able going conditions in both winter and summer, and for owners and trainers the ability to predict the going would thus become even more crucial.

Conclusions

Weather variables may be successfully employed to provide a predictive tool for estimation of the going at five Irish racecourses. Temperature, rainfall, sunshine and wind appear to explain approximately half the variance in this critical measure. Further fine tuning of the variables themselves and of the period chosen in advance of the meeting, the use of more proximate weather stations, and the possible incorporation of a soil texture variable would most probably enhance further the accuracy of the predictions concerned and offer a utility which trainers and racecourse managers, and even off-course betting agents, might find attractive.

Acknowledgements

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Rainfall over Accra, 1901–90

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Accra is the largest city and capital of Ghana. It is located in the south-east coastal plains of Ghana at 05°35′N, 00°60′W. The south-east coastal plains are low-lying with a general altitude less than 152 m above sea-level, while several parts of Accra which are prone to flooding are below 60 m. Rainfall is therefore one of the most important climatic factors to affect the peri-urban agriculture and socio-economic life of the city. Too much rain can result in severe flooding, as was witnessed on 4 July 1995, for example, when several parts of Accra recorded over 180 mm in a day. About 22 people lost their lives, and millions of US dollars' worth of properties were destroyed, including the city's entire communication network.

In this study we analyse rainfall data over 90 years. The analysis of such a long period of data will assist engineers, hydrologists, urban and transport planners, and agriculturists in the long-term planning of the city. The monthly and annual rainfall data used for the analysis were obtained from the Ghana Meteorological Services Department.

Seasonal rainfall

The distribution of rainfall over Accra is influenced by two airmasses in the lower level of the atmosphere: dry air from the north which originates from the Sahara Desert and moist air from the Atlantic Ocean. The boundary between these two airmasses is described as the inter-tropical discontinuity (ITD). The ITD, with its migratory tendency, controls the weather patterns of Ghana and the rest of west Africa.

In January, the ITD reaches its furthest position south between latitudes 5 and 7°N in Ghana. The areas north of the ITD are characterised by warm, dry, subsiding winds called the north-easterlies or harmattan winds. Between December and March, Accra and the rest of Ghana are dry. In April, the ITD lies at 15°N with the depth of the moist south-west airmass below the ITD about 1500 m, and Accra and the coastal plains begin to receive rainfall. In July, the ITD is located at about 20°N and the depth of the moist airmass (the south-west monsoon) is about 2500 m below the ITD (Hayward and Oguntoyimbo 1987). The greater part of Ghana receives copious rainfall from April to June with a peak in June for the major rainy season, while the minor rainy season runs from September to the middle of November with a peak in October. This applies to the southern half of the country where rainfall distribution is bimodal. Areas north of 8°N experience a unimodal regime with peaks in either August or September.

Figure 1 illustrates the mean monthly rainfall totals at Accra for 1901–90. Monthly rainfall totals increase progressively from January, peak in June and decline rapidly in July and August (the little dry season – see Ilesanmi 1972). Then the rainfall totals rise gradually to a secondary peak in October, before decreasing sharply thereafter due to the southward retreat of the ITD. January has a mean monthly rainfall of 14.6 mm which increases to 205.1 mm in June. The mean value then falls sharply to 20.3 mm in August, and rises again to 65.1 mm in October (the second minor peak). It drops again to 21.0 mm in December.

