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PRECIPITABLE WATER AND PRECIPITATION

by

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Abstract: *Hygrometric conditions of lower and middle troposphere at the Athens area (Hellinikon Airport, $\varphi = 37^0$ 54′ N, $\lambda = 23^0$ 44′ E, h = 15m) are examined and also their relation with precipitation.*

INTRODUCTION

In this paper we study the hygrometric conditions of lower and middle troposphere and especially precipitable water (total and in various thicknesses) and also its climatological relationship with precipitation. We also examine the dynamic causes that determine the above relationships and by statistical processes we give graphs, values and mathematical expressions that contribute to the prediction of precipitation.

Relative or similar studies have been effected by: Bannon-Steele[2], Barnes[3], Benwell[4], Berkofski[5 6], Bloutsos[7], Bolsegna[8], Brasefield[10], Cooney[12], Crisi[13], Gutnick-Salmela[14], Helinwell-McKenzie-Kelley[15], Hutcherson[16], Hutchings[17], Karalis[18], Klein[19], Luis-McQueen[20], Lowry[21], Lowry-Glahn[22], Mastenbrook[24], Möller[25], Peixoto[26], Peixoto-Crisi[27], Peterson[29], Pullen[30], Raschke-Bandeen[31], Reber-Swope[32], Reitan[33 34], Repapis[35], Retalis-Papathomas-Zervos[36], Schwartz[37], Showalter[38], Sissenwine-Grantham-Salmela[39], Smith[40], Smith-Howell[41], Solot[42], Starr-Peixoto-Livadas[43], Swayne[44], Tomlinson[45], et al.

The geographical area covered by our study is that of the Attica basin and specifically the Hellinikon airport ($\varphi = 37^0$ 54′ N, $\lambda = 23^0$ 44′ E, h = 15 m) and the period examined is 1968 to 1974.

The hygrometric conditions of the atmosphere and particularly those of the troposphere, are directly related with the qualitative, and under certain conditions, the quantitative prediction of precipitation (regardless of the method followed) and is an important meteorological and climatological factor.

Another, equally important factor, whose combination with the previous one contributes to answer satisfactorily the probleme of rain, in the height of constant pressure surfaces (and its variation with time) and consequently the thickness of in-between layers.

The statistical and dynamic examination of the relation of the above factors, and their effects on the pluviometric regime of a place, consist the aims of the present study.

Because of the great number of values of the above factors, which enter the problem, rendering it more difficult, certain acceptances are necessary in order to facilitate the procedure.

One such acceptance, depending from (and ocassionally imposed by) the way in which informations on atmospheric conditions are obtained, is that, no matter what the hygrometric parameter used, this has a linear variation between two constant pressure surfaces. This acceptance results in a considerable simplification, especially in the calculating part of the problem; however the errors resulting from this are also considerable.

As a matter of fact, the afore mentioned scientists, in collecting their basic material, used only data of standard levels or levels whose pressure differences are integral multiples of a standard value (i.e. per 50 mbs) thus automatically accepting the above assumption.

We, at present, avoid as far as possible their acception, by using data not only from standard levels but also from all the significant ones mentioned in the information (R/S). In this way we could introduce into the problem as many actual; data values as possible instead of calculated ones.

Finally, we have chosen precipitable water as hygrometric parameter, for the following reasons:

— Its calculation is easy, uniform and exact.

— It can be calculated from easily obtained information (R/S) which constitute the basic material of this study.

— In each case it represents, as far as possible, the prevailing atmospheric conditions.

— The acceptances necessarily introduced into the problem, do not affect this parameter considerably, so that the error resultant from these acceptances does not finally exceed the order of observational errors.

Geographic Survey and Ground Relief of the Area Examined.

Attica stands at the SE end of Sterea Hellas (Roumeli) and is separated from it by the mountains Kitheron (elevation 1409 m) and Parnis (elev. 1413 m). From this dividing helt, extending to some 40 km, Attica like a triangular tongue of land advances some 80 km southwards, ending in cape Sounion, between the sea areas of Saronikos (SW) and Evoikos (E) Gulfs.

MAP I. ATTICA BASIN

This is generally a mountainous area between whose mountain masses lie four plains, the principal one being that of Athens, the area examined herein, extending to some 220 km^2; this is the «plain» of ancient Greeks, today's «basin», where the urban complex of Greater Athens is limited from N W to SE by N by the mountains Aegaleo

(453 m), Parnis (1413 m), Pendeli (1107 m) and Hymettus (1026 m). Thus the basin is separated from Sterea Hellas by a «wall» rising to the N some 1000 m high, while to the S it ends at the sea area of Saronikos Gulf.

A chain of low hills divides the basin in two unequal sections from N to S; these hills are the Tourkovounia, Lykabettus, Strefi, Agoraeos Kolonos, Arios Pagos, Akropolis, Hill of the Nymphes, Pnyka, Philopappos, Ardittos, and Hill of Sikelia.

Within the basin and almost along its longitudinal axis, from NW to SE, stand the three stations whose data are used in the present study (Map I) that is:

1. Hellinikon Airport: $\varphi = 37^{\circ}\ 54'$ N, $\lambda = 23^{\circ}\ 44'$ E, h = 15 m.

2. National Observatory of Athens: $\varphi = 37^{\circ}\ 58'$ N, $\lambda = 23^{\circ}\ 43'$ E, h = 104 m.

3. Nea Philadelphia: $\varphi = 38^{\circ}\ 03'$ N, $\lambda = 23^{\circ}\ 40'$ E, h = 138 m.

The R/S whose data we use herein, were effected at the Hellenikon Airport (Upper Air Station).

The distances between the above three stations are approximately;

— Nea Philadelphia - National Observatory of Athens: 8,5 km.

— National Observatory of Athens - Hellinikon Airport: 10 km.

Among these three stations, that of Hellinikon Airport is considerably affected by the nearby sea area of Saronikos Gulf, while the other two can be considered as inland stations, and because of their relatively high elevations, they register different rainfall amounts than the station of Hellinikon.

Material and Sources.

Our basic material has been taken from Daily Weather Bulletin[47] and Monthly Climatological Bulletin[48] of the Hellenic National Meteorological Service (E.M.Υ.). These have been completed with data taken from the files of the E.M.Υ. (Climatological Section and Upper Air Station) and the National Observatory of Athens[46] as well.

The R/S of 00:00 and 12:00 GMT have been related with precipitation recorded during the twelve hours of 18-06 G.M.T. and 06-18 GMT respectively for each day. For the specific site of Hellinikon Airport, rainfall data from its own station have been used. However for the overall study of Attica basin, we have also used data of all three stations, that is Hellinikon Airport, Nea Philadelphia and National Observatory of Athens.

Since these three sites stand at quite a distance from each other, precipitation might be recorded in one station without been observed in either or both the other two. Because of this, and since an upper air sounding gives the atmospheric conditions aloft at quite a large range around the site where the release is effected, we defined as «twelve-hours with precipitation» at the Attica basin, the twelve hours when precipitation≥0.0 mm was recorded in at least one of the three stations, and as rainfall amount of these twelve hours the maxinum rainfall recorded in any of the three stations.

From the whole number of R/S effected at the Hellinikon Upper Air Sration at 00:00 and 12:00 GMT during the period 1968-74, we have chosen to use the ones giving temperature and humidity data up to the 500 mbs level or even higher, and we characterize the remaining R/S as incomplete, becasue «motor boating» occured in them or mechanical failure of the humidity element of the rahiosonde before reaching the 500 mb level height.

Process

By applying the method proposed by Solot[42] and the formula of Magnus and Tetens, we have drawn a program that was introduced in the UNIVAC 1106 computer of the Arisrotelian University, and yielded the following data:

— Specific humidity : q (gr/kgr) for each thickness between two consecutive surfaces recorded by the R/S.

— Precipitable water: Pw (mm) for each thickness as above.

— For every month of the period examined, the daily values of total precipitable water and the amount of total precipitable water for the month in question, for the R/S of 00:00 and 12:00 GMT separately.

Concerning the use of Magnus and Tetens formula $E = E_0 . 10^{\frac{at}{b+t}}$ we give the following explanations:

As it is known, in the above relation, constants a and b acquire different values when air temperature changes from positive to negative values.

We in this case have taken into account the change of a and b only as long as air temperature reached values $<-10^0$ C. And this, on one hand because as it is known atmospheric water stays in the liquid phase even at temperatures much below 0^0 C (Perrie[28], Borovikov et al.[8], Bayers[10], Mason[22]), and also because many years of research work conducted at the Mt Olympus Scientific Research Center (elev. 2817 m) gave us the experience of liquid phase persisting at temperatures from —5° to —10° C.

Precipitable Water and Precipitation

A. Total Precipitable Water.

According to what we mentioned above, we have divided the cases examined into the following categories:

I. 00:00 GMT

1. Sum total of dry and rainy cases (D + R):	1875	cases.
2. » » » » cases (D):	1470	»
3. Sum total of rainy cases (R) :	405	»

II. 12:00 GMT

1. Sum total of dry and rainy cases (D + R):	1216	cases.
2. » » » dry cases (D):	985	»
3. » » » rainy cases (R):	231	»

The mean values of the period-monthly and annual ones-of the following parameters: total precipitable water, absolute maxima and absolute minima, standard deviation and variability for the above categories of observations, are given in the adjoined Tables Ia, Ib, Ic, and their annual variation is given in Graph I. In these same as above Tables we also give the differences of mean precipitable water for each month at 00:00 and 12:00 GMT; while Table Ic (last column) also contains differences of precipitable water between rainy and dry cases.

We have found that:

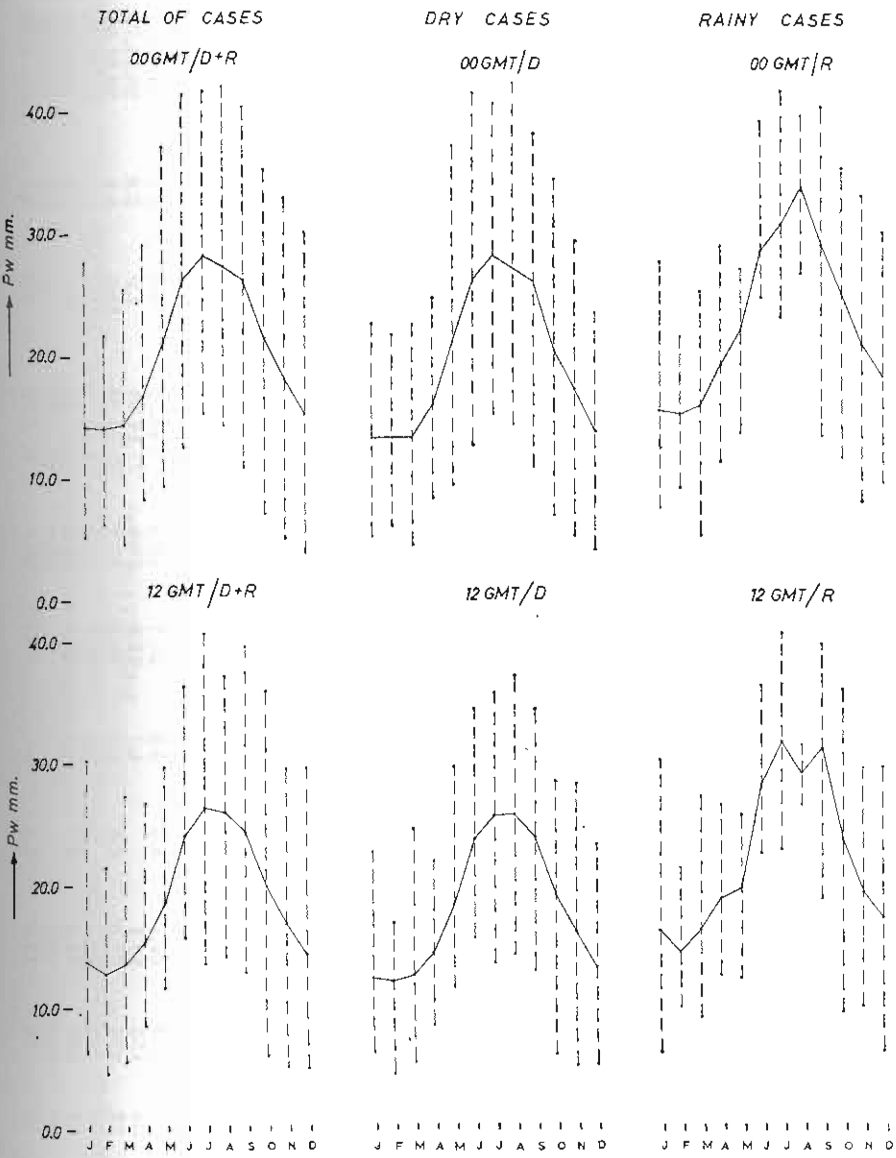
— The mean total precipitable water (for all the dry and rainy cases) has a single annual fluctuation, with a maximum in the warm and a minimum in the cold season.

