

FROST PENETRATION INTO THE SOIL AT THE  
METEOROLOGICAL STATION OF THE ARISTOTELIAN  
UNIVERSITY OF THESSALONIKI  
(1930-1974)

by

YAN. A. GOUTSIDOU and G. C. LIVADAS

(*Institute of Meteorology and Climatology, Aristotelian University of Thessaloniki*)

(*Received on 17.3.76*)

**Abstract:** *We study here) Cases when total or partial frost penetrates at depth into the soil in the area of the Meteorological Station of the University during the period 1930-1974; b) the frequency and probability of frost penetration at various depths during the year.*

*Results show that partial frost as well as total frost occurs only during the main winter quarter (December - February) and the frost depth does not exceed 10 cm.*

## INTRODUCTION

The subject of total or partial frost penetration into the soil, although of great importance for many scientific fields and practical applications as well, has been studied only by a few scientists in Greece, and then for very short intervals. Especially for the area of Thessaloniki we have only the works of Alexandrou<sup>2</sup>, Kyriazopoulos<sup>3</sup> and previous works by the authors (Livadas and Goutsidou<sup>9,10,12</sup>).

## MATERIAL

Measurements of soil temperature at various depths were started at the Meteorological Station of the University of Thessaloniki in 1930 and have been continued till today.

Data of the years 1930 - 1975, except for the interval of the Second World War (1940-1945), make up the material of the present work.

It should be mentioned that in 1959 the soil thermometers were removed to the new Meteorological Station, at some 200 m from its previous location (Livadas<sup>11</sup>). During the year 1959 a second set of

soil thermometers, placed in the old site, yielded monthly mean values differing  $< 0.1^{\circ} - 0.3^{\circ}$  C at various depths; as a consequence, we consider this as a single observational series.

Soil thermometers at the Meteorological Station of the University are placed at depths of 0.02 - 0.05 - 0.10 - 0.25 - 0.50 m. The reading of these thermometers are taken three times daily at 08<sup>h</sup> - 14<sup>h</sup> - 20<sup>h</sup>, local time (or 06 - 12 - 18 GMT); these readings consist the data of this paper.

Since the information about frosts consists in the readings of 08:00, 14:00, and 20:00 hours, we consider as a «total frost day» those days on which the readings of soil thermometer have been below 0° C in all three observations. As «days of partial frost» we consider days on which even one reading of a soil thermometer was negative.

TABLE 1

	J	F	M	A	N	D	Total
1930	0	0				0	0
1931	0	0				6	6
1932	0	0				0	0
1933	0	0				7	7
1934	0	0				0	0
1935	2	0				0	2
1936	0	0				0	0
1937	0	0				1	1
1938	9	0				0	9
1939	0	0				1	1
1940	13	1				-	14
1946	0	0				0	0
1947	4	0				0	4
1948	0	0				7	7
1949	2	2				0	4
1950	6	0				0	6
1951	0	0				1	1
1952	0	1				0	1
1953	0	0				5	5
1954	7	6				0	13
1955	0	0				0	0
1956	0	6				0	6
1957	0	0				3	3
1958	0	0				0	0
1959	0	0				0	0
1960	0	0				0	0
1961	0	0				3	3
1962	0	0				0	0

1963	6	0				0	6
1964	0	0				0	0
1965	0	1				0	1
1966	3	0				0	3
1967	4	0				1	5
1968	2	0				0	2
1969	0	0				0	0
1970	0	1				0	1
1971	0	0				0	0
1972	1	0				0	1
1973	0	0				0	0
1974	0	0				0	0
	59	18	0	0	0	35	112

## TOTAL FROST

Based on the data of the above mentioned 40 years of observations, we have drawn Table I, in which we give the number of total frost days for each month and year of the above period.

These cases amount to 112 for the whole period examined, and are distributed as follows, per various depths below soil surface.