The seasonal rainfall over Accra between 1901 and 1990 has been divided into three equal subsets: 1901–30, 1931–60 and 1961–90. Figure 2 is a combination of the three subsets. The mean monthly rainfall for April, and June to September is the highest in the more recent period (1961–90) (96.8, 221.8, 66.0, 28.2, and 67.8 mm respectively). The months of February, March, May, October and

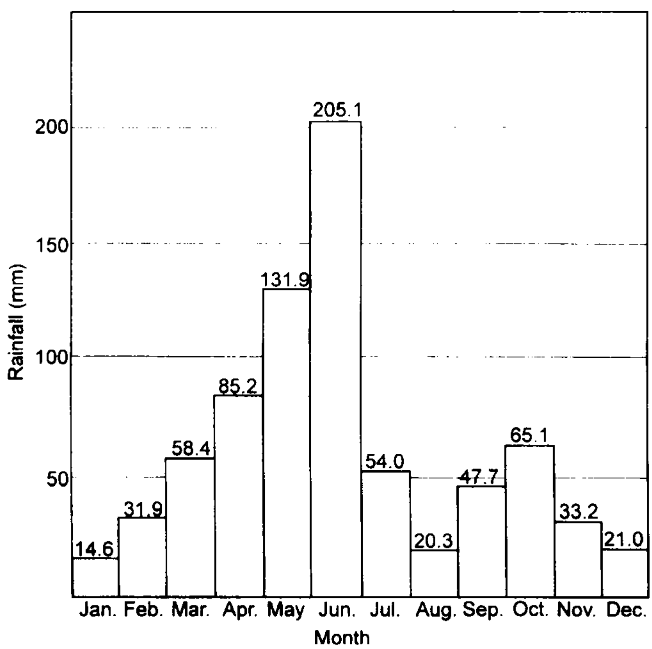

Fig. 1 Mean monthly rainfall at Accra, 1901–90

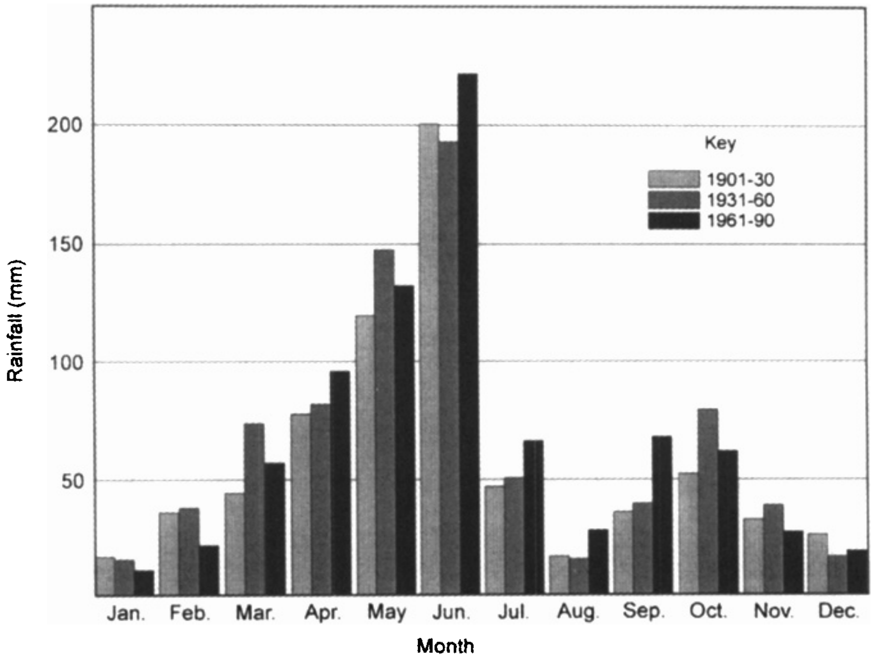

Fig. 2 Mean monthly rainfall at Accra for 1901–30, 1931–60 and 1961–90

Table 1 Rainfall statistics for Accra, 1901–90

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
(a) Monthly values													
Mean (mm)	14.6	31.9	58.4	85.2	131.2	205.1	54	20.3	47.7	65.1	33.2	21	767.7
SD (mm)	20.8	38.6	43.4	48	65.8	142.2	60.6	24.7	54	48.5	26.6	25.8	221
CV (%)	143	121	74	56	50	69	112	122	113	75	80	123	29
(b) Driest and wettest months													
Lowest rainfall (mm)	0	0	0	8	7	2	0	0	0	1	0	0	
No. of years, or year	30	10	1942	1926	1945	1947	2	12	5	1925	8	17	
Highest rainfall (mm)	95	159	224	257	308	715	371	121	276	201	139	134	
Year	1958	1913	1918	1972	1942	1962	1968	1963	1987	1955	1947	1926	
(c) Annual and monthly regression coefficients (mm per year) for various periods													
1901–30	0.117	−0.052	0.043	−0.047	0.009	−0.002	−0.008	−0.075	0.052	0.077	−0.092	0.081	0.002
1931–60	0.016	−0.049	−0.016	0.042	0.009	0.014	−0.007	0.067	0.005	0.034	0.001	0.022	0.011
