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THERMIC CONDITIONS IN THE AIR AND IN THE GROUND AND FREEZE AND THAW CYCLES IN THE UPPER VAL DI LIMA (PISTOIA APENNINES)

Abstract - *Thermic conditions in the air and in the ground and freeze and thaw cycles in the upper Val di Lima (Pistoia Apennines).* Air and soil temperatures at various depths, recorded during the year 1983 at Melo di Cutigliano, a site situated on the right slope of the Lima valley, in the upper Pistoia Apennines (1010 m. a.s.l.), are analysed. This was with the aim of studying the relationship between the thermic patterns and the freeze and thaw cycles in these two environments. General climatic conditions in the area can be referred to the *temperate-fresh* type, and the development of the hydro-climatic balance indicates *perhumid* conditions, with low *deficit* in July and August and a high *surplus* in the other months. In the year 1983 the average temperature in the air was 9.7 °C, while at ground level it was 10.3° and at a depth of 10 and 50 cm respectively 9.9° and 10.3°. Differences increase if we consider the average monthly temperatures, and get even more evident for the extreme ones: as for the latter, the absolute maximum temperature in the air was 34.5 °C (July 26th) – which is one of the highest values ever recorded in the 20th century, at such altitudes in the Apennines – while the absolute minimum reached -9.9°, face to, respectively, 19.9° and 1.3° recorded in the ground, at a depth of 50 cm. Our analysis points out that, in the thermic conditions recorded at Melo di Cutigliano in winter 1983, negative temperatures have only affected the ground from the surface down to a depth of about 10 cm. Thermographic records also enabled us to compare the number of freeze/thaw cycles in the air with those observed in the soil: it resulted that the number of temperature changes above and below zero at the ground level and at a depth of 10 cm represented respectively 13.8% and 1.5% of those occurring in the air, inside the meteorological cabin. Such data proved that, when analysing phenomena due to freeze activity at the ground level, the current practice of referring to the number of freeze/thaw cycles in the air is not suitable to provide a correct representation of thermic conditions in the soil.

Key words - Air and soil temperature, freeze and thaw cycles in the air and soil, Alta Val di Lima, Pistoia Apennines.

Riassunto - *Condizioni termiche nell'aria e nel suolo e cicli di gelo e disgelo nell'alta Val di Lima (Appennino Pistoiese).* Si analizzano le temperature dell'aria e quelle del suolo a varie profondità, raccolte nel 1983 al Melo di Cutigliano, località posta alla quota di 1010 m l.m.m. sul versante destro dell'alta Val di Lima (Appennino Pistoiese), allo scopo di studiare le relazioni fra gli andamenti termici e i cicli di gelo/disgelo nei due mezzi. Le condizioni climatiche nell'area rientrano nel tipo *temperato-fresco*, mentre lo sviluppo del bilancio idrico-climatico indica condizioni *perumide*, con un modesto *deficit* in Luglio e in Agosto e *surplus* elevato negli altri mesi.
Nell'anno in studio la temperatura media annua nell'aria è stata di 9,7 °C, quella alla superficie del suolo di 10,3° mentre quelle alle profondità di 10 cm e di 50 cm rispettivamente di 9,9° e di 10,3°. Differenze più accentuate sono state riscontrate per le temperature medie mensili e ancor più per quelle estreme: a proposito di queste ultime, la temperatura massima assoluta nell'aria è stata 34,5 °C (26 Luglio), che a queste altitudini appenniniche rappresenta uno dei valori più elevati del XX secolo, mentre la minima assoluta ha raggiunto -9,9°, contro rispettivamente 19,9° e 1,3° registrati nel suolo alla profondità di 50 cm. L'analisi dei dati indica che nelle condizioni termiche verificatesi al Melo di Cutigliano nell'Inverno del 1983 le temperature negative hanno interessato lo strato di suolo compreso fra la superficie e la profondità di circa 10 cm. Le registrazioni termografiche hanno altresì consentito di confrontare il numero dei cicli di gelo e di disgelo che si sono verificati nell'aria con quello registrato nel suolo: è risultato che il numero di passaggi della temperatura sopra e sotto lo zero alla superficie del suolo e alla profondità di 10 cm ha rappresentato il 13,8% e l'1,5% di quello verificatosi nell'aria in capannina meteorologica. Questi dati dimostrano che nello studio dei fenomeni che interessano lo strato superficiale del terreno, dipendenti dall'attività del gelo, la pratica in uso di far riferimento al numero di cicli di gelo/disgelo misurato nell'aria non è idonea ad una corretta rappresentazione delle condizioni termiche del suolo.

Parole chiave - Temperature nell'aria e nel suolo, cicli di gelo e di disgelo nell'aria e nel suolo, Alta Val di Lima, Appennino Pistoiese.

FOREWORD

The pattern of temperature change in the ground differs clearly from that observed in the atmospheric stratum above it. Indeed the ground has its own thermic regimes that depend both on the solar radiation absorbed and on its physical characteristics, its mineralogical and organic composition and its vegetation cover. In a mountain environment the relation between the air temperature measured in the meteorological cabin and that of the ground is made more complicated by the existence of mountain, valley and slope breezes. These transfer heat from one place to another and affect above all the temperature of the air, while that of the

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ground is linked almost exclusively to the solar radiation absorbed in the study site.
In the field of periglacial phenomena, influenced by the thermic state and regime of the rocks and the soil, due to the lack of observation stations for surface and ground temperatures, researchers are often obliged to resort to the air temperature measured in the cabin (Russel, 1943). This can lead to serious errors of assessment, especially in the determination of the actual number of freeze-thaw cycles affecting the ground, which are responsible for the processes of rock disintegration and transformation of the ground. Observation indeed shows that the temperatures of the two mediums present very complex correspondences (Mathys, 1974; Rapetti & Vittorini, 1975; Rapetti, 1981). The attempts described in this paper to establish a relationship between the temperature pattern of the air in the cabin and that in the ground must therefore be considered of strictly local significance, since it is a complex function of a multiplicity of factors, some of which may vary in time.

Location and characteristics of the station

In the locality of Melo di Cutigliano (1010 m a.s.l.), on the right slope of the upper val di Lima, not far from the head of the valley (Fig. 1), on a slope with a gradient of about 15°, covered by a thick grassy layer and exposed to the SW, a meteorological station was installed in 1983. It consists of a thermohygrograph and a three-element geothermograph. The thermohygrograph was placed in a cabin one and a half metres above the ground; the sensitive elements of the geothermograph were put at depths in the ground of about ten and fifty centimetres respectively. Observations, without significant interruptions, lasted from January 1983 to January 1984. The ground is of a regolithic nature and derives from the processes of modification of the *Macigno*, due to centuries of agricultural working, enriched in its surface portion with abundant organic matter, which gives it a dark colour.

