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WIND IN THESSALONIKI - GREECE

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Abstract: *Wind in the city of Thessaloniki is studied from data of the meteorologieal station of the Institute of Meteorology and Climatology of the Aristotelian University of Thessaloniki, for the 1930 - 1971 period.*

Conclusions are drawn as to the wind directions (prevailing winds) and their velocities.

INTRODUCTION.

The element of wind in the city of Thessaloniki has been the subject of relative studies by Alexandrou [1], Mariolopoulos [14], and Kyriazopoulos [16]. The first two used data of various meteorological stations that functioned for different intervals in various sites, in the city of Thessaloniki, within the 1892-1929 period, while the third research worker studied also data of the met. station of the University of Thessaloniki for the years 1930 - 1937 (Mariolopoulos [15]).

In the present work we examine data of the above station (AUT) for the years 1930-1971; these data have been published in the series «Observations Météorologiques de Thessaloniki» (Kyriazopoulos [17], Livadas [18]).

It should be meutioned that, out of the 1930-1971 observational period examined, the met. station of the AUT stopped operating, or it operated defectively, during the Greek-italian war and the subsequent German occupation, that is from November 1, 1940 till October 31, 1944, when the building of the University (on a special tower of which stood the anemograph of the met. station (Mariolopoulos [15] No. 1) Kyriazopoulos [7] No. 12) while the anemograph itself was destroyed during the retreat of the German occupation army.

A new anemograph, provided by the Greek National Meteorological Service *, began operating on the same site from January 1, 1950: Thus from the 41 years that elapsed since the installation of the first anemograph, we have only 31 full years of continuous operation, upon which our research has been based (1930-39 and 1950-71).

Also during the 31 years of operation there have occured :

a) Interruptions of the clockwork (drum) of the anemograph, mainly due to mechanical damage.

b) Interruption of the anemograph's operation, due to freezing of the water inside the float chamber, in cases of severe cold spells in the area of Thessaloniki, when current failures also occur, because aerial power lines are destroyed by heavy loads of ice and snow.

We give below Table I, containing two columns : the figures in the first column give the hours, per month, when the anemograph stopped operating, while figures in the second are the possible hours of operation.

TABLE I

Hours lost and possible hours of operation of Dines anemograph per month (M.S./AUT, period 1931 - 1939 & 1950 - 1971)

	Hours lost	Possible hours of operation
J	316	23.064
F	106	21.000
M	54	23.064
A	104	22.320
M	116	23.064
J	105	22.320
J	165	23.064
A	727	23.064
S	101	22.320
O	84	23.064
N	25	22.320
D	143	23.064
T	2046	271.668

It should also be mentioned herewith that, from January 1, 1931 till December 31, 1958 the two afore meutioned anemographs operated upon the tower of the old building of the University (Mariolopoulos[15] No. 1), with their head placed at a height H=53.5 m above M.S.L. From January 1, 1959 the anemograph was shifted to the new meteor. station, inside the campus, at a distance of some 150 m to the east

* All anemographs have been Dines pressure-tube anemographs : the first two (1931 & 1950) manufactured by Steffens-Hedde (Hamburg), and the third (1958) by C. F. Casella (London)

of its old position. The transmitter has been placed on a special steel mast (manuf. by Casella) erected upon a specially built hut, within the enclosure of the met. station. The head of the anemograph stands at a height H = 42.2 m above M. S. L. (Livadas [13]). This shifting was so slight, that the observational series has been considered continuous, and measurements as held in the same location.

A. Mean and extreme values of wind velocity.

a. Annual Mean.

The annual mean, as well as maximum and minimum wind velocity in the city of Thessaloniki, have as follows :

TABLE II

Annual maximum	2.80 m/sec (1935)
Annual mean	1.77±0.41
Annual minimum	1.25 m/sec (1950)

Annual mean wind velocities, are distributed as follows :

2.50 — 2.99 m/sec	2 years
2.00 — 2.49 m/sec	5 years
1.50 — 1.99 m/sec	13 years
1.01 — 1.49 m/sec	11 years

b. Monthly wind velocities.

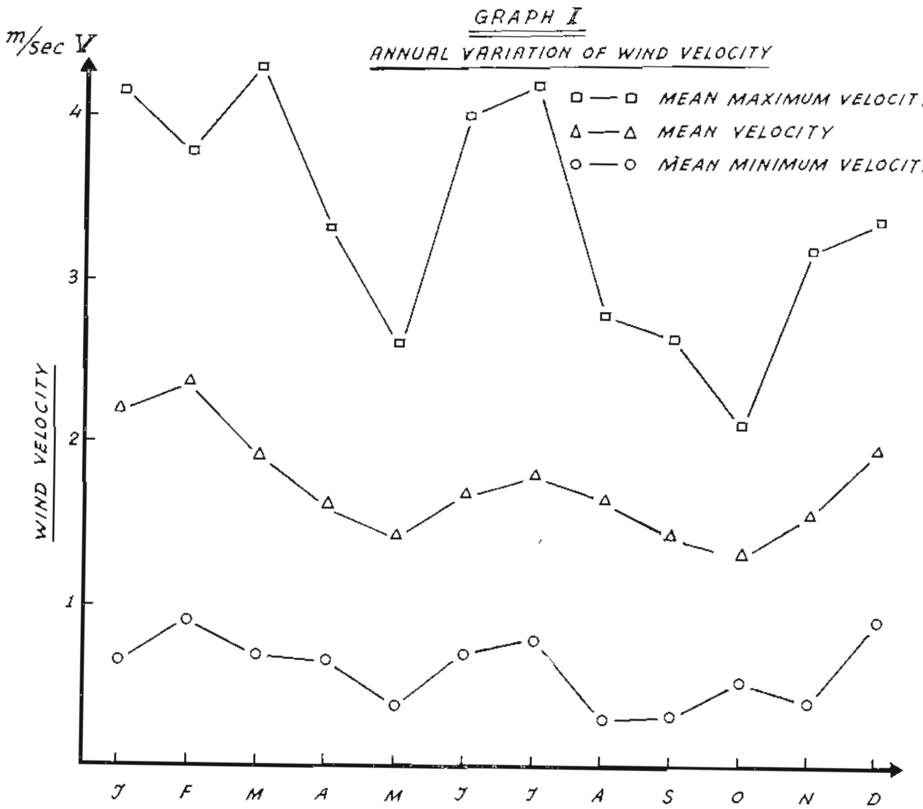
Monthly mean maxima, monthly mean, and monthly mean minima of wind velocity are given in Table III.

TABLE III

Monthly mean maxima, monthly mean and standard deviations (± σ), and monthly mean minima of wind velocity in Thessaloniki (period 1931-1939 & 1950-1971)

Month	Mean-max	Year	Mean	S.D.± σ	Mean-Min	Year
J	4.20	1935	2.20	0.68	0.58	1939
F	3.82	1934	2.37	0.86	0.87	1950
M	4.32	1935	1.94	0.79	0.70	1954
A	3.34	1933	1.63	0.61	0.58	1968
M	2.66	1961	1.47	0.48	0.39	1968
J	4.04	1969	1.69	0.68	0.72	1968
J	4.25	1970	1.81	0.71	0.83	1950
A	2.81	1969	1.64	0.69	0.29	1967
S	2.69	1931	1.44	0.60	0.33	1967
O	2.18	1936	1.34	0.41	0.56	1964
N	3.27	1953	1.60	0.63	0.42	1966
D	3.42	1931	1.99	0.69	0.92	1958
	4.32	1935	1.77		0.29	1967

From Table III and the adjoined Graph I, we conclude that the monthly mean wind velocity has a double fluctuation, with a primary maximum of $\geqq 2$ m/sec during the cold season (December - February) and a secondary maximum during the warm season (June-August).



This double fluctuation is mainly due to the following causes :

I. During the cold season transitory anticyclones moving along the main axis of Europe, produce strong north component winds.

II. Again, we have strong north component winds from the ridges of the Siberian high over the area of Balkans and Greece.

Also the local relief (Axios river valley) facilitates the development of north component winds, such as the Vardaris wind.

III. The cold Balkans mainland, with comparatively high pressures, and the warm Mediterranean - Aegean Sea, with its transitory lows, produce strong pressure gradients during the cold season.

IV. During the warm season, the ridge of the Azores high, combined with troughs from the Middle East (South Asia - Monsoon Low), produce the etesian winds prevailing in summer.

TABLE IV

Frequency of monthly wind velocities
(Period 1931 - 1939 & 1950 - 1971)

Beaufort scale	J	F	M	A	M	J	J	A	S	O	N	D
0	—	—	—	—	—	—	—	—	—	—	—	—
1	7	7	10	13	19	17	13	14	18	22	16	9
2	23	19	19	18	12	13	17	17	13	9	15	21
3	1	5	2	—	—	1	1	—	—	—	—	1

As to the distribution of monthly values, from Table IV we observe that it follows the curve of annual velocity variation, having months with 3 Beauforts wind force during the winter, from December to March, and the two summer months of June and July (4-months cold season and 2-months warm season).

As to the distribution of monthly mean wind velocities in the interval $\overline{X}$-3σ to $\overline{X}$+3σ, it has as per the following Table V :

TABLE V

—3σ		—2σ		—σ		0		+σ		+2σ		+3σ	
	2		59		136		118		45		9		3

The above Table V shows that 197 months, out of a total 372 (53.0%) have negative deviations and 175 months (47.0 %) have positive deviations, while 3 months (March 1935 with mean monthly velocity 4.32 m/sec, June 1969 with monthly mean velocity 4.04 m/sec, and July 1969 with monthly mean velocity 4.25 m/sec) or 0.81 % have positive deviations > + 3σ.

c. Diurnal Variation.

The diurnal variation of wind velocity in the city of Thessaloniki is illustrated in the adjoined Table VI and Graphs II - XIII.

Here we observe that as a rule, the diurnal variation acquires its peak values in the early afternoon hours (15:00 - 17:00 h) while minima occur during the night, from 20:00 to 08:00 hours, meaning that wind velocity increases with air temperature.

