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Long-Term Change in October Rainfall Patterns in Southern Israel

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With 5 Figures

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Summary

A comprehensive study of long-term changes in October rainfall patterns in southern Israel, a semi-arid fringe zone between the Mediterranean coastal plain and the Negev Desert, was carried out. It was earlier postulated that the observed positive trend in October rainfall amounts may result from land-use changes in the area following the installation of the National Water Carrier (NWC) in the early 1960s. The purpose of the present study is to delineate the anticipated local effects, as well as their spatial extent, in order to investigate the possibility of climatic change over a larger synoptic scale.

In the study region, a total number of 51 rainfall stations with long-term records up to 55 years, were analyzed, along with six control stations in other parts of the country. All stations were analyzed for trends in early seasonal rainfall, spatial variability during the two reference periods before and after the 60s, and for the ratio between rain per day (RPD) and number of rain days (NRD) during the two periods.

The results of the analyses point to a well defined localized climatic change in October rainfall patterns within the study area, that is traceable to intensive and extensive land-use changes following the installation of the NWC.

1. Introduction

In a recent paper by Otterman et al. (1990) it has been shown and tested statistically that the average October rainfall in southern Israel has steeply increased in the last quarter of the century. This has been attributed to land-use changes that have caused a reversal of the desertification processes over this semi-arid zone. In particular, emphasis was placed on the possibility that the increased vegetation cover, dormant towards the end of the dry summer season, have decreased the typical high albedo over this region leading to increased sensible heat flux and convection (Otterman, 1974, 1977a, b). The basic concept was that the weaker inversion capping the planetary boundary layer (PBL) during October then becomes susceptible to more frequent penetration of rain-bearing convective clouds. These conditions prevail mainly in October, due to the weakening of the subtropical high pressure system prior to the penetration of winter mid-latitude large-scale synoptic systems. The eastern Mediterranean is still warm at this period of the year and air masses moving towards the continent are unstable; local thermal forcing onshore could then trigger convective rain. This hypothesis has been left to further observational and theoretical investigations since the processes involved are quite complex. The latter include sensible and latent heat flux, soil heat flux and the radiation energy balance all calculated over semi-arid vegetation and further complicated by atmospheric/anthropogenic feedback mechanisms.

A different approach for explaining climatic change in southern Israel was given by Alpert and Mandel (1986). They observed a decrease in wind variability and in the daily temperature amplitudes over the same region starting in the early 1960s and have attributed these signs of decreased aridity to the operation of the National Water Carrier beginning in June 1964. The irrigation potential to increase rainfall was illustrated in the southern US by Branston and Schickendanz (1984). Segal et al. (1988) indicate changes in circulation between irrigated and non-irrigated areas or between the sea and a nearby non-irrigated area, which are traceable down to a scale of 3 km, and result from the associated temperature gradient. This supports the assumption that changes in land use lead to thermal forcing and thus enhance convective rains.

An alternative explanation focuses on the roughness increase due to increased anthropogenic activities. This mechanism and its influence on the rain in a semi-arid zone was discussed by Sud and

