Boniface Fosu<sup>1,1</sup>, Edward R $\rm Cook^{2,2},$  Michela Biasutti<sup>2,2</sup>, Brendan M $\rm Buckley^{2,2},$  and Sharon E $\rm Nicholson^{3,3}$ 

<sup>1</sup>Mississippi State University <sup>2</sup>Columbia University <sup>3</sup>Florida State University

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#### Abstract

Dendrochronology in West Africa has not yet been developed despite encouraging reports suggesting the potential for long tree-ring reconstructions of hydroclimate in the tropics. This paper shows that even in the absence of local tree chronologies, it is possible to reconstruct the hydroclimate of a region using remote tree-rings. We present the West Sub-Saharan Drought Atlas (WSDA), a new paleoclimatic reconstruction of West African hydroclimate based on tree-ring chronologies from the Mediterranean Region, made possible by the teleconnected climate relationship between the West African Monsoon and Mediterranean Sea surface temperatures. The WSDA is a one-half degree gridded reconstruction of summer Palmer Drought Severity indices from 1500–2018 CE, produced using ensemble point-by-point regression. Calibration and verification statistics of the WSDA indicate that it has significant skill over most of its domain. The three leading modes of hydroclimate variability in West Africa are accurately reproduced by the WSDA, demonstrating strong skill compared to regional instrumental precipitation and drought indices. The WSDA can be used to study the hydroclimate of West Africa outside the limit of the longest observed record and for integration and comparison with other proxy and archaeological data. It is also an essential first step toward developing and using local tree-ring chronologies to reconstruct West Africa's hydroclimate.

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5	Nicholson <sup>3</sup>
6	
7	<sup>1</sup> Department of Geosciences, Mississippi State University, Mississippi State, MS, USA.
8	<sup>2</sup> Lamont-Doherty Earth Observatory of Columbia University, Palisades, NY, USA.
9	<sup>3</sup> Earth, Ocean and Atmospheric Sciences, Florida State University, Tallahassee, FL, USA.
10	
11	Correspondence
12	Boniface O. Fosu, Department of Geosciences, Mississippi State University, MS State, MS, USA.
13	Email: <u>boniface.fosu@msstate.edu</u>

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#### 15 Abstract

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- 33
- 34 Keywords
- 35

36 West Africa, Mediterranean, Hydroclimate, Tree-ring network, Teleconnection, Drought Atlas

## 37 1.0 Introduction

Recent hydroclimatic changes in West Africa have visibly adverse socioeconomic ramifications
(Turco et al 2015). For instance, in 2015, severe drought limited water availability in the Volta
River Basin, an essential source of water distribution and economic activity in West Africa.
Consequently, electricity generation by several dams within the basin came to a halt, including
the Akosombo Dam, the single largest electricity source in Ghana, crippling the country's
economy and threatening the basic livelihood of many of its already impoverished
communities.

Policies premised on leveraging science and technology hold the greatest promise to mitigating
such climate driven economic impacts, but their formulation is limited by the lack of important
information and considerable uncertainty in the projections of hydroclimatic variability in
West Africa (Challinor et al 2007, Biasutti 2009, Roudier et al 2011, Biasutti 2013).

49 Long observational records for key climatic variables against which to evaluate the performance of climate models, the primary tools for climate projections, are rare in West 50 Africa. In fact, only during the 1930's did synoptic observation stations become generally 51 52 established in the sub-region and these remain sparse even today (Tarhule and Hughes 2002). The instrumental record is thus often too short to give an adequate account of the range of 53 54 possible behavior of the region's climate and is not enough to vet model performances in reproducing them. In addition, lack of long observational records limits our ability to 55 56 accurately attribute the relative contributions of human influences versus natural variability to recent hydroclimatic changes and provides an unreliable baseline for deriving 57 58 observationally constrained estimates of future climate projections based on a past climate regime. Ultimately, this precludes a proper assessment. 59

In the absence of ample instrumental records, dendrochronological methods of climate reconstruction have yielded unique insights into the natural variability of Earth's climate system (Cook and Kairiukstis 1990, Cook et al 2010, Buckley et al 2010, Anchukaitis 2017), thus allowing us to test model performances outside the limit of the longest observed record. Due to their strong response to environmental changes, trees are particularly well suited for studying hydroclimate variability (St. George 2014, St. George and Ault 2014), although the specific monthly or seasonal climate response can vary across regions and continents (St.

George et al 2010, Touchan et al 2014). Trees provide annually resolved information on past climate variability and can be dated to the exact calendar year, thus enabling quantitative and precise calibration and verification. Despite inherent uncertainties, proxy data, including tree rings can be used in conjunction with instrumental records to reduce uncertainty in hydroclimatic projections (Henderson et al 2009, Haywood et al 2019).