1961–90	−0.241*	−0.069	−0.076	−0.045	0.023	−0.035*	−0.033	−0.020	−0.002	0.041	−0.019	0.013	0.019
1901–90	−0.238	−0.151*	0.056	0.062	0.042	0.001	0.035	0.164	0.123*	0.086	0.119	−0.080	0.016

* Significant at 95% level.

November in the 1931–60 subset have the highest rainfall while December and January of the 1901–30 subset have the highest rainfall (27.1 and 16.8 mm). The coefficient of variability (CV), which is expressed as the percentage ratio of the standard deviation to the mean for 90 years annual rainfall, is 29% and is smaller than for the individual months whose CVs range from 50% in May to 143% in January.

Annual rainfall fluctuations

The mean annual rainfall at Accra from 1901 to 1990 is 767.7 mm with a standard deviation (SD) of 221 mm and a CV of 29% (Table 1(a)).

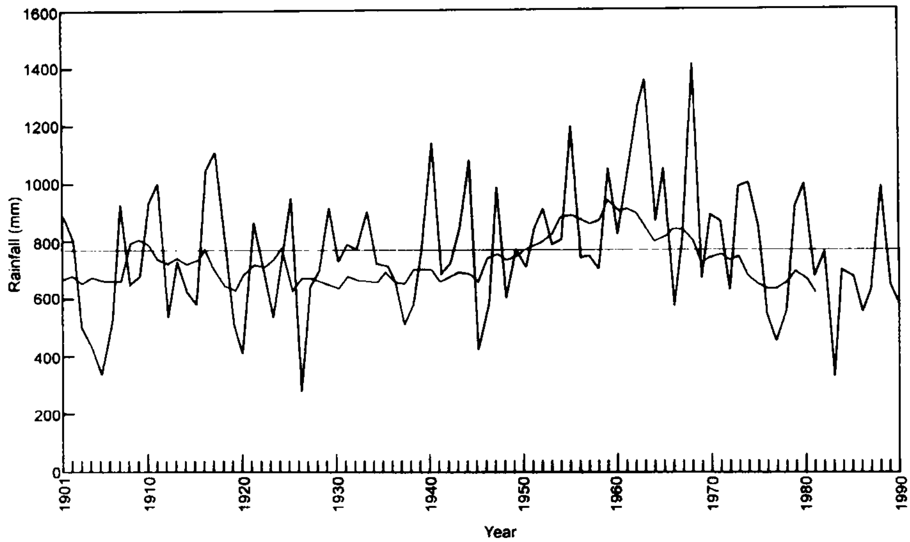

Fig. 3 Annual rainfall fluctuations and 10-year running means at Accra, 1901–90 (each 10-year running mean plotted at first of 10 years)

The driest and the wettest years were 1926 and 1968 (275.3 and 1415 mm) respectively. Figure 3 depicts annual rainfall fluctuations at Accra from 1901 to 1990. The oscillatory pattern shows several peaks and troughs. Some of the important peaks occur around 1911, 1918, 1941, 1956, 1961 and 1968. The significant troughs are found around 1905, 1920, 1926, 1945, 1977 and 1983. Since 1981, rainfall totals have been declining except in 1988. A 10-year running mean was used to smooth out the graph. Since the decade 1969–78, rainfall has been decreasing.