The mean range of the diurnal variation of wind velocity is < 1.0 m/sec during the cold semester from October to March (although

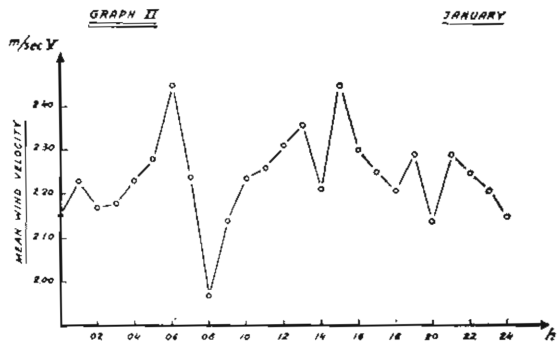
TABLE VI

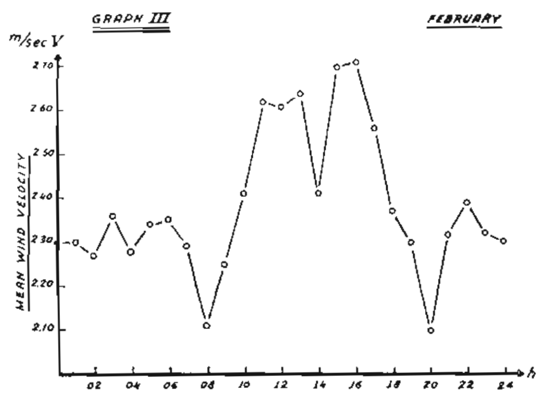
Diurnal variation of wind velocity (in m/sec) (period 1931 - 39 & 1950 - 71)

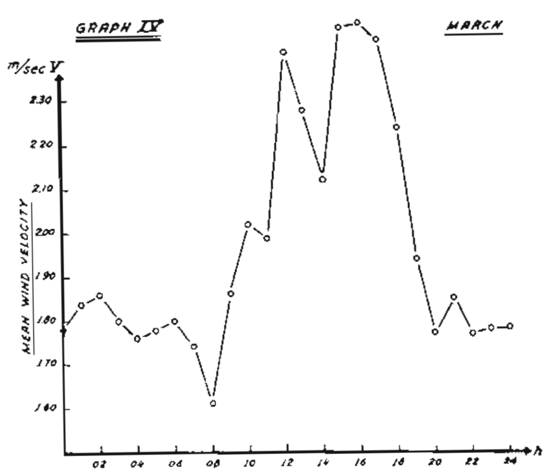
Month/Hours	1	2	3	4	5	6	7	8	9	10	11	12
J	2.23	2.17	2.18	2.23	2.28	2.45	2.24	1.97	2.14	2.24	2.26	2.31
F	2.30	2.27	2.36	2.28	2.34	2.35	2.29	2.11	2.25	2.41	2.62	2.61
M	1.84	1.86	1.80	1.76	1.78	1.80	1.74	1.61	1.86	2.02	1.99	2.41
A	1.14	1.22	1.18	1.19	1.20	1.24	1.33	1.19	1.45	1.69	1.79	1.97
M	0.96	0.96	0.94	0.95	0.93	0.89	0.95	1.02	1.24	1.54	1.72	1.90
J	0.99	0.96	0.99	0.98	0.98	0.99	1.11	1.20	1.50	1.75	1.89	2.13
J	1.24	1.30	1.26	1.28	1.25	1.16	1.24	1.28	1.53	1.68	1.87	2.23
A	1.20	1.25	1.29	1.24	1.27	1.18	1.24	1.17	1.35	1.43	1.62	1.88
S	1.13	1.17	1.23	1.27	1.22	1.17	1.32	1.06	1.36	1.42	1.56	1.76
O	1.19	1.23	1.19	1.13	1.18	1.19	1.23	1.13	1.27	1.39	1.50	1.60
N	1.64	1.64	1.59	1.58	1.62	1.51	1.50	1.42	1.56	1.55	1.67	1.70
D	2.02	2.03	2.08	1.95	1.95	1.92	1.81	1.69	1.80	1.89	1.94	2.08

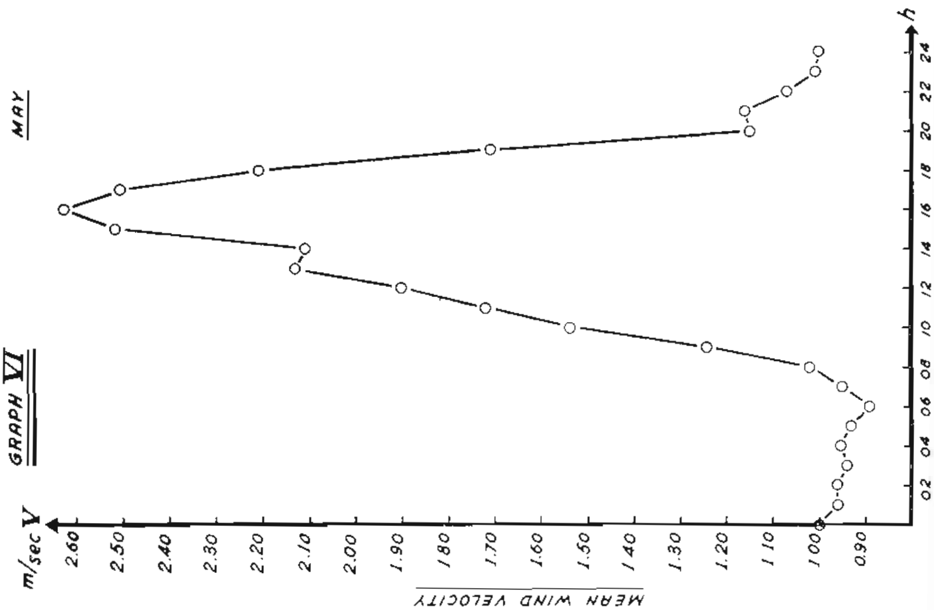
Month/Hours	13	14	15	16	17	18	19	20	21	22	23	24	MAX-MIN
J	2.36	2.21	2.45	2.30	2.25	2.21	2.29	2.14	2.29	2.25	2.21	2.15	0.48
F	2.64	2.41	2.70	2.71	2.56	2.37	2.30	2.10	2.32	2.39	2.32	2.30	0.61
M	2.28	2.12	2.47	2.48	2.44	2.24	1.94	1.77	1.85	1.77	1.78	1.78	0.87
A	2.14	2.10	2.45	2.55	2.54	2.29	1.82	1.32	1.38	1.30	1.25	1.15	1.37
M	2.13	2.11	2.52	2.63	2.51	2.21	1.71	1.15	1.16	1.07	1.01	1.00	1.74
J	2.36	2.40	2.94	3.10	3.08	2.69	2.24	1.48	1.41	1,23	1.17	1.06	2.14
J	2.63	2.45	3.04	3.07	3.06	2.76	2.33	1.55	1.34	1.32	1.27	1.20	1.91
A	2.07	2.21	2.63	2.76	2.76	2.52	2.00	1.33	1.21	1.16	1.13	1.14	1.63
S	1.98	1.93	2.33	2.33	2.22	1.91	1.51	1.14	1.14	1.11	1.09	1.08	1.27
O	1.60	1.59	1.68	1.62	1.56	1.37	1.29	1.14	1.24	1.19	1.20	0.96	0.72
N	1.71	1.61	1.76	1.62	1.59	1.55	1.58	1.48	1.58	1.62	1.60	1.62	0.38
D	2.12	1.97	2.25	2.16	2.03	2.00	2.05	1.87	2.02	1.97	1.98	2.03	0.56