The potential for dendrochronology in West Africa has not yet been developed, notwithstanding the vital role it often plays in our understanding of past hydroclimate variability and future climate projections. To date, paleolimnological investigations of the Kajemarum oasis in the Manga Grassland of northeastern Nigeria have furnished much of the information on Holocene climate for West Africa (Salzmann 1996, Waller and Salzmann 1999, Street-Perrot et al 2000).

78 In this study, we show that even in the absence of local tree chronologies, it is possible to reconstruct the hydroclimate of a region using remote tree-ring growth. We present a Palmer 79 80 Drought Severity Index (PDSI) reconstruction as a proxy for the hydroclimate over West Africa 81 based on tree-ring chronologies from the Mediterranean region. This is made possible by a 82 strong teleconnection signal between the Mediterranean region and West Africa. Rowell (2003) first demonstrated the positive influence of Mediterranean Sea surface temperatures 83 (SST) anomalies on West African Monsoon (WAM) precipitation through northerly moisture 84 85 advection from the Mediterranean toward the Sahel. Since then, a number of studies including Jung et al 2006, Peyrille and Lafore 2007, and Diatta et al 2020 have been dedicated to the 86 WAM-Mediterranean interaction and the existence of this teleconnection is now widely 87 accepted. 88



Figure 1: Geographic context for the study. Shaded black circles with gray outlines represent
the 333 sites of the tree-ring chronologies utilized in reconstructed scPDSI over West Africa
(i.e., WSDA). The one-half degree grid points (i.e., green dots) represent the WSDA grid.
Shading outside land areas represent the summer (JJA) correlation between SST and the time
series of EOF1 of instrumental scPDSI over West Africa, from 1901-2020.

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96 Our results are encapsulated in the novel West Sub-Saharan Drought Atlas (WSDA, figure 1), 97 an annually resolved spatial reconstruction of West Africa's hydroclimate over the past five 98 hundred years. The WSDA can be used to assess the performance of climate models and for 99 integration and comparison with other proxy, historical, and archaeological data. It is also an 100 important first step toward the goal of developing and using local tree-ring chronologies to 101 reconstruct West Africa's hydroclimate.

#### 102 2.0 Data and Methodology

#### 103 2.1 Tree-ring Network and Reconstruction Method

The tree-ring network we used for the WSDA reconstruction is based on the Mediterranean portion of the Old-World Drought Atlas tree-ring network (Cook et al 2015). It is comprised of 333 tree-ring chronologies and its spatial distribution is shown in figure 1. All chronologies begin on or before 1798 and end no earlier than 1990. We used this network because of its previous success in reconstructing past drought over the Mediterranean region and its clear association with the Mediterranean teleconnections that influence West Africa rainfall.

110 The method of reconstruction we used is the Point-by-Point Regression (PPR) method (Cook 111 et al 1999) and its extension to ensemble PPR (EPPR) as described most recently in Cook et 112 al (2020). PPR was specifically developed for the reconstruction of hydroclimate variability 113 from tree rings, but it originally relied on relatively local tree-ring chronologies to reconstruct 114 local hydroclimate (Cook et al 1999). This limitation was relaxed through the use of multiple 115 search radii for locating tree-ring chronologies in more remote locations to reconstruct 116 hydroclimate at each grid point and a novel correlation-weighted method for generating the principal component regression models used for reconstruction (Cook et al 2010a, 2020). This 117 118 resulted in an ensemble of reconstructions at each grid point (hence EPPR) that could be 119 evaluated for skill.

120 The tree-ring chronologies used for reconstruction have a common end year of 1990 because 121 of the widely varying years in which the trees were sampled but lose one year (1990) due to 122 the inclusion of a lagged tree-ring variable in the model (Cook et al 1999). For this reason,

the calibration period chosen for developing the reconstructions was set to 1951–1989. This
period includes the highest number of rainfall stations used for calculating the self-calibrating
Palmer Drought Severity Index (scPDSI) over West Africa (figure 2 in Nicholson et al 2018)
and therefore ought to be the highest quality period for calibrating each EPPR model. Of the
remaining pre-1951 scPDSI data, only the 1920–1950 period was used for model validation
because of the sharply declining number of rainfall stations over West Africa in the early 20<sup>th</sup>
Century (figure 2 in Nicholson et al 2018).

The WSDA reconstructions cover the period 1500-2018 CE. Each grid point reconstruction has
been scaled to recover lost variance due to regression (proportional to 1-R<sup>2</sup>). This enabled
each reconstruction to be updated from 1990 to 2018 with instrumental data.

