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JULY–AUGUST RAINFALL IN WEST-CENTRAL KENYA

T. D. DAVIES AND C. E. VINCENT
School of Environmental Sciences, University of East Anglia, Norwich, NR4 7TJ, U.K.

A. K. C. BERESFORD
Department of Maritime Studies, University of Wales Institute of Science and Technology, Cardiff, U.K.

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ABSTRACT

The annual rainfall distribution in west-central Kenya (34°–38°E, 1°N–1°S) exhibits marked spatial variation because of the complicated nature of the local topography. The annual distributions are classified into a number of types on the basis of 'rainfall seasons'. Over parts of the area of study, precipitation falling in July and August makes an important contribution to the yearly total (up to 33 per cent). The spatial variation of the rainfall in this period, during the so-called 'dry season' over much of Kenya (between the two main 'monsoon' rains) is examined in some detail, especially its relationship with altitude. The distribution of the July and August rainfall indicates that it is associated with a westerly airstream overlying the lowest layers of the atmosphere.

KEY WORDS Kenya rainfall July–August Kenya rainfall Rainfall seasonality in Kenya Rainfall–topography relationships in Kenya

RAINFALL IN EAST AFRICA

The main rain-bearing systems over much of East Africa are commonly associated with the passage of the Inter-Tropical Convergence Zone (ITCZ), although Griffiths (1972) concluded that it is impossible to fit large areas of the region into the classical double wet season equatorial model since mountains, plateaux and the larger lake basins distort the airflow and modify the rainfall distribution. The complicated nature of rainfall distribution was pointed out by Johnson (1962) who found that the evolution and decay of rainfall systems, often taking many days, were almost independent of any theoretical large-scale migrating rainbelt. Griffiths (1972) stressed the disturbance to the atmospheric flow caused by the highlands (especially in Kenya) and their influence on the movement of rainfall 'cells' or rain-producing 'storm cells'.

The comparative dryness of East Africa has been long noted (e.g. Trewartha, 1961; Griffiths, 1960). Only about one-quarter of the area of Kenya experiences average annual rainfall in excess of 500 mm. The annual distribution shows extreme areal variation (Survey of Kenya, 1971), especially around the central highlands (36°–38°E, 1°N–1°S). Annual totals are strongly related to altitude except near the coast, where distance inland is the major control; Trapnell and Griffiths (1960), Thompson (1966) and Coutts (1969) examined rainfall–altitude relationships in Kenya. Lumb (1970) considered both the influence of Lake Victoria and the local topography on rainfall distribution.

There are two major rainfall seasons over much of East Africa and a third season in parts of western Kenya and Uganda (East African Meteorological Department, 1962; Kenworthy, 1964). Hills (1978) used two six-day totals of rainfall per month to identify the timing of the rainy seasons in western Kenya and the Kenyan highlands. The first occurs in March–May; from July to September there is a wedge-shaped maximum stretching from the north-west which is particularly strong in August around the Lake Victoria and Mount Elgon areas and protruding towards Mount Kenya (Figure 1); the third

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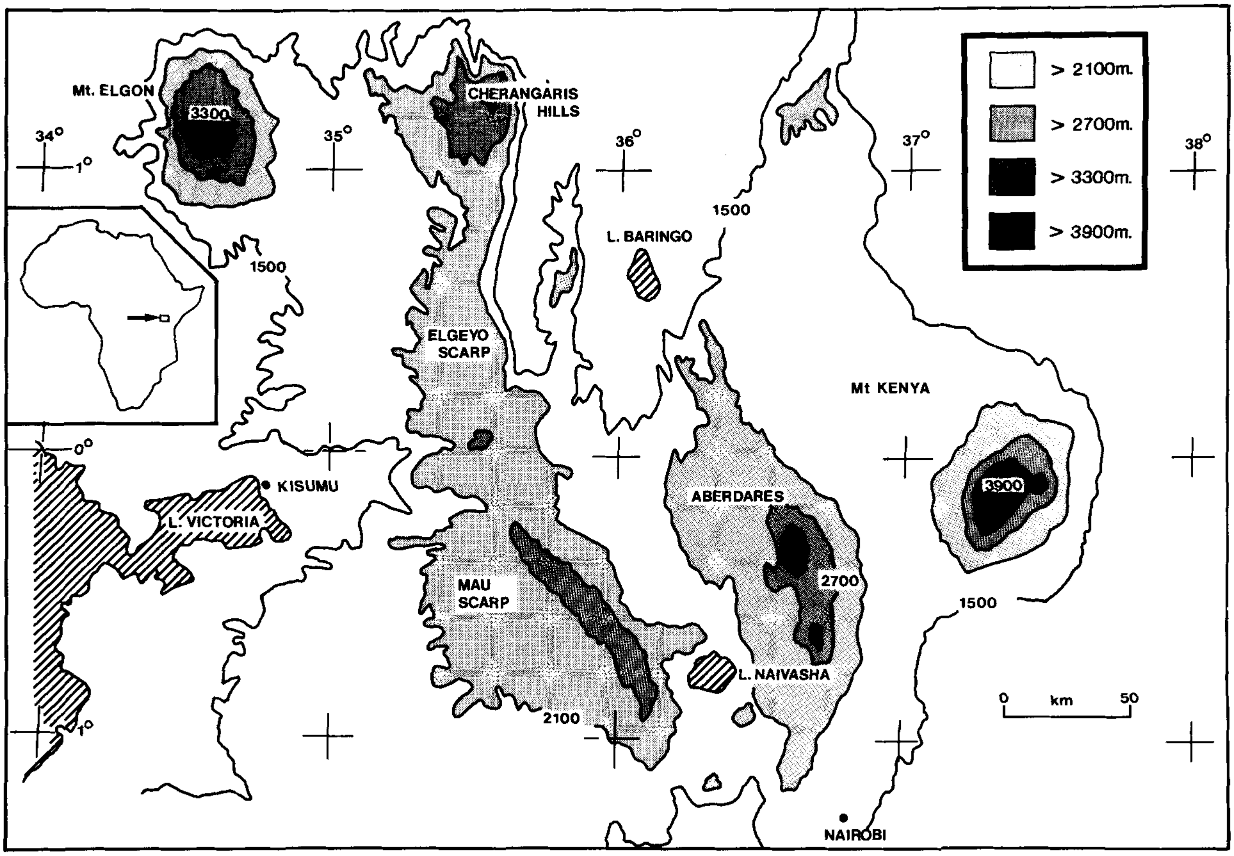

Figure 1. The area covered by this study. The contours are drawn at 600 m intervals from 1500 m upwards

rainy season is from October to December but seems to be most pronounced in November. Hills (1978) showed that the wedge-shaped distribution of rain which widens towards the north-west into Uganda in July and August is not internally homogeneous. These rains are unrelated to the two main rainy seasons and represent a resurgence of activity in a restricted area, although this may be connected with rainfall to the west. Hills (1979) suggested that the July–September rainfall in western Kenya is caused by fundamentally different mechanisms to the main seasons' rainfall.

Rainfall distribution maps in East Africa show considerable spatial variability, but the temporal variation is also pronounced so that there are important fluctuations in the nature of the two (or three, in a restricted area) rainy seasons, or the yearly cycle. Glover *et al.* (1954), Kenworthy and Glover (1958) and Griffiths (1972) have examined rainfall variability. An extreme example of the variability of East African rainfall is the heavy and persistent rainfall of late 1961, associated with the southward passage of the ITCZ. Thompson and Morth (1965) and Rodhe and Virji (1976) examined the nature of the event, and Bargman *et al.* (1965) speculated on the physical causes although these have not been firmly established. Odingo (1962), Thompson and Morth (1965), Morth (1971) and others, discussed the effects of the event and examined the likelihood of a repetition. Farmer (1981) examined the 1961 event and considered the regional variation in rainfall climatologies. This type of pronounced variability over time should be borne in mind when considering and assessing the rainfall climatology of East Africa.

