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CLIMATOLOGICAL BASIS FOR PREDICTION OF TEMPERATURE REGIME ON GROUND

Klimatološka osnova za prognozu klizavosti kolnika

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Abstract: Data on air and road surface temperatures not beeing available, climatological data from the site of the meteorological station have been used to determine the temperature relations needed for predicting road slipperiness. The analysis has been made for the cold period of the year (September to May) for the 10-year period 1971–1980 at the Zagreb-Maksimir station, located in the Sava River valley at the foot of Mount Medvednica. The analysis involves the relations between minimum air temperatures at two levels, 2 m and 5 cm as well as between minimum air temperatures at 2 m height and soil temperatures at 5 cm depth at 7 a.m. during various weather situations, defined according to average cloudiness, wind conditions, fog and frozen ground during the night preceding the occurrence of minimum temperatures.

In weather situations with prevailing radiation processes (clear/calm and partly cloudy/calm), the minimum surface air temperatures are always lower than at 2 m height. On the other hand, after cloudy nights, regardless of wind velocity, the minimum surface temperatures are lower than those at 2 m only above determined temperature levels. The minimum air temperatures at 5 cm height are lower than 0°C when the minimum temperatures at 2 m height are lower than 3°C during clear/calm, clear/windy and partly cloudy/calm situations. During partly cloudy/windy, cloudy/calm and cloudy/windy situations, the differences between minimum temperatures at these two levels are smaller, and consequently, negative minimum surface temperatures appear if the minimum temperatures at 2 m are about 0°C.

The relations between minimum air temperatures and soil temperatures do not differ significantly for different weather types. However, they differ considerably from month to month. According to these conclusions, soil temperatures should be predicted particularly by means of regression equations obtained for each month.

Key words: minimum air temperature, soil temperature, weather types, correlation

Sažetak: U nedostatku podataka o temperaturi na površini ceste, za prognozu klizavosti kolnika koriste se temperaturne veze prema klimatološkim podacima s meteoroloških postaja. Analiza je provedena za hladni dio godine (od rujna do svibnja) prema podacima za 10-godišnje razdoblje 1971–1980. s meteorološke postaje Zagreb-Maksimir, smještene u dolini rijeke Save u podnožju Medvednice. Proučavani su odnosi između minimalnih temperatura zraka na dvije visine, na 2 m i na 5 cm iznad tla, te veze između minimalnih temperatura na 2 m i temperature tla na dubini 5 cm u 7 h ujutro u različitim vremenskim situacijama. One su određene na temelju prosječne naoblake, vjetrovnih prilika, pojave magle ili tla zaleđenog u prethodnoj noći.

U vremenskim situacijama s prevladavajućim radijacijskim procesima (vedro ili djelomično oblačno vrijeme bez vjetra) minimalne temperature zraka na 5 cm nad tlom uvijek su niže od temperatura na visini od 2 m. Nasuprot tome, nakon oblačnih noći, bez obzira na vjetrovne prilike, temperature uz tlo niže su od onih na 2 m samo iznad određenih temperatura. Minimalne temperature na visini 5 cm niže su od 0°C kada su minimalne temperature na visini od 2 m niže od 3°C za vrijeme vedrih situacija, bilo mirnih bilo vjetrovitih, te za vrijeme djelomično oblačnih i mirnih vremenskih situacija. Za vrijeme djelomično oblačnih i vjetrovitih situacija te oblačnih i mirnih i vjetrovitih situacija, razlike između minimalnih temperatura zraka na dvije visine manje su, a negativne temperature uz tlo pojavljuju se kad su minimalne temperature na visini od 2 m oko 0°C.

Ključne riječi: minimalna temperatura zraka, temperatura tla, tipovi vremena, korelacija

1. INTRODUCTION

Road slipperiness is one of the main causes of car accidents. The benefits of a proper weather forecast, ensuring timely action by road maintenance services, are significant (Kempe, 1990; Thornes, 1990, Wass, 1990). For that reason the meteorological basis for road slipperiness is often the subject of investigation, especially along the road routes where the weather risk is great (Gustavsson, 1988; Waylen, 1988; Bogren and Gustavsson, 1989, 1991; Gustavsson and Bogren, 1990, 1994; Bogren, 1991; Takle, 1990; Gustavsson, 1991; Sass, 1992, 1993).

