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Long-Term Changes in Annual Rainfall Patterns in Southern Israel

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With 6 Figures

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Summary

Within the study region in southern Israel, the annual average rainfall during the period 1961–1990 increased by up to ~ 30%, with only minor changes in the control stations representing the central and northern parts of the country. The retreat of aridity is made even more pronounced by an appreciable decrease in the coefficient of variation (CV) in nearly all of the 30 rain stations within the study region. The geographical area where maximum CV reductions were found correlates well with the area where intensive land-use variations took place with the initial operation of the National Water Carrier in 1964. A global climate change in the sea surface temperatures starting in the early 1960's may have had an effect to increase seasonal rainfall. Current research is aimed at resolving this issue.

1. Introduction

A number of studies, carried out in Israel, have attempted to investigate long-term changes in annual rainfall patterns during various standard periods.

Elbashan (1966) drew a map of annual rainfall variations for the two standard periods: 1901–1930 and 1931–1960. According to his map, most regions show a decrease in amounts of precipitation in the second period, except for the central coastal plain, the Jordan valley and some stations in the southern part of Israel: these latter regions show an increase in precipitation amounts in the second period.

Striem (1967, 1977) found a decrease in average annual rainfall in Jerusalem, from 600 mm in the second half of the last century to 500 mm in the first half of this century. He indicates also a correlation between the increase in average barometric pressure and the decrease in rainfall amounts. He claims that the late 1960's show a decreasing trend of barometric pressure.

Superimposing the annual precipitation maps for the two periods of 1931–1960 and 1951–1980, respectively, over the semi-arid zone of the southern coastal plain and the northern Negev in Israel, reveals some appreciable southward shifts of the isohyetes, especially of the 400 and 500 mm contours (Fig. 1).

Some studies relate variations in annual rainfall to large scale flow patterns. Kutiel (1991) suggests that the Siberian high, which influences Israel during the winter, showed a decrease in average barometric pressure values during the period 1951–1980, compared to the period 1931–1960.

Tzvetkov (1985) links variations in precipitation amounts with variations in sea surface temperature in the southeast Mediterranean.

Another approach tries to explain variations in rainfall patterns by mesoscale land use changes in the area. Otterman et al. (1990) suggest that changes in land use – primarily albedo – may have led to the increase in October rainfall.

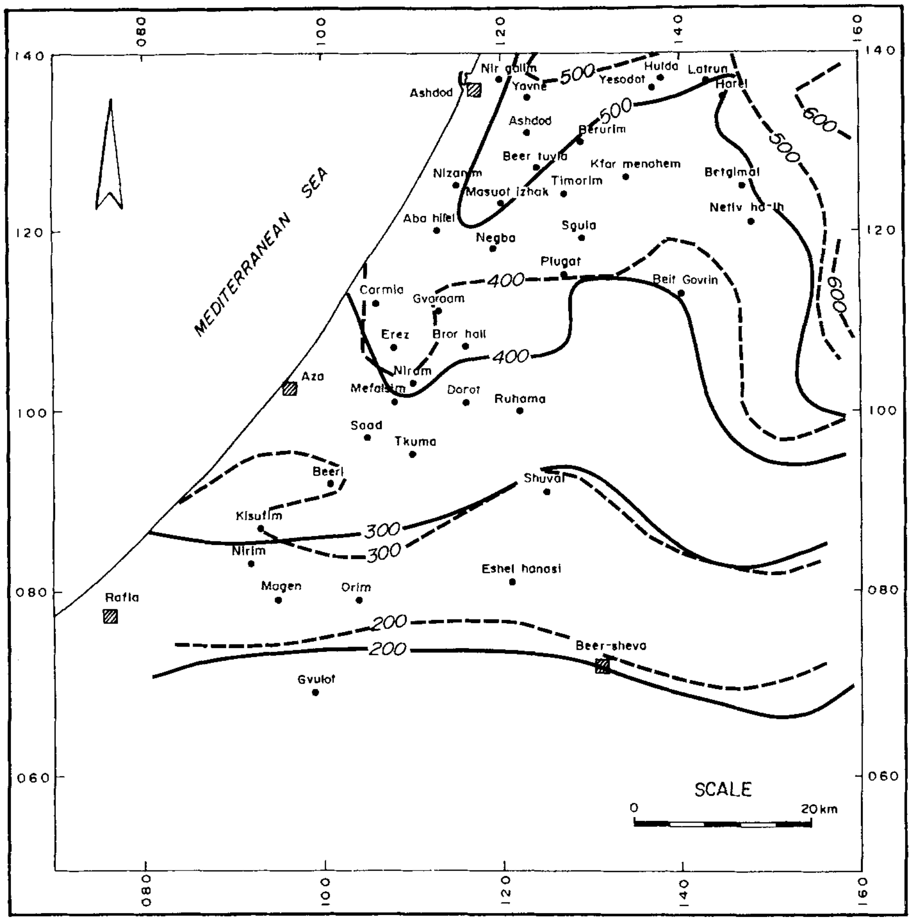

Fig. 1. Superimposed rainfall maps of 1931–1960 and 1951–1980 within the study area. Rain isohyetes for the first period are dashed. Isolines were drawn from maps over the whole area of Israel

