Best regards, David

JOURNAL OF CLIMATOLOGY, VOL. 1, 69–75 (1981) 551.515.43:551.577.2(688)

THE DISTRIBUTION IN SPACE OF LOCAL RAINFALL IN THE NAMIB DESERT

DAVID SHARON

Earth Sciences Institute, The Hebrew University of Jerusalem, Jerusalem, and Institute for Desert Research, Ben-Gurion University of the Negev, Sde-Boqer

Received 2 September 1980
Revised 19 November 1980

ABSTRACT

Spatial correlation analysis has been applied to Namib rainfall, in an attempt to identify possible patterns of the spatial organization of localized storms in this area. The utility of the above technique for areas with only sparse raingauge networks is explained. Results indicate that convective storms are *not* randomly scattered in space but, tend to form at preferred distances from each other, around 40–50 and 80–100 km, with no preferred locations of, or directions between, storms. Benard cells are mentioned as possibly imposing the inferred organization of convective storms in space.

KEY WORDS Convective storms Localized rainfall Spatial distribution of storms Spatial correlation analysis Desert rainfall Namib climate Benard cells

INTRODUCTION

Rainfall in the Central Namib is very low, ranging from an average of about 10 mm annually near the coast, to above 60 mm at an elevation of 1000 m, over 100 km inland (Seely, 1978). In general rainfall is highly localized and has been described as spatially and temporally irregular (Besler, 1972; Seely, 1978). The purpose of the present study is to find possible spatial patterns of storms in this area, that cannot be identified through conventional climatological methods.

Spatial correlation analysis has been employed in the study. The method has been previously applied in a number of areas of convective rainfall, including Sukumaland in Tanzania, the Southern Negev and the Jordan Valley in Israel (Sharon, 1972, 1974, 1979). The above references also include a discussion of the methodology and of the interpretation of resulting correlation functions in terms of the physical properties of the rain fields concerned. In essence, data from a number of raingauges are assimilated in the analysis to produce a spatially generalized correlation function, in which the spatial relationship between simultaneous events in any two of the gauges is preserved relative to a common origin representing a general point in space. As a result of the above generalization in space, a spatial correlation function based on data from only a few points can provide an estimate of the relationship between simultaneous rain amounts at *any* two points within a climatologically homogeneous region. Consequently, the above method is especially suitable for the study of spatial patterns in areas of sparse measuring networks, provided it is applied within regions that are homogeneous in this respect, i.e. the rainfall process within them is spatially stationary. Thus, homogeneity is used here as applying to the structural properties of rain fields only, and not to absolute amounts of rainfall.

The present study has become possible thanks to the recent availability of accurate data from a special network of monthly-operated autographic raingauges, that have been operated in the 1970s in the Central Namib by the Desert Ecological Research Unit (DERU) at Gobabeb, South West Africa. The data from these raingauges (and from three additional first order weather stations operated by the local Weather Bureau) have been made available through cooperation with Dr. Mary K. Seely from DERU.

0196–1748/81/010069–07$01.00

DATA

Daily rainfall totals at seven stations in the Namib have been analysed. Stations are shown in Figure 1 and Table I. Correlations were calculated for a period of almost 7 years, from January 1972 to the autumn of 1978, including all days with measurable rainfall in at least one station. Days with missing data in more than two stations were excluded. Thus a total of 193 events has been obtained. The number of events available for individual pairs of stations may be smaller owing to missing data in some stations.

The majority of above rainfall events were highly localized. However, on 10 days rainfall occurred simultaneously in all or most stations. This includes days with widespread low-intensity rains, with daily totals of up to 15 mm. In a single case (30 March 1976) rainfall exceeded 15 mm in all stations. These days have been excluded from the analysis, as they represent a separate type of rainfall that is relatively rare in this area. Also excluded were two days with exceptionally high totals at Ganab (61 mm and 80 mm respectively, both in January 1976). Thus, the analysis focuses on 181 raindays with typically spotty rain, such as prevails in the majority of storms in the study area.

Daily totals in most cases amount to a few mm. Of the 181 days included, rainfall exceeded 10 mm on only 2 to 5 days per station, except Ganab, where the number was 20. In general, the number of raindays increases gradually from the coast inland, along with increasing altitude (see Table I).

