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SOIL TEMPERATURE IN THESSALONIKI - GREECE

by

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Abstract: *Temperature of the soil at various depths (0.02m to 3.00m) is studied from data of the A.U.T. meteorological station ($\varphi = 40°37'N$, $\lambda = 22°57'E$, Hz: 30.40m). Mean annual and monthly values are given, as well as extreme values for each month separately.*

Cases of ground frost ($t<0°$ C) and of frozen ground are examined, and conclusions are drawn as to the frequency of such cases at various depths.

Introduction.

Although the subject of soil temperature at various depths is very interesting, involving such sciences as Agriculture, Soil Science etc., research papers concerning the area of Greece are quite rare covering rather short observational periods and regarding only two districts:

a. Athens (National Observatory): Aeginitis [1], Mariolopoulos [13,14,15].

b. Thessaloniki (Met. station of A.U.T.): Alexandrou [2], Kyriazopoulos [3].

Of these last two scientists, Alexandrou [2] based his work on data of the years 1931-1935, while Kyriazopoulos included in his study, besides the above, data of the years 1936 and 1937.

We, in this work, examine temperature of the soil at various depths down to 3 m, using data of the period between 1946-1970 from the meteorological station of the Aristotelian University of Thessaloniki. Part of these data have been published in the series «Observations Météorologiques de Thessaloniki» Mariolopoulos [16], Kyriazopoulos [4], Livadas [7], while the rest have been taken from the files and records of the above station.

In previous works the authors studied data of soil surface tempe-

rature (Part I - Bare Soil Surface / Part II - Grass covered Ground) (LIVADAS - GOUTSIDOU [9,10]).

MATERIAL.

Measurements of soil temperature in the met. station of the University of Thessaloniki were started on 1.1.1930, while data till the year 1937 have been studied, as already mentioned by ALEXANDROU [2] and KYRIAZOPOULOS [3].

During the second World War (1940-1945) measurments of soil temperature were interrupted and that is why in our own study we are restricted to the period between the years 1946-1970. It should be mentioned also that in 1959, soil thermometers were moved to the new site of the met. station within the campus, at about 200 m to the NE of its former site (LIVADAS [11]). However since measurements conducted simultaneously at the two sites in 1958 resulted in monthly mean values differing <0.1 - 0.3^{o}C at various depths, we consider this series continous (uniform).

Today in this station are installed the following sets of soil tbermometers.

I. Simple soil thermometers at depths of 0.02 - 0.05 - 0.10 - 0.25 - 0.50 m (since the year 1946).

II. Soil thermometers in metal shields at depths of 0.30 - 0.60 - 1.20 - 1.80 - 3.00 m (since 1959).

III. Soil thermometers in Lamont-box, at depths of 0.25 - 0.50 - 1.00 - 1.50 m (since 1946).

Observations are effected thrice daily, at 08 : 00,14 : 00,20 : 00 hours (Local Time = GMT + 2h).

The instruments of sets I, II and III have all been manufactured by R. Fuess-West Berlin.

Soil temperature at various depths.

a. Set I. Simple soil thermometers.

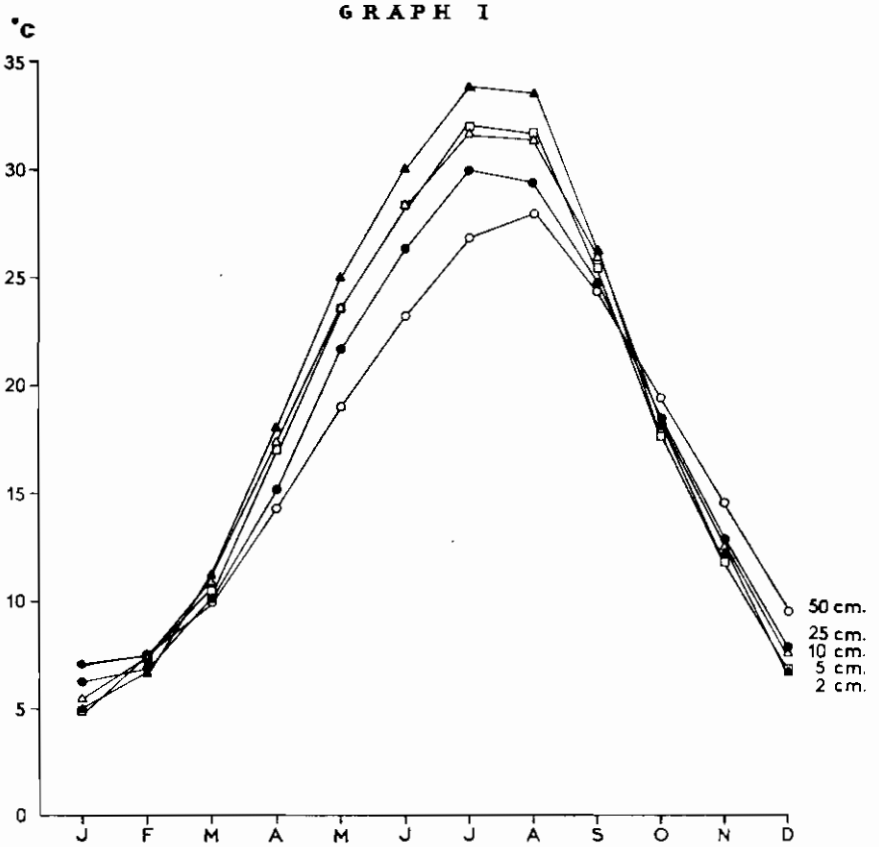
Monthly mean values of soil temperature at depths 0.02, 0.05, 0.10, 0,25, 0.50 m for the period investigated, are included in *Table I:*

