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ON THE DISTRIBUTION OF PRECIPITATION IN THE MAJOR AREA OF THESSALONIKI

by

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Abstract: *The distribution of preeipitation in the inner Thermaikos Gulf, and the effect of the local ground relief and the city on this distribution, are examined from precipitation data of the 1935-1973 period from the following three meteorological stations: Aristotelian University of Thessaloniki (AUT), Amerïean Farm School (AFS), Sindhos Cotton Institute (SCI).*

The seasonal precipitation index of the three locations is found, as well as the general trend of annual precipitation in them.

INTRODUCTION

In this paper we examine the distribution of precipitation in the major area of Thessaloniki-inner Thermaikos Gulf-as well as the effect of the city and the local ground relief upon this distribution; the study is based on precipitation data from the meteorological stations of the Aristotelian University of Thessaloniki (AUT), the American Farm School (AFS), and the Sindhos Cotton Institute (S.C.I.).

The observational periods of each of the above stations, have as follows: AUT: 1930-1973, AFS: 1925-1958, SCI: 1935-1973. Consequently the interval common to all three stations is restricted to the period 1935-1958. We, however have extended this to 39 full years, by adding to the observations of the American Farm School, those of the nearly Sedhes Airport of Thessaloniki (SAT: 1959 - Sept. 1972), and also those of Mikra Airport of Thessaloniki (MAT: Oct. 1972-1973).

Correlation of precipitation recorded at the met. stations of AFS and SAT during their commou observational period 1950-1958, resulted in correlation coefficients $\geqslant +72\%$, having as follows:

J	F	M	A	M	J	J	A	S	O	N	D	Year
98	95	93	97	72	83	88	90	98	90	99	93	97

The eventual few interruptions in the observational series of each station, have been filled in from data of the other stations, by using the regression equation

$$Y = \overline{Y} + \frac{\Sigma xy}{\Sigma y^2} (X - \overline{Y})$$

The subject of the present work has been the subject (as a whole or as part) of research works by *Alexandrou*[3], *Mariolopoulos*[10,11], *Kyriazopoulos*[8], *Mariolopoulos - Karapiperis*[12], *Abatzoglou*[1,2], *Livadas - Arseni*[9], *Angouridakis*[4], *Angouridakis - Maehairas*[5].

The material has been taken from the following sources:

— Observations Météorologiques de Thessaloniki[13].

— Records of meteorologieal observations of the Sindhos Cotton Institute.

— Records of the Hellenic National Meteorological Service.

— Bulletin Quotidien du Temps[14].

Before going any further, we give below *Table I* containing the correlation coefficients of the monthly and annual precipitation recorded in the three stations taken two by two, during the 1935-1973 observational period. This Table indicates that there is a stronger correlation between the met. stations of AUT and AFS, than between these two stations and that of the SCI. This fact differentiates the precipitation regime of the latter from that of the former two, as it will be noted and confirmed in the following chapters.

TABLE I

Correlation Coefficient (%) of Monthly and Annual Precipitation at the met. stations of AUT, AFS, SCI, taken two by two, for the period 1935-1973.

M.S.	J	F	M	A	M	J	J	A	S	O	N	D	Year
AUT/AFS	89	93	92	93	89	62	84	80	85	94	97	97	83
AUT/SCI	79	81	90	90	78	69	65	79	85	76	76	95	75
AFS/SCI	80	77	84	85	74	39	55	71	88	80	88	88	69

I. Mean annual variation of precipitation.

Data of Table II, contributed in the formation of Graph I, containing

GRAPH I

PRECIPITATION IN THE MAJOR AREA OF THESSALONIKI PERIOD: 1935-1973

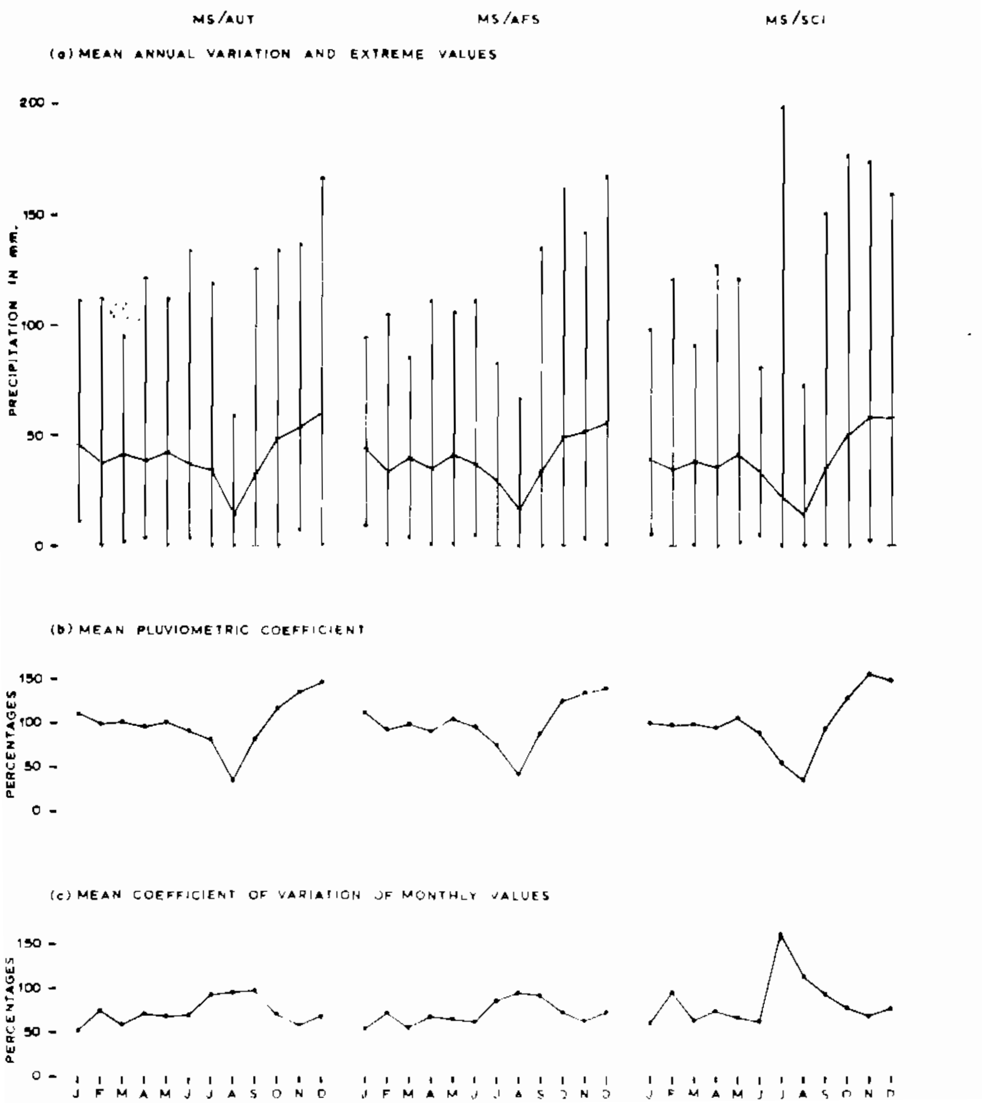


TABLE II

Pluviometric Data of the Major Area of Thessaloniki: AUT, AFS, SCI: 1935 - 1973.

