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Changes in temperature and precipitation extremes in western central Africa, Guinea Conakry, and Zimbabwe, 1955–2006

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[1] Understanding how extremes are changing globally, regionally, and locally is an important first step for planning appropriate adaptation measures, as changes in extremes have major impacts. The Intergovernmental Panel on Climate Change's synthesis of global extremes was not able to say anything about western central Africa, as no analysis of the region was available nor was there an adequate internationally exchanged long-term daily data set available to use for analysis of extremes. This paper presents the first analysis of extremes in this climatically important region along with analysis of Guinea Conakry and Zimbabwe. As per many other parts of the world, the analysis shows a decrease in cold extremes and an increase in warm extremes. However, while the majority of the analyzed world has shown an increase in heavy precipitation over the last half century, central Africa showed a decrease. Furthermore, the companion analysis of Guinea Conakry and Zimbabwe showed no significant increases.

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1. Introduction

[2] Extreme events cause property damage, injury, loss of life and threaten the existence of some species. Observed globally averaged warming and projected future warming over Central Africa have direct implications on the occurrence of extreme weather and climate events as. It is unlikely that the mean climate could warm without altering climatic extremes. Extreme events drive changes in natural and human systems much more than average climate [*Parmesan et al.*, 2000; *Peterson et al.*, 2008]. Yet quantifiable information describing how weather and climate extremes are changing over central Africa has, until now, been unavailable.

[3] In preparation for the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report [*IPCC*, 2007] a major effort was undertaken to analyze how extremes are changing over as much of the world as possible. This included intensive international collaboration on data exchange and analysis, and, where data were not available, holding regional climate change workshops to generate information on extremes [*Alexander et al.*, 2006]. However, neither of these efforts was able to provide information for central Africa.

2. Workshop in Brazzaville

[4] To remedy this situation, the World Meteorological Organization Joint Expert Team on Climate Change Detection and Indices (ETCCDI) organized a regional climate change workshop in Brazzaville, Congo, 23–27 April 2007. This workshop follows the successful format that evolved through 12 prior regional climate change workshops and is described by *Peterson and Manton* [2008]. Supported by the UK Met Office through WMO Voluntary Contribution Program funds and coordinated by WMO's World Climate Data and Monitoring Programme, the workshop immediately followed a Climate Data Management system training program, thereby providing an end to end approach to managing and using climate data. Representatives from nine countries participated, including six from western central Africa (Cameroon, Central African Republic, Democratic Republic of Congo, Gabon, Sao Tome and Principe, Republic of Congo) plus Angola, Guinea Conakry, and Zimbabwe.

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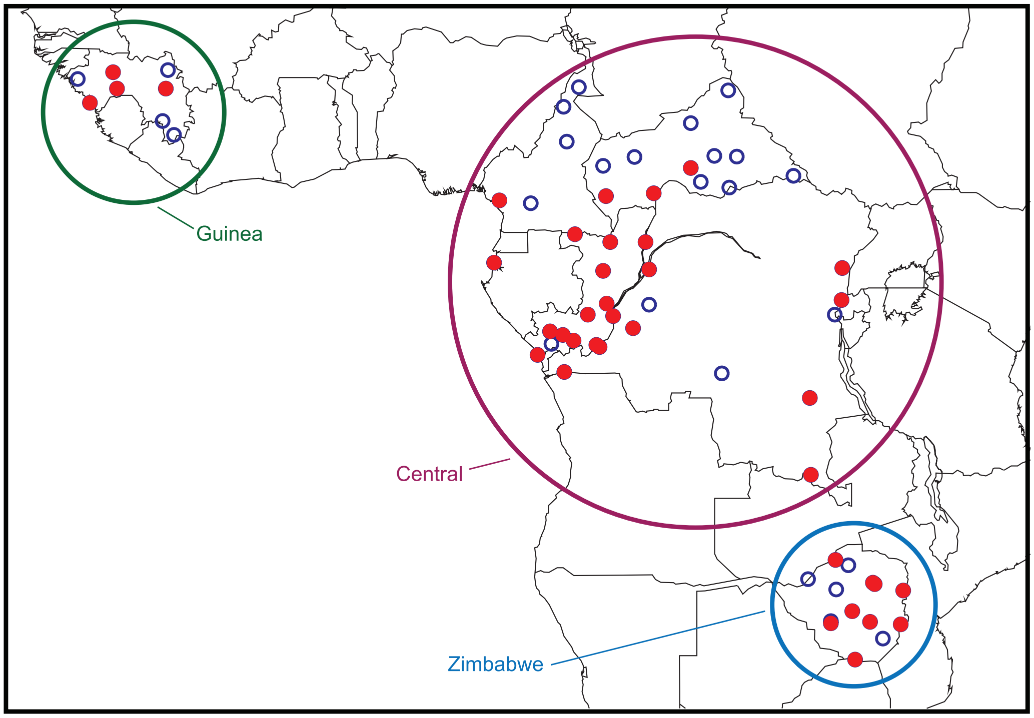

Figure 1. Location of the stations brought to the Brazzaville workshop. Stations with inadequate fidelity or length of period of record for use in this analysis are shown as open blue circles. Stations shown by solid red circles were used to produce three regional analyses: (1) Guinea includes stations from Guinea Conakry, (2) Central covers western central Africa and includes stations from Cameroon, Central African Republic, Democratic Republic of Congo, Gabon and Republic of Congo, and (3) Zimbabwe.

[5] The participants brought daily station time series of maximum and minimum temperature and precipitation to the workshop (see Figure 1 and Table 1 station locations) and were given hands-on data training, starting with quality control. Once the data passed the QC checks, they were evaluated for homogeneity. Finally workshop participants ran software which calculated a suite of indices to reveal how extremes are changing. For many of the participants, this was their first hands-on data analysis of climate change in their countries. As the exact calculation of the set of indices is coordinated by the ETCCDI, the results of this workshop are comparable with earlier analyses and workshops in other regions.