East Africa is overlain by easterly airstreams which are dynamically stable at the equator (Flohn, 1960a). This subsiding air, and its associated inversion, inhibits upward motion and acts as a 'lid'. From his examination of rainfall distribution around Mount Kenya, Thompson (1966) deduced that the top of the south-easterlies lies at about 3700 m. The topography of East Africa means that low-level air from the west can penetrate to the western zones of the area. Moist westerlies at middle altitudes

(2000–3000 m) were first recognized by Flohn (1960b), and Thompson (1966) realized their importance in influencing the rainfall distribution in parts of highland Kenya. The July–September period is characterized by an extensive area of westerlies in the western parts of East Africa up to heights of at least 850 mb (Hills, 1979). At 700 mb a flow from the north-west affects highland Kenya and at 600 mb appears a diffluent pattern over the Lake Victoria area, which lies just to the west of the Kenyan Highlands (Figure 1). The beginning of this 'westerly surge' (Hills, 1979), associated with the true West African monsoon, appears to be the trigger for rainfall in western Kenya in July and August (especially) and September. The 'frontal zone' between the westerly flow and the south-east monsoon in July and August may become active when it is associated with convectional systems developing over high ground. In the highland areas, anabatic winds are important initiators of convectional development. Hills (1979) also stresses the deflective influence of East African topography. There is relatively pronounced divergence at around 500 mb in August over East Africa (greater than in any other month of the year) and this might encourage precipitation below. So the July–September rainfall in western Kenya has a completely different climatological structure to the two 'main' rainy seasons and appears to be linked to the westerlies, which are inherently unstable and often associated with deep, convective, thundery development, especially over highlands. This complex flow often involves turbulent overturning which may lead to rainfall maxima on leeward as well as windward slopes (Thompson, 1966).

Griffiths (1972) divided East Africa into a large number of rainfall 'regions' based on the progressive movement of the 50 mm monthly isohyet. He conceded that the adoption of an arbitrary threshold could be criticized, but maintained that any other reasonable threshold would exhibit broadly the same pattern. The regional rainfall map is extremely complex, especially in the area of Mount Kenya and the Aberdare Mountains (Figure 1), where the nature of the seasonality is unspecified. Much of the area between 35°–37°E and 1°N–1°S, in Kenya, is assigned broad—but different—rainfall seasons which show much variation in timing as well as in intensity. Farmer (1981) examined the seasonality of rainfall in East Africa and used factor analysis to delimit homogeneous areas under the influence of specific seasonal regimes. In the area of west-central Kenya considered in this study he identified a 'core area', where the prevalent seasonal pattern was two rainfall maxima in April–May and July–August, distributed in a narrow tongue from the north-west, between Mount Elgon and the Cheranganis Hills (Figure 1) down to the Mau Escarpment. Other areas of the west-central highlands exhibited factor loadings which were too small for them to be assigned a seasonality regime. The seasonality distribution within this area appears to be very complicated, especially because of the existence of the July–August rainfall 'peak' which has a considerable spatial variation which requires some clarification (Vincent *et al.*, 1979), a requirement which Hills (1978) had earlier identified with an appeal for further information.

The objective of this study is to examine the fine structure of the seasonal rainfall distribution in west-central Kenya, particularly the nature of the July–August peak. This is the major contributor to the noticeable departure of this area from the 'classical' two-rainy season distribution of much of the rest of the country. This study is restricted to Kenya, although the July–August rainfall peak continues north-westwards and westwards into Uganda (Kenworthy, 1964; Hills, 1978).

RAINFALL DATA

The area covered by this study is illustrated in Figure 1. The rain-gauge network for this part of Kenya is one of East Africa's densest. Glover *et al.* (1954) mapped the distribution of rainfall stations by quarter-degree squares and Griffiths (1960) described the distribution of rainfall stations in East Africa with more than twenty-five years of data. Today, the pattern remains essentially the same, although the network has been improved and records have lengthened. In central Kenya there has been a fourfold increase, since 1960, in the number of stations with more than twenty-five years data. Figure 2 shows the registered rain gauges for the area 34°–38°E, 1°N–1°S and their length of record. The rainfall series are often imperfect from the point of view of analysis. Besides the problem of missing observations,

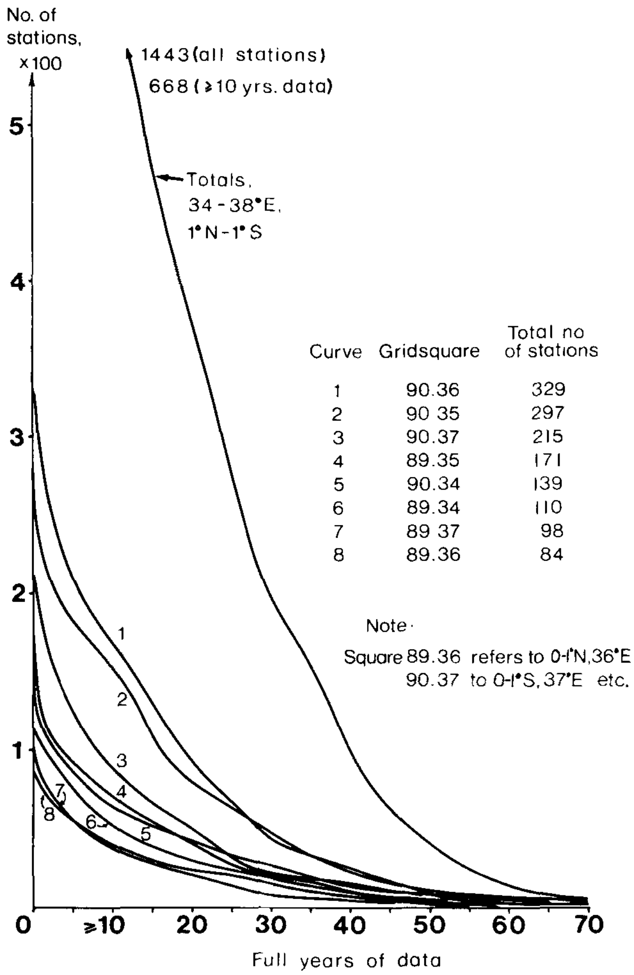

Figure 2. Registered rain gauges in central Kenya as at 1980 (source: Nairobi Meteorological Dept. H.Q.)

some of the series are not normally distributed. Griffiths (1960) tested 300 East African rainfall stations for normality and found that 24 per cent differed significantly from normal. After removing the highest annual total from these non-normal series, a further 14 per cent of the series became normal. Most of the remaining series were log-normally distributed. Rodhe and Virji (1976), in their analysis of 35 East African rainfall stations, found annual totals at 17 per cent of the stations to be non-normally distributed. They noted that deviations from normal were most common and most marked at the low-rainfall stations of northern Kenya.

Occasionally there are missing data, sometimes due to a particularly appropriate cause: '. . . the raingauge was washed away so I was unable to take readings for the next four months' (Kenya Meteorological Department rainfall records ledger). In spite of such irregularities, the records which have been assembled by the Kenya Meteorological Department are generally good, being well-ordered and well-presented. The small number of anomalies due to incorrect transcription or unit conversion are clearly evident on personal examination of the records.

For the purposes of this study the records from 346 stations were used. They were selected on the basis of:

(i) length and continuity of record (with >25 years of data where possible, but always with >10 years); of course, this is not ideal because trends do exist (e.g. Vincent *et al.*, 1979) although they have generally been ignored in previous studies

(ii) spread of altitudinal zones, from 1000 m to ~3000 m
(iii) coverage of each 1° grid-square in approximately the same proportion as the total number of available stations in each square.

The stations adopted are shown in Figure 3. The number of stations used to establish the July–August totals was so large that only the total number of rainfall records for each grid-square is illustrated.

Series from twenty-six 'primary' stations were also chosen to illustrate the variation in timing and intensity of the alternating dry and wet seasons within the study area. Locations of the 'primary' stations are shown in Figure 3; they were chosen on the basis of position and length of record.

RAINFALL SEASONALITY

Annual histograms for the primary stations are shown in Figure 4. Monthly mean values have been used. Some studies have used shorter periods (e.g. Hills, 1978) since there is a question over using a monthly interval in defining seasons, although sometimes the several-day periods used have not been consecutive, but have been separated by gaps. Other studies have used monthly values (e.g. Griffiths, 1972), although median values have also been used, especially for shorter-period rainfall totals, (Hills, 1978), because of non-normal distributions. However, the seasonal cycle on a monthly basis is normally expressed in terms of monthly means.