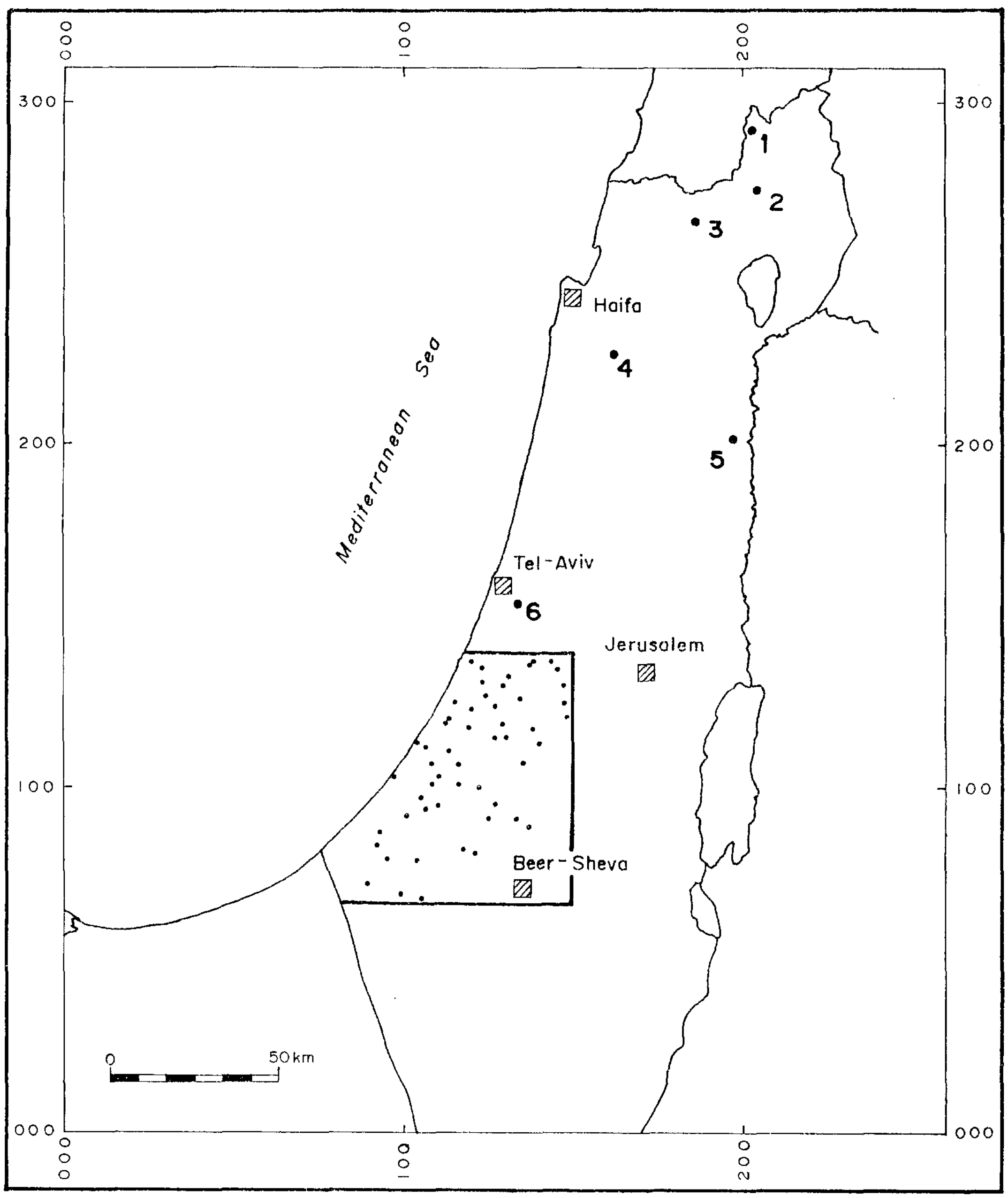

Fig. 1. Stations within the study area including the six control locations in northern Israel denoted by numbers 1 to 6

Smith (1985). Large-scale or synoptic variations as reflected by pressure (Kutiel, 1991); sea surface temperatures (Tzvetkov, 1985); or low tropospheric temperatures (Striem, 1981a, b), have also been associated with the rainfall changes in the larger area of Israel. Hence, the contribution of large-scale variations cannot be ruled out when dealing with the specific region of southern Israel.

This paper presents a comprehensive observational study within the research area attempting a sharper definition for the affected area limits. For this purpose, use was made of all the available rainfall data in the study region – over 50 stations – as well as six control locations in northern Israel (see Fig. 1). Obviously, the number of stations used varies according to data availability. For example, a station with missing data for one month results in its exclusion from the isomer analysis.

The following investigation also addresses the question whether the rainfall increase is due to enhanced convection or due to more rain days during the recent period. Obviously, if the number of rain days has increased, large-scale synoptic climatic change will then be difficult to exclude as another contributing factor to the total October rainfall increase.