Ben-Gai et al. (1993) in a study of the rainfall regime within the northern Negev, found an increase in October rainfall amounts during the past 25 years. This increase is noticeable in absolute amounts which are relatively small (~ 10 mm), but is also relative to the total seasonal amounts. In addition, the rainfall regime is found to be less sporadic in the second period. Most of the increase in rainfall amounts is related to daily amounts rather than to the number of rainy days.

Sud and Smith (1985) discuss the feedback formed by variations in roughness length and their influence on rainfall. Branston and Schickendanz (1984) discuss the potential of irrigation to increase rainfall in the southern USA. Anthes (1984) claims that surface complexities can cause circulation that will increase convective rainfall.

These studies support the hypothesis that land use can influence thermal conditions and consequently have an impact on convective rainfall.

In recent decades, the southern coastal plain of Israel has undergone significant changes in land use. These changes have caused variations in evapotranspiration, albedo and surface roughness. The hypothesis behind this study is that these changes may correlate with changes in rainfall amounts.

The study area (Fig. 2) consists of 30 rain stations in the southern coastal plain which are roughly located between the 500 and 200 mm isohyetes. Six control stations were also chosen in northern and central Israel.

In addition, we compared average annual rainfall within a standard period. Mapping these variations makes it possible to observe spatial variations in the periods before and after the operation of the NWC. The relative standard deviations of rainfall in this fringe zone are also of interest.

2. Methods and Data

The database for the rain stations in the study area, as well as for the control stations, consists of daily rainfall values from the Israel Meteorological Service for the rainy seasons of 1938/30

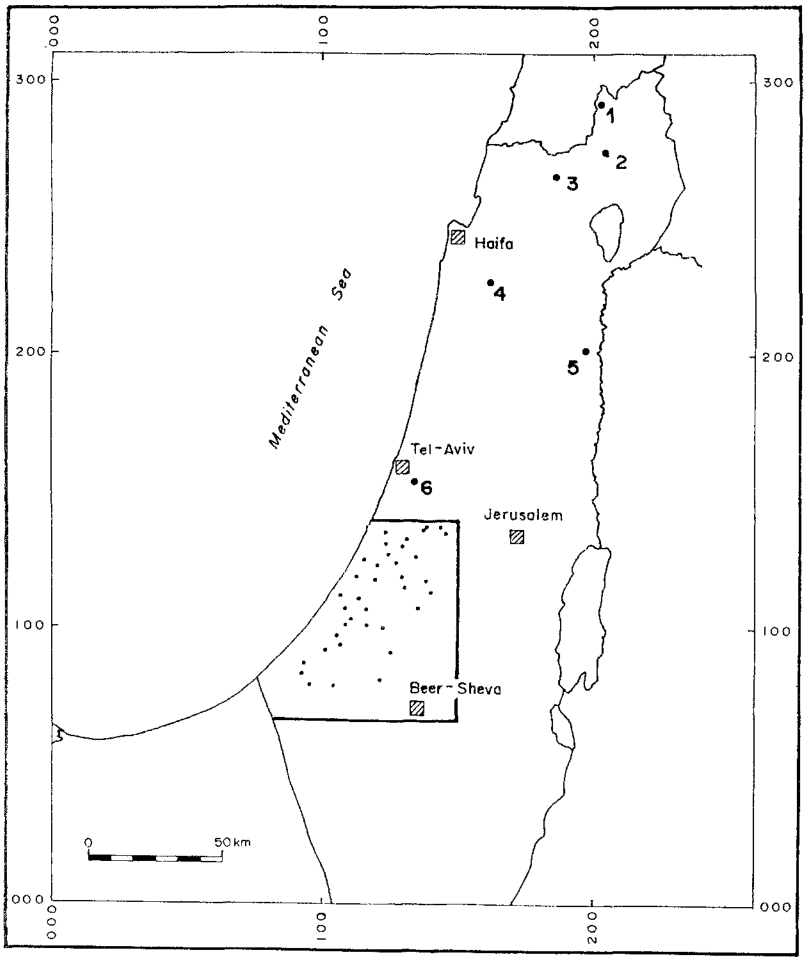

Fig. 2. Stations within the study area including the six control locations in northern Israel denoted by numbers 1 to 6

through 1984/85. This period was divided into two parts. The first consists of 1938/39–1962/63, predating the NWC operation, while the second refers to the seasons 1963/64–1984/85. The number of available years is 16 and 18 for the two periods, respectively.