TABLE I

Monthly mean values of soil temperatures at depths 0.02, 0.05, 0.10, 0.25, 0.50 m. Thessaloniki (1946-1970)

	0.02	0.05	0.10	0.25	0.50	Surfase
J	5.0	4.9	5.5	6.2	7.1	5.24
F	7.2	6.8	7.3	6.9	7.4	7.61
M	11.0	10.4	10.8	9.9	9.7	12.30
A	18.1	17.1	17.2	15.1	14.3	20.42
M	25.0	23.6	23.6	21.8	19.1	27.41
J	30.1	28.4	28.3	26.4	23.3	33.67
J	33.8	32.0	31.7	30.0	26.9	37.14
A	33.5	31.7	31.5	29.6	28.0	35.35
S	26.2	25.4	26.0	24.8	24.5	28.17
O	18.3	17.8	18.5	18.4	19.6	19.30
N	12.1	11.9	12.7	12.9	14.8	12.37
D	6.8	6.6	7.5	7.9	9.6	6.97
Year	18.9	18.1	18.4	17.5	17.0	20.51
Range	28.8	27.1	26.2	23.8	20.9	31.90

GRAPH I



The absolute maximum and minima of the same period have been included in *Table II.*

TABLE II

Absolute maxima and minima of soil temperature at various depths in Thessaloniki. (1946-1970).

	Absolute maximum					Absolute minimum						
	0.02	0.05	0.10	0.25	0.50	0.02	0.05	0.10	0.25	0.50	Surface	L.G-
J	18.9	17.0	15.8	13.3	11.7	—4.1	—4.1	—1.4	1.5	0.8	29.6	—13.0
F	26.8	23.0	19.6	15.9	12.0	—3.6	—2.6	—1.4	0.8	1.5	38.1	—9.4
M	35.5	30.7	23.4	22.3	15.2	—3.5	—0.3	1.2	3.9	3.0	48.5	—7.5
A	45.2	38.8	32.3	24.0	20.7	3.5	3.7	4.5	8.2	7.8	63.4	—4.5
M	54.6	46.0	38.2	35.8	26.4	10.6	9.3	11.2	13.1	11.8	67.8	0.4
J	55.0	48.5	45.0	38.2	29.0	14.0	14.4	15.8	17.2	16.1	67.8	5.2
J	57.0	49.8	48.2	41.9	32.4	17.3	17.5	19.9	19.8	20.3	70.5	10.5
A	56.9	49,2	48.6	39.4	31.8	13.2	12.8	14.5	23.1	22.2	68.7	7.7
S	51.6	46.0	41.6	36.3	30.7	11.1	12.0	13.3	17.1	17.6	65.0	0.5
O	41.0	41.0	35.4	27.6	25.9	3.0	4.2	6.4	11.4	14.6	54.2	0.9
N	31.2	28.8	24.6	20.4	20.2	—3.6	—1.2	0.8	4.2	8.0	39.8	—6.0
D	22.2	21.2	18.4	17.6	14.6	—5.6	—5.4	—3.2	2.5	4.0	32.4	—10.5
Abs Range						62.6	55.2	51.8	41.1	31.6		83.5

*LIVADAS - GOUTSIDOU [9].

According to the monthly mean values, we observe that January is the coldest month of the year, not only on bare-soil surface but also at all depths down to 1/2 meter.

July, the warmest month of the year, is also warmest at depths of 0.02 to 0.25 m, while at 0.50 m the equally warm month of August comes first, meaning that there is a certain lag in the heat-trowsfer within the ground (KYRIAZOPOULOS [5]).

