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Daily rainfall variability in southwestern Nigeria

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सार — व्यतिसहसंबंध (क्रॉस कोरिलेशन) तकनीक का प्रयोग करते हुए दक्षिण-पश्चिमी नाइजीरिया में वर्षा क्षेत्रों के मध्य दूरियों और उनकी स्थानिक संरचना का विश्लेषण किया गया। तीन मौसम स्थितियों अर्थात् रेखा वाताहृति, मानसून और गरजते तूफान अवधि के आंकड़ों को विश्लेषित किया गया।

प्रदेश में प्रभावी उठाव की प्रवृति अपनाते हुए दीर्घ अक्ष सहित, आकार में दीर्घ वृत्ताकार होने की सभी मौसम स्थितियों के लिए वर्षा व्यतिसहसंबंध क्षेत्र का पता लगाया गया। तथापि, मौसम स्थितियों के अनुसार वर्षा क्षेत्रों को अलग करने के लिए विशिष्ट दूरियां पाई गई है—मानसून वर्षा में 50 कि.मी. दूर, रैखिक वाताहृति वर्षा में 75 कि.मी. दूर किन्तु तड़ित झंझा वर्षा में 100 कि.मी. दूर पाई गई।

ABSTRACT. The spatial structure of, and distances between, rainfall-areas in southwestern Nigeria were analysed using the cross-correlation technique. Data were analysed for three weather situations, namely, line-squall, monsoon and thunderstorm periods.

The rainfall cross-correlation field was found for all the weather situations to be elliptical in shape with the major axis following the trend of the dominant relief in the region. However, typical distances were found to separate the rainfall areas according to the weather situtation: 50 km apart in monsoon rains, 75 km apart in line-squall rains but 100 km apart in thunderstorm rains.

1. Introduction

Based on theoretical considerations, Morth in a personal communication to Sharon (1974) commented on the feasibility of a preferred distance between adjacent convective rainstorms in Sukumaland, Tanzania. Using data on the average rainfall per storm and the water vapour content of the air in a model for convective rainstorms, he found a distance of roughly 50 km between cells as quite possible. By subjecting the prevailing distances between rain-areas to statistical analysis for the same region, Sharon (1974) reported a spacing of rainfall-producing cells which fall into two (or possibly even three) ranges of typical distances in Sukumaland, an inland part of Tanzania. Sharon (1974) found an average of 50 km between cells that are closer to each other and about 100 km for some other cells, further apart.

Austin *et al.* (1961) reported a similar spacing of cell groups in line-squall rains over the northeastern part of the United States while the study of Owen (1966) indicated a similar arrangement of cell groups in air-mass thunderstorm rains over New England.

West Africa receives rainfall from such convective systems, namely, line-squalls, thunderstorms and monsoons. This study is, therefore, concerned with the analysis of the spatial structure of, and distances between, rainfall-areas under different weather situations based on data analysed for southwestern Nigeria. It is pertinent to mention that Sharon (1974) definition of a rainfall-area as an area receiving rainfall during a given time was adopted in this study.

2. The nature of rainfall in southwestern Nigeria

The study area is southwestern Nigeria (Fig. 1). It is demarcated in the north by rivers *Teshi* and the *Niger* while only river *Niger* forms the boundary towards the east. The relief of the area is dominated by the Yoruba-Kurukuru hills which together form the southwest upland of Nigeria. This upland area approximately traverses the study area in the SE-NE direction.

Rainfall in southwestern Nigeria, as in the rest of West Africa, is induced by the presence of synoptic scale disturbances within the moist southwest airstream (the southwesterlies) which decreases in depth inland from the coast. These synoptic scale weather disturbances are the line-squalls, thunderstorms and the monsoons. Line-squalls (or disturbance lines) refer to a system of several thunderstorms organised in lines or bands and moving as organised systems. They have their axis oriented approximately north-south and propagate westwards from the east. Thunderstorms are of limited spatial extent and they have a short life span. Because they result from convection they tend to occur randomly in space. According to Omotosho (1985) the West African monsoon rain can be taken to be the prolonged

