PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

Long-term Climatic Change in the Western Indian Ocean

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Long-term climatic change in the western Indian Ocean

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Analysis of rainfall records for stations on Mahé (Seychelles), Mauritius, Minicoy and Amini Divi (Laccadives), and other western Indian Ocean stations, shows substantial fluctuations in mean annual rainfall over the past 100 years, with high rainfalls at the beginning of this century, at about 1930, and at the present day, with troughs during 1915–20 and 1940–50. Overlapping series of more recent records for Aldabra, Assumption and the Iles Glorieuses also suggest substantial variations, and the existence of these is supported by episodic historical records. The consequences of such changes for the land biota of Aldabra, especially for the giant tortoises, are discussed, and brief reference is made to other types of evidence for climatic change on the atoll.

Introduction

Detailed climatic records have only been maintained at Aldabra since late 1968, though some rainfall data are available for earlier years (Stoddart & Mole 1977). Figure 1 shows that the atoll is located in the driest sector of the western Indian Ocean. Since 1968 it has become apparent that the variability of climate and especially of rainfall from year to year has major significance for the flowering and fruiting of plants, and hence for the feeding and breeding of insects, birds and reptiles. In reconstructing the development of the terrestrial ecosystem, therefore, it is important to determine the range of historical fluctuations in climate, as well as the direction and scale of changes over recent geological time.

In this paper we first use historical records for a number of western Indian Ocean stations to establish a regional view of climatic periodicities over the last century; secondly, we discuss and extrapolate the instrumental record on Aldabra itself; and thirdly, we suggest some biological consequences of the variations to which we draw attention, on a time-scale extending into the late Pleistocene.

Climatic changes at western Indian Ocean islands

Annual Rainfall

Figures 2 and 3 show 10 and 20 year running means of annual rainfall over the past 80–100 years for six island locations in the western Indian Ocean. Three (Amini Divi, Minicoy, Pamban) are situated in the northern Indian Ocean between 8 and 12° N; Mahé is an equatorial station at 4° S; and Tananarive (Madagascar) and the Royal Alfred Observatory (Mauritius) are southern Indian Ocean stations between 18 and 21° S.

All the stations display considerable fluctuations over the period of record, and these are summarized (together with Zanzibar) in terms of 'rainfall epochs' in table 1. The epochs are based on the Seychelles record as identified from the annual deviations from the 1901–30 normals, although the magnitude and timing of epochs on different islands vary considerably.

In the northern Indian Ocean, Minicoy and Amini Divi were characterized by low rainfalls before 1905, higher rainfalls from 1905 to 1937, lower rainfalls from 1938 to 1958, and markedly higher rainfalls since 1959. The trends at Pamban are less clear, with high rainfalls before 1905 and from 1923 to 1937, and lower rainfalls from 1905 to 1922 and since 1938. Pamban does not show a recent increase. At Mahé, Seychelles, in the equatorial Indian Ocean, the changes in annual rainfall are dramatic in terms of scale, periodicity and consistency. High rainfalls

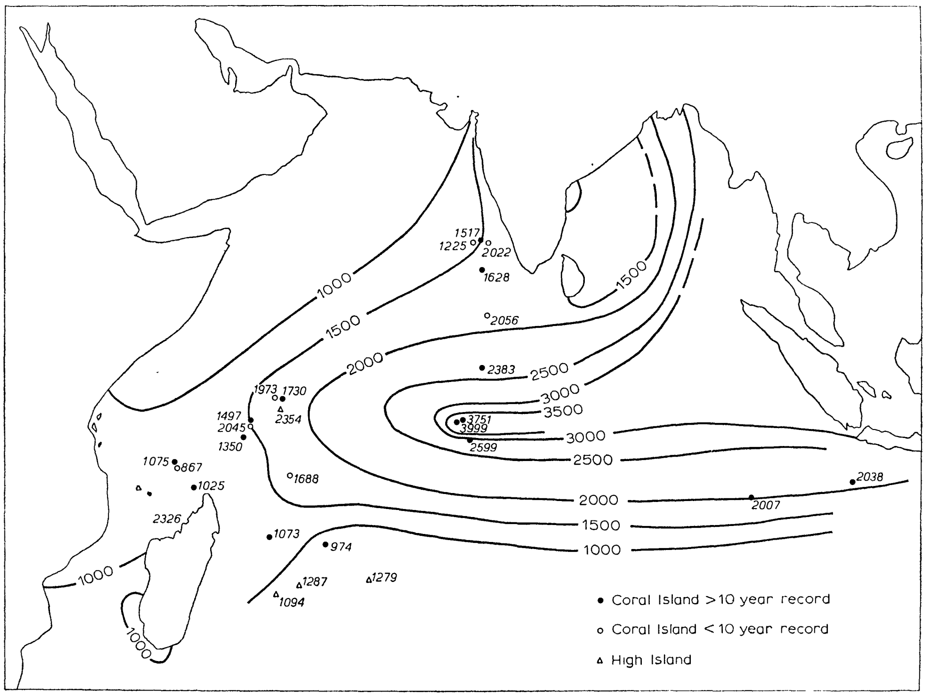

Figure 1. Distribution of mean annual rainfall (millimetres) over the Indian Ocean from coral island data.