Climatic features of the upper Pistoia Apennines

The head of the Val di Lima forms a stretch of the watershed between the Tyrrhenian and Adriatic slopes of the Northern Apennines, which develops at altitudes of between 1400 and 1950 m a.s.l. This geographical position, in relation to the orientation of the orographic structure and to the direction of the air masses of the general and local circulation, determines on the peaks very high meteoric inflows, of over 2500 mm a year, with a regime of *submediterranean* type (AWSS), characteristic of the Tyrrhenian side of the Northern

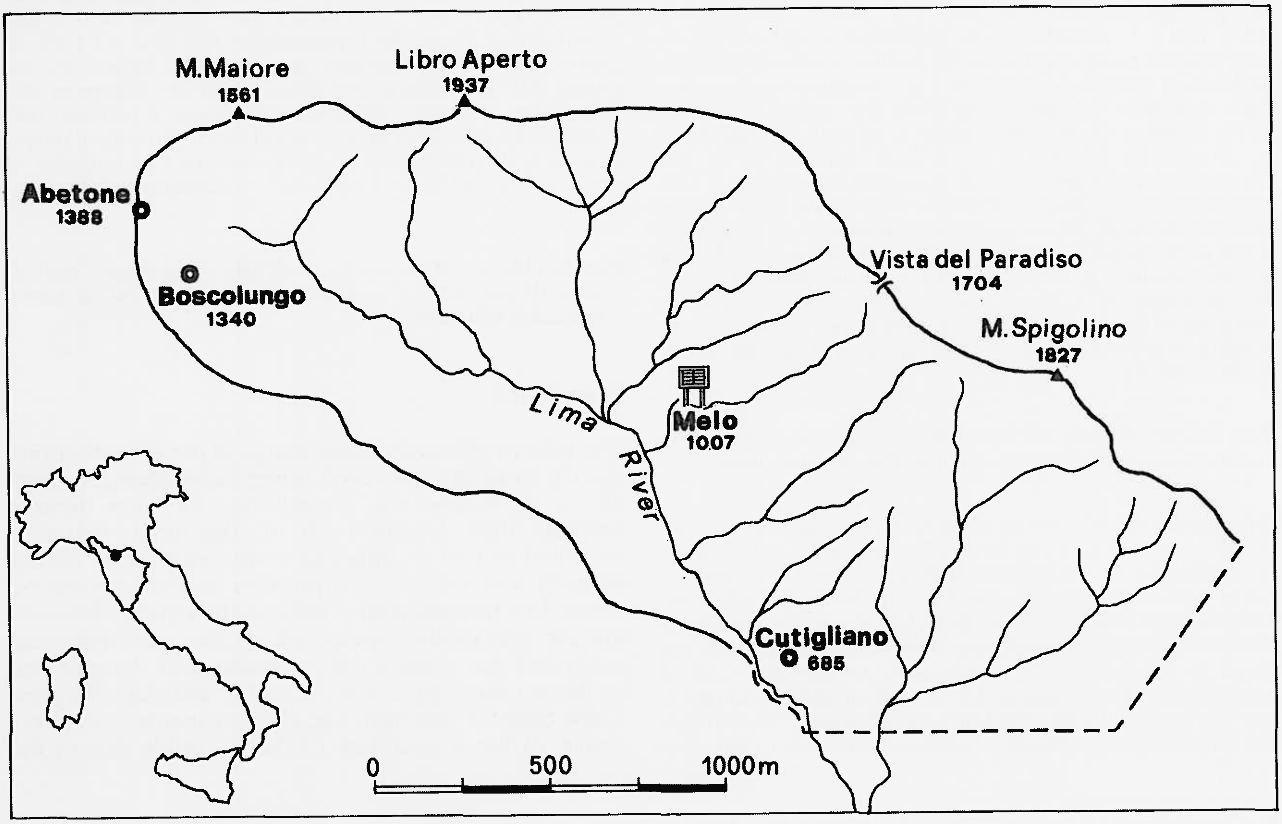

Fig. 1 - Map of the upper Lima river valley with the meteorological station of Melo di Cutigliano indicated.

Apennines (Pinna & Vittorini, 1985). The following values of exposure to the sun and of solar radiation, measured at the Aeronautical Meteorological Observatory of M. Cimone at 2137 m a.s.l. (lat. 44° 12'; long. 10° 42'), were recorded (Guerrini *et al.*, 1977) (Tab. 1).

The relatively low values of both exposure to sun and global radiation, despite the high altitude of the station and the open horizon, can be linked to the orographic cloudiness induced by the presence of relief, which interferes with the general and local circulation, determining the formation of cloud in all seasons. Indeed the annual exposure to the sun at M. Cimone, 1894 hours, is lower than that in the other stations of the radiometric network of Tuscany: at Viareggio, in the same period, 2127 hours were recorded, in Pisa 2349 hours and at Pianosa 2607 hours (regional maximum).

The annual mean temperature of the air, which decreases regularly with altitude, with a vertical thermic gradient of 0.58°/100 m, on the other ridges is around 5°, while it reaches the minimum value of 2.1° on Mt. Cimone, where six months with an average temperature of less than zero degrees were recorded (Rapetti & Vittorini, 1989). According to the classification criterion of the Italian thermic climate proposed by Pinna (1969), the stations of Boscolungo (1340 m a.s.l.) and Mt. Cimone (2165 m a.s.l.), near to the Melo di Cutigliano, fall, with some approximation, within the *temperate-fresh* type and the *temperate-cold* type respectively.

The development of the water-climate balance (Thornthwaite & Mather, 1957) makes it possible to classify the climate of Boscolungo as type $A\ C_2'\ r\ b_3'$ (perhumid, of the second microthermic, with a negligible summer water deficit, with an average-high value of the summer concentration of thermic efficiency) (Rapetti & Vittorini, 1989) (Tab. 2).

The discontinuous freeze of the Val di Lima

Along the valley of the Lima during the cold six months of the year, with an increase in altitude, there is a sensible rise in the increase in the *days with frost* ($T_{min} \leq 0°$), and at the higher altitudes of the Apennines also a significant number of frost days ($T_{max} \leq 0°$) (Troll, 1943). The number of such days is shown in the following table (Tab. 3).

It is observed that in this area of the northern Apennines the phenomenon of discontinuous freezing is not infrequent even at relatively modest altitudes. In the station of Bagni di Lucca (120 m a.s.l.) at the mouth of the Lima river valley, on average 58.9 days with frost a year are observed, but at Sperando (470 m a.s.l.) there are an estimated 102.7, followed by 129.3 days at Boscolungo (1340 m a.s.l.), situated on the right slope of the Lima, just below the Apennine watershed. The increase with altitude in the number of days with frost is not linear. While from Bagni di Lucca to Sperando it is 12.5 days/100 m, in the stretch from Sperando to Boscolungo it is 3.1 days/100 m. The altimetric variation in the days of frost is quite different: in the first stretch it is 0.6 days/100 m; in the second 5.1 days/100 m.

Tab. 1 - Absolute (F) and relative (F%) monthly and annual sun exposure (in hours). Absolute global radiation (G) in ly/day and monthly and annual relative global radiation (G%) at the Aeronautical Meteorological observatory of Mt. Cimone (1958-1972).

	J	F	M	A	M	J	J	A	S	O	N	D	Year
F	116	120	132	136	174	176	234	267	170	163	96	110	1894
F%	44	44	38	36	41	41	54	56	49	52	37	44	44
G	124	168	238	270	370	378	431	411	313	225	113	100	261
G%	42	40	39	34	39	37	44	47	46	46	34	39	40

Tab. 2 - Some parameters of the hydro-climatic balance of Boscolungo (1961-1980)

Station	P	PE	AE	D	S	I_h	I_a	I_m	SCTE	Climatic formula
Boscolungo	2525	561	559	2	1966	362.5	0.2	362.3	54.7	$A\ C_2'\ r\ b_3'$

Tab. 3 - Average number of days with frost and of frost days in some stations of Val di Lima (1980-1989).