2. Data and Method

Figure 1 shows the study area within southern Israel with 51 rainfall stations in addition to six additional control locations to the north denoted by numbers 1 to 6. The database consists of daily rainfall values from the Israel Meteorological Service archives for the years 1938/9–1984/5. The southern/northern borders of the study area nearly follow the 200 and 500 mm isohyets from 1930–1960 normals, respectively. Hence, the southern boundary is in close proximity to the aridity line.

Following Otterman et al. (1990) the entire period of observation was also subdivided; one for the years 1938/9–1962/3 and the other for 1963/4–1984/5. Artificial supplements of missing data were avoided. Consequently, the average number of available years became 16 and 18 years for the first and second periods, respectively. Some justification for using less than 20 years for studying climatic change was given by Court (1981), who compared rainfall averages in Jerusalem for various periods. Also, since the data were not consecutive at all stations, a coefficient of variation map for the first period was prepared and compared to an earlier one by Sharon (1965), in which missing data were supplemented by synthetic values, and the results were found to be nearly identical.

3. Trends in October Rainfall

For each rainfall station a trend analysis was performed by plotting the October rainfall values as a function of time and the corresponding least-square line. Figure 2a shows this graph for one of the stations (Beit Govrin) located within the study region. The slope of the line for this case is 0.5 mmy^{-1}, indicating an average increase of 0.5 mmy^{-1} between the years 1950–1984. The histogram for all slopes or trends (mmy^{-1}) is shown in Fig. 2b. The trend for the six control stations is indicated to the far left, underlined in bold followed similarly with the trend for 51 stations arranged from north (left) to south (right). Thus, the station to the extreme right is the most southern, just at the desert border.

A clear positive trend is noticed throughout nearly all the stations. Although this positive trend is found in the northern control stations as well, it is lower compared to the study area. The total average October rainfall in the northern part of the study area ranges from 15–25 mm in the first period, to 25–30 mm in the second. In the southern part of the study area, the average

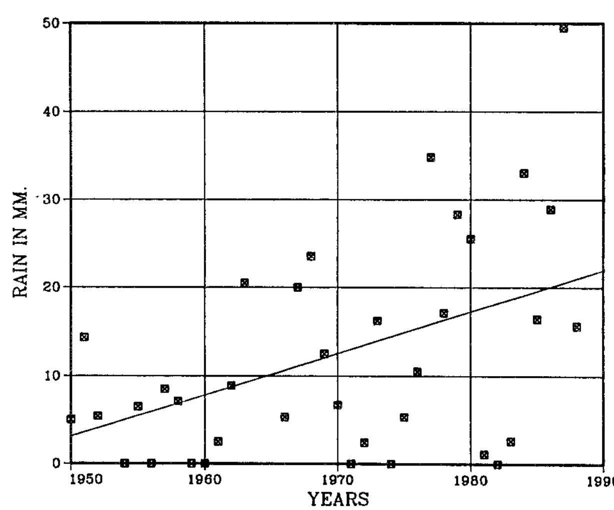

Fig. 2a. October rainfall amounts for Beit Govrin during 1950–1985. The slope of the line, which gives the average rainfall change, is 0.5 mmy^{-1}. The slope was obtained by application of a statistical trend analysis

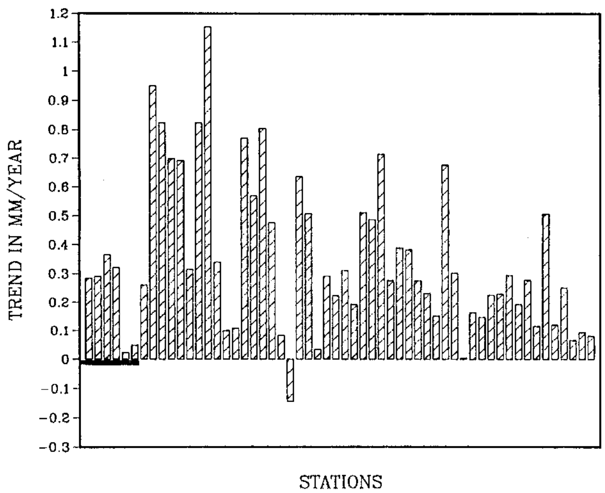

Fig. 2b. Trend histogram of October rainfall amounts for all stations in the study area including the control stations. The trends were obtained as demonstrated in Fig. 2a. Stations are arranged from north to south, so that the control stations appear to the left and are underlined in bold