	Max Precipitation / Year						Mean Precipitation			±σ		
Month	AUT		AFS		SCI		AUT	AFS	SCI	AUT	AFS	SCI
J	111.0	1951	94.6	1951	97.6	1951	45.6	43.8	39.0	23.5	24.1	23.8
F	111.4	1954	104.1	1954	120.0	1972	37.2	33.9	34.8	27.9	24.4	33.2
M	94.1	1936	85.2	1969	90.2	1971	41.5	39.6	38.5	24.1	22.3	24.4
A	120.6	1938	111.1	1944	127.1	1938	38.5	34.9	35.5	27.4	24.4	26.3
M	111.9	1963	105.9	1963	120.5	1967	42.4	41.5	41.4	29.1	27.7	27.6
J	133.3	1957	110.5	1955	80.5	1957	37.0	37.1	33.9	25.9	23.2	20.8
J	118.3	1972	82.6	1967	197.5	1970	34.0	29.7	21.4	31.7	25.6	34.5
A	58.8	1945	66.6	1966	73.0	1966	14.7	16.3	14.2	14.3	15.5	16.2
S	125.1	1967	135.0	1973	151.1	1945	32.8	33.6	35.3	32.4	31.1	33.0
O	133.6	1955	161.1	1955	176.6	1946	48.3	49.9	50.5	34.5	36.3	38.9
N	136.4	1937	141.7	1937	173.6	1937	54.0	51.6	58.8	32.4	32.9	39.3
D	166.2	1935	166.9	1935	159.2	1935	60.3	55.4	58.2	42.2	39.6	44.5
Year	639.9	1937	791.7	1955	640.4	1936	486.3	467.3	461.5	261.3	321.8	317.1
Max.	166.2/D/35		166.9/D/35		197.5/J_L/70							

TABLE II (Continued)

Pluviometric Data of the Major Area of Thessaloniki : AUT, AFS, SCI: 1935 - 1973.

	C.V. (%)*			P.C. (%)**			Min Precipitation / Year					
Month	AUT	AFS	SCI	AUT	AFS	SCI	AUT		AFS		SCI	
J	51.5	54.9	61.1	110.5	110.6	99.5	11.8	1964	9.8	1957	4.3	1938
F	75.0	72.0	95.4	98.8	93.7	97.5	0.1	1945	0.4	1945	0	1967
M	58.1	56.3	63.4	100.5	99.8	98.2	1.9	1943	3.9	1941	0.0	1952
A	71.2	69.9	74.1	96.3	90.9	93.6	3.6	1935	0.7	1970	0.0	1947
M	68.6	66.7	66.6	102.8	104.7	105.8	0.2	1962	0.7	1962	1.3	1945
J	70.0	62.6	61.3	92.6	96.6	89.4	3.6	1944	5.6	1971	5.0	1952
J	93.1	86.1	161.4	82.5	74.9	54.6	0.0	1948	0	1965	0.0	mt
A	97.3	94.9	113.9	35.6	41.2	36.3	0.0	1961	0.0	{1950, 1961}	0.0	mt
S	98.6	92.6	93.5	82.2	87.5	93.1	0	1942	0.0	{1942, 1965}	0.0	mt
O	71.3	72.7	77.0	117.1	125.8	128.9	0.0	1969	0.0	1969	0.0	1965
N	59.9	63.8	66.8	135.2	134.4	155.3	7.0	1970	3.6	1971	3.0	1970
D	69.9	71.4	76.4	146.2	139.8	148.6	0.8	1972	0.2	1972	0	1972
Year	53.7	68.8	68.7				290.2	1948	271.1	1958	237.1	1953
Min.							O/S/42		O/J_L/1965		O {F/1967, D/1972}	

*V.C.(%)=Coefficient of Variation: $\frac{\sigma}{\overline{H}} \times 100$

**P.C.(%)=Pluviometric Coefficient: $\frac{N.\overline{h}}{v.\overline{H}}$ (N = 365.25, v = 28,25 or 30 or 31, $\overline{h}$ = mean monthly rainfall, $\overline{H}$ = Annual mean rainfall) curves of the mean annual variation of: a) precipitation, b) pluviometric coefficient, c) the variability of precipitation for the three stations during the period examined.

All three stations have a triple oscillation with a primary maximum in December for the AUT and AFS stations and November for SCI, and a primary minimum in Angust for all three.

In a previons work[5], studying the mean annual variation of precipitation in the AUT station, we found a double oscillation instead of the triple oscillation mentioned herein. This alternative version which exists also for the other two stations, (AFS and SCI), can be accounted for as follows;

a) S t a t i s t i c a l l y: The observational periods, (1930-1973 for AUT and AFS and 1935-1973 for SCI) have been divided in five-year sequences, not overlapping each other (the last 1970-1973 a four-year one) and from these we formed all possible combinations: decades, fifteen-year periods, ..., fourty-four years period. The resulting periods of various duration, amount to 45 for the two stations of AUT and AFS, and to 36 for the SCI station.

Thus for each station and period we have found the mean annual variation of precipitation and from this we arrived at the various oscillations (double: 2, ..., quintuple: 5).

The results (frequencies) of this process, are given in Table III. As should be expected, in short periods ($\leqslant$ 15 years) have been recorded even quintuple oscillations, since, because of the small number of years, a high maximum or low minimum strongly affects the monthly mean value and consequently the annual variation of precipitation at a certain place. For periods $\geqslant$ 20 years, the oscillations are reduced to double or triple ones, with only two quadruple cases (AUT). Beyond thirty years, frequencies are even more strongly gathered around the double and triple oscillations. The percentages mentioned at the foot of Table III are characteristic.

Thus we arrive to the conclusion that, from the statistical point of view it is possible, because of the small difference between secondary maxima and minima and even more between tertiary ones, a strong or small (according to the case) rainfall may change the oscillation from double to triple or vice-versa.

b) C l i m a t o l o g i c a l l y: Coastal areas of the Mediterranean, present a mean annual variation of precipitation with a double oscillation, due to the seasonal regression of the Mediterranean front. The inner part of Thermaikos gulf undergoes this effect as belonging to the Mediterranean, on the other hand it undergoes the effect of the continent into which this gulf penetrates. Moreover, one should take into account the proximity of the mountain mass of Chortiates (elev. 1201 m) and how it influences, especially during the spring season, on the precipitation recorded in the three stations examined. Thus, according to the case, one effect may overshadow the other, and change the oscillation of the annual variation from double to triple, and vice versa.

TABLE III

Frequency of different variations, at different intervals, in the met. stations of AUT, AFS, SCI.
Frequency per variation and per station.