DIURNAL VARIATION OF WIND VELOCITY

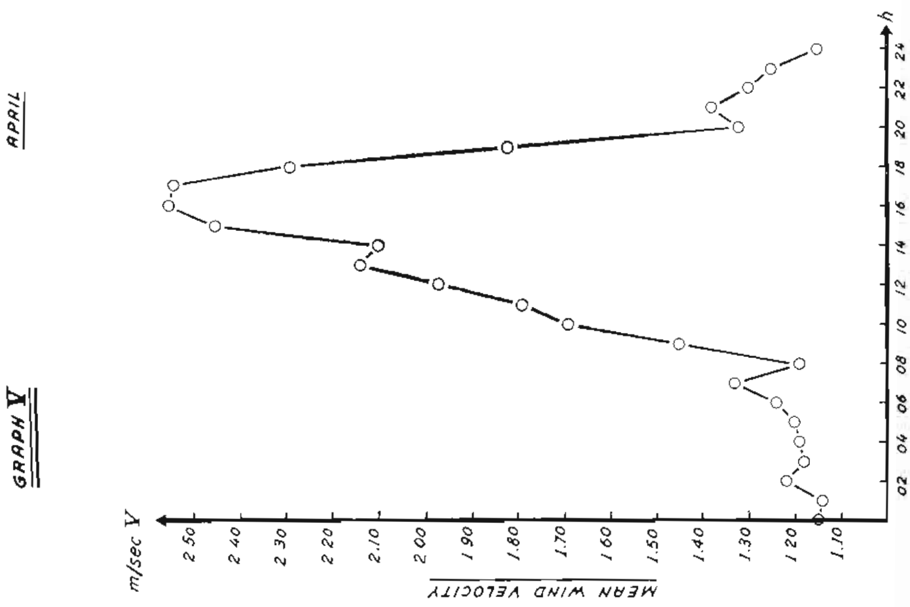




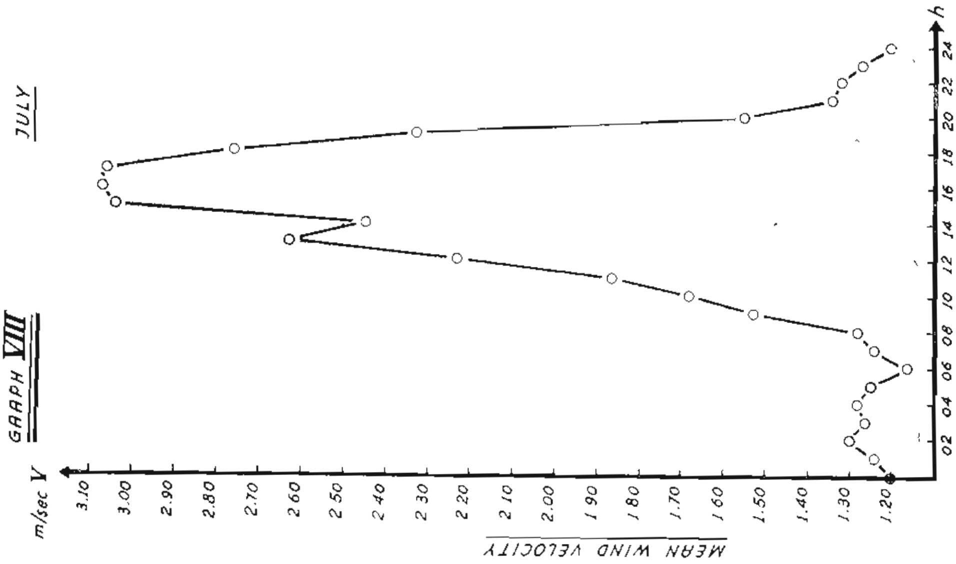


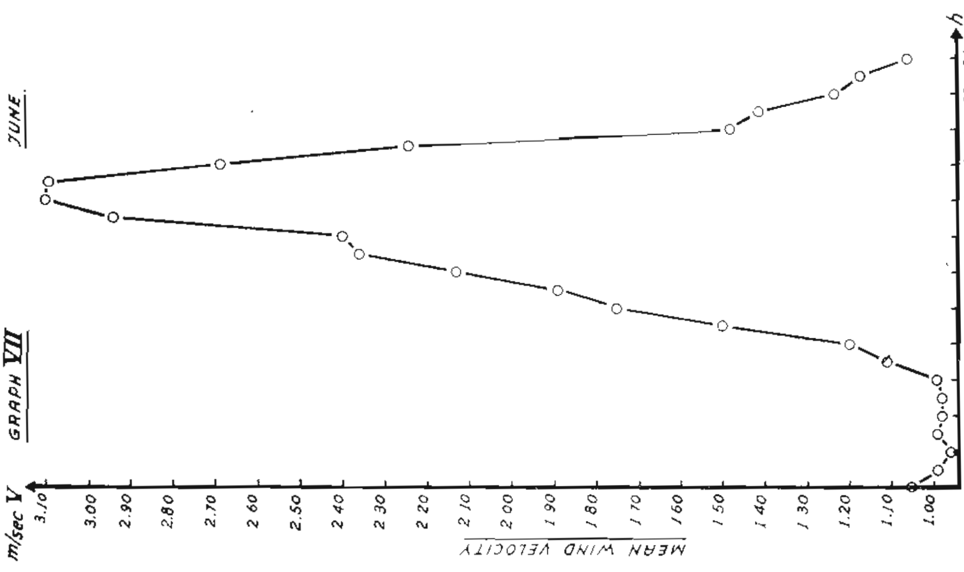


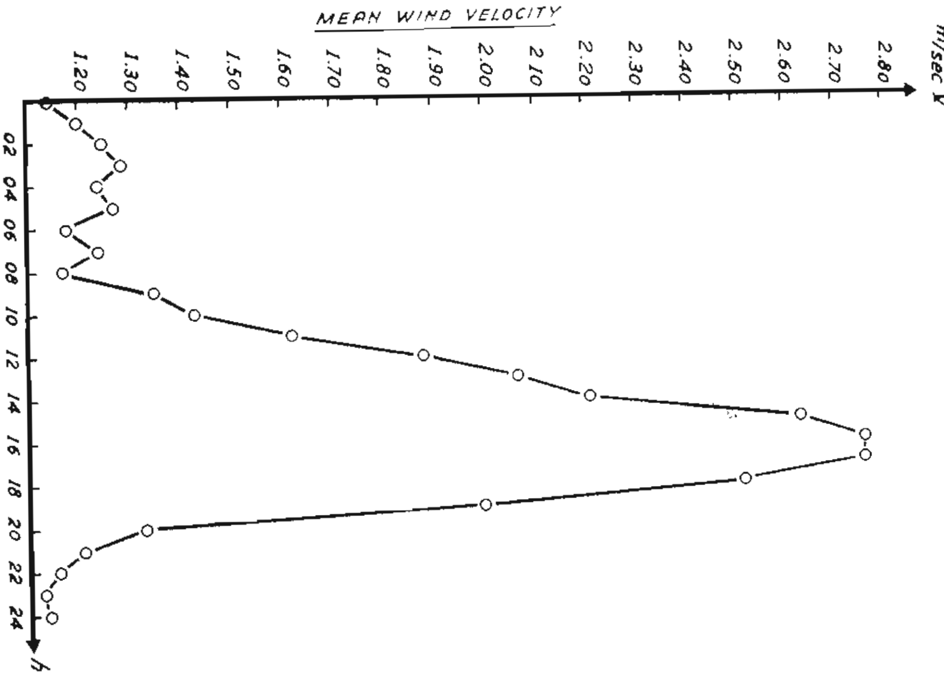
GRAPH VI
MAY
m/sec V
2.60
2.50
2.40
2.30
2.20
2.10
2.00
1.90
1.80
1.70
1.60
1.50
1.40
1.30
1.20
1.10
1.00
0.90
MEAN WIND VELOCITY
02
04
06
08
10
12
14
16
18
20
22
24
h



GRAPH V
APRIL
m/sec V
2.50
2.40
2.30
2.20
2.10
2.00
1.90
1.80
1.70
1.60
1.50
1.40
1.30
1.20
1.10
MEAN WIND VELOCITY
02
04
06
08
10
12
14
16
18
20
22
24
h

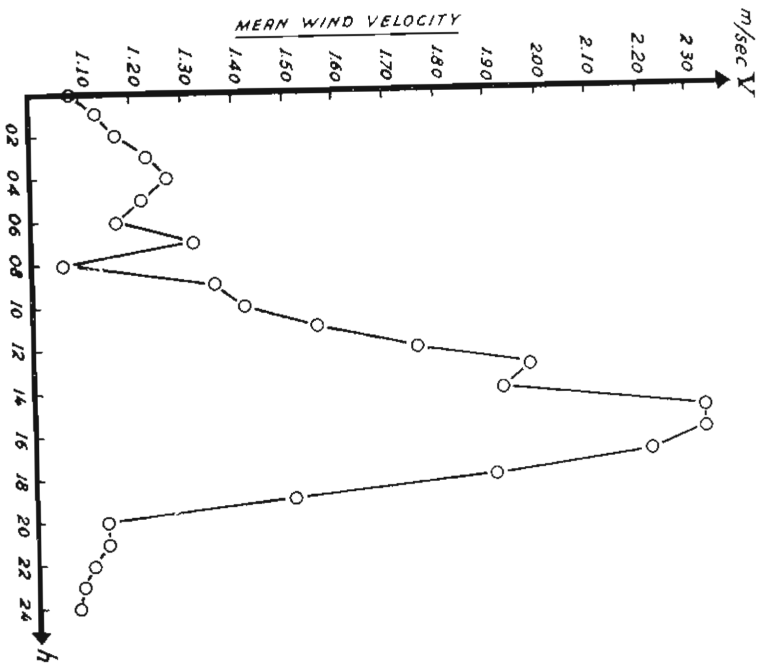

GRAPH VIII
JULY
m/sec V
MEAN WIND VELOCITY
3.10
3.00
2.90
2.80
2.70
2.60
2.50
2.40
2.30
2.20
2.10
2.00
1.90
1.80
1.70
1.60
1.50
1.40
1.30
1.20
02
04
06
08
10
12
14
16
18
20
22
24
h


GRAPH VII
JUNE
m/sec V
MEAN WIND VELOCITY
3.10
3.00
2.90
2.80
2.70
2.60
2.50
2.40
2.30
2.20
2.10
2.00
1.90
1.80
1.70
1.60
1.50
1.40
1.30
1.20
1.10
1.00
02
04
06
08
10
12
14
16
18
20
22
24
h



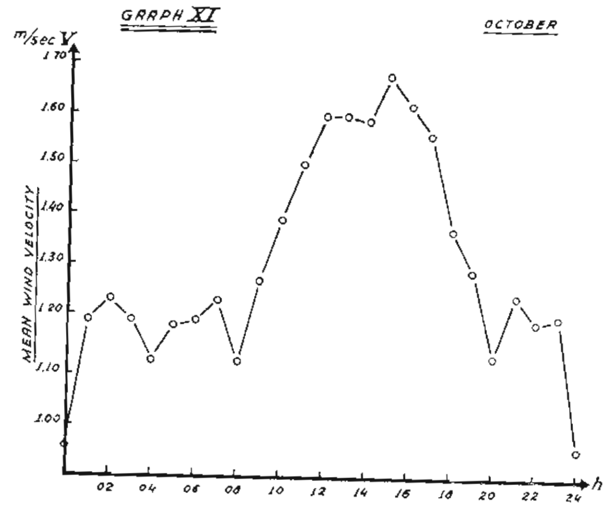
GRAPH IX

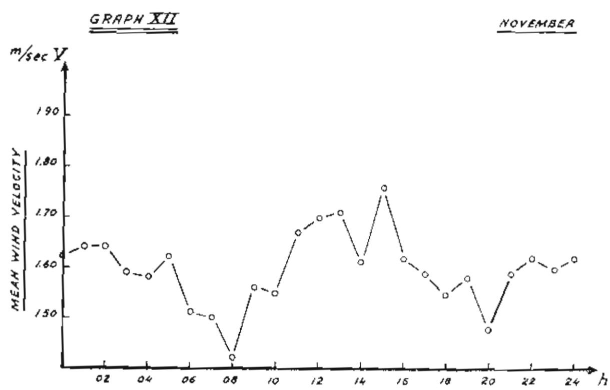
AUGUST

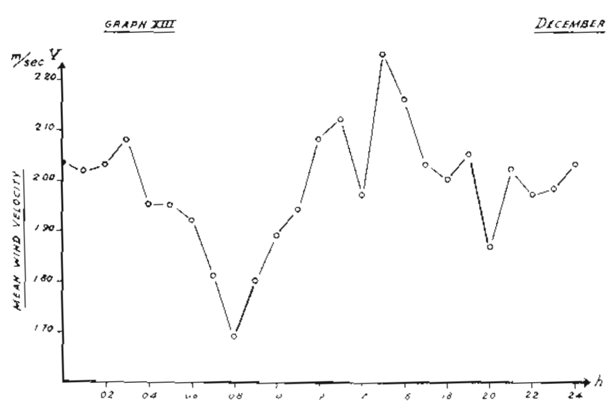


GRAPH X

SEPTEMBER


GRAPH XI
OCTOBER
m/sec V
MEAN WIND VELOCITY
1.70
1.60
1.50
1.40
1.30
1.20
1.10
1.00
02
04
06
08
10
12
14
16
18
20
22
24
h


GRAPH XII
NOVEMBER
m/sec V
MEAN WIND VELOCITY
1.90
1.80
1.70
1.60
1.50
02
04
06
08
10
12
14
16
18
20
22
24
h


GRAPH XIII
DECEMBER
m/sec V
MEAN WIND VELOCITY
2.20
2.10
2.00
1.90
1.80
1.70
02
04
08
18
20
22
24
h

velocities are higher then); this range becomes > 1 m/sec during the warm season from April to September and becomes maximum in June (2.14 m/sec).

This is due to the fact that while winds blowing in winter are caused by general dynamic factors, such as the passage of low or high pressure centers, and while the hour of their arrival - beginning is not related to any particular time of day, in the summer winds prevailing (as to frequency) in the coastal area of Thessaloniki, are sea - breezes, that is daytime winds, starting, according to the temperature difference between sea surface and the adjacent land, around 10:00-12:00 hours and acquiring their maximum velocities at the times when air temperatures also reach their maximum, that is between 15:00 and 16:00 hours; this is also the time when convective currents are stronger and air masses are lighter near the ground, because of increased temperatures. Sea breezes usually stop around 19:00 - 20:00 hours.

The effect of sea breezes upon the diurnal variation of wind velocity is characteristic (see Table VI): thus starting from velocities ~ 1 m/sec around 06:00 hours during the April - September semester, it rises to velocities > 2 m/sec at 12:00 hours during June and July, and at 13:00 h in April, May and August, and remains steady for 6-8 hours, with average velocities > 2 m/sec, while in September when sea-temperatures are highest, velocities exceed 2 m/sec around 15:00 hours, remaining at this comparatively high level for about 3 hours.