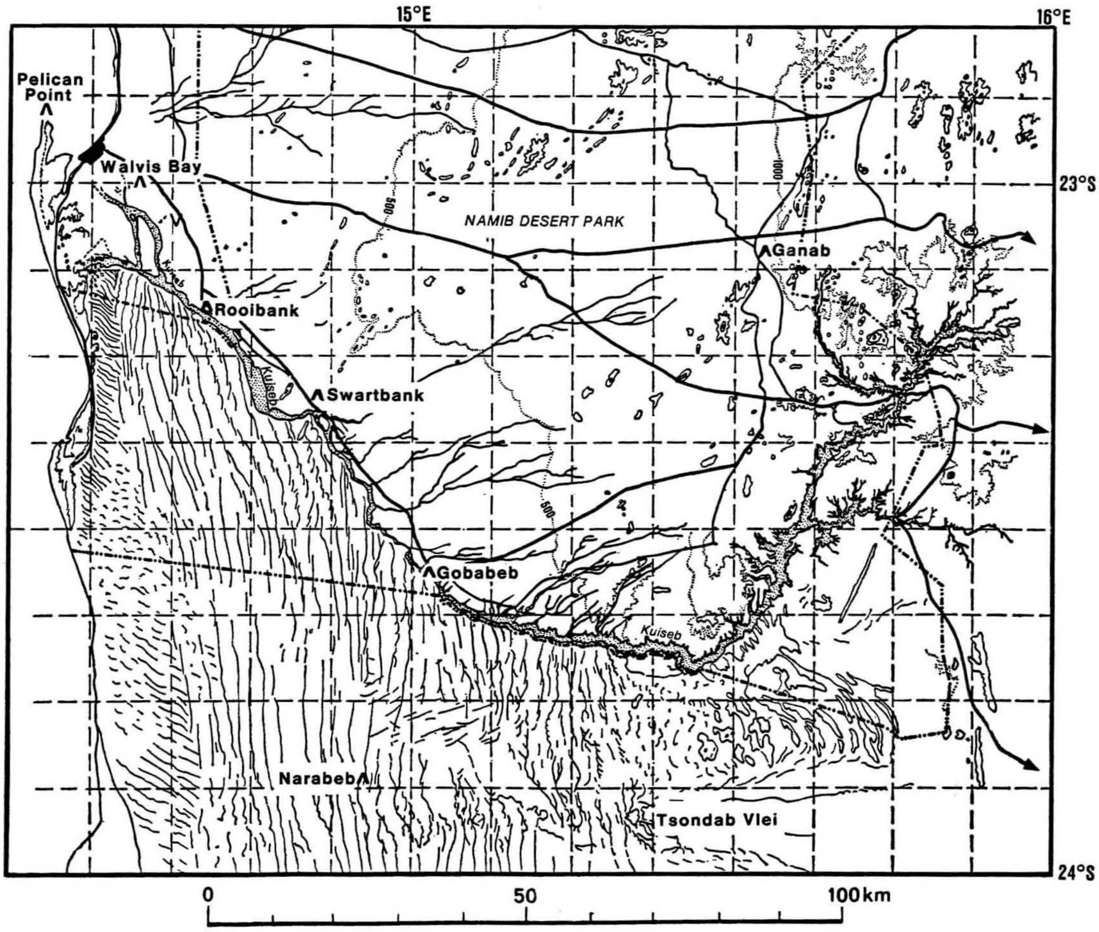

Figure 1. The study area and the location of stations

Table I. List of rain stations in the study area

Station	Distance from coast (km)	Elevation* (m)	Average no. of raindays per year (1972–78)
Pelican Point	0		
Walvis Bay	1	20	2·9
Rooibank	22	100	4·7
Swartbank	33	340	6·6
Narabeb	39		6·6
Gobabeb	56	407	9·1
Ganab	110	1 000	14·6

* After Besler (1972)

ANALYSIS OF RESULTS

Correlation coefficients between all points of measurement are shown in Table II. The localness of rainfall, typical for the study area, is immediately apparent from the low correlation values (below 0·4). The majority of values lie within ±0·2 and would be statistically insignificant if taken from a normal population.

A two-dimensional correlogram of the results has been prepared, on the basis of both the direction and the distance between respective stations. The result (Figure 2) reflects an apparently irregular pattern and does not furnish a basis for an unequivocal interpolation of a correlation surface. However, postulating isotropy and following results obtained from larger samples in other low-latitude areas (Sharon, 1974; Henry, 1974), the same resulting values have further been plotted on a unidimensional correlogram, as a function of distance alone (Figure 3a). The last step can lead to a meaningful correlation function only if the rain field is isotropic, i.e. if the change of correlation with distance is independent of direction. An isotropic pattern of convective rainfall has previously been found in a semi-arid tropical environment (Sharon, 1974) and is also implied by results obtained by Henry and his group in low latitudes (1974) and in Texas (unpublished MSc. theses).*