occurred before 1905, from 1923 to 1937, and since 1959; markedly lower rainfalls characterized the intervening 1905–22 and 1938–58 epochs: Aspin (1976) has already drawn attention to the scale of these variations since 1941. The changes are of the order of 500 mm, or 20% between each period, and all are statistically significant at the 99% confidence level. Similar fluctuations are indicated by the unfortunately shorter and broken record at Zanzibar (interrupted by a change of site), although here the peaks and troughs appear to occur a few years later than in Seychelles. Long series of rainfall data are not available for other equatorial stations, but records are available for five stations since 1931. Table 2 summarizes the results and shows that marked increases in rainfall have occurred along the equatorial east coast of Africa, at the northern tip of Madagascar, and in the Comores. In the cases of Garissa and Diego Suarez the increases were exceptionally high (35–36%) and even greater than those at Mahé.

In the southern Indian Ocean, the long Mauritius record at the Royal Alfred Observatory (which after its record ceased in 1959 was extended by cross-correlation with that at the nearby Pamplemousses S.I.R.I. station) displays interesting trends, recently confirmed by Morales (1977) for the nearby Pamplemousses Garden station. The underlying trend from 1875 until the 1930s is markedly positive. Very low rainfalls occurred in the early part of the record and recurred in the late 1930s and 1940s, with a series of drought years from 1947 to 1951. Rainfall

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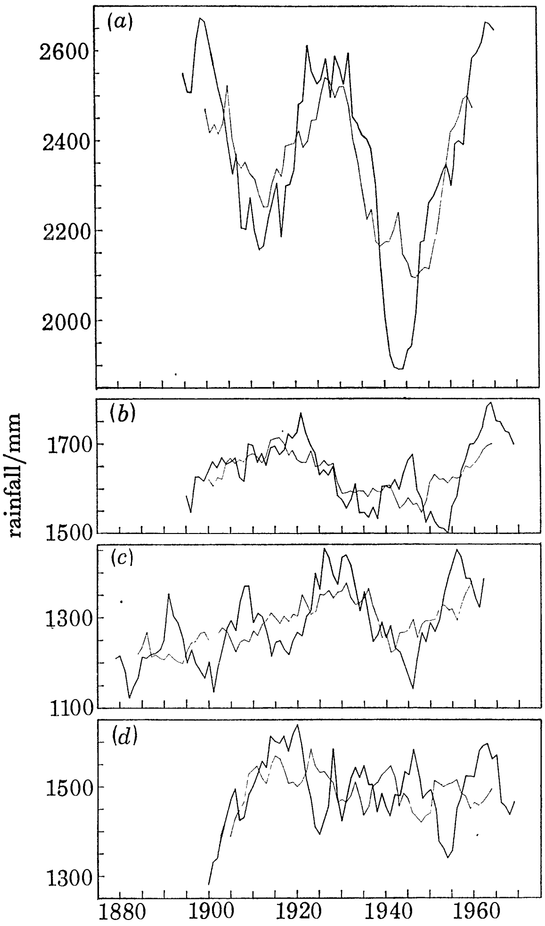

FIGURE 2. Annual rainfalls: 10 year (——) and 20 year (——) running means for (*a*) Mahé, (*b*) Minicoy, (*c*) Mauritius and (*d*) Amini Divi.

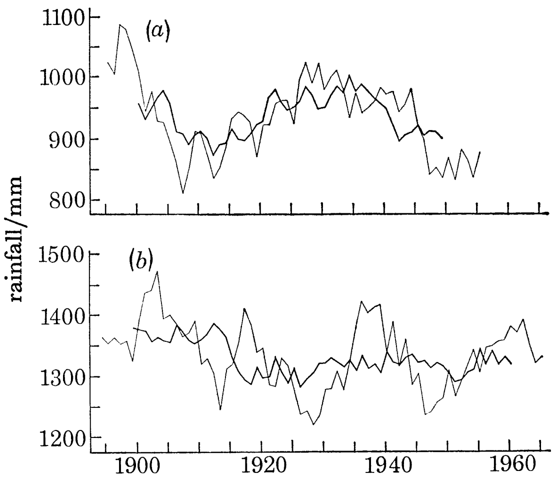

FIGURE 3. Annual rainfalls: 10 year (——) and 20 year (——) running means for (*a*) Pamban and (*b*) Tananarive.

