Literatur

BAKER, B. H.: Geology of the Mount Kenya area. Geol. Survey of Kenya, Report No. 79, 78 pp., 1967.

BRANDSTÄTTER, L.: Meßtechnik und Darstellungstechnik in der topographischen Kartographie. Erdkunde, 22, 39–41, 1968.

BREMER, H.: Musterböden in tropisch-subtropischen Gebieten und Frostmusterböden. Zeitschrift für Geomorphologie, 9, 222–236, 1965.

BÜDEL, J.: Klima-morphologische Arbeiten in Äthiopien im Frühjahr 1953. Erdkunde, 8, 139–156, 1954.

FURRER, G., und FREUND, R.: Beobachtungen zum subnivalen Formenschatz am Kilimandjaro. Zeitschrift für Geomorphologie, Suppl. Bd. 16, 180–203, 1973.

HASTENRATH, S.: Observations on the periglacial morphology of Mts. Kenya and Kilimanjaro, East Africa. Zeitschrift für Geomorphologie, Suppl. Bd. 16, 161–179, 1973.

– : On the pleistocene glaciation of the Cordillera de Talamanca, Costa Rica. Zeitschrift für Gletscherkunde und Glazialgeologie, im Druck, 1974a.

– : Spuren pleistozäner Vereisung in den Altos de Cuchumatanes, Guatemala. Eiszeitalter und Gegenwart, im Druck, 1974b.

– : Recession of Mount Kenya glaciers during the 20th century. Proceedings, National Seminar on Human Environment, Nairobi, forthcoming, 1974c.

HEINZELIN, J. DE: Carte des extensions glaciaires du Ruwenzori (versant congolais). Biuletyn Peryglacjalny, 11, 133–139, 1962.

HÖVERMANN, J.: Über die Höhenlage der Schneegrenze in Aethiopien und ihre Schwankungen in historischer Zeit. Nachr. d. Akad. d. Wiss. i. Göttingen, Math.-Phys. Kl., Nr. 6, 111–137, 1954a.

– : Über glaziale und „periglaziale" Erscheinungen in Erithrea und Nordabessinien. Veröff. Akad. Raumforschung und Landesplanung, Abhandlungen Bd. 28, Bremen–Horn, 87–111, 1954b.

HUMPHRIES, D. W.: Glaciology and glacial history. p. 31–71, in: C. Downie and P. Wilkinson: The geology of Kilimandjaro. Geology Department, University of Sheffield, 253 pp, 1972.

JACKSON, S. ed.: Climatological atlas of Africa. Government Printer, Pretoria, South Africa (55 maps), 1961.

KAZMIN, V.: Geological map of Ethiopia, 1:2 000 000. Ministry of Mines, Geological Survey of Ethiopia, 1973.

KULS, W., und SEMMEL, A.: Beobachtungen über die Höhenlage von zwei klimamorphologischen Grenzen im Hochland von Godjam (Nordäthiopien). Petermann's Mitteilungen, 279–284, 1962.

LUSANA, A.: L'Uogherà e l'Alto Semien. Gli Annali dell'Africa Italiana, anno 1, vol. 1, p. 1414–178, 1938.

MINUCCI, E.: Ricerche geologiche nella regione del Tana. p. 19–35, in: Missione di studio al Lago Tana, vol. 1. Reale Accademia D'Italia, Roma, 175 pp, 1938a.

– : Ricerche geologiche nella regione del Semien. p. 37–46, in: Missione di studio al Lago Tana, vol. 1. Reale Accademia D'Italia, Roma, 175 pp, 1938b.

MOHR, P. A.: General report on an expedition to the Semien Mountains. Bulletin of the Geophysical Observatory, Addis Abeba, vol. 3, no. 2, 155–167, 1963.

– : Review of the geology of the Simien Mountains. Bulletin of the Geophysical Observatory, Addis Abeba, vol. 10, 79–93, 1967.

– : The geology of Ethiopia. Haile Sellasie I University Press, Addis Abeba, reprinted, 268 pp, 1971.

NILSSON, E.: Traces of ancient changes of climate in East Africa. Geografiska Annaler, 17, 1–21, 1935.

– : Ancient changes of climate in British East Africa and Abyssinia. Geografiska Annaler, 22, 1–79, 1940.

OSMASTON, H. A.: The past and present climate and vegetation of Ruwenzori and its neighbourhood. Thesis, Oxford, 238 pp, 1965.

SCOTT, H.: Biogeographic research in High Simien (Northern Ethiopia), 1952–53. Proc. Linnean Society of London, vol. 170, part 1, 91 pp, 1958.

SIMOONS, F.: Snow in Ethiopia: a review of the evidence. Geogr. Review, 50, 402–411, 1960.

THOMPSON, B. W.: The climate of Africa. Oxford University Press, Nairobi–London–New York, 132 pp, 1965.

TROLL, G., und WIEN, K.: Der Lewisgletscher am Mount Kenya. Geografiska Annaler, 31, 257–274, 1949.

WERDECKER, J.: Beobachtungen in den Hochländern Äthiopiens auf einer Forschungsreise 1953/54. Erdkunde, 9, 305–317, 1955.

– : Das Hochgebirgsland von Semyen. Erdkunde, 22, 33–39, 1968.

SEASONAL RAINFALL DISTRIBUTION IN TANZANIA AND ITS CARTOGRAPHIC REPRESENTATION

With 4 figures and 2 supplements (III + IV)

S. NIEUWOLT

Zusammenfassung: Die jahreszeitliche Niederschlagsverteilung in Tansania und ihre kartographische Darstellung.

Regenzeiten in Tansania stehen in engstem Zusammenhang mit den jahreszeitlichen Veränderungen in der allgemeinen Zirkulation über Ost-Afrika, die ein Monsunsystem verursachen. In Tansania sind beide Monsune relativ trocken und die meisten Niederschläge fallen während der Übergangsperioden. Ein einfaches Modell einer Regenzone, die sich zweimal im Jahr über das Land bewegt, ist aber eine ungenügende Grundlage für eine Beschreibung der Niederschlagsverhältnisse, da starke örtliche und zeitliche Abweichungen von diesem Bilde häufig auftreten. Diese Variabilität der Regenfälle wird einerseits durch lokale Faktoren, andererseits durch Unterschiede in der jahreszeitlichen Entwicklung der allgemeinen Luftdruckverteilung verursacht.

Die traditionellen Methoden einer karthographischen Darstellung der Regenzeiten führen daher zu sehr komplizierten oder stark vereinfachten Karten. Wenn aber die Monatsdaten in Beziehung zur Jahresmenge gesetzt werden, bringen Stationswerte ein ziemlich klares und naturgetreues Bild. Dies wird weiter veranschaulicht durch zwei Indexziffern, die den allmählichen Übergang zwischen einer kurzen ununterbrochenen Regenzeit im Süden des Landes zu einer längeren, doppelten Regenperiode im Westen und Osten Tansaniens gut darstellen. Häufigkeitsdaten, basierend auf 5-Tage-Perioden, bestätigen dieses Bild weitgehend.

Tanzania, situated on the eastern side of Africa, adjacent to the generally warm Indian Ocean in latitudes where easterly winds prevail, might well be expected to receive copious rainfall (Suppl. IIIa). Yet "the most important climatic anomaly in all of Africa is the widespread deficiency of rainfall in tropical East Africa" (Trewartha, 1962, p. 121). Over most of Tanzania the mean annual rainfall is less than 1000 mm (Tomsett, 1969, p. 8). In these latitudes the lower limit for crop agriculture is around 750 mm of rainfall per year, and only about half of the country receives this amount regularly, that is four years out of five *(E. Africa Royal Commission,* 1961). The economic importance of rainfall is illustrated by the fact that well over 90 per cent of the Tanzanian population derive their income from agriculture, and that most development programmes concentrate on the improvement of water supplies to rural areas.