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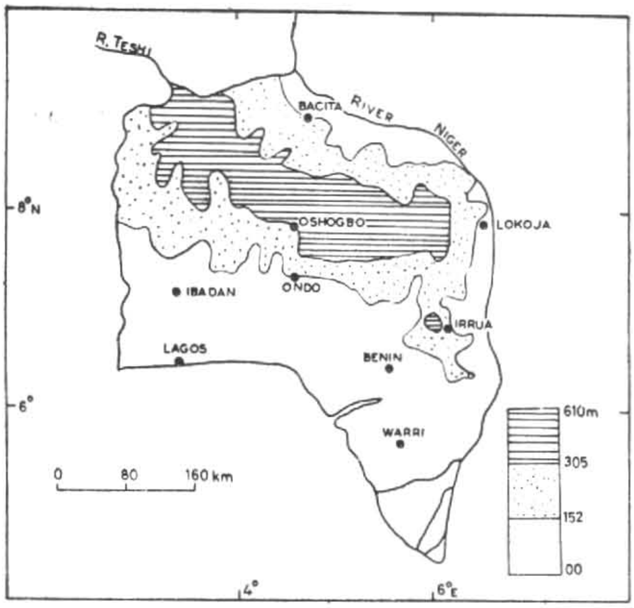

Fig. 1. Southwestern Nigeria showing relief and data collection stations

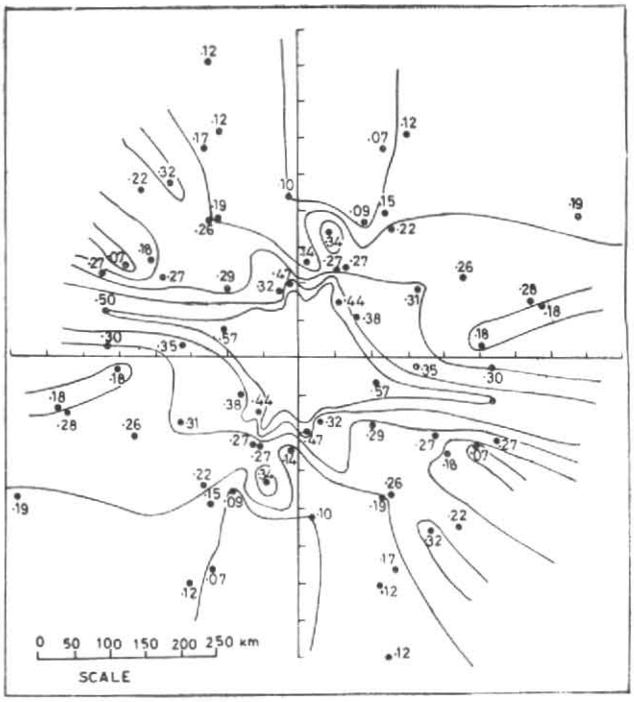

Fig. 2. Composite map of the spatial distribution of correlation coefficients of daily rainfall in southwestern Nigeria in May (period of line-squall rainfall)

rainfall with intermittent thunders whose periods of occurrence are much shorter than that of the rain with which they are associated. Thus, the occurrence of thunder is associated with thunderstorms and monsoons but it is of an intermittent nature and shorter duration in the latter.

Over southwestern Nigeria, squall activity exhibits a double maximum; a primary maximum in May while the secondary maximum occurs in October (Omotosho 1985). Balogum (1981) also reported two periods of maximum thunderstorm activity for the region : the first maximum occurs between April and May while the other occurs in October. For the study area monsoon rains are confined to the period between June and October with a peak about August (Omotosho 1985).

3. Methods of study

To study the spatial structure of rainfall-areas the distribution of correlation coefficients had been mapped by various authors, using r-estimates related to a single "key-station" at a time (*e.g.*, Huff and Shipp 1969; Hendrick and Comer 1970). For n stations, each map thus included $n-1$ points on which correlation lines could be based. To obtain a complete description of the correlation field, one has to map out the isocorrelation lines around each station of the region concerned. There are clear logistical limits to the number of such isocorrelation maps that can be drawn especially when the number of stations is large, while in addition, it becomes difficult to visualize in the aggregate the interdependence of the variables.

The composite (or cross) correlation analysis technique employed by Sharon (1974, 1978, 1979) and Sumner (1983) is free from these drawbacks. The technique involves the abstraction of the coefficients of each map from the specific stations with which they are originally associated. Thus, only the elements of distance and direction from the "key-station" will be preserved for each coefficient, independent of the identity of the stations themselves. The map will include $n(n-1)$ correlation coefficients, each in its appropriate distance and direction relative to its original "key-station". The location of all "key-stations" is identically represented at the centre of the composite map. Each r-estimate is included in the map twice, at diametrically opposite points relative to the centre. This results from the fact that each r-estimate is related to two stations, each of which serves as "key-station" to the other. Finally, it is important to note that the resulting map is a generalization applying to the area treated as a whole.