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Table 1. Changes in Indian Ocean rainfall

station	territory	period of record	mean annual rainfall/mm								
			–1904	1905–22	% change	1923–37	% change	1938–58	% change	1959–74	% change
Amini Divi	Laccadives	1889–1974	1310	1454	+11	1513	+4	1413	−7	1580	+12
Minicoy	Maldives	1891–1974	1593	1684	+6	1622	−4	1553	−4	1747	+12
Pamban	India	1891–1960	975	908	−7	982	+8	899	−8	.	.
Mahé	Seychelles	1891–1970	2600	2192	−16	2652	+21	2105	−21	2528	+20
Zanzibar	Tanzania	1892–1931	1560	1482	−5	1535	+4	.	.	.	.
Tananarive	Madagascar	1890–1970	1342	1385	+3	1280	−8	1311	+2	1331	+2
Royal Alfred	Mauritius	1875–1971	1202	1307	+9	1383	+6	1273	−8	1349	+6

has again been higher since 1952. Brooks (1919), using earlier records from 1853 to 1879, showed that the early marked upward trend in Mauritius rainfall dated back to at least 1853. He calculated the average increase in annual rainfall over the period 1853–79 to be 14.7 mm a^{-1}, or approximately 400 mm over the 27 year period. The Tananarive record, which dates from 1890, shows no really marked changes, although the 10 year running means show the existence of relatively minor rainfall peaks around 1903, 1918, 1938 and 1960, with intervening troughs. There has been a recent increase in rainfall, though this is much less marked than in the equatorial areas.

Table 2. Recent rainfall changes in the equatorial Indian Ocean region

station	territory	lat. S and long. E		rainfall/mm 1931–60	rainfall/mm 1961–73	% change
Garissa	Kenya	0° 25′	39° 40′	280	378	+35
Dar-es-Salaam	Tanzania	6° 29′	39° 18′	1043	1168	+12
Diego Suarez	Madagascar	12° 17′	49° 18′	915	1248	+36
Grande Comore	Comoro Is	11° 42′	43° 14′	2639	2714	+3
Mayotte	Comoro Is	12° 49′	45° 17′	1170	1283	+10

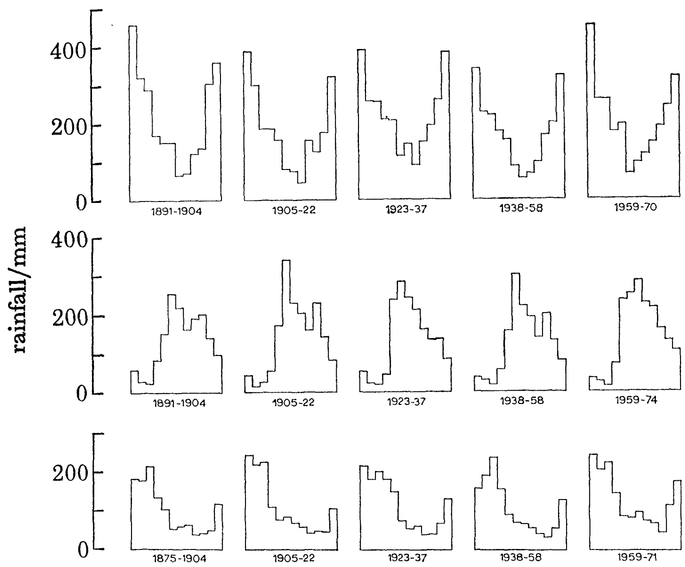

Figure 4. Changes in rainfall régimes at (*a*) Minicoy, (*b*) Mahé, and (*c*) Mauritius.

Seasonality and occurrence of dry periods

Changes in rainfall régime at Minicoy, Mahé and Mauritius are shown in figure 4; 10 year running means of the mean number of dry months (less than 4 in or 102 mm) per annum and 20 year frequencies of dry periods of different durations for the same three stations are shown in figure 5 and table 3.

