Evidence of trends in daily climate extremes over Southern and West Africa

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Abstract

There has been a paucity of information on trends in daily climate and climate extremes, especially from developing countries. We report the results of the analysis of daily temperature (maximum and minimum) and precipitation data from fourteen south and west African countries over the period 1961-2000. Data were subject quality control and processing into climate indices for release to the global community. Temperature extremes show patterns consistent with warming over most of the region, with regionally-averaged trends in extreme cold (5th percentile) nights and days of -7 and -4 days per decade, respectively; extreme hot (95th percentile) nights and days increased by 8 and 8.5 days per decade. Diurnal temperature range and most precipitation indices do not exhibit a consistent trend across the region. Total precipitation on rainfall days shows a decrease, but is not statistically significant. Dry spell shows a statistically significant increase of 2.8 days per decade.

Introduction

Since the second IPCC[1] report highlighted the paucity of information on trends and variability in daily climate and climate extremes [*Nicholls et al.*, 1996], a number of studies documenting such changes have emerged, both for specific countries [e.g., *Frei and Schar*, 2001; *Haylock and Nicholls*, 2001; *Karl and Knight*, 1998; *Osborn et al.*, 2000] and synthesising information across regions and globally [*Frich et al.*, 2002; *Groisman et al.*, 1999; *Karl et al.*, 1995; *Kiktev et al.*, 2003; *Klein Tank and Konnen*, 2003]. These studies tended to concentrate on regions where the daily meteorological observations required for such analyses were already quality controlled and archived. An early initiative to fill the remaining gaps was the 1998 workshop on climate indices funded through the Asia-Pacific Network (APN) for Global Change Research [*Manton et al.*, 2001]. Building on this, the WMO/CLIVAR[2] Expert Team on Climate Change Detection, Monitoring and Indices (ETCCDMI[3]) was charged with coordinating a series of regional workshops, where local scientists were supported in the quality control and analysis of daily temperature and precipitation data. By early 2005 workshops had been held in the Caribbean [*Peterson et al.*, 2002], North Africa [*Easterling et al.*, 2003], South America [*Haylock et al.*, 2005; *Vincent et al.*, 2005], South West Asia, South Asia [*Peterson*, 2005], and Southern Africa (this paper).

There are numerous regional and national studies of recent trends and variability in monthly climate over Africa [e.g., *Fauchereau et al.*, 2003; *Hulme et al.*, 2001; *Kruger and Shongwe*, 2004; *Mahe et al.*, 2001; *Malhi and Wright*, 2004; *Misra*, 2003; *Moron*, 1997; *Schreck and Semazzi*, 2004; *Unganai and Mason*, 2001]. However, there has been little work on precipitation or temperature related extremes in Africa, primarily because of the lack of easily available daily data for the region. Mason et al [1999] studied trends in extreme precipitation over South African at stations that had not undergone location changes (but without testing for other inhomogeneities), identifying significant increases in the intensity of extreme rainfall events between 1931-1960 and 1961-1990 over 70% of the country. Frich et al's [2002] global analysis includes precipitation data from South

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[1] Intergovernmental Panel on Climate Change - http://www.ipcc.ch
[2] http://www.wmo.ch; http://www.clivar.org
[3] http://www.clivar.org/organization/etccd

Africa, Zimbabwe, Zambia and Mozambique, and shows more variable patters over this wider domain; the most consistent pattern is an increase in maximum five-day rainfall over the second half of the twentieth century.

This paper builds on these earlier findings for southern and west Africa, by examining trends in indices of daily climate for these regions; the results arise from the WMO/CLIVAR and START co-sponsored Southern Africa climate extremes workshop, held in Cape Town, in June 2004. The workshop was attended by representatives from nine southern African and two west African nations, and provided the opportunity to quality control and analyse daily temperature and precipitation data from across the region. The results provide the first regional synthesis of trends in daily climate and extremes for southern Africa, and supplements the data for West Africa contributed at the earlier North African workshop [*Easterling et al.*, 2003].