3. Annual Average Rainfall Amounts

In order to present the results, we used histograms. Rain stations are sorted from north to south, so that the control stations appear to the left of each histogram. As can be seen in Figs. 3a and 3b, the rainfall amounts decrease from north to south. The histograms in Fig. 3c present the difference between the two periods. As can be noticed, the actual differences are larger within the study area, and are in the range of 40–140 mm y^{-1}, compared to those in the control stations, which reach at the most 64 mm. Although the number of control stations is considerably smaller than in the study area, they may be considered fairly representative due to the relatively large spatial coherence of rainfall patterns in the northern and central parts of the country (Katzenelson, 1964; Sharon, 1965).

Figure 4 presents the spatial distribution of the percentage increase over the second period. Most of the study area indicates an increase in rainfall amounts, which rises southward. An area of decrease in rainfall amounts is observed in the northern part of the study area

4. Geographical Distribution of the Coefficient of Variation (*CV*)

Semi-arid regions are characterized by a high rate of interannual rainfall variability (Lockwood, 1988). Katzenelson (1964) used the interseasonal coefficient of variation (*CV*) for drawing a map of the 1921–1950 normals. This coefficient emphasizes the seasonal strength and consecutive rain series in order to characterize climatic regimes and is of great value in agriculture (Katzenelson, 1964),

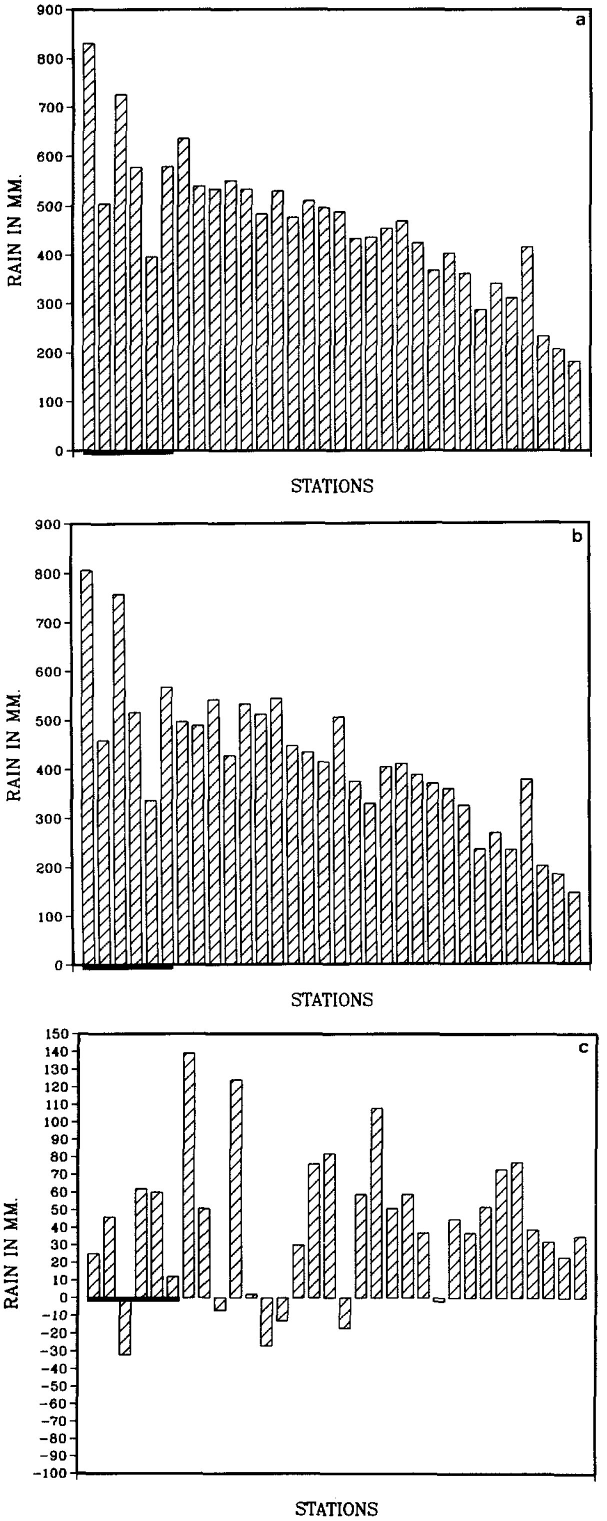

Fig. 3. Histograms of annual rainfall amounts in both periods and the differences between them. Stations are arranged from north to south so that the control stations appear to the left and are underlined in bold. (a) Average annual rainfall amounts for the first period (1938/39–1962/63). The amounts decrease southwards. (b) Average annual rainfall amounts for the second period (1963/64–1984/85). (c) Differences between the average annual rainfall amounts for the two periods

since it may serve as a tool for measuring inter-annual rates of change in rainfall amounts.