# 133 2.2 Calibration and Verification Statistics

134 We provide five rigorous calibration and verification statistics that are typically used for 135 assessing the quality of dendroclimatic reconstructions (e.g., Michaelsen 1987, Meko 1997, 136 Cook et al 1999). They include the calibration period coefficient of determination or  $R^2$ 137 (CRSQ) and cross-validation reduction of error (CVRE). The latter is a 'leave-one-out' procedure analogous to R<sup>2</sup> based on Allen's PRESS statistic (Allen 1971) and its R<sup>2</sup> equivalent 138 139 (Quan 1988) and is a more conservative measure of explained variance than CRSQ. In 140 extremely weak calibration cases CVRE can actually go negative, which is a clear indication of 141 no calibration skill.

142 The validation period statistics are the square of the Pearson correlation (VRSQ, sign of the 143 correlation applied), the reduction of error statistic (VRE), and the coefficient of efficiency 144 (VCE), and these can be interpreted as expressions of shared variance between the actual data and the tree ring estimates. Negative values indicate no reconstruction skill as measured. The 145 146 formulae of these statistics require that VRSQ is greater than or equal to VRE, which in turn is 147 greater than or equal to VCE when calculated from the same data, thus making VCE the 148 hardest validation statistic to pass. No theoretical significance tests are available for the VRE 149 and VCE. Simply, values greater than zero indicate that the reconstruction has skill in excess 150 of the calibration or verification period climatology of the instrumental data. In addition to 151 these validation metrics, the root mean square error (RMSE) statistic is provided as a simple 152 estimate of uncertainty. For a full explanation of these statistics, the reader is referred to Cook 153 et al (1999).

# 154 2.3 Hydroclimatic and SST Datasets

155 The instrumental hydroclimate data used for statistical calibration and validation in this study is the widely used self-calibrating Palmer Drought Severity Index (scPDSI; Wells et al 2004, 156 157 van der Schrier et al 2013), specifically the CRU TS 4.03 dataset that covers the period 1901-158 2018 (Barichivich et al 2018). It is calculated from the University of East Anglia's Climatic 159 Research Unit's instrumental temperature and precipitation dataset, available on a 0.5° 160 resolution from 1901 to the present. From these monthly data we reconstructed the summer 161 (June-August) average scPDSI over West Africa. This matches the season reconstructed for the 162 OWDA and also coincides with the summer rainfall season over the WSDA domain.

We also used the Joint Institute for the Study of the Atmosphere and Ocean (JISAO) Sahel
precipitation index which spans 1901 to present, derived from the 0.25° resolution Deutscher
Wetterdienst Global Precipitation Climatology Centre monthly precipitation dataset and the

Sahel rainfall time series from Nicholson et al (2018), which is based on 602 rain gauge records of variable length extending from 1854 to 2014. A comparative series for the Gulf of Guinea region to the south is also utilized. Together, the latter two rainfall indices from Nicholson et al (2018), hereafter referred to as NRI, collectively provide insight into the longterm variability of the West African monsoon.

Apart from these meteorological datasets, we make use of the Hadley Center Sea Ice and Sea
Surface Temperature dataset (HadISST, Rayner et al 2003), which is analyzed in concert with
the aforementioned instrumental scPDSI to deduce the connection between West African
hydroclimate and Mediterranean SST.

175 2.4 EOF Analysis

176 The primary goal of Empirical orthogonal function (EOF) analysis is to simplify a given space-177 time dataset by extracting the smallest set of independent modes of variability that can 178 adequately describe it (e.g., Lorenz 1956, LaMarche and Fritts 1971). Standard EOFs are 179 found by computing the eigenvalues and eigenvectors of the anomaly covariance matrix of a 180 field. The eigenvalues provide a measure of the percent variance explained by the corresponding mode, the latter are orthogonal to each other depending on the time period 181 182 being used. The time series (aka principal component or PC) of each mode is determined by 183 projecting the derived eigenvectors onto the spatially weighted anomalies.

Here, we use EOFs to identify the coherent patterns in the reconstructed hydroclimate over
West Africa and the Mediterranean Region and evaluate them against the instrumental scPDSI
and precipitation datasets. Typically, the first few modes contain the most variance as well as

physically interpretable patterns when it comes to atmospheric and hydroclimatic processes, so in this paper, we focus on the first three EOFs. All analyses are based on the Boreal summer months of June, July, and August (i.e., JJA). Also, datasets are normalized before use in order to prevent areas of maximum variance from dominance and facilitate comparison.