In countries where a road weather information system exists, most investigations deal with meteorological data measured along the road. In regions where road monitoring is not developed and not yet introduced into everyday practice, as the case is in Croatia, meteorological data from the regular meteorological network present valuable material for applied road weather climatological studies. The results can serve as initial information about the temperature climatological conditions that can cause road slipperiness in different parts of the country, as well as a base for the installation of a road weather information system.

As the surface temperatures vary, especially under different weather conditions of cloud cover and wind speed, the following analysis refers to the minimum temperature relations at two levels and to the relations of minimum temperatures at 2 m height and soil temperatures at 5 cm depth, at 7 a.m., under different weather conditions, in the continental lowland of Croatia, in the very southern part of the Pannonian lowland.

2. DATA AND METHOD

The analysis has been made for the Zagreb-Maksimir station at the foot of the Medvednica mountain, in the Sava River valley, for the 10-year period 1981/82–1990/91, taking into account only the cold period of the year (September to May), when minimum temperatures lower than 0°C at 5 cm height can be expected.

The correlations between minimum air temperatures at the heights of 2 m and 5 cm and the correlations between minimum air temperatures at the height of 2 m and soil temperatures at 5 cm, depth at 7 a.m., have been determined for eight different weather situations. Six of them were classified by means of mean cloudiness (C) and mean wind velocity (v), and two of them were situations with fog and frozen ground during the night (from 9 p.m. till 7 a.m.) which is in accordance with minimum temperatures appearing mostly early in the morning, influencing air and surface cooling. The following classes of weather situations were defined:

a) clear ($C < 2/10$) – calm ($v \leq 3.3\ ms^{-1}$)

b) clear ($C < 2/10$) – windy ($v > 3.3\ ms^{-1}$)

c) partly cloudy ($2/10 \leq C \leq 8/10$) – calm ($v \leq 3.3\ ms^{-1}$)

d) partly cloudy ($2/10 \leq C \leq 8/10$) – windy ($v > 3.3\ ms^{-1}$)

e) cloudy ($C > 8/10$) – calm ($v \leq 3.3\ ms^{-1}$)

f) cloudy ($C > 8/10$) – windy ($v > 3.3\ ms^{-1}$)

g) fog (visibility $\leq$ 1000 m)

h) frozen ground

3. MINIMUM AIR TEMPERATURES AND SURFACE TEMPERATURES

The relations between minimum air temperatures at 2 m and 5 cm height are linear: $\boldsymbol{y} = \boldsymbol{a} + \boldsymbol{bx}$, where y i s the expected minimum surface temperature ($t_{min-5cm}$), x is the minimum air temperature at 2 m height (t_{min-2m}), a denotes the y value for x = 0°C, and b is the slope of y. Their correlation coefficients (r) are highly significant. They are determined