Stations	N° days	J	F	M	A	M	J	J	A	S	O	N	D	Year
Bagni di L.	$T_{min} \leq 0°$	15.6	15.4	6.7	0.7	0	0	0	0	0	1.0	5.6	13.9	58.9
	$T_{max} \leq 0°$	0.3	0	1.0	0	0	0	0	0	0	0	0	0	0.4
Sperando	$T_{min} > 0°$	23.5	22.9	15.8	5.0	0.5	0	0	0	0	1.1	13.4	20.5	102.7
	$T_{max} \leq 0°$	1.8	0.5	0.2	0	0	0	0	0	0	0	0	0.1	2.6
Boscolungo	$T_{min} > 0°$	28.1	25.7	24.4	12.8	1.7	0	0	0	0	1.3	13.0	22.3	129.3
	$T_{max} \leq 0°$	13.4	12.5	7.2	1.3	1.0	0	0	0	0	0	3.7	9.1	47.3

Tab. 4 - Precipitation (mm), number of rainy days, intensity and pluviometric regime at Melo di Cutigliano in 1983, compared with the average precipitation for the period 1956-1985

	J	F	M	A	M	J	J	A	S	O	N	D	Year	Regimen
P	55.7	161.7	362.5	166.0	147.0	82.9	17.4	124.1	105.9	115.7	57.5	476.5	1872.9	WSAS
N°dd.	4	15	11	15	12	12	3	10	8	7	6	11	114	–
mm/h	13.9	10.8	33.0	11.1	12.3	6.9	5.8	12.4	13.2	16.5	9.6	43.3	16.4	–
P_{med}	228	204	217	210	168	124	77	101	166	256	314	305	2369	WASS

Pattern of the meteorological elements at Melo di Cutigliano in 1983

Precipitation

In 1983, in a period of 114 days, 1872.9 mm of precipitation were recorded. These were about 21% less than the average of the period 1966-1985, although there were 476.5 mm in December and 362.5 mm in March. The seasonal average rainfall was of the *Mediterranean* type, slightly different from the normal, with a substantial equivalence of precipitations between the winter (37.1%) and the spring (36.0%) (Tab. 4).

Snow

In this study the snow cover is of considerable interest since it makes it possible to analyse the thermic reaction of the ground during such an occurrence. The surface of the ground remained covered for a total of 58 days, 24 of which were observed in February. The snow reached a maximum thickness of 50 cm on February 14th (Tab. 5; Fig. 2).

Tab. 5 - Quantity of snow falling (cm) (I), number of days of snowfall (II), number of days of snow remaining on the ground (III).

	J	F	M	A	M	J	J	A	S	O	N	D	Year
I	5	66	7	28	–	–	–	–	–	–	–	25	131
II	1	10	2	5	–	–	–	–	–	–	–	5	23
II	4	24	10	8	–	–	–	–	–	–	–	12	58

The temperature in the air and in the ground

The temperature of the air depends both on the transfer of sensible heat between the surface of the ground and the air above, and on the thermic content of the air masses passing over the station considered. The temperature of the ground surface is linked to the net balance between the solar radiation and the long-wave radiation emitted by the surface, to the latent evaporation heat and to the conduction of the heat in the ground (Williams & Smith, 1989). In particular meteorological conditions, the energetic processes involving the two mediums may therefore determine significantly different air temperature patterns in the cabin and in the ground.

The average annual temperature of the air was 9.7°, with extreme monthly values of -0.8° in February and of 21.0° in July, with an annual range of 21.8° and a daily average of 8.3°. At ground level the annual average was 10.3°, that of the extreme months 1.1° (February) and 22.5° (July), with an annual range and daily average respectively of 21.4° and 5.0°. At a depth of 10 cm the annual average was 9.9°, with extreme values of 2.2° (several months) and of 20.3° in July, with an annual range and daily average respectively of 18.1° and 1.8°. Finally, at a depth of 50 cm the annual average was 10.3°, that of the coldest month and that of the warmest 4.1° (January) and 17.8° (July) (Tab. 6; Fig. 3).

The monthly regime of the thermic trends shows that the average temperature of the air was lower than that of the surface of the ground uninterruptedly from the middle of March to the middle of November. The most significant deviations were observed in December (T = 5.4 °C), in February (T = 1.9 °C) and in August (T = 1.8 °C). In the annual average values the difference between the two mediums was 0.6 °C. From a comparison between the average temperature of the air

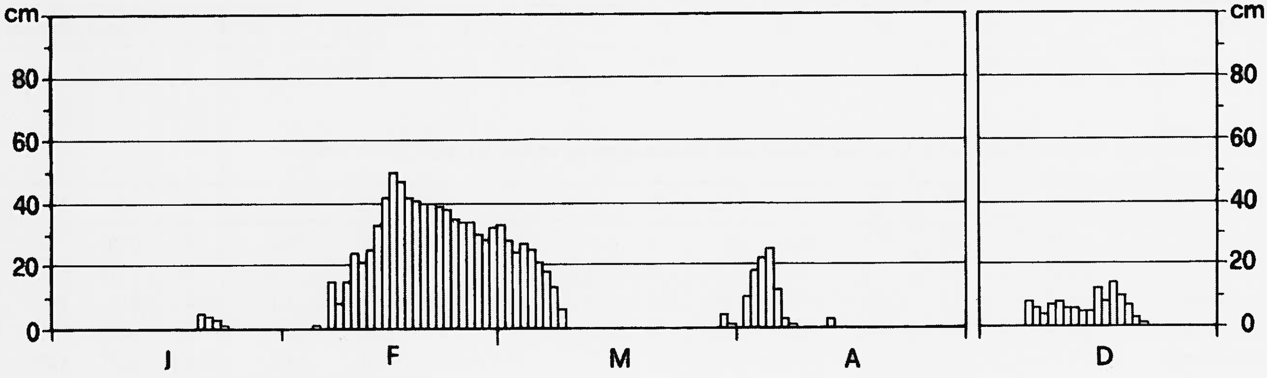

Fig. 2 - Pattern of the thickness of the snow layer.

Tab. 6 - Average minimum, maximum and mean temperatures of the air and of the ground, annual and daily variation (°C).

	Values	J	F	M	A	M	J	J	A	S	O	N	D	Av.	Ann. Var.
	Min	-0.6	-4.1	1.3	3.3	5.8	10.5	15.5	12.8	10.3	6.4	2.4	3.1	5.6	19.6
Air	Max	6.1	2.5	8.8	11.3	14.7	20.4	26.5	21.1	19.5	15.1	9.5	11.0	13.9	24.0
	Med	2.8	-0.8	5.0	7.3	10.2	15.4	21.0	17.0	14.9	10.7	6.0	7.0	9.7	21.8
	D. Var.	6.7	6.6	7.5	8.0	8.9	9.9	11.0	8.3	9.2	8.7	7.1	7.9	8.3	–
	Min	1.0	0.5	1.2	4.4	9.5	12.6	18.1	15.8	13.8	9.8	5.7	1.1	7.8	17.1
Ground	Max	3.7	1.7	7.8	14.0	14.5	21.3	26.9	21.8	18.3	12.8	8.4	2.2	12.8	25.2
	Med	2.3	1.1	4.5	9.2	12.0	17.0	22.5	18.8	16.1	11.3	7.1	1.6	10.3	21.4
	D. Var.	2.6	1.2	6.6	9.6	4.9	8.7	8.8	5.9	4.5	3.1	2.6	1.1	5.0	–
	Min	1.9	2.0	2.6	6.3	10.5	13.9	18.7	16.9	15.2	10.6	7.1	1.9	9.0	16.8
-10 cm	Max	2.5	2.4	4.7	9.6	12.3	17.2	21.9	19.4	16.8	12.0	8.1	2.5	10.8	19.5
	Med	2.2	2.2	3.7	8.0	11.4	15.5	20.3	18.2	16.0	11.3	7.6	2.2	9.9	18.1
	D. Var.	0.7	0.5	2.1	3.3	1.8	3.4	3.2	2.4	1.7	1.4	1.0	0.6	1.8	–
	Min	3.9	4.2	4.4	7.0	10.7	13.5	17.4	17.1	15.8	12.5	9.6	4.5	10.1	13.5
-50 cm	Max	4.2	4.5	4.8	7.6	11.2	14.2	18.3	17.4	16.1	13.0	9.8	4.9	10.5	14.1
	Med	4.1	4.3	4.6	7.3	10.9	13.9	17.8	17.3	16.0	12.8	9.7	4.7	10.3	13.7
	D. Var.	0.3	0.3	0.4	0.6	0.6	0.7	0.9	0.3	0.3	0.5	0.2	0.4	0.4	–