Where rainfall conditions are so marginal, it is the seasonal distribution that becomes decisive for the effectiveness of the rainfall received (Kenworthy, 1964). It determines the length of the growing season, because temperature conditions are favourable throughout the year. The choice of agricultural crops and production systems is therefore largely determined by the seasonal rainfall distribution.

Origin of the seasonal distribution

Rainfall seasons in Tanzania are closely related to the general circulation over eastern Africa and adjacent areas. During the course of the year this circulation experiences large changes (Suppl. III a–d). The maps are compiled for the 850 mb level, which is around 1500 m above sea level. For large parts of Tanzania this level illustrates conditions near the earth's surface. The 700 mb level (around 3150 m above sea level) represents conditions in the middle troposphere. The 500 mb charts, which correspond to an elevation of 5850 m, are near the upper limit of most seasonal variations in the troposphere.

It must be emphasized that these maps depict statistical means. They illustrate the large scale features, which can frequently be observed on daily weather maps, though the actual situation differs in detail from these average conditions, often to a considerable extent (Thompson, 1965, p. 5).

The maps for January illustrate the mean synoptic situation which prevails from about December to the end of February (Suppl. III a). During this period eastern Africa is mainly under the influence of northeasterly winds, the northeast monsoon which is locally called "kaskazi". The main origins of this air stream are in Saudi Arabia and Egypt, and since its way to eastern Africa is largely over land areas, its air masses are predominantly dry. Moreover, the air stream shows a low-level divergence, caused by the influence of two low pressure centres: the main one over the Indian Ocean and a secondary low over Central Africa in the Lake Victoria region (Suppl. IIIa, 850 mb map). This divergence, which causes large scale subsidence, is probably the main reason for the stability of the air masses of the northeast monsoon, which prevails to well south of the equator (Mörth, 1973).

At both the 850 and 700 mb levels, the equatorial through is situated at about 12 degrees South. This illustrates a typical "cross-equatorial drift" situation (Johnson and Mörth, 1960, p. 61). In this synoptic pattern, the main area of convergence within the air stream is where it has become more westerly, at a latitude around 10–20 degrees South. In this same latidudinal region the lower parts of the northeast monsoon meet with strong air currents from the east and southeast, at the 'Inter Tropical Convergence'-zone (I.T.C.). Here, convergence prevails from the surface up to elevations well over 3000 m. At the 500 mb level there is no trace of this pattern (Suppl. III a).

A secondary area of convergence is situated along the central parts of the East African Rift Valley, where the northeast monsoon meets with westerly winds from the Congo Basin. This is the 'African Rift Convergence Zone' (Flohn, 1965). The westerlies carry rather humid and unstable airmasses, which produce much precipitation when uplifted.

Both convergence areas are rather variable in intensity and position. Their influence is clearly reflected in rainfall maps for East Africa for these months (Tomsett, 1969, p. 9, 10, 20). These show a general increase of rainfall from north to south and, to a lesser extent, towards the western borders of Tanzania.

The synoptic situation during the period from about March to May is well illustrated by the maps for April (Suppl. III b). During these months the general circulation near the surface is sluggish and wind directions are variable. During the first part of this period the equatorial trough moves slowly and rather irregularly to its illustrated position near the equator. It usually leaves Tanzania towards the end of May.

The maps display a typical "equatorial duct" situation, which prevails up to the 500 mb level (Johnson and Mörth, 1960, p. 61). In this pattern the main area of convergence is at the entrance to the duct, that is over East Africa. This deep convergence causes widespread instability.

Rainfall maps illustrate the influence of this instability. Copious rainfall is received over large parts of East Africa (Tomsett, 1969, p. 11–13). Although there is a generally northward movement of some synoptic features, there is no clear evidence of a similar movement by a zonal belt of heavy rain. Rather, it seems that the zone of rainfall broadens until it reaches from about 10 degrees South to approximately 5 degrees North. In this zone the general instability of the troposphere causes rainfall wherever local conditions are favourable and the rainfall pattern shows little or no correlation with the actual synoptic situation (Johnson, 1962). Travelling disturbances are rare and most storms originate and develop in situ (Thompson, 1965, p. 12). Rainfall maps for this period therefore display a rather complicated picture and even the longterm means show large differences over short distances.

The synoptic situation from about June to September is well illustrated by the maps for July, as there is relatively little variation over eastern Africa during this period (Suppl. III c). The southeast monsoon or "kuzi" dominates the general circulation to well over 3000 m elevation. The pattern is again, as in January, a typical "cross-equatorial drift", but now Tanzania is on the dry side of the equator.

There are two main reasons why the southeast monsoon produces little rainfall in East Africa. The first is the character of the airmasses which it brings. These have their origin either in the continental high pressure area over southern Africa, and then they are obviously rather dry, or they come from the Indian Ocean. These latter air masses are originally quite humid in their lowest layers, but before they reach East Africa they have to cross over the steep mountains of Madagascar, where they drop most of their moisture. There is but little space for them to pick up water vapour over the relatively narrow Mozambique Channel and the humid layer near the surface in these air masses is therefore usually rather shallow. Above it an inversion layer prevails (Thompson, 1966).

Secondly, the southeast monsoon is under the influence of two low pressure areas. The major one, situated over Saudi Arabia, is related to the very strong low over the Indian subcontinent. The other low is over Central Africa, near Lake Victoria (Suppl. III c). The resulting low-level divergence in the air stream is widespread (Findlater, 1971). It is locally reinforced by coastal bifurcation and this is certainly a major factor north of the equator (Flohn, 1966). The general stability of the air masses, caused by the divergence, renders thermal convection during daytime rather ineffective as a producer of rainfall (Mörth, 1973).

Rainfall maps for the southeast monsoon season illustrate the effects of these conditions: most parts of East Africa receive less than 10 mm of rainfall per month (Tomsett, 1969, p. 14–17). Only three regions receive more precipitation because the effects of the divergence are neutralized. Over the Kenyan Highlands and the Lake Victoria region this is largely due to the East African Rift Convergence (Flohn, 1965). The coastal areas of Kenya and northern Tanzania receive rather variable amounts of rainfall from disturbances which travel with the southeast monsoon. Originally often related to cold fronts over southern Africa, these disturbances become more effective as rainbringers in the north because of the increased fetch over the Indian Ocean (Lumb, 1966). The third area of locally increased rainfall during this season is near the northern tip of Lake Nyassa, where a convergence of the southeasterlies is caused by relief features. A few isolated mountainous areas also receive more rainfall during this season than the surrounding lowlands.

The equatorial trough reaches eastern Africa again during October (Suppl. III d). At the 850 mb level the main discontinuity is still north of the equator, but at both the 700 and 500 mb levels the synoptic pattern is again of the "equatorial duct" type, with the low pressure centered over the equator. However, this is a real transition period and during October and November the daily variations in the synoptic pattern are large.

While the main zone of convergence is still north of the equator during October, it generally moves to its more southern position in November. The movement of the I.T.C. is, however, more rapid than in April. It seems as if this zone is retarded, for some time, by the Kenyan Highlands, and then moves rapidly southwards to catch up with its western parts which have already progressed to more southerly positions (Griffiths, 1972, p. 326).

Because of the relatively short stay of the I.T.C. over the country, rainfall in Tanzania during October and November is considerably lower than in the period from March to May (Tomsett, 1969, p. 18, 19). The general pattern shows a decrease from north to south, but in detail the distribution of rainfall is dominated by non-zonal features. A quasi-permanent low around Lake Victoria, caused by many local disturbances, brings higher rainfall in that region. The northeastern parts of the country are also favoured, because the I.T.C. sometimes remains static over that area for some time before moving away towards the south.