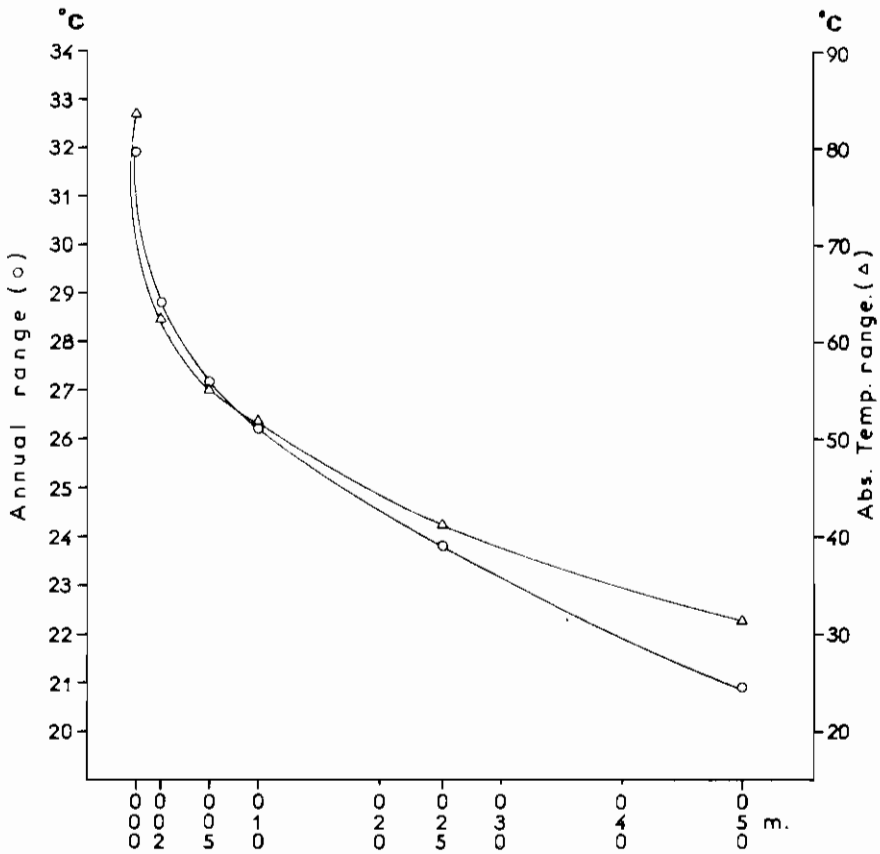
As to the values of the coldest month, we observe that temperature increases till the depth of 1/2 meter. This applies for every month between October to February, that is the two months before and the two after December, which is the month with the shortest sunshine duration (LIVADAS - FLOCAS [8]). On the other hand soil temperature decreases with depth during the warm season its lapse rate being considerable, $\geqq 5^0$ C, during the main warm period of July and August.

The annual mean temperature also follows this decreasing trend as a function of depth, of the order of $\geqq 2^0$ C, for the depths of group I examined herein.

Also the annual temperature range, as well as the normal tempe-

rature range dimishes with depth at a considerable rate, especially in the upper layer of the soil (0-10 cm).

GRAPH II



Examination of extreme values, indicates that absolute maxima have been recorded during the two warmest months, July and August; it should be noted that values of these months only slightly differ.

Also the absolute maxima even in the smallest depth of 0.02 m differ by $> 10^{\circ}$ C from the corresponding values of bare soil surface; at this depth have been recorded during the five summer months absolute maxima $>50^{\circ}$ C. Here we observe again that absolute maxima decrease at a speedy rate as a function of depth.

The absolute minima of temperature at depths of 0.02, 0.05, 0.10 m

have been recorded in December, that is the second coldest month of the year; these values correspond to a strong cold invasion that occured in the area of Thessaloniki on 30.12.1948. The temperature recorded on bare soil surface on this same day was —10.5° C (LIVADAS - GOUTSIDOU [10]).

It worth noting that values $< 0^0$ C have never been recorded at depths of 0.25 m and 0.50 m while temperatures below 0^0 C may be recorded at the surface from November till April, at depths between 0.02 - 0.05 m from November till March, and at the depth of 0.10 m only during the main cold December - February quarter.

b. Set II. Soil thermometers in metal shields.

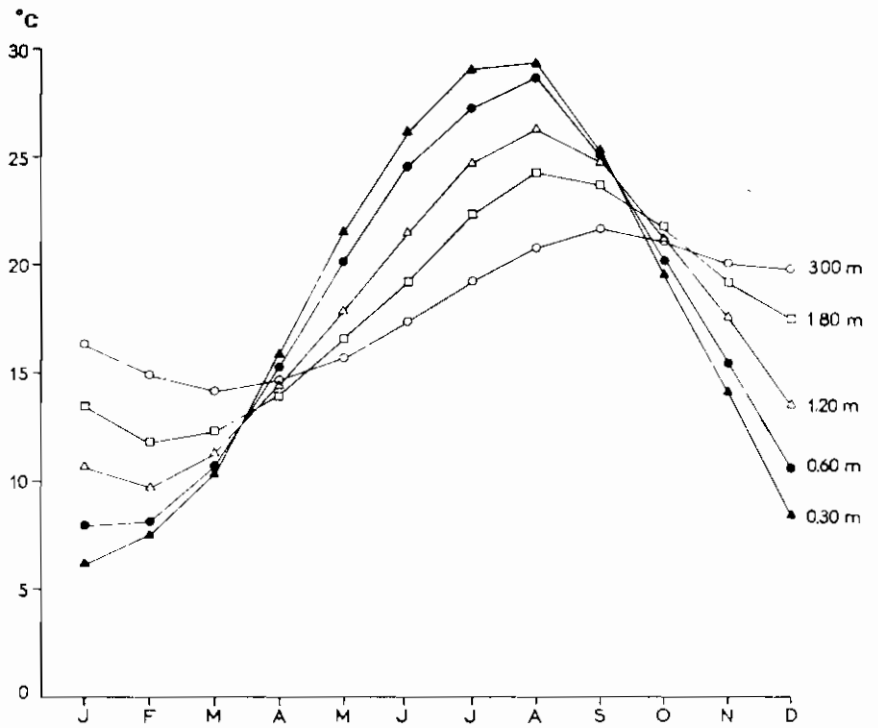
Monthly mean values of soil temperature at depths of 0.30, 0.60, 1.20, 1.80, 3.00 m for the 1959-1970 period are included in the following *Table III.*