— In dry cases and for every month, the mean total precipitable water of 00:00 GMT always has higher values than that of 12:00 GMT. The same applies in rainy cases too, with the exception of January, March, July and September.

— For every month the mean total precipitable water of rainy cases has always higher values than the corresponding values of dry cases, at the 00:00 GMT observation and the 12:00 GMT as well.

— The absolute maximum of total precipitable water has been recorded during the warm season and the absolute minimum during the cold one.

The above together with conclusions of the following chapter, will be fully discussed and analyzed at the end of this work.



GRAPH I

Annual mean variation of total precipitable water Athens (Hell.): 1968-74

TABLE Ia

ATHENS (HELLINIKON): 1968-74

Daily mean total precipitable water ($\overline{Pw}$ mm)— Standard deviations ($\pm \sigma$ mm)— Variability (V %)— Maxima and Minima (mm)

TOTAL OF CASES (D + R)

MONTH	GMT	N	$\overline{Pw}$ mm	$\overline{\Delta Pw}$ 00 ≗ 12 mm	$\pm \sigma$	V %	MAXIMUM Pw mm	MAXIMUM DATE	MAXIMUM PREC. mm	MININUM Pw mm	MININUM DATE	MININUM PREC. mm
J	00	168	14.2		4.2	29.7	27.8	8. 1.70	5.4	5.3	17. 1.74	—
	12	81	13.9	0.3	4.7	33.8	30.1	7. 1.70	6.0	6.5	14. 1.73	0.3
F	00	144	14.1		3.4	23.8	21.8	25. 2.72	—	6.2	7. 2.72	—
	12	72	12.9	1.2	3.2	24.8	21.5	28. 3.69	0.0	4.7	18. 2.70	—
M	00	153	14.4		3.7	25.6	25.4	15. 3.69	7.4	4.6	14. 3.71	—
	12	80	13.8	0.6	4.0	29.3	27.3	29. 3.70	0.0	5.6	2. 3.73	—
A	00	165	16.8		4.2	24.7	29.0	11. 4.70	0.0	8.5	5. 4.70	—
	12	95	15.5	1.3	4.2	36.5	26.7	30. 4.70	0.3	8.7	20. 4.74	—
M	00	162	21.3		4.7	22.2	37.2	22. 5.69	—	9.5	19. 5.72	—
	12	101	18.7	2.6	4.0	21.6	29.7	13. 5.73	—	11.8	6. 5.70	—
J	00	157	26.3		5.1	19.4	41.5	11. 6.70	—	12.6	13. 6.71	—
	12	114	24.2	2.1	4.1	15.2	36.4	16. 6.74	0.0	15.8	19. 6.72	—
J	00	132	28.4		5.2	18.1	41.7	12. 7.73	0.1	15.4	12. 7.69	—
	12	95	26.6	1.8	5.7	21.3	40.8	8. 7.72	0.0	13.7	27. 7.74	—
A	00	102	27.5		5.2	19.0	42.3	11. 8.74	—	14.5	23. 8.71	—
	12	89	26.1	1.4	4.6	17.7	37.1	27. 8.73	—	14.4	1. 8.74	—
S	00	164	26.4		6.2	23.4	40.4	24. 9.68	0.3	11.0	27. 9.69	—
	12	99	24.4	2.0	4.2	17.3	39.8	1. 9.70	3.5	13.1	28. 9.74	—
O	00	189	21.6		5.8	26.7	35.4	14.10.72	1.2	7.1	24.10.72	—
	12	129	20.1	1.5	5.0	25.1	36.0	2.10.70	10.0	6.3	23.10.72	—
N	00	156	18.1		4.7	25.9	33.1	27.11.69	1.3	5.3	28.11.72	—
	12	128	17.0	1.1	4.9	28.6	29.7	27.11.69	13.6	5.4	29.11.69	—
D	00	183	15.3		4.4	28.6	30.3	2.12.69	0.2	4.2	17.12.73	—
	12	133	14.6	0.7	3.8	26.2	29.7	2.12.69	0.4	5.4	16.12.73	—
YEAR	00	1875	20.4		—	—	42.3	11. 8.74	—	4.2	17.12.73	—
	12	1216	19.0	1.4	—	—	40.8	8. 7.72	0.0	4.7	18. 2.70	—

TABLE Ib

Athens (Hellinikon Airport) 1968 - 1974

Daily mean total precipitable water ($\overline{Pw}$ mm)—Standard deviations ($\pm \sigma$ mm)—Variability (V %)—Maxima and Minima

DRY CASES (D)

MONTH	GMT	N	$\overline{Pw}$ mm	$\overline{\Delta Pw}$ 00-12 (mm)	±σ	V %	MAXIMUM Pw mm	MAXIMUM DATE	MAXIMUM PREC. mm	MINIMUM Pw mm	MINIMUM DATE	MINIMUM PREC. mm
J	00	100	13.3		3.9	29.2	22.8	16. 1.70	—	5.3	17. 1.74	—
	12	53	12.6	0.7	3.5	27.9	22.8	5. 1.70	—	6.5	15. 1.73	—
F	00	87	13.4		3.5	26.5	21.8	25. 2.72	—	6.2	7. 2.72	—
	12	52	12.2	1.2	3.0	24.6	17.0	7. 2.74	—	4.7	18. 2.70	—
M	00	93	13.3		4.0	29.2	22.7	29. 3.70	—	4.6	14. 3.71	—
	12	58	12.7	0.6	3.6	28.7	24.6	14. 3.70	—	5.6	2. 3.73	—
A	00	129	16.0		4.3	26.6	28.1	10. 4.72	—	8.5	5. 4.70	—
	12	76	14.6	1.4	3.9	26.6	22.0	11. 4.72	—	8.7	20. 4.74	—
M	00	146	21.2		4.8	22.5	37.2	22. 5.69	—	9.5	19. 5.72	—
	12	88	18.5	2.7	3.7	20.0	29.7	3. 5.73	—	11.8	6. 5.70	—
J	00	146	26.1		5.2	19.9	41.5	11. 6.70	—	12.6	13. 6.71	—
	12	109	24.0	2.1	4.0	16.8	34.6	24. 6.73	—	15.8	19. 6.72	—
J	00	123	28.2		5.2	18.4	40.8	19. 7.74	—	15.4	12. 7.69	—
	12	84	25.9	2.3	5.3	20.6	35.6	18. 7.74	—	13.7	27. 7.74	—
A	00	97	27.2		5.3	19.5	47.3	11. 8.74	—	14.5	23. 8.71	—
	12	84	25.9	1.3	4.7	18.3	37.1	27. 8.73	—	14.4	1. 8.74	—
S	00	147	26.0		5.7	21.6	38.2	2. 9.71	—	11.0	27. 9.69	—
	12	82	23.0	3.0	5.5	23.9	34.4	6. 9.70	—	13.1	28. 9.74	—
O	00	149	20.6		5.4	26.0	34.5	15.10.71	—	7.1	24.10.72	—
	12	104	19.2	1.4	4.2	22.1	28.5	14.10.69	—	6.3	23.10.72	—
N	00	124	17.4		4.5	25.9	29.3	26.11.69	—	5.3	28.11.72	—
	12	102	16.3	1.1	4.5	27.3	28.4	26.11.69	—	5.4	29.11.69	—
D	00	129	13.9		3.4	24.5	23.6	28.12.68	—	4.2	17.12.73	—
	12	92	13.3	0.6	3.4	25.2	23.4	2.12.70	—	5.4	16.12.73	—
YEAR	00	1470	19.7		—	—	42.3	11. 8.74	—	4.2	17.12.73	—
	12	985	18.2	1.5	—	—	37.1	27. 8.73	—	4.7	18. 2.70	—

TABLE Ic

Athens (Hellinikon Airport) 1968-1974

Daily mean total precipitation water ($\overline{Pw}$ mm) - Standard deviations ($\pm\ \sigma$ mm)— Variability (V%) - Maxima and Minima (mm)

RAINY CASES (R)

MONTH	GMT	N	$\overline{Pw}$ mm	$\overline{\Delta Pw}$ 00-12 mm	$\pm\sigma$	V %	MAXIMUM Pw mm	MAXIMUM DATE	MAXIMUM PREC. mm	MINIMUM Pw mm	MINIMUM DATE	MINIMUM PREC. mm	PREC. MEAN mm DATE/ MONTH	$\overline{\Delta Pw}$ D-R mm
J	00	68	15.6		4.5	28.6	27.8	8. 1.70	5.4	7.8	16. 1.74	0.0	1.8/20.5	2.3
	12	28	16.4	—0.8	6.1	37.0	30.1	7. 1.70	6.0	6.4	14. 1.73	0.3	1.6/14.9	3.8
F	00	57	15.3		3.4	22.3	21.6	24. 2.69	0.1	9.5	27. 2.71	4.4	2.1/19.8	2.0
	12	20	14.7	0.6	4.1	27.7	21.5	28. 3.69	0.0	10.2	17. 2.70	0.0	4.6/30.6	2.4
M	00	60	16.0		3.8	23.4	25.4	15. 3.69	7.4	5.4	2. 3.73	0.5	3.3/32.6	2.7
	12	22	16.6	—0.6	4.4	26.6	27.3	29. 3.70	0.0	9.4	5. 3.70	0.2	3.0/16.4	3.9
A	00	36	19.6		4.4	22.4	29.0	11. 4.70	0.0	11.5	11. 4.70	0.0	1.7/10.0	3.6
	12	19	19.0	0.6	3.6	19.0	26.7	30. 4.74	0.3	12.9	16. 4.70	0.0	0.4/ 1.8	4.5
M	00	16	22.3		4.1	18.6	27.1	19. 5.74	0.0	13.9	4. 5.70	3.7	0.9/ 2.9	1.1
	12	13	19.9	2.4	3.7	18.3	25.8	26. 5.73	0.0	12.6	10. 5.74	0.2	2.9/ 9.3	1.5
J	00	11	28.8		3.8	13.1	39.3	13. 6.69	0.0	25.0	28. 6.69	0.0	0.5/ 1.1	2.7
	12	5	28.1	0.7	4.3	15.4	36.4	16. 6.74	0.0	22.8	1. 6.70	0.0	2.4/ 3.9	4.1
J	00	9	31.0		5.4	17.5	41.7	12. 7.73	0.1	23.3	5. 7.72	0.2	0.6/ 1.1	2.7
	12	11	31.9	—0.9	5.7	17.9	40.8	8. 7.72	0.0	23.0	13. 7.69	0.0	4.7/10.3	6.0
A	00	5	34.0		4.3	12.7	39.8	1. 8.73	0.2	26.9	27. 8.72	1.4	12.0/20.0	6.9
	12	5	29.4	4.6	3.9	13.2	31.6	26. 8.72	0.0	26.9	30. 8.74	2.9	4.5/ 7.4	3.5
S	00	17	29.2		6.8	23.3	40.4	24. 9.68	0.3	13.6	29. 9.70	0.2	0.4/ 1.0	3.2
	12	17	31.3	—2.1	4.3	13.8	39.8	1. 9.70	3.5	19.1	9. 9.73	0.8	3.1/10.6	8.3
O	00	40	25.3		5.1	20.0	35.4	14. 0.72	1.2	12.6	7.10.71	2.6	3.0/17.2	4.7
	12	25	23.8	1.5	5.1	21.4	36.0	2.10.70	10.0	9.7	24.10.70	0.0	3.9/19.3	4.7
N	00	32	21.1		4.8	23.0	33.1	27.11.69	1.3	8.1	30.11.73	1.1	5.1/23.4	3.7
	12	12	19.6	1.5	5.8	29.4	29.7	27.11.69	13.6	10.2	22.11.73	0.7	1.9/10.1	3.3
D	00	54	18.5		4.5	24.1	30.3	2.12.69	0.2	9.7	5.12.70	1.1	3.7/28.5	4.6
	12	12	17.4	1.1	3.5	19.8	29.7	2.12.69	0.4	6.6	7.12.74	0.1	3.2/26.2	4.1
YEAR	00	405	23.1		—	—	41.7	12. 7.73	0.1	5.4	2. 3.73	0.5	2.7/89.5	3.3
	12	231	22.4	0.7	—	—	40.8	8. 7.72	0.0	6.5	14. 1.73	0.3	2.9/55.2	4.2

B. Variation of precipitable water with height.

The variation of precipitable water with height for every atmospheric thickness between the levels: surface - 1000 mbs, 1000-850 mbs, 850-700 mbs, 700-500 mbs, 500-400 mbs., and 400—$<$400 mbs, as an average for the period and the area examined are given in the adjoined Tables: IIa, IIb, IIc, and their mean annual variation in Graphs IIa, IIb. Conclusions drawn from these will be discussed at the end of this study.