Data and methods

Participants brought station records of daily precipitation, maximum temperature and minimum temperature for recent decades (Table 1). Representatives from two countries (Namibia and Mozambique) had to withdraw from the workshop at the last minute, but we have included data for these countries in this analysis: station data for Mozambique were provided after the workshop by the Mozambique Meteorological Service; for

Namibia, we include daily data for four stations archived in the GCOS[1] Global Surface Network [*Peterson et al.*, 1997]. In all, 63 stations are included in the analysis.

Data were analysed using the RClimDex package (software and documentation available for download from http://cccma.seos.uvic.ca/ETCCDMI), which represents an enhancement of the EXCEL-based ClimDex software used in previous workshops [e.g., *Peterson et al.*, 2002]. Participants first used RClimDex for quality control of their data, through (1) automated checking for erroneous data (e.g. negative precipitation, maximum temperature less or equal to minimum temperature); (2) automated searches for outliers, where thresholds/limits are defined by the user in terms of standard deviations from the long-term (typically 1961-1990) daily mean; and (3) through generation of data plots enabling visual inspection of the data. Local meteorological knowledge proved crucial in assessing a number of large precipitation outliers.

After quality control, RClimDex was used to calculate climate indices from the daily data; the indices are then used in subsequent analysis and made available to the global community through ETCCDMI website. Use of indices overcomes the reluctance of many countries to release the original records of daily data: while the climate indices are valuable for climate monitoring, they are of little value for commercial activities such as weather forecasting. RClimDex calculates 10 precipitation and 15 temperature indices (Table 2 and Table 3), at annual and (where appropriate) monthly time steps. The aim of the ETCCDMI process is to collate a standardised set of indices enabling comparison

[1] Global Climate Observing System

across regions, but not all the indices are meaningful in an African context. For example, GSL (growing season length) is a temperature-dependent measure of growing season appropriate for mid to high latitudes, while growing season over much of Africa is defined by precipitation. We therefore only report on indices that are relevant for this region.

We use a non-parametric trend statistic, Kendall's tau for monotonic trends, which makes no assumptions about the distribution of the data or the linearity of any trends [*Hollander and Wolfe*, 1973, p. 115-120]. Kendall's tau also standardises the trend between -1.0 and 1.0, enabling comparison of trends across different parts of the region, where the absolute values of trends can vary. As Kendall's tau does not give an indication of the magnitude of trend, we also calculate the least-squares linear trends, and report the median for each variable; but we note that for some precipitation indices, interpretation is difficult due to large differences in the absolute amounts of precipitation across the region.

Summary of trends

Results for all indices are summarised over all stations in Figure 1. Nearly all of the temperature indices show a large proportion of stations with the same sign of trend. Negative trends exist for frost days (FD0), cold spells (CSDI) and the percentage of days when maximum and minimum temperature is less than the 1961-1990 10th percentile (TX10P and TN10P), indicating that the number of cold days and nights has decreased. Many of the trends at individual stations are statistically significant (at the 10% level). Similarly the temperatures of the coldest night and coldest days in each year (TNn and

TXn) show increasing trends. Approximately 60% (40% statistically significant at the 10% level) of stations show a decrease in diurnal temperature range (DTR).

The remaining temperature indices are related to hot extremes, and in all cases show at least 65% of stations with positive trends, indicating that both maximum temperature and minimum temperature hot extremes are increasing. Between 30-40% of the stations show statistically significant (10% level) increasing trends, compared to 5-10% with statistically significant decreasing trends.

Most precipitation indices exhibit a roughly equal proportion of increasing and decreasing trends for the whole region. In addition, only a few station trends are statistically significant (10% level). There is some evidence for decreasing overall precipitation, average precipitation intensity and increasing dry spell length: more stations show consistent trends in wet-day precipitation (PRCPTOT), heavy precipitation days (R10mm) and consecutive wet days (CWD), but again only a few of the trends are statistically significant. Precipitation intensity (SDII) and dry spell duration (CDD) show increasing (but generally non-significant) trends.