9 cases	at the first three depths of 0.02 - 0.05 - 0.10 m.
45 »	at the first two depths of 0.02 - 0.05 m
40 »	at depths of 0.05-0.10 m
21 »	at the first depth of 0.02 m
27 »	at the depths of 0.05 m
112	

From Table I we draw the following conclusions:

a) Total frost penetration into the soil at the city of Thessaloniki is limited to the three winter months, December, January and February with highest occurrence probability in January.

b) The annual mean value of total frost penetration into the soil is 2,8 days per year. The maximum of total frost days per year is 14 days recorded in 1940, while 15 whole years have been without any day of total frost penetration into the soil, and their frequency distribution per year is.

No. of days	0	1 - 2	3 - 5	6 - 10	11 - 14
No. of years	15	9	7	7	2

The probability of total frost penetration into the soil during the six months J - F - M - A - N - D is given in Table II.

The earliest date of total frost has been the 17 - 12 - 1961 and the latest the 21 - 2 - 1940. Thus, the season of the year with total frost probability is limited to 67 days, while the frost-free period is 298 days.

TABLE II

*Probability of Total Frost Penetration into the Soil, per month at Thessaloniki*

	Observational days	Total-frost days	Percentage (%)
N	1200	0	0
D	1240	35	2.9
J	1240	59	4.8
F	1120	18	1.6
M	1240	0	0
A	1200	0	0
		112	

Classifying total frost days, in groups of consecutive days of soil freezing, that is of days on which the readings of soil thermometers did not rise above 0° C, we have drawn Table III.

TABLE III

*Frequency of sequences of days with total frost penetration into the soil at Thessaloniki (1930-1974)*

No. of days in sequence	Total Frosts		Percentage (%)
	No. of cases	No. of days	
1	15	15	13.39
2	3	6	5.35
3	3	9	8.03
4	4	16	14.28
5	1	5	4.46
6	6	36	32.14
7	1	7	6.25
9	2	18	16.07
	35	112	

The duration of total frost penetration into the soil varies from one to nine consecutive days. The longest run of consecutive days down to the depth of 10 cm below the surface of the soil, lasted from 25.12.1948 till 2.1.1949. It should be mentioned that this case was preceded by a number of partial frost days in a run.

The lowest temperatures recorded were -5.6° C at 0.02 m below the surface of the soil; -5.4° C at the depth of 0.05 m and -3.2° C at the depth of 0.10 m. The date when these negative values were recorded is the 30.12.1948 and it coincides with the run of consecutive frost days between 25.12.1948 and 2.1.1949.

The study of total frost penetration into the soil in context with simultaneous readings of bare soil surface and air temperatures, shows that soil freezing does not necessarily go with air-frost or soil-surface frost. We can however state with certainty that total frost penetration into the soil goes with very small minimum air and soil surface temperatures, almost always negative; in a very small number of cases (12 out of a total of 112), the air temperature minimum was not below 0° C. Such non negative air temperature values, are usually observed toward the end of a sequence of total frost days in the ground.

In order to illustrate the above, we have drawn Table IV, including the soil temperature readings of the three daily observations for one sequence of total frost days and the corresponding values of air temperature and bare - soil surface temperatures.

There have been cases when we had frost on bare soil surface (ground frost) and not in the air, or vice-versa. This means that frost penetration into the soil does not follow a certain rule. It can be weaker, or stronger, or equal to air frost. Or as in most cases, it may never occur when air frost is not strong enough.

It has been observed that, during the years examined herein, total frost did never go beneath the first 10 cm from the soil surface. Even in the case of 30-12-48, that is the day with the maximum soil freezing, this did not reach the depth of 25 cm.

#### PARTIAL FROST PENETRATION INTO THE SOIL

In Table V we give the number of partial frost days for each month and year of the period examined. Such cases amount to 635 for the above period and are distributed as follows, per various depths below the soil surface:

356 cases only at the depth of	0.02 m
26 » » » » » »	0.05 m
1 case » » » » »	0.10 m
243 Cases simultaneously at the depts of	0.02 - 0.05 m
1 case » » » » »	0.02 - 0.10 m
8 cases » » » » »	0.02 - 0.05 - 0.10 m
635 total.	

The above data prove that partial frost did never penetrate below the first 10 cm from the soil surface.