Variability with time and place

In relation to these seasonal changes in the general synoptic situation, East African rainfall has been conceived as consisting principally of a zonal belt of maximum precipitation which moves with the seasons (Walter, 1952). This rainbelt would be over southern Tanzania and adjacent areas from December to February, then move northwards, leaving the country by the end of May. It would return to Tanzania during October and move to its southern position in November. This model would cause two separate rainfall maxima in northern Tanzania, around April and October. The two rainy periods would coalesce into a single one, from about November to March, in the southern parts of the country.

However, monthly rainfall maps give only limited support to this concept. A comparison of the large-scale distribution patterns during consecutive months indicates a general agreement with the zonal belt model, but the individual maps show many large and small non-zonal features which obviously do not fit in the above schedule (Tomsett, 1969, p. 9–20).

The smaller deviations from the zonal pattern are mainly the result of purely local factors. An examination of a relief map reveals that the eastern flanks of mountainous areas in Tanzania stand out as as areas with very high rainfall, while the corresponding western slopes are generally rather dry (Tomsett, 1969, p. 6). This is, of course, the result of orographic lifting and a rain-shadow effect caused by the predominantly easterly winds. Some seasonal differences in rainfall are caused by the effect of exposure in relation to changes in the main wind direction (Nieuwolt, 1973).

The amounts of rain caused by orographic lifting are usually increased by the strong convection over highlands, due to the rapid heating of the earth's surface during daytime at higher elevations (Coutts, 1969). If orographic lifting is accompanied by convergence, exceptionally heavy rainfall results. For instance over the northern tip of Lake Nyassa, where the air masses of the southeast monsoon are forced through a narrow gap between mountain ranges on both sides of the lake, very high rainfall occurs from April to July, though these air masses are generally rather dry (Tomsett, 1969, p. 11–14).

Apart from relief features, other local factors are responsible for many rainfall contrasts over short distances. When the general synoptic situation is favourable for the production of rainfall, the actual amounts received depend mainly on the intensity of local convection. As in most tropical climates, convection is the source of most rainfall in Tanzania. It usually occurs in the form of small, but very intensive storms, often accompanied by lightning. These storms frequently display very sharp boundaries of the areal distribution of rainfall. The development of these storms can often be related to elements of the earth's surface, such as hill slopes, coastlines, islands and areas with contrasting vegetation, soil or drainage conditions compared with the surrounding region. The expression 'random distribution of shower activity' is sometimes used to indicate that the responsible factors cannot be identified in every case (Johnson, 1962, p. 13, 16).

Other local factors that frequently produce rainfall are found near coastlines, both along the Indian Ocean and around Lake Victoria. Here, sea breezes can cause stroms along the sea breeze front and land breezes can trigger off thunderstorms during the night.

The effects of these local factors can largely be eliminated from further consideration by relating mounthly rainfall to the annual total (Walter, 1962).

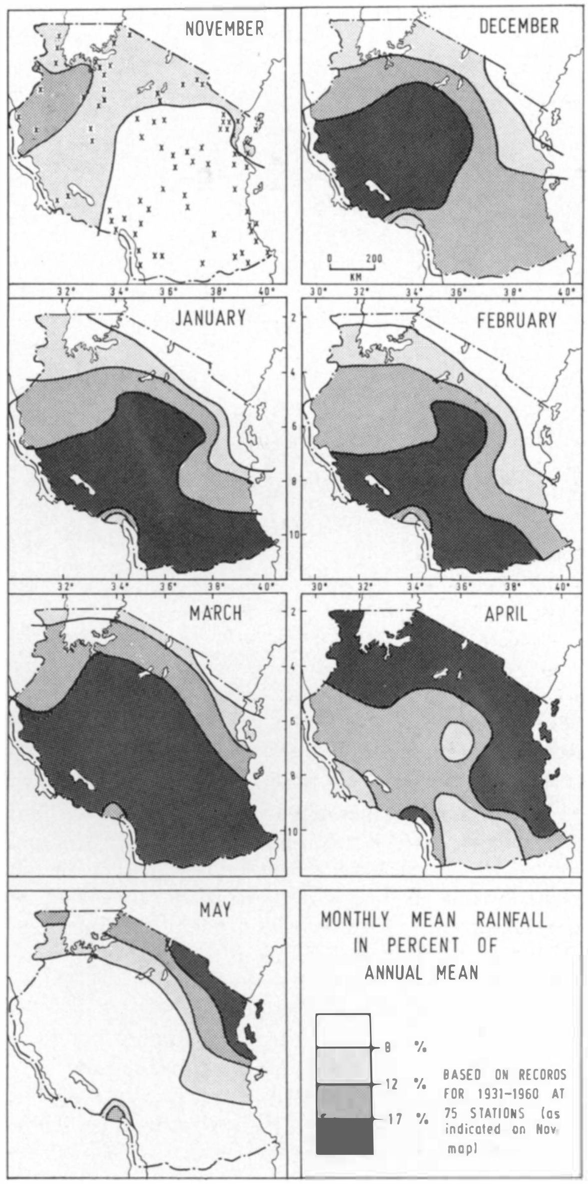

Fig. 1

If monthly means are expressed in per cent of the annual mean rainfall, the seasonal distribution is shown without purely local differences (Fig. 1).

These maps reveal a much closer approximation to the idea of a moving zonal belt of rainfall than the maps based on absolute rainfall figures. Nevertheless a number of non-zonal characteristics remain. These are caused by some parts of the synoptic situation which deviate from a strictly zonal pattern, such as the semi-permanent low pressure area near Lake Victoria and the high pressure ridge over the coastal lowlands (Suppl. III a–d). But they are also related to variations in the synoptic conditions, which rarely follow the simple latitudinal patterns suggested by

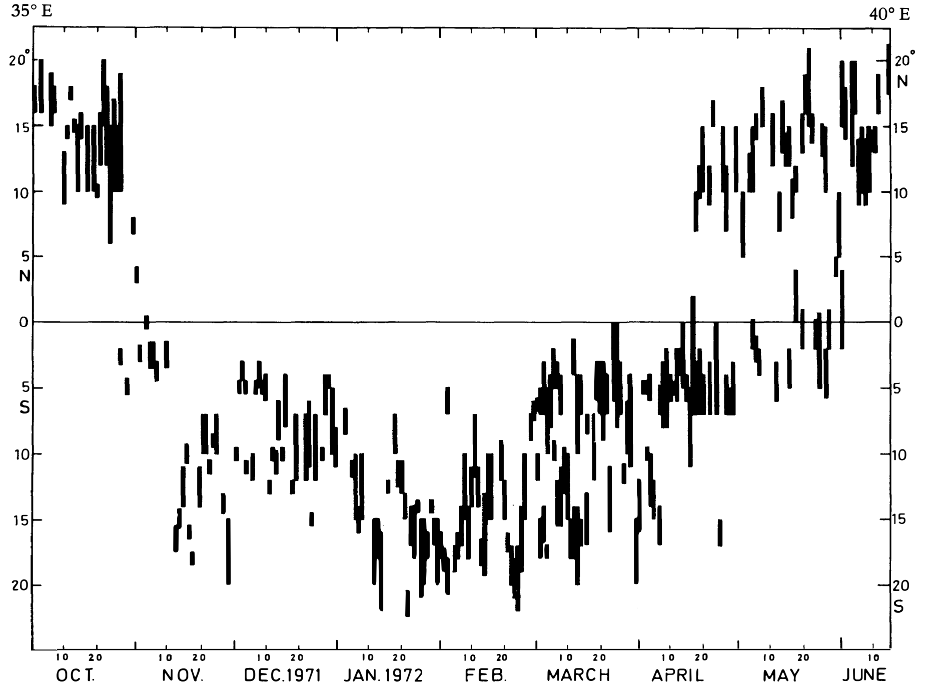

Fig. 2: Latitudes between 35 and 40° East where large scale surface convergence could be inferred from daily weather charts (Lake Victoria region excluded)

the mean maps. "Sometimes a season may pass without a good example of a particular synoptic model occurring" (THOMPSON, 1965, p. 9). This is the main reason why the zonal belt concept has little practical use in forecasting rainfall or even its probability (JOHNSON, 1962, p. 5; THOMPSON, 1957).