Spatial patterns and regional series

We now describe the spatial patterns of trends, concentrating on a few key indices, but noting where other indices show similar trends. For most of the temperature indices there is a tendency for trends to be strongest in the tropics and weaker in the extratropics; all the percentile trends (TX90P, TN90P, TX10P, TN10P) show this trend (Figure 2). This is at least partly because the interannual variability of temperature is lower in the tropics (this is the case for NCEP/NCAR Reanalysis daily data, and for the station data analysed here), and so emerging trends may be easier to detect. Although trends for hottest/coldest days/nights show a similar pattern (TXx, TNx, TXn, TNn), the strength of the trends are generally lower (Figure 3). Again, this is likely related to interannual variability, as for any station, the most extreme values will be more variable than the 90th and 10th percentiles. In general, the temperature of the hottest days (TXx) show stronger trends than the temperature of the coldest days (TXn); a similar, but less pronounced difference is evident for night temperatures (TNx and TNn), suggesting an overall increase in the variability of daytime and night extremes. Trends in diurnal temperature range (DTR; Figure 4) do not show a consistent pattern across the region, similar to previous analyses of diurnal temperature range [*Easterling et al.*, 1997].

We also calculate regionally-averaged series. Indices at each station were first expressed as anomalies (in standard deviations) relative to the 1961-1990 mean, and then averaged together to obtain a regional series. The series for temperature extremes (insets in Figures 2 & 3) exhibit strong (and statistically significant) trends for all the temperature variables, a reflection of consistent trends at individual stations over the whole region. For DTR, there is no overall trend in the region, but marked decadal variability.

Trends in precipitation indices are generally non significant, either at individual stations, or for the regionally-averaged series (Figure 5). For total precipitation (PRCPTOT), there are only a few statistically significant trends. However, there is a pattern of increasing trends aligned SW-NE through South Africa, Botswana, Zimbabwe and Mozambique, and a pattern of generally decreasing trends further north; similar patterns are evident for other extreme precipitation indices. Consecutive dry days (CDD) is the only precipitation index showing a consistent trend over the region, with nearly all stations showing an increase. While only a few stations show statistically significant trends, the standardised regional series does show a significant increasing trend. It should be noted that CDD represents the increase in the longest dry spell in the year, which corresponds in most instances dry-season length, rather than dry spells in the rainy season, which is probably a more appropriate index.

Conclusions

We have described the results of an analysis of indices of extremes in daily climate data arising from a workshop attended by representatives of southern and west African meteorological agencies. The data, covering at least the period 1961-2000 were quality controlled by workshop participants, and indices calculated using the RClimdex software.

There is a consistent pattern of trends in daily temperature extremes over the study area that is related to increasing temperatures. Extremely cold days and nights have decreased, and hot days and nights have increased. The statistical significance of these trends increases from sub-tropics to tropics, due to the lower variability of the latter.

There are few consistent and statistically significant trends in precipitation indices. Dry spell length shows a general pattern of increasing trends across the region, but few trends at individual stations are statistically significant.

Acknowledgements

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Table 1. Stations included in analysis.

Country	WMO Number	Station Name	Latitude	Longitude	Start	End
Botswana	68244	Gaborone	-24.4	25.55	1961	2000
Botswana	68054	Francistown	-21.1	27.31	1961	2000
Botswana	68148	Mahalapye	-23.07	26.5	1961	2000
Botswana	68226	Tshane	-24.01	21.53	1961	2000
Botswana	68328	Tsabong	-26	22.24	1961	2000
Malawi	67489	Mzuzu	-11.43	34.02	1961	2000
Malawi	67693	Chileka	-15.4	34.58	1938	2000
Seychelles	63980	Mahe-SIA	-4.4	55.3	1972	2003
Tanzania	63894	Dia	-6.8	39.1	1961	2003
Tanzania	63862	Dodoma	-6.17	35.77	1961	2003
Tanzania	63932	Mbeya	-8.93	33.47	1961	1990
Tanzania	63790	Moshi	-3.35	37.33	1961	1990
Tanzania	63856	Mwanza	-2.47	32.92	1961	1990
Tanzania	63971	Mtwara	-10.35	40.18	1961	1990
Tanzania	63832	Tabora	-5.1	32.8	1961	2003
Zambia	67561	Ndola	-13	28.4	1961	2000
Zambia	67743	Livingstone	-17.5	25.5	1961	2000
Zambia	67663	Kabwe	-14.45	28.47	1961	2000
Zambia	67475	Kasama	-10.13	31.1	1961	1999
Zambia	67461	Mansa	-11.1	28.85	1967	1999
Zambia	67551	Solwezi	-12.17	26.36	1961	1998
Zambia	67633	Mongu	-15.5	23.1	1961	2000
Zambia	67665	Lusaka	-15.32	28.45	1961	2000