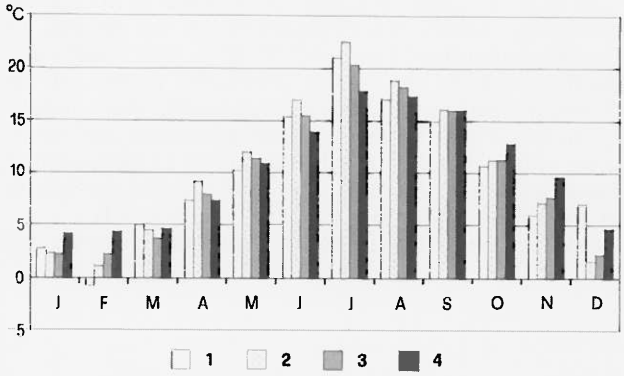

Fig. 3 - Monthly trend of the average temperature in the air (1); at ground level (2); at a depth of 10 cm (3); at a depth of 50 cm (4).

and that of the ground at a depth of 10 cm it emerges that the air is warmer than the ground in July, in March and from the middle of November to the middle of January. Between these levels the deviations are smaller, since they were little more than 0.2 °C. The relation between the temperature of the air and that of the ground at -50 cm seems more complex: the ground, except in December, is warmer than the air from the middle of August to the middle of March; in spring the thermic levels are equivalent, while in summer the temperature of the air is higher than that of the ground, with the greatest deviation in July (T = 3.2 °C). In the annual average values the ground is 0.6 °C warmer than the air. At ground level, higher monthly average temperatures than those measured at -10 cm were recorded from March to September; in the autumn months the thermic values were very similar, while in February the surface was colder. In the annual average values the surface proved to be 0.2 °C colder. The monthly average temperatures recorded at ground level were higher than those observed at -50 cm from March to September and lower in the other months, with the greatest deviations in July (T = +4.7 °C) and in February (T = -5.1 °C). At a depth of -10 cm the average temperature is higher than that at -50 cm from April to mid September, with the greatest deviations in July (+2.5°) and in December (-2.5°).

In the mountain environment of the middle latitudes, where in the course of the year the difference between the absolute minimum and maximum values in the air is many tens of degrees (at the Melo di Cutigliano in the year being studied T = 44.5 °C), the study of the extreme temperature values is of considerable practical interest, both in the field of vegetal ecology, and in the geomorphological field. The absolute minimum temperature in the air was -9.9° (February); that at ground level -2.8° (February), while at deeper levels -0.1° (March) and 1.3° (December) respectively were recorded. In the meteorological conditions of 1983 the freeze wave reached therefore a depth of about 10 cm. The absolute maximum temperatures, which occurred at the end of July, reached 34.5° in the air, 30.4° at the surface of the ground and 23.8° and 19.9° at depths of 10 and 50 cm (Tab. 7).

The daily temperature variation (thermoisoplethes)

The pattern of temperature change on the middle day of each month can be opportunely analysed with thermoisopleths, constructed on the basis of temperatures recorded every two hours. In the air, the lines of equal temperature develop almost symmetrically with respect to an axis parallel to the abscissas passing through the hour of 2 p.m.. The thermoisopletes of -2° and of 0° are present only in February; that of -2° from 10 p.m. to 8 a.m.; that of 0° from the early hours of the morning until 10 a.m., and from 5 p.m. to midnight. The only closed isolines are those of 20° and 24°: the first is present in the months of July and August, from 10 a.m. to 8 p.m.; the second refers only to the month of July from 12 a.m. to 6 p.m. The minimum and maximum values were respectively -2.6° (6 a.m. in February) and 26.0°

Tab. 7 - Extreme air and ground temperatures (°C).

	Values	J	F	M	A	M	J	J	A	S	O	N	D	Year
Air	Min	-5.5	-9.9	-2.0	-0.2	3.1	5.7	8.7	7.9	5.0	1.9	-3.0	-3.6	-9.9
	Day	6	23	27	4	29	17	1	4	13	23	23	1	
	Max	15.0	10.8	15.8	18.1	20.5	25.9	34.5	28.5	24.7	20.1	14.9	19.3	34.5
	Day	25	5	19	30	31	5	26	1	25	3	4	18	
Ground	Min	-0.1	-2.8	-0.1	1.0	7.0	10.1	16.2	13.3	11.3	4.9	1.9	-0.3	-2.8
	Day	various	5	6;7	various	4	20	16	5	18	25	16	19	
	Max	12	8.2	22	24	18.9	29.7	30.4	28.9	22.0	16.2	11.8	8.1	30.4
	Day	27	2	31	30	6	25	31	1	1	3	4	23	
-10 cm	Min	0.4	1.5	0.0	1.7	8.8	11.7	17	15.2	13	6.7	3.8	-0.1	-0.1
	Day	16	7	6	7	4	1	16	8	18;19	26	16	19	
	Max	6.2	4.9	9.9	15.4	14.5	22.0	23.8	23.4	19.8	15.2	10.9	5.6	23.8
	Data	30	2	31	30	15	26	31	1	1	4	4	25	
-50 cm	Min	2.8	3.9	2.1	4.3	9.8	11.0	16.1	16.4	14.2	9.8	7.1	1.3	1.3
	Day	16	24	6	8;9	various	1	5	19	28	27	28	19	
	Max	5.2	5.0	7.0	11.0	12.4	15.9	19.9	19.2	17.7	14.8	11.0	7.6	19.9
	Day	31	6;7	various	30	17	26	31	1	various	various	7	1	

(4 p.m. in July). The sinuosity of the isoplete shows that the daily variation in temperature is considerable in all seasons, with the maximum in July (Fig. 4A).

At the surface of the ground the temperatures of the middle day are always higher than 0°; around the maximum values closed isolines of 20° and 24° are observed: the first refers to the summer months, from 12 a.m. to 12 p.m., the second to the month of July from 2 p.m. to 8 p.m.. The minimum and maximum values are respectively 0.7° (8 a.m. in February) and 26.5° (4 p.m. in July). The sinuous pattern of the isopletes demonstrates that the daily variation is significant in all seasons (Fig. 4B). At a depth of 10 cm the minimum values were observed in the month of February at around 2 p.m. (-2.0°) (Fig. 4C); finally at a depth of 50 cm the almost rectilinear pattern of the thermoisoplethes indicates a considerable daily stability; in the course of the year the minimum and maximum values were recorded respectively in the month of January from 2 p.m. to 6 p.m. (4.0°) and in the month of July from 2 p.m. to 6 p.m. (18.2°) (Fig. 4D).