Trends in rainfall

Table 2 shows the mean annual rainfall divided into three equal subsets: 1901–30, 1931–60 and 1961–90. The mean annual rainfall is highest in the recent period (1961–90), being 809.8 mm, with the 1931–60 subset having the second highest (788.1 mm) and the 1901–30 subset the lowest (705.0 mm). The 1901–30 subset has an SD of 214.8 mm which reduced to 174.4 mm in the 1931–60 subset. This increased to 252.7 mm in the 1961–90 subset. The CV for 1901–30 is 30.5%, for 1931–60 is 22.1% and for 1961–90 is 31.2%. The three highest rainfall years on record (1968, 1963 and 1962) occur within the recent subset (1961–90) and this explains why the mean annual rainfall is highest then. Two of the three driest years on record (1926, 1905) coincide with the first subset (1901–30) with the other (1983) in the third subset (1961–90) (see Table 3). Annual rainfall trends are quite revealing. While the early part of the century (1901–30) exhibits decreasing annual rainfall totals, the recent period (1961–90) has the highest mean rainfall due to some years with very high rainfall totals, even though the majority of the individual years exhibit declining rainfall (Fig. 3). The existence of trends in the annual and monthly rainfall is determined by regression coefficients of rainfall with time. This parameter shows whether annual rainfall or rainfall in any particular month is increasing or decreasing over the years. The analysis is for the period 1901–90 as well as for the three subsets 1901–30, 1931–60 and 1961–90. The annual and monthly regression coefficients for the various periods are shown in Table 1(c). The regression coefficients for the months of the year indicate the overall gradual decrease in rainfall over the years. While one cannot detect any pattern of trend in the three subset periods, a decrease in rainfall over the years is more significant in the period 1961–90, a trend which has steepened since 1980.

Monthly rainfall fluctuations

Mean monthly rainfall totals, their SDs and CVs

Table 2 Monthly rainfall statistics for Accra for various periods

Month	1901–30 Mean (mm)	1901–30 SD (mm)	1901–30 CV (%)	1931–60 Mean (mm)	1931–60 SD (mm)	1931–60 CV (%)	1961–90 Mean (mm)	1961–90 SD (mm)	1961–90 CV (%)
Jan.	16.8	24.5	145.8	16.0	19.8	123.8	11.0	7.3	66.4
Mar.	44.6	44.8	100.4	73.5	40.2	54.7	57.1	40.1	70.2
June	200.7	153.1	76.0	192.6	123.0	63.9	221.8	147.0	66.3
Oct.	53.2	45.4	85.6	79.8	53.8	67.4	62.4	41.6	66.7
Dec.	27.1	35.2	129.2	17.9	17.0	95.0	18.7	20.3	112.2
Year	705.0	214.8	30.5	788.1	174.4	22.1	809.8	252.7	31.2

Table 3 Wet and dry rainfall years in Accra

Wet Year	Wet Amount (mm)	Dry Year	Dry Amount (mm)
1968	1415.0	1926	275.3
1963	1349.0	1905	333.0
1962	1229.7	1983	333.1
1955	1196.8	1920	403.1
1940	1140.0	1945	418.6
1917	1124.2	1977	545.2

are presented in Table 1(a). Monthly rainfall fluctuations for January and June are shown in Figs. 4(a) and (b). January, which represents the dry season, has six major significant peaks, four of them occurring between 1901 and 1926, while the other two are between 1956 and 1960 and 1966 and 1971 respectively. Rainfall was generally low between 1971 and 1990. The period 1918–22 witnessed extremely low rainfall. In February (not shown) about eight main peaks can be identified and in between the peaks are troughs of low rainfall. The period 1956–70 was characterised by low rainfall. Similarly, since 1977 rainfall totals have fallen with the exception of 1986. In June (wet season) 1961 has the highest peak, with the lowest trough in 1947. Since 1976 rainfall has been below the long-term mean. August rainfall is similar to that of July with several troughs and a few significant peaks. September and October have similar patterns with prominent troughs in 1982 and between 1901 and 1916. The highest peaks for November and December occur in 1948 and 1928 respectively. One distinguishing feature of January rainfall is that it has the greatest variation, followed by December and August as depicted by their CVs of 143, 123 and 122% respectively.