Using the univariate correlogram in Figure 3a, one can easily discern an oscillatory pattern of the spatial correlation function, similar to that previously found in independent studies by Henry (1974)

Table II. Correlation coefficients of daily rainfall on days with localized rain (upper value) and n (below)

	Ganab	Gobab.	Narab.	Swart.	Rooib.	Wal. B.
Pelican Point	0·16	0·60	0·04	−0·04	0·16	0·37
	163	181	113	176	145	181
Walvis Bay	0·30	0·19	0·00	−0·04	0·02	
	163	181	113	175	145	
Rooibank	0·18	−0·05	0·25	0·02		
	136	145	96	140		
Swartbank	0·00	−0·03	0·01			
	158	176	111			
Narabeb	−0·13	0·08				
	98	113				
Gobabeb	0·12					
	163					

* The author is grateful to Professor W. K. Henry of the Texas A & M University for having extended to him copies of unpublished work, previously unknown to the author.

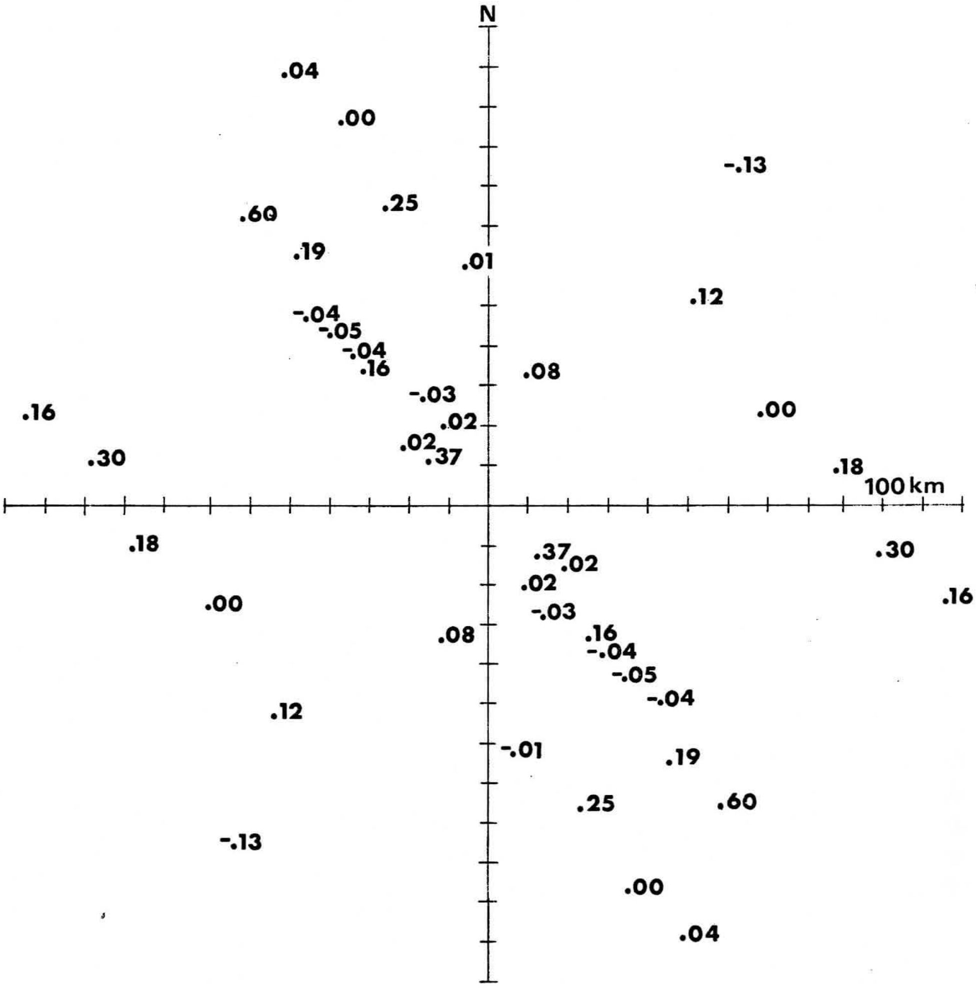

Figure 2. The composite correlation map of localized daily rainfall in the study area. Values are taken from Table II. Decimal points indicate respective locations

and Sharon (1974). However, owing to the smaller number of measuring points and/or rain events in the present study than in previous ones, present results are apparently subject to a greater sampling variability. Hence they could probably not serve by themselves as solid evidence for the said phenomenon. At the same time, however, the above results should be sufficient to support the hypothesis that a preconceived spatial pattern of localized convective storms, previously found elsewhere, does exist also in the area treated here.

