Water Resources Variability in Africa during the XXth Century (Proceedings of the Abidjan'98 Conference held at Abidjan, Côte d'Ivoire, November 1998). IAHS Publ. no. 252, 1998.

Interannual and interdecadal variability of rainfall over the African continent during the last two centuries

SHARON E. NICHOLSON

Department of Meteorology, Florida State University, Tallahassee, Florida 32306, USA
e-mail: sen@huey.met.fsu.edu

Abstract This paper examines the long-term variability of rainfall on a continental scale. Rainfall time series for 90 homogeneous regions of Africa are derived for the period 1901–1996 and their statistics evaluated. Special emphasis is placed on a comparison of Sahelian Africa and the semiarid regions of the southern hemisphere. The spatial patterns of rainfall anomalies and their changes during recent decades are also considered. Finally, an overview of rainfall variability during the nineteenth century is presented, using a new semi-quantitative database for the same 90 regions and miscellaneous long-term rainfall stations. The new data set, produced from a combination of conventional rainfall measurements and documentary evidence, consists of time series of anomaly classes. Seven classes representing various degrees of normal, above normal and below normal rainfall are used. Most time series begin prior to 1850 and several extend back to the 1820s.

INTRODUCTION

The African continent has experienced striking fluctuations of precipitation on both recent and historical time scales. In its sub-humid regions, droughts are an inevitable feature of climate. Those that have plagued the West African Sahel are particularly well known. This paper examines precipitation variability in Africa using primarily two data sources: modern quantitative precipitation records for the twentieth century and a new semi-quantitative historical archive for the nineteenth century. The analysis of modern data is primarily an update of earlier published papers (e.g. Nicholson, 1993). The historical material is new and combines actual rainfall measurements of the nineteenth century with various proxy data indicative of the character of the rainy season.

DATA

The modern record

The precipitation data archive (Fig. 1) used here is an update of that described in Nicholson (1986), that includes nearly 1400 station records. These have been combined into 90 regional series (Fig. 2) that describe rainfall trends in geographical areas that are relatively homogeneous with respect to the interannual variability of

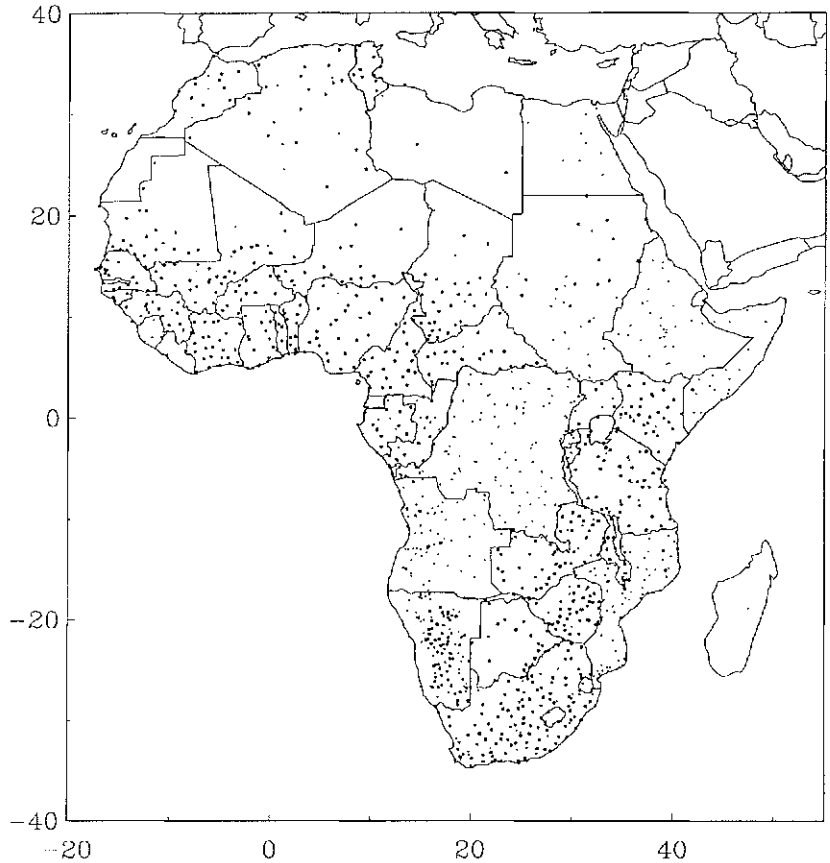


Fig. 1 Map showing the approximately 1400 modern rainfall stations in the data archive and the 90 rainfall regions. Large dots indicate stations with data continuing into the 1990s.

rainfall. About three-quarters of the station records begin prior to 1925 and most (those indicated with larger dots in Fig. 1) have been updated into the 1990s.