3.1. *The data base*

Daily rainfall totals for 5 years, 1976-80, from 9 stations in southwestern Nigeria were used. The stations for which data were collected are shown in Fig. 1. The stations were chosen from a grid network of approximately 120 × 120 km in size. The closest pair of stations are about 95 km apart. This indicates that none of the stations included are close enough to show the magnitude of the correlation within 95 km distance of a station.

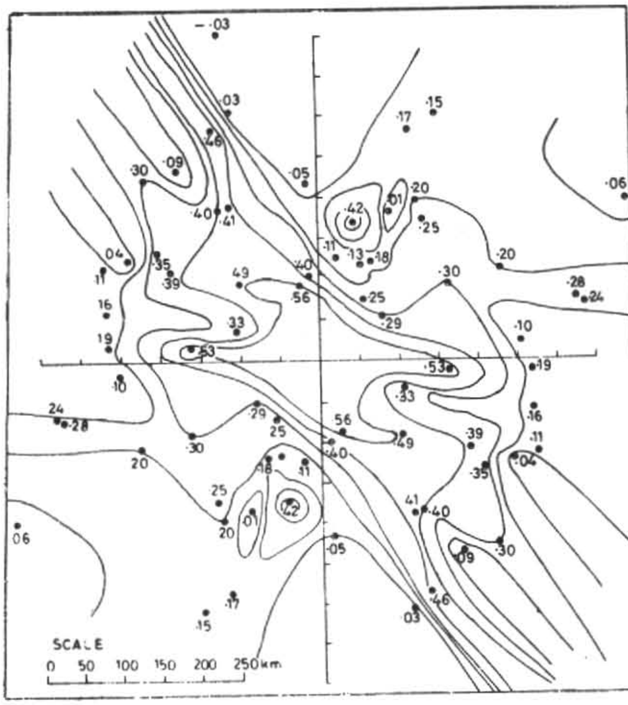

Fig. 3. Composite map of the spatial distribution of correlation coefficients of daily rainfall in southwestern Nigeria in August (period of monsoon rainfall)

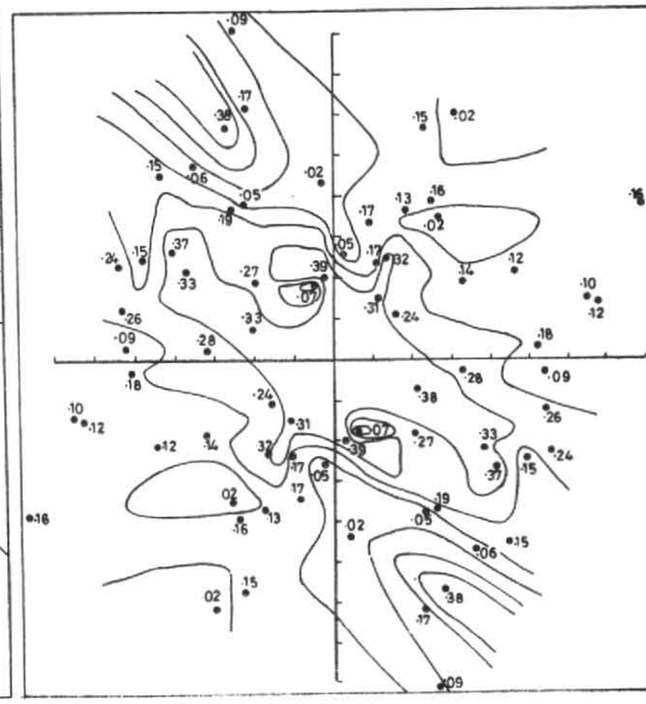

Fig. 4. Composite map of the spatial distribution of correlation coefficients of daily rainfall in southwestern Nigeria in in October (period of thunderstorm rainfall)

Data were analysed for only 3 months—May, August and October. May represents a peak period of line-squall activity over the study area, August represents the peak of the occurrence of monsoon rains while October is a period of thunderstorm activity over southwestern Nigeria. The r-estimates for May were based on 145 observations, August on 152 observations while for October 151 observations were used. Cross-correlations were computed only for those days when at least one station received 0.1 mm rainfall. Thus, significant cross-correlations at $p=0.02$ occur at $r=0.2$ for the different weather situations.