3. Data and Data Fidelity

[6] The question of which comes first, the digital daily data or the climate change analysis, is not a simple question to answer. The workshop participants brought digital data with them, but often the data were for very short periods of record. It can be difficult to justify the expense of digitizing data unless one sees a clear benefit. The preliminary analyses at the workshop revealed the value of long-term daily data. As a result many of the countries undertook digitization efforts following the workshop with marked success, particularly Cameroon, Central African Republic and Democratic Republic of Congo. For example, Cameroon's digital daily data available for the workshop was from 1966 through 2005 and only ~80% complete. Three months after the workshop the data were ~95% complete and covered the period 1951 through April 2007. Another good example (see Figure 2) is the increased data availability in Berberati, (Central African Republic) after the workshop.

3.1. Data Description

[7] Daily data from 66 stations were provided by each of the nine countries participating in the workshop. Long-term internationally exchanged data for this region are quite limited. However, where possible some series have been augmented with data from the Global Summary of the Day (GSOD) data set available from NOAA's National Climatic Data Center (ftp://ftp.ncdc.noaa.gov/pub/data/gsod). These data are mainly derived from synoptic observations transmitted over the Global Telecommunications System.

3.2. Data Fidelity

[8] Participants made great strides toward quality control (QC) and homogeneity assessment of the station data during the workshop. But because of the time limitations, careful post workshop analysis is still required to assure that no serious problems remain in the time series. For quality control, the statistical and visual procedures contained in the RClimDex package (available at the ETCCDI web site, http://cccma.seos.uvic.ca/ETCCDI/software.shtml) have been used and complemented with other tests. The applied tests follow the guidelines given by *Brunet et al.* [2008] and are focused on the detection of nonsystematic errors usually caused by data processing, most frequently during digitization. Impossible values (like negative precipitation or maximum temperature lower than minimum temperature) are

Table 1. Stations List[a]

WMO	Country	Station Name	Longitude	Elevation	Period Temperature	Period Precipitation	GSOD
618090	**GUI**	**Labe**	**−12.300**	**1026.0**	**1939–1995**	**1923–1995**	**X**
618110	**GUI**	Siguiri	−9.167	366.0	1944–1996	1931–1996	X
618160	**GUI**	Boke	−14.317	69.0	1932–1996	1931–1996	X
618200	**GUI**	**Mamou**	**−12.083**	**784.0**	**1933–1996**	**1931–1996**	**X**
618290	**GUI**	**Kankan**	**−9.300**	**384.0**	**1945–1995**	**1923–1995**	**X**
618320	**GUI**	**Conakry/Gbessia**	**−13.617**	**26.0**	**1903–2006**	**1940–2006**	**X**
618470	**GUI**	Macenta	−9.467	544.0	1941–1996	1932–1996	X
618490	**GUI**	Nzerekore	−8.833	470.0	1957–1995	1923–1995	X
N/A	ST&P	Aeroporto	N/A	N/A	1970–1979	1970–1978	-
N/A	ST&P	Angolares	N/A	N/A	1971–1988	1971–1988	-
640050	**DRC**	**Mbandaka**	**18.267**	**317.0**	**1971–2000**	**1971–1989**	**-**
640720	**DRC**	**Butembo**	**29.267**	**1840.0**	**1961–1993**	**1961–1992**	**-**
641080	**DRC**	**Bandundu**	**17.350**	**324.0**	**1971–2000**	**1971–2000**	**-**
641150	DRC	Inongo	18.267	300.0	1961–1990	1961–1989	-
641800	DRC	Bukavu	28.850	1612.0	1962–1998	1962–1982	-
641840	**DRC**	**Goma**	**29.233**	**1552.0**	**1961–2006**	**1961–2005**	**-**
642070	**DRC**	**Matadi**	**13.433**	**340.0**	**1971–2006**	**1971–2003**	**X**
642100	**DRC**	**Kinshasa/Ndjili**	**15.433**	**312.0**	**1971–2006**	**1971–2006**	**X**
642820	**DRC**	**Manono**	**27.433**	**633.0**	**1961–1998**	**1963–1992**	**X**
643600	**DRC**	**Lubumbashi-Luano**	**27.483**	**1298.0**	**1971–2006**	**1975–2005**	**X**
644000	**RC**	**Pointe-Noire**	**11.900**	**17.0**	**1934–2007**	**1932–2006**	**X**
644010	RC	Dolisie	12.700	331.0	-	1947–2004	
644020	**RC**	**Mouyondzi**	**13.950**	**512.0**	**1949–1997**	**1949–1996**	**X**
644030	**RC**	**Makabana**	**12.617**	**161.0**	**1964–1995**	**1964–1998**	**X**
644050	**RC**	**Sibiti**	**13.350**	**530.0**	**1950–1997**	**1950–1994**	
644500	**RC**	**Brazzaville/Maya**	**15.250**	**316.0**	**1932–2007**	**1932–2006**	**X**
644520	**RC**	**Mpouya**	**16.216**	**313.0**	**1941–1996**	**1940–1996**	**X**
644540	**RC**	**Gamboma**	**15.850**	**377.0**	**1950–1998**	**1949–1998**	**X**
644560	**RC**	**Makoua**	**15.650**	**380.0**	**1956–1996**	**1957–1996**	**X**
644580	**RC**	**Ouesso**	**16.050**	**352.0**	**1933–2000**	**1933–2000**	**X**
644590	**RC**	**Impfondo**	**18.067**	**327.0**	**1932–2000**	**1932–2000**	**X**
644600	**RC**	**Souanke**	**14.033**	**550.0**	**1951–2000**	**-**	**X**
645000	**GAB**	**Libreville**	**9.417**	**15.0**	**-**	**1961–2001**	**-**
646000	**CAR**	**Berberati**	**15.800**	**583.0**	**1950–2005**	**1950–2005**	**X**
646010	CAR	Bouar	15.633	1020.0	1951–1980	1951–1980	X
646100	CAR	Bossangoa	17.433	465.0	1955–1980	1955–1980	X
646500	**CAR**	**Bangui**	**18.517**	**366.0**	**1950–2007**	**1950–2006**	**X**
646540	CAR	Ndele	20.650	511.0	1950–1980	1950–1980	X
646550	CAR	Bria	21.983	584.0	1951–1980	1951–1980	X
646560	CAR	Bangassou	22.833	500.0	1950–1980	1950–1980	X
646580	CAR	Birao	22.783	464.0	1951–1980	1951–1980	X
646590	CAR	Obo	26.500	651.0	1955–1980	1955–1980	X
646600	**CAR**	**Bambari**	**20.650**	**475.0**	**1953–2006**	**1953–2006**	**X**
646610	CAR	Yalinga	23.267	602.0	1954–1980	1953–1980	X
646620	CAR	Alindao	21.200	449.0	1958–1980	1958–1980	X
648510	CAM	Maroua-Salak	14.250	422.0	1969–1994	1969–2000	X
648600	CAM	Garoua	13.383	244.0	1966–2006	1966–2006	X
648700	CAM	Ngaoundere	13.567	1104.0	1977–2002	1977–2001	X
649100	**CAM**	**Douala Obs.**	**9.733**	**9.0**	**1951–2006**	**1951–2006**	**X**
649500	CAM	Yaounde	11.517	760.0	1973–2006	1973–2002	X
677550	ZIM	Binga	27.333	617.0	1991–2000	1991–2000	X
677610	**ZIM**	**Kariba**	**28.883**	**518.0**	**1966–2006**	**1966–2006**	**X**
677650	ZIM	Karoi	29.617	1344.0	1978–2005	1978–2002	X
677740	**ZIM**	**Harare (Belvedere)**	**31.017**	**1472.0**	**1952–2003**	**1952–2002**	**X**
677750	**ZIM**	**Harare (Kutsaga)**	**31.133**	**1480.0**	**1978–2005**	**1978–2006**	**X**
678610	ZIM	Gokwe	28.933	1282.0	1964–2003	1964–2003	X
678670	**ZIM**	**Gweru**	**29.850**	**1429.0**	**1952–2006**	**1952–2006**	**X**
678890	**ZIM**	**Wyanga**	**32.750**	**1880.0**	**1952–2002**	**1952–2002**	**X**
679640	**ZIM**	**Bulawayo Goetz**	**28.617**	**1344.0**	**1952–2003**	**1952–2003**	**X**
679650	ZIM	Bulawayo Airport	28.617	1326.0	1978–2006	1978–2006	X
679750	**ZIM**	**Masvingo**	**30.867**	**1095.0**	**1952–2006**	**1952–2006**	**X**
679830	**ZIM**	**Chipinge**	**32.616**	**1132.0**	**1952–2003**	**1952–2003**	**X**
679910	**ZIM**	**Beitbridge**	**30.000**	**457.0**	**1952–2006**	**1952–2006**	**X**