Sharon (1965) presented a map of the coefficient of variation for the entire country for the seasons 1947/48–1962/63. Missing years were completed by reduction. A reduction of data at the station in the northern part of the Negev was founded on three base stations with a complete record, consisting of the average deviation at the base station.

In the present study the coefficient of variation has been applied.

In order to examine the coefficient of variation, the average relative standard deviation was calculated separately for each rain station and for the two periods, by the following formula:

$$CV = \frac{\alpha}{\bar{P}} = \frac{\sqrt{n \sum (P - \bar{P})^2}}{\sum P}$$

where α is the standard deviation, $\bar{P}$ is the average annual rainfall and P is the absolute annual rainfall.

Histograms and maps are used to present the results. Figure 5a – coefficient of variation in the first period – indicates lower values at the control stations, up to 25%, with the exception of Nir-David (located in the semi-arid region of the Harod valley) and Miqve Israel, south of Tel-Aviv, while most stations in the study area show values of 30–40% and even higher ones.

Figure 5b – coefficient of variation in the second period – shows a less prominent difference between the control stations and the study area. Figure 5c (differences between Fig. 5a and 5b) shows that the change between the two periods is much more pronounced within the study area compared to the control stations (with the exception of Nir-David, which is located near the arid zone of the Jorden valley).

Figure 6 presents the spatial variation within each period and the differences between them by means of coefficient of variation maps. Figure 6a (map of coefficient of variation in the first period) shows that the values are increasing southward, from 30–35% in the north to over 40% in the south. A meridional trend can also be noticed as the values increase from the coast inland. As can be seen in this map and in the maps of Katzenelson and Sharon, the variability increases towards the south, and is higher in the eastern (inner) part of the coastal plain.

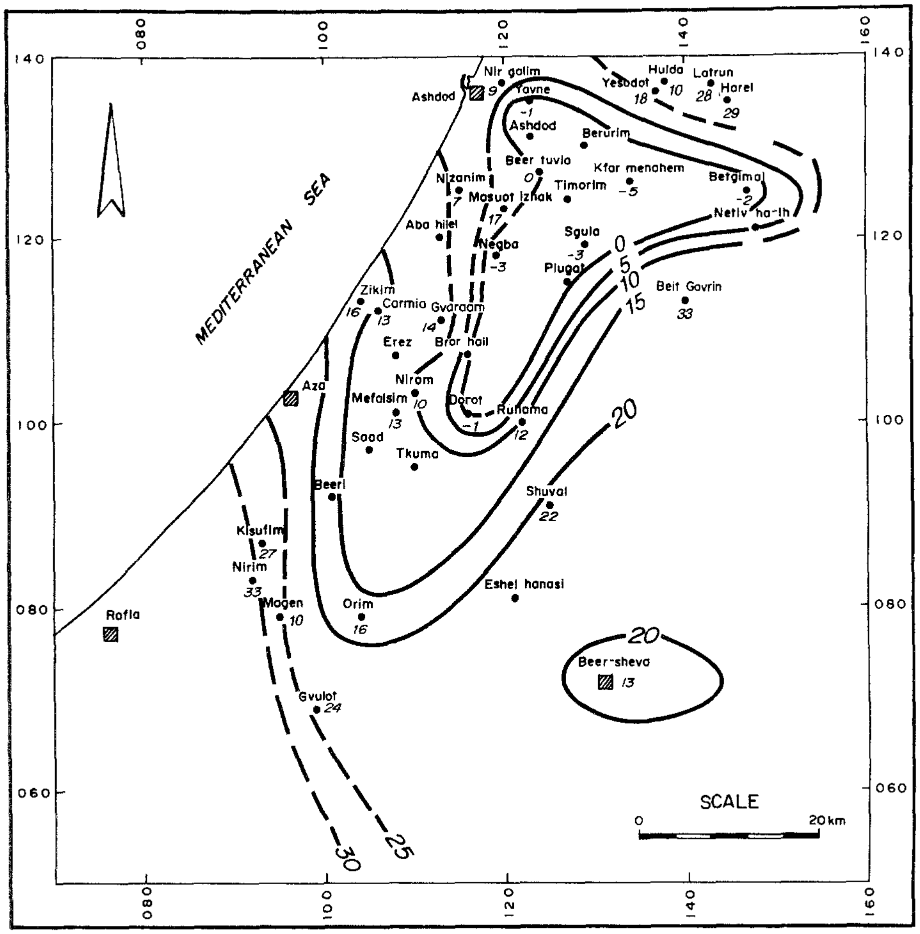

Fig. 4. Increase (%) of the average annual rainfall amounts for the second period in relation to the first period. Stations without data were not incorporated because of insufficient data for this map

Figure 6b (map of coefficient of variation in the second period) shows the same general trends as in Fig. 6a. One can still see that the variability increases towards the south and is lower in the coastal plain, but the values are lower. The values in the south range between 30 and 33% (while in the first period they were higher than 45%). In the northern part of the study area, the values are up to 30% compared to 39% during the first period.