The data represented in Figure 4 illustrate the difficulties of classification of rainfall distributions in this part of Kenya (Griffiths, 1972). There is a considerable spatial variability which is not easy to quantify. Most of the seasonal distributions of the twenty-six stations clearly exhibit the 'classical' two

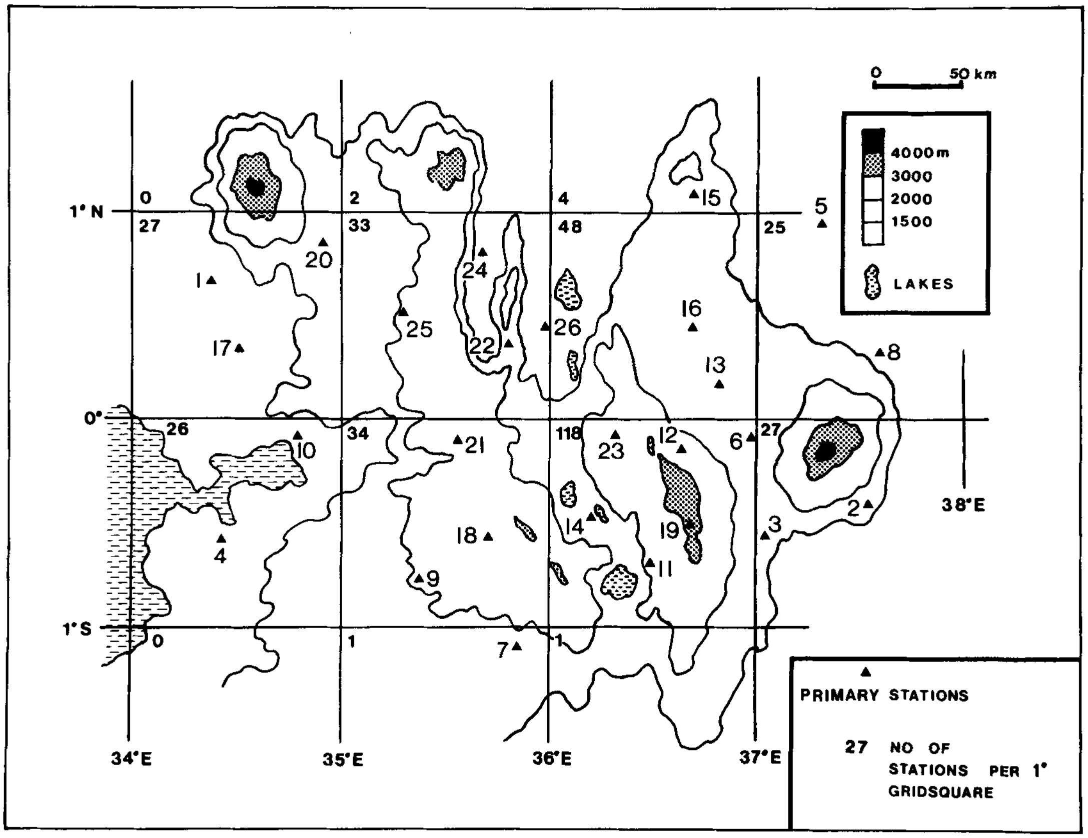

Figure 3. Location of central Kenyan rainfall stations used in this study. The figure 118 in the top left hand corner of gridsquare 0°–1°S, 36°–37°E indicates the number of stations used to provide monthly mean rainfall totals for the study

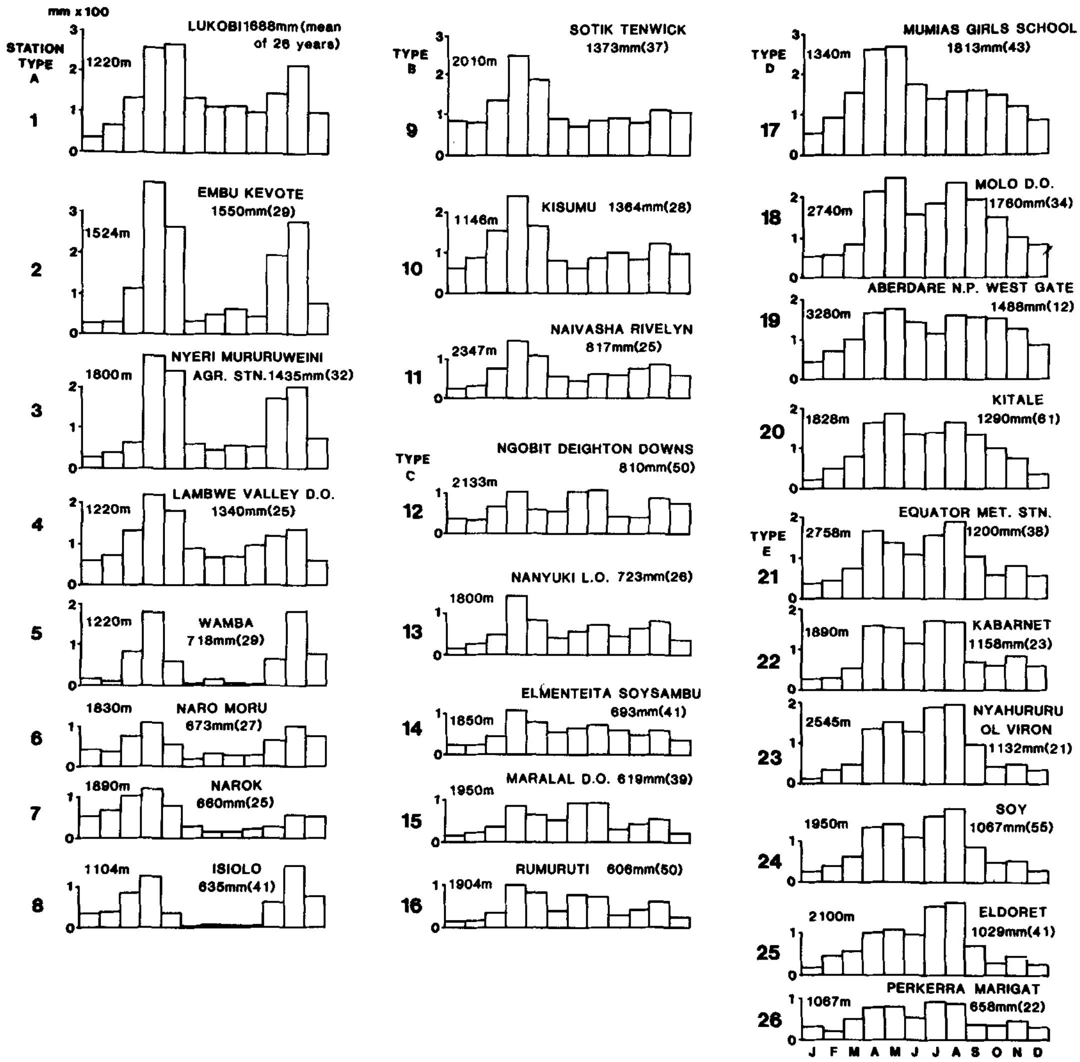

Figure 4. Rainfall histograms for the 'primary' stations shown in Figure 3 (1–26). The ordinate scale is mm (× 100). Indicated are station altitude, annual total and length of record in years. The distributions have been categorized according to rainfall seasonality. Station type A: two rainy seasons (April–May, October–November). Type B: one rainy season (April–May). Type C: three rainy seasons (April–May, July–August, October–November). Type D: two rainy seasons (April–May most pronounced, July–August). Type E: two rainy seasons (April–May, July–August most pronounced)

rainfall peaks at around April and around November, and the greater part of any departures from this pattern is due to the July–August contribution (compare stations 3 and 25, for example). At some locations, such as station 18, the 'July–August' peak may even have masked the November local maximum.