Period's	Frequency per variation and per station.														
Duration	M.S. /AUT					M.S. /AFS					M.S. /SCI				
in years	2	3	4	5	T	2	3	4	5	T	2	3	4	5	T
5	1	2	5	1	9	1	3	5		9	2	3	3		8
10		4	3	1	8		4	3	1	8		5	1	1	7
15	1	4	1	1	7	1	5	1		7	2	3	1		6
20		5	1		6	1	5			6	1	4			5
25	1	4			5		5			5	1	3			4
30	1	2	1		4	1	3			4	1	2			3
35	1	2			3	2	1			3		2			2
40	1	1			2		2			2		1			1
44		1			1		1			1					
Gen. Total	6	25	11	3	45	6	29	9	1	45	7	23	5	1	36
%	13	56	24	7	100	13	64	21	2	100	20	64	13	3	100
Periods ⩾ 20 years															
Total	4	15	2		21	4	17			21	3	12			15
%	19	71	10		100	19	81			100	20	80			100
Periods ⩾ 30 years															
Total	3	6	1		10	3	7			10	1	5			6
%	30	60	10		100	30	70			100	17	83			100

Finally from Table II and Graph I we confirm the existing similarity between the precipitation regime of the AUT and the AFS stations, against that of the SCI station; as for instance the ocurrence of the primary maximum of the mean annual variation of precipitation (AUT, AFS: December, SCI: November), and the coincidence of the absolute maximum monthly precipitation, quantitatively as well as seasonally (AUT: December 1935:166,2 mm - AFS: December 1935: 166,9 mm - SCI: July 1970: 197,5 mm).

Standard deviation values vary per month almost alike in the three stations, having their minima in August and their maxima in December.

Differences between the AUT and AFS stations on one hand and that of SCI on the other, appear again in the distribution of pluviometric coefficients for the three places. While the minimum for all three stations occurs in August, the maximum in the AUT and AFS stations is recorded in December, while in the SCI station it is recorded in November.

Concerning the coefficient of variability, a simple inspection of its annual variation in the three stations, (Graph I - Curve c), is rather convincing about the behavior of SCI differing from that of the other two stations.

Absolutely rainless months (precipitation: 0) have been recorded once in the AUT and AFS stations (September 1942 and July 1965 respectively) and twice in the SCI (February 1947, December 1972), while monthly precipitation of 0.0. mm have been quite often recorded in all three stations.

More than 3/4 of the total number of monthly values (Table IV, Graph II) are gathered in the grades between 0-29,9 mm and 30,0-59,9 mm; in any case, the above frequencies are distributed per descending order as the amount of precipitation increases. As concerns the annual amount of precipitation, their closest gathering is around 460 — 520 mm (AUT, AFS) and 400-460 mm (SCI), meaning that here again we observe a difference between the first two and the last station.

For all months and all three stations, values are gathered in the intervals: $\overline{H} \pm \sigma \geqslant 59\%$, $\overline{H} \pm 2\sigma \geqslant 92\%$, $\overline{H} \pm 3\sigma \geqslant 95\%$; as to positive or negative deviations, the last generally outnumber the first, except for the months of March (AUT, AFS, SCI) and February (AFS). Very few significant deviations ($> \overline{H} + 3\sigma$) have been recorded in the three stations. As to the annual values, we have found no significant deviations, while values from all three stations are gathered between the intervals $\overline{H} \pm \sigma = 100\%$ (AUT), 97% (AFS), 100%(SCI) and $\overline{H} \pm 2\sigma = 100\%$ (AFS).

After a detailed examination (per station) of the mean annual variation of precipitation, we deem expedient to give below Table V, containing the distribution of the general mean precipitation in the major

TABLE IV

Frequency Distribution of monthly and Annual Precipitation per Grades.
M. S. AUT, AFS, SCI: 1935-1973.

Grades (mm)	J	F	M	A	M	J	J	A	S	O	N	D	T	%	Annual Precipitation Grades (mm)	Frequency	%
(a) M.S./AUT																	
0.0- 29.9	12	18	15	18	18	20	21	34	22	13	12	9	212	45.3	280-340	2	5
30.0- 59.9	15	12	16	13	9	12	10	5	11	13	13	13	142	30.3	340-400	4	10
60.0- 89.9	10	7	7	5	10	6	6		3	8	8	7	77	16.6	400-460	7	18
90.0-119.9	2	2	1	2	2		2		2	4	4	6	27	5.8	460-520	14	36
120.0-149.9				1		1			1	1	2	3	9	2.0	520-580	8	21
150.0-179.9												1	1	0.2	580-640	4	10
(b) M.S./AFS																	
0.0- 29.9	15	17	14	20	16	16	21	31	21	14	12	11	208	44.4	220-280	1	3
30.0- 59.9	13	16	18	15	13	20	12	7	11	10	11	13	159	34.0	280-340	3	8
60.0- 89.9	10	5	7	2	7	1	6	1	4	10	11	8	72	15.4	340-400	9	23
90.0-119.9	1	1		2	3	2			1	4	3	4	21	4.5	400-460	6	15
120.0-149.9									2		2	1	5	1.1	460-520	10	26
150.0-179.9										1		2	3	0.6	520-580	6	15
															580-640	3	8
															640-700		
															> 700	1	3
(c) M.S./SCI																	
0.0- 29.9	13	21	15	20	14	20	32	34	24	12	11	11	227	48.5	220-280	2	5
30.0- 59.9	18	7	16	14	16	13	4	4	6	16	12	13	139	29.7	280-340	2	5
60.0- 89.9	5	9	7	3	7	6	1	1	8	7	7	8	69	14.7	340-400	7	18
90.0-119.9	3	1	1	1	1		1			2	7	1	18	3.8	400-460	10	26
120-0-149.9		1		1	1						1	3	7	1.5	460-520	4	10
150.0-179.9									1	2	1	3	7	1.5	520-580	9	23
> 179.9							1						1	0.2	580-640	4	10
															> 640	1	3