The dominant characteristic of the above Tables is that, in all cases the values of 00:00 GMT are higher than the corresponding values of 12:00 GMT, and the values of rainy cases are higher than the corresponding values of dry ones.

From these same Tables it also results that almost 90 % of the total precipitable water is contained in the atmospheric thickness lying between the 1000-500 mb isobaric surfaces.

Finally Graphs IIIa, IIIb, IIIc, IIId, where we have traced isopleths of precipitable water at 00:00 and 12:00 GMT, for both rainy and dry cases, clearly illustrate the distribution of precipitable water, with height and per month, in the lower and middle troposphere. We should mention that isopleths of precipitable water in the above Graphs, have been traced per 2 mm of precipitable water. Yet, in view of the small Pw values in the upper and lower thicknesses of the space examined, we have added curves of 0,5 mm and 0,1 mm Pw.

We believe that these graphs are of particular interest for climatological purposes, since they give the hygrometric conditions of the atmosphere throughout the year from the climatological point of view.

C. Saturation Thickness and Precipitation.

From what we have already exposed, is clearly evident the existence of a relation between precipitable water, the height of constant pressure surfaces and precipitation in a certain place.

The quest of the degree of this relation and its evaluation as a method for the prediction of precipitation in a certain place, is the object of this chapter but also one of the main objectives of this study.

According to the notion of saturation thickness-introduced by Swayne[44] in 1956— this can be considered as the minimum thickness at which water will stay in the gas state.

Besides, Lowry[20] (1972) described and applied a method for gra-

TABLE IIa

Mean values of precipitable water (mm) per thickness (Hellinikon: 1968-74)
A. Total of cases (D + R)

MONTH	Sur-1000 mbs	1000-850 mbs	850-700 mbs	700-500 mbs	500-400 mbs	<400 mbs	TOTAL	sur.-1000 mbs	1000-850 mbs	850-700 mbs	700-500 mbs	500-400 mbs	<400 mbs	TOTAL
	0000 GMT							1200 MGT						
J	1.0	7.0	4.1	2.0	0.3	0.1	14.2	1.0	6.8	3.8	2.1	0.3	0.1	13.9
F	0.9	7.1	3.9	2.1	0.3	0.1	14.1	0.8	6.6	3.5	1.8	0.2	0.04	12.9
M	0.9	6.9	4.1	2.3	0.3	0.1	14.4	0.9	6.8	3.7	2.2	0.3	0.1	13.8
A	0.9	8.0	4.7	2.8	0.4	0.1	16.8	0.9	7.4	4.2	2.5	0.4	0.1	15.5
M	1.1	10.0	6.3	3.4	0.5	0.1	21.3	1.2	8.9	5.3	2.8	0.4	0.1	18.7
J	1.2	12.3	7.7	4.3	0.7	0.2	26.3	1.3	11.6	6.9	3.8	0.5	0.1	24.2
J	1.2	13.4	8.5	4.6	0.7	0.2	28.4	1.3	12.9	7.7	4.0	0.6	0.2	26.6
A	1.2	13.0	8.2	4.3	0.7	0.2	27.5	1.4	12.9	7.4	3.8	0.6	0.2	26.1
S	1.4	12.5	7.5	4.2	0.7	0.2	26.4	1.5	11.9	6.5	3.9	0.6	0.2	24.4
O	1.3	10.1	5.9	3.6	0.6	0.1	21.6	1.4	9.6	5.4	3.2	0.5	0.1	20.1
N	1.3	9.0	4.7	2.7	0.4	0.1	18.1	1.3	8.4	4.5	2.4	0.4	0.1	17.0
D	1.1	7.3	4.2	2.4	0.3	0.1	15.3	1.1	7.1	3.9	2.2	0.3	0.1	14.6
YEAR	1.1	9.7	5.8	3.2	0.5	0.1	20.4	1.2	9.2	5.3	2.9	0.4	0.1	19.0

TABLE IIb

Mean values of precipitable water (mm) per thickness (Hellinikon: 1968-74)

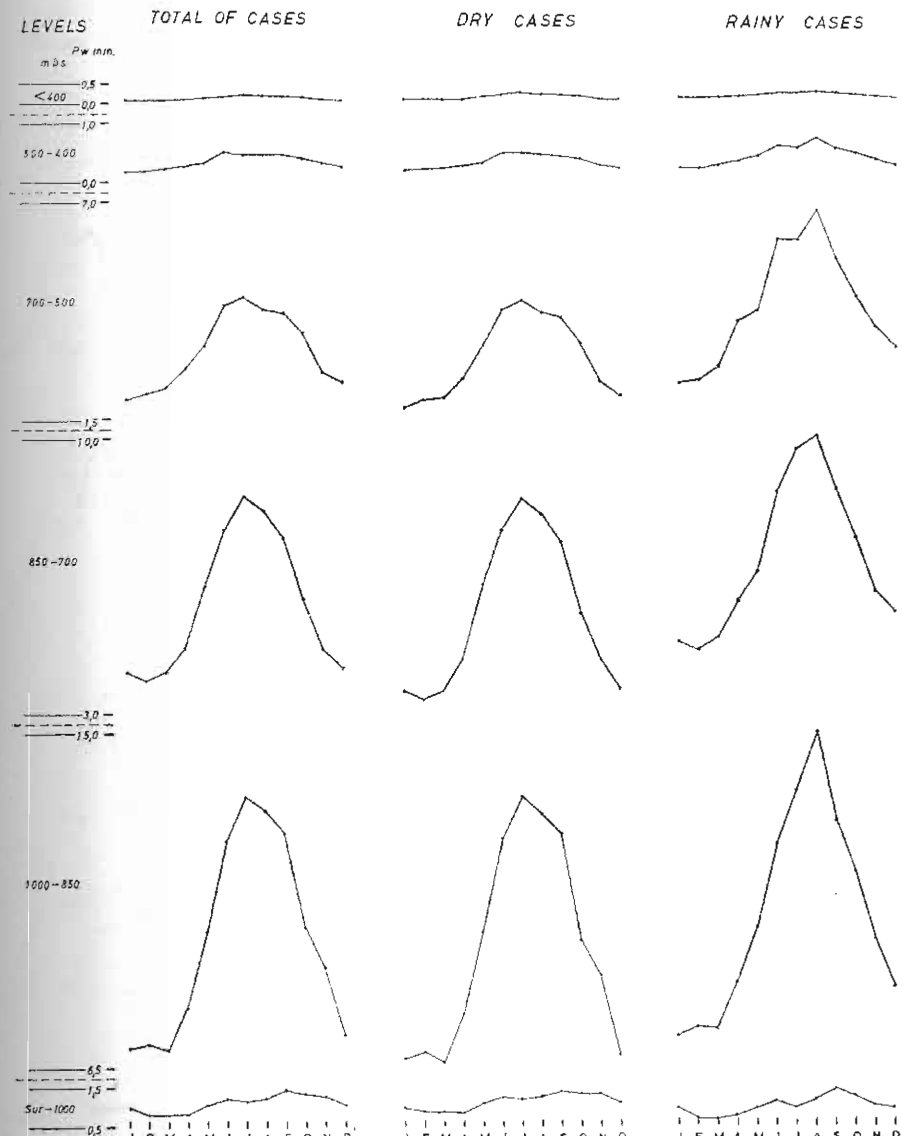
B. Total of Dry cases (D)

MONTH	Sur. -1000 mbs	1000-850 mbs	850-700 mbs 0000GMT	700-500 mbs	500-400 mbs	<400 mbs	TOTAL	sur.-1000 mbs	1000-850 mbs	850-700 mbs 1200 GMT	700-500 mbs	500-400 mbs	<400 mbs	TOTAL
J	1.0	6.7	3.6	1.7	0.3	0.1	13.3	1.0	6.3	3.3	1.7	0.2	0.1	12.6
F	0.9	6.9	3.4	1.9	0.3	0.1	13.4	0.9	6.3	3.2	1.7	0.2	0.1	12.2
M	0.9	6.6	3.6	2.0	0.3	0.1	13.3	0.9	6.3	3.2	2.0	0.3	0.1	12.7
A	0.9	7.9	4.4	2.5	0.4	0.1	16.0	1.0	7.2	3.9	2.2	0.3	0.1	14.6
M	1.1	10.0	6.2	3.3	0.5	0.1	21.2	1.2	8.8	5.2	2.8	0.4	0.1	18.5
J	1.2	12.3	7.6	4.2	0.7	0.2	26.1	1.3	11.6	6.8	3.7	0.5	0.1	24.0
J	1.2	13.4	8.4	4.5	0.7	0.2	28.2	1.3	12.7	7.5	3.7	0.6	0.2	25.9
A	1.2	12.9	8.1	4.2	0.7	0.2	27.2	1.4	12.9	7.4	3.6	0.6	0.2	25.9
S	1.4	12.5	7.4	4.0	0.6	0.2	26.0	1.5	11.5	6.0	3.4	0.5	0.2	23.0
O	1.3	9.7	5.5	3.4	0.5	0.1	20.6	1.4	9.4	5.0	3.9	0.5	0.1	19.2
N	1.4	8.8	4.3	2.4	0.4	0.1	17.4	1.3	8.1	4.2	2.3	0.4	0.1	16.3
D	1.1	6.8	3.6	2.1	0.3	0.1	13.9	1.1	6.5	3.4	2.0	0.3	0.1	13.3
YEAR	1.1	9.5	5.5	3.0	0.5	0.1	19.7	1.2	9.0	4.9	2.7	0.4	0.1	18.2

TABLE IIc

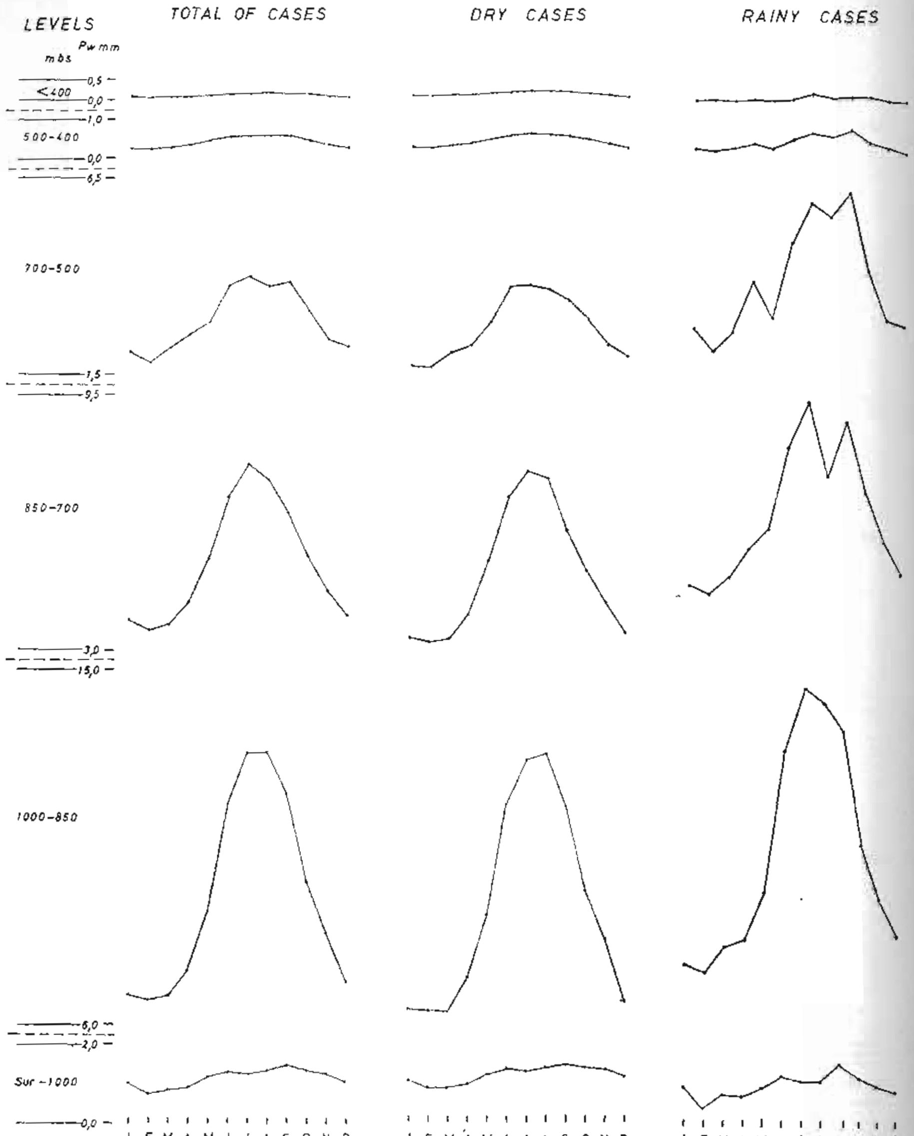
Mean values of precipitable water (mm) per thickness (Hellinikon: 1968-74)
C. Total of rainy cases (R)