Even the surface I.T.C., which moves mainly in meridional directions, rarely progresses regularly: its latitudinal changes are often interrupted or even temporarily reversed (Fig. 2). As the diagram indicates, the I.T.C. is on many days so weak that it cannot be recognized on the daily weather map. These variations in the movement and in the intensity of the I.T.C. differ largely from year to year, so that the same month may produce entirely different rainfall distribution patterns in consecutive years (JOHNSON, 1962, p. 11). This strong variability in time is mainly responsible for the occurrence of favourable and poor rainfall seasons in Tanzania.

Rainfall during the main monsoon periods also varies from year to year. Incursions of wet Congo air masses during the northeast monsoon, which are normally limited to the western regions of Tanzania, occasionally penetrate as far as the east coast, bringing widespread rain over most of northern Tanzania (TREWARTHA, 1962, p. 124). And disturbances during the southeast monsoon, usally restricted to the coastal areas of northern Tanzania, sometimes venture inland, producing freak storms and scattered showers in areas which are normally very dry.

Most of these irregularities of rainfall over time are suppressed by using long-term means. However, all characteristics which do not occur every year during the same month are also obliterated by this method.

The result of these variations over place and time is that the rainfall distribution in Tanzania is complex during most months, with large differences over small distances and strong variations from year to year. It is doubtful wheter the present network of raingauges is dense enough to record the full intricacy of the pattern, but a reasonable representation can be produced on the scale of the maps in this article.

Cartographic representation

The normal difficulties encountered when the variations of a distribution pattern over time are to be represented on a map, are enlarged by the high rainfall variability in Tanzania. The usual method to illustrate seasonal rainfall distribution is to delineate regions with a more or less homogeneous regime. When this method is used in Tanzania and is based on absolute amounts of rainfall, it produces very complicated patterns and a large number of regions. Over 50 different regions were recognized on the basis of monthly means of 100 and 150 mm (JACKSON, 1970). A simpler system, using the number of months with a mean rainfall over 51 mm (2 inches) still resulted in 24 different regions (GRIFFITHS, 1972, p. 325). Another disadvantage of this method is that the boundaries between the rainfall regions are rather unrealistic, since they rarely materialize in any one individual year, due to the large deviations from mean conditions. The boundaries, when drawn on a map, also tend to conceal the very gradual transition which prevails between the various types of regimes.

The use of harmonic analysis of monthly rainfall means produces quite the opposite result, with about 85 per cent of Tanzania belonging to one major region (Potts, 1971). A method which suggests such a uniformity in rainfall conditions cannot be very useful. Moreover, the double rainfall maximum, which prevails in large parts of Tanzania, is insufficiently represented by this method, as most of the country is shown as having a 'unimodal' regime. This is because the two rainfall maxima in Tanzania occur relatively close together in time, so that the influence on the ratio of 2nd to 1st harmonic amplitude is limited compared to other parts of East Africa (Potts, 1971, p. 36, Fig. 5).

An improvement over these methods can be obtained by expressing mounthly means as a percentage of the annual total rainfall, thereby reducing the influence of local factors.. In this way point values become representative for large areas and a limited number of stations can be used to indicate conditions over the whole country (Suppl. IV). On this map percentage values are grouped in five classes around the average for all months of 8.3% and some minor detail has been eliminated as a result. In the process some February values, depressed by the short duration of that month, were corrected for length of month.

The map illustrates two major features of the seasonal rainfall distribution in Tanzania. The first is the length of the dry period, which occurs almost everywhere in the country between May and October. If dry months are defined as those with less than three per cent of the annual total, the dry season lasts for five or six months in the southern and central parts of Tanzania. It decreases gradually in length to about one month in the Lake Victoria region and to an almost complete absence of dry months in the northeastern coastal region.

The second major characteristic is the transition between a single and double rainfall maximum. The single type prevails in the southern and central parts of Tanzania. The double maximum, indicated by at least one drier month between two with relatively heavy rainfall, occurs mainly in the west (Uruwira to Kigoma), coastal areas of the east (Amani – Kilwa Kivinje) and in some central parts of the country (Iringa, Mahenge, Mbulu). The dry month is either January or February or both.

A clear picture of the main seasonal rainfall types in Tanzania has been obtained. A single, short rainy season in the south changes gradually to a longer, usually interrupted rainy period in the northeast and northwest. However, the transition between these types is not very well illustrated by the point values. For this purpose two simple indices, which can be expressed on maps in the form of isolines, have been designed (Fig. 3).

The first of these is the Seasonal Concentration Index, computed as the total number of months with a mean rainfall either over 17 per cent or below 4 per cent of the annual mean. These values represent double, respectively half of the average for all months. The index illustrates both the duration and the intensity of the rainy season. Its distribution in Tanzania is rather simple, illustrating how the short and concentrated rainy season in the south of the country gradually changes to the longer, less concentrated rainy periods of the Lake Victoria region and the northeastern coastal belt (Fig. 3, left).

The Seasonal Interruption Index shows the percentage of all rainy seasons which were clearly interrupted (Fig. 3, right). The criterion for an interruption is the occurrence of one or more months with at least 20 per cent less rainfall than both the previous and following months. This limit was raised to 30 per cent when the dry month was February.

Unless they occur every year during the same month, which in Tanzania is rarely the case, these interruptions are insufficiently represented by long-term means. Values of the index were generally quite high in Tanzania: the lowest were around 45 per cent, they were recorded in the extreme south of the country. Highest indices occurred in the northeastern coastal areas and on the islands, where the index reached 100 per cent. These high values show that interruptions of the rainy seasons of such magnitude that they are reflected in monthly rainfall totals, are quite common, even in the areas with a single rainfall maximum indicated by mean figures. Most interruptions occurred during January and February, but some were recorded for December and March. In some cases rainfall seasons were interrupted twice by drier months.

It is clear that where the Seasonal Interruption Index exceeds 80, so that four out of five seasons exhibited an interruption, a double rainfall maximum exists normally. The map shows that this situation exists over large parts of northern and eastern Tanzania (Fig. 3, right).

The two index maps display similar distribution patterns. They demonstrate the existence of a large transition zone between the two main types of seasonal rainfall distribution in Tanzania. This zone of transition occupies most of the country.

Frequencies of occurrence

Monthly rainfall means, though widely used because of their general availability, possess several disadvantages. Firstly, by their very nature they cannot indicate any variations shorter than one month. Theoretically a dry season as long as seven weeks may