GRAPH II

DISTRIBUTION PER GRADE OF MONTHLY AND ANNUAL PRECIPITATION
IN THE MAJOR AREA OF THESSALONIKI. PERIOD: 1935-1973

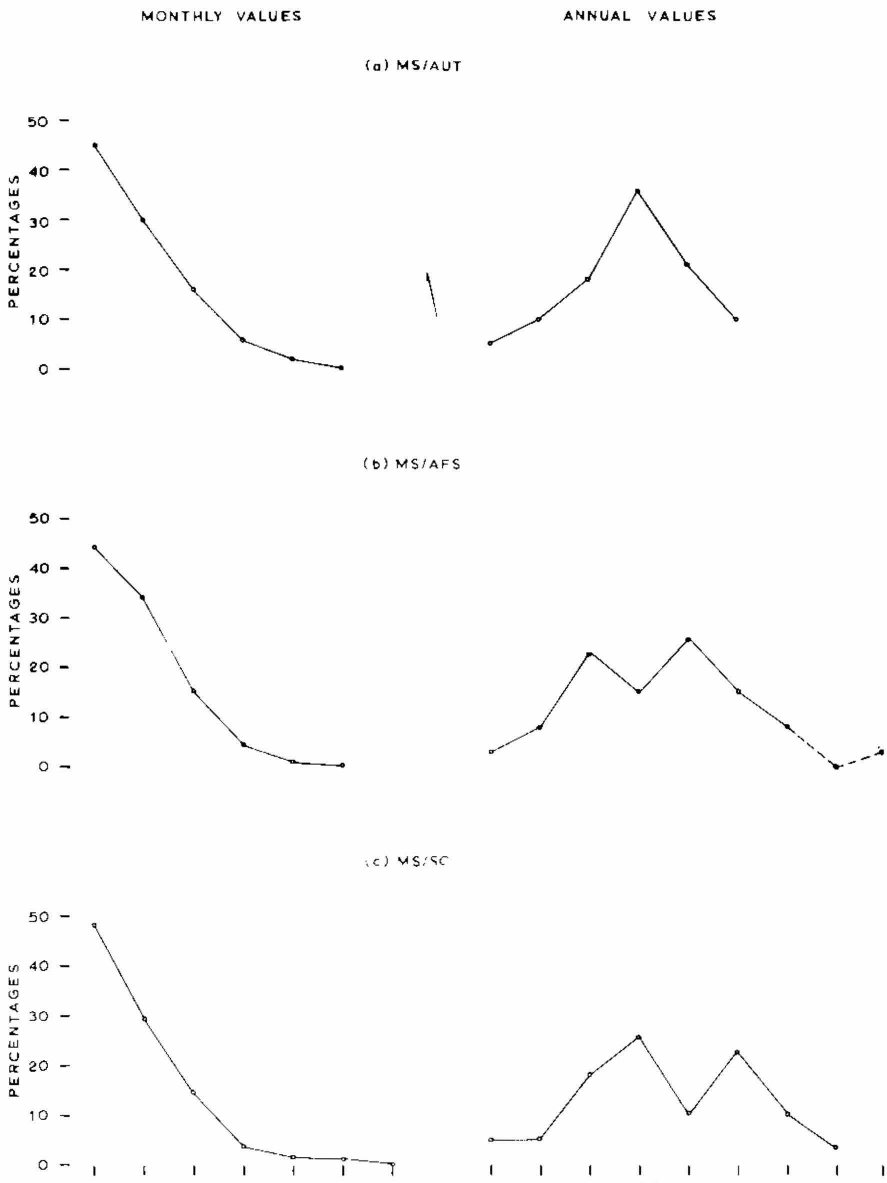


TABLE V

General mean precipitation in the major area of Thessaloniki: 1935-1973

$\left(\frac{\overline{H}_{AUT} + \overline{H}_{AFS} + \overline{H}_{SCI}}{3} \right.$ *and extreme values in mm).*

	J	F	M	A	M	J	J	A	S	O	N	D	Year
G.M.P.	42.8	35.3	39.8	36.3	41.8	36.0	28.4	15.1	33.9	49.6	54.8	58.0	471.8
Max.	111.0	120.0	94.1	127.1	120.5	133.3	197.5	73.0	151.1	176.6	173.6	166.9	791.7
Year	1951	1972	1936	1938	1967	1957	1970	1966	1945	1946	1937	1935	1955
M.S.	AUT	SCI	AUT	SCI	SCI	AUT	SCI	SCI	SCI	SCI	SCI	SCI	AFS
Min.	4.3	0	0.0	0.0	0.2	3.6	0	0.0	0	0.0	3.0	0	237.1
Year	1938	1967	1952	1947	1962	1944	1965	m.t.	1942	m.t.	1970	1972	1953
M.S.	SCI	SCI	SCI	SCI	AUT	AUT	AFS	m.st.	AUT	m.st.	SCI	SCI	SCI

area of Thessaloniki. In drawing up this Table we have taken as general mean precipitation the arithmetic mean of the mean monthly values of the three stations, and as absolute monthly maximum and minimum the largest maximum or smallest minimum recoreded among these stations.

As should be expected, the general mean precipitation in the major area of Thessaloniki, has a triple oscillation with a primary maximum in December and a primary minimum in August, while the annual general mean precipitation amounts to: 471,8 mm.

11. Seasonal Variation of Precipitation.

As an average of the period examined, in all three stations, summer is the driest season of the year with precipitation $\leqslant$ 17.8% of the mean annual precipitation. On the other hand the rainiest season is autumn in the AFS and the SCI stations, and winter for AUT. However, we should mention that in the AFS station winter has as an average of the whole period only 1,9 mm less than autumn.

Table VI

Mean Seasonal Precipitation in the Major Area of Thessaloniki.
(AUT, AFS, SCI: 1935-1973*)*

M.S.	Winter	Spring	Summer	Autumn	Year	C.P.	W.P.
AUT							
mm	143.1	122.3	85.7	135.2	486.3	278.3	208.0
%	29.4	25.1	17.6	27.8	99.9	57.2	42.8
AFS							
mm	133.1	115.9	83.1	135.0	467.1	268.1	199.0
%	28.5	24.8	17.8	28.9	100.0	57.4	42.6
SCRI							
mm	131.9	115.4	69.5	144.6	461.4	276.5	184.9
%	28.6	25.0	15.1	31.3	100.0	59.9	40.1

If we consider as cold season all the autumn and winter months, and warm season all the remaining months, we find that the cold season has in every station precipitation amounting to $\geqslant$ 57,2% of the annual rainfall, as an average for the whole period examined.

III. Number of Rain Days.

The period as an average of which we study the distribution of rain days in this area, is by necessity restricted between the years 1935-1970. This is due to the fact that precipitation data of the 1951-1958 period for the AFS station, have been taken from records of the National Meteorological Service, as cumulative monthly tables, because the original analytical sheets of observations were missing and consequently it has been impossible to single out the rain days of that period.

Table VII

Mean Number of Rain Days per Month and per year ($h \geq 0.1$ mm)
(AUT, AFS, SCI: 1935-1950*)*

AUT	10.7	7.7	7.9	8.9	8.6	7.1	3.8	3.5	4.8	8.0	9.9	11.4	92.3
AFS	11.1	8.1	8.0	8.2	7.4	6.0	4.4	2.5	4.6	7.2	9.1	12.1	88.7
SCI	5.5	4.3	5.1	6.6	5.4	5.2	2.3	2.3	3.3	5.6	7.6	7.2	60.4

Moreover we have chosen to ignore the rain-days of the period 1959-1973 *(S.A.T., M.A.T., Monthly Climatological Bulletin*[14]*)* because we consider expedient to study the shorter but uninterrupted period 1935-1950, instead of the longer, but interrupted for an eight-year interval period between 1935-1950 and 1959-1973. Thus the period for which we have an homogeneous material to study (rain-days $\geq$ 0,1 mm) has been limited from 1935 to 1950.

The mean annual variation of rain-days' number in the three stations has a double oscillation with a primary maximum in December (AUT, AFS) or November (SCI), and a primary minimum in August (for all) and July (SCI).

The maximum per month number of rain days, as an average of the period examined, is between 1/3 and 1/4 aproximately of the number of days of the mean month; while to the exception of September 1942, (which has been absolutely rainless), no other month in any station has had rain-days < 2 (speaking always about the period 1935-1950).

We observe again that the number of rain-days at the SCI is quite smaller than that of the other two stations, meaning that here again the station of SCI differs from those of AUT and AFS.

The maximum per year number of rain days has been recorded in the AUT station (92,3), and the minimum in the SCI station (60,4).

The difference between the mean annual number of raindays at the AUT mentioned herein, and the number mentioned in a previous study of ours[5], which was 130,2, is due to the fact that here we consider as rain-days those with precipitation h ⩾ 0,1 mm and not h ⩾ 0.0 mm (previous study).