[a]Stations used in the final analysis are in bold. The listed years represent the first and last year for which at least 300 daily values are available. GSOD column indicates station with data supplemented from the Global Summary of the Day data. Country Acronyms: GUI, Guinea Conakry; ST&P, Sao Tomé and Principe; DRC, Democratic Republic of Congo; RC, Republic of Congo; GAB, Gabon; CAR, Central African Republic; CAM, Cameroon; ZIM, Zimbabwe.

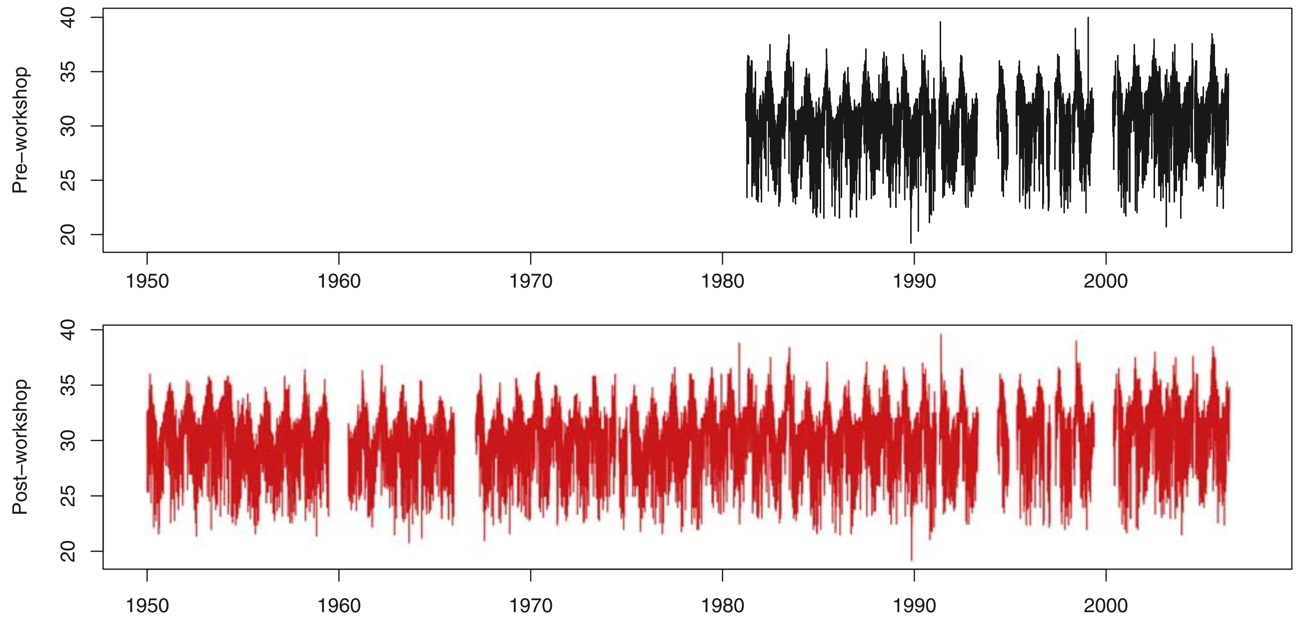

Figure 2. Daily maximum temperature time series of station number 646000, Berberati, from the Central African Republic, (top) at the Brazzaville workshop April 2007 and (bottom) after postworkshop digitalization efforts by the Central African Republic's Aviation Civile et de la Météorologie.