The distribution of daily mean values (24-hours mean) is given in the following Table VII, based upon data of 11.047 daily values.

Examining Table VII, we observe that the percentage of calms per year is 15.1 % and that winter months hold larger percentages of calms than months of the warm (April - September) season.

Daily values ≧ 6 Beaufort force occur only during the two months of maxima in the annual variation of wind velocity (see Graph I).

Consequently it can be maintained that, frequencies of daily values confirm the annual variation of wind velocity, and also that the coastal city of Thessaloniki has a comparatively small percentage of calms during the warm season, and this is due to sea-breezes, produced by the proximity of land and sea (Thermaikos Gulf).

d. Extreme Values.

The absolute maxima of wind velocity, that have been recorded in the city of Thessaloniki, are given in Table VIII.

Here again we observe that, velocities > 30.0 m/sec occur during the cold semester, while the absolute maximum of this observational

TABLE VII

Percentoge distribution of daily mean wind velocities in the city of Thrssalloniki.

Beauf. Scale	M/SEC	J	F	M	A	M	J	J	A	S	O	N	D	YEAR
7	13.86 - 17.15	0.11	—	—	—	—	—	—	—	—	—	0.11	0.10	0.03
6	10.76 - 13.85	0.63	0.23	0.52	—	—	0.22	0.31	0.11	—	—	0.22	0.21	0.20
5	7.96 - 10.75	1.89	2.53	1.14	0.86	0.10	0.75	0.94	0.64	0.54	0.21	1.08	1.88	1.04
4	5.46 - 7.95	9.05	9.87	6.25	3.24	1.87	2.58	3.97	3.32	1.73	2.71	4.30	7.43	4.79
3	3.36 - 5.45	15.15	16.53	11.46	7.67	6.46	7.42	7.94	7.29	6.99	6.45	11.08	12.55	9.73
2	1.56 - 3.35	19.47	22.85	22.92	23.43	23.44	25.59	27.32	24.33	20.14	21.23	17.29	20.19	22.38
1	0.26 - 1.55	30.84	28.13	43.13	56.91	60.73	58.60	55.19	53.70	58.11	46.61	37.64	32.75	46.70
0	0.01 - 0.25	15.15	11.36	9.79	5.94	5.21	4.30	3.76	7.50	10.76	15.71	16.02	13.70	9.94
C	CALME	7.71	8.50	4.79	1.95	2.19	0.54	0.63	3.11	1.73	7.08	12.26	11.19	5.19

period has been recorded on February 21, 1933 and was 40.0 m/sec, with E direction. This was a katabatic wind from the near-by Chortiatis mountain (elev. 1201 m, horizontal distance 13.0 km).

TABLE VIII

Absolute maxima of wind velocity in Thessaloniki (m/sec).

	Maximum		Mean	
Month	M/sec	Date	M/sec	S.D. $\pm \sigma$
J	35.0	17 - 1 - 57	2.20	0.68
F	40.0	21 - 2 - 33	2.37	0.84
M	28.8	31 - 3 - 35	1.94	0.79
A	25.5	14 - 4 - 32	1.63	0.61
M	26.8	16 - 5 - 33	1.47	0.48
J	25.0	22 - 6 - 69	1.69	0.68
J	28.0	30 - 7 - 55	1.81	0.71
A	23.1	20 - 8 - 68	1.64	0.69
S	23.2	15 - 9 - 33	1.44	0.60
O	30.5	26 - 10 - 39	1.34	0.41
N	30.6	13 - 11 - 32	1.60	0.63
D	30.0	9 - 12 - 35	1.99	0.69
Y	40.0	21 - 2 - 33	1.76	

A study of all the daily maxima of wind velocity, for the 11.047 days of the period examined, leads to the following observations :

1. It is possible for wind velocities higher than gale force (Beaufort scale) to occur during the whole year. Nevertheless the largest percentage of gales has been recorded during the cold season, mainly between November and April; the percentage of gales has a second peak in the month of July.

2. On the other hand it is also possible during the cold season, and especially during the November - February interval, for the 24-hours maximum to remain in the grade of calm, for a percentage of cases $\geqq 7$ %. This percentage becomes < 0.5 % in June and July, meaning that it is quite rare during the warm season for a whole day to pass with wind velocity staying in the calm grade (0 Beaufort force). This is due to the fact that, even when the characteristic summer winds do not blow, sea-breezes do.

During this 31-year period there have been recorded in all 416 cases of gale, that is cases when wind velocity reached or exceeded 8 Beauforts force.

Table X shows that 9 Beauforts wind force may be recorded in every month of the year, while forces above $\geqq 11$ Beauforts, that is

TABLE IX

Percentage distribution of maximum wind velocities in Thessaloniki.

Beauf. scale	M/SEC	J	F	M	A	M	J	J	A	S	O	N	D
13	36.96 - 41.45	—	0.12	—	—	—	—	—	—	—	—	—	—
12	32.66 - 36.95	0.11	0.12	—	—	—	—	—	—	—	—	—	—
11	28.46 - 32.65	0.00	0.00	0.10	—	—	—	—	—	—	0.10	0.22	0.22
10	24.46 - 28.45	0.32	0.58	0.52	0.22	0.10	0.33	0.42	—	—	0.21	0.32	0.32
9	20.76 - 24.45	1.48	1.16	1.15	0.54	0.21	0.76	0.52	0.43	0.75	0.10	0.86	1.53
8	17.16 - 20.75	4.01	5.09	3.02	2.60	1.36	1.63	2.51	1.70	1.19	1.67	2.15	4.13
7	13.86 - 17.15	8.65	9.36	6.66	5.18	4.29	5.74	5.55	5.05	3.99	3.35	5.69	7.27
6	10.76 - 13.85	14.77	15.72	9.20	7.69	7.91	9.43	9.22	9.67	6.26	8.34	8.92	11.49
5	7.96 - 10.75	13.82	16.19	18.42	14.52	16.51	19.17	16.54	12.87	14.13	13.45	14.09	15.70
4	5.46 - 7.95	13.29	14.80	16.35	24.92	27.46	28.60	25.86	25.35	21.03	17.83	14.09	15.07
3	3.36 - 5.45	10.76	9.26	18.42	26.11	25.74	24.45	27.33	25.23	26.86	18.35	12.79	9.68
2	1.56 - 3.35	11.08	11.90	16.04	13.33	13.06	8.88	10.89	14.72	18.88	18.98	15.91	11.91
1	0.26 - 1.55	14.13	8.32	6.68	4.01	1.99	0.81	0.84	2.58	3.78	11.89	14.73	13.07
0	0.01 - 0.25	1.16	1.04	0.73	0.22	0.10	0.00	0.00	0.11	0.43	0.42	0.32	0.95
	CALM	6.42	6.34	2.71	0.66	1.27	0.20	0.32	2.29	2.70	5.31	9.91	8.66

storms damaging trees and buildings, can be recorded during the cold season from October to March. A percentage of cases with velocities ≧ 10B is gathered again in the cold season, while a small peak occurs in July. On the contrary the months of May and September have the smallest percentage of gales.

TABLE X

Synoptic Table of cases with velocities ⩾ 8 Beauforts in Thessaloniki for the period between 1930 - 1939 and 1950 - 1971.

Beaufort scale	J	F	M	A	M	J	J	A	S	O	N	D	Total
13	—	1	—	—	—	—	—	—	—	—	—	—	1
12	1	1	—	—	—	—	—	—	—	—	—	—	2
11	—	—	1	—	—	—	—	—	—	1	2	2	6
10	3	5	5	2	1	3	4	—	—	2	3	3	31
9	14	10	11	5	2	7	5	4	7	1	8	14	88
8	38	44	30	24	13	15	24	16	11	15	20	38	288
Total	56	61	47	31	16	25	33	20	18	19	33	57	416
%	13	15	11	7	4	6	8	5	4	5	8	14	100

According to Table X, days of gale per month and per year have as in the following Table XI.

TABLE XI

Mean number of gales (≧8 Beauforts) per month in Thessaloniki (period 1931 - 39 & 1950 - 71)

J	F	M	A	M	J	J	A	S	O	N	D	Year
1.8	2.0	1.5	1.0	0.5	0.8	1.1	0.7	0.6	0.6	1.1	1.8	13.5

From the above two Tables we find that for this 31-year period, the mean per year number of days with gale is 13.5, the maximum is 50 cases in 1933, when also the three absolute maxima were recorded (see Table VIII). Minima with (0) value have occured in the years 1956, 1958, 1967.

As to the distribution of days with gale during the year, this coincides with the distribution of percentages of gales, meaning that the maximum occurs in the December - March quarter, the minimum in May, and there is a second peak in July.

Consequently we can assume that gale maxima occur during the highest activity of the Mediterranean branch of the polar front.

B. Wind Direction.

Taking the hourly readings of wind direction and velocity from the anemograph recordings of the meteorological station of the AUT, we can study the prevailing wind direction in the city of Thessaloniki, or better the frequency of each direction during the 1931-1971 period examined.

Here again the 1940-1949 decade has not been included, for the same afore mentioned reasons, and also the year 1965, when the mechanism recording wind direction was destroyed, and till it could be replaced, direction recordings were impossible.

Other interruptions have occured during the remaining 30 years, for reasons similar to those mentioned in the first chapter (Wind Velocity) (damages of clokwork etc.).

TABLE XII

Month	Hours lost	Possible hours of observation
J	131	22.320
F	93	20.330
M	17	22.320
A	11	21.600
M	330	22.320
J	310	21.600
J	129	22.320
A	118	22.320
S	10	21.600
O	84	22.320
N	28	21.600
D	47	22,320
Total	1308	262.970

The 262.970 hourly readings of wind direction - velocity, have been distributed per frequency of each direction (16 directions).

It should be mentioned that, the city of Thessaloniki should not be considered as a windy city, since the percentage of calms during the different months, varies between 44.54 % (July) and 56.88 % (October). Calm, especially during the nocturnal 12-hours, is the characteristic of Thessaloniki.

It is possible in a small percentage of cases (0.20 % in July, to 10.23 % in November - see Table IX) for the maximum wind velocity to remain in the (0) grade of the Beaufort scale (0.00-0.25 m/sec). Such cases may occur during every month of the year. This fact is illustrated in the following Table XV, in which we have included all the 479 days with maximum wind velocity of 0 Beauforts.