TABLE III

Monthly mean values of soil temperature at depths of 0.30, 0.60, 1.80, 3.00 *m in Thessaloniki. (1959-1970)*

	0.30	0.60	1.20	1.80	3.00
J	6.3	7.9	10.8	13.6	16.4
F	7.5	8.1	9.8	11.9	15.0
M	10.4	10.7	11.2	12.3	14.2
A	15.9	15.3	14.3	14.0	14.5
M	21.5	20.1	17.9	16.5	15.7
J	26.2	24.6	21.6	19.3	17.3
J	29.1	27.3	24.8	22.4	19.2
A	29.4	28.8	26.3	24.4	20.9
S	25.4	25.4	24.9	23.9	21.7
O	19.7	20.4	21.5	21.9	21.3
N	14.2	15.6	17.8	19.3	20.0
D	8.4	10.5	13.6	17.6	19.9
Year	17.8	17.9	17.9	18.1	18.0
Range	23.1	20.9	16.5	12.5	7.5

GRAPH III



On the other hand absolute maxima and minima recorded during the same period and the same as above depths have been included in *Table IV*.

As to annual mean values, we observe that the layer between 0.30 - 3.00 m is quasi isothermal.

While the annual range is different for each depth, smoothly decreasing as a function of depth, for depths down to 1.80 m the warmest month is August, while for greater depths down to 3.00 September is the warmest month. This means that the rule of delayed maxima, observed in the thermometers of set I, applies also for the group of thermometers in metal shields.

The coldest month for small depths of 0.30 and 0.60 m is again January, just like the former set of small depth thermometers. On the other hand, is biggest depths the coldest month is February for the depth of 1.20 m and 1.80 m and March for the depth of 3.00 m, meaning that the rule of delayes minima applies also for the coldest months.

As to extreme values, we observe that they also are delayed as a

TABLE IV

Absolute maxima and minima of soil temperature at various depths in Thessaloniki (1959-1970)

	Abs. Maximum					Abs. Minimum				
	0.30	0.60	1.20	1.80	3.00	0.30	0.60	1.20	1.80	3.00
J	11.8	11.7	13.6	15.9	18.0	1.6	3.7	7.6	11.4	14.6
F	13.3	12.5	12.2	13.5	16.3	1.7	3.5	7.0	10.6	13.5
M	15.5	15.3	13.4	13.7	14.9	4.1	6.2	8.5	10.8	13.3
A	24.3	20.0	17.3	16.0	15.7	10.0	11.5	11.7	12.2	13.5
M	30.7	28.8	21.7	18.8	17.1	14.0	15.5	14.6	13.9	14.0
J	33.7	29.6	25.2	22.0	18.9	17.8	19.7	18.5	16.8	15.5
J	34.8	32.0	27.4	24.2	20.0	23.0	23.3	22.3	19.8	17.7
A	39.7	39.0	28.8	25.8	22.6	22.7	24.6	24.4	22.0	19.5
S	32.2	30.9	28.6	26.0	22.9	18.5	20.2	21.8	22.2	20.5
O	28.3	25.6	25.2	24.8	22.9	12.8	15.3	18.1	19.6	19.9
N	19.3	19.8	21.2	21.8	21.7	7.8	11.1	14.5	17.0	18.5
D	14.3	14.4	17.0	18.7	20.2	2.6	6.2	10.3	14.1	15.3
Abs Range						38.1	35.5	21.8	15.4	8.6

function of depth thus absolute maxima at the first three levels have been recorded in August, at the fourth level in September while at the depth of 3 m absolute maximum have been recorded in September and October.