The oscillatory pattern of correlation functions obtained in previous studies has been firmly established in a number of large, independent samples of up to 970 raindays. One of these, pertaining to Sukumaland, Tanzania, is shown in Figure 3b. Two secondary peaks have been found there, besides the obvious maximum value at zero distance. The peaks were interpreted as indicating typical distances at which large convective storms apparently tend to develop from each other, in the absence of disturbing topographical effects. The similarity to the result of the present study is immediately apparent.

Having identified the pattern of change of the function in Figure 3a, one may now more accurately distinguish between trend and noise. Subsequently, the rain field in the study area may be evaluated with a fair degree of confidence as being both homogeneous and isotropic, i.e. the change of the function with distance is independent of both direction and location within the study area. This can be

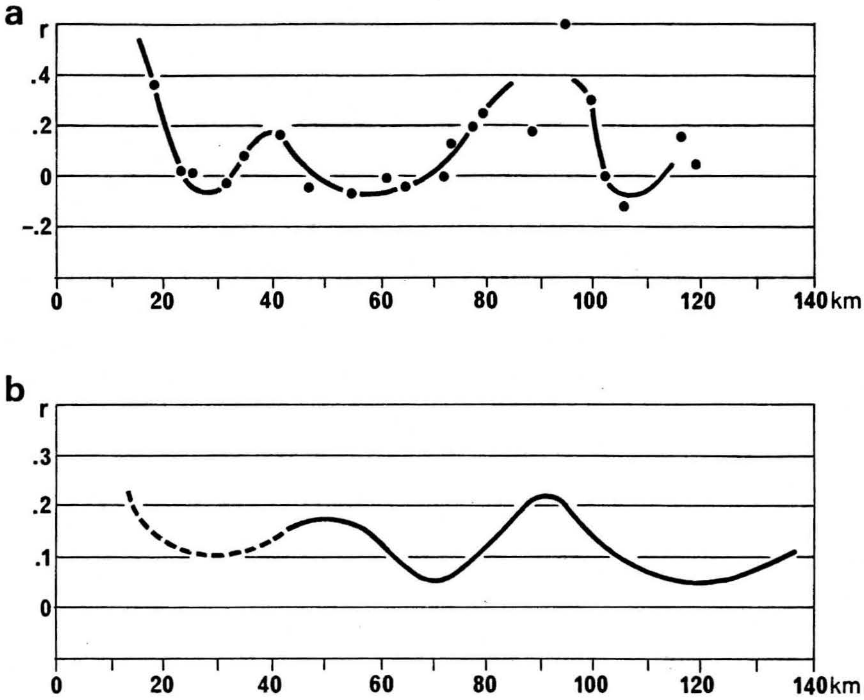

Figure 3. Univariate correlation functions of localized daily rainfall: (a) in the Namib study area, using the same data as in Figure 2; (b) in Sukumaland, Tanzania (after Sharon, 1974)

qualitatively inferred from the regularity of the results in Figure 3 and from the consistence with results of previous studies in which isotropy has been more directly demonstrated. By 'regularity' is meant that values of correlation for similar distances but different directions—or locations—are also similar, or at least, that they vary in conformance with the values for other distances of the same order.

In practice, the above results imply that,

(a) There is no significant tendency for storms to occur at preferred locations in the study area (homogeneity). However, in view of the following point (below), this is not to be confused with a random distribution of storms in space.

(b) Outside an already existing storm, additional storms should be expected on the same day at preferred distances of about 40 or 80–100 km from each other.

(c) Storms occurring within the same day are arranged in an essentially isotropic system of points with no preferred direction between them. The position of the system as a whole in respect to the ground, may vary from day to day.

Another result concerns the possible movement of storm cells. Within the scales of reference adopted in the present study, preferred distances can become apparent in a unidimensional correlogram only when individual rainfall areas are roughly circular, or only slightly elongated in shape. A pattern of this type implies that storms are quasi-stationary, such as they generally are in the tropics (Nieuwolt, 1977). Judging from the homogeneity and isotropy of the resulting correlation function (Figure 3a), this is apparently also true of storms in the Namib Desert.

The above conclusions apply equally well to the other areas for which similar results have been quoted above. In view of this, the above results apparently have more general significance. From the point of view of cloud physics, the minimum distance that has been found between storms may reflect the magnitude of space required by a single storm cell in a stagnant atmosphere to derive the water vapour and energy necessary to drive it. Furthermore, the subsiding motion that prevails outside the ascending drafts near storm centres, probably suppresses the formation of further storm cells between existing ones.