From Table XV we find that 15.4 (4.1 %) is the mean per year

TABLE XIII

Frequency (%) of wind direction in Thessaloniki
*Period 1931 - 1971 **

Direction Months	N	NNE	NE	ENE	E	ESE	SE	SSE	S
J	15.72	7.51	3.97	2.78	4.86	2.13	1.96	1.55	1.27
F	14.77	7.44	3.86	2.06	4.91	2.06	2.62	1.43	1.80
M	12.14	4.56	3.87	2.27	4.86	2.12	2.78	2.28	2.62
A	9.82	3.67	2.49	1.51	3.09	2.01	2.50	2.22	4.26
M	10.03	3.27	1.95	1.06	1.85	1.46	2.10	1.86	4.06
J	10.73	3.68	1.89	0.88	1.53	0.85	1.76	1.88	4.62
J	12.51	3.16	1.65	0.65	0.92	0.94	1.51	1.68	5.05
A	11.17	3.91	1.92	0.82	1.18	0.94	1.47	1.64	5.09
S	7.60	3.78	2.37	1.15	2.56	1.64	2.05	2.12	4.09
O	8.06	4.07	2.94	1.72	3.79	2.46	2.33	1.89	2.13
N	10.06	4.39	2.85	2.68	5.96	2.83	2.67	1.44	1.16
D	12.38	5.42	3.85	3.04	6.40	2.53	2.62	1.74	1.64
Year	11.25	4.57	2.80	1.72	3.49	1.83	2.20	1.81	3.15

Direction Months	SSW	SW	WSW	W	WNW	NW	NNW	C	
J	0.90	1.14	0.63	0.95	1.18	2.57	3.76	47.12	100.00
F	1.01	1.70	1.02	1.25	1.22	3.36	4.60	44.89	100.00
M	2.47	3.34	1.56	1.73	1.68	2.91	3.35	45.47	100.01
A	4.66	5.91	1.89	1.70	1.13	2.97	2.69	47.45	99.97
M	5.74	6.95	2.40	1.95	1.21	3.06	2.72	48.34	100.01
J	6.65	6.69	2.09	1.62	1.11	3.91	3.71	46.42	100.02
J	7.27	7.18	2.27	1.44	1.06	3.81	4.34	44.54	99.98
A	6.41	6.64	1.82	1.44	0.92	2.54	4.56	47.53	100.00
S	5.41	5.47	1.85	1.28	0.94	2.73	4.02	50.95	100.01
O	2.10	2.67	1.18	1.34	1.03	2.33	3.07	56.88	99.99
N	0.88	1.18	0.63	0.97	0.95	2.35	2.76	56.23	99.99
D	0.58	0.80	0.52	0.83	0.96	2.63	3.17	50.91	100.02
Year	3.67	4.14	1.49	1.38	1.12	2.93	3.56	48.89	100.00

* Missing data of years 1940 - 1949, and 1965 have not been taken into account.

number of days with complete calm; these days are assembled in the winter semester from October to March. During this period it is possible for high pressure systems to remain stationary over this area, producing weather conditions that were known to the ancient Greeks as «alcyone (or halcyon) days».

TABLE XIV

Frequency (%) of wind direction in Thessaloniki (Period 1931 - 1971) *

Direction / Months	N	NE	E	SE	S	SW	W	NW	C	
J	21.36	9.12	7.31	3.81	2.49	1.90	1.85	5.04	47.12	100.00
F	20.78	8.61	6.97	4.37	3.02	2.72	2.36	6.27	44.89	99.99
M	16.10	7.29	7.06	4.97	4.99	5.35	3.34	5.42	45.47	99.99
A	13.01	5.09	4.86	4.62	7.70	9.18	3.21	4.88	47.45	100.00
M	13.03	4.11	3.11	3.75	7.86	11.02	3.75	5.02	48.34	99.99
J	14.42	4.17	2.39	3.12	8.88	11.06	3.22	6.32	46.42	100.00
J	16.27	3.56	1.72	2.81	9.52	11.97	3.10	6.51	44.54	100.00
A	15.41	4.29	2.06	2.76	9.11	10.76	2.81	5.28	47.53	100.01
S	11.50	4.83	3.96	3.93	7.85	9.10	2.67	5.21	50.95	100.00
O	11.63	5.84	5.88	4.51	4.13	4.31	2.45	4.39	56.88	100.02
N	13.63	6.38	8.72	4.80	2.32	1.93	1.76	4.21	56.23	99.98
D	16.68	8.07	9.18	4.75	2.80	1.35	1.56	4.69	50.91	99.99
Year	15.32	5.95	5.27	4.01	5.89	6.72	2.67	5.27	48.89	99.99

* Missing data of years 1940 - 49 and 1965 have not been taken into account

The minimum of days with calm occurs in June and July; during these months we have a small decrease of hourly calms too. These, as already mentioned, are par excellence the months of the etesian winds,

TABLE XV

Days with maximum wind velocity O (Beaufort scale) or days of complete calm per month in Thessaloniki (1931 - 39 & 1950 - 71)

J	F	M	A	M	J	J	A	S	O	N	D	Year
2.3	2.0	0.9	0.3	0.4	0.06	0.1	0.7	0.8	1.8	3.0	3.0	15.4

and of almost continuous occurence of sea breezes.

The prevailing wind directions in the city of Thessaloniki, have as follows :

a. North component winds (NW - N - NE). These winds during the cold season are produced by high pressure systems mostly advancing on trajectories north of Thessaloniki ($\varphi = 40^0$). These north component winds include the local Vardaris wind (Alexandrou [1], Kyriazopoulos [6]), which usually blows as NNW, with its frequency equally distributed throughout the year.

During the summer season, winds blowing through this quarter, are the characteristic etesian winds of the Greek and East Mediterranean region.

b. Sea breezes that blow the whole year round, (Alexandrou [1]) with increasing frequency from winter to summer, and then decreasing again till December. The direction of sea breezes in Thessaloniki, varies between S - SSW - SW.

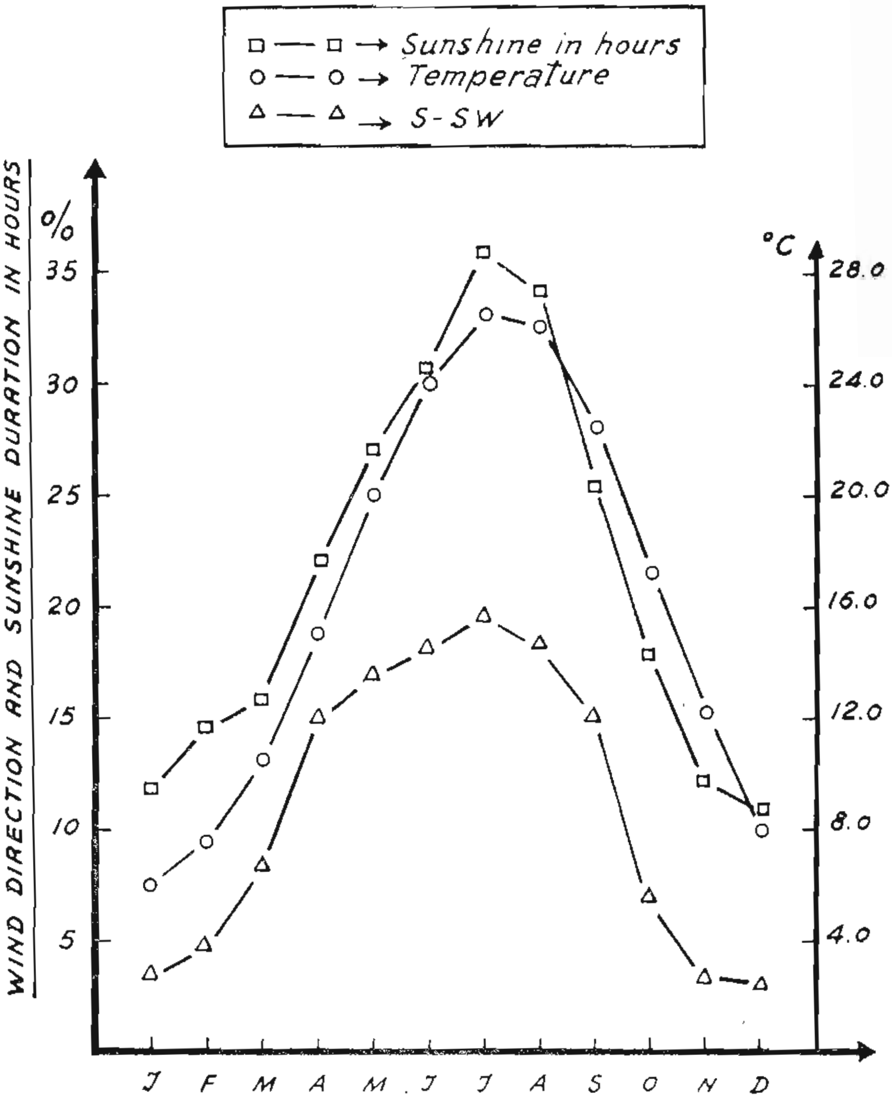
TABLE XVI

Frequency of the two prevailing wind directions in Thessaloniki.

	NW N NE (NNW NNE)	S-SSW-SW
J	33.53%	3.31%
F	34.03	4.51
M	26.83	8.43
A	21.64	14.83
M	21.03	16.95
J	23.92	17.96
J	25.47	19.50
A	24.10	18.14
S	20.50	14.97
O	20.47	6.90
N	22.41	3.22
D	27.45	3.02
Year	25.11	10.96

Data of Tables XIII and XVI prove that the frequency of sea breezes increases considerably (becoming sixfold) from December - January till the May-August quarter, and then starts decreasing to reach its minimum in December - January. If we want to compare the annual variation of sea breezes' occurence (Graph XIV) we find that its course is similar to the annual variation of air temeperature, while its curve of annual variation is almost identical with that of sunshine duration in Thessaloniki [10,12], that is the amount of insolation (incoming solar radiation), and that of annual variation of air temperature. If we consider that the main cause of sea breezes is the temperature difference between land t_e and sea surface t_s, the larger the amounts

GRAPH XIV


□ — □ → Sunshine in hours
○ — ○ → Temperature
△ — △ → S-SW
WIND DIRECTION AND SUNSHINE DURATION IN HOURS
%
35
30
25
20
15
10
5
°C
28.0
24.0
20.0
16.0
12.0
8.0
4.0
J F M A M J J A S O N D

of insolation the greater the frequency and intensity of sea breezes.

On the other hand the frequency of north component winds with its double fluctuation curve, is due to more general dynamic factors (effect of the Azores high in summer, and transitory anticyclones are ridges from the Siberian high).

CONCLUSIONS.

The study of the element of wind (direction and velocity) in the city of Thessaloniki for the 1931-1971 period, leads to the following conclusions :

1. The annual mean of wind velocity shows a decreasing trend, if we compare the 1930-1939 decade, before the second World War, with the following decades.

We attribute this fact to the continuous expansion of the city, horizontally as well as in height of buildings, especially after the year 1950. It should be noted that the main part of the city of Thessaloniki, stands to the north and west of our meteorological station, and tbe increase of the buildings' heigbt resulted in the decrease of wind velocity in the meteor. station of the A. U. T.