# 191 3. Results and Discussion

192 Figure 1 shows the locations of the tree-ring chronologies used for reconstructing the WSDA, 193 the WSDA domain limits, and how the first principal component (PC1) of instrumental scPDSI 194 over the WSDA is correlated to SSTs in the Mediterranean from 1901-2020. The strength and 195 pattern of the correlations are consistent with the known teleconnection between the two 196 regions, which is primarily characterized by the WAM response to thermal Mediterranean 197 forcing. When the Mediterranean is warmer than normal, it reinforces the northward migration of the monsoon system and surface convergence in the vicinity of the intertropical 198 199 convergence zone (ITCZ) through stronger moist convection south of the Sahara. The 200 increased moisture convergence feeds the convective activity leading to increased precipitation 201 (Rowell 2003, Gaetani et al 2010, Fontaine et al 2010). On the other hand, the alternate effect 202 of WAM dynamics on Mediterranean climate is not as clearly understood, although a few 203 studies including Rodwell and Hoskins (2001) argue that the Rossby wave response to West 204 African monsoonal heating, interacting with midlatitude westerlies, does impact205 Mediterranean climate by producing a strong region of adiabatic descent there.



Figure 2: Reconstruction drought calibration and verification statistics. (a-b) Mediterranean
Region cross-validation RSQ (CVRE) and validation period RSQ (VRSQ). (c-d) WSDA
calibration period RSQ (CRSQ) and cross-validation RSQ (CVRE). (e-g) WSDA validation RSQ

(VRSQ), validation period reduction of error (VRE) and validation period coefficient of
Efficiency (VCE). Unlike CRSQ, which can never be negative, CVRE, VRSQ (by retaining the
sign of r after squaring), VRE and VCE can have negative values, indicating that there is no
skill in the estimates. All but RSME are in units of fractional explained variance. RSQ is R<sup>2</sup>.

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215 Calibration and verification results over the Mediterranean and WSDA grids are presented in figure 2, providing an avenue to measure the quality of reconstructions from the local 216 217 chronologies and a benchmark against which to evaluate the reconstruction of the remote 218 hydroclimate in West Africa. Most of the grid points show reasonably robust calibrations 219 (figure 2(a)), with a validation skill map that exhibits a diagonal split between high skill in 220 the northwest and relatively low skill in the southeast (figure 2(b)). The latter may be caused 221 in part by a decline in the number of rainfall records contributing to the scPDSI estimates 222 especially over Turkey and the Middle East, thus resulting in reduced instrumental data quality 223 especially before 1930. Recall that the Mediterranean tree ring chronologies utilized in this 224 study were previously used to build the Old World Drought Atlas (OWDA) as presented in Cook et al. 2015, which elaborates further on the quality of instrumental and proxy 225 226 reconstructions in the region.

Over the West Africa grid, we present four additional validation metrics, given that the WSDA
is the main focus of this paper. Much like the Mediterranean, the entire WSDA grid calibrates
well (figures 2(c) and (d)), with weaker but useful validations indicated by the positive VRSQ,
VRE and VCE, scattered across the domain (figures 2(e) – (g)). Judging by the VCE, which is
the hardest metric to pass, it is clear that the most consistent and reliable validation occurs

along the main river systems of two of the three biggest watersheds in West Africa (figure S1).
Within the Volta River Basin to the east, the best grids show up along the Volta River in Ghana.
In the west, they appear along the Sénégal River within the Senegal River Basin (figure 2(g)).
The RMSE's in figure 2(h) provide more insight into the magnitude of the total errors of the
WSDA reconstructions, both bias and variance. In congruence with the other validation
metrics, the lowest reconstruction skill is largely found over the central part of the region.

One possible reason for the low skill validations is the poor quality of observations particularly 238 239 before 1951, when fewer stations are available and most grid point interpolations are relaxed 240 towards the climatology as available stations diminish. The relatively strong validity of the 241 reconstruction over the Northwestern Mediterranean and within specific river basins is also 242 not surprising. Historically, humans have settled close to water bodies and food sources 243 because of commerce and trade and would provide an economic incentive to take hydroclimatic measurements there. Any long systematically measured data within the WSDA 244 245 grid implicitly augurs well for its validation.

Considering the limitations with historical data at the grid point scale, we proceeded to evaluate the utility of the WSDA on a regional scale by comparing EOFs of the instrumental and reconstructed summer scPDSI in figure 3. EOF1 of the instrumental scPDSI (figure 3(a)) explains 44% of the total variance and exhibits a monopole mode of variability or anomalous conditions of the same sign throughout the region. EOF2 explains 10% of the variance and is characterized by a meridional dipole pattern of variability, which represents the well-known dipole of hydrological conditions over the Sahel region and the Gulf of Guinea (e.g., Nicholson et al 2013). So, wet conditions in the Sahel are opposed by dry conditions on the Guinea Coast,and vice versa. Nicholson and Grist (2001) describe these two modes as so fundamental that



Figure 3: EOF patterns of (a) instrumental scPDSI over West Africa (spanning 1901-2020)
and (b) reconstructed scPDSI over West Africa or WSDA (spanning 1500–2018 CE). (c-e) EOF

time series: WSDA is the gray line and red is instrumental scPDSI. The NRI Sahel rainfall index is superimposed on the PC1 of WSDA in blue and the JISAO Sahel index in yellow. The Gulf of Guinea index is also superimposed on the PC3 of WSDA in blue. PC1 of WSDA is correlated to PC1 of instrumental scPDSI at R=0.77, the Sahel rainfall index from Nicholson et al. 2018 at R=0.66 and the JISAO Rainfall index at R=0.61. If an 11-year running mean is applied, R goes up to 0.86, 0.92 and 0.91 respectively.