Zambia	67581	Chipata	-13.55	32.6	1961	2000
Zimbabwe	67991	Beitbridge	-22.28	29.9	1951	2002
Zimbabwe	67774	Hre-Belvedere	-17.9	31.13	1951	2002
Zimbabwe	67983	Chipinge	-20.2	32.62	1951	2002
Zimbabwe	67964	Byo-Goetz	-20.02	28.61	1951	2002
South Africa	-	Addo	-33.97	25.7	1959	2000
South Africa	68816	Cape Town	-33.97	18.6	1956	2000
South Africa	-	Emarald Dale	-29.93	29.95	1960	2000
South Africa	-	Glen College	-28.95	26.33	1959	2000
South Africa	-	Langgewens	-33.28	18.7	1959	2000
South Africa	68842	Port Elizabeth	-33.98	25.62	1958	2000
South Africa	-	Pretoria PUR	-25.73	28.17	1959	2000
South Africa	68424	Upington	-28.42	21.27	1953	2000
Lesotho	68452	Mokhotlong	-29.28	29.07	1960	2001
Lesotho	-	Butha-Buthe	-28.76	28.4	1960	2001
Lesotho	68454	Maseru	-29.3	27.5	1960	2000
Lesotho	-	Teyateyaneng	-29.15	27.73	1960	2001
Lesotho	-	Leribe	-28.88	28.05	1960	2001
Uganda	63654	Masindi	1.68	31.72	1950	2003
Uganda	63682	Jinja Met St.	0.45	33.18	1903	2003
Uganda	63702	Mbarara met	-0.6	30.68	1951	2003
Uganda	63630	Gulu met St	2.78	32.28	1937	2003
Mozambique	67297	Beira	-19.8	34.9	1964	2003
Mozambique	67295	Chimoio	-19.08	33.5	1951	2003
Mozambique	67323	Inhambane	-23.9	35.5	1951	2003
Mozambique	67217	Lichinga	-13.22	35.18	1951	2003
Mozambique	67341	Maputo/Mavalane	-25.58	32.53	1951	2003
Mozambique	67237	Nampula	-15.1	39.3	1956	2003

Mozambique	67215	Pemba	-13	40.5	1951	2004
Nigeria	65208	Ibadan	7.43	3.9	1961	2000
Nigeria	65046	Kano	12.05	8.53	1961	2000
Nigeria	65201	Lagos Ikeja	6.58	3.33	1961	2000
Nigeria	65101	Ilorin	8.48	4.58	1961	2000
Gambia	61701	Yundum	13.35	-16.63	1945	2002
Gambia	61721	Janjanbureh	13.53	-14.77	1948	2002
Namibia	68110	Windhoek	-22.6	17.1	1913	2003
Namibia	68014	Grootfontein	-19.6	18.1	1917	2003
Namibia	68106	Gobabeb	-23.6	15.1	1962	2003
Namibia	68312	Keetmanshoop	-26.5	18.1	1949	2003
Mauritius	61988	Rodrigues	-19.7	63.4	1961	2004

Table 2. Precipitation indices calculate by RClimDex. RR is the daily rainfall rate. A wet day is defined when RR>= 1mm and a dry day when RR<1mm. All indices are calculated annually from January to December.