Kyriazopoulos[6] studying data of wind from this met. station of the University of Thessaloniki for the 1931-1937 period (7years) finds an annual mean wind velocity of 2.3 m/sec. While the study of wind velocities in the present work, covering the 1931-1971 period and using 31 full observational years, from this same met. station, resulted in an annual mean wind velocity of 1.77 m/sec. This difference should be attributed to the aforementioned fact that, the two-or three-storeyed buildings of the city, have been replaced after 1950 by eight - storeyed buildings, 28-30 m high, that is equally high or even higher than the opening of the anemograph' s head. Also the buildings have been agglomerated into blocks, thus forming a barrier against north and west component winds.

On the contrary the south section is the least affected by block buildings, because the whole area of the University Campus, and the International Fair of Thessaloniki, together with the municipal Park remain independent and free of the city planning, and thus the building of separate edifices and not continuous blocks has been maintained here.

2. A similar effect is observed in high values of wind velocity : Table XVII contains a comparative list of days with gale (cases with wind force $\geqq$ 8 Beauforts).

Numbers of days with «strong wind» (as they were characterized during the 1899-1911 period (Alexandrou [1]), when Thessaloniki still was a middle - eastern type of town, with 50.000-60.000 inhabitants, are followed by the numbers of days with gale from the met. station of the A. U. T., mentioned by Alexandrou [1] and Kyriazopoulos [6]; these numbers resemble each other, and also those mentioned by us in the first column of this Table for the 1931-1939 period in the same station. On the contrary, the second column of ours, covering a period of 31 observational years (including the 1931-39 interval) is representative of a Balkan city of 100.000-120.000 inhabitants. This column indicates a considerable decrease in the annual mean as well as in the monthly

TABLE XVII

Mean per month number of days with gale ($\geq 8B$) in Thessaloniki according to different authors.

	ALEXANDROU (1)		KYRIAZOPOULOS (6)	LIVADAS-SAHSAMANOGLOU	
	Bulgarian met. St. 1899-1911	A.U.T. 1930-32	A.U.T. 1931-37	A.U.T. 1931-39	A.U.T. 31 years
J	6.1	2.0	2.5	2.4	1.8
F	5.1	3.0	3.7	4.0	2.0
M	5.5	3.0	3.0	3.3	1.5
A	3.1	2.0	2.0	2.4	1.0
M	1.5	0.5	0.6	0.9	0.5
J	3.3	1.3	1.1	1.4	0.8
J	2.1	1.7	1.3	2.1	1.1
A	3.0	0.7	0.9	0.8	0.7
S	1.9	0.7	0.6	0.8	0.6
O	2.3	1.7	0.9	1.6	0.6
N	3.9	3.0	1.9	2.0	1.1
D	3.9	1.7	1.9	3.0	1.8
Year	41.6	19.5	20.1	24.7	13.5

mean numbers of gales (the city has reached now the level of european cities, with 600.000 inhabitants). Also both periods (1931-39 and 1931-71) show the same annual variation (double fluctuation), with the only difference that the longer period is reduced as compared with that of 1931-39.

3. The annual variation of wind velocity has a double fluctuation, with a primary maximum in the main winter season from December to February, and a secondary maximum during the main summer season,

from June to August. The 1931-37 period, studied by Kyriazopoulos [6], had a similar variation.

The number of days with gale has an analogue variation. Causes, as already mentioned, are that the north component winds, which consist 1/4 of the prevailing in the area winds, are due :

a. During the cold season, to anticyclonic systems (moving along trajectories > 45° N (Livadas [8]), or to ridges of the Siberian high (Mariolopoulos [14], Livadas [8,9], Karalis [3]).

A special case of north component wind, is the local wind V a r d a r i s, which blows quite often in this area. Because of its importance this local wind has been studied by quite a number of research workers, (i. e. Kuhlbrodt [4,5], Alexandrou [1], Mariolopoulos [15], Kyriazopoulos [6], Livadas [9] et al.).

b. During the warm season prevail the etesians, starting late in May with the precursor etesians, and later- on the typical etesians (Aristoteles [2], and many others ever since). These winds blow till the end of September, depending purely on the pressure patterns of the North Hemisphere, and mainly on the association of the positions and intensity of the Azores high aud the low pressure area of southern Asia (Monsoon low), during the May-September interval.

The above two independent categories of north component winds, produce the double fluctuation in the annual variation of wind velocity (Tables III, VII, VIII, XV, Graph I) as well as that of wind direction (Tables XIII, XIV, XVI, Graphs II-XIII).

4. The effect of the city in decreasing wind velocities, resulted in increasing the number of calms. Comparing our frequencies of wind direction with those mentioned by previous researchers, using met. data before 1940 (Tables XVI and XVII) we observe a considerable increase in the percentage of calms from the 1892-1929 period (27.9 % to 48.9 %) as well as for the 1931-37 (from 26.4 % to 48.9 %). On the other hand, both pre-war intervals (before 1940) almost coincide as to the frequency of calms (27.9 % - 26.4 %).

We should also point out the decrease in the frequency of south component winds : Alexandrou [1] and Mariolopoulos [14] characterize as prevailing wind direction for the March to October interval during the 1892-1929 period, the SW winds, and they consider N winds as prevailing only during the cold season; on the other band Kyriazopoulos [6], studying data from the met. station of the Aristotelian University (A.U.T.), finds as prevailing wind direction for the 1931-37 period that of N component winds from October till March, and again in July and

August, and only in April-June and September the SW direction.

On the contrary, in the present work, the frequency of N component winds is higher than that of SW in every month of the year, and gets even higher during the cold season.

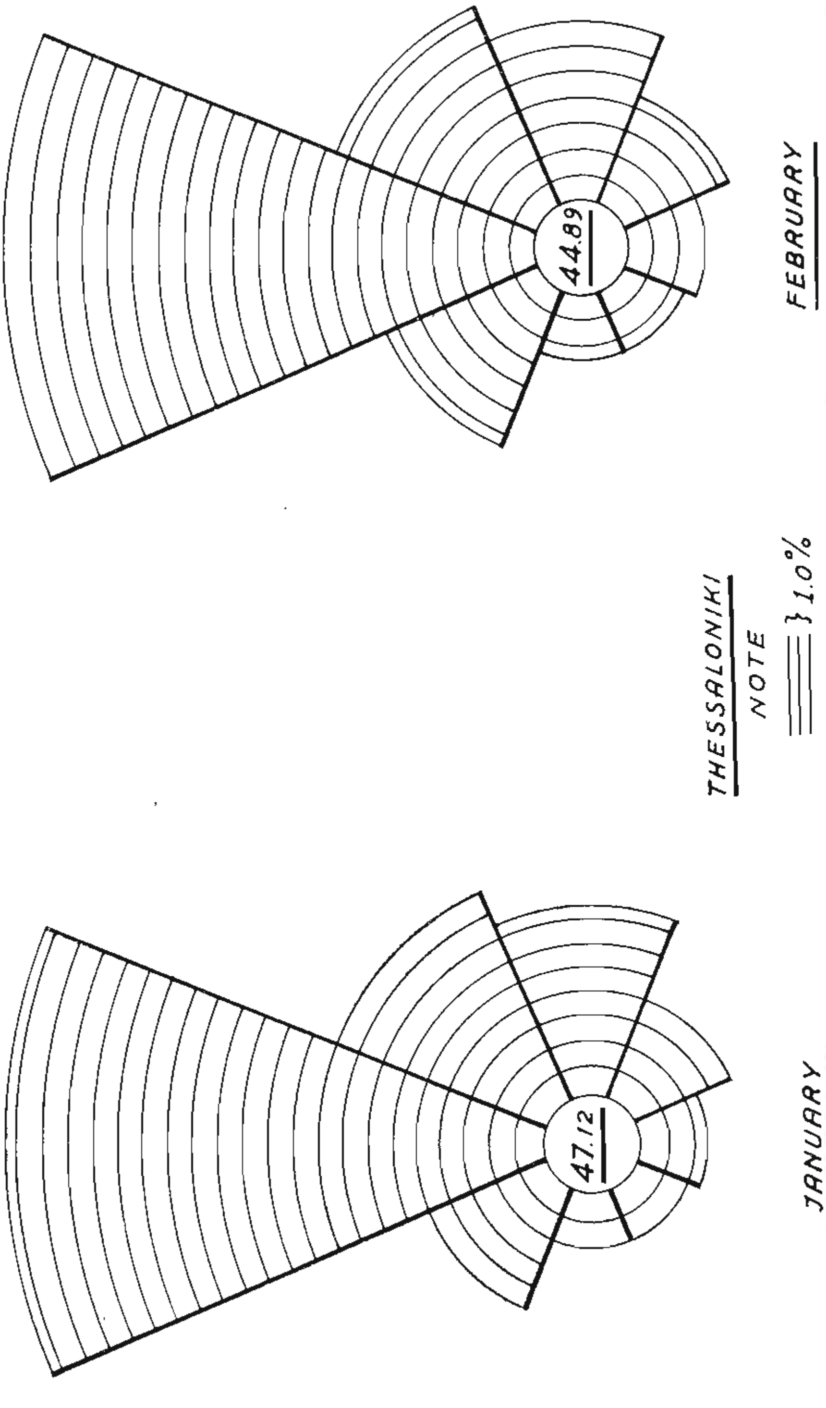
5. Calms, covering 2/4 of all hourly observations (48.9 % mean yearly), are of paramount importance. Calm is a characteristic of the nocturnal 12-hours (20:00 to 08:00h) in the city of Thessaloniki. This is perhaps the cause «par excellence» of an extremely unpleasant and undesirable climatic feature. Especially during the cold season, when the high relative humidity, frequent temperature inversions, and frequent fogs keeping in the near the ground layer the whole amount of pollutants of a rather developed industrial area, and the consequent atmospheric pollution from the traffic of all kinds of vehicles and the heating installations of a city of 1.000.000 inhabitanits, lend to the city of Thessaloniki the character of a city much more infected than should be expected.