Although there is considerable variation in the shape of the annual curves, they are not suitable for simple objective analysis like harmonic-fitting because of the large variations in the amplitude of the two, or three, 'dominant' peaks; there is also a less noticeable phase shift. However, it is possible to ascribe crude 'seasonality regimes' on the basis of a semi-objective analysis which considers the relative magnitudes of the identifiable peaks (in relation both to other peaks and the 'non-peak' months). The analysis is not undertaken to provide a definitive classification of rainfall seasonality since these stations represent a relatively sparse network in an area which is known to be complex in rainfall climatology (Griffiths, 1972) and which has pronounced relative relief. Rather, it is to assess the range of seasonality regimes to provide a context into which can be placed the subsequent discussion of the nature of the July–August maximum.

Type A regimes (Figure 4) experience two marked rainy seasons (around April–May and October–November) with two dry seasons separating them. The criterion adopted was that each peak (one or two months) should have values more than twice as high as the mean of the other (non-peak months) and that there should be a pronounced trough between the peaks. Station 2 (Embu Kevote) does have a statistically significant (Student's *t* test, 5 per cent level) increase in rainfall from June to July and decrease from August to September but the July–August maximum is so overwhelmed by both the April–May and October–November peaks (each at least five times greater) that this station has been categorized as type A. Mean annual totals for this regime are very different from one station to another, with a range of 1688 mm (Lukobi; station 1) to 635 mm (Isiolo; station 8). Nyeri (station 3) and Embu (Station 2) experience the highest relative peaks of the high annual total stations, and both are especially exposed to the two trade wind systems (on the lower south-eastern slopes of the Aberdare Mountains and Mount Kenya, respectively). Two of the drier stations (Wamba, station 5; Isiolo, station 8) receive virtually no rain from June to September (in contrast to the other type A stations). Both stations are relatively low in elevation (1220 m and 1104 m) lying on gently undulating plains well to the east of the larger plateaux and escarpments. They are therefore less likely to be influenced by the moist winds of westerly origin between about 2000 and 4000 m elevation which may be a source of precipitation in July and August (Vincent *et al.*, 1979).

Type B rainfall regimes have well-defined 'long rains' in April and May which are much more dominant than the 'short rains' (November). The criteria for inclusion in this category were (a) the short-rain peak should be higher than July and August rainfall, and (b) the greatest rainfall month in the 'long rains' season should have a total which is at least 1·5 times the total of the greatest rainfall *month* in the 'short rains'. The stations in this category represent a large altitudinal range, from Naivasha Rivelyn (station 11) at 2347 m (in the Rift Valley, bounded by higher land to the east and west) to Kisumu (station 10) at 1146 m. Both stations are located on gentle west facing slopes, but Kisumu, on the shore of Lake Victoria's Winam Gulf, receives hot, humid air, mostly of lake origin, throughout the year. The effects of the north-east trades at Kisumu, Naivasha Rivelyn, Sotik (station 9) and other stations similarly located on west or south-west facing slopes are diminished by a simple lee effect. The relative dryness of Naivasha Rivelyn, despite its altitude, is probably due to the 'rain-shadow' effect of the Aberdare Mountains (3000–4000 m) to the south-east, east and north-east and of the Mau Escarpment (3000 m) about 40 km to the west.

The criteria for the type C regimes were (a) three distinct rainy seasons (confirmed by Student's *t* test for the differences in rainfall totals between the one, or two, months representing the peak and the monthly values either side of the peak, with a 5 per cent significance level), (b) the July–August peak to be less than twice the height of the November peak. All the five stations included in this category are at altitudes of between 1800 m and 2200 m and on the undulating plateau to the north and north-east of the Aberdare Mountains. At Maralal (station 15) and Ngobit Deighton Downs (station 12) 70 km further south, the mean rainfall received during July and August is greater than that recorded during either the 'long' or the 'short' rains. Both these stations are on relatively steep slopes (compared with the other type C stations) facing eastwards. Flohn (1960b) pointed out that the eastwards extension of potentially very moist Congo airstreams at about 2000–4000 m over the Kenyan highlands, which are most pronounced in July and August, may be bounded above and below by easterlies with either a southerly or northerly component. Turbulent overturning of the moist westerlies may bring this 'dry season' rainfall to the lee of high land. Nakamura (1969) further examined the nature of the westerlies and Vincent *et al.* (1979) postulated on the connection between these winds and July–August rainfall.

Rainfall types D and E stations are both 'double maximum' (April–May and July–August) annual distributions. Type D stations have the higher peak in April–May. None of the four stations in this group exhibits a separate 'short rain' (November) peak, probably because there is an interference by the July–August (and probably September) rains which is masking any smaller, and subsequent, contribution associated with the southward movement of the ITCZ. Each station exhibits a monthly decline in precipitation from September (August in three cases) to January. The July totals for each station are significantly different (5 per cent level) from the June totals. Type E rainfall stations have July–August peaks absolutely greater than both 'short rain' and 'long rain' peaks. It is also interesting to note that the November total is greater than either the October or December totals at type E stations, although the differences are not statistically significant in all cases. All stations of types D and E are either high-altitude (>2500 m), very exposed to westerly flow, or both. At Equator (station 21) and Nyahururu (station 23) the July–August peak is most pronounced.

Although the rainfall stations are relatively sparsely distributed and the lengths of records are not the same, the combination of semi-objective criteria and statistical testing appears justified by the coherence and consistency in the pattern of the rainfall types (Figure 5). The type E rainfall stations have characteristics which coincide with those of stations in one of the rainfall seasonality 'core' areas identified by Farmer (1981). Figure 5 is not intended as a definitive seasonality classification map but it enables closer examination of the July–August rainfall to be made. It should be reiterated, at this stage, that Kenyan rainfall is variable and, in any one year, any rainfall peak might be more or less pronounced or may occur earlier or later. However, there does seem to be considerable year-to-year persistence; for example, the stations with three rainfall peaks (type C) exhibit this regime during about 75 per cent of all years, whereas during about 25 per cent of the years one of the three rainy seasons is not apparent. So, these mean annual distributions provide a suitable basis for simple spatial analysis. There appears to be a fairly restricted area in west-central Kenya in which stations experience three rainfall maxima of roughly equal magnitude and duration (type C). These stations stretch northwards

Figure 5. Distribution of the five 'rainfall seasonality' types A–E (based on Figure 4)

from the Aberdare Mountains (Figure 5). The area where the July–August precipitation is either the greatest peak of the year (type E), or more important than the 'short rains' (type D), lies to the east or south-east of this zone. The main reason for the difficulty of rainfall classification in this area, and its ensuing complexity (e.g. Griffiths, 1972) is the contribution of the July–August (and, in some cases, September) rains. At higher altitudes, and further west and north, the July–August rainfall 'merges' with the preceding 'long rains', for example at Kitgum, Uganda (32° 53′E, 03° 20′N) (Kenworthy, 1964). Here, after August, monthly rainfall totals steadily decline to a January minimum and then rise again into May. Further west, the timing of the wet seasons shows quite considerable variation from place to place, with the 'short rains' being delayed (November–December) at some stations, whereas other locations exhibit a delay in the 'long rains' incidence (May–June).

During the north-east monsoon which brings the 'short rains' to East Africa the overlying trade-wind inversion normally weakens or even disappears, perhaps due to the increased heating from below during the airstream's long land trajectory over Arabia and the Horn of Africa (Trewartha, 1961). Consequently, stations at higher altitudes generally receive a greater proportion of their total annual rainfall during this period (see annual distributions for stations over 2500 m in Figure 4), or during July and August (Vincent *et al.*, 1979).

THE JULY–AUGUST RAINFALL PEAK

(i) *July + August total rainfall*

The inter-monsoon period rainfall can be of several forms. Persistent drizzle is often noted in the region of Ngobit on the lower slopes of the eastern Aberdares at about 2200 m (Carnegie, 1979). Similar drizzle is also experienced 100 km to the south at Nairobi, but is here insufficient in amount to create a July–August maximum. Sudden convectional storms may also occur, especially at the highest altitudes (Davies *et al.*, 1977). Johnson (1962) and others observed sequences of well-developed convectional cells bringing heavy, often thundery, rainfall to the plateaux of the northern Aberdares and to the Equator area (station 21 in Figure 3).