At all the levels considered the maximum temperatures

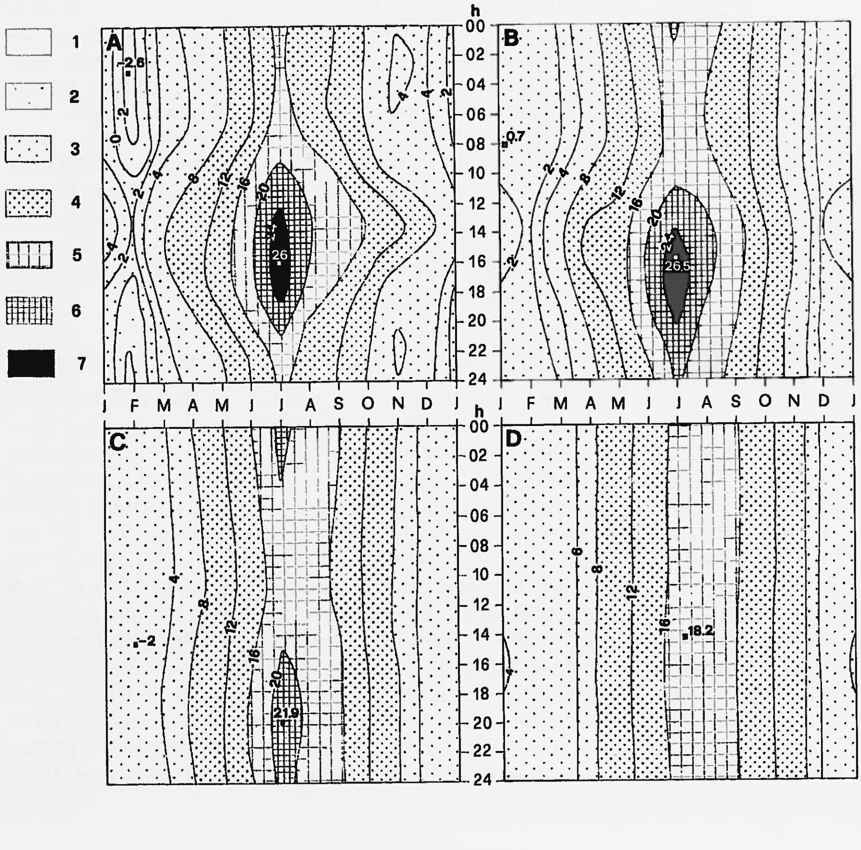

Fig. 4 - Thermoisoplethes of the temperature: A (air), B (ground surface), C (depth of 10 cm), D (depth of 50 cm). 1: t ≤ -2°; 2: -2° < t ≤ 0°; 3: 0° < t ≤ 8°; 4: 8° < t ≤ 16°; 5: 16° < t ≤ 20°; 6: 20° < t ≤ 24°; 7: t > 24°.

of the middle day occurred in the month of July, however with some significant hourly phase displacements: in the air and at the surface of the ground the maximum was observed at 4 p.m.; at a depth of 10 cm at 8 p.m.; at a depth of 50 cm with a delay of twenty-four hours with respect to the air and the ground surface (Fig. 5).

RELATIONSHIP BETWEEN AIR TEMPERATURE AND GROUND LEVEL TEMPERATURE

The relationship between the temperature of the air measured in the cabin and that of the ground surface in a mountain environment is very complex. It is not describable in general terms, since it is a function of numerous factors, such as latitude, altitude, the nature, colour and humidity of the ground, the type and phenological state of the vegetation, slope exposure and gradient and the topography of the relief forms in the area of the station.

In the year of observation statistical analysis made it possible to determine the equations of the lines of regression between the temperature of the ground surface and that of the air. The coefficients of determination (R^2) indicate that in the months of snow cover the correlation between the temperatures of the two mediums is very weak, since the ground remains insulated by the snow layer. This brings about a substantial independence of the temperatures in the two environments. The small degree of dependence between the temperatures of the two mediums also occurred in other meteorological conditions, e.g. the sudden variations in air temperature, concomitant with the screening action exercised on the solar radiation by the variable snow cover, particularly frequent in certain months, with the ground which, because of its greater inertia, remains in a more stable thermic state (Fig. 6).

AIR AND GROUND TEMPERATURES: SOME PARTICULAR CASES

Thermic trend with the disappearance of the snow cover

The snow cover, even if of modest thicknesss, determined the absence of significant thermic variations at the surface of the ground. Indeed, with the reduction of the thickness of the snow cover, until its complete disappearance, occurring between March 8th and 11th, the increase in the temperature at the ground surface was extremely modest, with an estimated increase of no more than 0.5 °C. A different pattern was observed from 5 p.m. on March 11th, and more markedly from the following day, on which the thermic response of the ground to the solar radiation was typical of a surface without snow (Fig. 7).

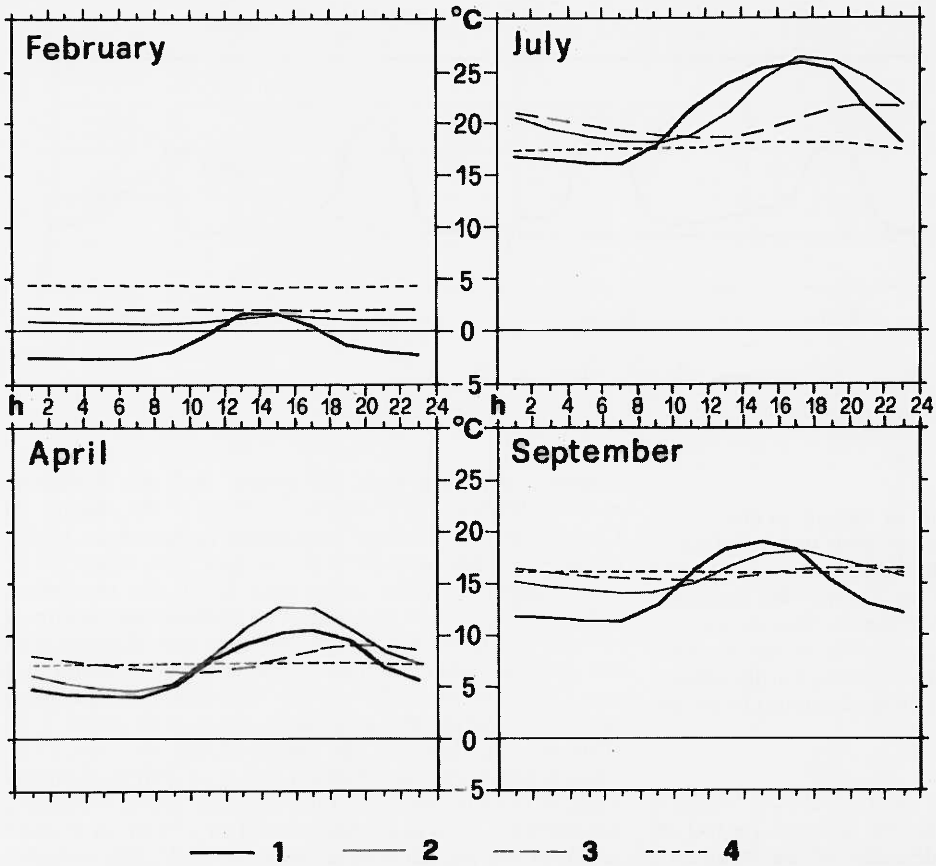

Fig. 5 - Thermic trend: 1 - air; 2 - ground surface; 3 - depth of 10 cm; 4 - depth of 50 cm.