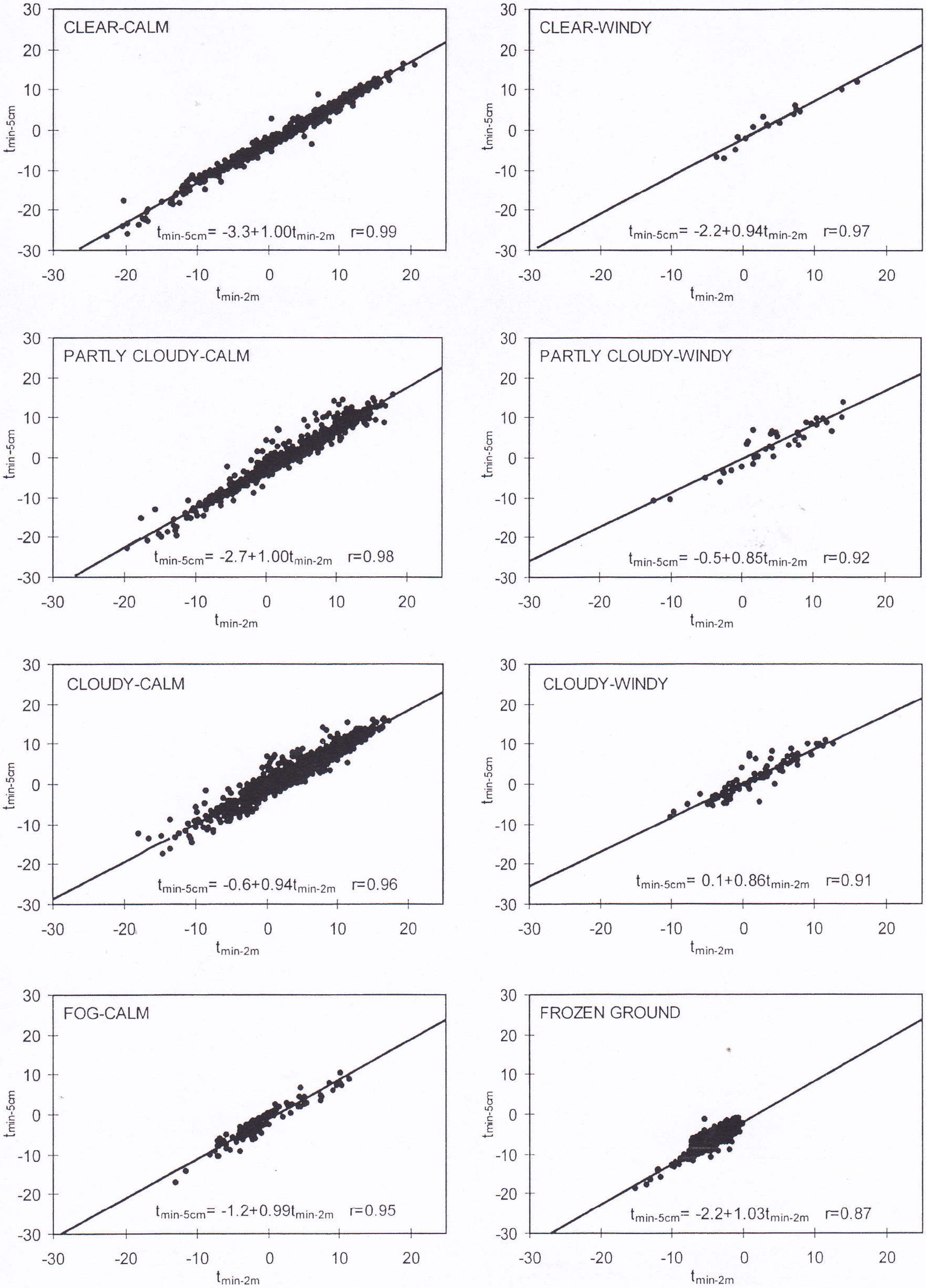

Figure 1. Regression lines of minimum air temperatures at 2 m (t_{min-2m}) and 5 cm heights ($t_{min-5cm}$) during the cold period (September–May), Zagreb-Maksimir, period: 1981/82–1990/91.

Slika 1. Pravci regresije između minimalnih temperatura zraka na visini 2 m (t_{min-2m}) i na visini 5 cm ($t_{min-5cm}$) u hladnom dijelu godine (IX–V), Zagreb-Maksimir, razdoblje: 1981/82–1990/91.

Table 1. The values of t_{min-2m} below which $t_{min-5cm}$ have negative values at Zagreb-Maksimir. Period: 1981/82–1990/91.

Tablica 1. Vrijednosti t_{min-2m} ispod kojih su $t_{min-5cm}$ negativne na postaji Zagreb-Maksimir. Razdoblje: 1981/82–1990/91.

	a	b	c	d	e	f	g	h
IX	2.9		1.4		-0.3			
X	3.2		2.6		-0.3		1.2	
XI	3.1		2.3		0.2	-1.7	0.9	2.8
XII	2.7		2.6		0.7	1.1	0.2	1.3
I	3.0		3.0		0.5		0.3	1.9
II	3.5		2.4		-0.8	-0.5	1.3	2.5
III	3.6		2.8		1.1	0.6		3.0
IV	3.8		3.0	-4.3	0.3	-0.9		
V	3.4		2.8		1.1			
IX–V	3.3	2.3	2.7	0.6	0.6	-0.1	1.2	2.1

Table 2. The values of t_{min-2m} for which $t_{min-5cm}$ have lower values than t_{min-2m} at Zagreb-Maksimir. Period: 1981/82–1990/91.