PRCPTOT	Wet-day precipitation	Annual total precipitation from wet days	mm
SDII	Simple daily intensity index	Average precipitation on wet days	mm/day
CDD	Consecutive dry days	Maximum number of consecutive dry days days	days
CWD	Consecutive wet days	Maximum number of consecutive wet days days	days
R10mm	Heavy precipitation days	Annual count of days when RR>=10mm days	days
R20mm	Very heavy precipitation days	Annual count of days when RR>=20mm days	days
R95p	Very wet day precipitation	Annual total precipitation when RR>95th percentile of 1961-90 mm	mm
R99p	Extremely wet day precipitation	Annual total precipitation when RR>99th percentile of 1961-90 mm	mm
RX1day	Max 1-day precipitation	Annual maximum 1-day precipitation	mm
RX5day	Max 5-day precipitation	Annual maximum consecutive 5-day precipitation	mm

Table 3. Temperature indices calculated by RClimDex. TX is the daily maximum temperature; TN is daily minimum temperature; TG is daily mean temperature.

FD	Frost Days	Annual count when TN(daily minimum)<0ºC	days
SU	Hot Days	Annual count when TX(daily maximum)>25ºC	days
ID	Cold Days	Annual count when TX(daily maximum)<0ºC	days
TR20	Warm Nights	Annual count when TN(daily minimum)>20ºC	days
GSL	Growing Season Length	Annual count between first span of at least 6 days with TG>5ºC after winter and first span after summer of 6 days with TG<5ºC	days
TXx	Hottest day	Monthly highest TX	°C
TNx	Hottest night	Monthly highest TN	°C
TXn	Coolest day	Monthly lowest TX	°C
TNn	Coolest night	Monthly lowest TN	°C
TN10p	Cool night frequency	Percentage of days when TN<10th percentile of 1961-1990	%
TX10p	Cool day frequency	Percentage of days when TX<10th percentile of 1961-1990	%
TN90p	Hot night frequency	Percentage of days when TN>90th percentile of 1961-1990	%
TX90p	Hot day frequency	Percentage of days when TX>90th percentile of 1961-1990	%
WSDI	Warm spell	Annual count of days with at least 6 consecutive days when TX>90th percentile of 1961-1990	days
CSDI	Cold spell	Annual count of days with at least 6 consecutive days when TN<10th percentile of 1961-1990	days
DTR	Diurnal temperature range	Monthly mean difference between TX and TN	°C