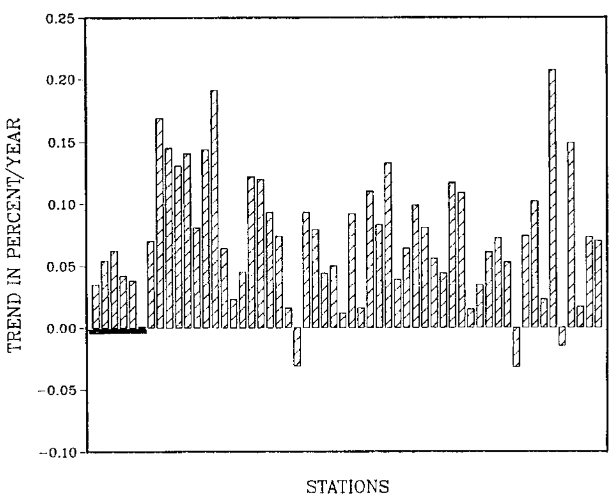

Fig. 2c. As in Fig. 2b but for the average rate of change of October rainfall portion within the season (isomers in percentages). Note that the stations within the study area show a trend which is double that of the control stations

October rainfall varies between 1–3 mm for the first period to 7–10 mm for the second.

Since the total amount of the annual rainfall in the northern part of the study area is higher than in the south, it is therefore of interest to compare the trends not of the absolute rainfall amounts as in Fig. 2b, but rather of the percentage of the October rainfall from the total annual amounts or in brief, the monthly isomer. Thus, Fig. 2c presents, in analogy to Fig. 2b, the histogram of the trend in the October isomer. Figure 2c illustrates the major positive trend in the study region in nearly all stations which in many cases is more than double that of the control points. Comparing Fig. 2c to Fig. 2b, one can notice a relatively large isomeric trend even at some stations at the southern boundary of the study region, where absolute rainfall values for October are quite small – less than 5 mm.

The proportion between the isomers for the second to first periods indicates several hundred percent increase and the result for all stations within the study area is shown in Fig. 3. In the southern region between the city of Be'er-Sheva and the Mediterranean coast, one can notice a maximal region exceeding 300%. Of particular interest is the steep gradient of increase over a short distance of only about 10–15 km east of the coast line.

4. Correlation Maps

A powerful method for the analysis of geographical patterns and their variation is by correlation maps. In this method, the correlation between rainfall at one station and that at another is calculated on the basis of a time interval that varies according to each study. The correlation method may point to a possible rain-inducing source. In general, high correlation values are typical of rainfall events, with a large spatial distribution of rainfall events while low values may indicate spottiness. Sharon (1978), for example, applied this method to seeded and non-seeded days in order to identify the possible seeding effect on rainfall patterns. That method was also utilized for the investigation of diurnal variations in the spatial structure of rainfall in the northern Negev Desert (Kutiel and Sharon, 1981).

Here, the method is applied over monthly rainfall values at the northern section of the study area where at least eight stations with consecutive data for the same eight years were available for both periods. Correlations were calculated only for the northern part of the study area due to a decrease in rainfall amounts approaching the arid zone in the south. Tables 1 and 2 show the resulting correlation coefficient matrices for the periods 1949–56 and 1977–84 respresenting the two abovementioned periods, respectively. The higher correlation coefficients are in general found in the