Tablica 2. Vrijednosti t_{min-2m} kod kojih su $t_{min-5cm}$ niže od t_{min-2m} na postaji Zagreb-Maksimir. Razdoblje: 1981/82–1990/91.

	a	b	c	d	e	f	g	h
IX	all		all		>3.0			
X	all		all		>2.3		all	
XI	all		all		>-1.5	>8.2	<5.8	all
XII	all		all		>-4.3	>-3.1	<1.4	<8.8
I	all		all		>-5.6		<2.1	all
II	all		all		all	>12.5	all	all
III	all		all		all	>-2.9		all
IV	all		all	>3.8	>-2.1	>-3.0		
V	all		all		all			
IX–V	all	all	all	>-3.3	>-10.0	>0.7	all	all

for all cases with a number of data exceeding 10 (Fig. 1).

a) clear – calm

Temperature inversion usually occurs in these weather situations, and $t_{min-5cm}$ can be expected to be lower than t_{min-2m} in each month in the period September to May. The coefficient b is close to 1 and the coefficient a is negative. It means that $t_{min-5cm}$ will be approximately a°C lower than t_{min-2m}. The coefficients a are similar in each month and are in the interval of –2.7°C to –3.5°C. The difference between t_{min-2m} and $t_{min-5cm}$ in this weather situation is the greatest, compared to other situations. Negative values of $t_{min-5cm}$ will appear when t_{min-2m} are below 2.7°C in December and below 3.8°C in April (Tab. 1, column a).

b) clear – windy

These weather situations are rather rare. They appeared only 1–5 times per month from October to May, and then the temperatures were mainly higher than 0°C. The difference between t_{min-2m} and $t_{min-5cm}$ is smaller than during clear nights without wind, because of stronger air mixing.

c) partly cloudy – calm

During the whole period from September to May one can expect lower $t_{min-5cm}$ than t_{min-2m} (Tab. 2, column c), but the difference is smaller than in clear – calm situations. According to the calculation for the whole period, this difference is only 0.6°C. The levels of t_{min-2m} below which $t_{min-5cm}$ are lower than 0°C are presented in Table 1. (column c), and it can be seen that the level values do not differ a lot during the cold part of the year. One can expect negative $t_{min-5cm}$ when t_{min-2m} are lower than 3°C in January and April, and lower than 1.4°C in September.

d) partly cloudy – windy

It was not possible to determine the correlations between $t_{min-5cm}$ and t_{min-2m}, because of an insufficient number of cases (<10) for all months except April (12), when the observed temperatures were higher than 0°C, which was not of interest for the application discussed. According to the coefficient a, it is evident that the differences between t_{min-2m} and $t_{min-5cm}$ in partly cloudy but windy situations are smaller by for about 2°C than in calm situations.

e) cloudy – calm

In these weather situations, which are the most frequent from November to February, the differences between t_{min-2m} and $t_{min-5cm}$ are relatively small (0.2°C to 1.1°C) compared to other weather situations. They have not the same sense in all months: $t_{min-5cm}$ are sometimes lower and sometimes higher than t_{min-2m}