At Minicoy, the most marked feature is the absence of the normal secondary maximum of rainfall in October during the recent 1959–74 period, when the markedly increased annual rainfall has been concentrated into the summer period. Thus, interestingly, lengths of drought were longer in the wetter than the drier epochs, although the mean number of dry months did not change significantly during the period of record. At Mahé, most of the increase in rainfall in the wetter epochs occurred in the summer months. Markedly longer droughts characterized

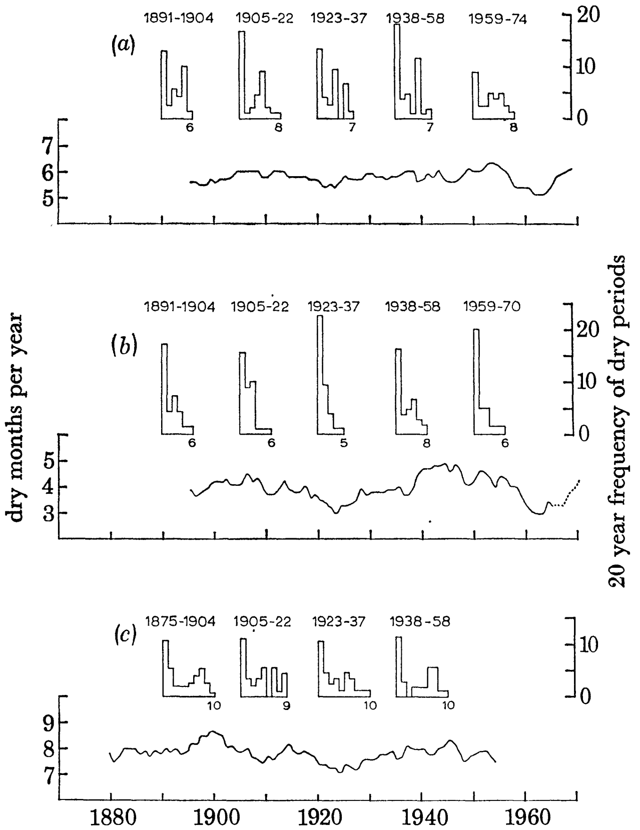

FIGURE 5. Ten year running means of number of dry months (102 mm) per annum (curves) and 20 year frequencies of dry periods of different durations (histograms) for (*a*) Minicoy, (*b*) Mahé and (*c*) Mauritius.

TABLE 3. TWENTY YEAR FREQUENCIES OF LENGTHS OF DRY PERIODS OF DIFFERENT DURATIONS IN DIFFERENT RAINFALL EPOCHS

station	period	length of dry period (successive months each with less than 102 mm) 1	2	3	4	5	6	7	8	9	10	mean number of dry months per year
Minicoy,	1891–1904	12.9	2.8	5.7	4.3	10.0	1.4	—	—	—	—	5.71
Laccadives	1905–1922	16.7	1.1	2.2	4.4	8.9	2.2	1.1	1.1	—	—	5.83
	1923–1937	13.3	4.0	2.7	9.3	0.0	6.7	1.3	—	—	—	5.14
	1938–1958	18.1	3.8	4.8	1.0	11.4	1.0	1.9	—	—	—	6.00
	1959–1974	8.8	2.5	2.5	5.0	3.8	5.0	2.5	1.3	—	—	5.50
Mahé,	1891–1904	17.2	4.3	7.2	4.3	1.4	1.4	—	—	—	—	4.00
Seychelles	1905–1922	15.5	8.9	10.0	1.1	1.1	1.1	—	—	—	—	4.00
	1923–1937	22.6	9.3	4.0	1.3	1.3	1.9	—	—	—	—	3.26
	1938–1958	16.2	3.8	4.8	6.7	2.9	1.9	—	—	—	—	4.57
	1959–1971	20.0	5.0	5.0	1.7	1.7	1.7	—	—	—	—	3.50
Royal	1875–1904	10.7	5.4	2.0	2.0	2.0	2.7	4.0	5.4	2.7	0.7	8.10
Alfred,	1905–1922	11.1	3.3	2.2	3.3	5.5	0.0	5.5	1.1	4.4	—	7.50
Mauritius	1923–1937	10.6	4.7	2.4	3.5	1.2	4.7	3.5	1.2	1.2	1.2	7.47
	1938–1958	11.4	2.9	0.0	1.9	1.9	1.9	5.7	5.7	1.2	1.2	7.87
	1959–1974				no comparable data							—

the very dry 1938–58 epoch. The mean number of dry months per year ranged from 4.00 in the two early epochs, down to 3.27 in the wet 1922–37 period, to as high as 4.52 in the dry 1938–58 period, declining to 3.50 since 1959. At the Royal Alfred Observatory, the two wet epochs are characterized by longer wet seasons. In the wet 1922–37 epoch, rainfall was markedly higher in April and May (at the end of the wet season); in the recent 1959–71 wet period, most of the increase in rainfall was accounted for during the early part of the wet season in November and December. Significantly longer droughts occurred in the dry 1875–1904 and 1938–58 periods than in the wetter 1923–37 epoch.