The fixed distance between storm centres and the isotropy of the rain field, may also be manifestations of Benard or Rayleigh cell patterns forming over the relatively uniformly heated desert surface. If such cells actually develop in the area, they may control the distribution of storm clouds in space by aligning them with points of maximum ascending motion at the periphery or the centres of these uniformly shaped meso-scale cells. The occurrence of storms within these cells is certainly not the *general* case, as these cells tend to be rather shallow (Agee *et al.*, 1973). But, restricting ourselves to only those occasions on which other conditions for the occurrence of rain in the Namib are also favourable, it appears quite reasonable to expect the above meso-scale mechanism to determine the locations of points where storms are most likely to develop. These occasions must be rare not only absolutely, as reflected in the low frequency of rain (see Table I), but also relatively to the appearance of Benard or Rayleigh cells.

The preferred distances between storms as found here, fit quite well to cells averaging 30–50 km in diameter, with maxima well over 100 km, that have been reported on by various investigators, although mostly over oceans (Hubert, 1966; Agee *et al.*, 1973). Agee *et al.*, also present a map in which the cold Benguela Current off the south western coast of Africa appears among the favoured regions of frequent cellular convection of the above-mentioned type. The result of the present study may be an indication to the effect that such cells also occur 100 km or more inland, whether independently or simultaneously with more easily identifiable and better documented oceanic systems.

CONCLUSIONS

Rainfall in the Namib is mostly of the localized convective type. Using spatial correlation analysis, it has been shown that the distribution of localized storms in space is similar to that previously found in a few other low-latitude areas. Correlation of daily rainfall at distances of 25–35 km are close to zero, i.e. at any two locations separated that much, rainfall occurs independently, as at an infinite distance.

The spatial correlation function is homogeneous and isotropic, and shows peaks at 40–45 km and at 80–100 km, as had been previously found in another area. In the physical realm this indicates that,

(a) Convective storms in the Namib are relatively stationary, as they are generally in the tropics, and unlike in mid-latitudes where storm cells tend to migrate tens of km while precipitation is occurring in them.

(b) The frequency of storms in the study area is apparently increasing with altitude from the coast inland (see Table I). However apart from this trend, storms occur throughout the study area at no preferred locations, or preferred directions between simultaneously developing ones.

(c) Convective storms tend to form at preferred distances of 40–50 km or 80–100 km from each other. This means that in spite of the preceding result, (b), local rainfall is *not* randomly scattered in space.

The above pattern points at Benard or Rayleigh cells as a possible broader mechanism controlling the distribution of localized convective storms in the study area, and possibly in low latitudes in general.

On a few days rainfall in the Namib is more widespread, with low-intensity rains occurring either intermittently or continuously for a few hours throughout most of the area. The frequency of these occurrences, and their relative contribution to the total annual rainfall, cannot be accurately estimated from the present extent of available data.

ACKNOWLEDGEMENTS

The author wishes to thank Dr. Mary K. Seely, director of the Desert Ecological Research Unit at Gobabeb, SWA, for kindly supplying the detailed data for this study and to her and Professor Peter D. Tyson from the University of the Witwatersrand, Johannesburg, for valuable comments on the manuscript. Figures 2 and 3 have been prepared by N. Z. Baer. Figure 1 was adapted from a DERU publication.

REFERENCES

Agee, E. M., Chen, T. S., and Dowel, K. E. 1973. 'A review of mesoscale cellular convection', *Bull. Amer. Meteor. Soc.*, **54,** 1004.
Besler, H. 1972. 'Klimaverhaeltnisse und Klimageomorphologische Zonierung der zentralen Namib', *Stuttgarter Geographische Studien*, **83,** 1.
Henry, W. K. 1974. 'The tropical rainstorm', *Mo. Wea. Rev.* **102,** 717.
Hubert, L. F. 1966. 'Mesoscale cellular convection', *Report No.* 37, U.S. Dept. Comm., ESSA, Meteor. Satellite Lab., 68pp.
Nieuwolt, S. 1977. *Tropical Climatology*. Wiley, Chichester, pp. 74 and 125.
Seely, M. K. 1978. 'The Namib dune desert, an unusual ecosystem', *J. Arid Envir.*, **1** 117.
Sharon, D. 1972. 'The spottiness of rainfall in a desert area', *J. Hydrol.*, **17,** 161.
Sharon, D. 1974. 'The spatial pattern of convective rainfall in Sukumaland, Tanzania—a statistical analysis', *Arch. Meteor. Geophys. Bioklim.*, **22B,** 201.
Sharon, D. 1979. 'Correlation analysis of the Jordan Valley rainfall field', *Mon. Wea. Rev.*, **107,** 1042.