The total July + August rainfall is shown in Figure 6. Data from the 346 selected stations were used in the compilation of this map. Use was made only of a rainfall series of ten or more full years to maintain a balance between record length and network density. There is a sharp increase in July + August rainfall totals into the central plateaux (from 250–450 mm) and away from the Lake Victoria Basin (~100 mm) and eastern plains (<50 mm). July + August rainfall is generally greater in the west of the region than in the east, even at similar elevations. A pronounced local rainfall minimum is found in the Rift Valley, which has a low elevation in relation to the surrounding hills but is still higher than the Lake Victoria lowlands, where totals are ~200 mm less than on the surrounding slopes and there are also minima further to the east. Between the Aberdares and Mount Kenya, July + August rainfall is low (50–100 mm); the driest areas coinciding with the lowest sections of the plateau. Heavier July + August rainfall occurs especially at 2500–3000 m on north-western as well as western slopes and maxima occur most frequently 10–20 km to the north-west of the major topographic barriers, for example the Mau Escarpment, the Aberdare Mountains and Mount Kenya (where it is relatively heavy around 2500 m altitude, but lighter above and below this level). If a moist westerly airstream at about 3000–5000 m is accepted as the main source of precipitation during July and August (Flohn, 1960b; Vincent *et al.*, 1979) and the westerly airstream has a northerly component over the Kenyan Highlands (Hills, 1979), then this pattern of distribution is to be expected through orographic effects. The Sacho Ridge also experiences a pronounced maximum which falls off less rapidly to the north-west than in other directions.

One of the most noticeable features of Figure 6 is the large positive 'anomaly' on the south-eastern slopes of Mount Kenya at around 2500 m. July + August rainfall reaches 370 mm, around 150–200 mm more than anywhere else on the mountain. In spite of this maximum in the July–August rainfall

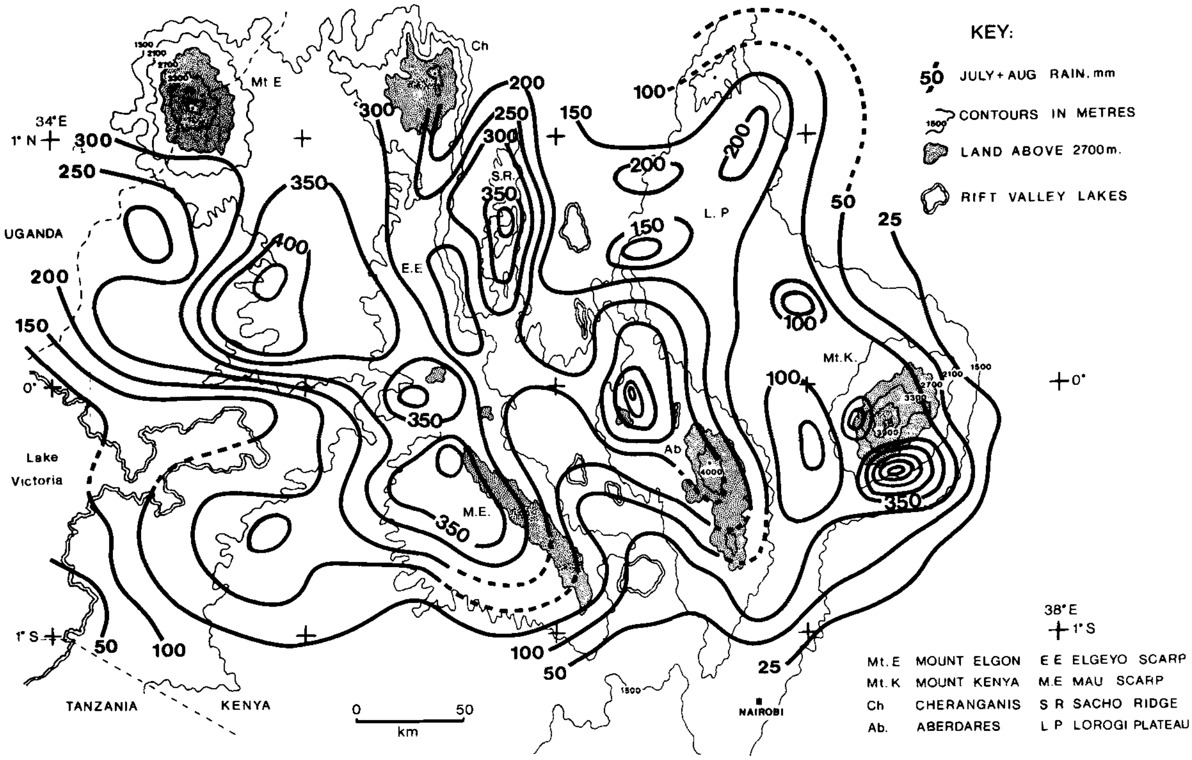

Figure 6. July + August rainfall distribution (mm) over central Kenya

distribution map, the south-eastern slopes of Mount Kenya are *relatively* dry in July–August when compared to precipitation in April–May and October–November. The explanation may be associated with the degree of exposure of these slopes to easterly winds. Until the mountain is encountered, and it is a very large topographic protrusion (summit 5200 m), the south-east trades have 500 km unbroken land fetch from the Indian Ocean. An alternative explanation is that the shape of the Mount Kenya topographic barrier is such that a particular flow is created in its lee. Scorer (1958) suggests that narrow mountains often produce marked uplift downwind, if the airstream is already in a wave-train (as it might be with north-westerly winds flowing over the Aberdare Mountains ridge). This type of wave enhancement results in maximum lee instability and anomalously high rainfall downwind of the mountain. Thompson (1966) and Kidson (1977) suggested that, in East Africa, turbulent overturning of moist layers, combined with topography-channelling effects, can bring about a reorientation of the winds and significant rainfall amounts to lee slopes.

The low July + August rainfall (50–100 mm) over much of the low land around eastern Lake Victoria, despite the proximity of the lake as a potential moisture source, also indicates the importance of orographic uplift of any moist westerly airstream of lake or Congo origin.

(ii) *The relative importance of July + August rainfall: indices*

(a) The first index is the contribution of July + August rainfall to annual totals, expressed as a percentage (the 'percentage index').

The distribution of the July + August percentage index is shown in Figure 7. There is considerable spatial variation, but the percentage index is at its highest within the central highlands. The relative importance of the July + August rainfall season diminishes rapidly eastwards of the 1500 m contour, especially around Mount Kenya, which marks the approximate eastern boundary of Kenya's central plateaux. At similar elevations, the percentage index is generally greater in the west than in the east. A