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they are evident on both interannual and interdecadal time scales and in the historical record of past centuries. EOF3 is a zonal dipole that explains 6% of the total variance and has been related to a recently observed long term intensification of the Saharan heat low (Lavaysse et al 2015) and enhancing effects from anthropogenic global warming (James et al 2013).

269 The EOFs of the reconstructed scPDSI (figure 3(b)) match their instrumental counterparts 270 (figure 3(a)), although EOF2 and EOF3 switch precedence, which is unsurprising considering 271 the fact that the WSDA spans a much longer period of time (519 years, 1500-2018 CE) relative 272 to the instrumental record (120 years, 1901-2020). Indeed, computing the EOFs from 1901-273 1989, which is a period where the WSDA encompasses tree-ring only data, yields identical 274 loading patterns and are ordered in the same way (figure S2). Further, we correlate the PCs 275 of the WSDA to the corresponding PCs of instrumental scPDSI and rainfall indices from JISAO 276 and NRI over their respective overlapping time periods (figures 3 (c)-(e)). Except for the NRI 277 Gulf of Guinea index, all the other indices are significantly correlated to both the dominant 278 monopole mode of variability (EOF1) and the dipole mode (EOF3 in WSDA) that distinguishes 279 the hydrological conditions over the Sahel from the Gulf of Guinea. The NRI Gulf of Guinea index is only significantly correlated to EOF3 (Table S1). This is quite intriguing, especiallygiven the absence of local tree-ring chronologies in the WSDA.

282 4. Conclusions

The West Sub-Saharan Drought Atlas (WSDA) is a new paleoclimatic reconstruction of drought and wetness that reproduces several aspects of the spatio-temporal hydroclimatic variability over West Africa. It is a one-half degree gridded reconstruction of summer scPDSI from 1500–2018 CE and is made possible by the teleconnected climate relationship between West Africa and the Mediterranean region. An ensemble version of the point-by-point regression (EPPR) was used to produce the WSDA.

289 The reconstructed scPDSI of the WSDA accurately reproduced the three leading modes of 290 hydroclimate variability in West Africa and demonstrated strong skill when compared to 291 regional instrumental precipitation and drought indices. The inclusion of local tree-ring 292 chronologies in the WSDA is planned for the future and promises to yield a more robust 293 reconstruction, with a much more complete and local understanding of hydroclimatic 294 variability in West Africa. This is evident in figure S3 which shows the correlation of summer 295 (JJA) rainfall index over the Sahel with Mediterranean SST. The correlation between the 296 detrended rainfall index and SST in the Mediterranean is strong (figure S3(a)) but weakens 297 significantly when the rainfall index is first differenced (figure S3(b)). The rainfall data in 298 figure S3(a) was detrended by removing its linear best fit, which reduces the interannual 299 variability at any given location and in this case transforms the data to an overall decadal 300 variation. While differencing has the effect of removing trend and multi-year variability in a 301 data series, it also results in one fewer observation than the original series (figure S3(b)). This

seems to suggest the WSDA in its current form fails to retain all hydroclimatic information,
especially on the interannual timescale, making a strong case for the inclusion of local tree
ring chronologies. We also recognize the potential role modes of climate variability and remote
SST patterns can play in modulating the timescale of the teleconnection response in
Mediterranean trees, which warrants further studies.

307 It was widely believed that usual tree-ring dating methods may not be suitable for trees that 308 grow in Africa because they do not necessarily grow annual rings, but that is no longer the 309 general viewpoint today. Several researchers including Hummel 1946, Lowe 1961, Mariaux 310 1981, Detienne 1989, Jacoby 1989, Buckley et al 1995 and D'Arrigo et al 1997 have provided 311 evidence that annual rings form in several tropical species. In West Africa, some success in 312 producing annual tree-ring chronologies has also been recently reported from the Ivory Coast 313 (Ridder et al 2013) and the Cameroons (Battipaglia et al 2015). But several factors, including the difficulty in identifying and interpreting growth bands, the lack of precedents 314 315 demonstrating successful cross dating, political instability, economic and logistical difficulties 316 have contributed to stifling further investigations of these promising results. The situation is 317 further exacerbated by the fact that most practitioners of dendrochronology are from the mid-318 latitudes and have limited time and resources for devoting effort to evaluating tropical trees 319 for dendrochronological research (Tarhule and Hughes 2002). However, the limited success 320 in African dendrochronology reported to date suggests that the potential is there to develop 321 long tree-ring chronologies.