TABLE IV

Sequence of days with total-frost penetration into the soil and collateral values of air and soil surface temperatures. (25.12.48 - 2.1.49)

	Air			Bare Soil						0.02m		0.05m		0.10m	
	Mean	Max.	Min.	Mean	Max.	Min.	08:00	14:00	20:00	08:00	14:00	20:00	08:00	14:00	22:00
25/12/48	1.00	2.2	-0.1	-1.27	0.4	-5.0	-1.2	-1.0	-1.0	-1.0	-1.2	-1.1	0.0	0.2	0.2
26/12/48	0.53	3.1	-2.3	-0.97	5.6	-3.6	-1.2	-0.9	-1.1	-1.2	-1.0	-1.1	0.0	0.3	0.1
27/12/48	-1.50	2.8	-5.2	-2.33	7.4	-8.2	-2.6	-1.2	-2.1	-2.4	-1.6	-1.8	-0.6	-0.4	-0.5
28/12/48	-1.90	2.7	-4.9	-1.10	4.2	-9.5	-4.0	-1.4	-2.6	-3.7	-1.9	-2.2	-1.4	-0.9	-0.9
29/12/48	-2.06	3.5	-5.4	-2.67	5.0	-9.5	-3.7	-1.6	-2.8	-3.7	-2.0	-2.4	-2.0	-1.2	-1.0
30/12/48	-1.63	2.6	-5.1	-2.50	5.9	-10.5	-5.6	-1.7	-3.0	-5.4	-2.2	-2.4	-3.2	-1.5	-1.1
31/12/48	-0.83	3.2	-4.3	-1.57	6.1	-10.4	-5.0	-1.6	-2.1	-5.0	-2.2	-1.8	-3.0	-1.5	-1.1
1 / 1 / 49	1.93	3.4	-0.9	0.60	4.1	-8.0	-2.2	-1.3	-1.0	-2.4	-1.8	-1.5	-1.4	-1.0	-0.9
2 / 1 / 49	4.86	6.0	2.9	1.60	4.1	-1.8	-1.0	-0.1	0.0	-1.4	-1.0	-0.7	-0.8	-0.5	-0.5

TABLE V

	J	F	M	A	N	D	Total
1930	0	0	0		0	0	0
1931	0	0	0		0	2	2
1932	14	12	1		0	4	31
1933	6	0	0		0	7	13
1934	13	12	0		0	0	25
1935	9	12	0		0	0	21
1936	0	3	0		2	12	17
1937	17	6	0		1	7	31
1938	3	6	1		0	0	10
1939	5	4	0		0	2	11
1940	6	5	5		-	-	16
1946	0	2	0		0	0	2
1947	4	1	1		0	0	6
1948	1	5	0		3	18	27
1949	11	9	6		0	2	28
1950	12	5	0		0	0	17
1951	8	0	0		1	13	22
1952	11	14	9		0	0	34
1953	11	9	8		8	12	48
1954	7	11	0		1	8	27
1955	2	5	4		6	4	21
1956	1	2	1		0	5	9
1957	11	0	2		0	12	25
1958	6	4	0		0	2	12
1959	11	12	0		0	0	23
1960	6	3	0		0	0	9
1961	7	1	0		0	6	14
1962	3	5	0		0	0	8
1963	1	0	0		0	0	1
1964	7	3	0		0	0	10
1965	2	5	0		0	0	7
1966	1	0	0		0	0	1
1967	5	7	0		0	3	15
1968	6	0	0		0	0	6
1969	7	1	0		1	0	9
1970	5	2	0		0	8	15
1971	1	6	5		1	0	13
1972	3	2	0		4	9	18
1973	11	2	3		0	4	20
1974	4	0	0		0	7	11
	238	176	46	0	28	147	635

From Table V we draw the following conclusions:

a) The penetration of partial frost into the soil is limited in the five months of November till March.

b) The annual mean number of days with partial frost penetration into the soil, is 15.88 days per year. The maximum number of such cases (48) was recorded in 1953, while the only year without any partial frost cases is 1930, against the 15 years without any total frost days.