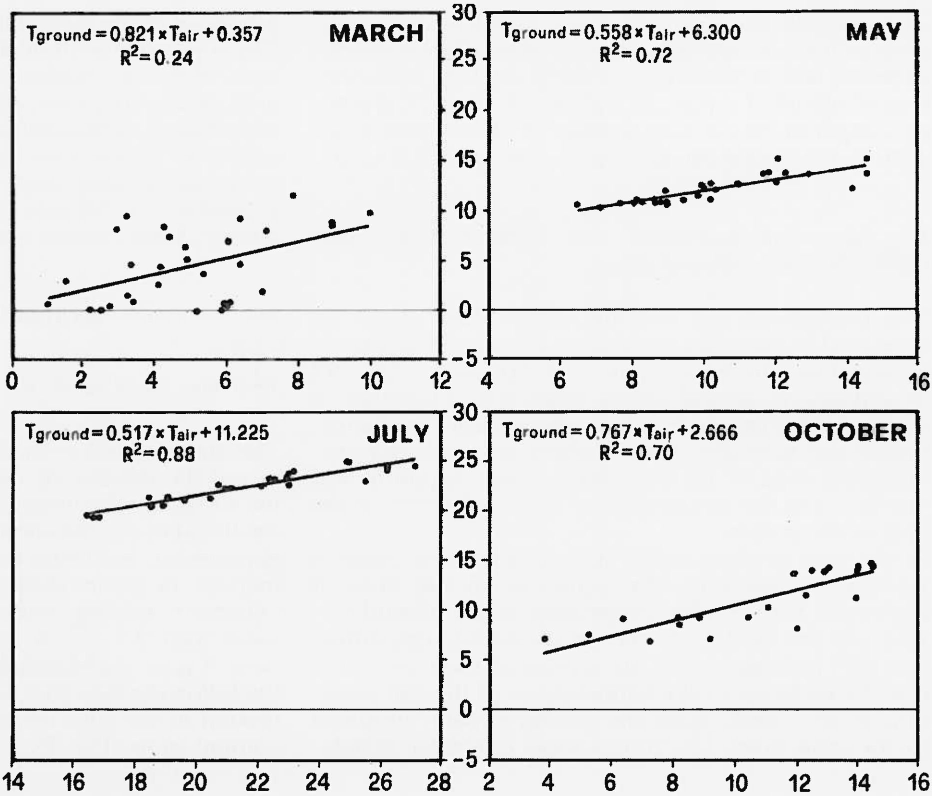

Fig. 6 - Regression lines between the temperature of the ground at the surface (in abscissa) and that of the air in the cabin (in ordinates) at Melo di Cutigliano in the months of March, May, July and October.

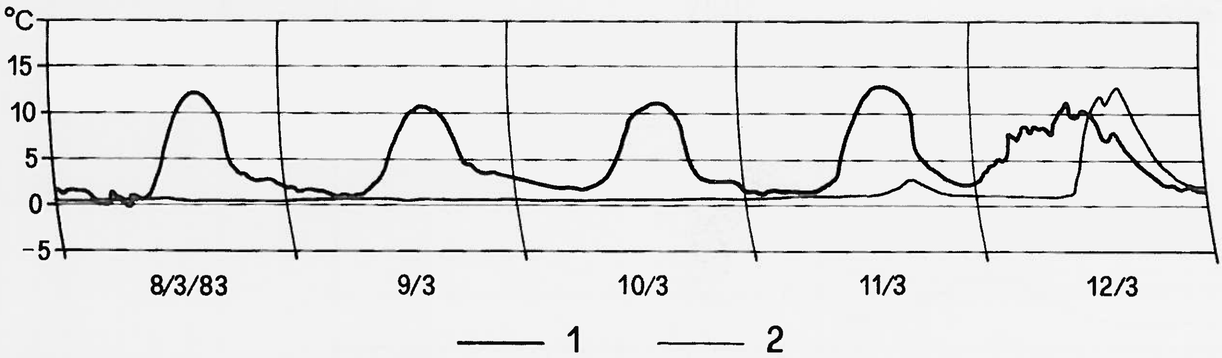

Fig. 7 - Thermic trend with melting snow.

The coldest day

The annual absolute minimum in the air occurred on February 23rd, when 9.9 °C below zero was reached at 5 a.m.; from that moment on the temperature rose until it reached a maximum of 2.9° at 1 p.m. The temperature of the ground, from the surface to -50 cm, mainly because of the presence of a protective layer of snow 34 cm thick, remained at positive levels, hardly affected by the considerable thermic drop occurring in the air (Fig. 8).

The warmest day

In the last week of July and in the first days of August 1983 Tuscany was invested by the longest period of intense heat since the early decades of the twentieth century, affecting both the plains and the Apennine relief (Rapetti & Vittorini, 1992). At Melo di Cutigliano the absolute maximum temperature in the air was reached at 5.30 p.m. on July 26th, when 34.5° was recorded, while at ground level the maximum value of 29.8° was reached. The thermic maximum at -10 cm was more attenuated and more out of phase than the previous ones, with the value of 23.8° reached at 8 p.m. At a depth of 50 cm the maximum temperature was 19.2°, while the amplitude range was about 1 °C (Fig. 9). On this day the range of the air was 15.6° (which represents the highest value of 1983), with the highest velocity rate of temperature increase, occurring between 8 a.m. and midday, equal to 2 °C/h; at ground level, in the presence of a range of 10.6°, the velocity

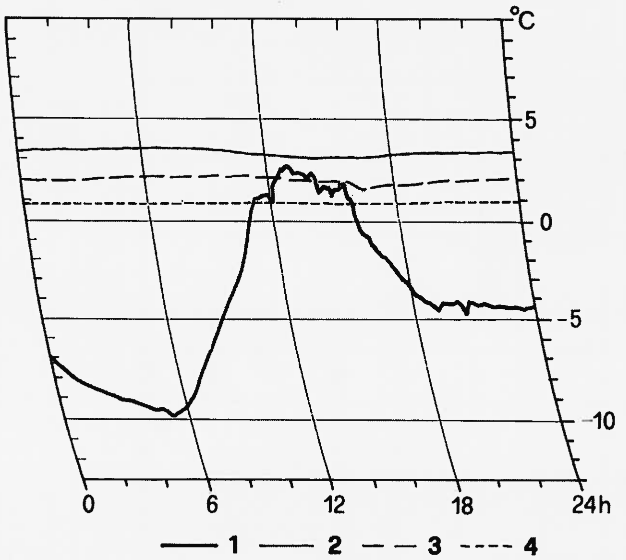

Fig. 8 - Temperatures on the coldest day (February 23rd 1983). 1 - air; 2 - ground surface; 3 - depth of 10 cm; 4 - depth of 50 cm.