Because of the variability of annual means within regions, the precipitation time series are derived as normalized departures from the long-term mean. Thus a departure is calculated as the difference between the annual rainfall total at a given station and the station's long-term mean; this is then divided by the standard deviation of annual totals at the station. In a given year, the values at all stations in the region are arithmetically averaged. This method of expression permits the combination of diverse stations, reduces the impact of missing data and reduces the influence on the analyses and time series of arid regions with extreme high rainfall variability.

The historical archive

Many types of information are useful for historical climate reconstruction. References to the character of the rainy season, landscape descriptions, references to famine and drought, and agriculture are just some examples. A portion of the archive

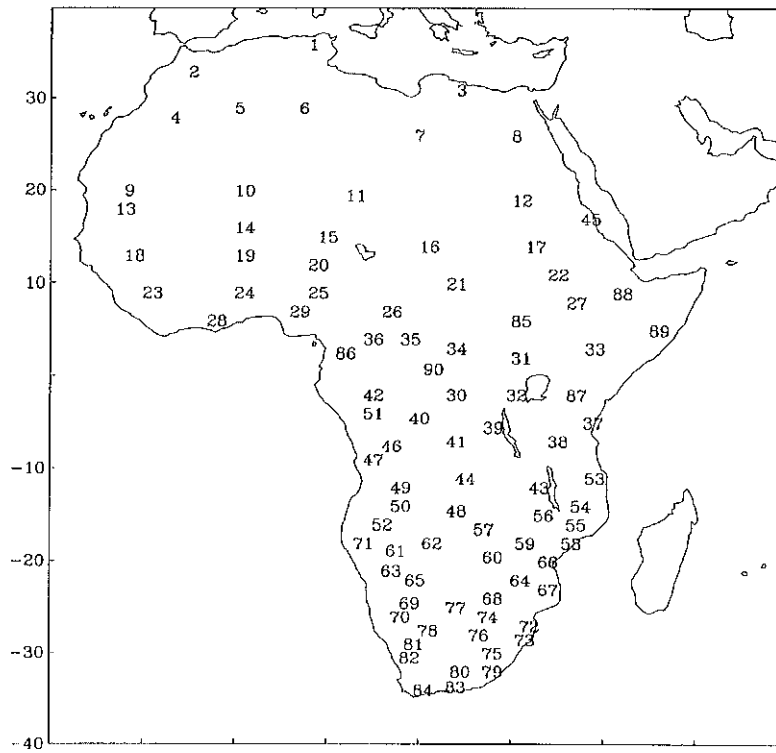


Fig. 2 Approximate location of regions, with numbers corresponding to those in Table 1.

for Lesotho is reproduced in Table 1. The major sources of material for such information include climate and weather chronologies for various African locations, based generally on historical information from diaries, journals, archives and maps; local historical chronicles; lake-level chronologies based on similar information; nineteenth century precipitation records; and geological studies providing sedimentary, geochemical and pollen information from lake cores.

The archive utilized in our study is a compilation of all available nineteenth century precipitation records and a vast body of historical indicators, such as described above. While probably well over 95% of all rainfall records up to 1890 or 1895 are included, only a portion of the potentially available historical material has been exploited. Nevertheless, a data set with high temporal and spatial detail covering most of the nineteenth century has been produced.

As a first step, a time and location are determined for each entry in the archive. On the basis of location, each entry is assigned to one of the 90 rainfall regions shown in Fig. 2. It is also assigned to a semi-quantitative anomaly class. Seven classes are used, with -3, -2 and -1 respectively representing severe drought, drought and dry and +1, +2 and +3 respectively representing good rains, wet and very wet. Near normal conditions are assigned a value of zero. The number of regions, year by year, represented in the archive are shown in Table 2. This ranges from about 10 to 15 regions in the 1820s to about 40 to 60 regions in the 1880s and later.

Table 1 Excerpts from the historical chronology of Lesotho.