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#### 329 5. References

- Allen D M 1971 Mean square error of prediction as a criterion for selecting variables.
   Technometrics 13 469–475.
- 332

335

338

342

345

348

351

- Anchukaitis K J 2017 Tree rings reveal climate change past, present, and future Proc. Am.
   Philos. Soc. 161 pp. 244–263.
- 336 3. Barichivich J, Osborn T J, Harris I, van der Schrier G and Jones P D 2018 Drought [in
  337 "State of the Climate in 2018"]. Bull. Amer. Meteor. Soc. 100 S1–S306.
- 339 4. Battipaglia G, Zalloni E, Castaldi S, Marzaioli F, Cazzolla-Gatti R, Lasserre B, Tognetti R,
  340 Marchetti M and Valentini R 2015 Long Tree-Ring Chronologies Provide Evidence of
  341 Recent Tree Growth Decrease in a Central African Tropical Forest. PLOS ONE.
- 343 5. Biasutti M 2013 Forced Sahel rainfall trends in the CMIP5 archive. Journal of Geophysical
  344 Research. 118(4) 1613–1623.
- Biasutti M, Sobel A H and Camargo S J 2009 The role of the Sahara low in summertime
  Sahel rainfall variability and change in the CMIP3 models. J. Clim. 22 5755–5771.
- 349 7. Buckley B, Barbetti M, Watanasak M, D'Arrigo R, Boon-chirdchoo S and Sarutanon S 1995
  350 Preliminary dendrochronological investigations in Thailand. IAWA Bulletin 16 393–409.
- Buckley B M, Anchukaitis K J, Penny D, Fletcher R, Cook E R, Sano M, Nam C, Wichienkeeo
   A, Minh T T, Hong T M 2010 Climate as a contributing factor in the demise of Angkor,
   Cambodia. Proc. Natl. Acad. Sci. 107 6748–6752.
- 356 9. Challinor A, Wheeler T, Garforth C, Craufurd P and Kassam A 2007 Assessing the
  vulnerability of food crop systems in Africa to climate change. Clim. Change 83 381–399.
  358

- 10. Cook E R, Anchukaitis K J, Buckley B M, D'Arrigo R D, Jacoby G C and Wright W E 2010a
  Asian Monsoon Failure and Megadrought During the Last Millennium. Science 328 (5977)
  486–489.
- 362
  363 11. Cook E R and Kairiukstis L A 1990 Methods of Dendrochronology. Applications in the
  364 Environmental Sciences. International Institute for Applied Systems Analysis. Kluwer
  365 Academic Publishers, Dordrecht, 394 p.
- 366
  367 12. Cook E R, Meko D M, Stahle D W and Cleaveland M K 1999 Drought reconstructions for
  368 the continental United States. J. Clim. 12(4) 1145–1162.
- 369
- 13. Cook E R, Seager R, Heim Jr R R, Vose R S, Herweijer C and Woodhouse C 2010b
  Megadroughts in North America: placing IPCC projections of hydroclimatic change in a
  long-term palaeoclimate context. J. Quaternary Sci. Vol. 25 pp. 48–61.
- 374 14. Cook E R, Solomina O, Matskovsky V. et al 2020 The European Russia Drought Atlas
  375 (1400–2016 CE). Clim. Dyn. 54 2317–2335.
- 376
- 377 15. Cook E R, Seager R, Kushnir J, Briffa K R, Buentgen U, Frank D, Krusic P J, Tegel W, van 378 der Schrier G, Andreu-Hayles L, Baillie M, Baitttinger C, Bleicher N, Bonde N, Brown D, Carrer M, Cooper R, Cufar K, Dittmar C, Esper J, Griggs C, Gunnarson B, Gunther B, 379 380 Gutierrez E, Haneca K, Helema S, Herzig F, Heussner K-U, Hofmann J, Janda J, Kontic R, 381 Kose N, Kyncl T, Levanic T, Linderholm H, Manning S, Melvin T, Miles D, Neuwirth B, Nicolussi K, Nola P, Panayotov M, Popa I, Rothe A, Seftigen K, Seim A, Svarva H, Svoboda 382 M, Thun T, Timonen M, Touchan R, Trotsiuk V, Trouet V, Walder F, Wazny T, Wilson R 383 and Zang C 2015 Old world megadroughts and pluvials during the Common Era. Sci. Adv. 384 385 1(10) e1500561.
- 387 16. D'Arrigo R, Barbetti M, Watanasak M, Buckley B, Krusic P, Boonchirdchoo S and Sarutanon
  388 S 1997 Progress in dendroclimatic studies of mountain pine in northern Thailand. IAWA
  389 Bulletin 18 433–444.
- 390