The frequency of occurrence of partial-frost days per year is given in Table VI

TABLE VI

*Frequency distribution of partial-frost days per year (Thessaloniki, 1930-1974)*

No. of days	No. of years	No. of days	No. of years
0	1	26 - 30	3
1 - 5	4	31 - 35	3
6 - 10	9	36 - 40	0
11 - 15	8	41 - 45	0
16 - 20	5	46 - 50	1
21 - 25	6		

The probability of partial frost penetration into the soil during the above months, is given in Table VII.

TABLE VII

*Probability of partial-frost penetration per month at Thessaloniki*

	Observational days	Days of partial - frost	Percentage (%)
N	1200	28	2.33
D	1240	147	11.85
J	1240	238	19.19
F	1120	176	15.71
M	1240	46	3.71
		635	

The earliest date for the occurrence of partial frost penetration into the soil, was the 18-11-1953 and the latest the 18-3-1947. The 18th of March has been a partial-frost day in a number of years.

Thus the period of the year when partial frost penetration into the soil is probable, extends to 121 days (that is 54 days longer than the corresponding total frost period), while the frost-free period is 244 days.



Classifying partial frost days in groups of consecutive days of partial frost penetration into the soil, we have sequences of up to 10 days. In Table VIII, is given the frequency of sequences of partial-frost days.

TABLE VIII

*Frequency of sequences of days with partial-frost penetration into the soil at Thessaloniki (1930-1974)*

No. of days in sequence	No. of cases	No. of days	Percentage (%)
1	100	100	15.75
2	58	116	18.27
3	38	114	17.95
4	23	92	14.49
5	12	60	9.45
6	10	60	9.45
7	3	21	3.31
8	2	16	2.51
9	4	36	5.67
10	2	20	3.15
		635	

Many times partial frost days are interrupted by a spell of total frost days in a sequence, and then are resumed again or a frost-free interval elapses and then they start again.

The lowest negative value recorded with partial frost penetration is  $-3.6^{\circ}$  C at 0.02 below the soil surface, and this in the morning observation (08h) only.

As already mentioned, total or partial frost did never penetrate beyond 10 cm into the soil. Yet, in another set of soil thermometers (Lamont case thermometers) negative temperatures have been observed at the depth of 0.25 m, but in a very small percentage of cases (0.03%).

#### CONCLUSIONS

Our study of the above data, led to the following conclusions:

- 1) Total or partial frost did never penetrate beyond 0.10 m into the soil.
- 2) January has the highest frequency of frost penetration into the soil. December comes next in cases of total frost and February in cases of partial frost.
- 3) The occurrence probability for total frost penetration, extends

in the main winter three-months, December-February. For partial frosts the probability extends to the five months from November till March.

4) The occurrence of total frost penetration into the soil does not always involve the occurrence of ground frost, or air frost and vice versa.

5) Frost dangers for agriculture are comparatively small, because of their small frequency and their being limited to the main winter months.

Nevertheless, partial frosts are more dangerous in the area of Thessaloniki and Northern Greece in general, because of their greatest frequency and especially their unforeseen occurrence in the spring month of March.

As to technical applications in public works and especially on the surface of highways, constructors in their surveys should take into account the frequency of frost penetration into the ground, at depths resultant from the present study.