Region	Rain anomaly	Year	Entry
74	+1	1831	On Bain's journey north, he encountered extreme cold and uninterrupted snowfall in early June near Mafeking (region 74). This was a reasonably good year, as he was given abundant provisions by the natives and described a reasonably green countryside with no lack of water.
75	-3	1833	In June 1833 E. Casalis, in the *P.E.M.S. Annals*, says it snowed for 2 or 3 days following their arrival in Basutoland. In December 1833 Rolland says famine of the last three months played havoc in Basutoland; this would suggest a poor rainy season in 1832/1933. Drought was universal and there was no hope for a harvest, except possibly at Mothetto (Motito); this would relate to the 1833/1934 rainy season.
75	-2	1834	In June 1833 E. Casalis, in the P.E.M.S. Annals, says it snowed for 2 or 3 days following their arrival in Basutoland. In December 1833 Rolland says famine of the last three months played havoc in Basutoland; this would suggest a poor rainy season in 1832/1933. Drought was universal and there was no hope for a harvest, except possibly at Mothetto (Motito); this would relate to the 1833/1934 rainy season.
75	-2	1822-1833	Drought, famine and cannibalism in Basutoland
76	+1	1833	1833 described as a year of abundance in index; description stems from Thaba Nchu (29°15'S, 26°45'E) in June of 1833
74/76	+2	1835	On February 18, 1835, Rolland's journey was delayed by the Hart River, which was high. The Vaal River was twelve foot deep and they waited three months, until it fell to four feet, to cross it.
75	+3	1836	In January, 1836, Arbousset found plenty of grass at Morija (29°30'S, 27°30'E), reaching to the knees of the cattle. There was a magnificent garden with maize seven feet high. The rains had been plentiful for the last two months. In June, the rains had been over for two months. Arbousset said that this rainy season was one of the wettest ever there and throughout Southern African in general.

Spatial detail is then added on the basis of linear correlation between regions. These correlations are based on the modern record and are calculated from approximately 80–90 years of record. For the historical archive, if a region lacks data in a given year, it is assigned a value based on the values in regions with which it is highly correlated. Generally, 0.5 is considered an acceptable correlation, but the regions must be in relatively close proximity. This cut-off value is well above the 0.1% significance level. When the regional data set is expanded via these correlations, the number of regions represented increases considerably. The number now ranges from about 14–46 regions in the 1820s to about 70 regions or more in the 1880s and later.