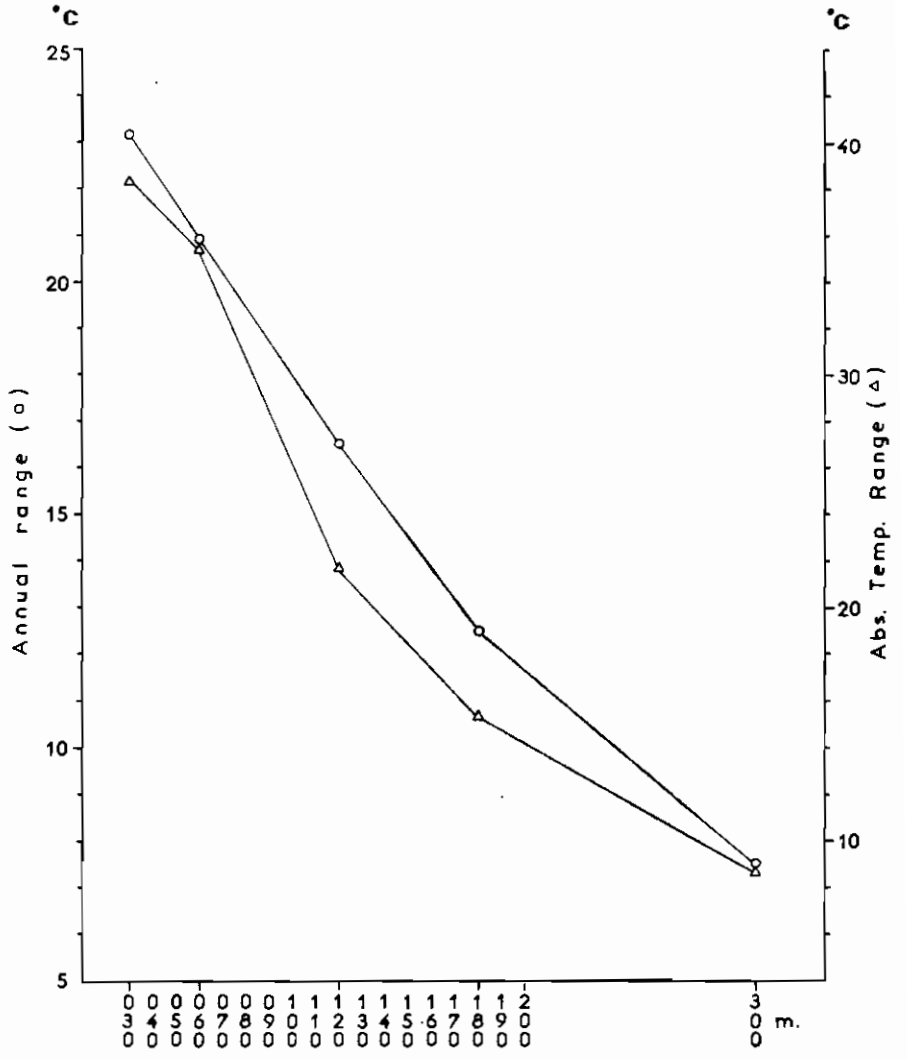
Absolute minima on their side are also delayed as a function of depth: thus they have been recorded at 0.30 m in January, at 0.60 and 1.80 m in February, and at 3 m in March.

Comparing monthly mean values of temperature at the depths of 0.30 m with those of bigger depths, we observe that the former are smaller during the October - March semester, while they remain higher in the April-September semester.

c. Set III. Soil thermometers in Lamont-Box.

Monthly mean values of soil temperature at depths of 0.25, 0.50, 1.00, 1.50 m, as recorded by Lamont-Box thermometers between the years

GRAPH IV



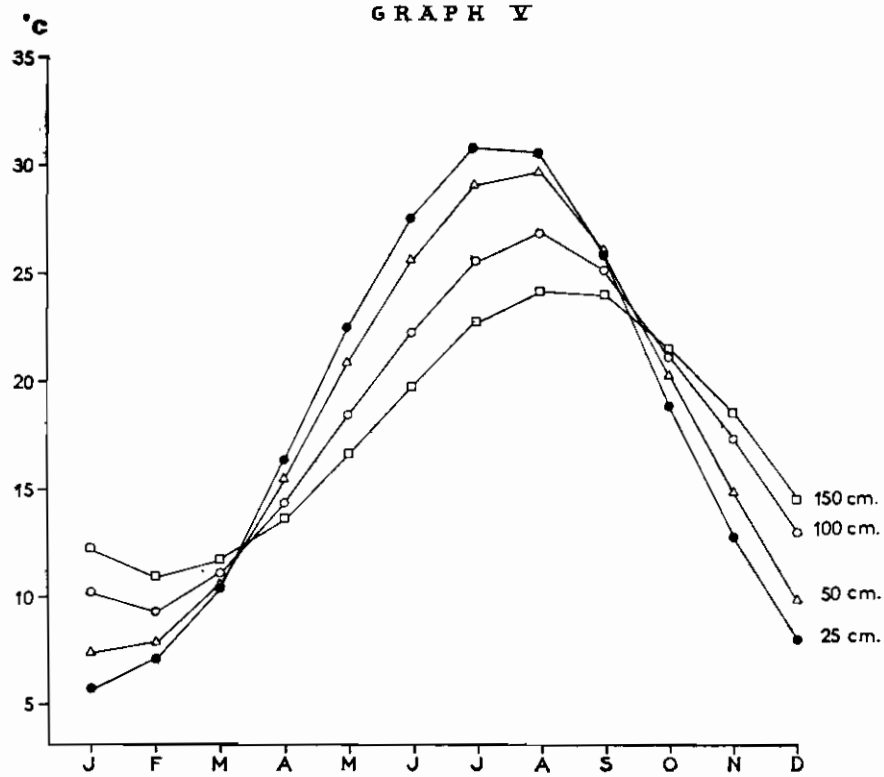
from 1946 to 1970 have been included in Table V, while absolute maxima

TABLE V

Monthly mean soil temperature values at depths of 0.25, 0.50, 1.00, 1.50 m (Lamont box) in Thessaloniki. (1946-1970)