## REFERENCES

1. AEGINITIS, D. 1907 «Τὸ Κλίμα τῆς Ἑλλάδος». Τόμος Α, σελ. 521. Ἀθήναι. «The Climate of Greece». Athens. Vol. A p. 521.
2. ALEXANDROU, I.. 1939 «Ἐπὶ τῆς θερμοκρασίας τοῦ Ἐδάφους κ.τ.λ. εἰς Θεσσαλονίκην» Ἐπιστ. Ἐπετηεὶς Φ.Μ. Σχολῆς Πανεπιστημίου Θεσσαλονίκης. «On Ground Temperature in Thessaloniki». Sci. Annales of the Faculty of Physics and Mathem., Univ. of Thessaloniki.
3. KYRIAZOPOULOS, B. 1939 «Τὸ Κλίμα τῆς Ἑλληνικῆς Κεντρικῆς Μακεδονίας». Δημοσ. Ἔργαστ. Γεωργ. Φυσικῆς καὶ Κλιματολογίας, ἀρ. 14, Ἀθήναι. «The Climate of Greece Central Macedonia». Publ. Lab. Agric. Physics and Climatology, No. 14, Athens.
4. KYRIAZOPOULOS, B. 1940-1964 Observations Meteorologiques de Thessaloniki 1938-1958. Annuaire de l' Institut Meteorologique, Nos. 9-25.
5. KYRIAZOPOULOS, B. 1964 «Μαθήματα Γενικῆς Μετεωρολογίας». «Courses of General Meteorology».
6. LIVADAS, G. 1955 «Περὶ τῶν Καιρικῶν Συνθηκῶν Ὁμάδων Ἡμερῶν Ἀποτόμου Μειώσεως τῆς Θερμοκρασίας ἐν Ἑλλάδι». Διατριβὴ ἐπὶ Διδακτορία. Θεσσαλονίκη.  
«on Weather Conditions of Groups of Days with Sudden Decrease of Temperature in Greece». Doctoral Thesis. Thessaloniki.
7. LIVADAS, G. 1970-1973 Observations Meteorologiques de Thessaloniki 1959. 1960-1970, No. 26, 28-38.
8. LIVADAS, G. C. and FLOKAS, A. A. 1972 «Sunshine Duration in Thessaloniki». Greece (III). Sci. Annals, Fac. Physics & Mathem., University of Thessaloniki, Vol. 12.
9. LIVADAS, G. C. and GOUSIDOU, YAN. 1972 «Ground Surface Temperature». Part I Bare Soil Surface. Sci. Annals, Fac. Phys. & Mathem., Univ. of Thessaloniki. Vol. 12 and Meteorologika No. 22.
10. LIVADAS, G. C. and GOUSIDOU YAN. 1973. «Ground Surface Temperature». Part II Grass-covered ground. Sci. Annals Fac. Phys. & Mathem., Univ. of Thessaloniki, Vol. 13, pp. 29-43 and Meteorologika No. 24.
11. LIVADAS, G. C. 1973 Observations Meteorologiques de Thessaloniki (num. Special I). Annuaire de l' Institut Met. - Climat. No. 27.
12. LIVADAS, G. C. and GOUSIDOU, YAN. 1974 «Soil Temperature in Thessaloniki-Greece». Sci. Annals, Fac. Phys. & Mathem., Univ. of Thessaloniki, Vol. 14 pp. 207-224 and Meteorologika No 41.
13. MARIOLOPOULOS, E. 1928 «Ἐπὶ τῆς Θερμοκρασίας τοῦ Ἐδάφους εἰς Ἀθήνας». Πρακτικὰ τῆς Ἀκαδημίας Ἀθηνῶν, τόμος 3, σελ. 445 «On Soil Temperature in Athens». Pract. Acad. of Athens, Vol. 3. p. 445.
14. MARIOLOPOULOS, E. 1928 «Sur la Temperature a la Surface du Sol et a differentes Profondeurs a Athenes. Extrait des Annales de l' Observ. d' Athenes, tome X.
15. MARIOLOPOULOS, E. 1938 «Τὸ Κλίμα τῆς Ἑλλάδος». Ἀθήναι. «The Climate of Greece» Athens. p. 89.
16. MARIOLOPOULOS, E. 1935-1938 Observations Meteorologiques de Thessaloniki No. 1-8 (1930-1937).

ΠΕΡΙΛΗΨΙΣ

ΔΙΕΙΣΔΥΣΙΣ ΠΑΓΕΤΟΥ ΕΙΣ ΒΑΘΟΣ ΕΝΤΟΣ ΤΟΥ ΕΔΑΦΟΥΣ ΤΟΥ  
ΜΕΤΕΩΡΟΛΟΓΙΚΟΥ ΣΤΑΘΜΟΥ ΤΟΥ ΑΡΙΣΤΟΤΕΛΕΙΟΥ  
ΠΑΝΕΠΙΣΤΗΜΙΟΥ ΘΕΣΣΑΛΟΝΙΚΗΣ (1930-1974)