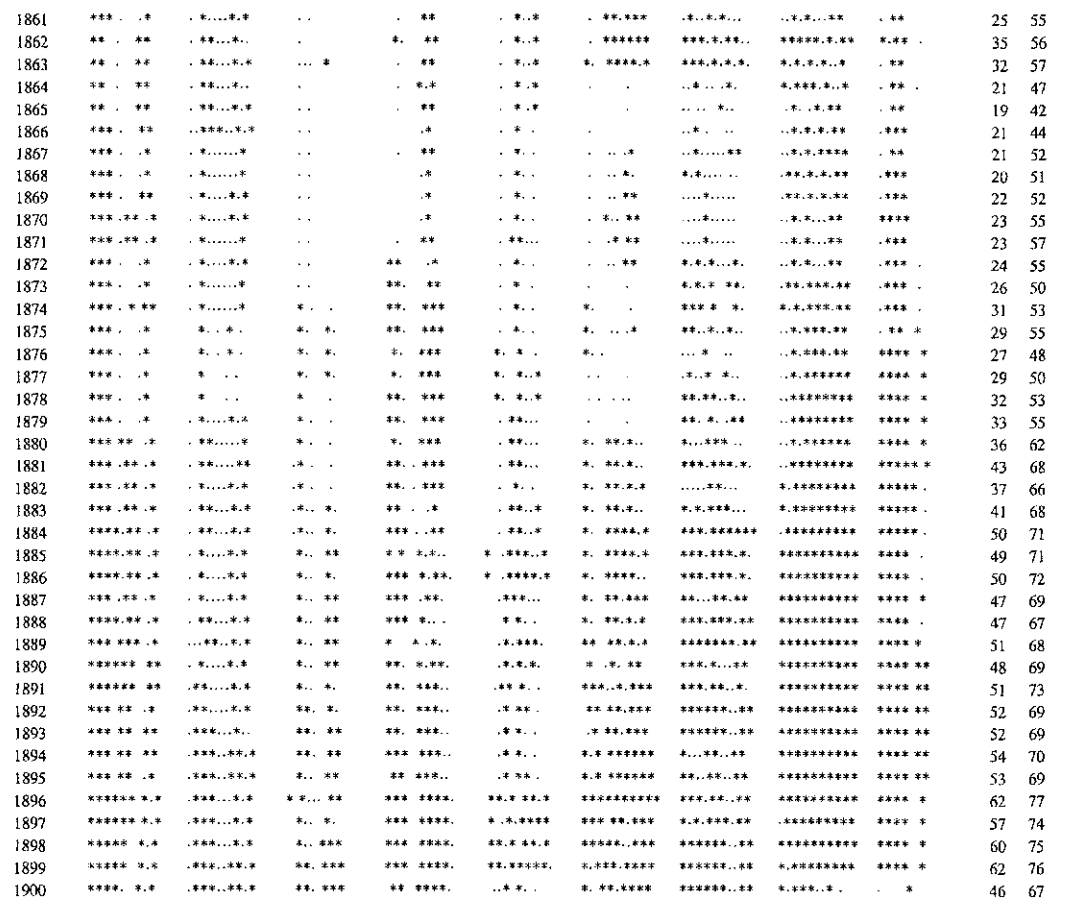
PRELIMINARY RESULTS

Select examples of recent rainfall fluctuations

Earlier work (Nicholson, 1993) has demonstrated that rainfall fluctuations over Africa tend to be continental in scale and that relatively dry conditions prevailed over

Table 2. Availability by year and region number of data in the historical archive. Actual information, from either documentary sources or rainfall stations, is represented by a star. Regions with data assigned via statistical correlations are indicated with dots. The total number of regions available by year is indicated in the last two columns to the right. The first of these indicate the number of regions with specific information and the second column indicates the total number when those with statistically assigned data are included.

	1–10	11–20	21–30	31–40	41–50	51–60	61–70	71–80	81–90		
1801	*	.*******.*	.		* .					3	13
1802	* *	.*.....*	.		* .					5	15
1803		.*******.*	.				.	.....	*. *	3	19
1804	*	.*******.*	.				.. . ..	. .**..	** *	7	25
1805	*	.*******.*	.		* .				*	4	14
1806	*	.*******.*	.		. *.	.	..* * ..	. ...	*	6	26
1807		.*******.*	.			*	.... .	.		2	16
1808		.*******.*	.		. .*					2	13
1809		.*******.*	.. *			.	..* * ..	. ...		4	23
1810		.*******.*	.. *							2	12
1811	*.	.*******.*	.				.. . ..	...**...	.***	7	29
1812	* .	.*****.*	.				.. . ..	...**..*	*.	7	27
1813		.*******.*	.		* .					2	12
1814					* .					1	2
1815	**				* .					3	4
1816	**				* .					3	4
1817	**				.* *.					4	6
1818	**					.	..* * ..	. . .*.*.	.	6	18
1819		.	* .		* .		.. . ..	. . .*.*.	.	4	18
1820	* *				* .	.	.. ..	..* .*.**	.	7	21
1821							.. . ..	. . .*.**	. *	4	14
1822	*	.*******.*	.		* .	*	.. . ..	. . .*.**	** *	10	29
1823	.	. .*.....*	.			*	.. . ..	. . .*.**	** *	9	27
1824	** .	. .*.....*	.. *			*	.. . ..	**. .*..*	.	10	30
1825	** .	. .*...**.	.	. *.	*.	. *	.. . ..	...**..*	.	11	34
1826	.	. *.....				* .	. .. *..	...*...*	.	5	26
1827	.	. *.....			*. *	. ....**.	..*.*..*..	.**..*...*	.	12	41
1828	.	...**....*	* * .. .		*. *	....**.	. ...	**..*..**	.	14	43
1829	* .	...**....*	* ... *		*. *	...**.	. ....*..	**..*..**	. *	17	46
1830		..***....*	* .... *	. *.	. *	...*..	. . . ..	...*...*	. *	12	42
1831	.	..***....*	* .... *		*	.....	. . . . .	.* ....*	.* *	11	37
1832	* .	...**....*	* ... *				.. . ..	. .**.*	. *	10	30
1833	.	...**..*.*	* ... *			.	*.* * **	.**.****.*	. *	19	35
1834	. .*	...**..***	* ... *			.	.. .. *..	**.******	.	17	36
1835	* .** .*	*...*..*.*	* ..	. *.	. .	**. ..	.. ... *..	***.***.*	. *	21	48
1836	* *. ** .*	* .....*.*	* ..	.. .			.. . ..	**.*.*.**	. *	16	38
1837	* * .** .*	* .....*.*	* ..			.	..* . *.	. ...***.*	.	15	36
1838	* * .** .*	* .....*.*	* .. *		.* **	* .	... .	. .*.***.*	. **.	21	47
1839	* * .** .*	* .....*.*	.. *		.* **	*	... . ..	.. .*.****	** *	21	42
1840	* * .** .*	* .....*.*	.. *		.* **	*	... . ..	. ...**.*..	.* *	18	42
1841	* * .** .*	* .....*	.. *		.* **	*	..* * ..	.....*****	. *	20	42
1842	* * .** .*	* .....*	.. *			.	.. ..	..***.**.	. **	15	39
1843	* * .** .*	* .....*	.			.	.. ..	..*.*.**.	. *	12	36
1844	* * .** .*	* .....*	.		.	. . ..	***.**. *.	.*..**.*..	. *	18	43
1845	*** .	. .*.....*	.	.*	. .	. . ..	.* ..*....	***.*.**.	. *	15	42
1846	* * .	. .....*.*	.	.*	. .	. .	.*. *. ...	...*.*.**.	. *	12	39
1847	* * .	. .....*.*	*. .	* .*	. .	. .	.*. *. ...	...*.*.**.	. *	14	42
1848	* * .	. *....*.*	*. .	*. **	. .	. .	.** *. .*.	...*.****.	. *	19	43
1849	* * .	. .....*.*	*. .	*. **	. .	. .	.** .. .*.	...*.****.	. *	17	43
1850	** .	.. . *. .	* .	*.* ***	. *.*.	. ...*	.**.*..*..	...******	. * *	24	50
1851	* . .*	. *....*.*	*. .	* .*	. .	* .* .*	.**.*..**.	....******	. *	23	48
1852	* .* .*	. **...*..	.. *	.*	. .	. .* ..	.**.*. ***	*..**.****	. *	23	47
1853	** .** .*	. *....*.*	. .	.*	. ..***	* ..* .*	.**.*..*..	...**.****	. *	26	54
1854	** .* .*	. **...***	. .	.*	. .	. .**.*	.* ....*..	.*.**.****	. *	23	47
1855	*** .* **	..*.*..*.*	. .	.*	. .*.*	. .** .*	.*	.*. .*.**	. *	22	51
1856	*** .* .*	. *....*.*	. .	.*	. *..	. *.	.** * ..	..*. .*.**	.* *	20	45
1857	** .* .*	*. . *. .	.	. **	. * ..	. ...*	.**.*..**.	..** .*.*.	. *	20	45
1858	** .* .*	*. . *. .	.	*. **	. *. .	. .*. ..	.**.*** ..	..*.*.*.*.	. * .	21	48
1859	*** .* .*	*. . *. .	.. *	. ***	. *. .	*. **. .*	.**.*.....	..*.***.*.	. ** .	26	54
1860	*** . .*	*. . *. .	.. *	. **	. *. .	. **. **	.**.*.*...	..***.*.*.	. **	25	50