MONTH	Sur. -1000 mbs	1000-850 mbs	850-700 mbs	700-500 mbs	500-400 mbs	<400 mbs	TOTAL	sur .-1000 mbs	1000-850 mbs	850-700 mbs	700-500 mbs	500-400 mbs	<400 mbs	TOTAL
			0000 GMT							1200 GMT				
J	0.9	7.3	4.8	2.3	0.3	0.1	15.6	1.0	7.6	4.7	2.8	0.3	0.1	16.4
F	0.7	7.5	4.6	2.4	0.3	0.1	15.3	0.5	7.3	4.5	2.2	0.3	0.1	14.7
M	0.7	7.4	4.9	2.7	0.3	0.1	16.1	0.8	8.0	4.9	2.7	0.3	0.04	16.7
A	0.7	8.6	5.8	3.9	0.5	0.1	19.6	0.7	8.2	5.6	4.0	0.5	0.1	19.0
M	0.9	10.0	6.6	4.1	0.5	0.1	22.3	0.9	9.5	6.2	3.0	0.3	0.1	19.9
J	1.1	12.2	8.6	6.0	0.8	0.2	28.8	1.2	13.0	8.3	4.9	0.6	0.1	28.1
J	1.0	13.5	9.7	5.9	0.8	0.2	31.0	1.1	14.6	9.5	6.0	0.8	0.2	31.9
A	1.2	15.0	10.0	6.7	1.0	0.2	31.0	1.1	14.3	7.6	5.6	0.6	0.1	29.4
S	1.4	12.8	8.6	5.5	0.7	0.2	29.2	1.6	13.6	9.0	6.2	0.8	0.2	31.3
O	1,3	11.4	7.4	4.5	0.6	0.1	25.3	1.2	10.7	7.1	4.3	0.5	0.1	23.8
N	1.0	9.8	6.1	3.7	0.5	0.1	21.1	1.0	9.3	5.9	3.0	0.4	0.1	19.6
D	0.9	8.5	5.5	3.2	0.3	0.1	18.5	0.9	8.4	5.1	2.8	0.3	0.1	17.4
YEAR	1.0	10.3	6.9	4.3	0.6	0.1	23.1	1.0	10.4	6.5	4.0	0.5	0.1	22.4



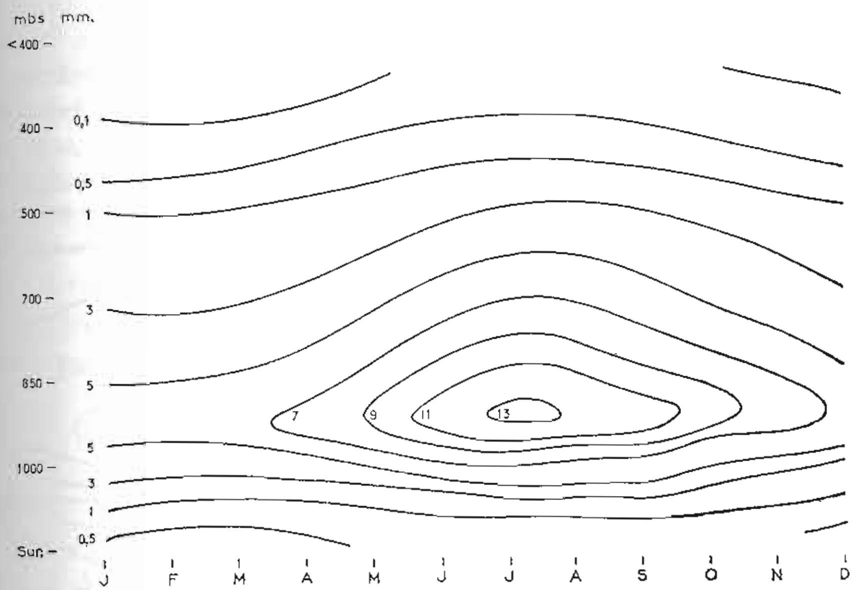
GRAPH IIa

Annual mean variation of precipilable waler (mm) per thickness
Athens (Hellinikon): 1968-74 : 0000 GMT

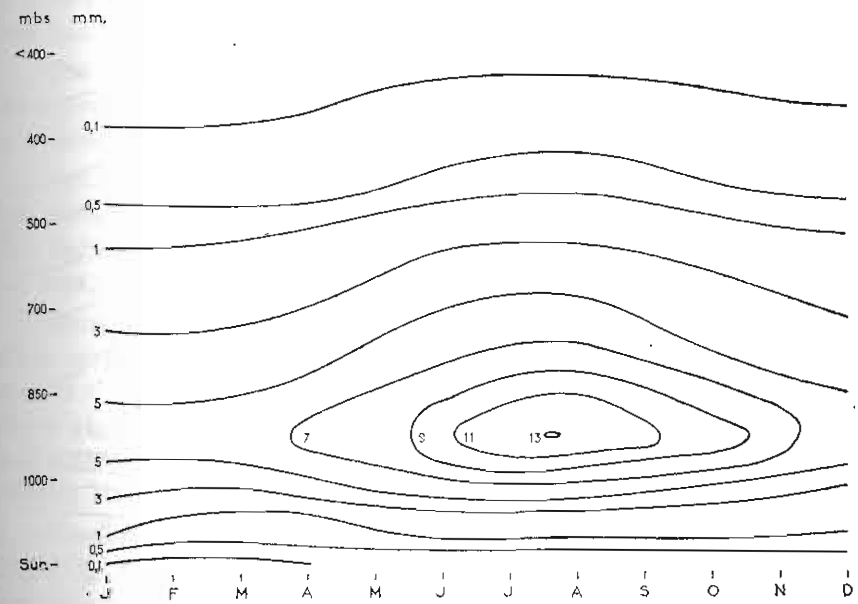


GRAPH IIb

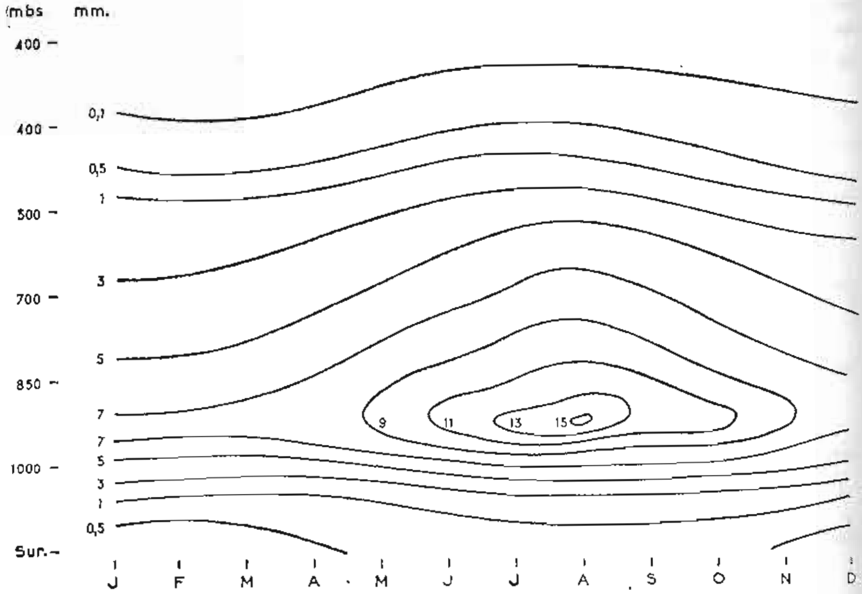
Annual mean variation of precipitable water (mm) per thickness
Athens (Hellinikon): 1968–74 : 12,00 GMT



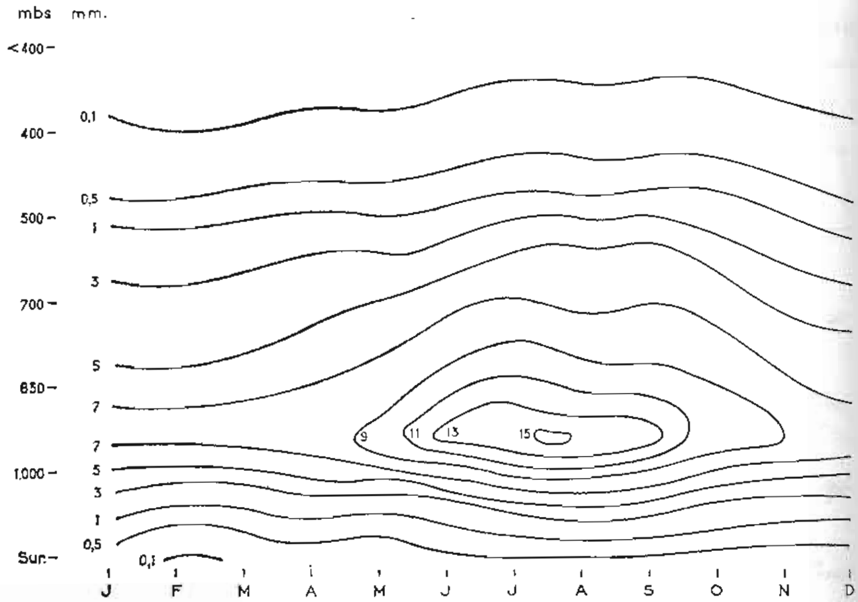
GRAPH IIIa
Isopleths of precipitable water (mm). Athens (Hell.): 1968–1974
cases, with no precipitation : 00:00 GMT



GRAPH IIIb
Isopleths of precipitable water (mm). Athens (Hell.): 1968–1974
cases with no precipitation: 12:00 GMT



GRAPH IIIc
Isopleths of precipitable water (mm). Athens (Hell.): 1968 1974
cases with precipitation : 00:00 GMT



GRAPH IIId
Isopleths of precipitable water (mm). Athens (Hell.): 1968-1974
: cases with precipitation : 12:00 GMT

phical correlation of precipitable water, thickness, and precipitation. According to this method, upon a rectangular coordinates system, where axis X denotes the elevations of the 500 mbs constant pressure level: hs gpm, and axis Y the natural logarithm of the corresponding precipitable water (In Pw), observed at the surface to 500 mbs thickness, a point is marked for each observation, from the corresponding values of the above variables. This point denotes bu (o) a dry case and by (x) a rainy one.

Thus Lowry arrived at a straight line determined by the points corresponding to rainy cases, and gave its mathematical expression as:

$$h_s = 5550 + \text{In Pw} + 0{,}1 \text{ E}$$

where : hs the saturation thickness (gpm)

Pw the precipitable water observed as above, in inches.

E the station elevation in meters.

We, in this case, applying Lowry's method for the Hellinikon airport have gone even further, dividing rainy cases in two categories: (a) cases when the amount of precipitation recorded was $0{,}0 \leq R < 5{,}0$ mm and (b) cases when the amount of precipitation was$\geq 5{,}0$ mm.

The results have been very satisfactory and this is evident from the correlation coefficients of log Pw and h_s in the first and second categories of cases described above (Tables IIIa and IIIb).

Besides the correlation coefficients, the above Tables also give the mathematical expressions of the straight line defining the saturation thickness as an average of the period examined, per month and per season.

Moreover, after studying this subject for the precise site of Hellinikon airport, we have also studied this same subject for the whole area of the Attica basin, and drawn the correlation coefficients of the above quantities as well as the mathematical expressions of the straight line determining the saturation thickness, per month and per season (Tables IIIc, IIId).

Finally, as an example —and for seasons only— we give graphs IVa-IVh, which resulted from the application of Lowry's graphical correlation, for Hellinikon airport — 00:00 and 12:00 GMT— for cases witb precipitation $<5{,}0$ mm and cases with precipitation$\geq 5{,}0$ mm.