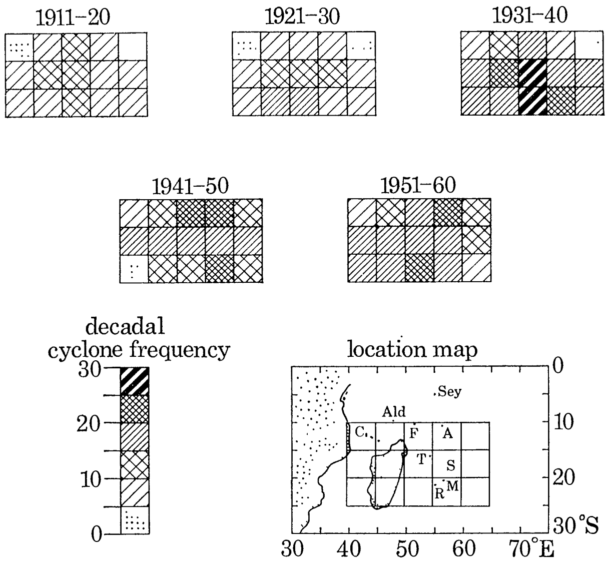

FIGURE 6. Changes in the spatial distribution and frequency of cyclones in the southwest Indian Ocean 1911–60.

Tropical cyclones

Milton (1974) examined changes in cyclone frequency for the main hurricane belts of the world, including those of the Indian Ocean. In both the Bay of Bengal and the southwestern Indian Ocean, there have been marked fluctuations since 1890. In the Bay of Bengal, peaks occurred around 1900 and from 1920 to 1950, with troughs from 1900 to 1910 and since 1950. In the southwestern Indian Ocean, similar peaks and troughs are evident, although they occur about 10 years later than in the Bay of Bengal.

By using charts of cyclone tracks compiled by Chaussard & Laplace (1964), changes in the spatial distribution of cyclones in the southwest Indian Ocean between 10 and 25° S were plotted for 5° squares of latitude and longitude during each decade from 1911 to 1960 (figure 6). There are marked spatial changes in cyclone frequency. The general increase in frequency in the 1930s was concentrated in the central Madagascar, Tromelin, and Mauritius–Réunion squares and the area off the southeastern coast of Madagascar. In the decade 1941–50, the main area of cyclone activity shifted north into the Farquhar and Agalega squares, although frequencies remained high in the Mauritius–Réunion area. The 1951–60 period was characterized by a marked increase in cyclone frequency over southern Madagascar and in the adjacent ocean areas off the southern eastern and western coasts of the island. Clearly local spatial shifts in cyclone tracks are as important as regional changes in cyclone frequency in this sector of the Indian Ocean.

Mechanisms of change

The changes in rainfall here identified can be related to known variations in atmospheric circulation and associated changes in ocean currents and sea surface temperatures. These variations have been of different character in different sectors of the Indian Ocean.

The sustained increase in Mauritius rainfall from 1853 until the 1930s can be directly correlated with a marked southward shift in the location of the intertropical trough at the height of the southern summer in January (Lamb & Johnson 1959), from a mean position of $5\frac{1}{2}°$ S in 1850–89 to $10\frac{1}{2}°$ S in the period 1900–39. This shift may also account for the increased cyclone frequency in the Mascarenes in the 1930s.

Table 4. Aldabra: monthly rainfall (in millimetres)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	total for year
1949	—	—	—	—	—	2	26	0	0	0	13	57	—
1950	95	219	423	272	6	24	0	16	37	10	23	67	**1192**
1951	92	60	—	221	46	—	13	32	0	7	70	—	—
1952	160	306	29	250	13	18	4	0	—	—	—	—	—
1953	—	—	54	67	30	38	—	—	—	—	—	—	—
1958	92	101	40	36	2	2	9	8	4	2	45	40	**381**
1959	102	199	6	1	0	1	1	4	4	0	19	12	**349**
1967	—	—	—	—	—	—	—	—	—	3	147	5	—
1968	12	28	133	72	21	38	70	15	10	117	57	85	**547**
1969	153	147	152	394	176	37	39	14	19	12	55	57	**1254**
1970	48	85	140	211	32	30	34	26	7	21	13	56	**700**
1971	245	57	286	193	35	66	14	19	9	6	90	202	**1220**
1972	225	15	112	162	28	100	55	75	4	13	26	240	**1055**
1973	261	287	263	57	57	48	81	25	22	34	9	78	**1221**
1974	291	115	381	346	50	29	52	32	2	1	19	149	**1467**
1975	131	163	111	167	77	41	16	15	15	3	92	136	**966**
1976	358	177	261	87	67	64	65	35	5	0	17	104	**1241**
n	14	14	14	15	15	15	15	15	14	15	15	14	**12**
mean	162	140	171	169	43	36	32	21	9	8	46	92	**966**