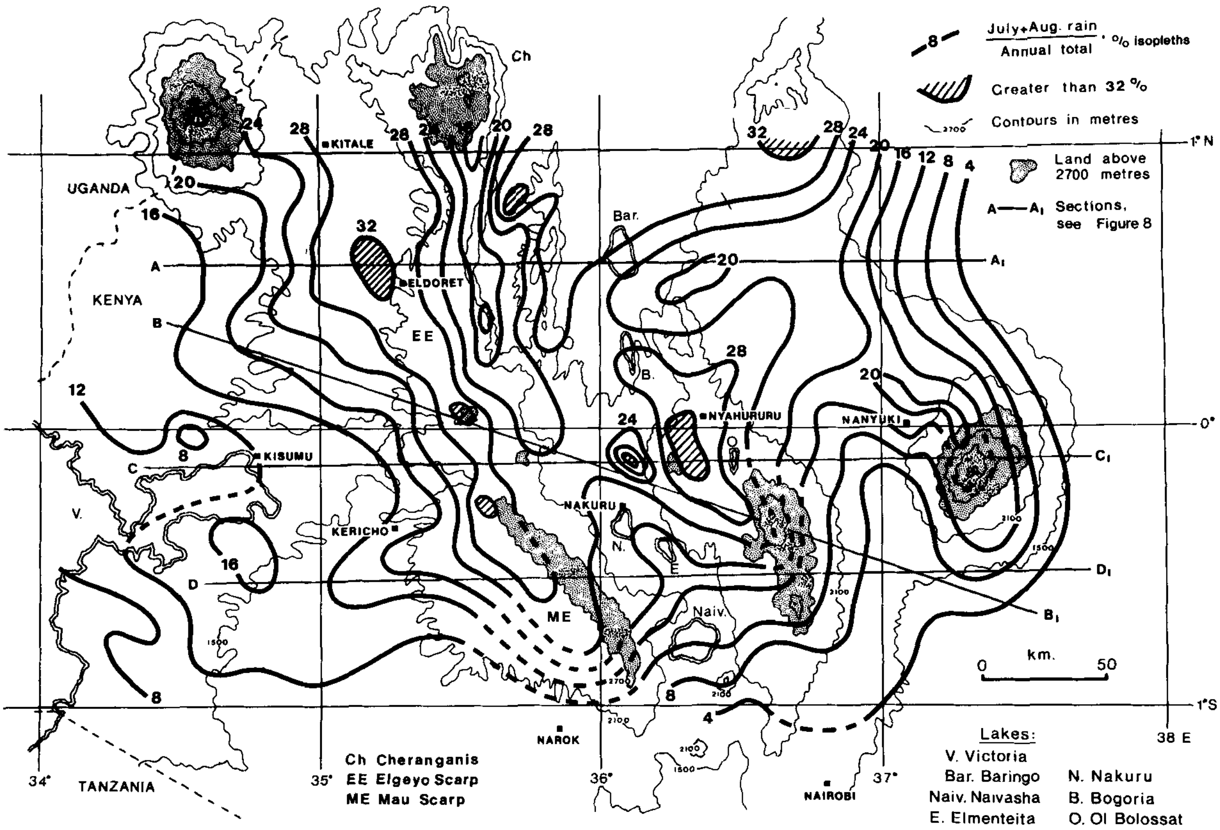

Figure 7. July + August rainfall as a percentage of the annual total for central Kenya (percentage index)

well-defined maximum (in which ≥28 per cent of annual rainfall is received during July–August) is evident 10–50 km west of the Cherangani Hills, the Elgeyo Escarpment and the Mau Escarpment. Figure 7 shows that there is a distinct association between the gradient in the percentage index and the topographic gradient. The gradient in the percentage index appears particularly steep southwards from the Mau Escarpment towards Narok. Here there is a drop in elevation—even down the dip slope—of 1200 m in 50 km. A maximum (32 per cent) occurs west of Lake Ol Bolossat; this maximum is 20–40 km north-west of the main Aberdare peaks. Within the Rift Valley, July + August rainfall is relatively less important than over the surrounding escarpments, constituting 10–22 per cent of mean annual rainfall around lakes Naivasha, Elementeita and Namuru for example.

The relationship between the July + August percentage index and altitude is statistically significant ($r = 0{\cdot}34$ for 346 stations, significant at the 1 per cent level). Figure 8 shows cross-sections (marked in plan in Figure 7) which illustrate the main features of the relationship. Section AA_1, through the Elgeyo and Lorogi Escarpments and the Rift Valley, appears to show perhaps the greatest anomaly within the general July + August percentage index–altitude relationship. This is especially true on the Elgeyo Escarpment and up the steep Sacho ridge west of the Lake Baringo basin; in the lake basin the percentage index value remains high. It is not appropriate to speculate on physical causation since the percentage index depends not only on July + August rainfall, but also on the amount of rainfall throughout the rest of the year, but it is possible that the sort of topographic influences discussed earlier are playing a role. Section BB_1 shows a good relationship between the percentage index and topography, with the index reaching a maximum 5–20 km west of the mountain ridges, a feature also reflected in Section CC_1. In Section DD_1, the percentage index is much greater over the more exposed (to the west) Mau Escarpment than it is over the Aberdare Mountains. Again the index appears most pronounced about 10 km to the west of the major topographic features.

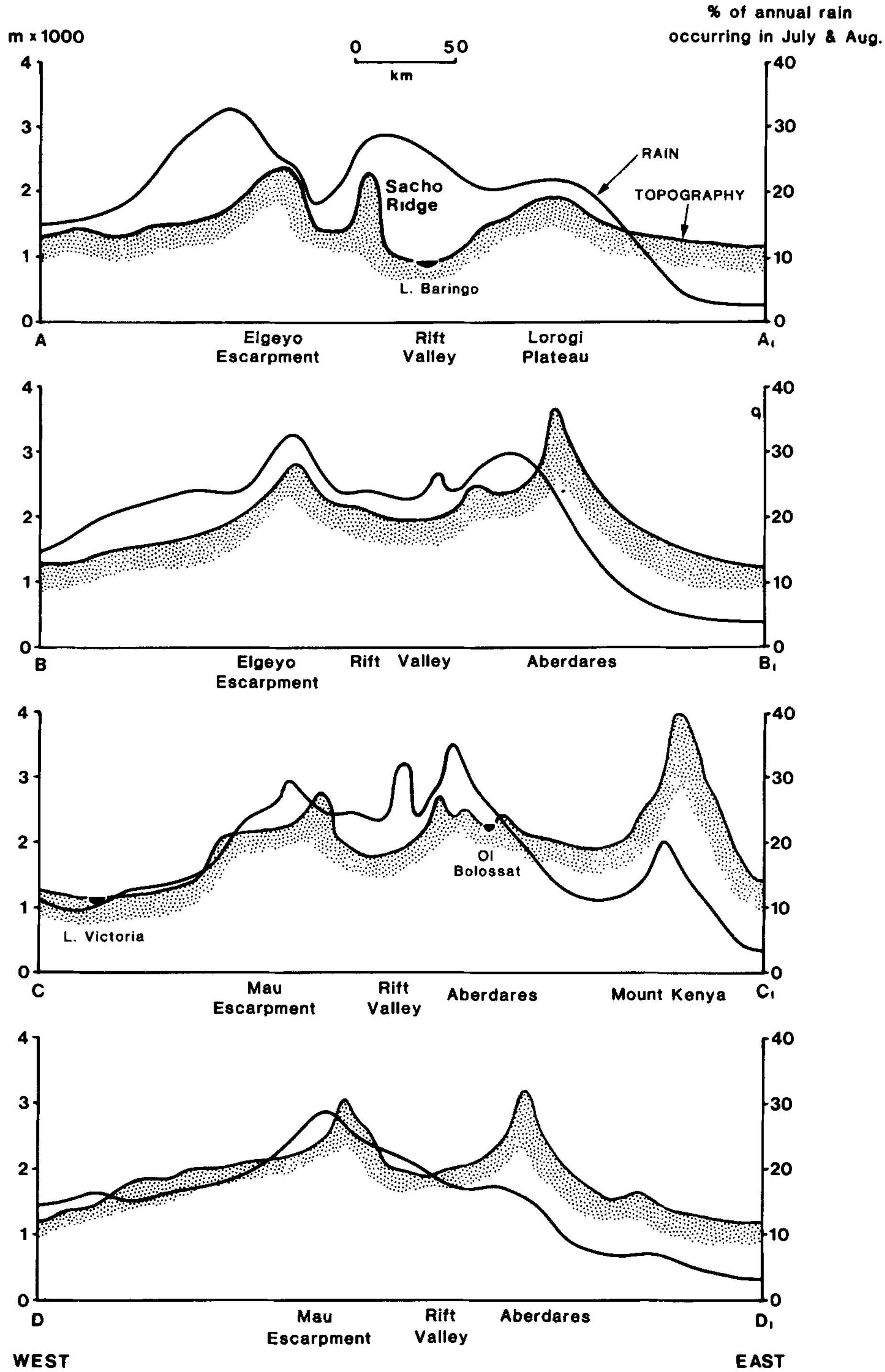

Figure 8. Central Kenya cross-sections (shown in plan on Figure 7) illustrating the July + August (as a percentage of the annual total) rainfall–topography relationship

Since the July + August percentage index is inversely proportional to the annual rainfall total, any discussion of its physical relationship with, for example, westerly airstreams cannot be rigorously undertaken but the spatial analysis is consistent with conclusions drawn in the introduction. The importance of the July + August rainfall contribution, relative to the annual total, exhibits a relationship with altitude and appears to favour the westerly aspects of topographic barriers.