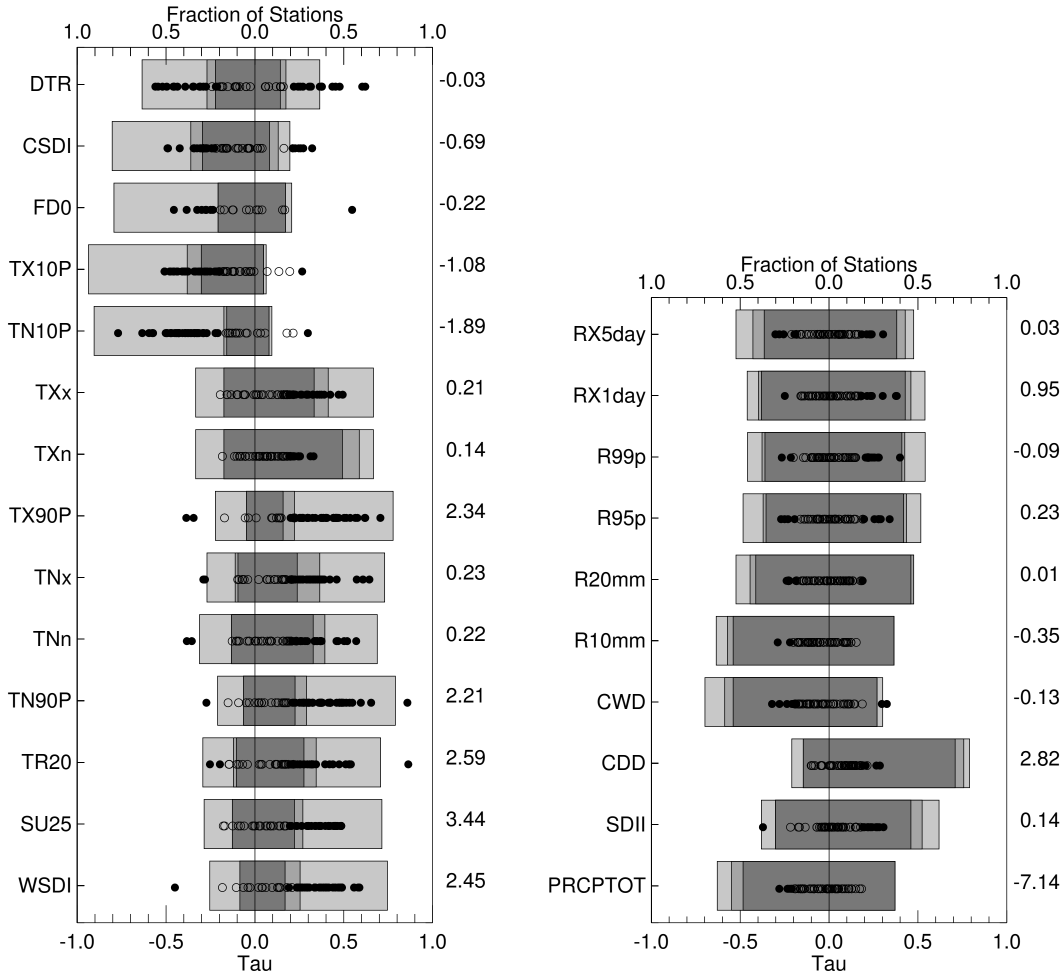
Fraction of Stations
1.0 0.5 0.0 0.5 1.0
DTR
CSDI
FD0
TX10P
TN10P
TXx
TXn
TX90P
TNx
TNn
TN90P
TR20
SU25
WSDI
-0.03
-0.69
-0.22
-1.08
-1.89
0.21
0.14
2.34
0.23
0.22
2.21
2.59
3.44
2.45
-1.0 -0.5 0.0 0.5 1.0
Tau
Fraction of Stations
1.0 0.5 0.0 0.5 1.0
RX5day
RX1day
R99p
R95p
R20mm
R10mm
CWD
CDD
SDII
PRCPTOT
0.03
0.95
-0.09
0.23
0.01
-0.35
-0.13
2.82
0.14
-7.14
-1.0 -0.5 0.0 0.5 1.0
Tau

Figure 1. Summary of trends (Kendall's tau) for all indices. Bars show the fraction of stations with positive and negative trends. Shading indicates the proportion of stations with trends that are statistically significant. Dark grey = $p > 0.10$; medium grey = $0.05 > p \geq 0.10$; light grey = $p \leq 0.05$. Trends for individual stations are shown by circles, with solid circles indicating $p \leq 0.10$. Figures on the right axes show the median trends in absolute units per decade (see Table 1 for units; for example, the median trends for DTR and CSDI are -0.03°C/decade and -0.69 days/decade respectively).