	0.25	0.50	1.00	1.50
J	5.8	7.4	10.2	12.3
F	7.2	7.9	9.5	11.0
M	10.5	10.6	11.1	11.7
A	16.3	15.5	14.3	13.7
M	22.5	20.9	18.3	16.7
J	27.3	25.6	22.2	19.8
J	30.6	29.0	25.5	22.8
A	30.5	29.5	26.8	24.1
S	25.6	25.8	25.0	23.9
O	18.7	20.0	21.2	21.4
N	12.6	14.7	17.1	18.4
D	7.8	9.7	12.8	14.4
Year	17.9	18.1	17.8	17.5
Annual Range	24.8	22.1	17.3	13.1

GRAPH V



and minima recorded during the same period are included in *Table VI.*

TABLE VI

Absolute maxima and minima of soil tempetarure at depths of 0.25, 0.50, 1.00, 1.50 (Lamont, box), Thessaloniki. (1946-1970).

	Abs. Maximum				Abs. Minima			
	0.25	0.50	1.00	1.50	0.25	0.50	1.00	1.50
J	12.2	11.5	13.3	14.8	—0.6	3.0	7.0	9.6
F	15.0	12.2	12.5	13.2	0.6	3.0	6.5	8.2
M	20.0	16.6	14.4	13.6	3.0	5.7	7.5	9.5
A	25.6	21.6	18.0	16.3	8.4	9.9	9.9	10.6
M	32.5	26.9	22.4	19.7	11.8	15.2	14.9	14.1
J	37.6	31.3	26.0	23.5	16.5	19.7	18.7	17.2
J	37.7	35.0	28.4	26.0	21.1	22.1	21.8	19.8
A	36.4	33.0	29.3	27.3	21.0	24.6	24.1	22.0
S	32.0	31.3	29.1	27.2	16.3	20.3	21.6	21.2
O	27.7	26.7	25.6	26.6	10.9	14.4	17.5	18.3
N	20.2	20.0	21.0	21.5	2.9	6.4	12.2	15.3
D	14.9	19.9	16.4	18.0	0.4	3.9	9.0	12.0
Abs. Range					38.3	32.0	22.8	19.1

As to monthly mean values we observe that conditions for set III (Lamont box thermometers) are as an average isothermal, at all its depths. Here again the annual temperature range decreases as a function of depth. The absolute temperature range also decreases in the same proportion. We observe however, in this set too, a certain discontininty in the rate of decrease of the absolute temperature range between thermometers of small depths < 1.0 m and those of bigger depths.

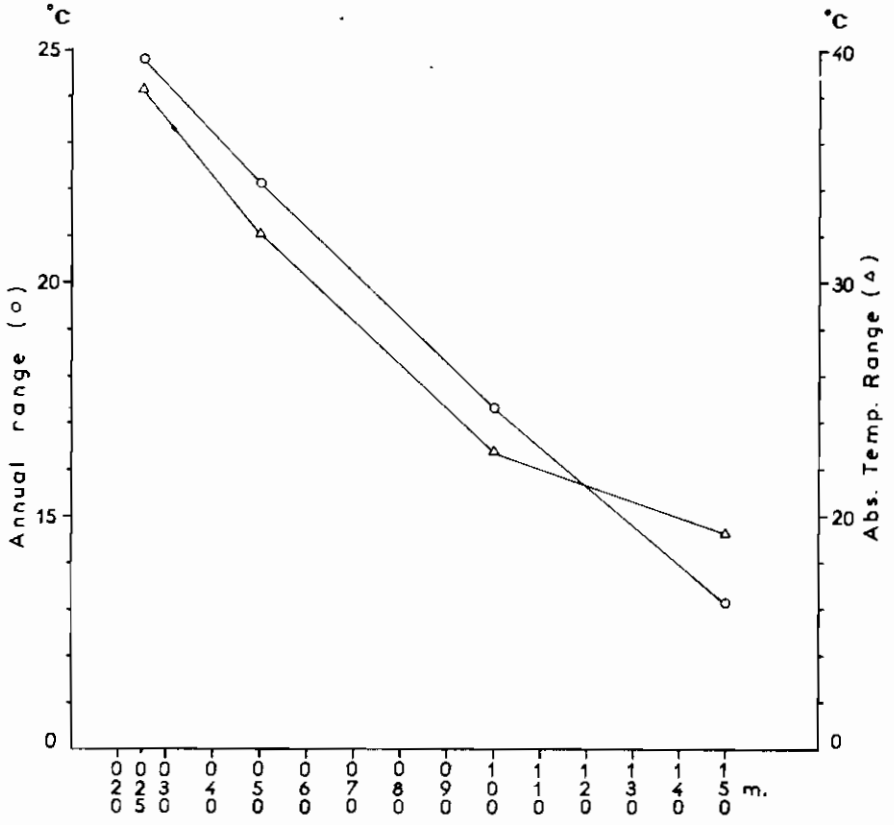
The warmest month at the depth of 0.25 m is July, while at higher depths the maximum occurs in August, and at the last depth the warmest month is September; meaning that in this group too maximum temperatures are delayed.

Coldest month at small depth in January, and at depths $\geqq 1.0$ m this is February; thus we observe the same delay for minima as well.

From October till March smallest depth is also the coldest, becoming the warmest during the warm season from April to September.