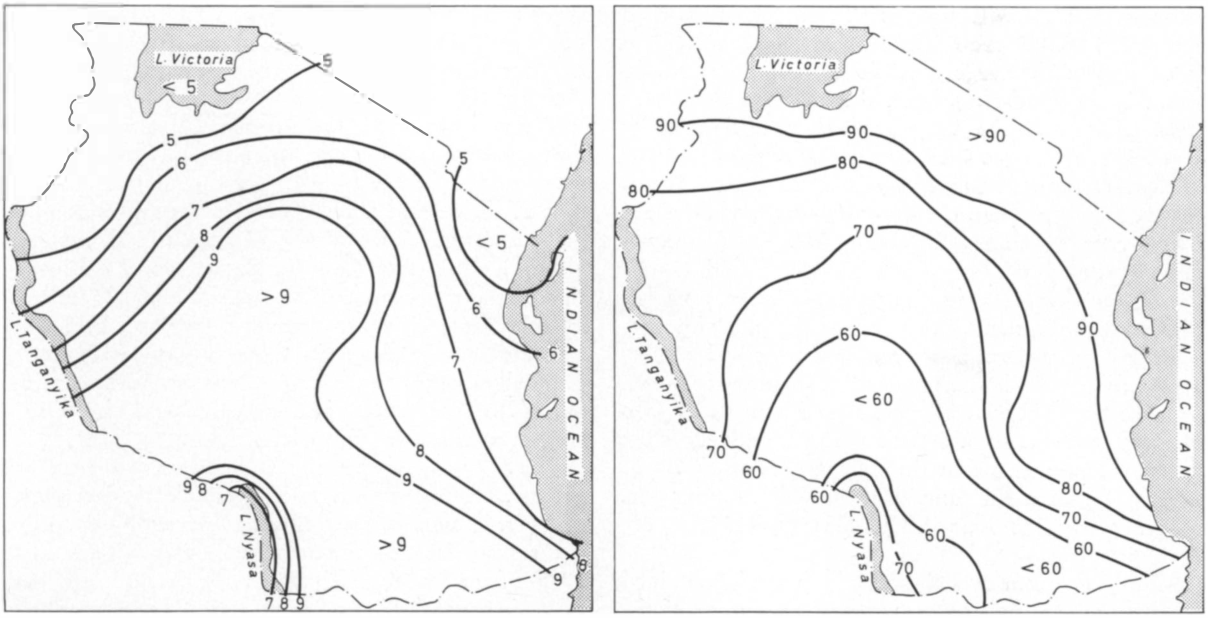

Fig. 3 – left: Seasonal Concentration Index over Tanzania (total number of months with either more than 17% or less than 4% of the annual mean rainfall)
right: Seasonal Interruption Index over Tanzania (per cent of all rainy seasons which showed a clear interruption) Based on records for the period 1931–1960

not show in monthly records if it is adjoined by heavy rains at the beginning and end of a period of two months. Secondly, as was mentioned above, monthly means fail to represent all features which do not occur every year during the same month. A third drawback is that monthly means tend to indicate higher amounts of rainfall than can normally be expected with a probability of 50 per cent. This effect is due to the positive skewness of the frequency distribution of individual monthly rainfall totals. This inflation of the mean is, moreover, rather variable from place to place and from month to month, as is illustrated by the following table:

Mean rainfall in per cent of the median for the same month

Station	Nov.	Dec.	Jan.	Feb.	March	April	May
Bukoba	111	102	97	103	110	97	100
Musoma	101	110	112	128	93	110	102
Moshi	120	129	190	112	104	121	97
Kigoma	105	112	110	112	108	112	114
Dodoma	1100	91	123	103	94	128	600
Dar es Salaam	146	132	102	140	120	113	118
Mbeya	200	96	101	103	101	108	100
Mahenge	125	116	98	118	107	102	118
Lindi	136	99	104	118	98	97	105

(Based on records for the period 1931–1960)

Because the results obtained in the above part of this article were largely based on monthly means, it was considered necessary to compare the conclusions with some frequency figures, which do not suffer from the disadvantages of long-terms means. Frequencies were computed at 14 stations over a period of 20 years and each month was divided into six pentades (5-day periods). An adjustment was made for the different length of the final pentade for those months with 28, 29 or 31 days.

For each pentade the frequency of occurrence was recorded for:

1) raindays (days with more than 5 mm of rain). This limit was chosen to exclude frequent very light falls of rain, which are of little importance in hot climates. The frequency of raindays is expressed per mille of the annual total at each station; the curves for all stations are therefore comparable,
2) dry spells (all five days received less than 5 mm of rain). Dry spells are indicated by the number occurred during twenty years.

Both curves were smoothed mathematically by 3-pentade moving means. The dry spell diagram indicates the general rainfall trends, while the rainday curve supplies finer detail (Fig. 4).

The frequency diagrams largely confirm the conclusions drawn in the earlier parts of this study. The concentration of the rainy season is well illustrated: it is high in the southern and central parts of Tanzania (Mbeya, Songea, Iringa, Dodoma) and much lower in

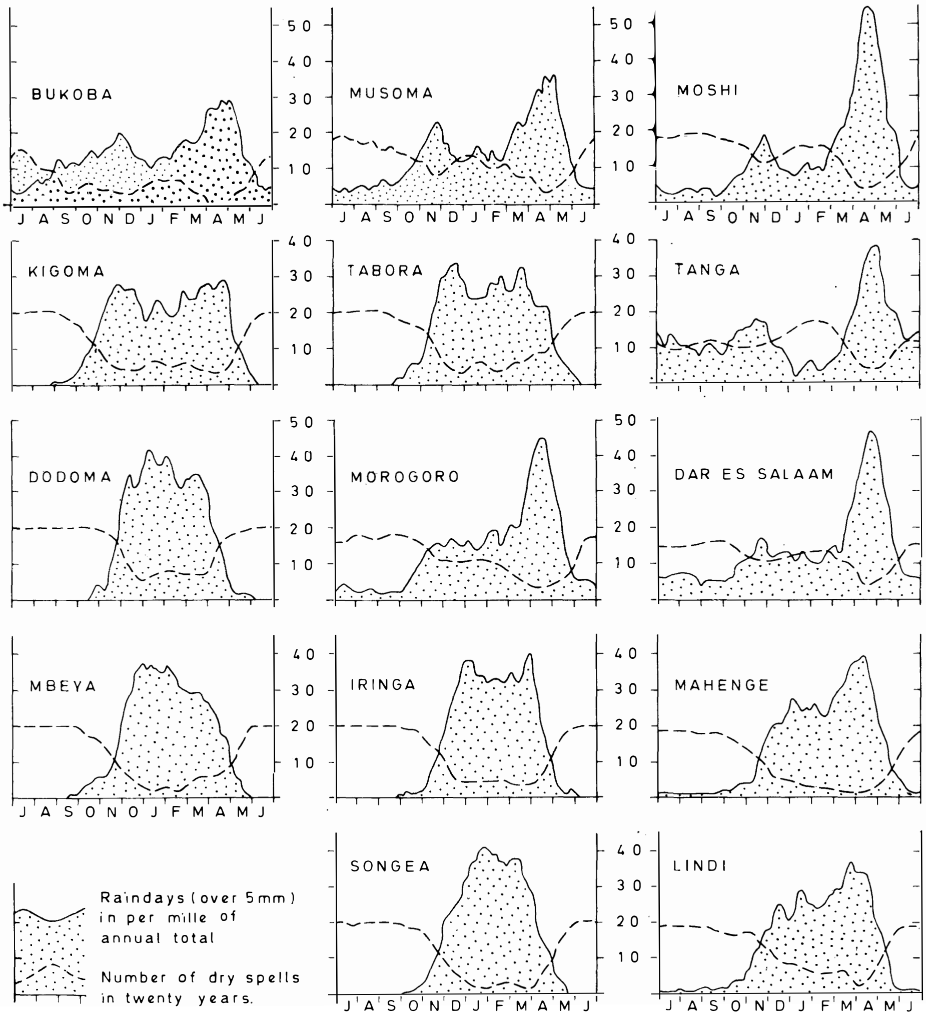

Fig. 4: Frequency of occurence of raindays (over 5 mm) and dry spells (periods of 5 days, each with less than 5 mm of rain) at selected stations in Tanzania
Based on records over 20 years

the north and east, where frequency curves are much flatter, as shown by Bukoba, Tanga and Dar es Salaam. Short interruptions of the rainly season are also clearly indicated: all stations except Mbeya and Songea show this feature. Short breaks are most frequent at the northern stations, but still present at Iringa, Mahenge and Lindi.

The strong variability of rainfall in Tanzania is illustrated by the relatively large number of dry spells even during the height of the rainy season, when most stations had three or four dry spells in twenty years. Only at Bukoba, Mbeya and Mahenge the number of dry spells during the peak of the rains is considerably less.

We can therefore conclude that the monthly means, despite their disadvantages, produced a realistic picture of the seasonal rainfall distribution in Tanzania. Using these monthly means in relation to the annual means, and by referring to individual monthly totals, a good representation of actual conditions has been obtained.