6. On the other hand, a rather favorable climatic factor for this city, are sea breezes.

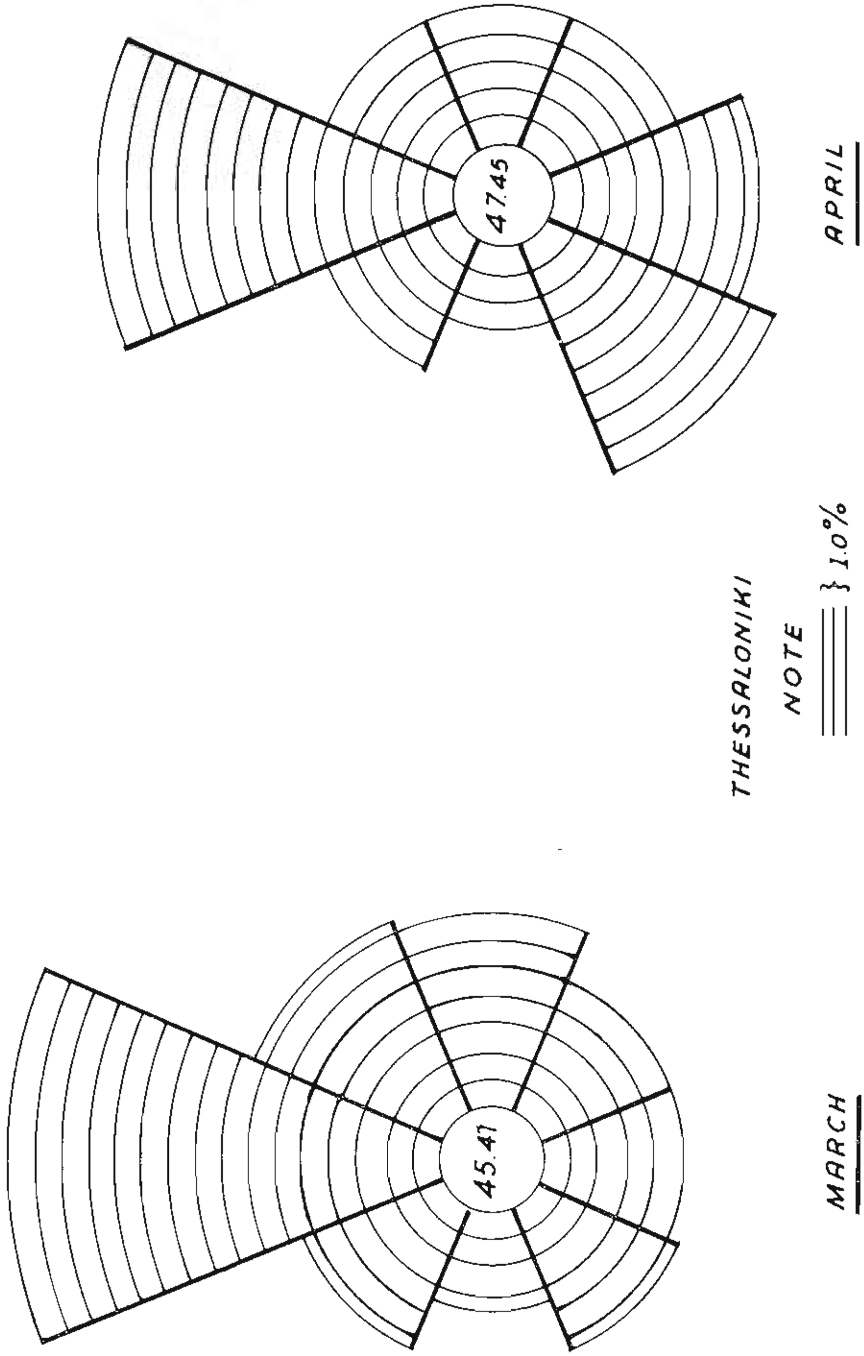
It should be mentioned that, the city of Thessaloniki is built on the northern coast of Thermaikos Gulf, and continues to spread on both sides, tending to form a semi-circle around the inner Thermaikos.

Sea breezes blow here the whole year round; however their maximum frequency occurs in the warm season, when sea breezes moderate the summer heat.

The direction of sea breeze in the semi-circular city of Thessaloniki, varies from one observational site to another, and so does its starting and ending time. This perhaps accounts, up to a point, for the decrease in the frequency of SW wind directions. Yet as a further investigation of the problem of sea breezes is out of the scope of the present paper, we shall not go any further into this question.



44.89
FEBRUARY
THESSALONIKI
NOTE
} 1.0%
47.12
JANUARY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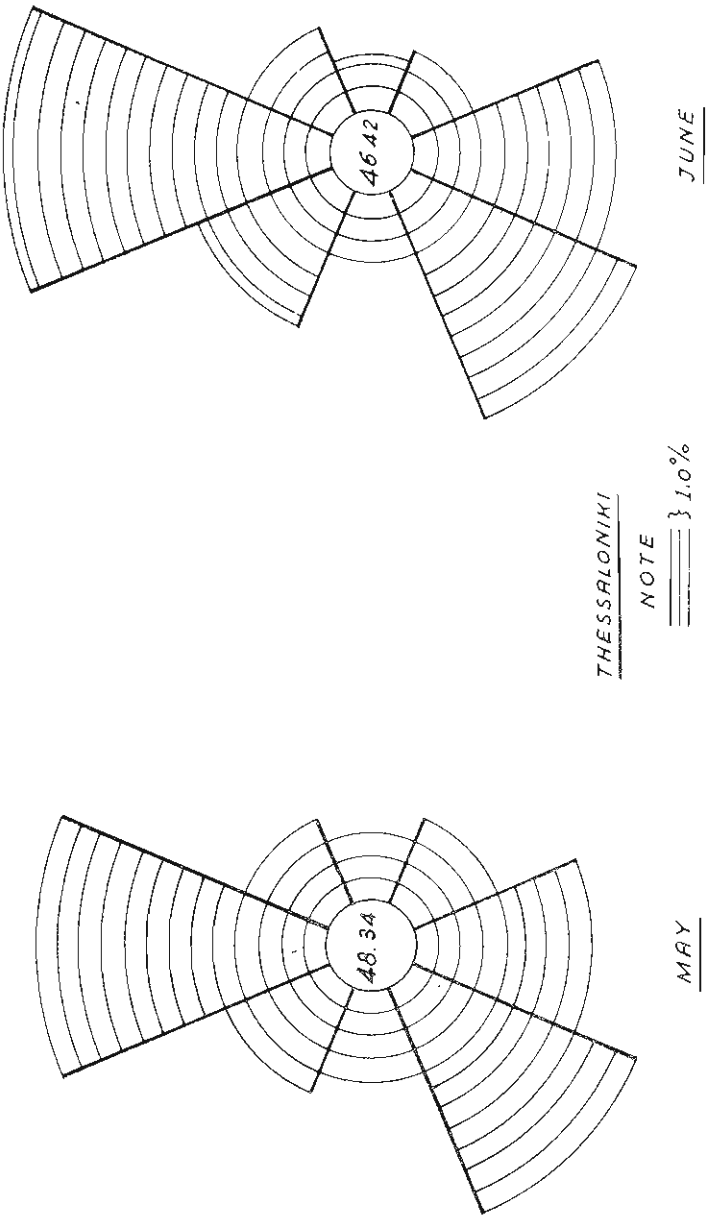
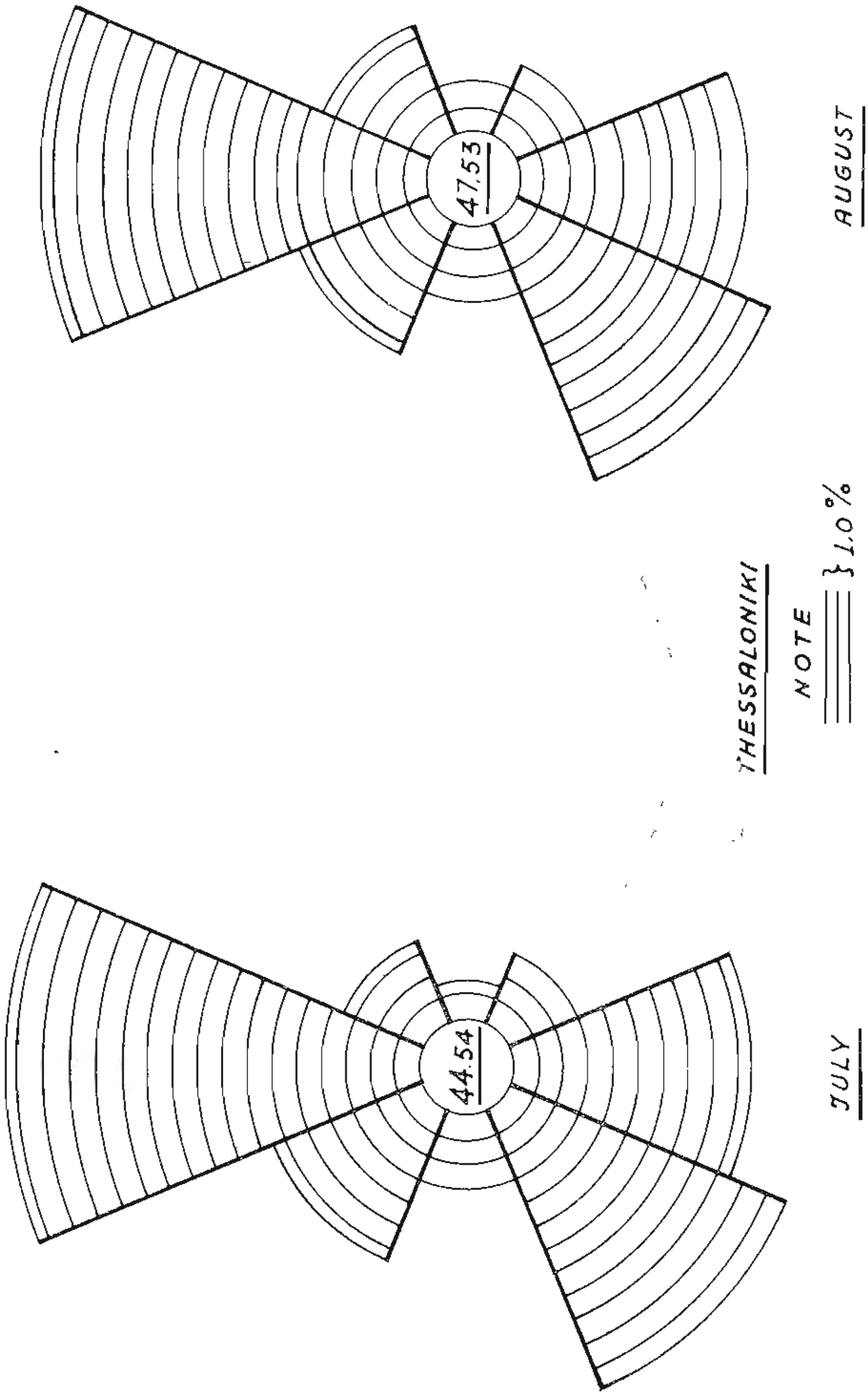
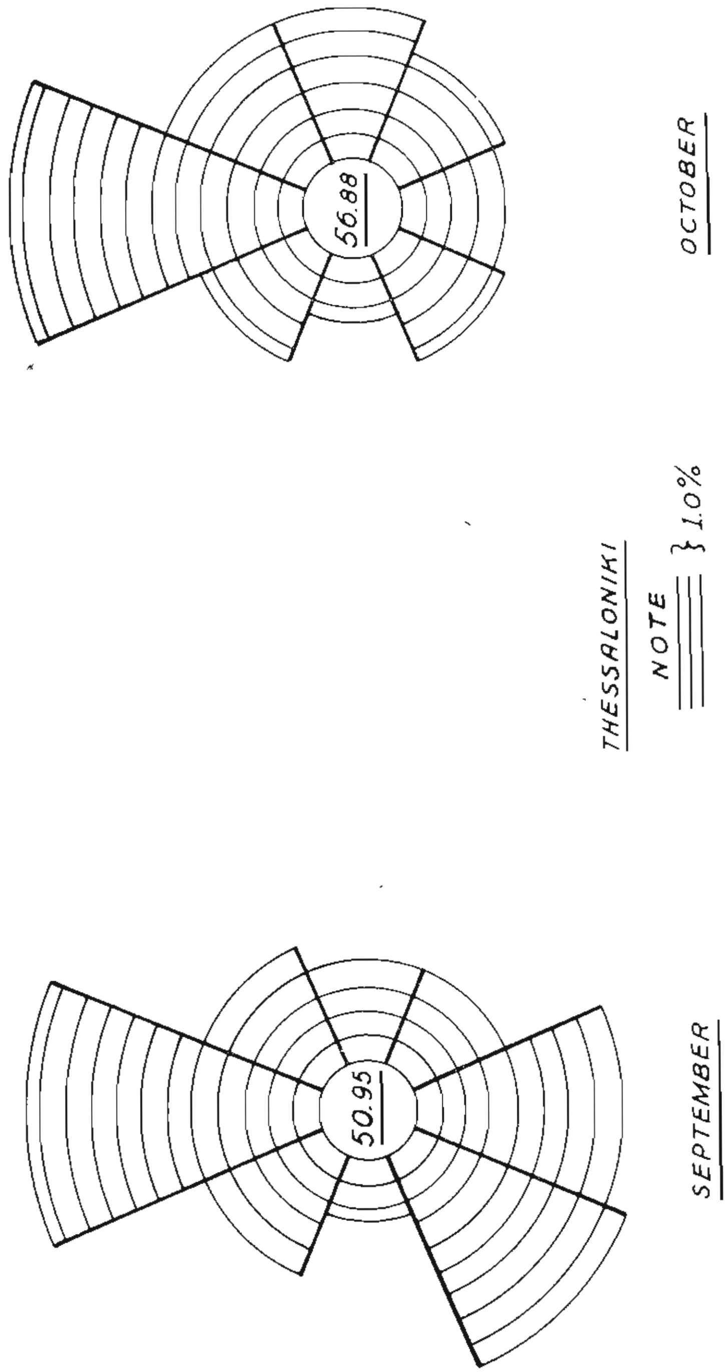
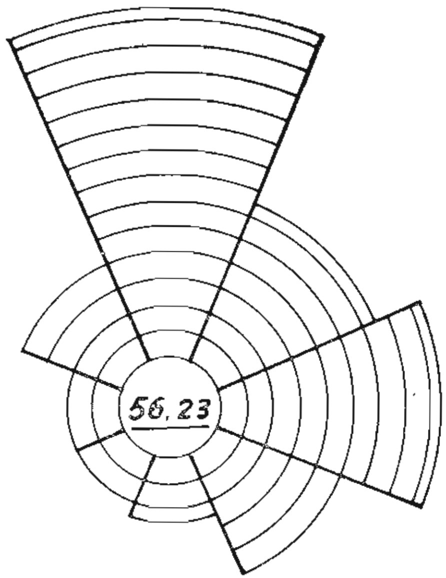
APRIL
THESSALONIKI
NOTE
} 1.0%
45.41
MARCH