much of the continent during the 1970s and over nearly all of Africa during the 1980s. These conditions were much in contrast to the relatively wet decades of the 1950s and 1960s. During the period 1990–1996 conditions were still predominantly dry, but this conclusion is preliminary since for parts of the continent (notably northeastern Africa and Angola) we have not been able to obtain recent data.

The mean regional patterns of rainfall anomalies in the years 1990–1996 are shown in Fig. 3. On average rainfall was below normal throughout the continent except for small sectors in the northwest and far south and in a band in the equatorial region. A look at maps for the individual years (not shown) indicates that a substantial number of regions showed positive anomalies in 1991 and in 1994. Both of these were El Niño years, but the spatial pattern of anomalies was quite different in the two years, with the central Sahel being wet only in 1994. In 1990, 1992, 1993, 1995 and 1996 wet conditions were apparently mainly in limited parts of equatorial Africa or the temperature extremes of the continent.

Time series for more specific regions of West Africa, eastern Africa and southern Africa are shown in Figs 4 and 5; region location is shown in Fig. 6. These cover the period 1901 to 1996 or 1997. Since trends to 1990 have been described

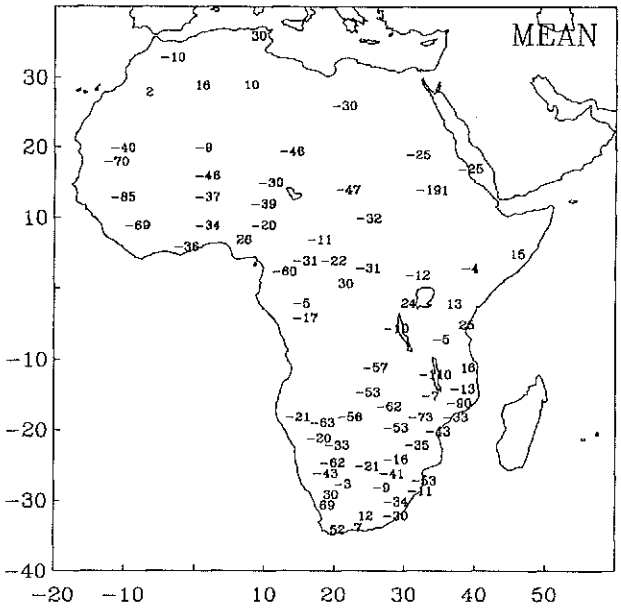


Fig. 3 Map showing the average regional anomaly for the period 1990 to 1996. Data are regionally averaged standard departures from the long-term mean (i.e. over the period of record).