Figure 6c (the differences between Fig. 6a and 6b) indicates this general decrease in values, which is more noticeable in the south. The Kisufim and Orim stations, within the study region, show the highest variations between the two periods. Kisufim also changes its relative location: while having higher values than stations north of it in the first period, it is situated in a local minimum during the second period. Beer–Sheva and Gvulot stations, on the other hand, show the least differences in the south. Furthermore, during the first period these stations had lower values than their neighboring stations, and in the second period they show values similar to adjacent stations.

Lockwood (1988), referring to a map prepared by Trewartha (1968), indicates spatial changes of the coefficient of variation, and points out the inverse proportion between the coefficient and the amount of precipitation: the figures drop as the average annual precipitation increases by moving from desert to temperate areas. The apparent decrease in the coefficient of variation between the two periods, as demonstrated here, may be related to this inverse proportion, as a function of time rather than a function of latitude: This means that changes which took place in the rainfall regime are not attributed only to the amounts of rain but also to its variability.

5. Discussion and Summary

The availability of a relatively dense network of rain stations in a region which was typically arid, prior to the operation of the National Water Carrier, and was subsequently converted into a heavily irrigated agricultural region, provided a unique opportunity to study empirical long-term changes in annual rainfall patterns in the region.

A maximum increase of annual average precipitation during the second period, of about 30%, is reached in the southern most part of the study region.

This increase in annual rainfall coincides with a strong decrease of the coefficient of variation during the second period.

The *CV* map for the second period (Fig. 6b) indicates considerable changes in the coefficient of variation. The control stations, on the contrary, show no significant changes except for two of the six stations. One is located in a semi-arid zone and the other is close to the study area.

An examination of the *CV* differences map between the two periods (Fig. 6c) indicates that the differences increase as we go southward, which is also the trend in increased land use changes. Meagre changes in values are indicated on the border of the arid zone itself (the Magen–Beer-Sheva line) as this is the southern most extent of water transported for irrigation.

A small drop in the *CV* values can be seen in the northern part of the study area, between Kfar–Menahem and Beit–Govrin. A possible explanation for this phenomenon may stem from the fact that while most of the study area receives rainfall from lows approaching from the northwest, this area may be affected more by lows connected to the "coastal front", which forms as a result of converging westerly winds above the southeast Mediterranean sea and southwesterly winds onshore (Rosenfeld, 1980). This coastal front crosses the Israeli coast between Ashdod and Ashkelon and its orientation is west-east.

It is assumed that the southern and northern parts of the study area are affected by interaction between the synoptic systems and the mesometeorological circulation patterns, mainly induced by surface features. The southern part has gone through more inhomogenities than the north, which was cultivated prior to the operation of the NWC.

It seems that an antidesertification process – the retreat of aridity – takes place in this region. It should also be pointed out that there is evidence of a significant change in the Atlantic zonal mean sea surface temperature (SST) anomalies during the second period, starting 1963–1964 (Kushnir,