identified. Also, the distribution of the precipitation data is visually inspected, as are plots of the temperature and precipitation time series in order to detect outlying values. In the case of temperature, statistical outliers, identified as daily values outside a threshold of the mean value for that particular day plus/minus four standard deviations, were also flagged. The suspicious data were validated, set to missing or corrected with the help of local climate knowledge and on the basis of subjective inspection of partial time series for the adjacent days at the same and other years and by spatial comparison with close neighboring stations if available. For example, a temperature record for Garoua (Cameroon) showed values of 20.4°C for maximum temperature and 30.4°C for minimum temperature. The record was corrected by switching the two values.

[9] Once quality control has removed the unreasonable data points, the time series are subjected to homogeneity tests to determine if there were artificial changes at the station (such as station moves) that significantly impacted the observations. The approach used the RHTest software, developed at the Climate Research Branch of Meteorological Service of Canada, and also available from the ETCCDI web site. This program is capable of identifying multiple step changes at documented (by station history information) or undocumented change points in a time series. It is based on a two-phase regression model with a linear trend for the entire series [*Wang*, 2003, 2008a, 2008b]. Although the low density of the network prevents us from using reference series, inhomogeneous sections have been clearly identified. The example of Ouesso (Republic of Congo) is shown in Figure 3. Inhomogeneous segments of time series are removed from the analysis.

[10] To be included in the analysis, time series need to have a homogeneous period of at least 30 years, ending no earlier than 1995 and contain fewer than 20% of missing/rejected values. The reference period of 1971–1995 was chosen to maximize the number of stations with data available for calculation of the percentile-based indices (see section 4.1 for indices description). Even with this maximization, only 38 of the 66 original stations had long

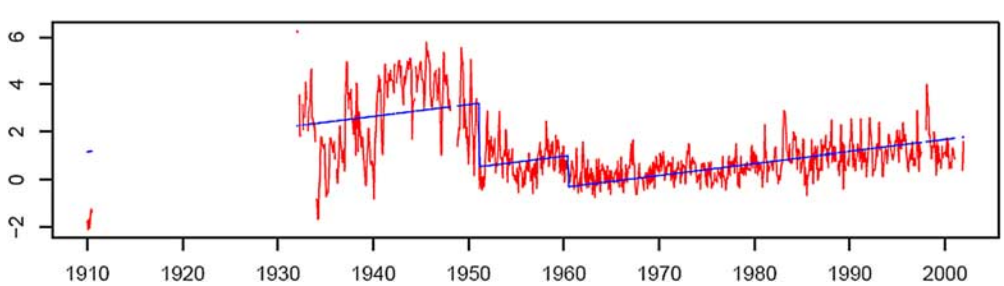

Figure 3. Example of inhomogeneous data. Daily maximum anomalies series for station number 644580, Ouesso, in the Republic of Congo. The homogeneity testing software detected two large inhomogeneities in 1950 and 1960. To avoid having these inhomogeneities artificially bias the results, data prior 1960 were removed from the analysis, including a few isolated observations in 1910. The rest of the series is comparatively homogeneous.