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References

Coutts, H. H.: Rainfall of the Kilimanjaro area, Weather, Vol. 24, p. 66–69, 1969.

East Africa Royal Comission: Report for 1953–1955, London, p. 252–254 and Map. 3, 1961.

Findlater, J.: Mean monthly airflow at low levels over the western Indian Ocean, Geophysical Memoir No. 115, Met. Office, London (H.M.S.O.), p. 6, 24, 25, 1971.

Flohn, H.: Studies on the meteorology of tropical Africa, Bonner meteorologische Abhandlungen, No. 5, p. 20, 25, 1965.

– : On the causes of the aridity of North Eastern Africa (translated from Würzburger Geographische Arbeiten, Vol. 12, 1964), East African Meteorological Dept., Nairobi, p. 13, 14, 1966.

Griffiths, J. F.: Eastern Africa, in: Climates of Africa, Vol. 10, of World Survey of Climatology, Amsterdam–New York, p. 313–347, 1972.

Jackson, I. J.: Some physical aspects of water resource development in Tanzania, Geografiska Annaler, Series A, Vol. 52, p. 179, 1970.

Johnson, D. H.: Rain in East Afrika, Quarterly Journal of the Royal Meteorological Society, Vol. 88, p. 1–19, 1962.

Johnson, D. H. and Mörth, H. T.: Forecasting research in East Africa, in: Bargman, D. J. (Editor) – Tropical Meteorology in Africa, Nairobi, p. 56–137, 1960.

Kenworthy, J. M.: Rainfall and the water resources of East Africa, in: Steel, R. W. and Prothero, R. M. (Editors) – Geographers and the Tropics: Liverpool essays, London, p. 129, 1964.

Lumb, F. E.: Synoptic disturbances causing rainy periods along the East African coast, Meteorological Magazine, Vol. 95, p. 152–154, 1966.

Mörth, H. T.: Summary of discussions on rainfall, Technical Conference on the agroclimatolgoy of the highlands in eastern Africa, Nairobi, p. 1–3, 1973.

Nieuwolt, S.: The influence of aspect and elevation on daily rainfall: some examples from Tanzania, paper presented at the Technical Conference on the agroclimatology of the highlands in eastern Africa, Nairobi, p. 2–6, 1973.

Potts, A. S.: Application of harmonic analysis to the study of East African rainfall data, Journal of Tropical Geography, Vol. 33, p. 31–43, 1971.

Thompson, B. W.: Some reflections on equatorial and tropical forecasting, East African Meteorological Department, Nairobi, Technical Memoir No. 7, p. 5, 1957.

– : The Climate of Africa, Nairobi, 108 pages. 1965.

– : The mean annual rainfall of Mount Kenya, Weather, Vol. 21, p. 48, 1966.

Tomsett, J. E.: Average monthly and annual rainfall maps of East Africa, East African Meteorological Department, Nairobi, Technical Memorandum No. 14, 20 pages (new rainfall maps were produced in 1972) 1969.

Trewartha, G. T.: The Earth's problem climates, Madison, p. 121–137, 1962.

Walter, M. W.: A new presentation of the seasonal rainfall of East Africa, East African Agricultural Journal, Vol. 18, p. 11–20, 1952.

DEUTUNG VON ORTS- UND FLURNETZEN IM HOCHLAND VON MEXIKO ALS KULTRELIGIÖSE RELIKTFORMEN ALTINDIANISCHER BESIEDLUNG

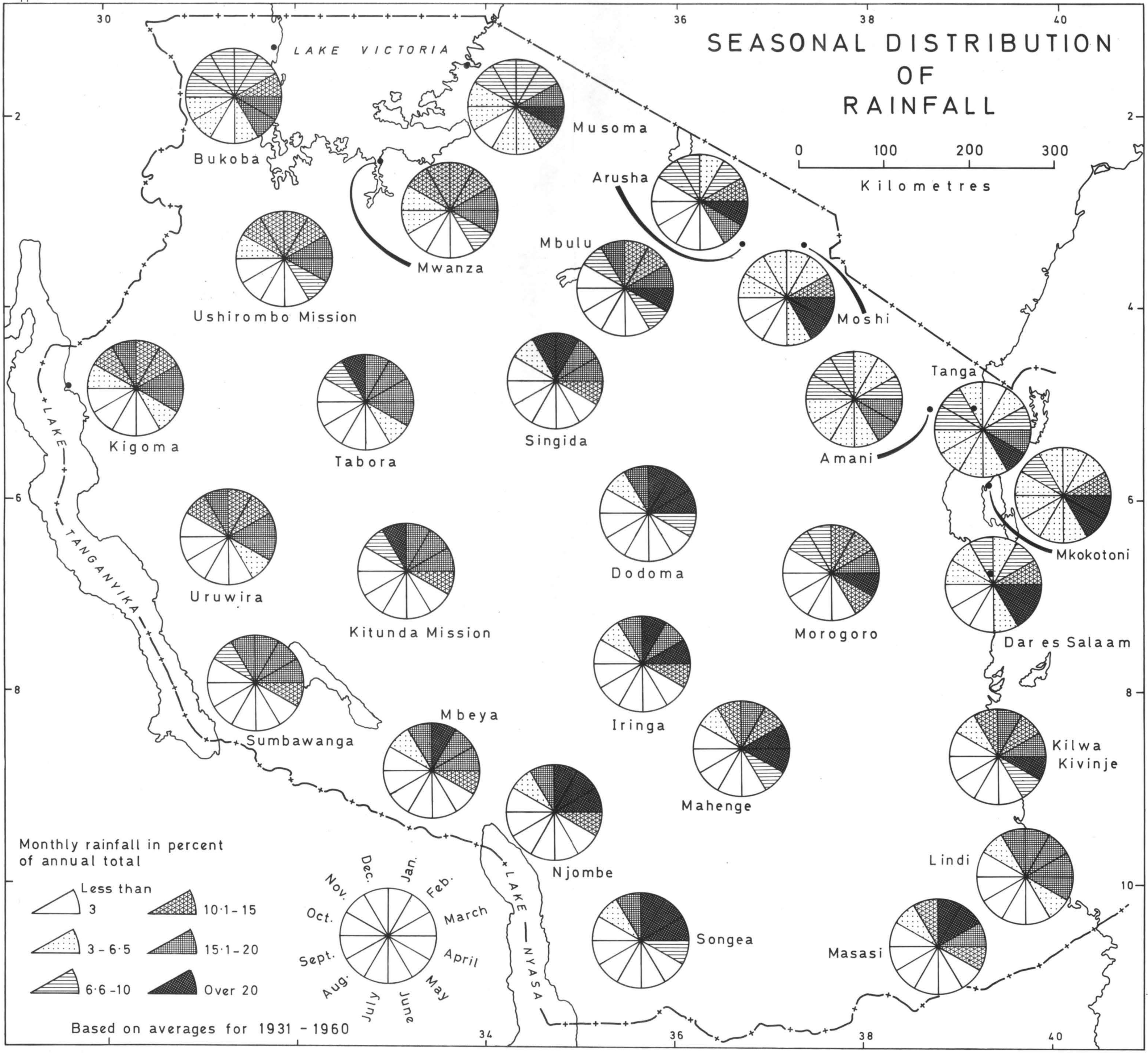
Franz Tichy

Mit 5 Abbildungen und 1 Beilage (V)

Summary: Evidence of village and field networks in the Highlands of Mexico as relict forms of religious cults in early Indian settlement.