4. Results and discussion

4.1. *The spatial distribution of correlation coefficient*

The spatial distribution of correlation coefficients can be studied from the composite maps of all coefficients shown for the different weather situations (Figs. 2-4). The composite cross-correlation field appears in Fig. 2 for line-squall rainfall, *i.e.,* for the month of May. Generally speaking Fig. 2 shows an elliptical pattern of isocorrelates with the major axis in the ESE-WNW direction. There is evidence of the maintenance of higher correlation, relative to distance, in this direction compared with other directions.

There is also a repetition of high correlation coefficients in some directions. At a distance of 176 km in the NNE/SSW directions one site records $r=0.34$ while another site records $r=0.32$ at a distance of 300 km to the northwest/southeast. Adjacent to these regions on either side, correlations are low, sometimes with minima in the vicinity of $r = 0.10$.

For the period of monsoon rain, *i.e.,* August, the elliptical shape of the composite cross-correlation field becomes more pronounced compared with what obtains during the period of line-squall rainfall making the dominant trend of alignment of the isocorrelates to be now focussed on the direction of SE-NW (Figs. 2 and 3). This is clearly depicted by the area bounded by $r=0.3$ isocorrelate in Fig. 3. Clearly, higher correlations are maintained in the SE-NW direction, relative to distance, compared with any other direction. There is a sharp decrease in the correlation at a distance of 90 km along bearing 10°-20° (and also bearing 190°-200°) but after this initial decrease correlation increases again within the range of 165 km along these bearings.

A similar elliptical arrangement of the isocorrelates as in May and August (the period of line-squall and monsoon rains respectively) is also obtained for October when thunderstorm rains predominate over southwestern Nigeria (Fig. 4). For this weather situation it is the area bounded by $r=0.2$ that is markedly elliptical. Also for this weather situation, repetition of higher correlation occurs to the northnorthwest/southsoutheast at a distance of 320 km, a distance which is considerably much higher than those at which repetition occurs in line-sqall and monsoon rains.

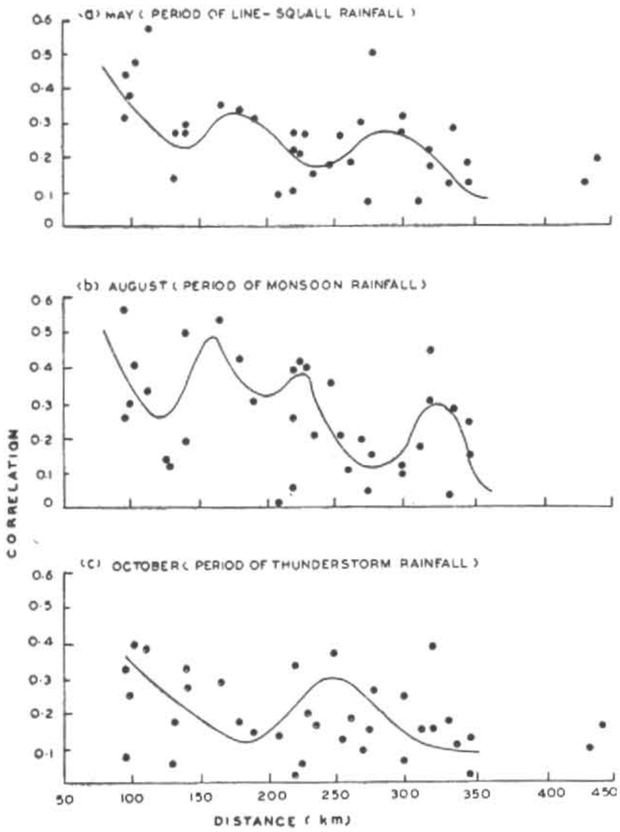

Fig. 5. Composite scatter diagram of correlation coefficient of daily rainfall in southwestern Nigeria for different weather situations

The results presented above have thus shown that in each of the three weather situations—line-squall, monsoon and thunderstorm rains—the rainfall-area assumes the shape of an ellipse over southwestern Nigeria. Although in line-squall rains, the major axis of the ellipse was found to follow the ESE-WNW direction but the SE-NW direction in monsoon and thunderstorm rains, this difference in the alignments of the isocorrelates can be regarded to be of degree rather than of kind. It can, thus, be concluded that the long axis of the cross-correlation composites in the different rainfall situations has been found to follow the trend of the southwest upland, *i.e.,* SE-NW. The situation arises that each of these different weather storms interacts with the upland region thereby producing increased convectional activity along the upland during these weather conditions over the region.