JUNE
46.42
THESSALONIKI
NOTE
1.0%
MAY
48.34


AUGUST
47.53
THESSALONIKI
NOTE
1.0 %
JULY
44.54


56.88
OCTOBER
THESSALONIKI
NOTE
1.0%
50.95
SEPTEMBER

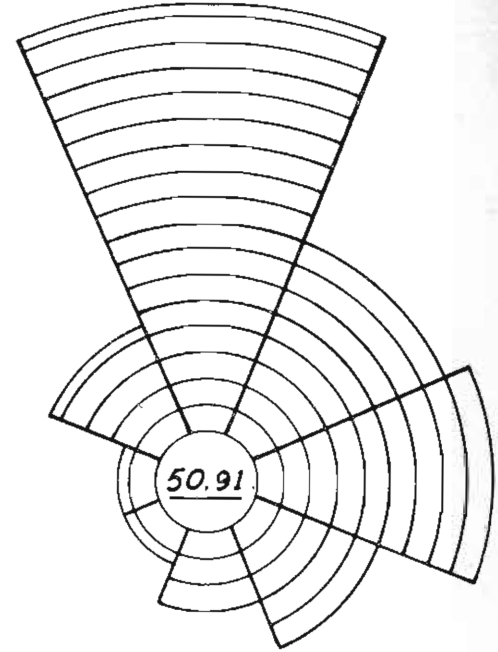


NOVEMBER

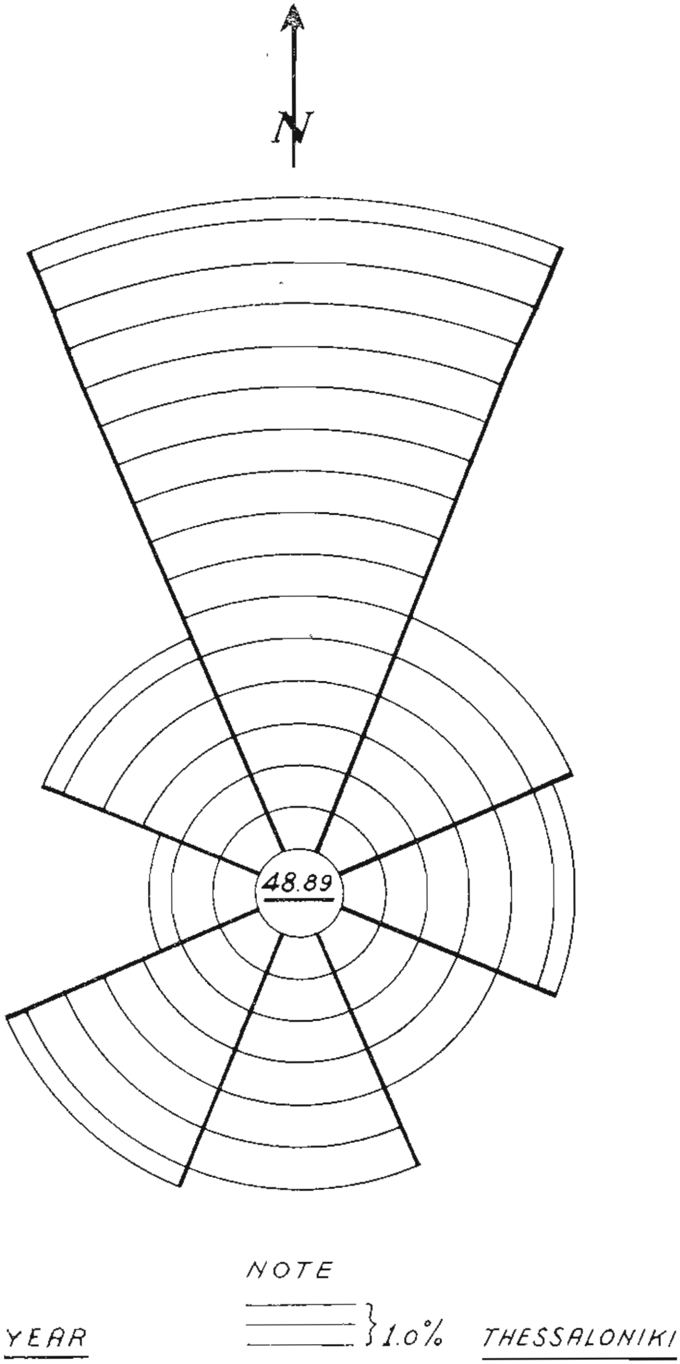
THESSALONIKI

NOTE

═══ } 1.0%



DECEMBER


N
48.89
NOTE
1.0%
YEAR
THESSALONIKI

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ΠΕΡΙΛΗΨΙΣ

Ο ΑΝΕΜΟΣ ΕΙΣ ΤΗΝ ΘΕΣΣΑΛΟΝΙΚΗ

Ὑπὸ

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Μελετᾶται ὁ ἄνεμος εἰς τὴν πόλιν τῆς Θεσσαλονίκης, ἀπὸ στοιχεῖα τοῦ Μετεωρολογικοῦ Σταθμοῦ τοῦ Ἰνστιτούτου Μετεωρολογίας καὶ Κλιματολογίας τοῦ Ἀριστοτελείου Πανεπιστημίου Θεσσαλονίκης, τῆς περιόδου 1930-1971.

Ἐξάγονται συμπεράσματα, τόσον ὡς πρὸς τὴν διεύθυνσιν τοῦ ἀνέμου, ὅσον καὶ ὡς πρὸς τὴν ταχύτητά του. Δίδεται ἡ μέση ἐτησία τιμὴ ταχύτητος τοῦ ἀνέμου 1,77 m/sec., αἱ μέσαι μηνιαῖαι τιμαὶ αὐτῆς κατὰ τοὺς διαφόρους μῆνας τοῦ ἔτους, ὡς ἐπίσης καὶ αἱ κατανομαὶ τῆς μέσης ἡμερησίας τιμῆς (24ωρον).

Μελετῶνται ἐπίσης αἱ σημειωθεῖσαι ἀπολύτως μέγισται τιμαὶ τῆς ταχύτητος τοῦ ἀνέμου καὶ δίδεται ἡ κατανομὴ τῶν μεγίστων τιμῶν ταχύτητος εἰς Θεσσαλονίκην. Κατόπιν μελετᾶται ἡ σχέσις ἐμφανίσεως τιμῶν $\geq$ 8 Beaufort ἐν συνδιασμῷ μὲ τοὺς ἐπικρατήσαντας τύπους καιροῦ.

Ὡς πρὸς τὴν διεύθυνσιν δίδονται 13 ἀνεμορόμβια (12 μηνιαῖα καὶ τὸ ἐτήσιον), ἀναλύονται δὲ αἱ συχνότητες ἐμφανίσεως τῶν ἀνέμων διαφόρων διευθύνσεων.

Τελικῶς δικαιολογεῖται ἡ μεταβολὴ τῆς ταχύτητος τοῦ ἀνέμου, ὡς ἀποτέλεσμα τῆς αὐξήσεως τῆς πόλεως τῆς Θεσσαλονίκης καθ' ὕψος καὶ ἔκτασιν. Τονίζεται ἰδιαιτέρως, τὸ μεγάλο ποσοστὸν τῶν νηνεμιῶν εἰς τὴν πόλιν τῆς Θεσσαλονίκης (48,9%).

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