elsewhere (Nicholson, 1993), only the years since then are described here. Dry conditions have generally prevailed throughout West Africa from 1990 to 1997. The year 1994 was near normal in much of the region, but dry conditions returned in some areas in 1995 and in most of the region in 1996. The persistence of the dry conditions has been particularly strong in the Sahel and Soudan zones, where since 1969 rainfall has exceeded the long-term mean in only one year (1994). In eastern Africa, conditions have varied during the period 1991–1996, with very dry conditions in 1993 and very wet conditions in 1994. Rainfall was also above normal in 1990. Throughout the period 1990–1995 relatively dry conditions prevailed in most northern sector of southern Africa delineated in Fig. 6, but 1996 and 1997 were near average. The 1990s were also relatively dry further south, except for 1991 and 1996. The recent dry period in southern Africa is more or less contemporaneous with the extended El Niño from 1991 to 1995.

Select examples of historical rainfall fluctuations

Most of the historical data set has not yet been systematically analysed. For this reason, only a handful of select examples of time series are presented (Fig. 7). These refer to various areas of southern Africa, as depicted in the map in Fig. 8. The time series for the northeast Cape area and southern Botswana begin around 1800, those for central and southern Namibia about 1825 and those for Zambia and Zimbabwe around 1850.

A number of trends in rainfall are suggested by the time series in Fig. 7. The first is relatively dry conditions early in the nineteenth century, a trend also shown

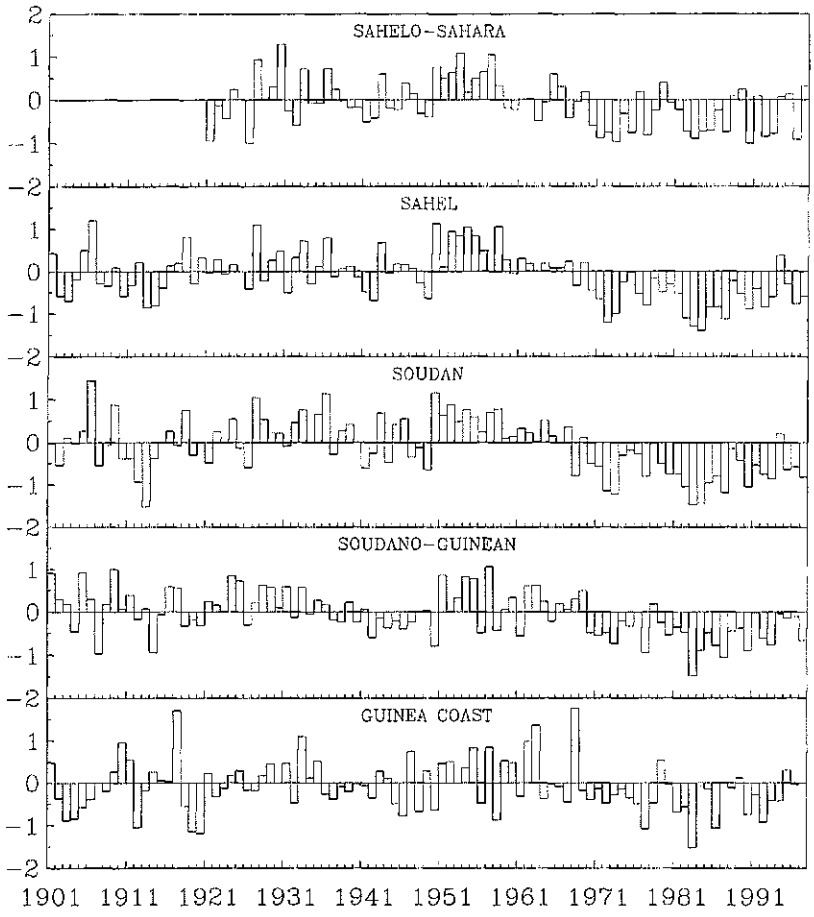


Fig. 4 Rainfall fluctuations in West Africa (1901–1990), expressed as a regionally-averaged standard departure (departure from the long-term mean divided by the standard departure). Location of the five regions is indicated in Fig. 1.