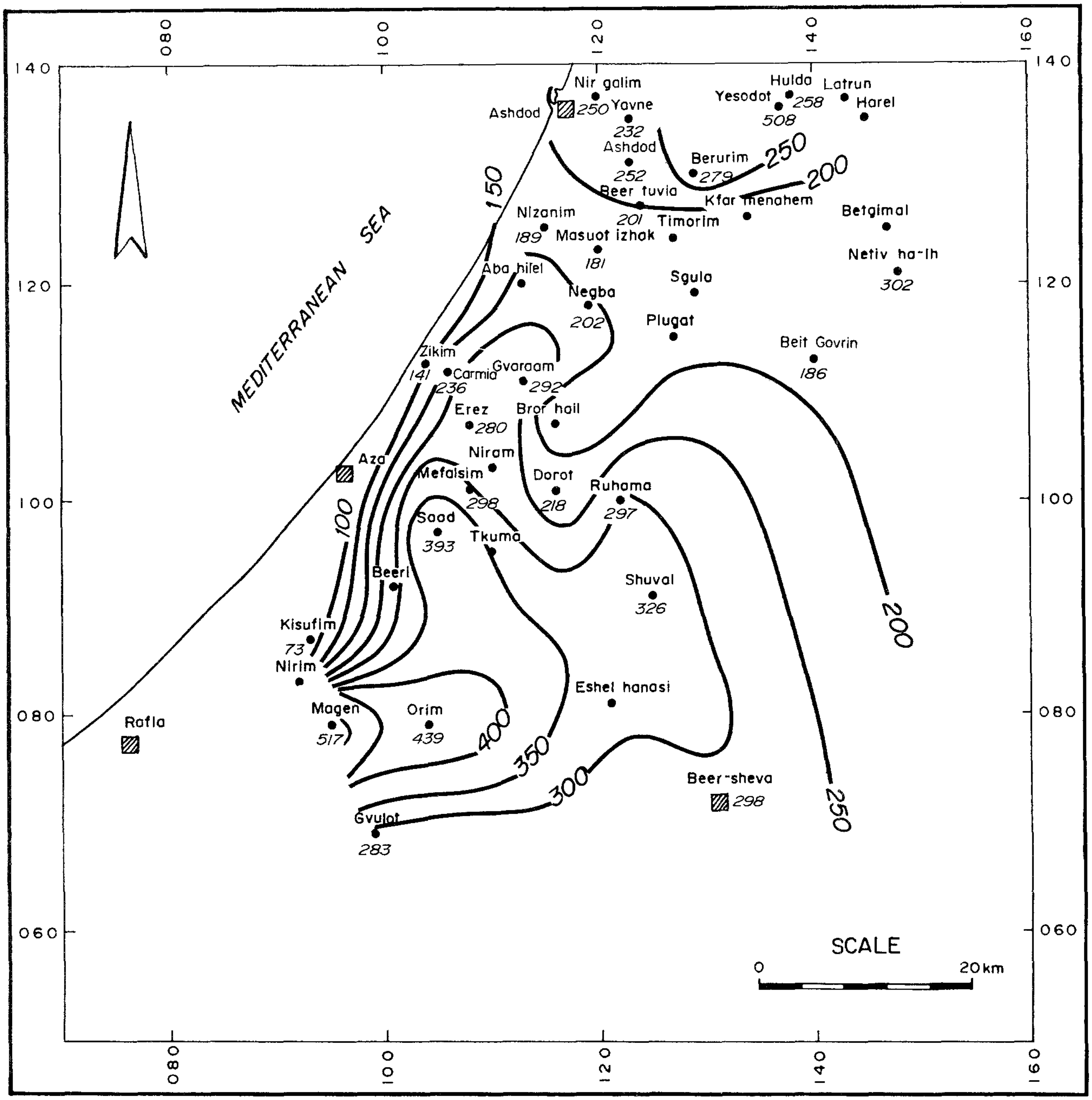

Fig. 3. Percentage increase of the average October isomers for the second period (1963/4–1984/5) with respect to the first period (1938/9–1962/3). The map indicates an increase in the second period for the whole area with the southwestern corner having the higher values

Table 1. *Coefficients of October Rainfall Correlation Among Eight Stations in the Northern Part of the Study Area During 1949–1956*