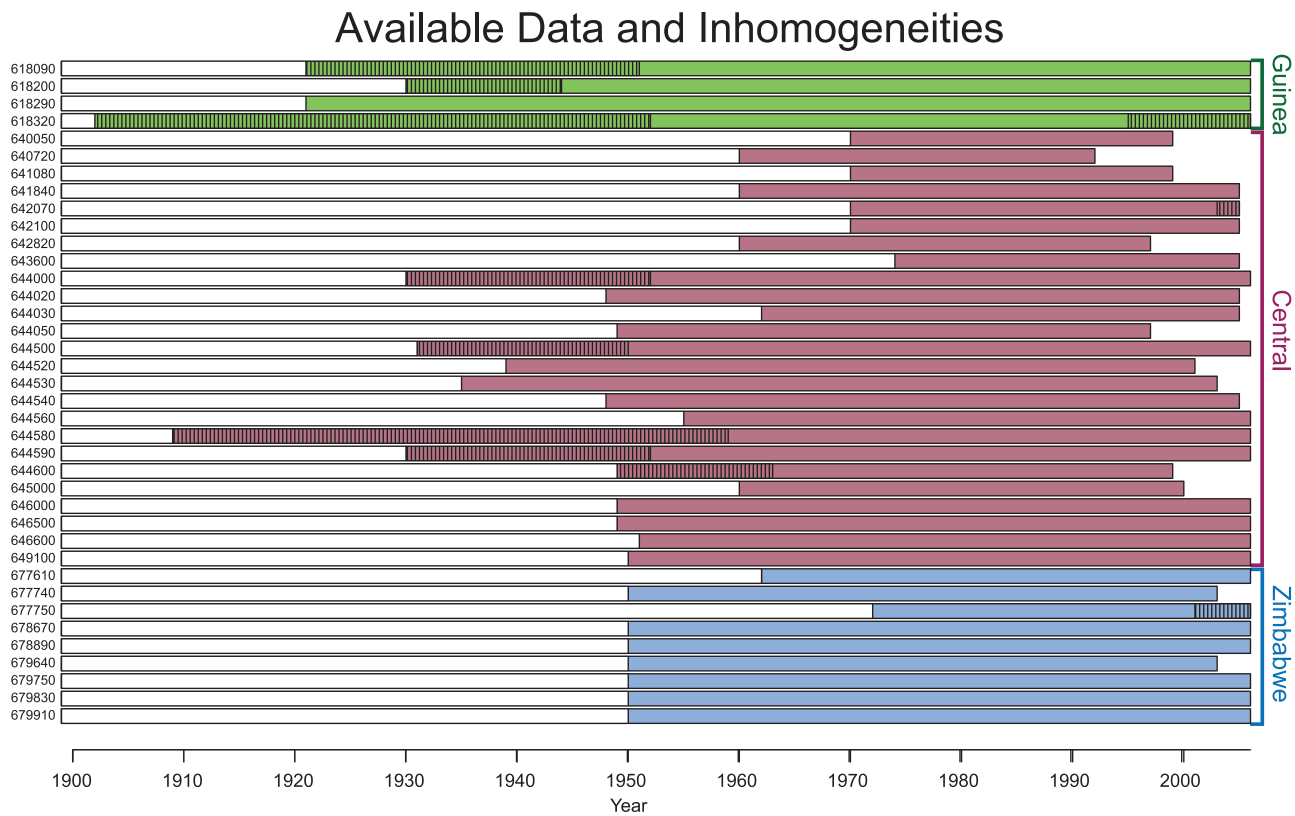

Figure 4. Available data for the time series used in the analysis. White indicates no data; hatched indicates inhomogeneous sections detected in the temperature series and removed from the analysis; and solid colors represent data included in each of the three analysis. Station numbers, station names, latitudes, longitudes, and elevations are listed on the Expert Team's web site http://cccma.seos.uvic.ca/ETCCDI.

enough homogeneous periods to be included in the analysis, and not all the indices were calculated for all the stations. Figure 1 shows their locations and Figure 4 shows the homogeneous period for these stations. Of the nine countries that participated in the workshop, no homogeneous daily data time series were available from only two countries, Sao Tome and Principe, and Angola A third country, Gabon, only provided precipitation data. As many of the stations had homogeneity problems in data prior to 1955, the analysis is limited to the period 1955 to 2006.

4. Methods

4.1. Indices

[11] A set of 27 indices formulated and coordinated by the ETCCDI were calculated using software available on the Expert Team's web site. The indices are primarily based on station level thresholds calculated over a base period, such as the 90th percentile of minimum temperature. These thresholds are determined for each day of the year using data from that day and two days on either side of it over the course of the base period. For detailed descriptions of the indices and the exact formulae for calculating them, please see the ETCCDI web page.

[12] For percentile-based indices (e.g., the number of days exceeding the 90th percentile of minimum temperature) the methodology uses bootstrapping for calculating the baseline period values, in order to avoid discontinuities in the indices time series at the beginning or end of the base period, following the approach by *Zhang et al.* [2005a]. The 26 years of the 1971–1995 base period is long enough to produce indices nearly as robust as 30-year base periods. This unique base period will make it more difficult to compare the actual values of the indices time series with those from other regions, however, the trends remain basically the same when compared to those produced using 1971–2000 or 1961–1990 as base period. All the indices have been calculated as annual values and a subset of them were also calculated as quarterly values for standard 3-month seasons (i.e., DJF, MAM, JJA, SON). Although standard seasons loose much of their meaning in this region, trends for these subannual values are also studied for comparison with other works.

4.2. Area Averaging and Trend Calculation

[13] Three different regions were analyzed: western central Africa (Cameroon, Central African Republic, Democratic Republic of Congo, Gabon and Republic of Congo), from now on referred to as "Central," Guinea Conakry (Guinea), and Zimbabwe as shown in Figure 1. Regional averages of the indices were calculated starting with the arithmetical mean of all the available station indices in the area. As the number of stations with indices varies over time, particularly for the Central region, the average time

Table 2. Regional Trends in Temperature Indices[a]

Index	Guinea	Central	Zimbabwe	Global	Units
Warmest day	**0.14**	**0.25**	0.15	**0.21**	°C/decade
Warmest night	**0.17**	**0.21**	0.10	**0.30**	°C/decade
Coldest day	**0.23**	**0.13**	0.00	0.37	°C/decade
Coldest night	0.04	**0.23**	0.02	**0.71**	°C/decade
Diurnal temperature range	0.12	0.00	**0.11**	**−0.08**	°C/decade
Cold night frequency	−0.21	**−1.71**	**−1.24**	**−1.26**	percent of days in a year per decade
Cold days frequency	**−2.15**	**−1.22**	**−1.05**	**−0.62**	percent of days in a year per decade
Warm night frequency	**1.19**	**3.24**	0.71	**1.58**	percent of days in a year per decade
Warm day frequency	**1.56**	**2.87**	**1.86**	**0.89**	percent of days in a year per decade

[a]The trends for the globe are from *Alexander et al.* [2006] and are based on the time period 1955 to 2003. A trend significant at the 5% level is marked with bold font.

series have been adjusted to reduce changes in variance introduced by the changing number of data points available for each year using the approach by *Osborn et al.* [1997]. This approach was originally applied to proxy data, but has also been employed in many works dealing with observational data [e.g., *Brunet et al.*, 2007]. Furthermore, regional averages have not been computed for those years with fewer than three time series available which creates a few gaps in the regionally averaged time series.

[14] As all the indices are essentially anomalies from the same base period, they are easily averaged together. However, some precipitation indices could potentially be dominated by those stations with the greatest precipitation, as those stations may see precipitation vary from year to year by more than the total annual precipitation at stations with the least total precipitation. To determine whether this was the case in these three regions, precipitation indices averages were also calculated by first standardizing the indices (dividing by the index's standard deviation). As a comparison of both approaches revealed similar shape and trends, the standardized indices are not used and the results are provided through the analysis of the simple anomaly series.