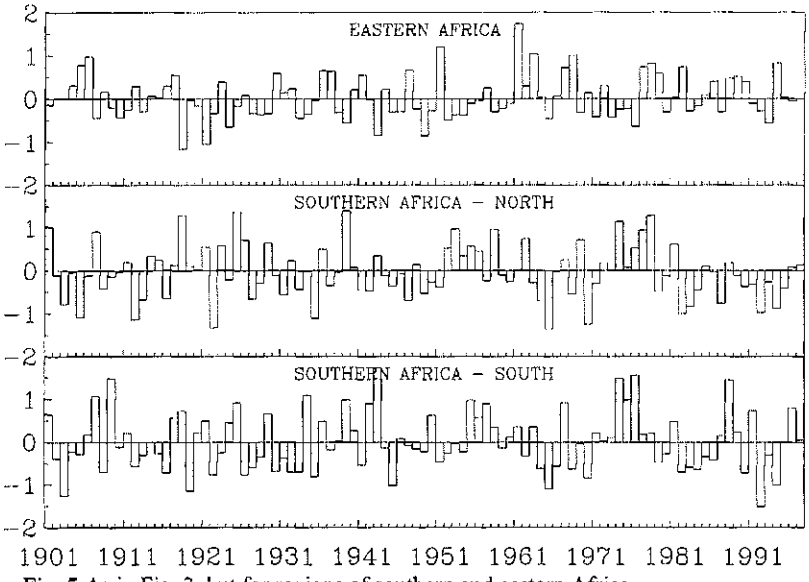


Fig. 5 As in Fig. 3, but for regions of southern and eastern Africa.

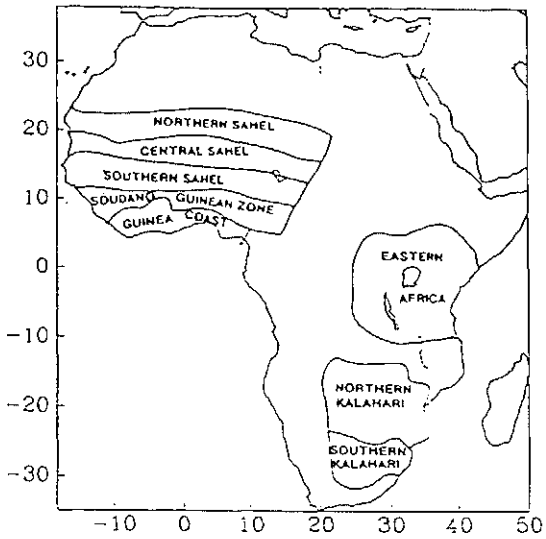


Fig. 6 Map indicating location of regions in Fig. 4 and Fig. 5.