4.2. *Correlation-distance relationship*

The pattern of the correlation coefficients as a function of distance wás next examined. This has been done for the three weather situations and the resulting scatter diagrams are shown in Fig. 5.

The results shown in Fig. 5 bring out in a clearer fashion what has already been observed from the correlation maps. The main points are well illustrated between a distance of 95 & 350 km. For the period of line squall rain (Fig. 5a) the main points illustrated are : before a distance of 95 km an area of maximum correlation occurs and within 25-50 km of this maximum an area of minimum correlation is encountered. A secondary maximum occurs within 75 km of the first maximum and at about 20-50 km of this secondary maximum-minimum correlations are encountered again. At a distance of 75 km of the second maximum, correlations resume higher values while at a distance of 25 km of the third secondary maximum low correlations are recorded again. Although there is no direct evidence here to show that this pattern is true for distances within 95 km, there is no obvious reason to believe that this situation will change within the first 95 km.

The results of the correlation-distance relationship in monsoon rainfall (Fig. 5b) show essentially the same features as those for line-squall rains, though there are some distinctions. The most prominent one is the existence of four secondary maxima within the same range of distance, 95-350 km, thereby indicating that distances between rainfall-producing cells are lower in monsoon than in line-squall rains. For this weather situation, *i.e.*, monsoon rain, the distance between two adjacent maxima approximates 50 km.

The reverse of the situation discussed for the monsoon rain is encountered in thunderstorm rainfall. Two maxima occur within the same range of distance and the distance between adjacent rainfall-areas is found to increase to 100 km (Fig. 5c).

In this study, therefore, a pattern of alternating high and low correlation at successive distance ranges has been obtained. The pattern of correlation-distance relationship obtained for southwestern Nigeria, therefore, fits the findings of Sharon (1974) for Sukumaland very well. Sharon (1974) reported a spacing of rainfall producing cells which fall into two (or possibly three) ranges of typical distances in Sukumaland : an average of 50 km between cells that are closer to each other and about 100 km for some other cells, further apart. However, for southwestern Nigeria it has been found that the distances between rainfall producing cells vary according to the weather situation : 50 km apart in monsoon rains, 75 km apart in line-squall rains and 100 km apart in thunderstorm rains. It is pertinent to mention that for corresponding weather situations in the temperature regions—line-squall rains (Austin *et al.* 1961) and air-mass thunderstorms (Owens 1966)—comparatively lower distances between cells have been reported.

The results reported above for southwestern Nigeria and Sukumaland, Tanzania apply to large areas of the tropics which are affected by convective systems. Over areas of small spatial extent in the tropics where the rainfall producing system is homogeneous, a decay of correlation with distance has been reported. For example, Sharon (1974) reported such a relationship for the area of Mwadui in inland Tanzania over a range of 20 km while Sumner (1983) obtained a similar relationship for a small spatial extent of coastal Tanzania.

The existence of a pattern of alternating high and low correlation at successive distance ranges obtained in this study confirms the view expressed by Sharon (1974) that the occurrence of one isolated storm within an entire region is a rarity. This is clearly consistent with the arrangement of the rainfall producing cells as described for the different weather situations of line-squall, monsoon and thunderstorm rainfalls in section 2 above.

5. Conclusions

Some basic features of the meso-scale structure of rainfall areas in southwestern Nigeria have been studied using the composite cross-correlation technique. Data were analysed for three weather situations : line-squall, monsoon and thunderstorm rainfalls.

The spatial distribution of correlation coefficients revealed a pattern of higher correlation extending in the direction of the major upland of the region in all the different weather situations.

When the correlation coefficients were examined in relation to distance, a pattern of alternating high and low correlation at successive distance ranges was found for all weather situations. Nonetheless, the spacing of rainfall areas was found to vary according to the weather situation : 50 km of each other in air-mass monsoon, 75 km of each other in air-mass line-squalls, and 100 km apart in air-mass thunderstorms.

The results of the analysis have confirmed the view that isolated storm cells do not, in general, develop accidentally at a single spot, rather such cells tend to develop concurrently with each other as part of broader cloud systems.

Acknowledgements

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