Table 1(b) illustrates the driest and wettest rainfall months at Accra. While the highest January rainfall amount of 95 mm was recorded in 1958, zero rainfall was recorded in 30 out of the 90 years. June recorded its highest rainfall on record (715 mm) in 1962 and its lowest (2 mm) in 1947.

Rainfall and ENSO

In west Africa the occurrence of the El Niño Southern Oscillation (ENSO) has been found to have an effect on the main rain-producing mechanism (Adedoyin 1989). El Niño refers to a warm surface ocean current that occasionally appears along the coast of Ecuador and Peru. El Niño typically occurs towards the end of the year, hence the name El Niño (boy child) for the Christmas season. In a mature El Niño, air pressure over Australia and Indonesia increases and the warm water of the west and central Pacific spreads eastwards across the entire Pacific basin and the atmospheric convergence zone moves eastwards to the central Pacific. Associated with El Niño is the Southern Oscillation (SO) which is the irregular fluctuation of the sea-level pressure field between the western tropical Pacific and the south-eastern tropical Pacific. The Southern Oscillation Index (SOI) shows the anomalous sea-level pressure difference (in terms of the number of SDs between Tahiti and Darwin (north Australia)), and during an El Niño phase the SOI is negative (Bigg 1990). During El Niño the upwelling of water in the east Pacific decreases and the sea surface temperatures (SSTs) rise, with the result that the thermal gradient is decreased and a weaker Pacific convergence or convection occurs.

El Niño events generally last about 1 year, with perhaps 3–4 years between events. Many