Through the analysis of field and village plans, in conjunction with the measurement of the orientation of ruins and churches of the colonial period, three differently arranged rectangular systems were recognised and delimited in the historically settled basin area of the south east Mexican Highlands. Because of preclassical ruins arranged in the same way, at least two of the three systems can be dated around the time of the birth of Christ. The orientation 17° and 26–28° are solar oriented from an hypothetical observatory mountain. The 17° system is connected with the time of maize sowing in the dry field system. The three systems are thought to be relict forms of a religious cult, and have survived from the time of the early Indian settlement by a people of the Mesoamerican High Culture, because they provided a basis for church building and urban foundation in the early colonial period. A fourth rectangular system exists in the chess-board ground plans of a number of villages which received Franciscan monasteries and are mostly oriented by compass direction. The colonial period brought a number of important changes with the foundation of haciendas, sometimes on the sites of former village settlements, but only seldom altered the ground plan systems.

In den dichtbesiedelten Ebenen des Hochbeckens von Puebla und Tlaxcala zeigt die Anordnung der Dorfsiedlungen einige recht auffällige regelhafte Züge. Besonders deutlich sind Reihen von Siedlungen in WNW-OSO-Richtung in der Ebene südlich von Cholula und im Atoyac-Zahuapan-Schwemmland erkennbar. Es ist dies nahezu die gleiche Richtung, der die Straßen in den meisten Dörfern und auch in den Städten Cholula, Puebla und Tlaxcala folgen. Im Zusammenhang mit der Erforschung der Genese der Kulturlandschaften in diesem Raum stellte sich die Frage, ob der Anordnung der Siedlungen und deren Grundrissen ein Rechtecksy-


SEASONAL DISTRIBUTION OF RAINFALL
0 100 200 300
Kilometres
LAKE VICTORIA
LAKE TANGANYIKA
LAKE NYASA
Bukoba
Musoma
Mwanza
Arusha
Mbulu
Moshi
Ushirombo Mission
Kigoma
Tabora
Singida
Amani
Tanga
Mkokotoni
Uruwira
Kitunda Mission
Dodoma
Morogoro
Dar es Salaam
Sumbawanga
Mbeya
Iringa
Mahenge
Kilwa Kivinje
Njombe
Lindi
Songea
Masasi
30
34
36
38
40
2
4
6
8
10
Monthly rainfall in percent of annual total
Less than 3
3 - 6·5
6·6 -10
10·1-15
15·1-20
Over 20
Jan.
Feb.
March
April
May
June
July
Aug.
Sept.
Oct.
Nov.
Dec.
Based on averages for 1931 - 1960

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Mean Synoptic Situations

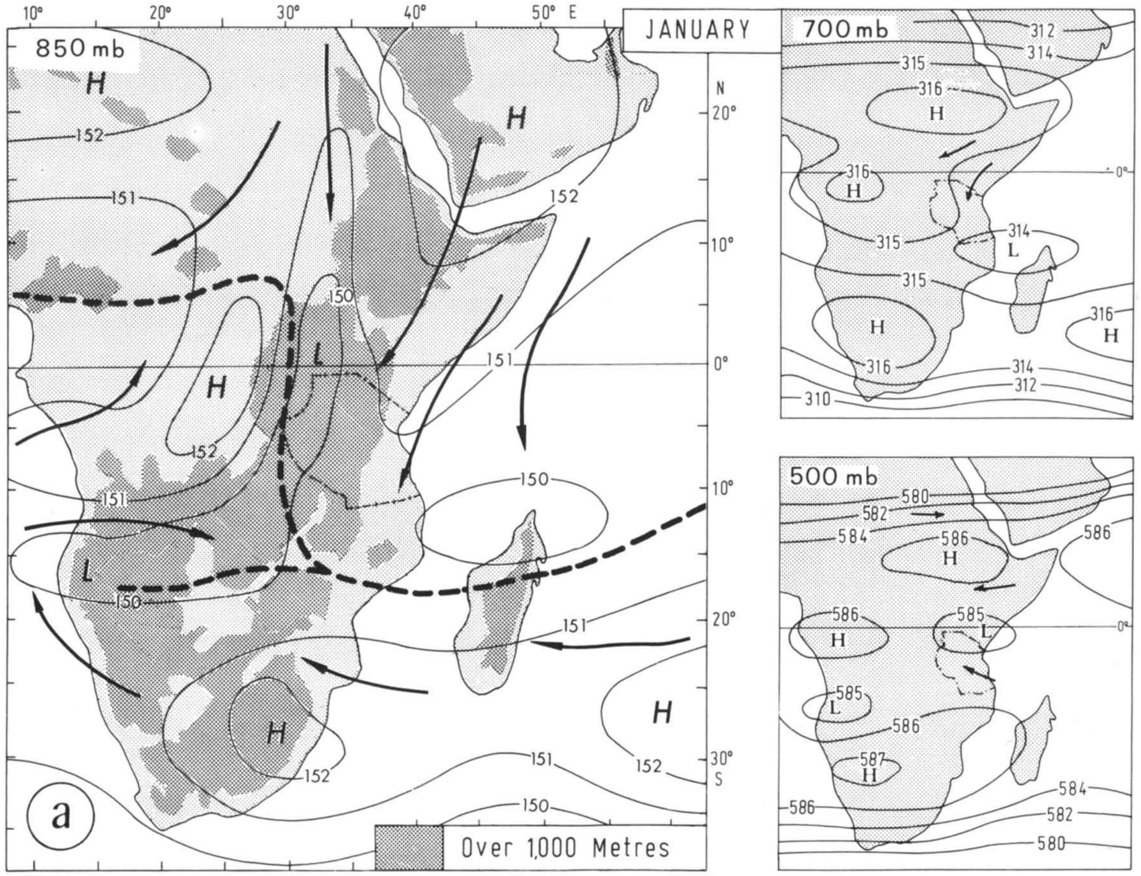


Fig. a Mean synoptic situation during January

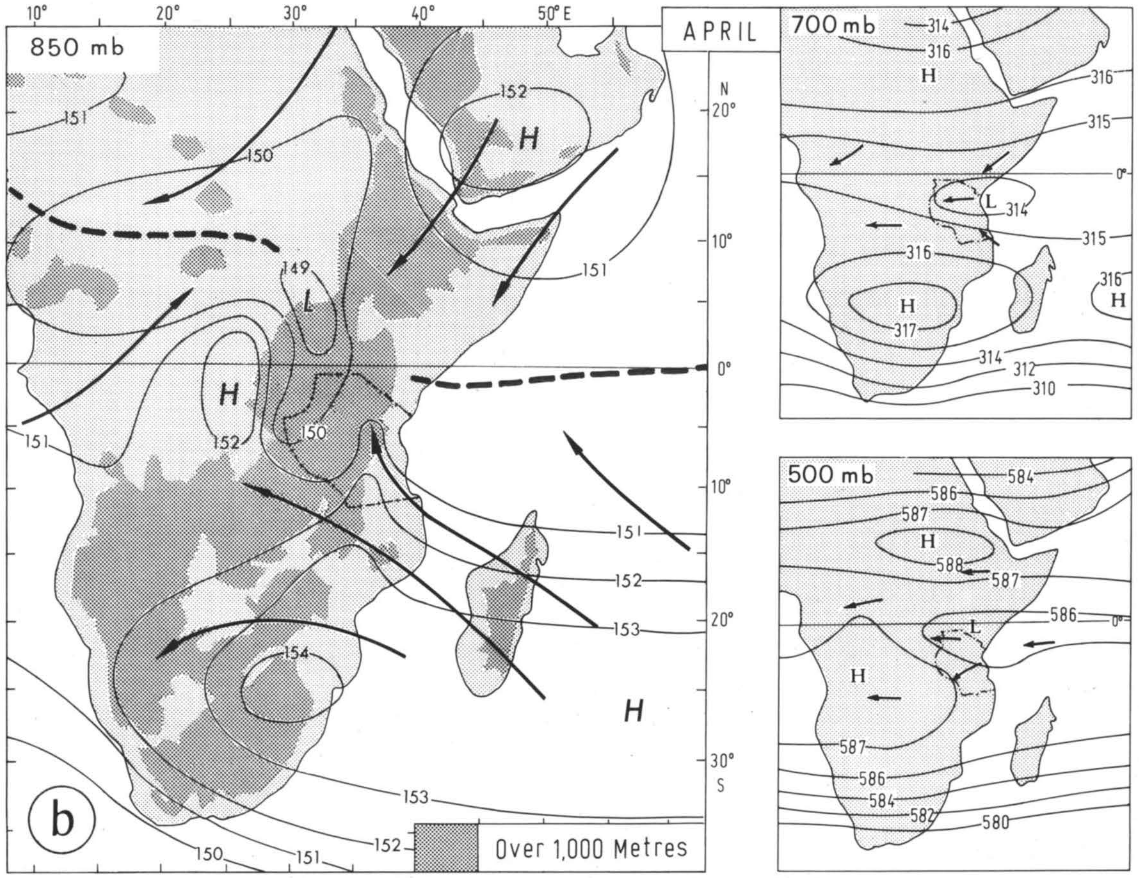


Fig. b Mean synoptic situation during April

Contour lines in geopotential dekametres; arrows indicate prevailing wind directions.
The heavy broken lines on the 850 mb maps denote the mean position of the surface I.T.C.