The recent marked increase in rainfall and the disappearance of the double maximum at Minicoy and Amini Divi may result from the failure of the northern hemisphere intertropical trough to advance as far north over the Indian subcontinent as formerly. A second factor, noted by Sana (1974), may be a decrease in strength of the southwest monsoon winds, with a parallel decrease in the strength of monsoon-driven currents. When the monsoon is strong (as during 1930–59), cool upwelling water from the Somali coast arrives in the Laccadives in midsummer, and the consequent reduced sea surface temperatures lead to a decline in evaporation and rainfall until the current weakens in the autumn. Since 1960 the current has often not been as strong as formerly: sea surface temperature and midsummer rainfall have increased, giving a single rather than a double rainfall peak. A third possible factor is the decline in cyclone frequency in recent years, giving a reduction in autumn rainfall and also accounting for the occurrence of longer dry periods in recent years.

Changes in rainfall over the equatorial Indian Ocean are complex and cannot yet be fully explained. There has, however, been a shift towards the equator of the subtropical high pressure belts in recent years, with the restriction of the intertropical troughs to narrower zones on either

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side of the equator (Lamb 1966, 1974). This has resulted in increased rainfall in the equatorial belt and markedly decreased rainfall over most of the rest of the tropics. The earlier peaks in rainfall noted in the Seychelles before 1905 and from 1923 to 1937 are more difficult to explain. The southward shift in the January position of the southern intertropical trough to a position of 10° S by the 1930s may account in part for the decline in rainfall after 1905, but the 1923–37 peak remains unexplained.

An important factor in explaining rainfall trends in the western Indian Ocean is that of sea surface temperatures, ocean currents, and upwelling and advection of cool water off the East African coast south of the equator at the height of the northwest monsoon in January and February. In 1963–4 the International Indian Ocean Expedition noted two areas of very warm water (27–29 °C) separated by a tongue of cold water (17–20 °C) off the East African coast (Lamb 1966). Changes in the strength of the northwest monsoon and in the location of cold and warm water areas will have marked consequences on rainfall. Changes in cyclone frequency in the Bay of Bengal can be directly related to changes in sea surface temperatures (Frost 1966). It is generally accepted that sea surface temperatures of at least 26–28 °C are necessary for cyclone development, and shifts of the magnitude of those identified in the western Indian Ocean could be of critical importance in controlling cyclone frequency. The lower temperatures of 1900–29 and 1960–4 account for the lower frequency of cyclones in those years, and the higher temperatures of 1930–59 explain the higher cyclone frequency of that period. Comparable changes have been identified in the Caribbean area, where more data are available (Walsh 1977).

Climatic change at Aldabra

The rainfall records for Aldabra (table 4 and figure 7) and for adjacent islands are short and discontinuous. Good records date only from 1968. All that can be said about rainfall trends at Aldabra is that compared with the 12 year mean, 1950 was reasonably wet, 1951–3 relatively dry, 1958 and 1959 extremely dry, 1968 dry, and the years 1969–76 rather wet. However, analysis of such limited data is clearly inconclusive as regards longer term trends.

Extrapolation of trends, based on cross-correlation of existing Aldabra data (1950, 1958–9, 1968–76) with the corresponding annual data of other Indian Ocean stations with much longer records, was attempted, with mixed results (table 5). Reasonable positive correlations were obtained between Aldabra rainfall and that of Amini Divi and Minicoy in the Laccadives, and a strong negative correlation (−0.80) emerged between Aldabra and Mauritius rainfall. This was expected: Aldabra (10° S), like the Laccadives (10° N), is relatively equatorial and hence has higher rainfall when the intertropical troughs are more confined to equatorial latitudes; high rainfalls in Mauritius (20° S), on the other hand, occur when the intertropical trough migrates further from the equator. Extrapolating from these relations, one would expect that the present rainfall on Aldabra is considerably higher than that of the period 1930–60. One would also expect Aldabra to have been markedly wetter in the mid-nineteenth century, when Mauritius rainfall was low and the intertropical trough in January was located near $5\frac{1}{2}$° S.