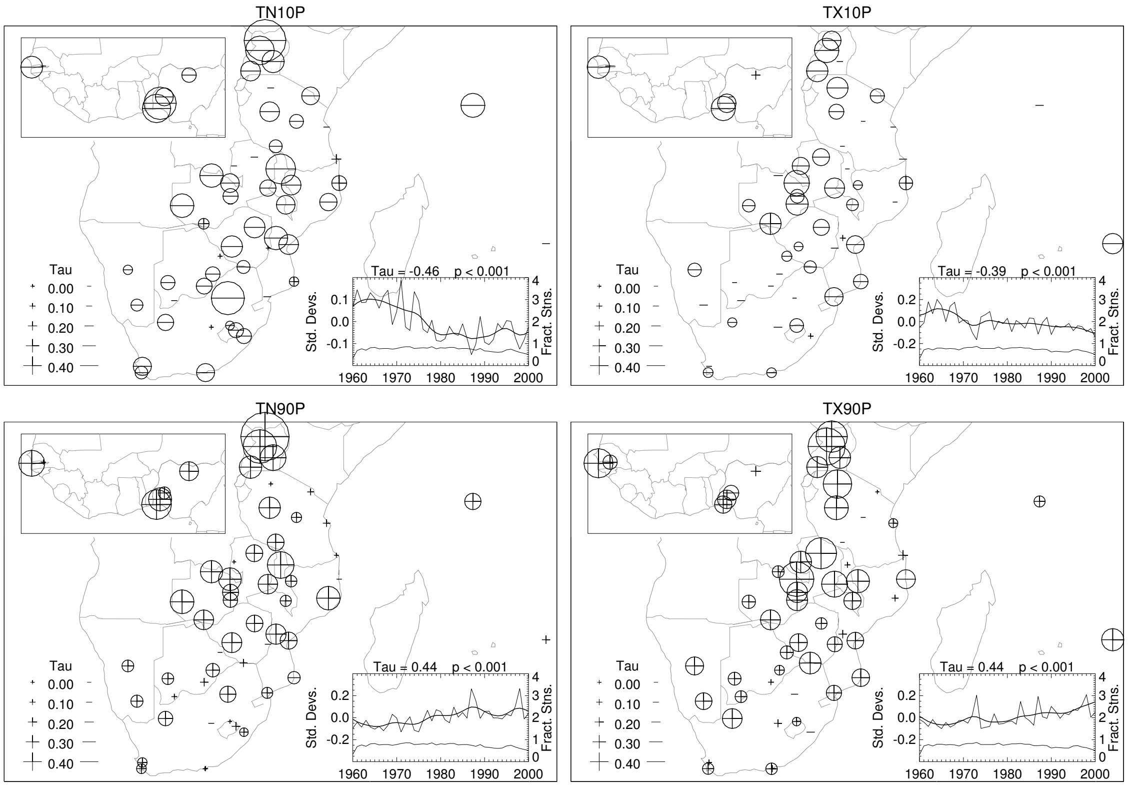

Figure 2. Spatial pattern of trends (Kendall's Tau) and regionally averaged standardised series for maximum and minimum temperature 10th and 90th percentiles. Positive trends are shown as "+", negative trends as "-". Trends that are significant at the 90% level are circled. Inset shows the regionally-averaged standardised anomalies relative to 1961-1990.

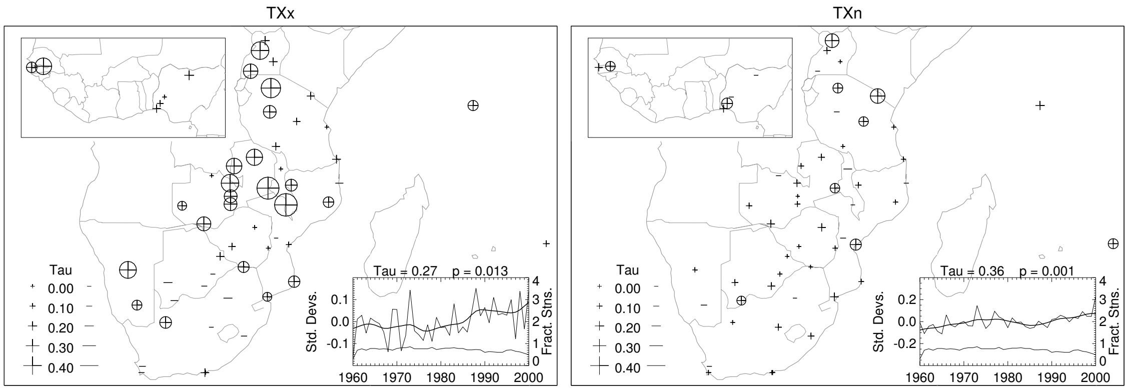

Figure 3. As for Figure 2, but for trends in maximum temperature annual extremes.