Υπό

ΓΙΑΝ. Α. ΓΚΟΥΤΣΙΔΟΥ και Γ.Κ. ΛΙΒΑΔΑ

Είς τήν παρούσαν έρευνητικήν έργασίαν, μελετοῦνται:

α) Αί περιπτώσεις κατεισδύσεως τοῦ όλικοῦ καί μερικοῦ παγετοῦ εἰς βάθος έντός τοῦ εδάφους εἰς τήν περιοχὴν τοῦ Μετεωρολογικοῦ Σταθμοῦ τοῦ Ἀριστοτελείου Πανεπιστημίου Θεσσαλονίκης, διὰ τήν χρονικήν περίοδον 1930-1974.

Συνολικῶς έμελετήθησαν 112 περιπτώσεις όλικοῦ παγετοῦ (ἤτοι καί εἰς τὰς τρεῖς παρατηρήσεις,) 08 - 14 - 20<sup>α</sup>, αἱ ένδειξεις τῶν θερμομέτρων ἤσαν < τοῦ μηδενός) ὡς έπίσης καί 635 μερικοῦ παγετοῦ (δηλαδή, ὅταν μία τουλάχιστον ένδειξις εκ τῶν τριῶν άνωτέρω παρατηρήσεων, ἦτο 0° C).

ΠΙΝΑΞ Α

Ἀριθμὸς περιπτώσεων όλικοῦ καί μερικοῦ παγετοῦ, ὡς καί πιθανότης εμφάνισεως κατὰ τήν διάρκειά τῆς ψυχρᾶς περιόδου εἰς Μ.Σ. Α.Π.Θ. (1930-1974).

	Ἡμέραι παρατηρήσεων	Ἡμέραι όλικοῦ παγετοῦ	Ἡμέραι μερικοῦ παγετοῦ	Πιθανότητες εμφάνισεως (%)	μερικοῦ παγετοῦ
N	1200	0	28	0	2.3
Δ	1240	35	147	2.9	11.8
Ι	1240	59	238	4.8	19.2
Φ	1120	18	176	1.6	15.7
Μ	1240	0	46	0	3.7
Α	1200	0	0	0	0
Σύνολον	7240	112	635	1.5	8.8

β) Ἐμελετήθησαν έπίσης αἱ πιθανότητες εμφάνισεως παγετοῦ έντός τοῦ εδάφους.

Ἐκ τῆς ὅλης έρεύνης διεπιστώθη ὅτι, αἱ κατεισδύσεις τοῦ μερικοῦ καί όλικοῦ παγετοῦ, οὐδέποτε, κατὰ τήν ὑπό μελέτην περίοδον, ἔφθασαν τὸ βάθος τῶν 25 cm ένῶ οἱ παγετοὶ εἰς τὰ μικρότερα βάρη εἶναι συχνοὶ καί ἡ διάρκειά

αὐτῶν πολλάκις ὑπερβαίνει τὴν μίαν ἡμέραν (βλέπε ΠΙΝΑΞ ΙΙΙ καὶ ΠΙΝΑΞ VIII).

Κατὰ τὴν ὑπὸ μελέτην περίοδον, ὀλικὸς παγετὸς ἐσημειώθη κατὰ τὸ διάστημα ἀπὸ 17/12 μέχρι 21/2 (ὁ πρῶτος τὸ 1964 καὶ ὁ τελευταῖος τὸ 1940), ἦτοι καὶ οἱ ὀλικοὶ παγετοὶ τοῦ ἐδάφους παρουσιάσθησαν κατὰ τὴν χρονικὴν περίοδον κατὰ τὴν ὁποίαν παρουσιάζονται καὶ τὰ ἐτήσια ἐλάχιστα τοῦ ἀέρος (Λιβαδῆς)<sup>6</sup>.

Ἐνῶ ἡ περίοδος κατὰ τὴν ὁποίαν ἐσημειώθη μερικὸς παγετὸς εἶναι πολὺ εὐρύτερα, 18/11 μέχρι 18/3 (ὁ πρῶτος τὸ 1953 καὶ ὁ τελευταῖος τὸ 1947).