386

- 391 17. Diatta S, Diedhiou C W, Dione D M, Sambou S 2020 Spatial Variation and Trend of
  392 Extreme Precipitation in West Africa and Teleconnections with Remote Indices.
  393 Atmosphere 11(9) 999.
- 394
- 395 18. Detienne P 1989 Appearance and periodicity of growth rings in some tropical woods. IAWA
   396 Bulletin 10(2) 123–132
- 397
- 398 19. Eshun M E & Amoako-Tuffour J 2016 A review of the trends in Ghana's power sector.
  399 Energy, Sustainability and Society, 6(9).
  400
- 401 20. Fontaine B, Garcia-Serrano J, Roucou P. et al 2010 Impacts of warm and cold situations in
  402 the Mediterranean basins on the West African monsoon: observed connection patterns
  403 (1979–2006) and climate simulations. Clim. Dyn. 35 95–114

- 405 21. Gaetani M, Fontaine B, Roucou P & Baldi M 2010 Influence of the Mediterranean Sea on
  406 the West African monsoon: intraseasonal variability in numerical simulations. J. Geophys.
  407 Res., 115 D24115.
- 408
  409 22. Grist J P and Nicholson S E 2001 A study of the dynamic factors influencing the variability
  410 of rainfall in the West African Sahel. J. Clim. 14 1337–1359.
- 411

419

- 412 23. Haywood A M, Valdes P J, Aze T. et al 2019 What can Palaeoclimate Modelling do for you?
  413 Earth Syst Environ 3 1–18.
  414
- 415 24. Henderson, Gideon & Collins, Matt & Hall, Ian & Lockwood, Mike & Pälike, Heiko &
  416 Rickaby, R.E.M. & Schmidt, Gavin & Turney, Chris & Wolff, Eric. 2009 Improving Future
  417 Climate Prediction using Palaeoclimate Data (an outcome of The Leverhulme Climate
  418 Symposium 2008 Earth's Climate: Past, Present and Future).
- 420 25. Hummel F C 1946 The formation of growth rings in Entandrophragma rnacrophyllurn and
  421 Khaya grandifolia. Empire Forestry Review 25 1.
- 422
  423 26. Jacoby G C 1989 Overview of tree ring analysis in tropical regions. IAWA Bulletin 10(2)
  424 99–108.
  - 425
    426 27. James R, Washington R and Rowell D P 2013 Implications of global warming for the
    427 climate of African rainforests. Phil. Trans. R. Soc. B 368, 20120298.
  - 428
    429 28. Jung T, Ferranti L & Tompkins A M 2006 Response to the summer of 2003 Mediterranean
    430 SST anomalies over Europe and Africa. J. Clim. 19 5439-5454.
  - 431
    432 29. LaMarche V C and Fritts H 1971 Tree Rings, Glacial Advance, And Climate In The Alps.
    433 Zeitschrift Fur Gletscherkunde Und Glazialgeologie VII.
  - 435 30. Lavaysse C 2015 Warming trends: Saharan desert warming. Nat. Clim. Change 5(9) 807–
    436 808
  - 437
    438 31. Lorenz E N, 1956 Empirical orthogonal functions and statistical weather prediction.
    439 Statistical Forecasting Project Report 1, MIT Department of Meteorology p 49.
  - 32. Mariaux A 1981 Past efforts in measuring age and annual growth in tropical trees. In Age
    and growth rate of tropical trees: new directions for research, edited by E H. Borman, and
    G. Berlyn, 20–30. Yale University School of Forestry and Environmental Studies, Bulletin
    94.
  - 33. Meko D M 1997 Dendroclimatic reconstruction with time varying predictor subsets of tree
    indices. J. Clim. 10 687–696.
  - 448

434

440

34. Michaelsen J 1987 Cross validation in statistical climate forecast models. Journal of
Climate and Applied Meteorology 26 1589–1600.