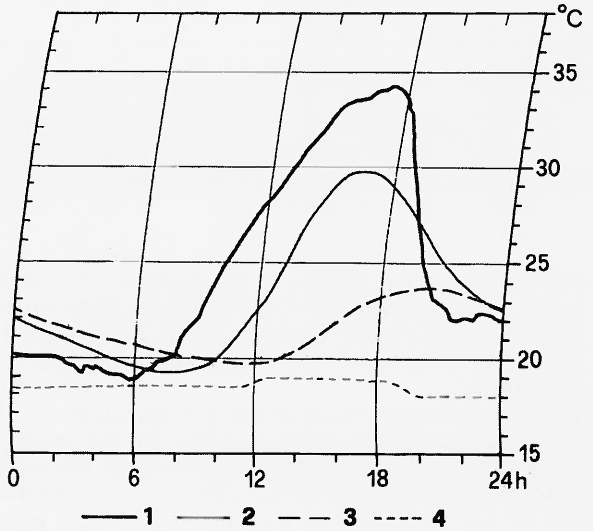

Fig. 9 - Pattern of the temperatures on the warmest day (July 26th 1983). 1 - air; 2 - ground surface; 3 - depth of 10 cm; 4 - depth of 50 cm.

of increase, in the same time interval, was 0.8°/h. The maximum velocity of decrease in the air, in the interval between 6 p.m. and 8 p.m., was 4.5°/h, while in the ground it was 1.2°/h.

THERMIC PROFILE IN THE GROUND AND IN THE AIR

The vertical profile of the temperature in the ground-air system, from a depth of 50 cm to the altitude of the thermograph, situated at 150 cm at the field level, presents different patterns in the course of the year:

- in the month of February the thermic range on the middle day, from a depth of 50 cm to 10 cm, was less than 0.5°; at the surface of the ground it rose to 1.2°; in the cabin the value of 6.6° was reached. It is also observed that the average temperature of the ground at -50 cm was higher than the maximum recorded in the air (Fig. 10A).
- in the month of March the thermic range, which at a depth of 50 cm was 0.4°, rose to 2.1° at 10 cm, to 6.6° at ground level, up to 7.5° recorded in cabin. The minimum temperatures at the surface and in cabin were equal; the maximums, on the other hand, differed by 1° and were higher in the air (Fig. 10B).
- in the month of July the highest value ($\Delta t = 5$ °C) of the difference between the maximum temperature at -10 cm and that at ground level was recorded; this was even higher than the maximum observed in cabin, although with a difference of only 0.4° (Fig. 10C).
- in the month of October the pattern of the maximum and minimum temperatures along the thermic profile was almost rectilinear, to which constant daily ranges correspond (Fig. 10D).

In general, with the exception of the months of March and December, the minimum temperatures recorded at ground level are greater than the minimum temperatures observed in the cabin. The maximum temperatures of the surface are higher than those in the cabin in the months from April to August, with the exception of May (Tab. 6).

THE STATE OF IMBIBITION AND THE THERMIC WAVE IN THE GROUND

Water content plays an essential role in the thermic conductivity of the medium and in the freeze-and-thaw phenomena. With regard to the temperature limit at which the ground water solidifies, numerous experiments, carried out in different types of ground, have shown that freezing occurs at temperatures considerably below 0 °C. Such a phenomenon is linked, as it is known, to the saline concentration of the solutions circulating in the meatuses of the ground, which lowers the freezing temperature of water. In the absence of experimental data regarding the water content of the ground, it was necessary to estimate this element through the development of the water-climate balance of Thornthwaite and Mather (1957) which, with appropriate calculations, makes it possible to determine the annual regimes of water *surplus* (S) and *deficit* (D). In the months in which $S > 0$ the ground, from the surface to the maximum depth of the roots of the plants supported by it, is considered saturated with water. In the months in which the potential evapotranspiration exceeds precipitation a progressive water impoverishment of the ground, expressed by the *deficit*, occurs. Taking into consideration the granulometry of the substratum and the type of vegetation cover at the station, the *field capacity* (ST)[1] is established; the ground reached saturation from October to May (Tab. 8; Fig. 11).

In the month of June the *water deficit* began, reaching

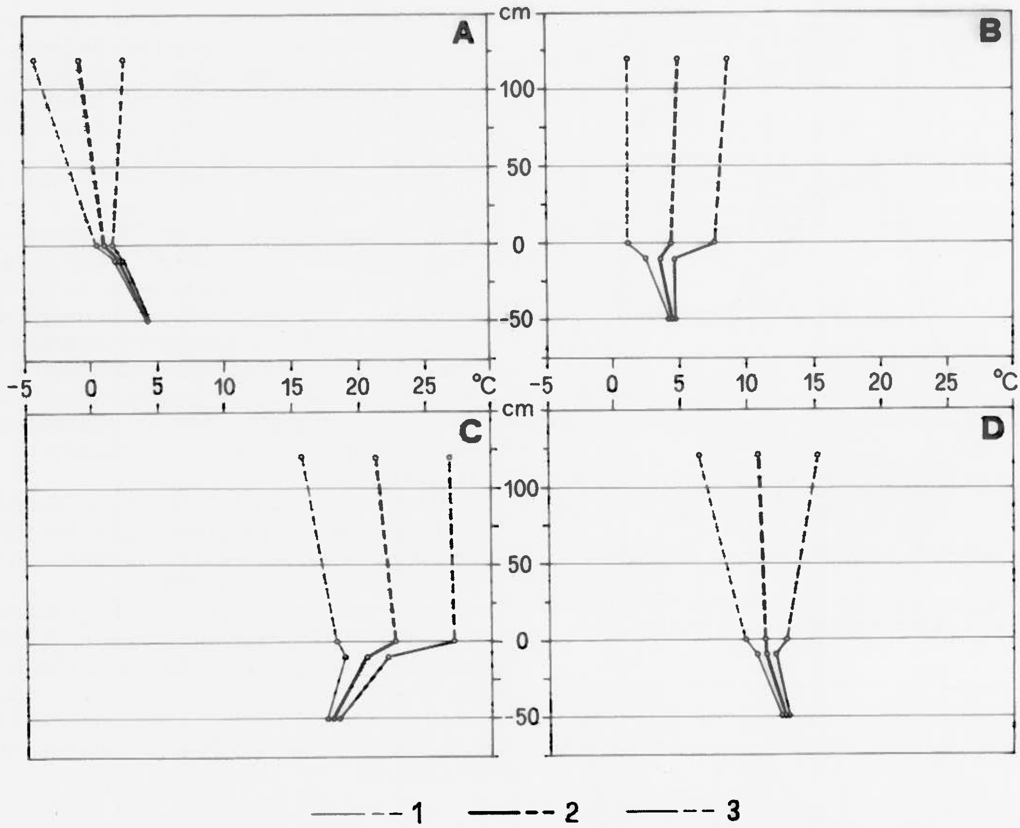

Fig. 10 - Vertical thermic profile of the minimum (1), average (2) and maximum (3) temperatures in the months of February (A), March (B), July (C) and October (D).

its maximum value in July with 59.3 mm, which determined a state of pronounced dryness in the ground. In the months of August and September, with the resumption of precipitation, the reconstitution of the reserve began, with the restoration of full *field capacity* (100 mm) from the beginning of October. The *surplus* (S), following the abundant precipitation, reached its maximum values in March and in December, during which the ground certainly reached the condition of complete saturation. It should, however, be considered that the effective recharging of the ground depends on certain conditions, such as the vegetation cover, with its power of interception, slope gradient and the state of imbibition of the ground surface at the moment of meteoric influx. The consequence of this is that the water content of the ground, which results from the development of the hydro-climatic balance, can in some cases be overestimated.