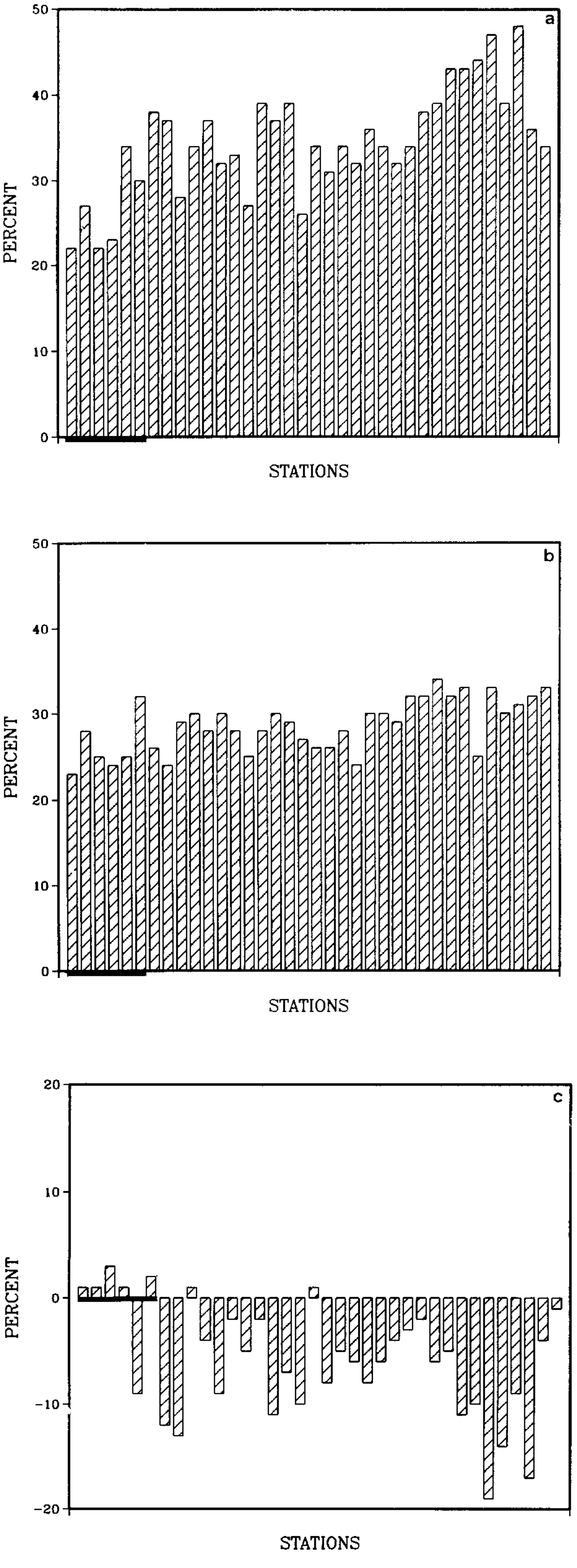

Fig. 5. Histograms for the coefficients of variation for each station in the two periods ((a), (b) respectively) and the differences between them (c). The two periods are 1938/39–1962/63 and 1963/64–1984/85. Station arrangement as in Fig. 3

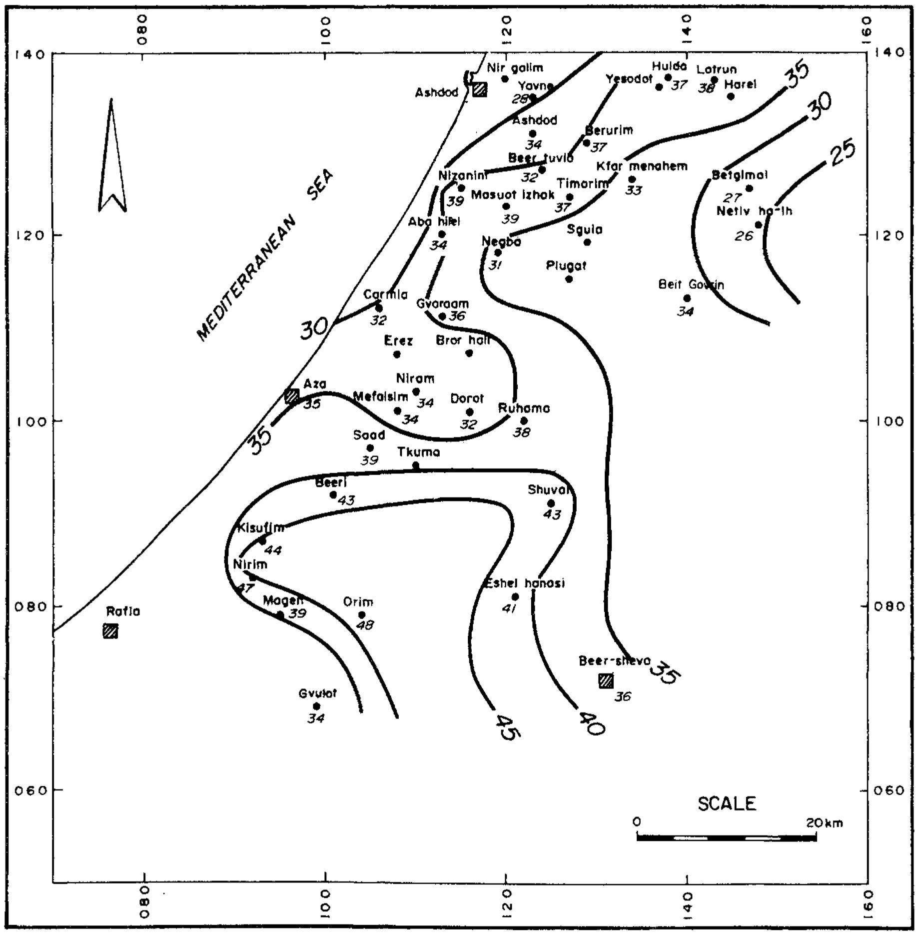

Fig. 6a. Geographical distribution of the coefficients of variation for the first period in the study area