(b) The second index is a composite one which attempts to quantify the local seasonal importance of the July–August peak, its contribution to the annual rainfall total, and its importance relative to the 'long' and 'short' rains. The composite index is:

$$10\frac{(\text{July + August rain})}{(\text{June + September rain})}+100\frac{(\text{July + August rain})}{\text{annual rain}}+\frac{(\text{July + August rain})}{10r}.$$

where r is a rain-season ranking parameter:

$r = 1$ if July + August is the wettest season
$r = 2$ if July + August is the second wettest season
$r = 3$ for other cases

The weighting of each term in the composite index was evolved empirically to 'balance' the contribution of the terms. The distribution of the composite index (Figure 9) is broadly similar to that of the simple index (Figure 7), except that the relationship with topography is even clearer. There are maxima on the Elgeyo Escarpment, on the Mau Escarpment, on the Aberdare Mountains and a (local)

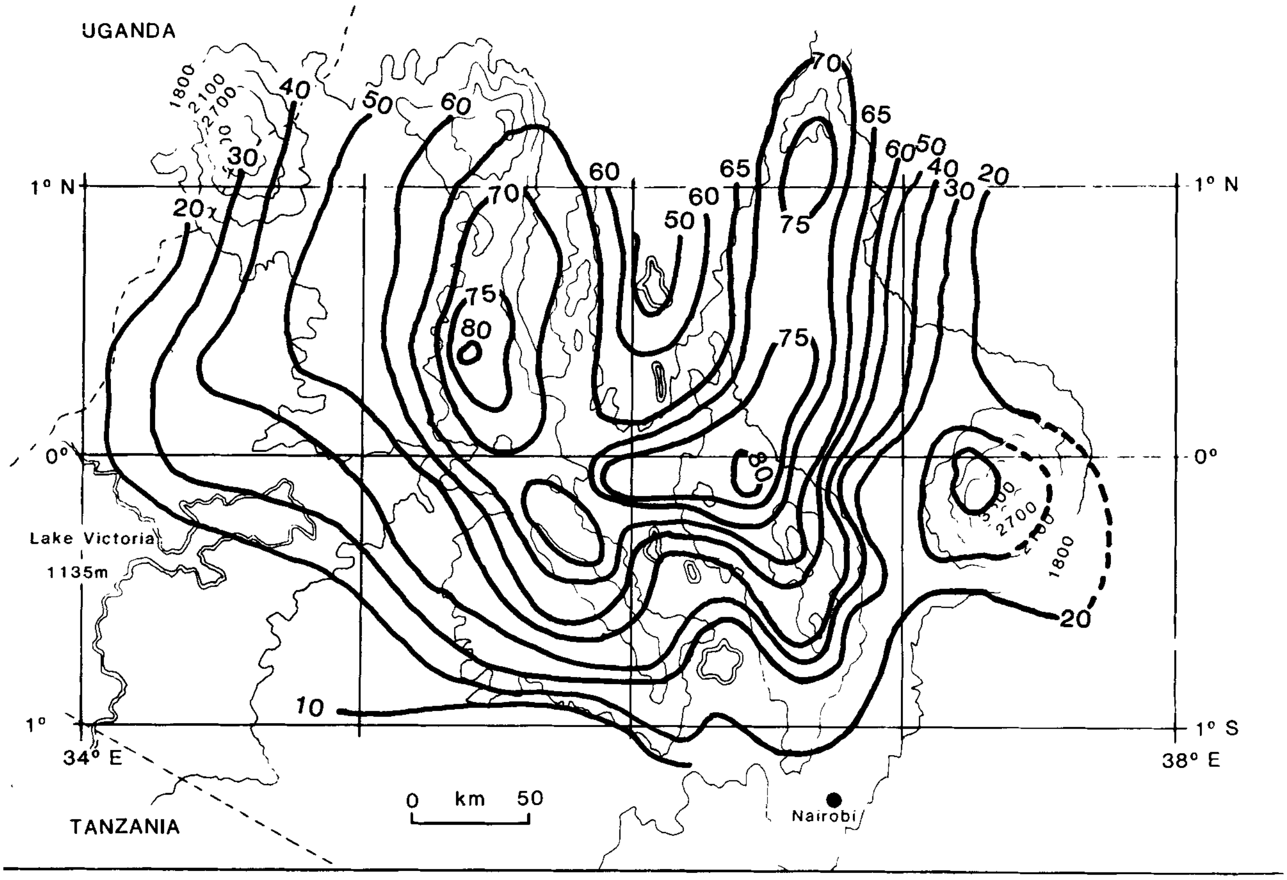

Figure 9. Distribution of the 'composite index' of July + August rainfall

maximum on Mount Kenya. Perhaps the most noticeable feature is that they are on the north-west faces of all of these topographic barriers. There is a zone of minimum values from the Lake Baringo Basin to Lake Naivasha (the Rift Valley) except for locally-high values to the north-west of the Aberdare Mountains. Within west-central Kenya, the distribution of the high values of the composite index seems very restricted and strongly related to topography. This would seem to strengthen the postulations about upper westerly flow and July–August rainfall discussed in previous sections. Although the July–August contribution to annual rainfall is important to the north-west into Uganda, the isolines in Figure 9 exhibit closed patterns to the north-west of the area. This is consistent with the findings of Tomsett (1969) who showed that July and (especially) August rainfall exhibited local maxima in the west-central highlands of Kenya and in central Uganda with the broad band of elevated July–August rainfall stretching south-eastwards from Uganda.

THE RELATIVE IMPORTANCE OF OTHER WET SEASONS IN WEST-CENTRAL KENYA

The contribution of the April + May 'long rains' to annual total is shown in Figure 10. The 26 stations shown in Figure 4 were used in the compilation of this map, and so the spatial resolution is considerably less in the examination of the April + May rains than in the examination of the July + August rainfall. Nevertheless, the broad pattern is evident. The April + May 'long rains' form the smallest proportion of annual totals along the Elgeyo Escarpment, the northern Aberdares and the Baringo basin. The 30 per cent isopleth coincides roughly with the 1500 m contour with generally higher values at lower altitudes and lower values above. A correlation coefficient of $-0{\cdot}47$ (significant at the 2 per cent level) is found between the percentage of annual rainfall occurring during April + May and altitude for the 26 stations (compared with $+0{\cdot}51$ for the same stations July + August relative contribution, significant at 1 per cent).

Similar analysis of the short rains (October + November) is rather less conclusive, producing a

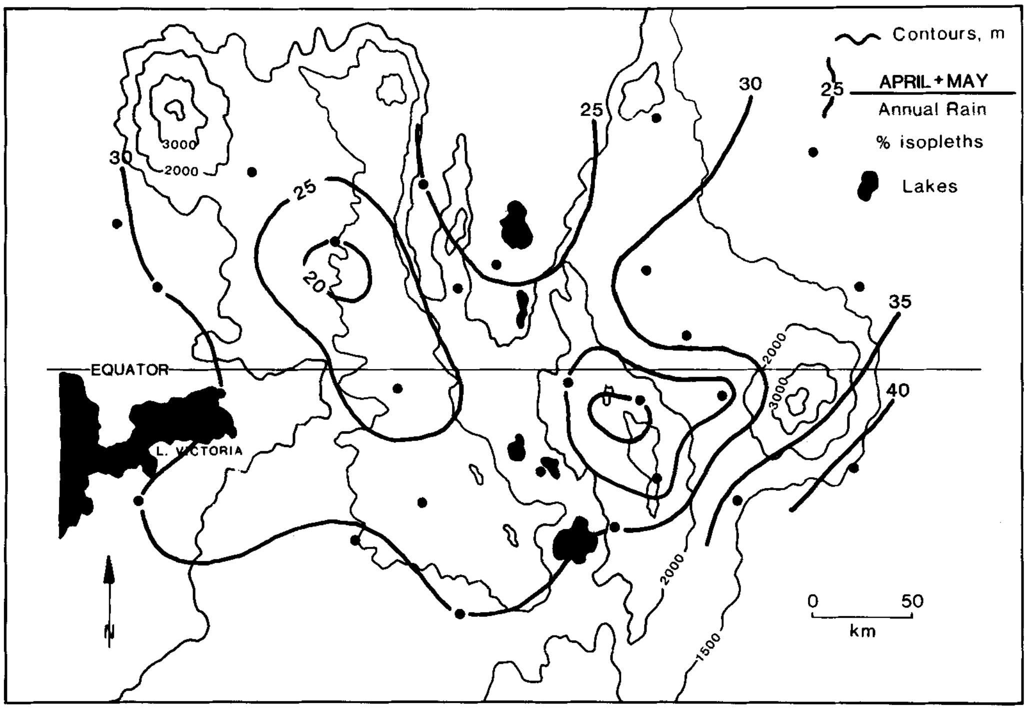

Figure 10. April + May rainfall as a percentage of the annual total

rainfall-altitude correlation coefficient of −0·38 (just insignificant at the 5 per cent level). Nevertheless, the isopleths do follow approximately the same pattern, reaching minima (10–35 per cent of annual rain) over the central plateaux and maxima (30–35 per cent) in the Lake Victoria basin and the eastern plains (Figure 11). In the case of the October + November short rains, the isopleths tend to exhibit a north–south orientation paralleling the contours, especially of the southern highlands, rather less than the April + May long rains contribution.