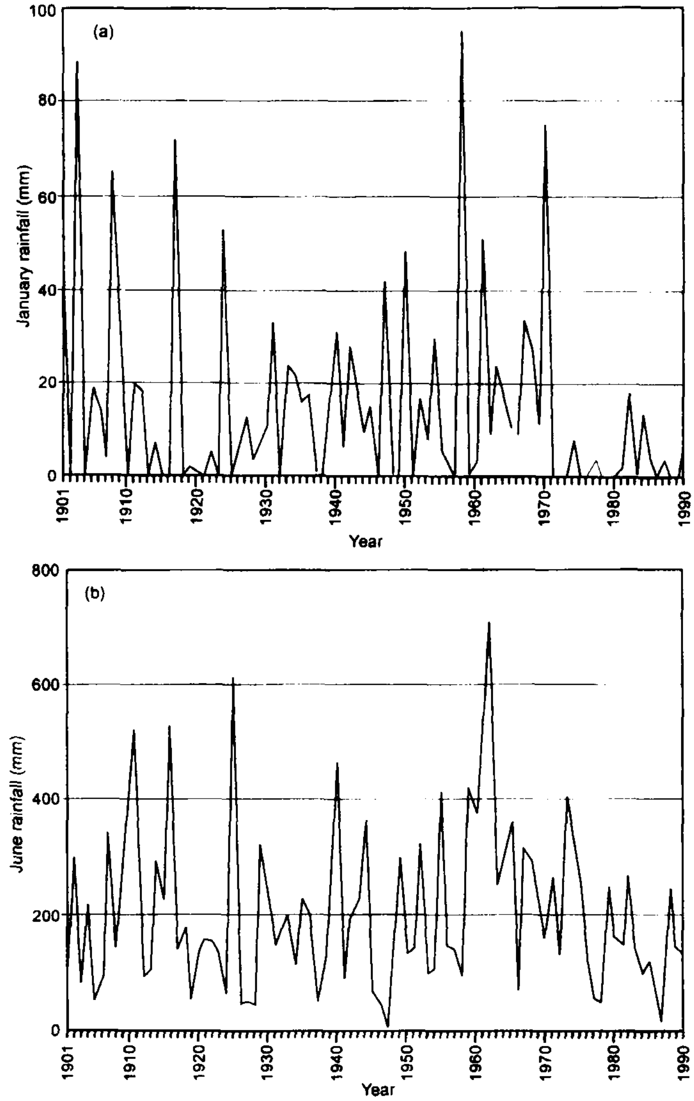

Fig. 4 Monthly rainfall fluctuations at Accra, 1901–90, for (a) January and (b) June

tropical droughts have been related to prolonged El Niño events; for example, 1854–56, 1878–80, 1911–13 (Lough 1992), and 1939–42 (Bigg and Inoue 1992).

Some recent studies indicate that rainfall trends in virtually the whole of Africa are influenced by global-scale SST anomalies. Rainfall trends in Africa between 1901 and 1985 have been shown by Hastenrath (1984), Lough (1986) and Folland *et al.* (1986) to be directly influenced by contrasting patterns of SST anomalies on a global scale. Using general circulation model experiments, Folland *et al.* (1986) and Palmer (1986) found that the Atlantic and Pacific SST anomalies tend to reduce total rainfall amounts over Africa, while Indian Ocean anomalies produce an enhancement. This has also been confirmed by Fontaine and Bigot (1993).

It is now thought likely that these global-scale SST anomalies influence African rainfall by changing the tropical circulation pattern. The El Niño events are able to change the Hadley circulation by shifting the Pacific ascending branch eastward and creating subsidence over some parts of Africa. On the other hand, if the South Atlantic SST rises, the meridional temperature gradient of SST south of the

ITD is reduced, and this weakens the Hadley meridional circulation. The Hadley circulation consists of rising air near the equator, sinking air over the poles, and an equatorward flow of air over the surface with a return flow aloft. This circulation cell, which moves north and south, is located between 0 and 30°N and 0 and 30°S. It controls the weather and climate within the tropics. In times of ENSO the north–south circulation system is weakened and affects the monsoon rainfall of west and central Africa. Several areas of west Africa tend to experience drought during an El Niño when the circulation is weakened within the tropics. This in turn reduces the intensity of the south-west monsoon winds into west and central Africa. The persistence of drought in the Sahel and other parts of west Africa can be partly explained in terms of the higher than normal SST in the South Atlantic (Lough 1986).

A number of the El Niño events coincide with periods of drought in Accra. Accra experienced drought in 1903–06, 1912, 1915, 1919–20, 1923, 1926, 1937–38, 1966, 1978, 1982–83, 1986 and 1990. Figure 5 shows the SOI. It is quite clear that the 1966 ENSO year coincided with the drought year in Accra. The droughts of 1978, 1983, 1986 and 1990 all coincided with ENSO events too. The negative values of the index (El Niños) can be correlated more easily with rainfall peaks. A persistent change in the downward (negative) direction signals El Niño, while such a change in the upward (positive) direction signals La Niña.

It has been established that during an El Niño event the global-scale SST anomalies influence rainfall in Africa by altering the tropical circulation, thereby shifting the Walker circulation (which is a thermally driven longitudinal cellular circulation extending across the Pacific Ocean from Indonesia to the Peruvian coast and forming a component of the SO) to the east thus creating subsidence over some parts of Africa. Drought in Ghana and other parts of Africa can be related to the occurrence of ENSO (Ofori-Sarpong 1996). It is being suggested that perhaps the South Atlantic SST anomalies bear some relationship to rainfall in west Africa as this basin has warmed since 1960 (Adedoyin 1989).