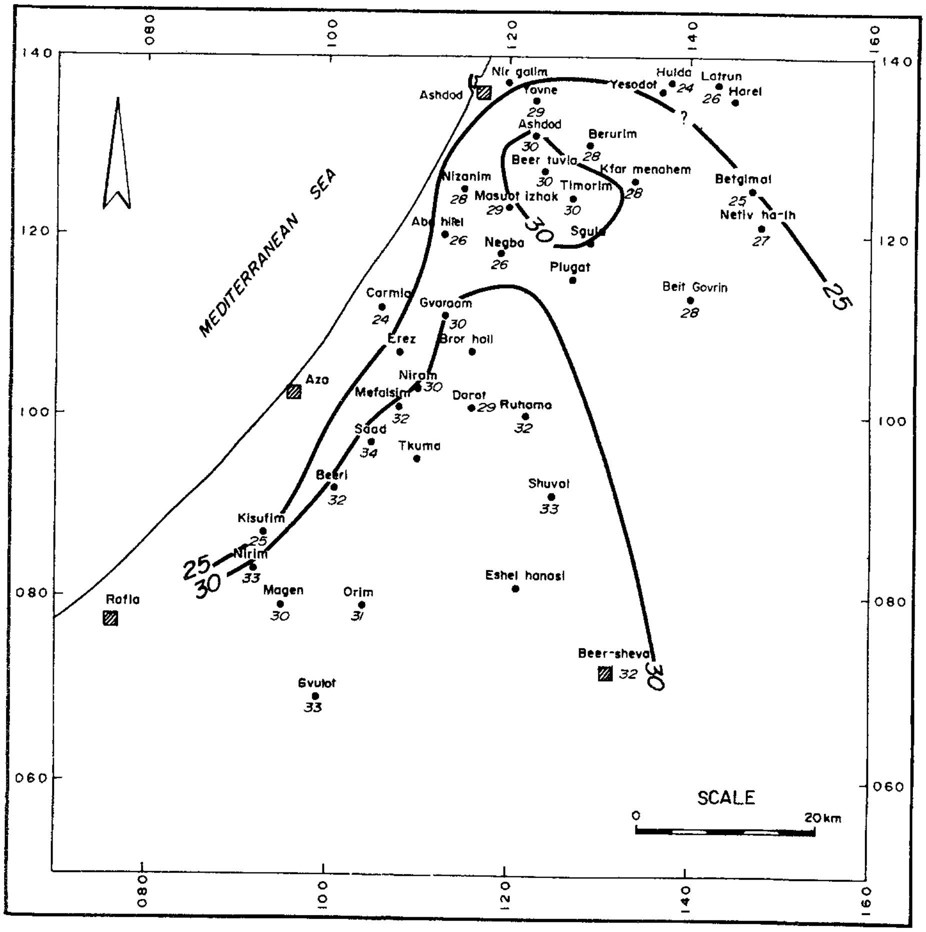

Fig. 6b. As in Fig. 6a, but for the second period

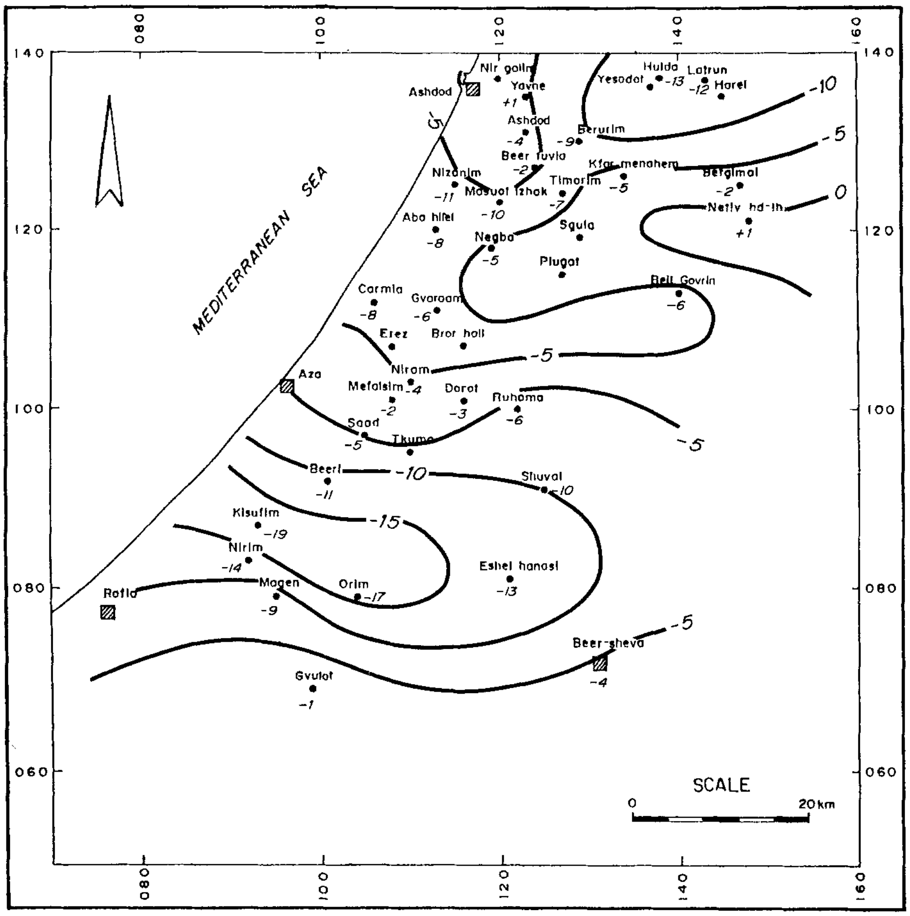

Fig. 6c. As in Fig. 6a, but with the differences between Fig. 6a and 6b

1993). This may indicate a global change that could have affected our region as well and may partly explain the seasonal rainfall increase.

The much larger relative increases in October (Ben-Gai et al., 1993) probably cannot be explained by the global effect due to the reasons that have already been discussed in the former paper.

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References

Alpert, P., Mandel, M., 1986: Wind variability – an indicator for a mesoclimatic change in Israel. *J. Climate Appl. Meteor.*, **25**, 1568–1576.

Anthes, R. A., 1984: Enhancement of convective precipitation by mesoscale variations in vegetative covering in semiarid regions. *J. Climate Appl. Meteor.*, **23**, 541–554.

Ben-Gai, T., Bitan, A., Manes, A., Alpert, P., 1993: Seasonal climatic change in early rainfall patterns in southern Israel. *Theor. Appl. Climatol.*, **46**, 209–217.

Branston, A. G., Schickedanz, P. T., 1984: The effect of irrigation on warm season precipitation in the Southern Great Plains. *J. Climate Appl. Meteor.*, **23**, 865–888.

Elbashan, D., 1966: Monthly rainfall isomers in Israel. *Isr. J. Earth Sci.*, **15**, 1–5.

Katzenelson, Y., 1964: The variability of annual precipitation in Palestine. *Arch. Met. Geoph. Biokl., Ser. B*, **13**, 163–172.

Kushnir, Y., 1993: Interdecadal variations in north Atlantic sea surface temperature and associated atmospheric conditions. *J. Climate* (in press).