TABLE IIIa

Saturation thickness - Athens (Hell.): 68-74/0000 GMT. Coefficients of corellation and regression's equations, per month and per season (Rainy cases)

	RAIN ⩾ 0,0 mm			RAIN ⩾ 5,0 mm		
	N_1	r_1	$\Upsilon_1 = a_0 + a_1X_1$	N_2	r_2	$\Upsilon_2 = a_0 + a_1X_2$
J	66	+0.51	$\Upsilon_1 = -2.030 + 0.00076X_1$	11	+0.69	$\Upsilon_2 = -2.075 + 0.00060X_2$
F	56	+0.44	$\Upsilon_1 = -1.520 + 0.00049X_1$	6	−0.03	$\Upsilon_2 = 1.485 - 0.00005X_2$
M	60	+0.44	$\Upsilon_1 = -1.815 + 0.00067X_1$	13	+0.51	$\Upsilon_2 = -2.485 + 0.00082X_2$
A	36	+0.47	$\Upsilon_1 = -2.017 + 0.00059X_1$	3	+0.85	$\Upsilon_2 = -4.352 + 0.00103X_2$
M	15	+0.79	$\Upsilon_1 = -3.034 + 0.00078X_1$	—	—	—
J	11	+0.75	$\Upsilon_1 = -2.095 + 0.00062X_1$	—	—	—
J	9	+0.22	$\Upsilon_1 = -0.764 + 0.00039X_1$	—	—	—
A	5	+0.45	$\Upsilon_1 = -2.215 + 0.00064X_1$	1	—	
S	16	+0.56	$\Upsilon_1 = -5.304 + 0.00100X_1$	—	—	—
O	40	+0.44	$\Upsilon_2 = -3.048 + 0.00160X_1$	7	+0.81	$\Upsilon_2 = -8.051 + 0.00160X_2$
N	32	+0.72	$\Upsilon_1 = -5.563 + 0.00120X_1$	9	+0.90	$\Upsilon_2 = -6.788 + 0.00015X_2$
D	54	+0.27	$\Upsilon_1 = -0.635 + 0.00034X_1$	8	+0.64	$\Upsilon_2 = -3.232 + 0.00083X_2$
WINTER	179	+0.45	$\Upsilon_1 = -1.900 + 0.00056X_1$	25	+0.50	$\Upsilon_2 = -1.200 + 0.00044X_2$
SPRING	111	+0.61	$\Upsilon_1 = -0.980 + 0.00040X_1$	16	+0.48	$\Upsilon_2 = -2.809 + 0.00075X_3$
SUMMER	25	+0.51	$\Upsilon_1 = -2.083 + 0.00062X_1$	1	—	—
AUTUMN	88	+0.70	$\Upsilon_1 = -4.740 + 0.00108X_1$	16	+0.90	$\Upsilon_2 \quad -6.937 + 0.00148X_2$

TABLE IIIb

Saturation thickness - Athens (Hell.): 68-74/1200 G.M.T. Coefficients of Corellation and regression's equations, per month and per season (Rainy cases)

	RAIN $\geqslant$ 0.0 mm			RAIN $\geqslant$ 5.0 mm		
	N_1	r_1	$\Upsilon_1 = a_0 + a_1X_1$	N_2	r_2	$\Upsilon_2 = a_0 + a_1X_2$
J	28	+0.63	$\Upsilon_1 = -4.955 + 0.00110X_1$	2	+0.999	$\Upsilon_2 = -9.830 + 0.00200X_2$
F	20	+0.65	$\Upsilon_1 = -5.021 + 0.00110X_1$	9	+0.80	$\Upsilon_2 = -7.841 + 0.00166X_2$
M	22	+0.52	$\Upsilon_1 = -2.443 + 0.00066X_1$	1	—	—
A	19	+0.57	$\Upsilon_1 = -2.887 + 0.00074X_1$	—	—	—
M	13	+0.68	$\Upsilon_1 = -3.507 + 0.00084X_1$	3	+0.76	$\Upsilon_2 = -0.617 + 0.00034X_2$
J	5	+0.72	$\Upsilon_1 = -3.826 + 0.00090X_1$	1	—	—
J	11	+0.65	$\Upsilon_1 = 1.000 + 0.00100X_1$	2	+0.99	$\Upsilon_2 = -3.566 + 0.00090X_2$
A	5	+0.04	$\Upsilon_1 = 1.339 + 0.00020X_1$	1	—	—
S	17	−0.40	$\Upsilon_1 = 4.647 - 0.00500X_1$	2	+0.99	$\Upsilon_2 = -1.807 + 0.00060X_2$
O	25	+0.46	$\Upsilon_1 = -2.893 + 0.00080X_1$	5	+0.60	$\Upsilon_3 = -3.178 + 0.00080X_2$
N	26	+0.54	$\Upsilon_1 = -4.570 + 0.00100X_1$	3	+0.22	$\Upsilon_2 = -0.576 + 0.00040X_2$
D	41	+0.16	$\Upsilon_1 = 0.108 + 0.00020X_1$	7	+0.29	$\Upsilon_2 = -1.297 + 0.00045X_2$
WINTER	89	+0.44	$\Upsilon_1 = -2.130 + 0.00060X_1$	18	+0.86	$\Upsilon_2 = -5.455 + 0.00122X_2$
SPRING	54	+0.63	$\Upsilon_1 = -2.980 + 0.00075X_1$	4	+0.67	$\Upsilon_2 = -0.840 + 0.00038X_2$
SUMMER	21	+0.57	$\Upsilon_1 = -2.777 + 0.00074X_1$	4	+0.99	$\Upsilon_2 = -4.270 + 0.00100X_2$
AUTUMN	68	+0.67	$\Upsilon_1 = -3.650 + 0.00088X_1$	10	+0.46	$\Upsilon_2 = -2.779 + 0.00074X_2$

TABLE IIIc

Saturation thickness-Attiea basin: 68-74/0000 G.M.T. Coeffieients of Corellation and regression's equations, per month and per season (Rainy eases)

	RAIN $\geqslant$ 0.0 mm			RAIN $\geqslant$ 5.0 mm		
	N_1	r_1	$\Upsilon_1 = a_0 + a_1X_1$	N_2	r_2	$\Upsilon_2 = a_0 + a_1X_2$
J	79	+0.49	$\Upsilon_1 = -3.004 + 0.00080X_1$	17	+0.53	$\Upsilon_2 = -1.830 + 0.00060X_2$
F	67	+0.49	$\Upsilon_1 + -1.602 + 0.00050X_1$	10	−0.02	$\Upsilon_2 = 1.139 - 0.00020X_2$
M	66	+0.43	$\Upsilon_1 = -2.835 + 0.00070X_1$	20	+0.46	$\Upsilon_2 = -2.107 + 0.00060X_2$
A	47	+0.42	$\Upsilon_1 = -1.641 + 0.00050X_1$	5	+0.80	$\Upsilon_2 = -2500 + 0.00070X_2$
M	19	+0.78	$\Upsilon_1 = -3.493 + 0.00090X_1$	—	—	—
J	18	+0.49	$\Upsilon_1 = -2.038 + 0.00060X_1$	1	—	—
J	15	+0.31	$\Upsilon_1 = -1.823 + 0.00060X_1$	2	+0.996	$\Upsilon_2 = -12.901 + 0.00250X_2$
A	7	+0.45	$\Upsilon_1 = -1.153 + 0.00050X_1$	1	—	—
S	18	+0.51	$\Upsilon_1 = -4.925 + 0.00110X_1$	1	—	—
O	51	+0.45	$\Upsilon_1 = -3.841 + 0.00090X_1$	13	+0.49	$\Upsilon_2 = -9.121 + 0.00190X_2$
N	38	+0.56	$\Upsilon_1 = -4.112 + 0.00100X_1$	11	+0.89	$\Upsilon_2 = -5.945 + 0.00130X_2$
D	69	+0.28	$\Upsilon_1 = -1.193 + 0.00040X_1$	13	+0.60	$\Upsilon_2 = -2.382 + 0.00070X_2$
WINTER	215	+0.39	$\Upsilon_1 = -1.579 + 0.00050X_1$	39	+0.56	$\Upsilon_2 = -1.245 + 0.00045X_2$
SPRING	132	+0.58	$\Upsilon_1 = -3481 + 0.00085X_1$	25	+0.44	$\Upsilon_2 = -1.839 + 0.00056X_2$
SUMMER	40	+0.49	$\Upsilon_1 = -2.728 + 0.00070X_1$	4	+0.31	$\Upsilon_2 = -3.650 + 0.00090X_2$
AUTUMN	107	+0.62	$\Upsilon_1 = -4.626 + 0.00110X_1$	25	+0.70	$\Upsilon_2 = -5.505 + 0.00120X_2$

TABLE IIId

Saturation thickness-Attica bazin: 68-74/1200 G.M.T. Coefficicnts of corellation and regression's equations, per month and per season (Rainy cases).

	RAIN ⩾ 0.0 mm			RAIN ⩾ 5.0 mm		
	N_1	r_1	$\Upsilon_1 = a_0 + a_1X_1$	N_2	r_2	$\Upsilon_2 = a_0 + a_1X_2$
J	36	+0.67	$\Upsilon_1 = -5.274 + 0.0016X_1$	3	+0.77	$\Upsilon_2 = -7.836 + 0.0016X_2$
F	30	+0.36	$\Upsilon_1 = -2.144 + 0.0006X_1$	10	+0.50	$\Upsilon_2 = -4.367 + 0.0010X_2$
M	29	+0.57	$\Upsilon_1 = -3.606 + 0.0009X_1$	3	+0.26	$\Upsilon_2 = -0.261 + 0.0003X_2$
A	23	+0.71	$\Upsilon_1 = -3.810 + 0.0009X_1$	—	—	—
M	16	+0.53	$\Upsilon_1 = -1.536 + 0.0005X_1$	4	+0.92	$\Upsilon_2 = -0.733 + 0.0004X_2$
J	16	+0.67	$\Upsilon_1 = -4.422 + 0.0010X_1$	2	+0.95	$\Upsilon_2 = -2.855 + 0.0008X_2$
J	15	+0.61	$\Upsilon_1 = -4.620 + 0.0011X_1$	3	+0.97	$\Upsilon_2 = -3.445 + 0.0009X_2$
A	10	+0.08	$\Upsilon_1 = 0.983 + 0.0001X_1$	3	+0.92	$\Upsilon_2 = -2.413 + 0.0007X_2$
S	19	−0.42	$\Upsilon_1 = 4.857 - 0.0006X_1$	5	−0.33	$\Upsilon_2 = 6.061 - 0.0009X_2$
O	33	+0.50	$\Upsilon_1 = -3.064 + 0.0008X_1$	7	+0.62	$\Upsilon_2 = -2.631 + 0.0007X_2$
N	34	+0.51	$\Upsilon_1 = -3.495 + 0.0008X_1$	3	+0.22	$\Upsilon_2 = -0.576 + 0.0004X_2$
D	50	+0.31	$\Upsilon_1 = -1.346 + 0.0005X_1$	8	+0.27	$\Upsilon_2 = -1.510 + 0.0005X_2$
WINTER	116	+0.47	$\Upsilon_1 = -1.935 + 0.00056X_1$	21	+0.78	$\Upsilon_2 = -5.947 + 0.00131X_2$
SPRING	68	+0.67	$\Upsilon_1 = -3.289 + 0.00080X_1$	7	+0.79	$\Upsilon_2 = -1.321 + 0.00050X_2$
SUMMER	41	+0.51	$\Upsilon_1 = -3.497 + 0.00090X_1$	8	+0.91	$\Upsilon_2 = -3.844 + 0.00090X_2$
AUTUMN	86	+0.82	$\Upsilon_1 = -6.913 + 0.00150X_1$	15	+0.46	$\Upsilon_2 = -1.468 + 0.00050X_2$