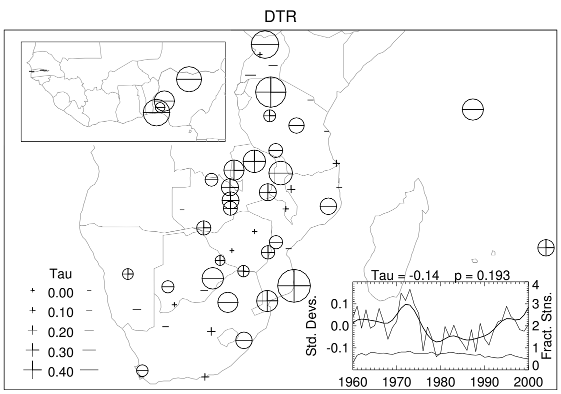

Figure 4. As for Figure 2, but for trends in diurnal temperature range.

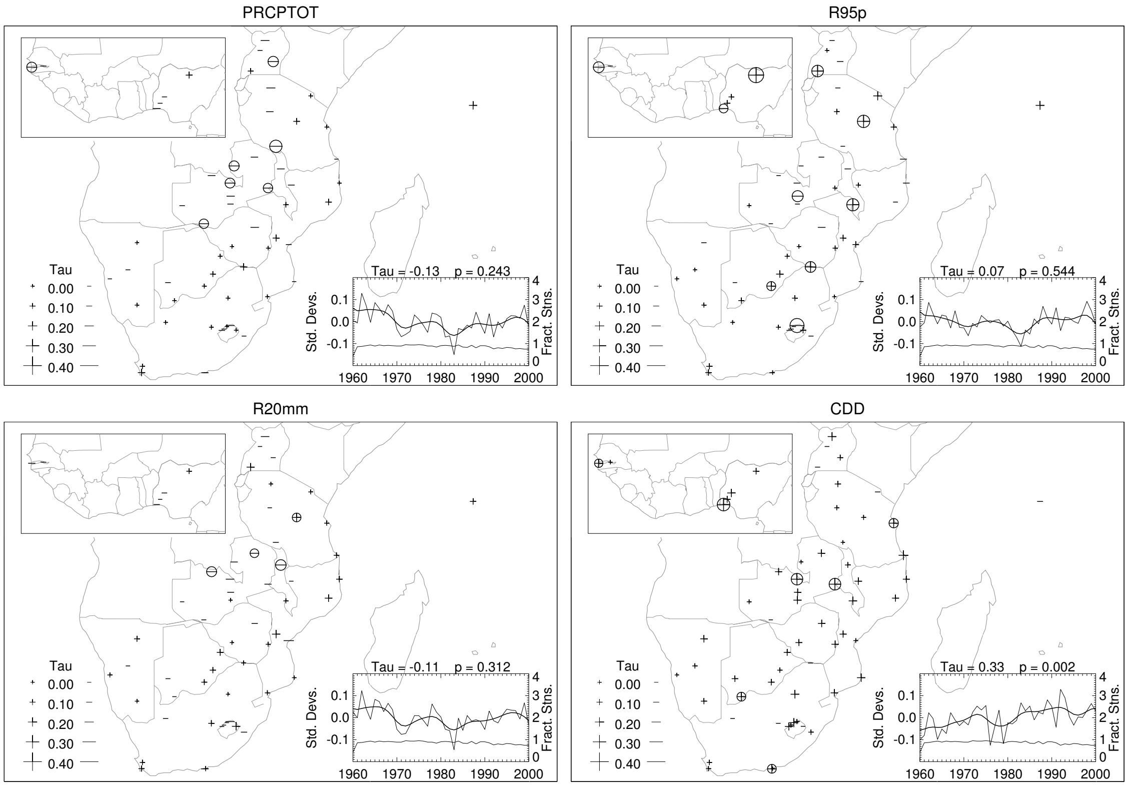

Figure 5. As for Figure 2, but for trends in precipitation indices.