TABLE VIII

Mean Number of Rain Days (h⩾ 0.1 mm) per Season
(AUT, AFS, SCI - Period 1935-1950*)*

M.S.		Winter	Spring	Summer	Autumn	Year	C.P.	W.P.
AUT	R.d.	29.8	25.4	14.4	22.7	92.3	53.5	39.8
	%	32.3	27.5	15.6	24.5	99.9	56.8	43.1
AFS	R.d.	31.3	23.6	12.9	20.9	88.7	52.2	36.5
	%	35.3	26.6	14.5	24.7	101.1	60.0	41.1
SCI	R.d	17.1	17.1	9.8	16.4	60.4	35.5	26.9
	%	28.3	28.3	16.2	27.2	100.0	55.5	44.5

Of all the seasons winter is the one that has the maximum mean number of rain days in every station; and only at the SCI station spring has the same number of rain-days as winter. It is worth noting that in every station spring has more rain-days than autumn, and also that the cold period (autumn and winter) has the maximum number of rain days in all three stations.

The frequency distribution of rain days in each station, per month and per year during the period examined, proves that the greatest frequency belongs to the grade between 4-7 rain-days, for every month within this period, with maximum frequency at the SCI station (42,2%) and minimum at the AFS station (31,3%).

We do not have, in any station, any month of August with recorded rain-days > 7.

We observe here again certain similarities between the two stations of AUT and AFS, as well as corresponding differences of the SCI station·

— AUT, AFS stations: only August does not exceed the two first grades of the scale, while in the SCI station this happens in July and September too,

Table IX

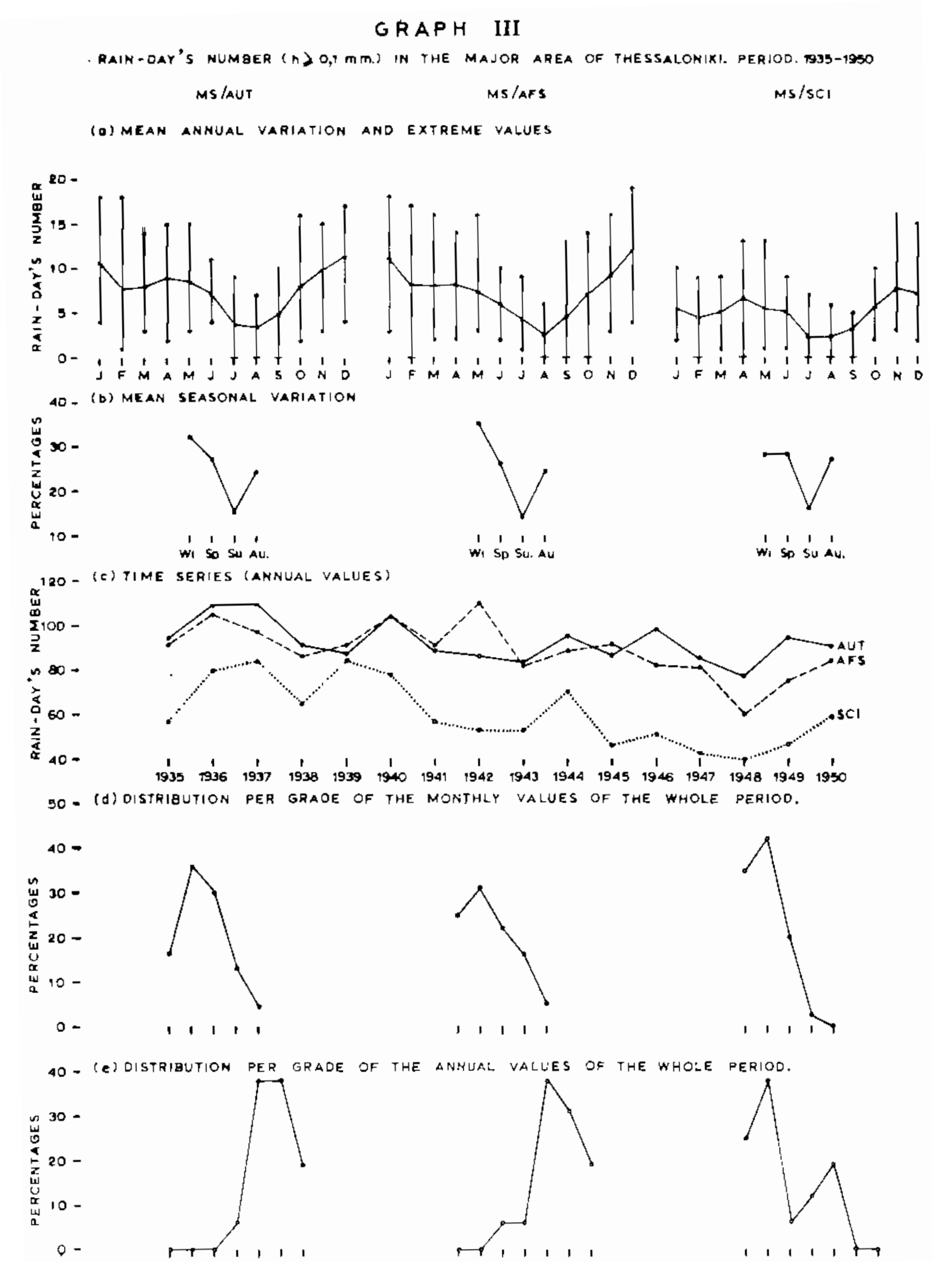
Pluviometric Data of the Major Area of Thessaloniki: AUT - AFS - SCI

A. Frequency of Rain Days (h ≥ 0.1 mm): M.S./AUT, AFS, SCI: 1935-1950.

Grades	I	F	M	A	M	J	J	A	S	O	N	D	Total	%
(a) AUT														
0- 3		4	2	2	2		6	9	5	1	1		32	16.7
4- 7	2	4	6	2	3	11	9	7	9	7	4	5	69	35.9
8-11	7	5	6	10	9	5	1		2	5	5	3	58	30.2
12-15	5	2	2	2	2					2	6	4	25	13.2
16-19	2	1								1		4	8	4.2
Total	16	16	16	16	16	16	16	16	16	16	16	16	192	100.2
(b) AFS														
0- 3	2	3	3	2	4	4	6	12	7	3	2		48	25.0
4- 7	1	3	6	6	5	8	8	4	7	5	5	2	60	31.3
8-11	5	8	3	3	5	4	2		1	5	2	5	43	22.4
12-15	6	1	3	5	1				1	3	6	5	31	16.1
16-19	2	1	1		1						1	4	10	5.2
Total	16	16	16	16	16	16	16	16	16	16	16	16	192	100.0
(c) SCI														
0- 3	5	7	5	3	6	3	13	13	6	4	1	1	67	34.9
4- 7	6	6	8	6	6	11	3	3	10	7	8	7	81	42.2
8-11	5	3	3	6	3	2				5	6	6	39	20.3
12-15				1	1						1	2	5	2.6
16-19														
Total	16	16	16	16	16	16	16	16	16	16	16	16	192	100.0

B. Frequency of Annual Precipitation (h ≥ 0.1 mm), M.S./AUT, AFS, SCI: 1935-1950.

Grade/%	40-49	%	50-59	%	60-69	%	70-79	%	80-89	%	90-99	%	100-109	%	T
AUT							1	6	6	38	6	38	3	19	16
AFS					1	6	1	6	6	38	5	31	3	19	16
SCI	4	25	6	38	1	6	2	12	3	19					16


GRAPH III
. RAIN-DAY'S NUMBER (h ≥ 0,1 mm.) IN THE MAJOR AREA OF THESSALONIKI. PERIOD. 1935-1950
MS/AUT
MS/AFS
MS/SCI
(a) MEAN ANNUAL VARIATION AND EXTREME VALUES
RAIN-DAY'S NUMBER
J F M A M J J A S O N D
(b) MEAN SEASONAL VARIATION
PERCENTAGES
Wi Sp Su Au.
(c) TIME SERIES (ANNUAL VALUES)
1935 1936 1937 1938 1939 1940 1941 1942 1943 1944 1945 1946 1947 1948 1949 1950
AUT
AFS
SCI
(d) DISTRIBUTION PER GRADE OF THE MONTHLY VALUES OF THE WHOLE PERIOD.
(e) DISTRIBUTION PER GRADE OF THE ANNUAL VALUES OF THE WHOLE PERIOD.