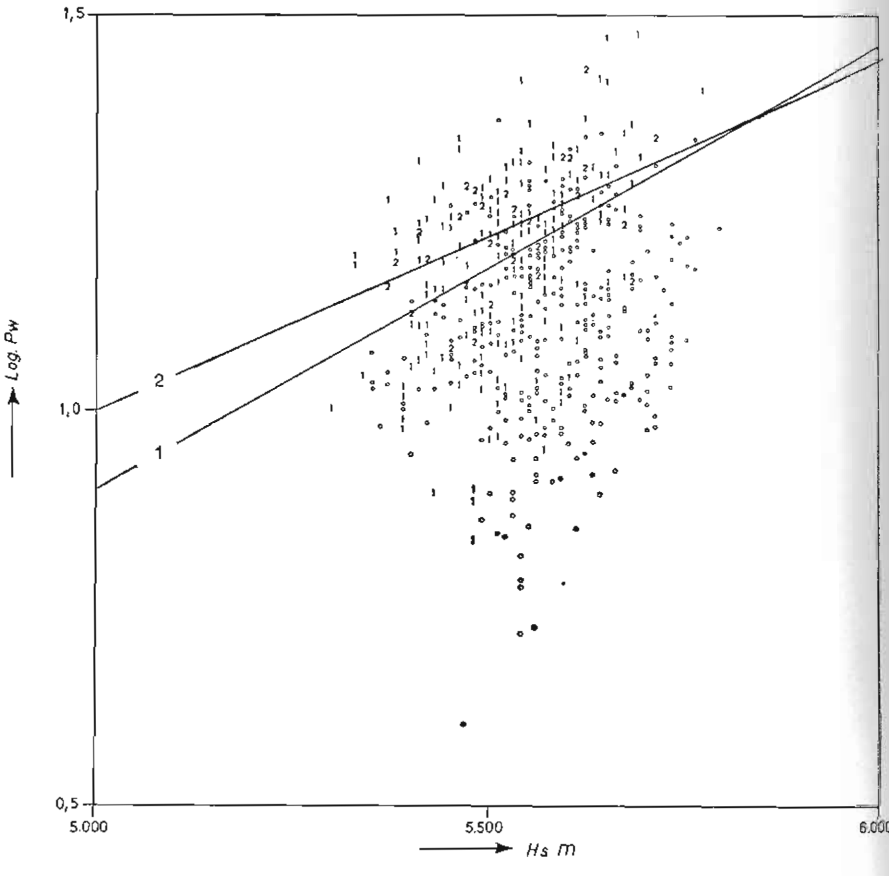
GRAPH IVa

WINTER : 68–74/0000 GMT (HELL.)

0 = Dry cases

1 = Rain ≥ 0,0 mm

2 = " ≥ 5,0 mm



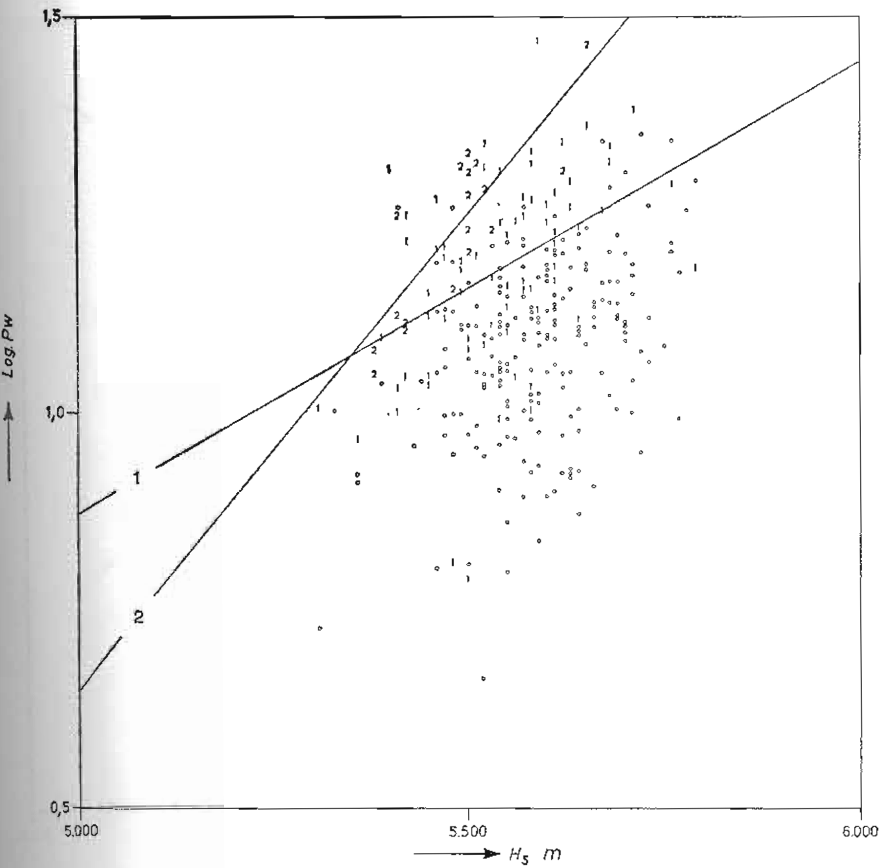
GRAPH IVb

WINTER : 68–74/1200 GMT (HELL.)

O = Dry cases

1 = Rain ≥ 0,0 mm

2 = " ≥ 5,0 mm



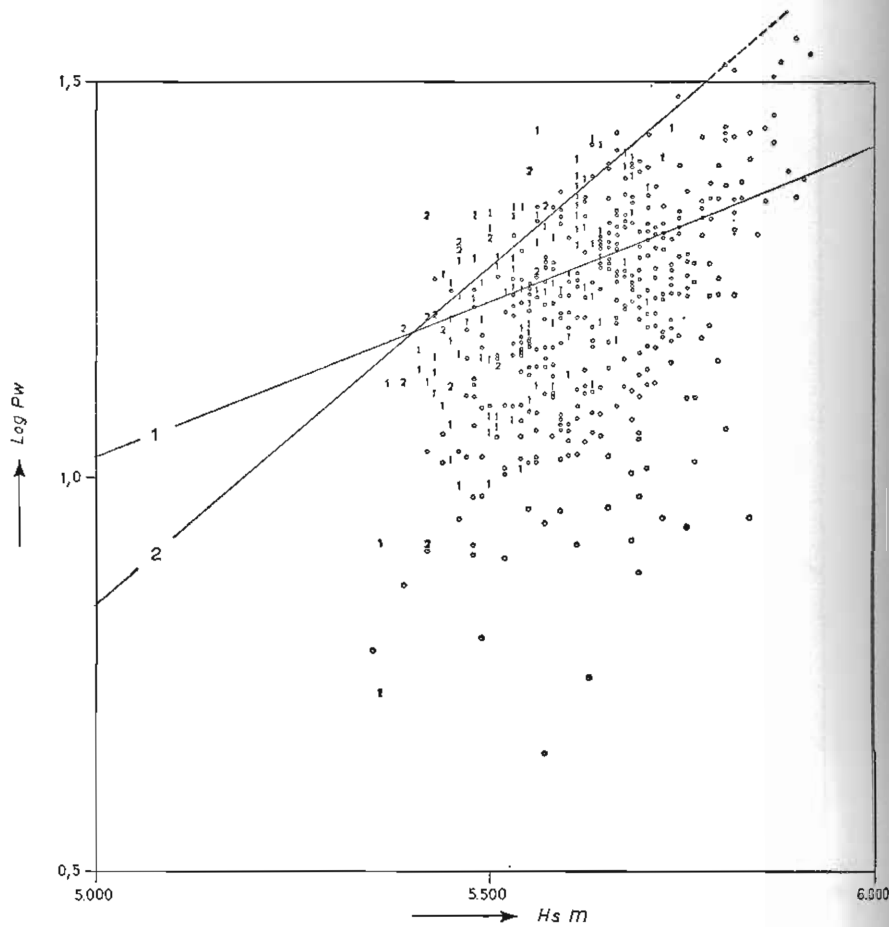
GRAPH IVc

SPRING : 68-74/0000 GMT (HELL.)

O = Dry cases

1 = Rain ⩾ 0,0 mm

2 = ,, ⩾ 5,0 mm



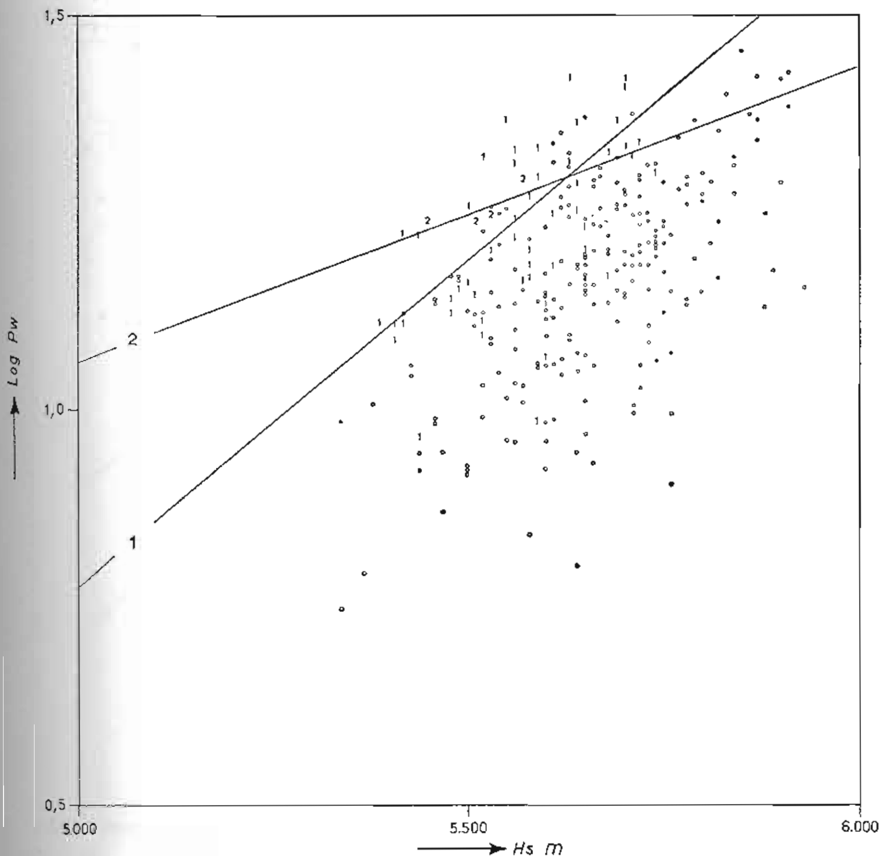
GRAPH IVd

SPRING : 68-74/1200 GMT (HELL.)

O = Dry cases

1 = Rain ≥ 0,0 mm

2 = " ≥ 0,5 mm



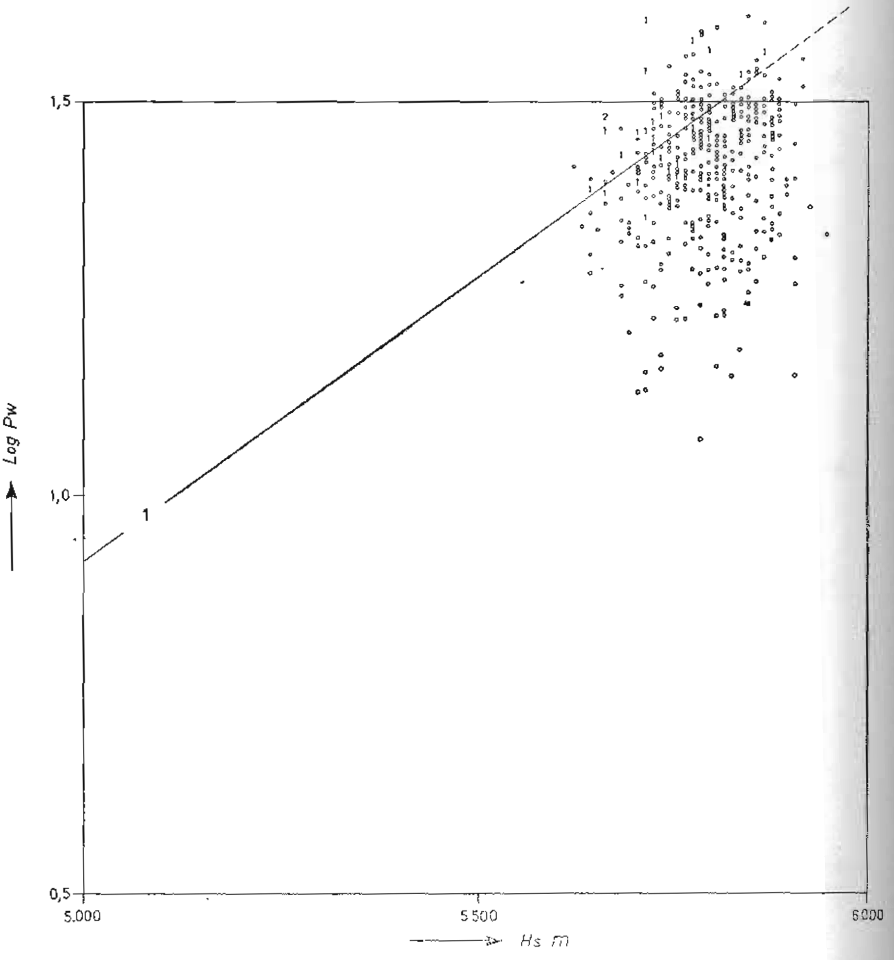
GRAPH IVe

SUMMER : 68-74/0000 GMT (HELL.)