Fig. c Mean synoptic situation during July

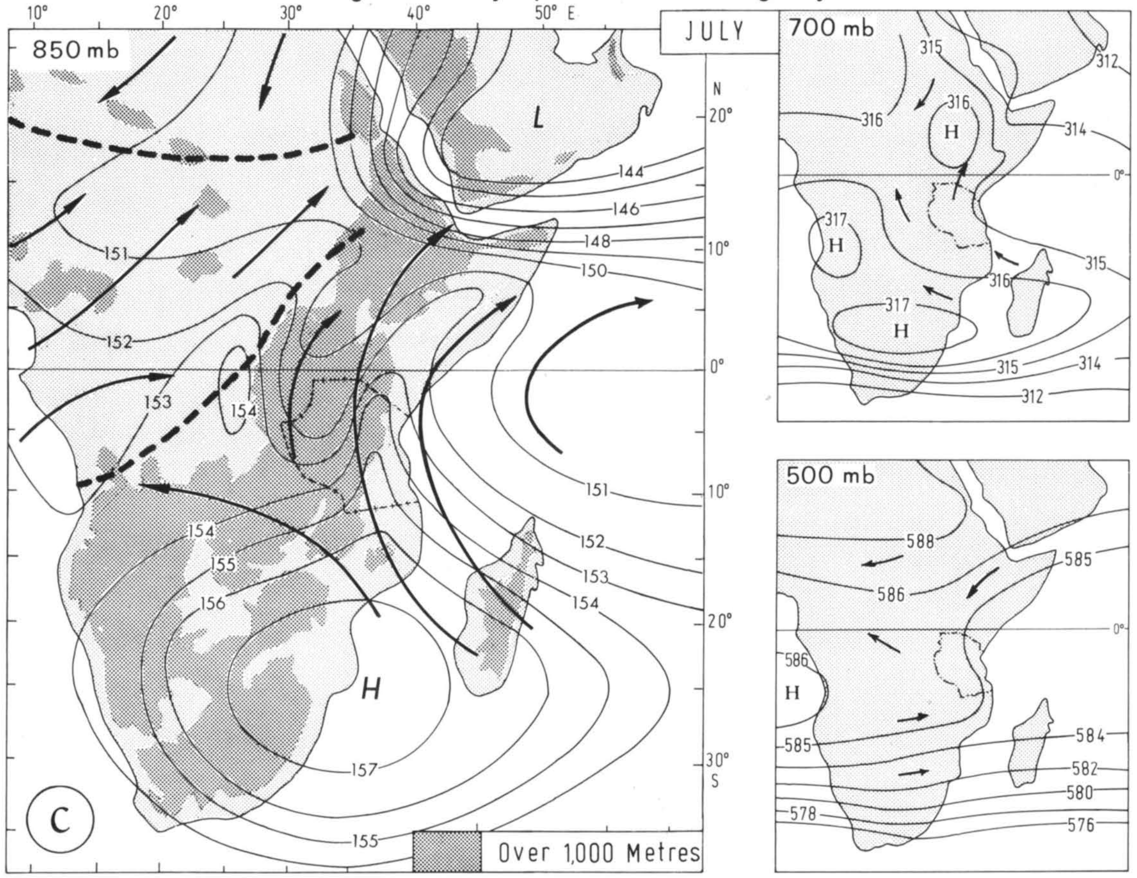
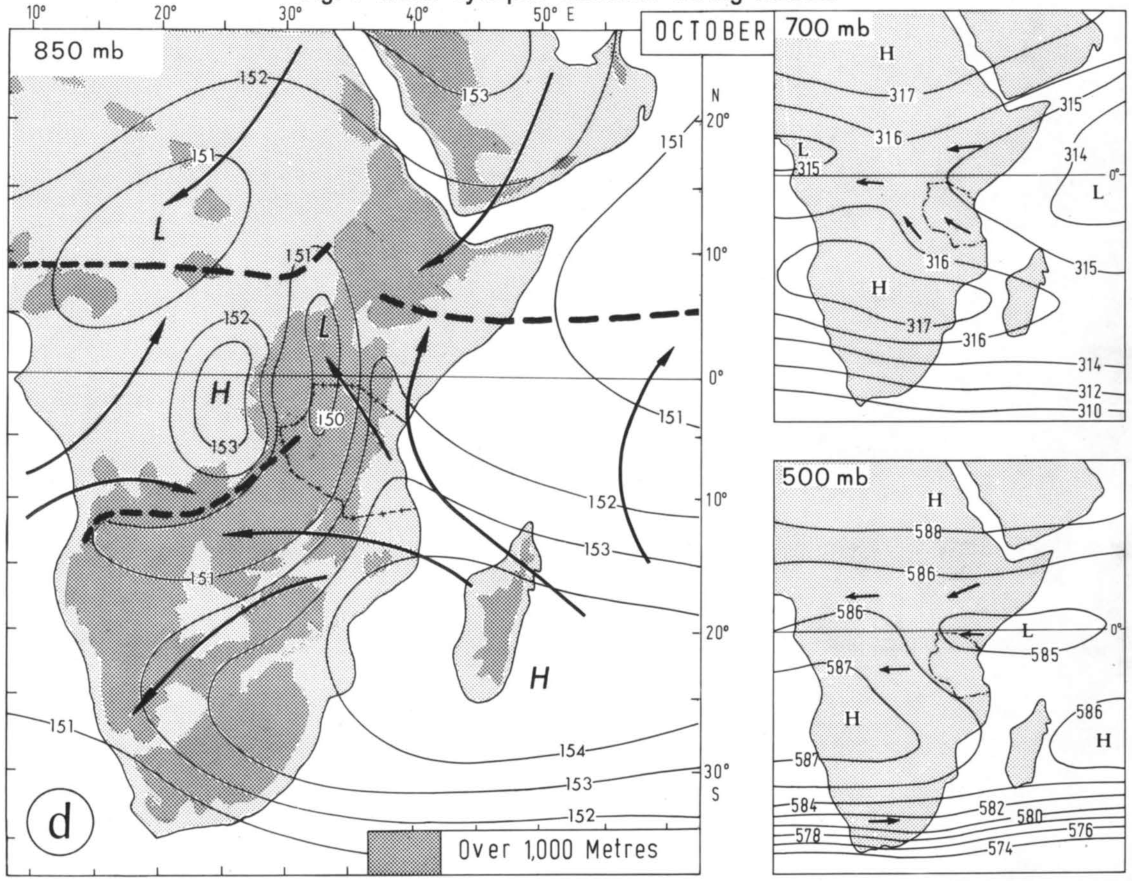


Fig. d Mean synoptic situation during October



(Sources for Fig. a-d: Findlater, 1971; Thompson, 1965)