Yavne	Ashdod	B. tuvia	Negba	K. menahem	Gimal	Yesodot	B. govrin		
0.51	0.13	0.74	0.70	0.77	0.61	0.38	0.20	Nizanim	
	0.78	0.88	0.64	0.30	0.43	0.93	0.83	Yavne	
		0.63	0.63	0.32	0.58	0.80	0.80	Ashdod	OCTOBER
			0.87	0.63	0.69	0.90	0.75	B. tuvia	'49–'56
				0.89	0.95	0.72	0.62	Negba	
					0.95	0.34	0.24	K. menahem	
						0.52	0.45	B. gimal	
							0.93	Yesodot	
Yavne	Ashdod	B. tuvia	Negba	K. menahem	Gimal	Yesodot	B. govrin		

Table 2. *As in Table 1, but for the Period 1977–1984*

Yavne	Ashdod	B. tuvia	Negba	K. menahem	Gimal	Yesodot	B. govrin		
0.78	0.90	0.96	0.69	0.87	0.63	0.89	0.83	Nizanim	
	0.97	0.88	0.74	0.82	0.67	0.96	0.64	Yavne	
		0.95	0.74	0.89	0.68	0.98	0.73	Ashdod	OCTOBER
			0.83	0.95	0.80	0.96	0.89	B. tuvia	'77–'84
				0.93	0.95	0.84	0.77	Negba	
					0.87	0.93	0.84	K. menahem	
						0.76	0.87	B. gimal	
							0.76	Yesodot	
Yavne	Ashdod	B. tuvia	Negba	K. menahem	Gimal	Yesodot	B. govrin		

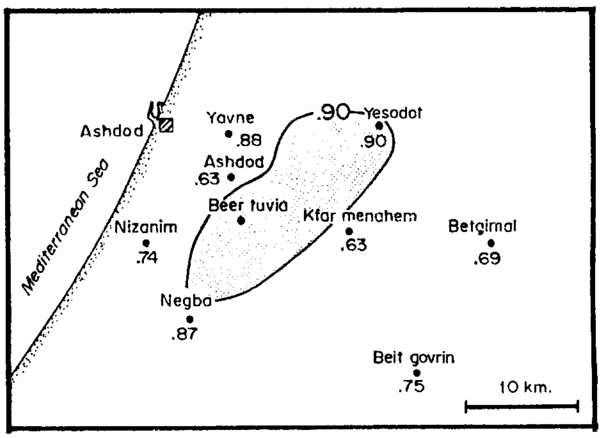

Fig. 4a. Correlation map for the Be'er Tuviya station (base station) and the other stations for the period 1949–1956. The values were taken from Table 1. Shading indicates values exceeding 0.9

more recent period. In order to examine the spatial variability, Figs. 4a and b show the correlation maps where the location Be'er-Tuviya was chosen as the base station. Results show significantly lower correlation coefficients for the first period with a large variation within the range of 0.63–0.95 (Fig. 4a), compared to a range of 0.80–0.95 in the recent period (Fig. 4b). Results point to a change from spotty rain events in the first period toward a larger spatial distribution. A south-west to north-east axis of high values is found in both periods indicating the typical direction of movement for the rain-bearing systems (Sharon, 1978).

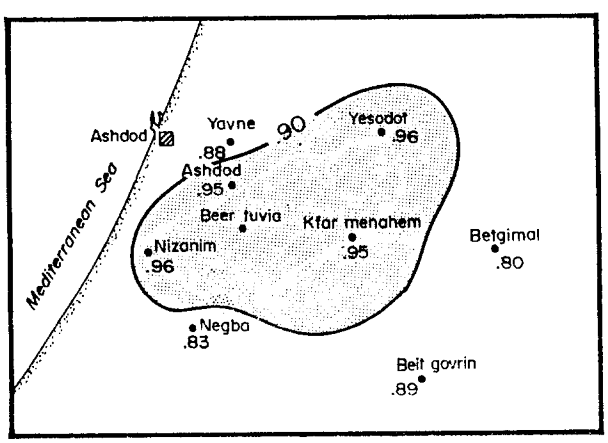

Fig. 4b. As in Fig. 4a but for the period 1977–1984. Note the southwest-northeast axis of high correlation on both figures (Table 2)