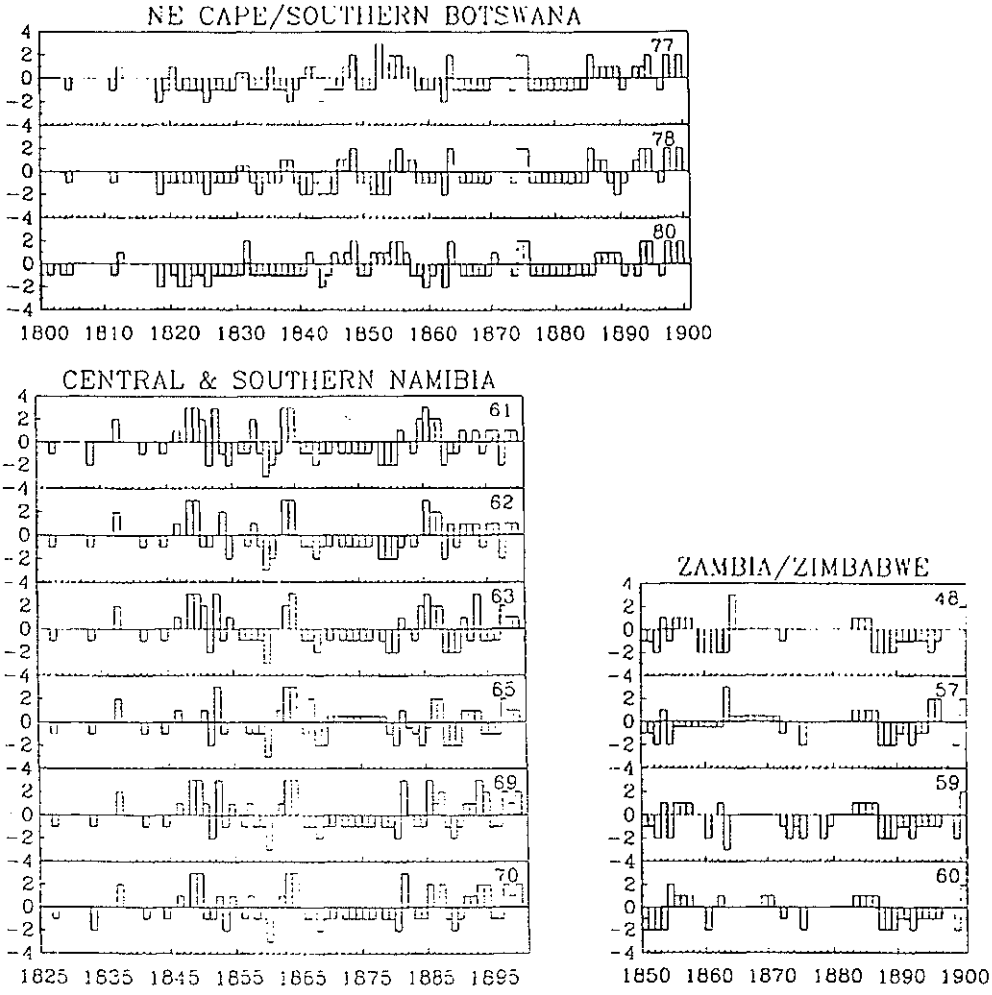


Fig. 7 Rainfall anomalies by year for select regions of Zambia/Zimbabwe, central and southern Namibia, and the northeast Cape Province/southern Botswana. The numerical values refer to anomaly classes, with 0 representing normal conditions. The values –1, –2, –3 represent dry, drought and severe drought; +1, +2 and +3 represent good rains, wet and very wet. These cannot be interpreted in quantitative terms of rainfall amount.

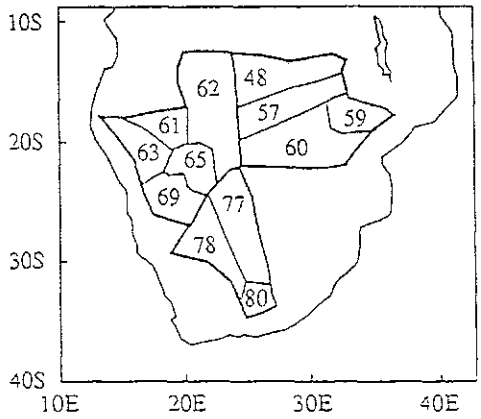


Fig. 8 Map showing locations of regions depicted in Fig. 7.

by numerous lakes (Nicholson & Yin, 1998) and by more generalized studies of historical variations (e.g. Nicholson, 1981). It also appears that relatively wet conditions prevailed in the western regions in mid-century, with relatively dry conditions from around the 1860s to about 1880. The 1880s and 1890s appear to have been decades of relatively good rainfall. Nearly the opposite situation prevails in the more eastern regions, in Zambia and Zimbabwe, although information is scant for the 1870s. In particularly, there is evidence of relatively dry conditions in the 1850s and since the late 1880s.

SUMMARY

The above results, although preliminary, clearly show that in recent decades relatively dry conditions have prevailed in Africa. A comparison of these decades with historical trends requires analysis of the historical data set herein described. This data set will permit the assessment of conditions in Africa during the nineteenth century and will help to show whether the characteristics of rainfall variability evident on modern time scales are also evident in the historical record.

REFERENCES

Nicholson, S. E. (1981) The historical climatology of Africa. *Climate and History* (ed. by T. M. L. Wigley, M. J. Ingram & G. Farmer), 249–270. Cambridge Press, Cambridge, UK.

Nicholson, S. E. (1986) The spatial coherence of African rainfall anomalies: interhemispheric teleconnections. *J. Clim. Appl. Met.* **25**, 1365–1381.

Nicholson, S. E. (1993) An overview of African rainfall fluctuations of the last decade. *J. Climate* **6**, 1463–1466.

Nicholson, S. E. & Yin X. (1998) Variations of African lakes during the last two centuries. In: *Water Resources Variability in Africa during the XXth Century* (ed. by E. Servat, D. Hughes, J.-M. Fritsch & M. Hulme) (Proc. Abidjan'98 Conf., Abidjan, Côte d'Ivoire, November 1998). IAHS Publ. no. 252, this volume.