[15] Trends for regional and individual stations are calculated by adapting *Sen's* [1968] slope estimator. This method, also applied in other similar works describing extreme indices [*Aguilar et al.*, 2005; *Zhang et al.*, 2005b] was adapted to climatological data by *Zhang et al.* [2000] in a study of annual temperatures over Canada and by *Wang and Swail* [2001] in their analysis of extreme wave heights over the Northern Hemisphere. Trend significance is evaluated at the 0.05 level. To avoid biased estimates, station level trends were not calculated for series with excessive missing values.

5. Results

[16] In order to put this region's results into a global perspective, global results for a similar period (1955 to 2003), using the same trend calculation method, based on the work of *Alexander et al.* [2006] are also included.

5.1. Temperature Indices

[17] Trends for the temperature indices are shown in Table 2. With warm extremes increasing and cold extremes decreasing, these series clearly indicate significant warming. There are two types of indices in Table 2. The first is actual changes in the temperature of the coldest and warmest day and night of the year (the highest and lowest maximum temperature and minimum temperature of the year). The warmest day and night of the year is warming at a rate approximately comparable to the global average. The coldest day and night of the year is warming slower than the global average, although planetary trend for the coldest day is nonsignificant. Spatial coherence of these trends is high as can be seen in Figure 5 which shows the regional series and station trends for the warmest day of the year. The diurnal temperature range which is decreasing globally is slightly increasing at similar rates for Guinea and Zimbabwe but showing little change in the Central region.

[18] The second type of index involves the number of days that are above or below the 90th or 10th percentile. This is essentially a normalized metric that can be compared across regions and not be impacted by the variability or range of observations. For these percentage metrics, the Central region is warming faster than the global average. The low variability of tropical temperatures may imply that daily temperatures are more likely to exceed their percentile threshold.

[19] For the majority of the temperature indices, the Central region exhibits the greatest warming. Trends in quarterly percentile indices time series extracted from standard seasons (not shown) highlight some differences across the year. Central has significant trends in the four indices in all four seasons, with larger slopes on average during June–July–August (JJA). For Guinea, trends are larger between June and November for daytime metrics and larger during March–April–May (MAM) for nighttime values. No significant trends are found during December–January–February (DJF).

5.2. Precipitation Indices

[20] The trends calculated for precipitation indices are shown in Table 3. First and foremost, Guinea and Central show significant decreases in total precipitation, meanwhile the global average increases. For Guinea there is a sharp drop in the total annual precipitation time series around 1970. Likely associated with the decrease in total precipitation the length of the maximum number of consecutive dry days is increasing in Guinea and the length of the maximum number of consecutive wet days shows a significant decrease in Central. Additionally, part of the consecutive dry day trend in Guinea, is derived from very low values before 1960. The Simple Daily Intensity Index which measures how the average amount of rainfall per day that it rains shows no significant changes.