Conclusion

The foregoing analysis of rainfall over Accra shows some temporal characteristics. The seasonal rainfall for the 1961–90 subset indicates that April, June, July, August and September have a higher 30-year mean rainfall than in the preceding two subsets (1901–30 and 1931–60). The 1931–60 subset experienced the highest 30-year rainfall in February, March, May, October and November, while the subset for the early part of the century (1901–30) recorded the highest 30-year rainfall in December and January. The annual rainfall fluctuations exhibit patterns of varying periods. There is a general decrease in annual rainfall over the period under study. The decrease has been sharper since the drought period of 1980.

The trend for various equal subsets shows some remarkable departures from the long-term trend. The early part of the twentieth century (1901–30) depicts a general decrease in rainfall with an annual mean of 705.0 mm while the subset in the middle of the century

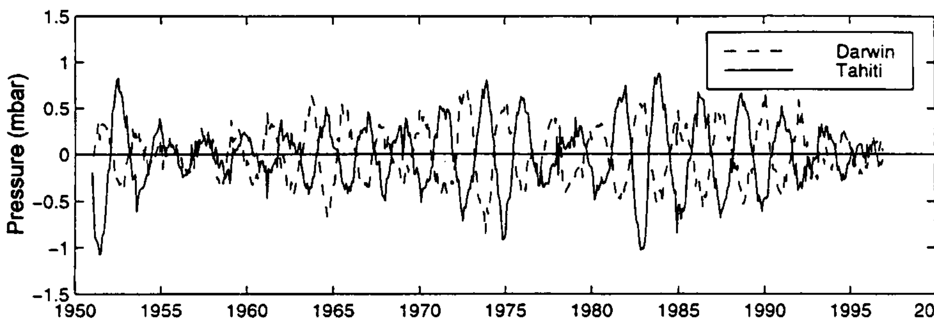

Fig. 5 The Southern Oscillation, the interannual fluctuations in pressure that are out of phase at Darwin (Australia) and Tahiti (from Philander 1998)

(1931–60) has an annual mean of 788.1 mm. This middle period is used as the standard 'normal' in Ghana. However, the later subset (1961–90) has the highest annual mean rainfall (809.8 mm). This period of highest rainfall is attributed to a few years of high values, particularly 1968, 1963 and 1962.

In west Africa, the occurrence of ENSO has been found to influence the rain-producing mechanism. Studies have revealed that rainfall trends in Africa are influenced by the global-scale SST anomalies as the tropical circulation pattern is changed. This reduces the intensity of the south-west monsoon into west Africa. A number of ENSO events coincide with periods of drought in Accra (1903–06, 1912, 1915, 1919–20, 1923, etc.). It is being realised that the South Atlantic SST anomalies bear some relationship to west African rainfall (Adedoyin 1989).

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Readers' Forum

Readers are invited to contribute short questions on any meteorological topic. We will endeavour to obtain answers to all submitted questions.

I recently watched a video called "Savage skies"(the section called "Riders of the storm") and was very interested in learning about the existence of sympathetic lightning patterns. These have been observed from the space shuttle and pilots of high-altitude flight tests, such as the X15 project of the early 1960s. I understand that little is known of this phenomenon. It occurs from the tops of thunderheads and it is thought to be a plasma discharge in the form of jets and sprites up to 100 km in altitude. I would be interested to learn more about this.

Aylesford, Kent **Stuart Ayley**

Craig J. Rodger (Department of Physics, University of Otago) replies:

To the best of my knowledge sympathetic lightning (also known as synchronous lightning) is unrelated to red sprites and blue jets. The sympathetic lightning phenomenon that was discussed has been reported by some space-based lightning observers. A discharge from one thunderstorm complex might trigger lightning discharges from other (nearby) thunderstorms, such that it appears that separated thunderstorms discharge simultaneously (obviously we expect near-simultaneity, with a small delay between the discharge that triggers another). This idea is based on observations from NASA astronauts and the Mesoscale Lightning Experiment, a ground-controlled payload-bay camera carried by the space shuttle. For