Kutiel, H., 1991: Recent spatial and temporal variations in mean sea level pressure over Europe and the Middle East, and their influence on the rainfall regime in the Galilee. *Theor. Appl. Climatol.*, **44**, 151–166.

Lockwood, J. G., 1988: Climate and climatic variability in semi-arid regions at low latitudes. In: Porry, M. L. et al., (eds.) *The Impact of Climatic Variations on Agriculture,* vol. 2: Assessments in Semi Arid Regions. Boston: Kluwer Academic Publ., 85–120.

Otterman, J., Manes, A., Rubin, S., Alpert, P., Starr, D. O'C., 1990: An increase of early rains in southern Israel following land use change? *Bound.-Layer Meteor.,* **53**, 333–351.

Rosenfeld, D., 1980: Characterization of rain cloud systems in Israel using radar and satellite images. M. Sc. Thesis, Hebrew Univ., Jerusalem (in Hebrew).

Sharon, D., 1965: Variability of rainfall in Israel. *Isr. Explor. J.,* **15**, 169–176.

Striem, H. L., 1967: A comparative study of rainfall frequency-distribution spectra for Jerusalem and Rome. *Isr. J. Earth Sci.,* **16**, 52–29.

Striem, H. L., 1977: A long term (1860–1970) change in the regime of barometric pressure at Jerusalem, and its relation to rainfall. *Isr. J. Earth Sci.,* **26**, 24–29.

Sud, Y. C., Smith, W. E., 1985: The influence of surface roughness of deserts on the July circulation. *Bound.-Layer Meteor.,* **33**(1), 15–49.

Trewartha, G. T., 1968: An Introduction to Climate, 4th edn. New York: McGraw Hill.

Tzvetkov, E., 1985: Heat storage in the Eastern Mediterranean and winter precipitation in Israel. *Isr. J. Earth Sci.,* **34**, 65–69.

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