On the other hand, correlations were very low between the rainfall at Aldabra and at other much closer Indian Ocean stations. Thus the correlation with Seychelles was −0.13, with Diego Suarez −0.14, and with the Iles Glorieuses (the closest meteorological station to Aldabra) only +0.01. These may be explained in terms of the very localized nature of rainfall and rainfall-producing mechanisms both in the tropics in general and the western Indian Ocean in particular.

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These include: (1) the precise position of the intertropical troughs during any one summer; (2) the relation between the exact longitudinal positions of the recently discovered cross-equatorial low-level jets (Findlater 1969) and rainfall patterns in the area in any one summer; and (3) the spatial distribution and extent of cold and warm bodies of water off the East African coast, particularly in the southern hemisphere summer. Also, it should be stressed that the lack

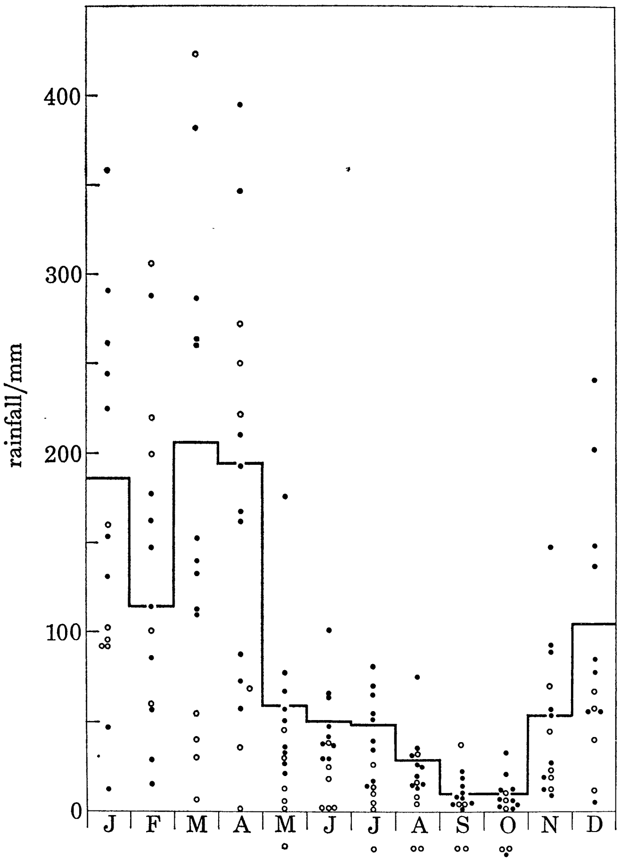

FIGURE 7. Monthly rainfalls at Aldabra (open circles 1949–59; closed circles 1967–76).

TABLE 5. ALDABRA RAINFALL: CORRELATIONS WITH THE ANNUAL RAINFALL OF OTHER INDIAN OCEAN STATIONS

location	territory	lat. and long.		no. of years overlap	correlation coefficient	rainfall since 1961 as % of 1913–60 mean
Amini Divi	Laccadives	11° 07′ N	72° 44′ E	10	+0.33	+7
Pamban I.	India	9° 16′ N	79° 35′ E	8	+0.53	+1
Minicoy	Laccadives	8° 18′ N	73° 00′ E	10	+0.30	+9
Garissa	Kenya	0° 25′ S	39° 40′ E	6	−0.63	+35
Mahé	Seychelles	4° 37′ S	55° 27′ E	6	−0.13	+20
Dar-es-Salaam	Tanzania	6° 29′ S	39° 18′ E	7	−0.24	+12
Aldabra		9° 22′ S	46° 28′ E	*	*	*
Agalega		10° 30′ S	56° 00′ E	6	−0.70	ND
Isles Glorieuses		11° 30′ S	47° 20′ E	8	+0.01	ND
Grande Comore	Comoro Is	11° 42′ S	43° 14′ E	6	+0.48	+3
Diego Suarez	Madagascar	12° 17′ S	49° 18′ E	8	−0.14	+36
Mayotte	Comoro Is	12° 49′ S	45° 17′ E	8	+0.67	+10
Tananarive	Madagascar	18° 54′ S	47° 32′ E	6	−0.13	+5
Royal Alfred	Mauritius	20° 06′ S	57° 33′ E	7	−0.80	+3

of correlation between *annual* data at two locations does not preclude the existence of *longer-term* correlations between rainfall trends at the two stations.