If the contribution of the two wet seasons to annual rainfall is combined into a single map (Figure 12) an altitude–rainfall relationship again emerges. The correlation coefficient of −0·41 in this case is significant at the 5 per cent level. Rainfall during the two major wet seasons accounts for up to 70 per cent of annual totals east of Mount Kenya and 50 per cent around Lake Victoria. Figures for the central plateaux are mostly 30–44 per cent. Clearly then, topography is an important control on the timing and intensity of the major as well as the 'minor' wet seaons in central Kenya, the latter generally increasing in importance with altitude.

CONCLUSIONS

Rainfall in East Africa is seasonally and spatially variable. The wet seasons may vary in timing and this is masked by ascribing, for example, the months July and August exclusively to one of the wet seasons. Use of time series of different lengths is, of course, an especial problem. However, there is little alternative, unless the data set is pruned to an unacceptable degree.

There have been attempts to classify East African climates according to rainfall seasonality (e.g. Griffiths, 1972). Although the existence of a rainfall maximum in July–August within the dry season has been recognized in west-central Kenya (and extending north-westwards into Uganda), there have been no previous attempts to determine its relative importance within the rainfall year in combination with its spatial distribution. This study has concentrated on a restricted area of west-central Kenya. To the north-west, over large parts of Uganda, the October–November 'short rains' are much less prominent

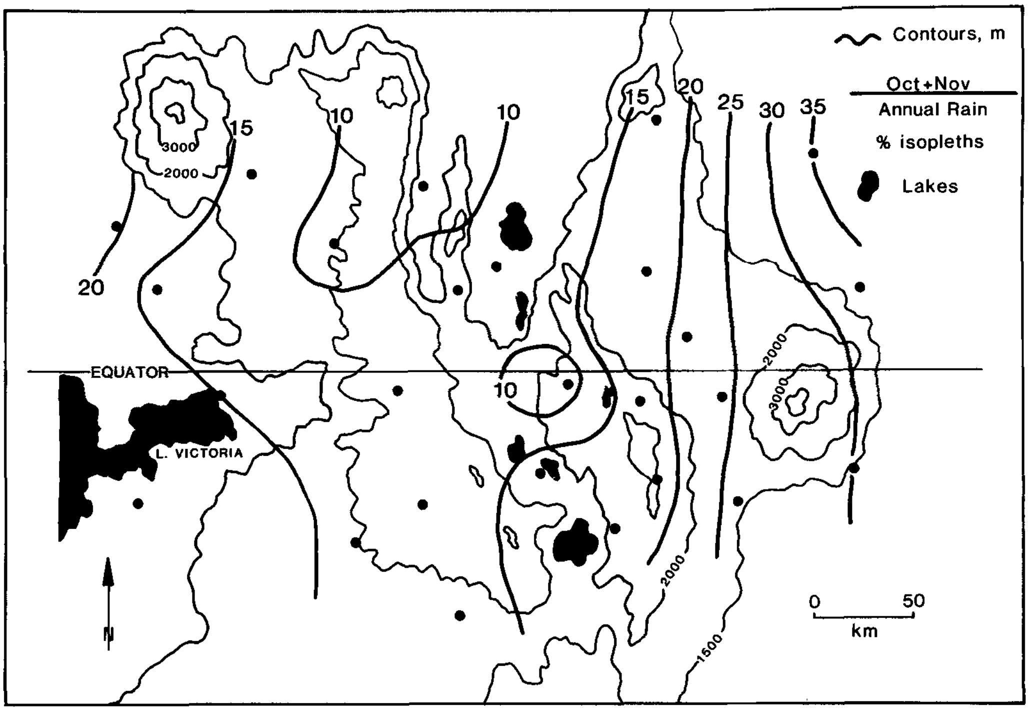

Figure 11. October + November rainfall as a percentage of the annual total

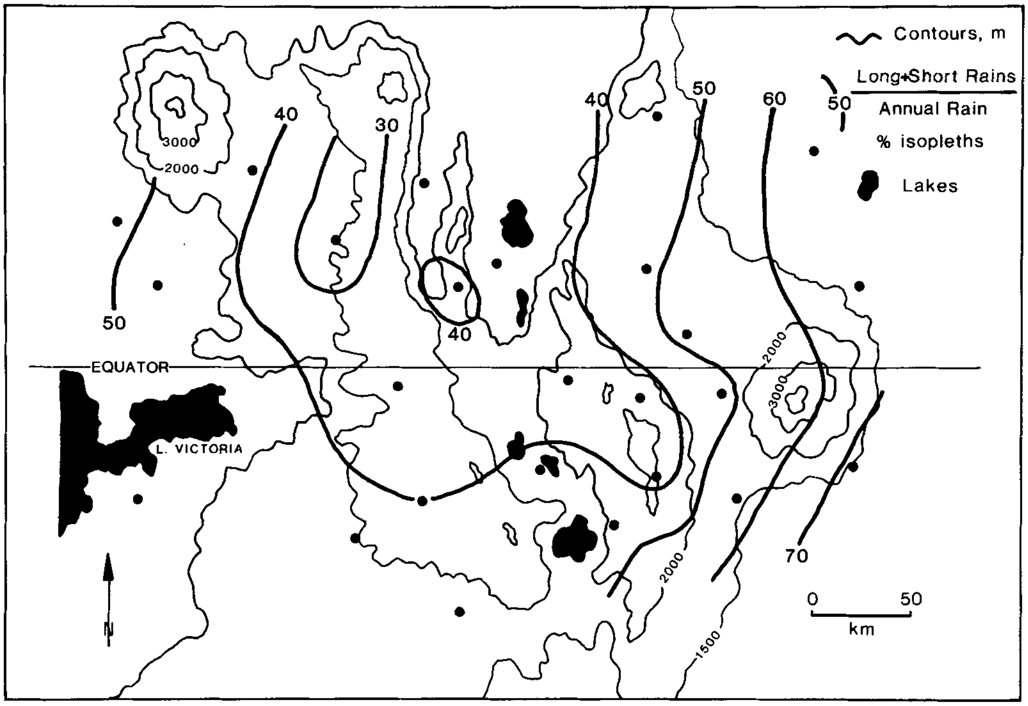

Figure 12. April + May plus October + November rainfall as a percentage of the annual total

than the July–August rains. The annual rainfall histograms of some stations in central Uganda (Kenworthy, 1964) resemble the type E station distributions of this study.

Maps of the July–August total rainfall and its contribution to annual rainfall compiled here provide an indication of the source of the 'dry season' moist airstream. July–August rainfall is normally at a maximum to the west or north-west of higher land; precipitation being greatest at 2000–3000 m, indicating the existence of a moist, westerly airstream overlying the lowest layers. The apparent July + August rainfall anomaly on the south-west slopes of Mount Kenya is really a result of exceptional wetness here at all seasons. Relative to the mean annual rainfall, these two months are not especially wet. It is clear from this analysis that certain zones within this area of west-central Kenya experience important contributions to their annual precipitation during the months July and August. It is not possible to precisely map the distribution and nature of this local maximum because of the relative paucity of high-altitude rainfall stations. However, this analysis highlights the importance of local topographic influences on the seasonal rainfall regime, the variability of which has such an influence on the levels of many of the Kenyan Rift Valley lakes (Vincent *et al.*, 1979).

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