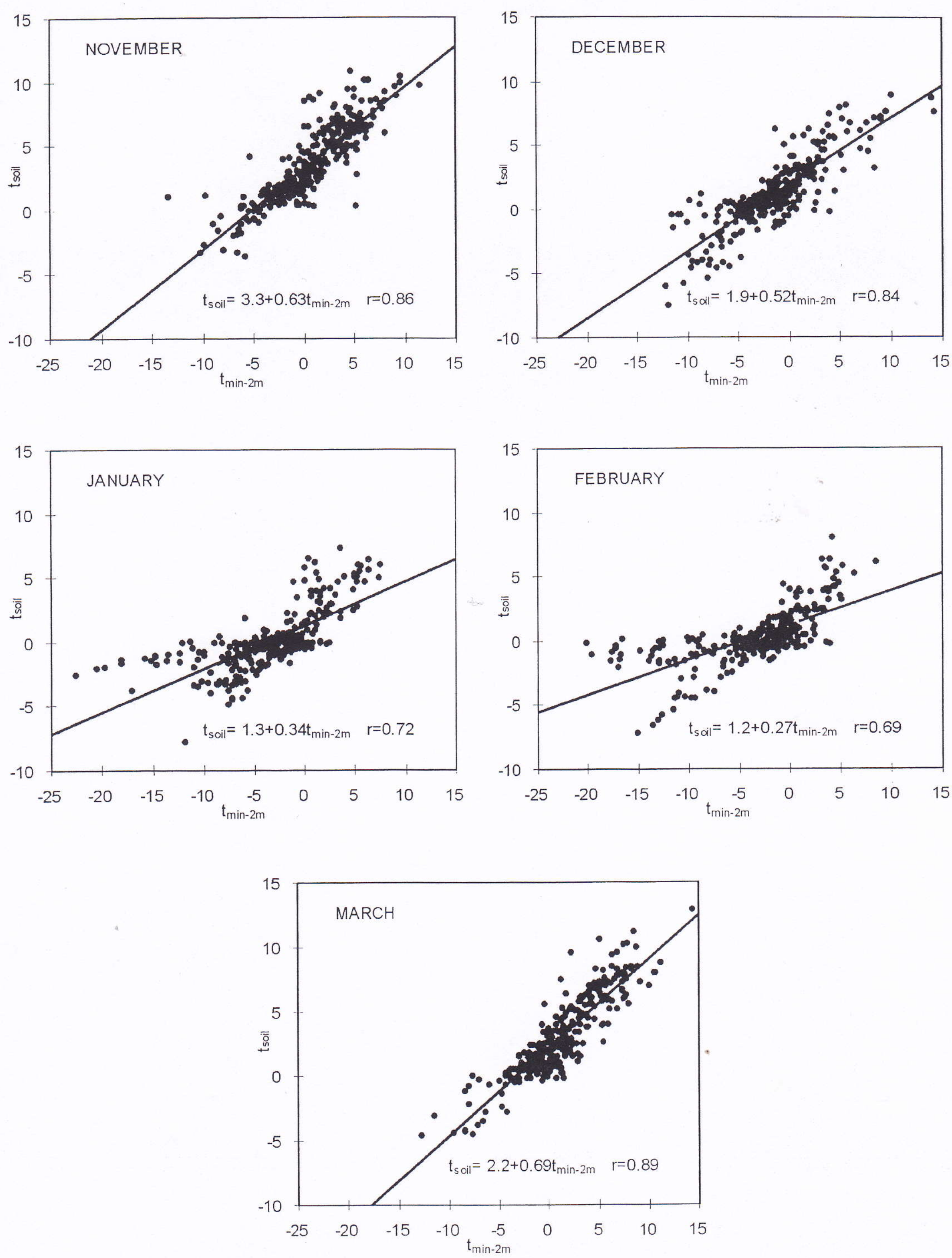

Figure 2. Regression lines of minimum air temperatures at 2 m height (t_{min-2m}) and soil temperatures at 5 cm depth at 7 a.m. (t_{soil}) from November to March, Zagreb-Maksimir, period: 1981/82–1990/91.

Slika 2. Pravci regresije između minimalnih temperatura zraka na visini 2 m (t_{min-2m}) i temperatura tla na dubini 5 cm u 7 h (t_{soil}) od studenog do ožujka, Zagreb-Maksimir, razdoblje: 1981/82–1990/91.

(Tab. 2, column e). $t_{min-5cm}$ are lower than 0°C for the values of t_{min-2m} from −0.8°C in February to 1.1°C in March and May (Tab. 1, column e).

f) cloudy – windy

The weather situation cloudy – windy appeared in all months, although very rarely. In November, December, February, March, and April there were in total 10–22 such days per month. For the whole period, in average, $t_{min-5cm}$ are lower than t_{min-2m} for t_{min-2m} > 0.7°C. Analogous relations for each month are presented in Table 2. (column f). $t_{min-5cm}$ are lower than 0°C for the values of t_{min-2m} between −1.7°C in November and 1.1°C in December (Tab. 1, column f). As opposed to the other weather situations (clear and partly cloudy), the differences between t_{min-2m} and $t_{min-5cm}$ are small and similar in both calm and windy cloudy nights.

g) fog

In weather situations with fog in the early morning hours, in the interval from 4 to 7 hours, the night is calm. Such situations appeared only in the coldest part of the year, from October to February. During the whole temperature interval, in these situations, $t_{min-5cm}$ are lower than t_{min-2m} only in October and February, while in the period November to January this happens only when t_{min-2m} are below defined levels (Tab. 2, column g). A negative $t_{min-5cm}$ will appear in average for t_{min-2m} lower than 1.2°C (September to May), but it can differ from month to month (between 0.2°C and 1.3°C) (Tab. 1, column g). Coefficient *b* shows that in situations with fog $t_{min-5cm}$ changes faster than t_{min-2m}, compared to other situations.

h) frozen ground

Situations with frozen ground at the meteorological station site, appeared from November to March. $t_{min-5cm}$ were lower than t_{min-2m} for the whole temperature interval in all months except December, when this relation can be found for t_{min-2m} lower than 8.8°C (Tab. 2, column h). A negative $t_{min-5cm}$ can be expected for t_{min-2m} lower than 1.3°C in December to lower than 3.0°C in March (Tab. 1, column h).