451 452 35. Nicholson S E 2013 "The West African Sahel: A Review of Recent Studies on the Rainfall 453 Regime and Its Interannual Variability", International Scholarly Research Notices, vol. 454 2013, Article ID 453521, 32 pages. 455 456 36. Nicholson S E, Fink A H, Funk C 2018 Assessing recovery and change in West Africa's 457 rainfall regime from a 161-year record. Int J Climatol 2018:1–17. 458 459 37. Peyrille P & Lafore J P 2007 An idealized two-dimensional framework to study the West 460 African monsoon. Part II: Large-scale advection and the diurnal cycle. J. Atmos. Sci. 64 461 2783-2803. 462 463 38. Quan N T 1988 The prediction sum of squares as a general measure for regression 464 diagnostics. J. Bus. Econ. Stat. 6 501-504. 465 466 39. Rayner N A. et al 2003 Global analyses of sea surface temperature, sea ice, and night 467 marine air temperature since the late nineteenth century. J. Geophys. Res. Atmos. 108. 468 469 40. Ridder M D, Trouet V, Van den Bulcke J, Hubau W, Van Acker J and Beeckman H 2013 A 470 tree-ring based comparison of Terminalia superba climate-growth relationships in West and Central Africa. Trees, DOI 10.1007/s00468-013-0871-3. 471 472 473 41. Rodwell M and Hoskins B 2001 Subtropical Anticyclones and Summer Monsoons. J. Clim. 474 14 3192-3211. 475 476 42. Rowell D P 2003 The impact of Mediterranean SSTs on the Sahelian rainfall season. J. 477 Clim. 16 849-862. 478 479 43. Roudier P, Sultan S, Quirion P and Berg A 2011 The impact of future climate change on 480 West African crop yields: what does the recent literature say? Glob. Environ. Change 21 481 1073-1083. 482 483 44. Salzmann U 1996 Holocene vegetation history of the Sahelian zone of NE-Nigeria: 484 preliminary results. Paleoecology of Africa and the surrounding islands. 24 103–114. 485 486 45. Stanzel P, Kling H and Bauer H 2018 Climate change impact on West African rivers under 487 an ensemble of CORDEX climate projections. Climate Services. 11 36-48. 488 489 46. Street-Perrott E A, Holmes J A, Waller M P, Allen M J, Barber N G H, Fothergill P A, Harkness D D, Ivanovich M, Kroon D and Perrott R A 2000 Drought and dust deposition in 490 491 the West African Sahel: a 5500-year record from Kajemarum Oasis, northeastern Nigeria. 492 The Holocene 10(3) 293–302. 493 494 47. St. George S 2014 An Overview of Tree-Ring Width Records across the Northern 495 Hemisphere. Quaternary Science Reviews 95 132-50. 496

- 497 48. St. George S and Ault T R 2014 The Imprint of Climate within Northern Hemisphere Trees.
  498 Quaternary Science Reviews 89 1–4.
- 499
- 49. St. George S, Meko D M and Cook E R 2010 The Seasonality of Precipitation Signals
  Embedded within the North American Drought Atlas. The Holocene 20 983–88
- 502

505

509

512

515

- 503 50. Tarhule A, Hughes M K 2002 Tree-ring research in semiarid west Africa: Need and
  504 potential. Tree-Ring Research 58(1/2) 31–46.
- 506 51. Touchan R, Anchukaitis K J, Shishov V V, Sivrikaya F, Attieh J, Ketmen M, Stephan J,
  507 Mitsopoulos I, Christou A and Meko D M 2014 Spatial Patterns of Eastern Mediterranean
  508 Climate Influence on Tree Growth. The Holocene 24 381–92.
- 510 52. Turco M, Palazzi E J and von Hardenberg, Provenzale A 2015 Observed climate change
  511 hotspots. Geophys. Res. Lett. 42 3521–3528. doi: 10.1002/2015GL063891
- 513 53. van der Schrier G, Barichivich J, Briffa K R, and Jones P D 2013 A scPDSI-based global
  514 data set of dry and wet spells for 1901–2009. J. Geophys. Res. Atmos. 118.
- 54. Waller M and Salzmann U 1999 Holocene vegetation changes in the Sahelian zone of NE
  Nigeria: The detection of anthropogenic activity. Paleoecology of Africa and the surrounding islands. 26 85–102.

519

520 55. Wells N, Goddard S and Hayes M J 2004 A self-calibrating Palmer drought severity index,
521 J. Clim. 17 2335–2351.

	(i) Instrumental scPDSI	(ii) JISAO Sahel Rainfall	(iii) NRI Sahel Rainfall	(iv) NRI Gulf of Guinea Rainfall
WSDA PC1	0.77* (PC1)	0.61*	0.66*	0.18
WSDA PC2	0.42* (PC3)	0.08	0.13	0.21
WSDA PC3	0.59* (PC2)	0.45*	0.39*	0.43*

**Table S1:** Correlation between the PCs of WSDA and the (i) PCs of instrumental scPDSI, (ii) the JISAO Sahel rainfall index, (iii) the NRI Sahel rainfall index, and (iv) the NRI Gulf of Guinea rainfall index over their respective overlapping time periods. Note that PC2 (PC3) of WSDA is correlated to PC3 (PC2) of instrumental scPDSI. \* denotes significance at p < .01.



**Figure S1:** West Africa with its 10 river basins , including the Senegal River Basin (1) and Volta River Basin (7). Stanzel et al. 2018.



**Figure S2:** EOF patterns of reconstructed scPDSI over West Africa (i.e., WSDA). The percent variance explained by each principal component is indicated. The EOF analysis is based on 1901-1989, a period that compares instrumental-only to tree-ring-only scPDSI.



-0.3

-0.3