As to extreme values, we observe that for the two thermometers that stand at depths <1.0 m, the absolute maxima are recorded in July, and for the other two thermometers that stand at depths $\geqq 1.0$ m they are recorded in August. On the other hand absolute minima for the first couple are recorded in January and for the second they are recorded in

GRAPH VI



February, while at the depth of 0.25 m a value $< 0^0$ C has been recorded once.

FREQUENCY OF TEMPERATURE VALUES AT VARIOUS DEPTHS.

We have gathered all the temperature values recorded at various depths from the thermometers of Sets I-III, and the resulting percentages of various values are given in *Tables VII*, *VIII*, *IX*. These Tables indicate that temperature values $< 0^0$ C rarely occur, all such cases being gathered in the most shallow levels. As a matter of fact a relative study (LIVADAS - GOUTSIDOU [9]) indicated that such cases of depth of 0.02 were 87 out of 9.117 recordings; at the depth of 0.05 they numbered 75

TABLE VII

Percentage of various soil temperature values at various depths in Thessaloniki. (Set I).

	0.02	0.05	0.10	0.25	0.50
40.1 - 44.0	0.09	—	—	—	—
30.1 - 40.0	22.38	17.55	17.17	9.14	3.15
20.1 - 30.0	23.64	26.48	27.61	33.43	38.07
10.1 - 20.0	27.29	27.79	29.74	31.89	35.63
4.1 - 10.0	20.31	20.97	20.47	22.94	21.16
2.1 - 4.0	3.40	4.51	3.53	2.18	1.70
0.0 - 2.0	1.94	1.87	1.36	0.42	0.29
—0.1 - (—2.0)	0.84	0.78	0.12	—	—
—2.1 - (—4.0)	0.11	0.04	—	—	—

TABLE VIII

Percentage of various soil temperature values at various depths in Thessaloniki. 1959-1970 (Set II)

	0.30	0.60	1.20	1.80	3.00
30.1 - 40.0	6.20	3.53	—	—	—
20.1 - 30.0	37.50	39.07	40.82	37.39	29.71
10.1 - 20.0	31.58	37.74	51.53	62.61	70.29
4.1 - 10.0	22.69	19.48	7.65	—	—
2.1 - 4.0	1.70	0.19	—	—	—
0.0 - 2.0	0.33	—	—	—	—
—0.1 - (—2.0)	—	—	—	—	—

TABLE IX

Percentage of various soil temperature values at various depths in Thessaloniki, 1946-1970 (Set III)

	0.25	0.50	1.00	1.50
30.1 - 40.0	12.84	5.73	—	—
20.1 - 30.0	30.78	37.56	40.54	37.34
10.1 - 20.0	30.62	34.66	48.71	61.38
4.1 - 10.0	21.78	21.67	10.75	1.28
2.1 - 4.0	3.09	0.37	—	—
0.0 - 2.0	0.86	—	—	—
—0.1 - (—2.0)	0.03	—	—	—

cases out of 9.127, and at the depth 0.10 m they numbered 11 cases out of 9.122.

Only the thermometers of Set III (Lamont) recorded temperatures $< 0^0$ C at the depth of 0.25 m in 3 cases out of a total 9.085. All the above prove that frosts in Thessaloniki seldom penetrate into the ground.

As we advance in depth the temperature ranges are getting smaller: thus from —4.0 to +44.0 at the depth of 0.02 m (see *Table VII*), it is reduced between 10.1-30.0 at the depth of 1.80 m as well as that of 3,00 m

CONCLUSIONS.

All the above mentioned remarks lead to the following conclusions:

a. The annual temperature range, (that is the difference between the monthly mean temperature of the warmest month and that of the coldest month), as well as the absolute temperature range (that is the difference between absolute maximum and absolute minimum), both decrease as a function of depth, with a rate that is noteworthy at the first levels (*Graphs II, IV, VI*).

The average variation of the annual temperature range per 1 m is 8.13° C, from the surface down to the depth of 3 m, which is the limit of our measurements.

b. The annual mean temperature of the soil at various depths is higher than the *normal* mean temperature of the air (16.20° C), but smaller than the mean temperature of bare soil surface (20.51° C).

We observe that the annual mean temperature decreases as a function of depth down to 0.25-0.30 m, while from that point down to 3 m conditions are almost isothermal ($\sim$18° C).

c. It should be mentioned that differences exist between the annual mean temperatures recorded at various depths by each set of thermometers; however such differences are not considerable.

d. As to monthly mean values, we observe that during the summer months the isotherm of 30° C penetrates down 0.25, while that of 25° C goes as deep as $\geqq$ 1.20° m.

On the other hand in January we observe a closed isotherm inside the layer of 0.02 - 0.05 m, while the isotherm of 10° C penetrates down to 1.20 m in February. The effect of this penetration is a closed isotherm of 15° C at depths $>$ 2 m during the two cold months January and February.

e. As already mentioned, although frosts are quite frequent (14.35 %) on bare soil surface, they are extremely rare inside the ground.