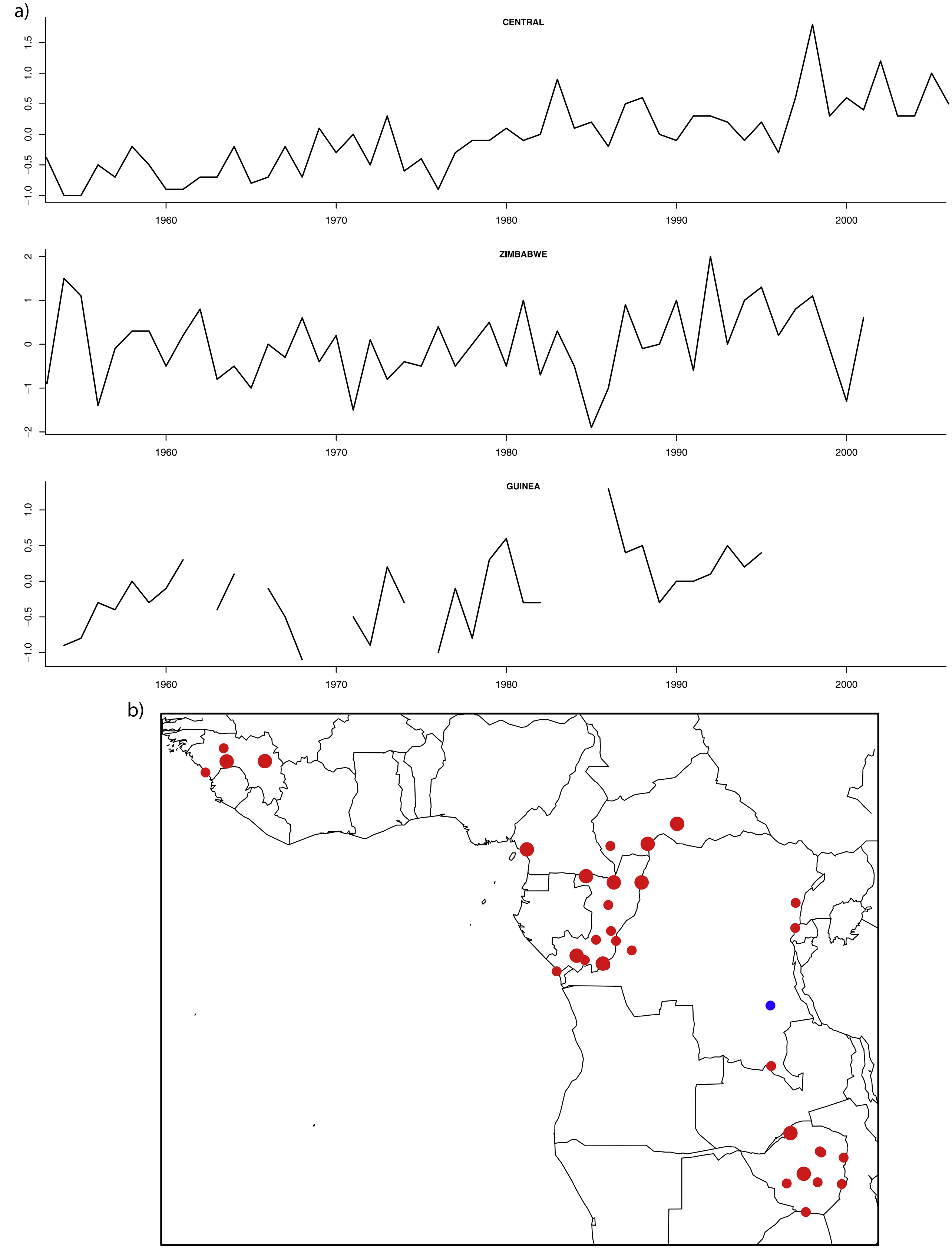

Figure 5. Warmest day of the year. Regional time series and individual stations trends. (a) Regionally averaged time series of anomalies to 1971–1995 reference period for Central region, Zimbabwe, and Guinea. (b) Individual station trends. Positive (negative) trends are shown in red (blue) circles. Large (small) circles indicate significant (nonsignificant) trends.

Table 3. Regional and Global Trends in Precipitation Indices[a]

Index	Guinea	Central	Zimbabwe	Global	Units
Total precipitation amount	**−83.75**	**−31.13**	8.33	**10.59**	mm/decade
Simple daily intensity index	−0.10	0.06	0.16	0.05	mm/day/decade
Consecutive dry days	6.56	−0.06	2.92	−0.55	days/decade
Consecutive wet days	−0.80	**−0.35**	0.11	−0.02	days/decade
Number of heavy precipitation days	−1.89	**−0.67**	0.15	**0.29**	days/decade
Number of very heavy precipitation days	−0.83	−0.17	0.16	**0.17**	days/decade
Very wet day precipitation	**−45.52**	−12.19	8.26	**4.07**	mm/decade
Extremely wet day precipitation	−21.15	−3.66	3.44	**2.52**	mm/decade
Maximum 1-day precipitation	−3.31	−0.87	1.35	**0.85**	mm/decade
Maximum 5-day precipitation	**−8.82**	−1.54	2.04	0.55	mm/decade

[a]The global trends are from *Alexander et al.* [2006] and are based on the time period 1955 to 2003. A trend significant at the 5% level is marked in bold.

[21] The measures of heavy precipitation are decreasing in Guinea and Central. This includes both percentile measures (i.e., rainfall above the 95th (very wet) and 99th (extremely wet) percentiles), as well as the maximum one and five day precipitation amount recorded in a year. However, spatial coherence for precipitation is lower than for temperature indices (e.g., Figure 6). For the majority of the world, the amount of rain falling in the heaviest events is increasing. Zimbabwe, however, has no significant trends in any of the precipitation indices over the period 1955–2003.

6. Discussion

[22] In most of the world, cold extremes are warming faster than warm extremes. This makes physical sense in that the amount of water vapor in the air in winter is frequently less than in summer so the fractional change in greenhouse gas radiative forcing is greatest in winter. Also, winter weather is often more variable than summer. However, in equatorial Africa, the demarcation between cold season and warm season is not as great as the extratropics. *Nicholson* [2001] highlights the small annual temperature range in extra-Saharan Africa and suggests that a true cold season only exists on the poleward extremes of the continent. So a more uniform warming in cold and warm extremes in this region makes physical sense.

[23] Comparison to an analysis of monthly mean temperature for the Democratic Republic of Congo (not shown), which was more complete than the daily time series, complemented and confirmed the warming. The identified warming matches well with the results by *New et al.* [2006], in their study for Southern Africa, including Zimbabwe. Although the comparison is not straightforward, as the regions studied are largely different, it concurs with us in significant increasing (decreasing) trends for warm (cold) days and nights, and absolute daytime and nighttime maximum and minimum temperatures. DTR in work by New et al. shows a mixed pattern of increases and decreases, leading to a nonsignificant reduction. In agreement with our study, stations in Zimbabwe show small increases.

[24] In relation to rainfall, we find a clear reduction in the total precipitation amount in Guinea and to a lesser extent in Central, meanwhile nonsignificant increases are found in Zimbabwe (largely forced by the last years in the time series). This is in agreement with *Nicholson* [2000, 2001], who highlights in her study of monthly African precipitation data, a shift from relatively wet conditions from the 1920s to the early 1950s to dry conditions from the 1970s onward, especially in the Gulf of Guinea. Nicholson quantifies the reduction of precipitation in this area, compared to 1931–1960, as 6% for 1970–1979 and about 7% between 1980 and 1989. The northernmost part of Southern Africa, including Zimbabwe, presented an increase in the 1970s of 6% followed by a reduction of 5% in the eighties. These patterns are in agreement with our data. No estimates are provided for western central Africa, so our results indicating slight reductions represent an important contribution.

[25] Moreover, we can conclude that extreme precipitation is not significantly increasing in any of the studied regions. On the contrary, indications about the reduction of precipitation intensity are found for, especially, western central Africa and Guinea Conakry. This is in contrast with above mentioned work by *New et al.* [2006] for neighboring regions, which spatially extends the reduction in total precipitation, but describes a situation more prone to increases in extreme rainfall, and especially on the simple daily intensity of precipitation.

[26] In relation to our findings regarding precipitation, some model projections studying the evolution of the Congo River discharge forecast for the end of this century report slight increases [*Manabe et al.*, 2004; *Nohara et al.*, 2006]. *Nohara et al.* [2006] find, after a multimodel experiment, an increase in the Congo's river discharge of about 4.4% (from 1979 to 2003 average), very similar to other equatorial large rivers (Amazon, +5.4%) but much lower than the other African river studied, the Nile (+12.7%). Actually, the divide between the Congo and the Nile basins seems to mark, according to *Nohara et al.* [2006], the transition from modest to largest increases in precipitation for the end of the century.

7. Conclusions

[27] We have examined, for the first time, a set of temperature and precipitation extreme indices for western central Africa, Guinea Conakry and Zimbabwe derived from daily maximum and daily minimum temperature and daily precipitation amounts.