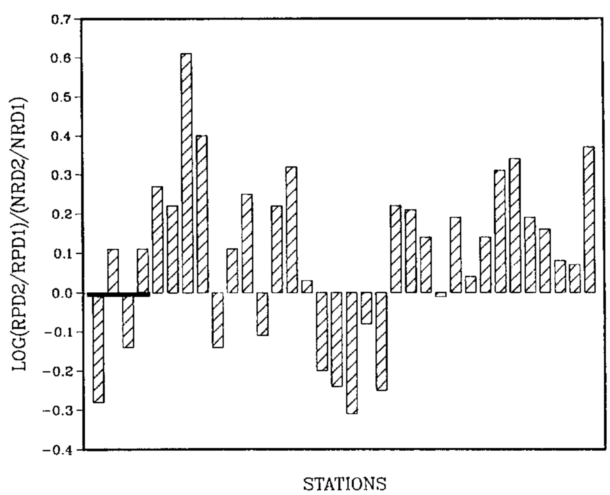

Fig. 5a. Histograms of π values for October. The two periods are 1938/9–1962/3 and 1963/4–1984/5. The stations are arranged as in Fig. 2b. Positive values on the logarithmic scale indicate that the *RPD* increase during the second period was larger than the *NRD* increase

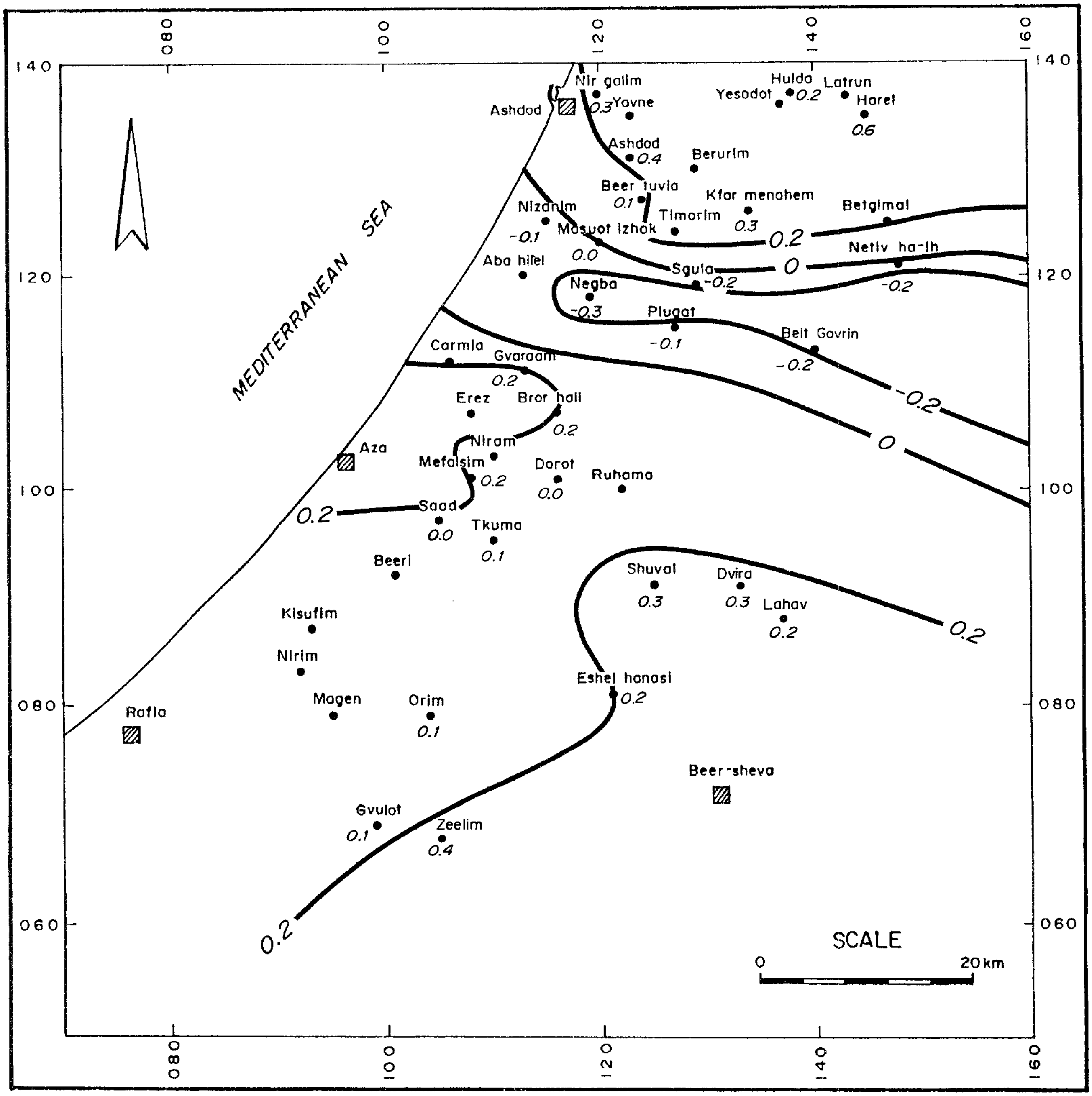

Fig. 5b. Map of π values for October. Most of the study area is dominated by an increase in *RPD*. A negative strip extending east from Abba-Hillel indicate the *NRD* dominance

5. Discussion and Summary

A comprehensive analysis of the early seasonal rainfall patterns observed at 51 stations in the study region, situated at the northwestern boundary of the Negev Desert, shows a definite and well-defined increasing trend in October rainfall.

The most pronounced positive trend appears in the October isomer during the second period (1963–1984), exceeding 300% with respect to the first period (1938–1962) at stations between Be'er-Sheva and the Mediterranean coast.

The climatic change in early seasonal rainfall patterns in the study area is also substantiated by the diminishing spatial variability (spottiness) of rainfall, which is typical for semi-arid regions. This recession of aridity from the study area is revealed by comparing the correlation maps in both periods.

The increase of October rain in the later period could be related either to an increased number of rain days (*NRD*) or to an increase of rain per day (*RPD*). In the latter case, enhanced local convection due to an anthropogenic impact may be the cause while synoptic influences seem to be more likely when a change in *NRD* is observed.