GRAPH VII

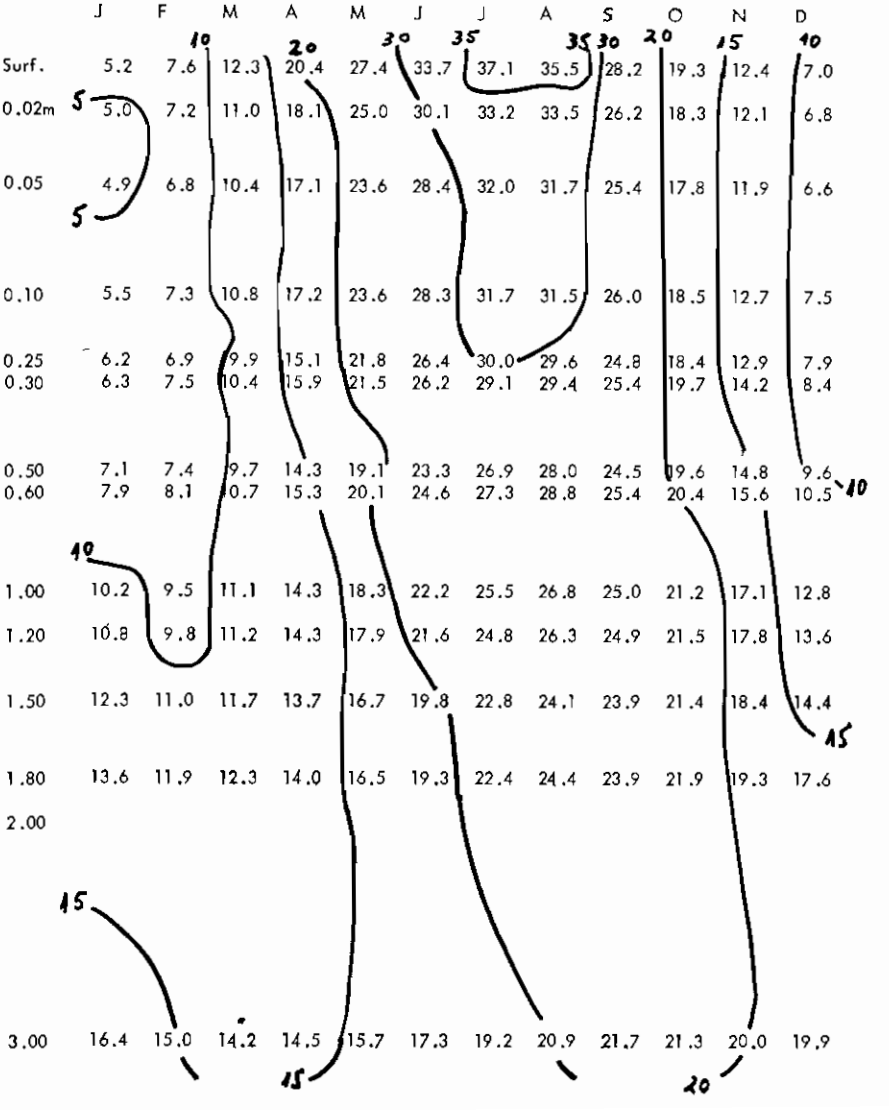


TABLE X

Percentage of frosts ($t<0°$) on the surface and at various depths.

Surface	14.35%
0.02 m	0.94
0.05 m	0.82
0.10 m	0.12
0.25 m (Lamont)	0.03

It is our belief that this information alone, that is the fact that frosts inside the ground are extremely rare, was worth the whole effort made for this study. Besides, a further investigation of the subject would prove useful for agricultural research, as well as for the surveying of public works, and especially in road-building, where as a rule provisions are made for frost penetration at considerable depths, thus considerably raising the cost of these works.

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ΠΕΡΙΛΗΨΙΣ

ΘΕΡΜΟΚΡΑΣΙΑ ΕΔΑΦΟΥΣ ΕΙΣ ΘΕΣΣΑΛΟΝΙΚΗ - ΕΛΛΑΣ

ὑπὸ

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Μελετῶνται αἱ τιμαὶ τῆς θερμοκρασίας τοῦ ἐδάφους εἰς διάφορα βάθη (0,02m-3,00m) διὰ τὴν χρονικὴν περίοδον 1946-1970 εἰς τὸν Μ. Σταθμὸν τοῦ Α.Π.Θ. ($\varphi = 40^{o}37'N$, $\lambda = 22^{o}57'E$, $Hς = 30,40m$).

Δίδονται αἱ μέσαι τιμαὶ αὐτῆς (ἐτήσιαι καὶ μηνιαῖαι) ὡς ἐπίσης καὶ αἱ ἄκραι τιμαί, κατὰ τοὺς διαφόρους μῆνας τοῦ ἔτους.

Μελετῶνται ἐπίσης αἱ περιπτώσεις ἐμφανίσεως παγετοῦ ($t<0^{o}C$) ὡς καὶ ἡ διείσδυσις αὐτοῦ εἰς βάθος. Ἐξάγονται συμπεράσματα ὡς πρὸς τὴν συχνότητα ἐμφανίσεως τούτων εἰς τὰ διάφορα βάθη ἐντὸς τοῦ ἐδάφους.