— AUT, AFS stations: certain months-mainly winter ones-record > 15 rain days (thus covering the highest grades of the scale), while no month in the SCI station ever registered > 15 rain-days.

— AUT, AFS stations: every December of the period examined record > 3 rain-days, while one December at the SCI recorded < 3 rain-days.

— Regarding the number of rain-days per year, the SCI station covers every grade between 40-89 rain-days, while at the AUT and AFS stations there is not one year with < 60 raindays.

— Finally, frequencies between 70-109 rain-days per year are practically the same in both the AUT and the AFS stations.

All the above mentioned facts illustrate the influence of the local relief and the location of each station on the precipitation recorded. This will be discussed again in the end of this paper.

IV. Seasonal Index

By the method of the centered 12-month moving average and percentages of moving average[6] we find the seasonal index for percipitation in the three stations (AUT, AFS, SCI) as an average of the 1935-1973 period.

In Graph IV (based on data included in Tables II and X) we have included the following curves:

a) Mean annual variation of precipitation, b) pluviometric coefficient, c) seasonal index (the full line denotes the arithmetic mean, and the dotted line the median). The seasonal index of medians was included in this Graph only indicatively, since we rely mainly on the seasonal index derived from the arithmetic mean, because the mean of its monthly values, for all three stations, is almost 100% (Table X - last column).

In Graph IV, is clearly seen a similarity between the curves of pluviometric coefficients and those of the seasonal index, with a small deviation for the SCI in the month of March. However this deviation may be ignored since the seasonal indices of February, March, and April are almost equal (95,5, 94,6, and 94,9 respectively), and also because the seasonal index of these months at the SCI station, derived from the median (dotted line), balances the situation.

In any case, we can now say that the annual variation of precipitation in the stations of AUT, AFS, and SCI has a triple oscillation

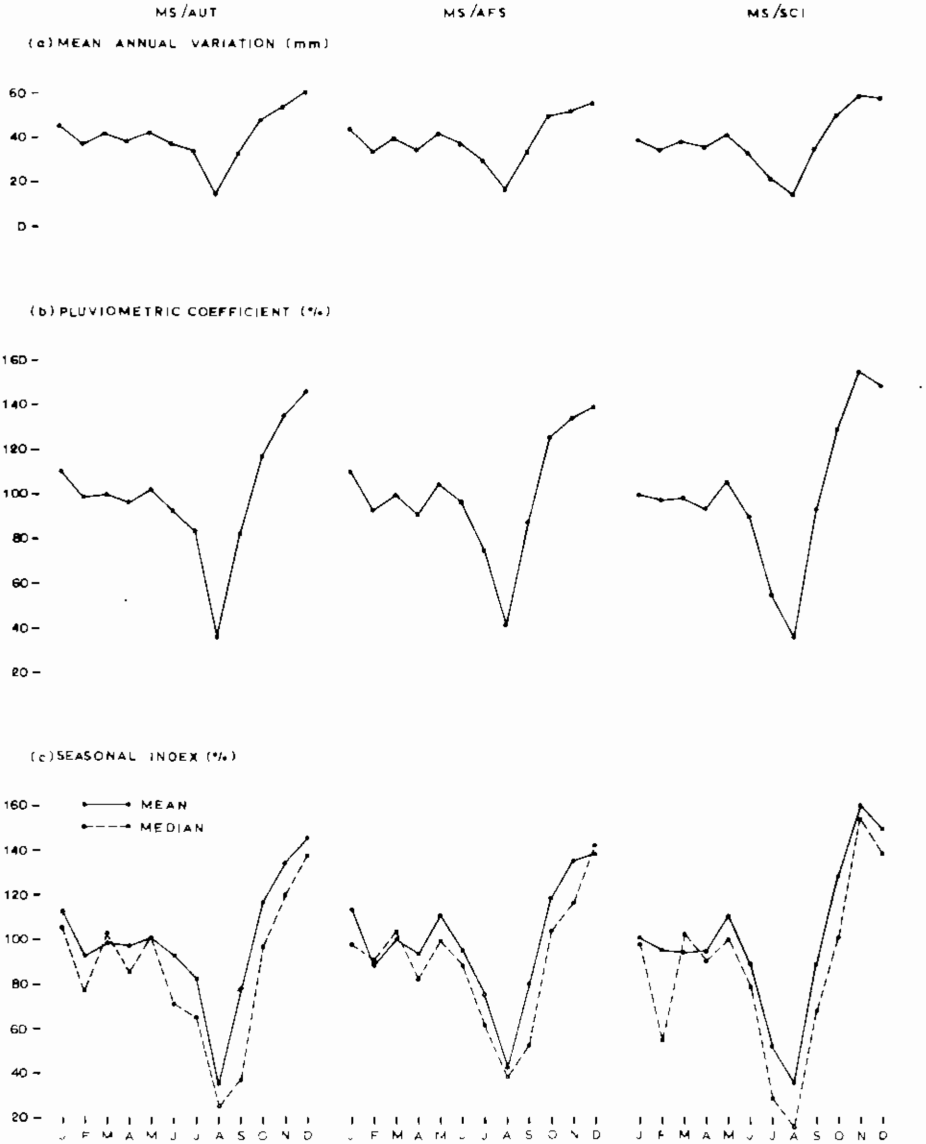
TABLE X

Seasonal Index by the Method of Centered 12-month Moving Average and Percentages of Moving Average for Precipitation in the Major Area of Thessaloniki (%)
1935-1973

	J	F	M	A	M	J	J	A	S	O	N	D	$\frac{Total}{12}$
M.S./AUT													
Mean	112.7	92.9	98.6	97.5	101.1	93.0	82.2	35.5	78.7	116.5	134.4	145.8	99.1
Median	105.7	77.7	103.4	85.4	101.3	71.2	64.9	25.0	37.6	97.4	119.8	138.0	85.6
M.S./AFS													
Mean	113.1	88.7	100.8	93.3	111.1	95.0	75.2	42.3	80.0	118.7	135.2	138.9	99.4
Median	97.7	90.8	103.6	82.2	98.7	88.3	61.8	38.4	52.7	103.9	116.1	142.5	97.3
M.S./SCI													
Mean	100.7	95.5	94.6	94.9	110.2	88.6	51.9	35.5	88.7	128.5	160.1	149.3	99.9
Median	98.5	54.5	102.4	90.4	100.3	78.6	28.6	15.2	67.7	101.7	153.8	136.5	85.7

GRAPH IV

SEASONAL INDEX OF PRECIPITATION IN THE MAJOR AREA OF THESSALONIKI PERIOD: 1935-1973



(speaking always about the period 1935-1973, and with the reservations mentioned in paragraph 1), with a primary maximum in December (AUT, AFS) or November (SCl) and a primary minimum in August (in every station).