An alternative, simpler, and perhaps more conclusive way of estimating recent changes in rainfall at Aldabra is to examine general spatial patterns of change in the Indian Ocean. It is almost certain that the rainfall of Aldabra since 1960 has been considerably above that of the 1931–60 normal, since all stations in the region recorded an increase in this period (table 5),

TABLE 6. ALDABRA RAINFALL (millimetres) 1949–59 AND 1967–76

period	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	year
1949–59	108	177	110	141	16	14	9	10	9	4	34	44	676†
n_1	5	5	5	6	6	6	6	6	5	5	5	4	—
1967–76	192	119	204	188	60	50	47	28	10	10	53	111	1075†
n_2	9	9	9	9	9	9	9	9	9	10	10	10	9
change	+84	−58	+96	+47	+44	+36	+38	+18	+1	+6	+19	+67	+399

† Annual mean calculated from sum of monthly means.

and the locations nearer to Aldabra markedly so. This inference is supported by the limited Aldabra data available (table 6). Broad comparisons with long-term trends in the Seychelles and Zanzibar suggest wet phases around the turn of the century, from 1922 to 1937, and since 1960, and markedly drier phases in the intervening periods. Both the Aldabra record and shorter-period records form a larger number of stations in the equatorial Indian Ocean appear to confirm the last two of these phases, namely the dry phase of the 1930s, 1940s and 1950s and the considerable increase in rainfall since 1960. Lastly, and more tentatively, much higher rainfalls in Aldabra around the middle of the nineteenth century are indicated by correlation with the Mauritius records and the documented evidence of the intertropical trough lying much closer to the equator at that time.

There is only fragmentary direct evidence for such changes at Aldabra and nearby islands before the first modern records in 1949. In 1878, goats were reported to have died on Cosmoledo because of lack of rainfall (Rivers 1878). Spurs (1891, p. 48) reported a fall of 6 in (152 mm) of rain in 24 h at Aldabra during a cyclone (the most recent daily maximum is 166 mm on 7 April 1969), but Abbott (1893, p. 760) commented that in spite of this 'sometimes many months elapse during which not a drop of rain falls'. Abbott himself (1893, p. 761) recorded monthly totals of 0 in October, 0 in November, and 15 in (381 mm) in December 1892. Voeltzkow (1897, p. 75) cites the same figures but gives the year as 1895, the time of his own visit. Baty (1895) stated that no rain fell at Astove and Cosmoledo from June to November 1895, or at Aldabra for two months before 17 November 1895. Dupont (1907) gives monthly figures for October 1906 to January 1907. The total fall in this period was 866 mm, which compares with the recent October–January mean of 352 mm, but 73% of the total came in the month of January, with 636 mm (recent January maximum 358 mm), presumably from a hurricane. These scattered figures are at least consistent with the inferences given above. It might also be noted that in the late 1930s, D. Vesey-FitzGerald (1942), a very experienced ecologist, estimated the annual rainfall of Aldabra as only 15 in (less than 400 mm).

Some implications

If, as seems likely, mean annual rainfall has fluctuated at Aldabra between *ca.* 500 and *ca.* 1500 mm over a period of decades, the consequences for geomorphology and especially land biota will have been considerable. Thus there is evidence in the surface features, especially in the platin, that freshwater pools have been much more extensive in the past than at present (Stoddart *et al.* 1971, p. 60). Abbott (1893, pp. 760 and 763) suggested that large dead trees with trunks up to 2 ft (60 cm) in diameter on Picard indicated former wetter conditions, and Grubb (1971, p. 355) considered that climatic change might have been responsible for the extensive death of *Guettarda* trees along the south coast. There is scope for analysis of growth conformations and tree rings in some of the larger trees and shrubs on Aldabra, to see if any periodicities are revealed. Cogan *et al.* (1971, p. 322) comment also on the effect of dry years on the insect fauna. But the most obvious effect may well have been on the tortoises. Bourn (1977) has shown a direct relation between breeding behaviour and rainfall, and elsewhere in this volume Stoddart & Peake (1979) summarize historical evidence of fluctuations in the tortoise population.

On a longer time scale, linkages become more speculative. Braithwaite *et al.* (1973, p. 330) suggested a higher rainfall than at present during the last glacial maximum, forming submarine solution grooves and buttresses along the north coast (and perhaps also the 6 m deep karren on Ile Esprit). Arnold (1976, p. 113), on the other hand, proposed that extended drought in the late Quaternary may have led to lizard extinctions through a reduction in habitat diversity. Simulations of late Pleistocene climate, however, suggest no marked divergence either in wetness or dryness in this sector of the Indian Ocean (Climap 1976; Manabe & Hahn 1977), and certainly the effect of sea level change alone, through water table fluctuation, would probably have outweighed purely climatic effects on the local biota.

Nevertheless, speculative as these comments are in the longer term, our analysis has suggested that any interpretation of the present terrestrial ecosystem on Aldabra must take account of considerable climatic fluctuations over the lifespan of the dominant organisms now inhabiting the atoll.

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