O = Dry cases

1 = Rain ≥ 0,0 mm

2 = " ≥ 5,0 mm



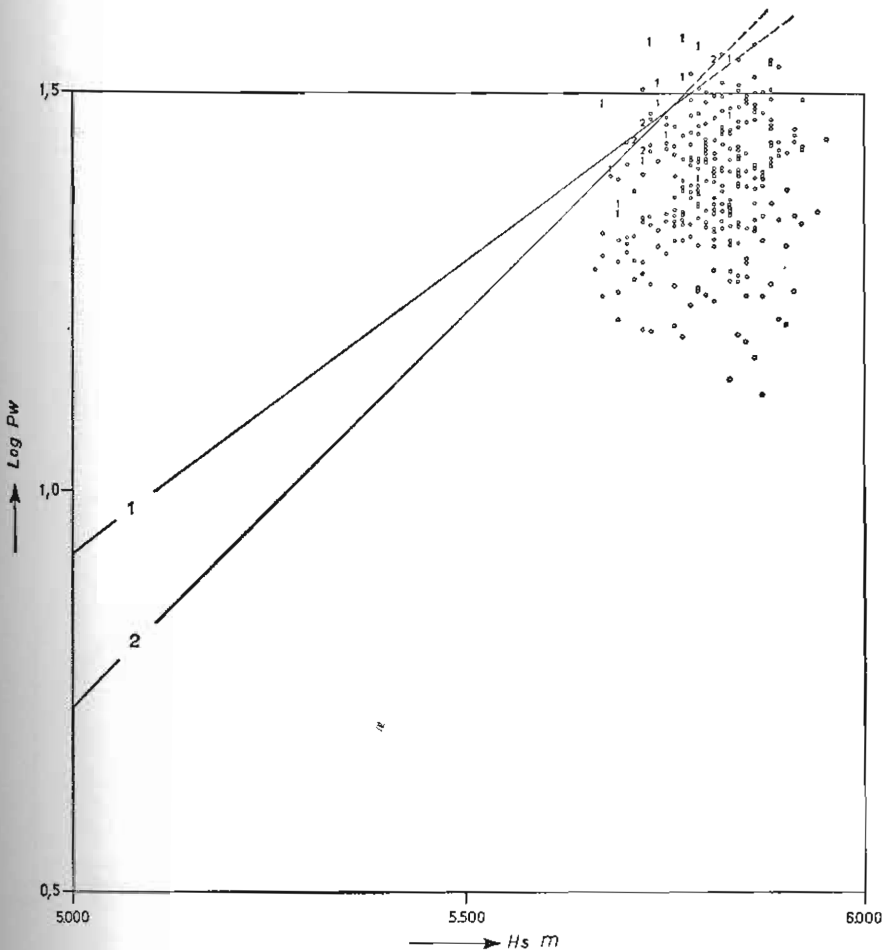
GRAPH IVf

SUMMER : 68-74/1200 GMT (HELL.)

O = Dry cases

1 = Rain ≥0,0 mm

2 = " ≥5,0 mm



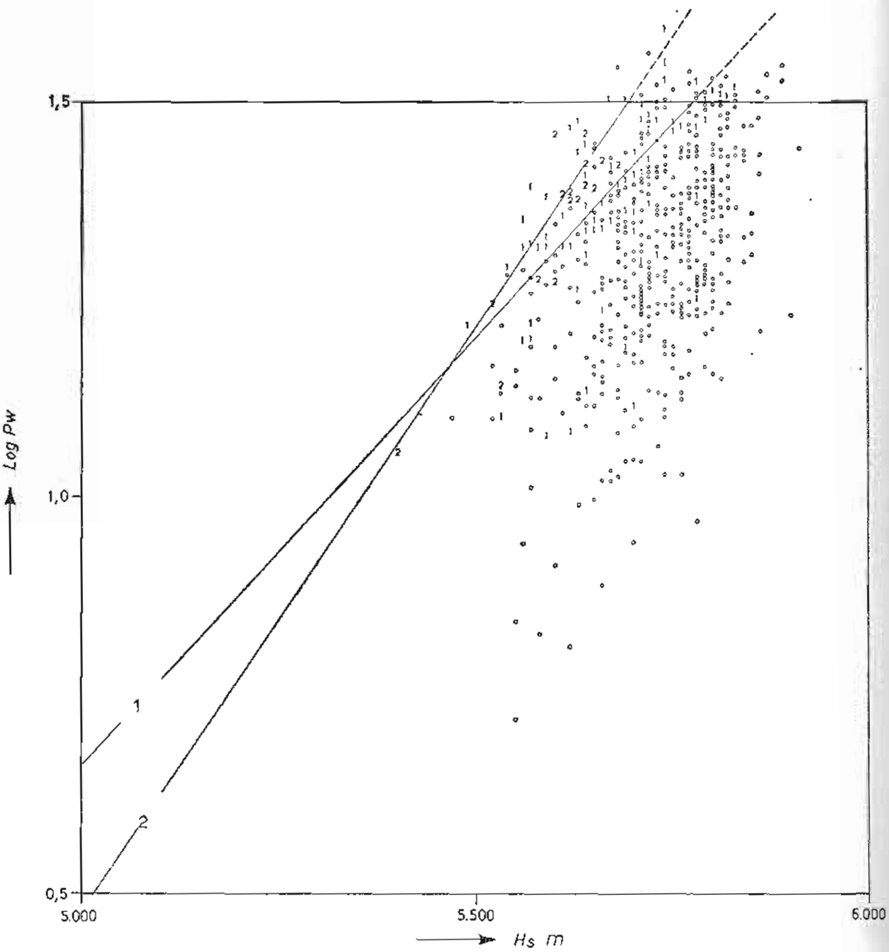
GRAPH IVg

AUTOMN : 68-74/0000 GMT (HELL.)

O = Dry cases

1 = Rain ≥ 0,0 mm

2 = " ≥ 5,0 mm



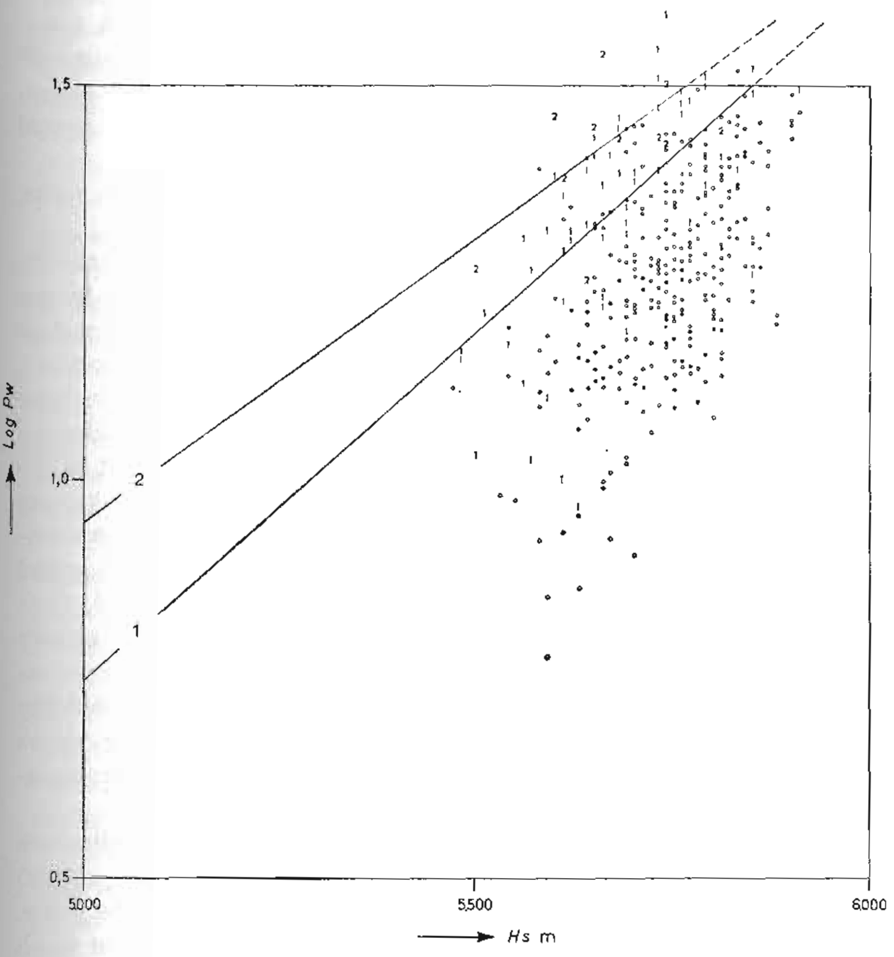
GRAPH IVh

AUTUMN : 68-74/1200 GMT (HELL.)

O = Dry cases

1 = Rain ≥0,0 mm

2 = " ≥5,0 mm



Conclusions - Discussion

From the study of what we have already mentioned, we arrived at the following conclusions:

— The total precipitable water of both (D) and (R) cases, for both observation times, increases during the warm season, with a maximum in July or August, and decreases during the cold season with a minimum in January, February, or March; thus its mean annual variation follows, with a high degree of approximation, the mean annual variation of air temperature in the area examined[1].

We interpret this form of fluctuation of the total precipitable water, as follows:

(a) Warm season: (i) The increase of temperature entails the increase of evaporation (from ground and the adjoining sea area), having as a direct result the concentration of water vapors, first in the surface layers of the atmosphere and then of higher layers (due to convection), with final result the increase of precipitable water. (ii) The increase of temperature in the various air layers together with the increase of the height of constant pressure levels during this season, result in the increase of capacity for water vapor of the air mass examined, keeping it away from saturation point, and having as a consequence the maintenance of high values of precipitable water. (iii) In case of the arrival of a new air mass (new water vapors), over the area examined, there is again an increase of precipitable water, since the air mass already has an increased capacity for water vapor (§ ii) and is far from saturation point; thus, only if other conditions concur (i.e. instability etc.) condensation occurs, hut as a rule the arrival of new water vapors during the warm season contrihutes to the increase of total precipitahle water.

(h) Cold season: (i) Low temperatures reduce or even eliminate evaporation, at the same time increasing condensation (⌂, ⌴, ≡, clouds) and as a consequence reduce the amount of total precipitable water. (ii) The decrease of height of constant-pressure levels, because of which —in combination with lower tempetatures— the capacity for water vapor of the air mass examined is also reduced, facilitates the condensation process and this again results in the decrease of the amount of total precipitable water. (iii) The arrival of new air masses over the area examined, decreases as a rule during the cold season the amount of precipitable water, because the resulting mixture (of the old and new air mass) has a maximum vapor pressure, smaller than the arithmetic mean of maximum vapor pressures of its component air masses (old and new one); thus the mixture is brought nearer to saturation point, and with the assistance of the already small air capacity for water vapor (§ ii) condensation is produced, which of course decreases the value of total precipitable water.

— Except for the months of January, March, July and September, in the group of rainy cases, in every other case, for every month separately and for the whole year as well, the amount of total precipitable water at 00:00 GMT (Pw_0) is higher than the corresponding amount of 12:00 GMT (Pw_{12}); the difference between the two amounts: $\Delta\bar{P}w = \bar{P}w_0 - \bar{P}w_{12}$, generally increases from the winter towards the summer season and vice-versa.

We attribute this fact mainly to cloudiness being as a rule smaller at night than during the day-time. As a consequence, the increase of cloudiness during the twelve-hours of daylight, induces the decrease of precipitable water at 12:00 GMT. On the other hand cloudiness, being as a rule heavier during the winter season, and persisting at a high degree even at night, tends to equalize the hygrometric conditions of the air during the two twelve hours, thus decreasing the Pw difference.

Finally, we remind that the above mentioned exceptions are observed in the group of rainy cases, and the consequently cloud conditions of the nocturnal twelve hours of the above months should be considered responsible for the reversal of the difference $\Delta\bar{P}w = \bar{P}w_0 - \bar{P}w_{12}$.