4. MINIMUM AIR AND SOIL TEMPERATURES

The relations between minimum air temperatures at 2 m height and soil temperatures at the depth of 5 cm are linear: $y = a + bx$, where y is the expected soil temperature (t_{soil}), x is the minimum air temperature at 2 m height (t_{min-2m}), a denotes the y value for x = 0°C, and b is the slope of y.

It turned out that relations between minimum air temperatures at 2 m (t_{min-2m}) and soil temperatures at the depth of 5 cm (t_{soil}) do not differ significantly for different weather types, but they differ considerably from month to month. The relations between t_{min-2m} and t_{soil} have been determined for all months in the cold part of the year when soil temperatures lower than 0°C can be expected (from November till March) (Fig. 2).

Highly significant correlation coefficients (r) indicate that, knowing the minimum air temperatures, one can estimate soil temperatures very well by means of these equations. However, for very low minimum air temperatures (<−10°C) the difference between the real and estimated soil temperature can be greater.

The slope b<1 indicates that the soil temperature changes slower than the minimum air temperature. The changes of t_{soil} are the slowest in the coldest months – if t_{min-2m} changes by 1°C, the change in soil temperature will be about 0.3°C in January and February, and up to 0.6 to 0.7°C in November and March.

At lower temperatures, the soil temperatures are higher than the minimum air temperatures at 2 m height, while the opposite occurs at higher temperatures. The limits at which t_{soil} become lower than t_{min-2m} differ from

Table 3. The values of t_{min-2m} above which t_{soil} becomes lower and the values of t_{min-2m} below which t_{soil} becomes negative. Zagreb-Maksimir, period: 1981/82–1990/91.

Tablica 3. Vrijednosti t_{min-2m} iznad kojih t_{soil} postaju niže i vrijednosti t_{min-2m} ispod kojih t_{soil} postaju negativne. Zagreb-Maksimir, razdoblje: 1981/82–1990/91.

	XI	XII	I	II	III
t_{soil}<t_{min-2m}	8.9	4.0	2.0	1.6	7.1
t_{soil}<0°C	−5.2	−3.7	−3.8	−4.4	−3.2

month to month (Tab. 3). In November, soil temperatures will rarely be lower than minimum air temperatures because the limit values of t_{min-2m} at which this happens are almost the same as the maximum values they can reach. On the other side, during January and February this condition will be fulfilled already for t_{min-2m} higher than 1.6°C or 2°C.

For traffic safety it is much more interesting to determine the minimum air temperatures at which the soil temperatures will be negative, as in these situations slipperiness can appear. In November, this condition will be very rare because the minimum temperature has to be lower than –5.2°C, which is not very often. During winter, slipperiness can appear if the minimum air temperature is lower than about –4°C (–4.4°C in February and –3.7°C in December) (Tab. 3).

5. CONCLUSIONS

This analysis is an example of how climatological data can be used in the prediction of minimal temperatures and all these parameters dependent on them. The results are applicable to the insurance of safer road traffic (prediction of road slipperiness) and can help in forecasting hazardous weather situations.

In weather situations with prevailing radiation processes (clear/calm and partly cloudy/calm) the minimum surface air temperatures are always lower than those at 2 m height. On the contrary, after cloudy nights, regardless of wind velocity, the minimum surface temperatures are smaller than those at 2 m only above determined temperature levels. The minimum air temperatures at 5 cm height are lower than 0°C when the minimum temperatures at 2 m height are lower than 3°C during clear/calm, clear/windy and partly cloudy/calm situations. During partly cloudy/windy, cloudy/calm and cloudy/windy situations the differences between the minimum temperatures at two levels are lower, and consequently, negative minimum surface temperatures appear if the minimum temperatures at 2 m are about 0°C.

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