The annual thermic wave in the ground, because of the known conductivity characteristics of the medium, attenuates rapidly with depth. Indeed, from the surface to 10 cm, a decrease in the range of 3.3° was observed, and of 7.7° from the surface to 50 cm. This pattern should be related to the thermic conductivity of the ground (λ), which is a function of the granulometry and of the relation between the different mineral, organic,

Tab. 8 - Water-climate balance according to Thornthwaite and Mather.

	J	F	M	A	M	J	J	A	S	O	N	D	Year
T	4.8°	0.4°	6.9°	9.0°	11.8°	15.8°	21.6°	18.2°	14.9°	11.0°	6.0°	7.9°	10.7°
P	55.7	161.7	362.5	166.0	147.0	82.9	17.4	124.1	105.9	115.7	57.5	476.5	1872.9
PE	14.9	0.8	28.7	43.0	66.9	95.5	138.6	104.8	71.9	46.1	19.1	25.1	655.5
ST	100.0	100.0	100.0	100.0	100.0	88.2	26.2	45.6	79.6	100.0	100.0	100.0	
AE	14.9	0.8	28.7	43.0	66.9	94.7	79.3	104.8	71.9	46.1	19.1	25.1	595.5
D	0.0	0.0	0.0	0.0	0.0	0.8	59.3	0.0	0.0	0.0	0.0	0.0	60.1
S	40.8	160.9	333.8	123.0	80.1	0.0	0.0	0.0	0.0	49.2	38.4	451.4	1277.4
RO	141.6	151.2	242.5	182.7	131.4	65.7	32.9	16.4	8.2	28.7	33.5	242.5	1277.4

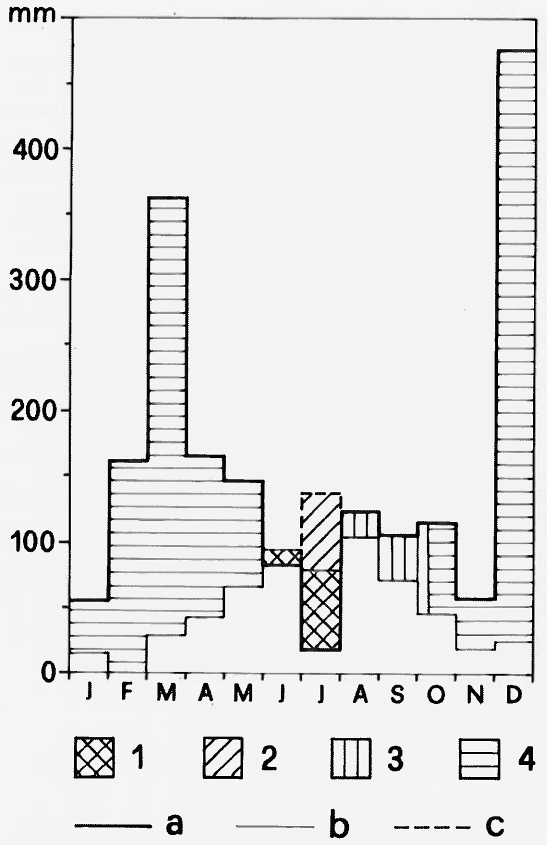

Fig. 11 - Some parameters of the water-climate balance. a: precipitation; b: actual evapotranspiration; c: potential evapotranspiration. 1: storage decrease; 2: evapotranspiration deficit; 3: storage reconstitution; 4: surplus.

water and aeriform fractions. In the absence of experimental data on conductivity, some mathematico-physical models make it possible to compute λ on the basis of the recording of temperatures at different depths (Horton & Wierenga, 1983; Horton, Wierenga & Nielsen, 1983; Sharratt *et al.*, 1992). According to Gamba (1929) the following relation holds:

$$\theta_h = \theta_0 \times e^{-h/a} \times (\pi/\lambda \times T)^{1/2} \quad (1)$$

with θ_h = annual thermic range at a depth h (°C); θ_0 = annual thermic range at the surface of the ground (°C); e = base of Napierian logarithms; λ = coefficient of thermic conductivity (cal $\times$ s^{-1} C^{-1} cm^{-1} C^{-1} $\times$ °C^{-1}); T = period (s). From the relation (1), assuming the specific heat of mass (c) equal to 0.5 cal $\times$ g^{-1} $\times$ °C^{-1}, we can obtain the coefficient of thermic conductivity, which results from the relation (2):

$$\lambda = a^2 \times c \quad (2)$$

where:

$$a = h - h_0/\ln \theta_0/\theta_h \times (\pi/T)^{1/2} \quad (3)$$

The coefficient of thermic conductivity assumed in all cases a higher value in the deep ground layers than in the surface layers: in the month of May, for example, $\lambda_{(10/-50)}$ was about 13 times $\lambda_{(0/-10)}$. This fact can certainly be linked to the greater compacting and greater water content of the deeper layers of the ground (Tab. 9).

Tab. 9 - Coefficient of conductivity between the surface and some levels in the ground.

	λ driest day	λ most humid day	λ May	λ July
Sup./-10 cm	1.80 10^{-4}	1.20 10^{-3}	5.85 10^{-5}	5.73 10^{-5}
Sup./-50 cm	4.51 10^{-3}	3.64 10^{-3}	3.32 10^{-4}	2.82 10^{-4}
-10 /-50 cm	2.89 10^{-3}	5.49 10^{-3}	7.77 10^{-4}	5.83 10^{-4}

The decrease in the annual range with depth follows, in this case, a parabolic law which makes it possible to predict the annulment of the thermic wave at a depth of about 3.7 metres.

CONCLUSIONS

From the studies carried out in 1983 at the station of Melo di Cutigliano on the number of freeze-and-thaw cycles occurring in the air (cabin) and those occurring in the ground, a clear difference between the two mediums emerged (Tab. 10). The most significant decrease in the number of cycles occurred in the transition between the air and the surface of the ground: in particular, the number of transitions above and below zero occurring at the surface represented hardly 13.8% of that in the air (Pinna, 1963). The reduction in the number of such cycles with depth is likewise very rapid, since at -10 cm only two were counted, while at a depth of 50 cm the absolute minimum, with 1.3°C (December 19), remained well above the freezing temperature of water.

Tab. 10 - Number of freeze-and-thaw cycles.

		J	F	M	A	N	D	Total
Air	max-min cycles	18	32	20	8	10	24	112
	diagram cycles	22	36	22	12	14	24	130
Surf. ground	max-min cycles	2	6	8	0	0	2	18
	diagram cycles	2	6	8	0	0	2	18
Ground -10 cm	max-min cycles	0	0	2	0	0	0	2
	diagram cycles	0	0	2	0	0	0	2

By no means significant, on the other hand, are the errors that are committed in the calculation of the number of cycles when the daily minimum and maximum values are considered in place of the more correct use of continuous recordings of temperature; in the air the difference between the two methods was indeed 13.8%. It should however be taken into consideration that the studies conducted on the basis of the temperature recorded in the air, if they do not allow an evaluation of the number of freeze-and-thaw cycles occurring in the ground, are still of considerable importance, since they make it possible to obtain a picture of the phenomenon in general geographical terms.

FOOTNOTES

[1] The field capacity is the maximum water content that the ground can hold.

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