[28] For most of the region, this is the first time that such a data set has been compiled and analyzed. The data set has been carefully quality controlled and passed an intensive homogeneity assessment. Although the data are incomplete both in time and space, a clear picture of climate change in the region has emerged: The region is clearly warming, with cold extremes decreasing and warm extremes increasing. Total precipitation is decreasing in western central Africa

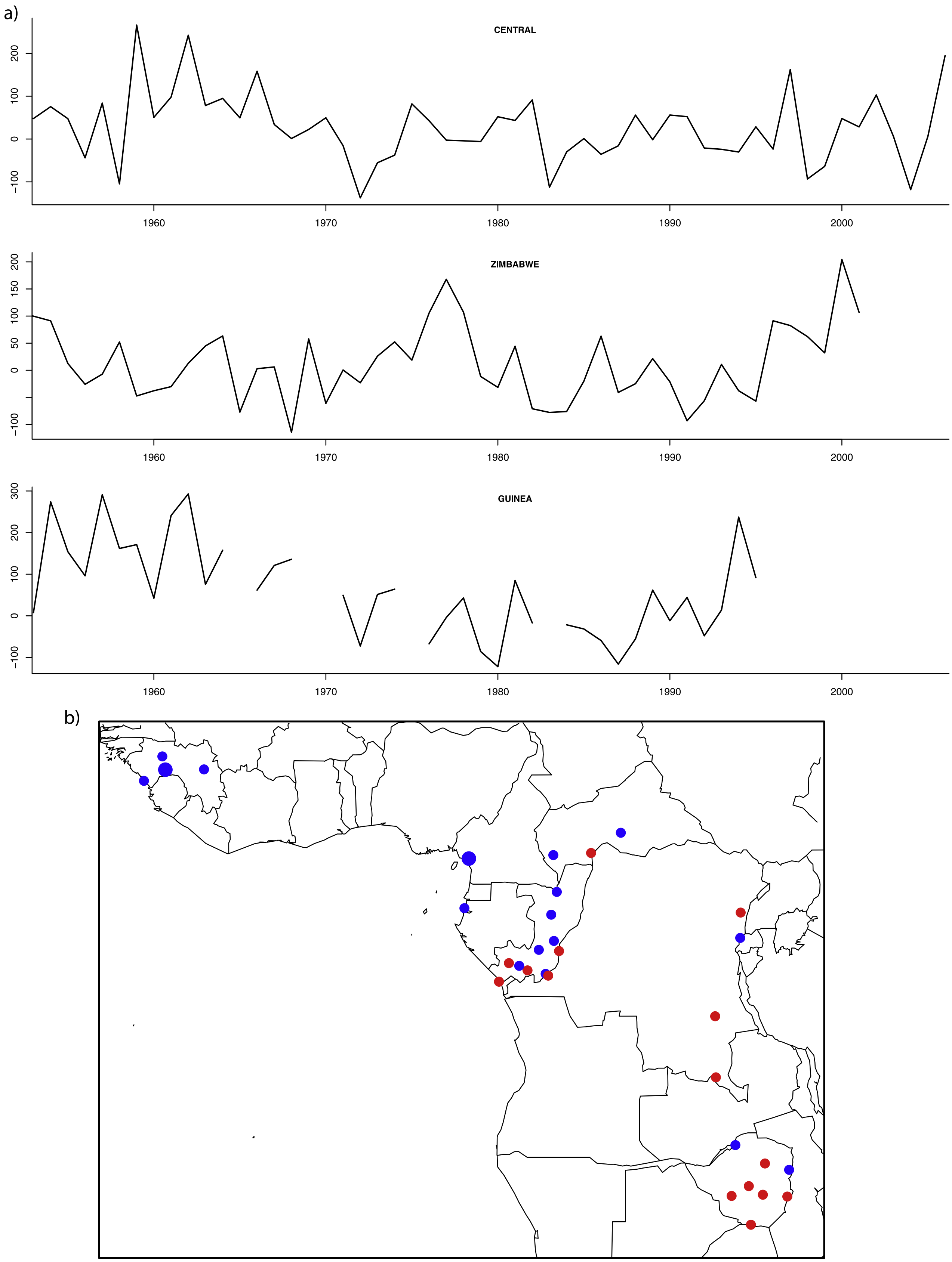

Figure 6. Very wet days. Regional time series and individual stations trends. (a) Regionally averaged time series of anomalies to 1971–1995 reference period for Central region, Zimbabwe, and Guinea. (b) Individual station trends. Positive (negative) trends are shown in red (blue) circles. Large (small) circles indicate significant (nonsignificant) trends.

and Guinea Conakry, as is the amount of precipitation from heavy events. Zimbabwe, however, has no significant trends in precipitation over the period 1955–2003.

[29] This analysis highlights the benefits that can be obtained through international cooperation and hands-on data regional climate change workshops. The participating countries belong to three different World Meteorological Organization (WMO) subregions: central Africa, West Africa and Southern Africa. WMO helps these countries, in particular the least developed ones, to acquire the capacity of implementing this plans. The WMO World Climate Data and Monitoring Program is the WMO technical arm in coordinating and facilitating the implementation of climate data component in collaboration with regional climate institutions such as the African Centre of meteorological applications for development (ACMAD, Niamey Niger) as well as with other subregional bodies and NMHSs. This workshop achieved, besides the knowledge development in a climatologically important and understudied region of the world, an important positive side effect, which is the collective involvement of experts from NMHSs from these regions who were able to demonstrate the importance of climate data in addressing climate change issues.

[30] Workshop attendees have generously made all the indices calculated for these station time series available for the international research community at the ETCCDI's Web site (http://cccma.seos.uvic.ca/ETCCDI). In a region with limited international exchange of data, this is a significant advance and opens up possibilities for many additional lines of research related to these measures of observed climate change, such a links between climate and variability in agricultural production or ecosystem responses.

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