— The mean total precipitable water of rainy cases for every month and the whole year, at 00:00 GMT and 12:00 GMT as well, is higher than the corresponding value of cases with no precipitation: $\bar{P}w_R > \bar{P}w_D$. We consider this fact a significant one, since it consists a «qualitative» prediction of precipitation, and we interpret it as follows:

As already mentioned at the beginning of this paper, for every time of observation (d) of rainy cases, we have alloted a twelve-hours period: $(d - 6^h) - (d + 6^h)$, during which precipitation was recorded. If we consider at random a rainy case, regardless of the cause that produced the precipitation, it is known that an interval preceded when the air mass has been gradually approaching the saturation point. Thus, during this preliminary stage, the amount of precipitable water increased (more or less, according to the rain-producing mechanism). But as a rule, such conditions are followed by convergence of air masses[26 27]; thus after the beginning or even the end of rain, air masses surrounding the one over the area affected, converge and bring into it new water vapors, in this way increasing again the total precipitable water. Notably sometimes, in cases of rainstorms, this convergence is so strong that, because of large amounts of water vapor being continuously added to the overlying atmosphere, the amounts of total precipitable water recorded, are extremely high[26].

According to the above, it is of no importance whether precipitation is observed before or after observation time (d) since in both cases the total precipitable water will certainly increase. This is very important, because the increase of total precipitable water precedes precipitation, so that its assessment renders timely prediction of precipitation possible.

— It has been found that almost the whole amount of water vapors of the troposphere ($\simeq 90\%$) is contained in the 1000-500 mbs thickness and as a consequence the $\overline{P}w$ of this thickness is the one that models the mean annual variation of the total precipitable water. The surface to 1000 mbs thickness as well as the thickness above 500 mbs, have a small range and rather irregular annual variation of their precipitable water, depending on the particular conditions ocasionally prevailing in the troposphere.

— The excess of Pw_R over the corresponding Pw_D per month, per year and for both observation times, is also found in individual thicknesses.

—We emphasize here the climatological significance of isopleths of precipitable water (Graphs IIa, b, c, d) which not only give the mean hygrometric conditions of the troposphere for every month in the area examined, but also stress the superiority of precipitable water values in rainy cases over values of dry cases.

— Finally, the improvement of Lowry's graphical correlation method, by separating rainy cases in small ($<5,0$ mm) and large ones ($\geq 5,00$ mm), is made clear from the examination of correlation coefficients of these two groups, as they are given in Tables IIIa and IIIb, while the application of this method for the Attica basin in general goes to show that it can also be applied in a larger area, adjoining the space of the R/S launching (in this case the Hellinikon airport Upper Air Station).

REFERENCES

1. Arseni-Papadimitriou, A. «On the annnal variation of air temperatnre in Athens», METEOROLOGIKA No 31, Thessaloniki, 1973.
2. Bannon J. K., Ssteele C. P. «Average water Vapor of the air» Met. Office, Air Ministry, Geoph. Mem., 102 (38p.), 1960.
3. Barnes A. A. Jr. «Atmospheric Water Wapor Divergence: Measnrements and Applications» Humidily and Moisture, (ed) Wexler A., Vol. II, London, 1965.
4. Benwell G. R. R. «Estimation and Variability of precipitable water» Met. Mag. 94 (319-327), 1965.
5. Berkofski L. «Comments on Notes on the relationship between total precipitable water and snrface dew point» J. App. Met. Vol. 6 (959) Notes and Correspondance, 1967.
6. Berkofski L. «Further eomments on «Note on the relationship between total precipitable water and surface dew-point». J. App. Met. Vol. 7 (719) — Notes and Correspondance, 1968.
7. Bloutsos A. «Climate of the free atmosphere above Athens Doctoral Thesis, Thessaloniki 1975.
8. Bolsegna S. J. «The relationship between total atmospheric water vapor and surface dew-point on a mean daily and hourly basis». J. App. Met. Vol. 4 (430-432)., 1965.
9. Borovikov A. M., Khrgian A. K. «Clond Physics» Translated from Russian, Israel Program for Scientific Translations, Jernsalem 1963.
10. Brasefield J. C. «Measurements of Atmospheric Hnmidity to 35 km» J. Meteor., Vol. 11 (412). 1954.
11. Byers H. R. «Elements of Cloud Physics» Un. Chic. Press., Chicago 1965.
12. Cooney A. J. «Comparison of Water Vapor Profiles obtained by Radiosonde and Laser Backscatter» J. App. Met., Vol. 10 (301), 1971.
13. Crisi A. R. «Hemispheric Water Vapor Balance during 1958» Hnmidity and Moisture, (ed) Wexler A., Vol. II, Loudon, 1965.
14. Gutnick M., Salmela H. «Reevaluation of the Mid-Latitude Moisture Profile» Humidity and Moisture (ed.) Wexler A., Vol. II, London, 1965.
15. Helinwell N. G., Mc Kenzie J. K. and Kelley M. J. «Some further observations from Aircraft of frost point and temperature up to 5000 ft» Quart. J. Roy. Met. Soc., 83 (356): 257-262, Bracknell, England, 1957.
16. Hutcherson C. D. «Water Vapor in the Atmosphere» Humidity and Moisture, (ed.) Wexler A., Vol. II, London, 1965.
17. Hutchings W. J. «Water Vapor flux and flux-divergence over Southern England: Snmmer 1954» Quart. J. Roy. Met. Soc., 83 (355): 30-48,1957.
18. Karalis D. J. «Precipitable water and its relationship to surface dew-point and vapor pressure in Athens». J. App. Met., Vol. 13 (760), 1974.
19. Klein H. W. «Five-day Precipitation Patterns derived from Circulation and Moisture» Humidity and Moisture, (ed.) Wexler A., Vol. II, London, 1965.

20. Louis F. J., Mc-queen M. R. «Spetroscopic Observation, of water Vapor near the troposphere» J. App. Met. Vol. 9 (722), 1970.
21. Lowry D. A. «Climatological relationship among Precipitable water, thickness and precipitation» J. App. Met., Vol. 11 (1326), 1972.
22. Lowry D. A., Glain H. R. «Relationship between intergrated atmospheric moistnre and surface weather» J. App. Met., Vol. 8 (762-768), 1969.
23. Mason B. J. «Clouds, Rain and Rainmaking» Cambridge Univ. Press., 1962.
24. Mastenbrook J. H. «Water-vapor distribution in the Startosphere and High Troposphere» J. Atm. Sci., Vol. 25 (299), 1968.
25. Möller F. «Atmospheric Water Measurements at 6-7 microns from a Satellite» Planet. Sp. Sci., Pergamon Press, Vol. 5 (202-206), Great Britain, 1961.
26. Peixoto J. P. «Hemispheric Humidity conditious during the year 1950» M. I. T., Dept. Met., AFRI-TN-58-609 (p. 142), 1958
27. Peixoto J. R., Crisi A. R. «Hemispheric Humidity conditions during the I.G.Y.» M.I.T. Dept. Met. Sci. Rep., No 6 (166). AFCRI-65-794, 1965.
28. Perrie D.W. «Cloud Physics» John Wiley and Sons, Iuc., New York., 1950.
29. Peterson R. K. «A precipitable water nomogram» Bull. Am. Met. Soc., Vol. 42, No 2 (119) 1961.
30. Pullen R. A. «Computation of the moisture content of the atmosphere using surfase level climatological data» J. Hydrology, 6 (168-182). Amsterdam-Holland, 1968.
31. Raschke E., Bandeen «A Quasi-Global Analysis of Tropospheric Water Vapor Content from TIROS IV Radiation Data» J. App. Met. Vol. 6, (468), Boston, 1967.
32. Reber E. E., Swope J. R. «On the correlation of the total precipitable water in a vertical Column and absolute Humidity at the surface» J. App. Met. Vol. 11 (1322), 1972.
33. Reitan H. C. «Distribution of precipitable water over the Continental United States» Bull. Am. Met. Soc., Vol. 41, No 2 (79), 1960.
34. Reitan H. C. «Surface dew-point and water vapor aloft» J. App. Met. Vol. 2 (776-779), 1963.
35. Repapis Chr. «On warm invasions at the lower tropospbere in Greece». Doctoral Thesis, Joannina, 1975.
36. Retalis D., Papathomas S. and Zervos P. «Contribution on the study of precipitable water at Hellinikon area.» Memoires of the National Observatory of Athens, Serie II, Meteorology No 31, Atheus, 1974.
37. Schwartz, K. F. «Comments on Note on the relationship between total precipitable water and surface dew-point», J. App. Met. Vol. 7., (509) — Notes and Correspondance, 1968.
38. Showalter A. K. «Precipitable water template» Bull. Am. Met. Soc., Vol. 35 No 3 (129), Correspondance, 1954.
39. Sissenwine N., Grantham and Salmela H. A. «Mid-latitude Humidity to 32 km» J. Atm. Sci., Vol. 25 (1129), 1968.
40. Smith L.W. «Note ou the relationship between total precipitable water and surface dew-point» J. App. Met., Vol. 5 (726), Notes and Correspondance, 1966.

41. Smith L.W., Howell B. H. «Vertical distribution of Atmospheric water vapor from satelite Infrared spectrometer measurements», J. App. Met., Vol. 10 (1026), 1971.

42. Solot S. B. «Computation of depth of precipitable waterin a column of air» Mon. Weather Rev., 67 (100-103), 1939.

43. Starr P., Peixoto J. P., and Livadas G. C. «On the meridional flux of water vapor in the Northern Hemisphere» Geofisica Pura e Applicata-Milano, Vol. 39 (174-185), 1958.

44. Swayne W. W. «Quantitative analysis and forecasting of winter rainfall pattern» Mon. Weather Rev., 84 (53-65). 1956.

45. Tomlinson A. I. «Precipitable water statistics from the surface to 400 mbs, at New Zealand stations, from 1959 to 1972» Ministry of Transport, N. Z. Met. Serv. Miscel. Publ. 144, 1973.

MATERIALS

46. National Observatory of Athens «Precipitation Records from the files of the met. station of the National Observatory of Athens». 1968-1974.

47. E.M.Y. «Daily Weather Bulletin», Hellenic National Meteorological Service, 1968-1974.

48. E.M.Y. «Monthly Climatological Bulletin», Hellenic National Meteorological Servise, 1968-1974.

ΠΕΡΙΛΗΨΗ

ΥΕΤΙΣΙΜΟΝ ΥΔΩΡ ΚΑΙ ΒΡΟΧΟΠΤΩΣΕΙΣ

ὑπὸ

ΒΛΑΔΙΜΗΡΟΥ ΕΜ. ΑΓΓΟΥΡΙΔΑΚΗ

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'Εκ τῆς κατανομῆς τοῦ ὑετισίμου ὕδατος, τῆς ἐτησίας μεταβολῆς του καὶ τῶν κλιματικῶν σχέσεων πού τὸ συνδέουν μὲ τὴν βροχήν, μελετᾶται ἡ ὑγρομετρικὴ κατάστασις τῆς κατωτέρας καὶ μέσης τροποσφαίρας, ἐπὶ τῇ βάσει τῶν στοιχείων 3091 R/S πραγματοποιηθεισῶν εἰς τὸ ἀεροδρόμιον τοῦ 'Ελληνικοῦ ('Αθῆναι: $\varphi = 37^{o}\ 54'$ N, $\lambda = 23^{o}\ 44'$ E, h = 15 μ) τῆς περιόδου 1968-74 καὶ κατὰ τὰς ὥρας 00 GMT (1875 R/S) καὶ 12 GMT (1216 R/S).

'Εκ τοῦ συνόλου τῶν ἀνωτέρω R/S, αἱ 636 συνδυάζονται μὲ βροχὴν σημειωθεῖσαν εἰς τὴν θεωρουμένην περιοχὴν κατὰ τὸ ἀντίστοιχον δωδεκάωρον, ἐξ ὧν αἱ 405 κατὰ τὴν 00:00 GMT καὶ αἱ 231 κατὰ τὴν 12:00 GMT. Διαμορφοῦνται οὕτως αἱ κατηγορίαι τῶν ἀβρόχων (D) καὶ βροχερῶν (R) περιπτώσεων, καὶ ἡ ἀξιολόγησις τῶν σημειουμένων διαφορῶν μεταξὺ τῶν τιμῶν (ἀντιστοίχων) τοῦ ὑετισίμου ὕδατος τῶν ἀβρόχων καὶ βροχερῶν περιπτώσεων, ὁδηγεῖ εἰς συμπεράσματα συμβάλλοντα εἰς τὴν πρόγνωσιν τῆς βροχῆς,.