The ratio of *NRD* and *RPD* between the second and the first periods was calculated. Results show that both *NRD* and *RPD* increase in the recent period. The question is, which of the two is dominant. Denoting by the indices 1, 2, the pertinent periods, an π index is defined by

$$\pi = \log\left(\frac{RPD_2/RPD_1}{NRD_2/NRD_1}\right) = \log P.$$

When π is positive ($P > 1$), the *RPD* increase is dominant. Inversely, when π is negative, the *NRD* increase is dominant. Figure 5a shows the π-histogram for 30 stations within the study area as well as for four control stations. The results indicate dominance of the *RPD* increase at most stations. Figure 5b presents the geographical distribution of the π index. In most parts of the study area, *RPD* increases more than *NRD*, supporting the concept that local variations were responsible rather than synoptic or global changes.

The stations showing a larger increase in *NRD* rather than *RPD* are located within the northern part of the study area along an axis directed east from Abba-Hillel (Fig. 5b). The same area shows also the smallest increase in October isomers for the second period (Fig. 3).

It should be mentioned that the absolute rainfall increase is quite small, varying from 5 mm at the southern boundary to about 15 mm in the north. These small amounts, however, are quite significant for the local agriculture as discussed by Otterman et al. (1990). But, what seems to be more important is the fact that an anthropogenic impact on local climate could be traced and defined within an area which has undergone major settlement and irrigation since the 1960s.

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