V. Chronological Series (Time Series).

In a previous study[5], we had found an increasing trend of the annual precipitation in the AUT station, deriving this general linear trend by the method of least squares, moving average, and semi-averages.

However we have preferred here to find the trend by a second degree curve (parabola) rendering more accurately the general trend as well as its variations.

Thus, by applying the method of least squares for a second degree curve, we arrived in finding the trends of the three stations, for the period 1935-1973, whose mathematical expressions have as follows:

$$\text{AUT: } Y = 458{,}179 - 0{,}509t + 0{,}222t^2 \quad (1)$$
$$\text{AFS: } Y = 444{,}583 - 1{,}889t + 0{,}179t^2 \quad (2)$$
$$\text{SCI: } Y = 444{,}718 - 0{,}038t + 0{,}132t^2 \quad (3)$$

Here we observe a decreasing trend of annual precipitation till the year 1954, and from then on an increasing trend, which is faster iu the AUT station and slower in the AFS.

Besides, from the time series (Graph V), appears a certain periodicity, of the order of 4-7 years for the first half of the period examined, while during the second half of the same period this periodicity is reduced to 3-4 years.

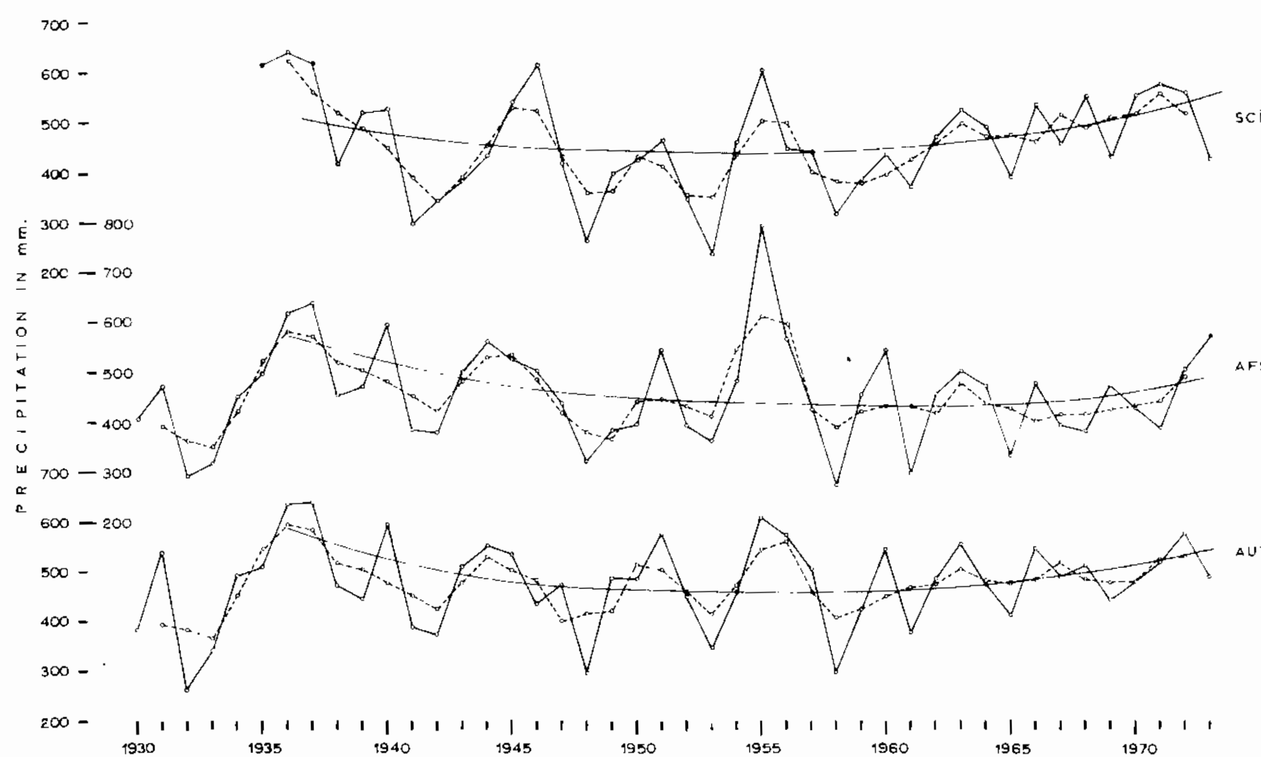
A detailed examination of time series proves the similarity in the variation of annual precipitation of the AUT, and the AFS stations, and the difference between those two and the SCl.

The largest differences are observed during the following intervals: 1938-1940, 1942-1944, 1946, 1950. On the contrary, towards the end of the period examined (1968-1973), we observe a similarity between the stations of AUT and SCI, and a difference between those two and the AFS. This may be attributed - with certain reservatious - to the increase of industrial units in the area of SCI.

From the time series of each month and each season, for the three stations, we observe again the similarity between the AUT and AFS stations, and their difference from the SCI.

GRAPH V

TIME SERIES (o—o) 3 YEAR RUNNING MEAN (o--o) AND TRENDS (—) OF ANNUAL VALUES OF PRECIPITATION IN THE MAJOR AREA OF THESSALONIKI



VI. Precipitation in the major Area of Thessaloniki.

The area examined herein consists of a strip of land of varying width (2-5 km), sheltered from the north by the low hills of Varna, Redziki, Asvestohorion (elev. 400-500 m) and Mt Chortiates (elev. 1201 m), and bound to the south by the coasts of the inner Thermaikos Gulf, like an ark curving southwards.

This strip of land borders to the west upon the Axios river valley, and to the east upon the valley of Anthemous; the three met. stations examined are allineated almost symmetrically along the longitudinal axis of the strip, following the curving of the coast.

Of these three stations, only that of AUT functions within an inhabited area (a little to the east of the city center of Thessaloniki), while the other two are situated outside of inhabited areas defining the limits of the above strip (W - Axios valley - SCI station / E - Anthemous valley - AFS station).

This arrangement of the station, as well as the morphology of the examined area will allow us in the conclusions (always taking into account the differences and similarities mentioned in former chapters) to correlate the distribution of precipitation with the ground relief, the city (as an urban unit) and the location of each station.

Conclusions

As an average for the 1935-1973 period, the annual variation of precipitation in the area examined, has a triple oscillation, with a primary maximum in December (AUT, AFS) or November (SCI), and a primary minimum in August (for every station).

In a previous study[5] we had come to the conclusion that the mean annual variation of precipitation in the AUT station has a double oscillation (with the same as above primary maximum and minimum). This apparent contradiction is explained in paragraph I of the present study.

The occurence of the primary maximum and minimum, during the cold and the warm season respectively, is explained by the cyclonic activity in the area examined, during the cold season and its absence during the warm one, concurred in the second case by the comparatively low sea temperatures, against those of the surrounding lands.

In this paper, we consider as our main contribution, the conclusions drawn - on a microclimatic scale - as to the distribution of precipitation in the area examined and the effect of the ground relief, the city, and the location of each station upon this parameter:

We observe a general similarity between the two stations of AUT and AFS as to the distribution of precipitation chronologically as well as in the amount of precipitation, while the station of SCI differs, as for instance:

(i) The absolute maximum monthly precipitation has been recorded in both the AUT and AFS stations in December 1935, while in SCI it was recorded in June 1970.

(ii) Except for the months of June and September, in all the remaining months the correlation coefficients between monthly values of the AUT and AFS stations are higher than those between these two stations and the SCI. The same applies for the correlation coefficients of annual precipitation.

(iii) The primary maximum in the mean annual variation of precipitation occurs in the AUT and AFS stations in the month of December, while in SCI it occurs in November.

The above and other similarities or dissimilarities noticed in former chapters, are explained as follows:

a) The distance between the AUT and the AFS stations is about 7 km, while between the AUT and the SCI stations it is almost 13,5 km.

b) The distance of both the AUT and the AFS stations from the sea, is less than 1,5 km, while that of the SCI is almost 6,5 km.

Paragraphs (a) and (b) partly explain the similar precipitation regime of the first two stations and their difference from the SCI; still the main explanation is given by the evaluation of the ground relief, as below:

c) The SCI station has an open horizon especially to the north, while the other two stations are sheltered from the north by the low hills of Varna - Redjiki - Asvestohorion (elev. 400-500 m) and from the north-east by Mt Chortiates (elev. 1201 m).

Thus the SCI station experiences more strongly and frequently the effect of the cold-dry cloud-dispersing wind Vardaris, a north-sector wind that is less felt by the other two stations.

d) The AUT and AFS stations are situated on the inner side of the basin formed around the inner Thermaikos Gulf. As a consequence we have quite often above these two stations convective clouds(orographic or due to relief), in a certain measure increasing the rainfall, in which the SCI does not always participate.

This fact is illustrated by the small correlation coefficient between monthly values of the first two stations and those of the last one in the months of June and July.

As a matter of fact the effect of the ground relief and the location of each station, becomes more pronounced during the warm season, since then we do not have rainfalls of general characters in extensive areas, while the few intense ones, mainly of orographic character, increase the amount of rainfall wherever the process of orographic rains is active, that is in the AUT and AFS stations.

e) The effect of the ground relief formation (AUT and AFS stations upon the course of rising air masses of south to southwest sector) on one hand, and the effect of open horizons (SCl) on the other, favor the arrival of moist air masses from the sea more in the first two stations, and consequently cloudiness and then rainfall over them (with the concurrence of other meteorological conditions too).

f) The existence of the city, contributes to the increase of rainfall mainly over the AUT station, but also over the nearest station of AFS.

The effect of the city is explained, by the friction of moving air-masses (mainly southerly ones) upon the rough surface of the city buildings, their deceleration due to friction, and then their, couvection assisted by the general relief, as already mentioned.

Another contribution of the city to the increase of rainfall, are the numerous sources of condensation nuclei (exhaust gases from traffic, residential central heating, industries, ship riding at anchor in the harbor etc.); all those facilitate conditions for condensation, which together with the above mentioned convection (due to friction), result in the formation of clouds and then rain.

This contribution of the city to the increase of rainfall is mentioned by other scientists too *Landsberg*[7]; however it has not been absolutely established, because of the comparatively short observational period examined by each research worker.

Finally, from the time series of annual precipitation in the three stations examined, we observe a decreasing trend from 1935 till 1954, and from then on an increasing trend, that seems faster in the AUT station.

We should mention particularly for this last station, that the year 1954 marks the begining of a high building season in the city of Thessaloniki which combined with the facts mentioned in paragraph (f) of this chapter, should explain the faster increase (as compared with other sites) of rainfall in the AUT station after the year 1954.

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MATERIAL

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ΠΕΡΙΛΗΨΙΣ

ΕΠΙ ΤΗΣ ΚΑΤΑΝΟΜΗΣ ΤΗΣ ΒΡΟΧΗΣ ΕΙΣ ΤΗΝ ΠΕΡΙΟΧΗΝ ΜΕΙΖΟΝΟΣ ΘΕΣΣΑΛΟΝΙΚΗΣ

Ὑπὸ

ΒΛΑΔΙΜΗΡΟΝ ΕΜΜ. ΑΓΓΟΥΡΙΔΑΚΗ

Ἐκ τῆς μελέτης τῶν μηνιαίων καὶ ἐτησίων βροχομετρικῶν ὑψῶν τῆς περιόδου 1935-1973 εἰς τοὺς ΜΣ/ΑΠΘ, ΑΓΣ καὶ ΙΒΣ, προκύπτει ὅτι οἱ ΜΣ/ΑΠΘ καὶ ΑΓΣ ἐμφανίζουν σαφεῖς ὁμοιότητας μεταξύ των, ἐνῶ ὁ ΜΣ/ΙΒΣ διαφέρει τούτων, καθ' ὅσον ἀφορᾶ εἰς τὴν βροχομετρικὴν συμπεριφορὰ αὐτῶν.

Τοῦτο αἰτιολογεῖται ἐκ τῆς ἐπιδράσεως ἐπὶ τῆς βροχῆς, τοῦ ἀναγλύφου καὶ τῆς πόλεως.

Τὰ κύρια μέγιστον καὶ ἐλάχιστον τῆς βροχοπτώσεως - κατὰ μέσον ὅρον τῆς περιόδου - εἰς τὰς τρεῖς θέσεις, κατὰ τὴν χειμερινὴν καὶ θερινὴν ἀντιστοίχως περίοδον, ὀφείλονται εἰς τὴν δραστηριότητα τοῦ μεσογειακοῦ μετώπου κατὰ τὴν χειμερινὴν περίοδον, καὶ εἰς τὴν ἔλλειψιν αὐτῆς κατὰ τὴν θερινὴν τοιαύτην, συνεπικουρουμένης τῆς τελευταίας καὶ ἐκ τῶν χαμηλῶν θερμοκρασιῶν τῆς θαλάσσης ἔναντι αὐτῶν τῶν περιβαλλουσῶν ξηρῶν κατὰ τὴν θερινὴν περίοδον.

Ἐκ τῶν μέσων μηνιαίων βροχομετρικῶν ὑψῶν, τῶν βροχομετρικῶν συντελεστῶν καὶ τοῦ ἐποχικοῦ δείκτου, εἰς τὰς τρεῖς θέσεις διὰ τὴν ὡς ἄνω χρονικὴν περίοδον, συνάγεται ἡ κατανομὴ τῆς βροχῆς κατὰ τὴν διάρκειαν τοῦ ἔτους, εἰς τὴν μελετωμένην περιοχήν.

Τέλος, δίδεται ἡ μαθηματικὴ ἔκφρασις τῆς γενικῆς τάσεως τῶν ἐτησίων βροχομετρικῶν ὑψῶν εἰς τὰς τρεῖς θέσεις, ἥτις ἐμφανίζει ἀρχικῶς μίαν πτῶσιν καὶ ἐν συνεχείᾳ μίαν αὔξησιν, ἥτις εἶναι ταχυτέρα προκειμένου περὶ τοῦ ΜΣ/ΑΠΘ, συμπίπτουσα ἐν προκειμένῳ, μὲ τὴν αὔξησιν οἰκοδομικοῦ ὀργασμοῦ εἰς τὴν πόλιν τῆς Θεσσαλονίκης.