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# EVALUATION OF THE POSSIBILITY OF THE ESTIMATION OF BARE SOIL TEMPERATURE ON THE BASIS OF AIR TEMPERATURE MEASUREMENT

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**Abstract**. Basis of the study was made up of the results of automatic, hourly measurements of air temperature and bare soil temperature originating from the agrometeorological station in Lipnik (53°21' N; 14°58' E, 30 m AMSL) from the period of 2001-2005. Basing on the results of the linear regression analysis, relationships for particular months were determined between daily soil temperature at four depths and air temperature set in seven different combinations. It was stated that the highest possibilities of daily soil temperature prediction in profile to 50 cm are characteristic for the air temperature that is the average from 24 hourly measurements. Average absolute differences between the actual soil temperature and the one calculated from equations for this relation oscillate in the particular months between 1.3°C at the depth of 5 cm and 0.5°C at the depth of 50 cm. On average, the smallest differences apply to the warm half of the year and the depth of 50 cm. It was shown that significantly smaller possibilities of the estimation of daily soil temperature values are characteristic for daily air temperature amplitude.

**Key words**: air temperature, soil temperature, soil temperature estimation

## INTRODUCTION

A number of meteorological elements influences the daily course of soil temperature, such as radiation, insolation, air temperature, air humidity deficiency, and wind [Kapuściński 1991, Kossowski 2003, Michalska and Nidzgorska-Lencewicz 2005], and also the topography of the environment, thermal properties of the soil, time of year and day, and the properties of the active area in which the transformation and exchange of energy take place [Walczak 1987, Walczak and Usowicz 1994, Usowicz and Marczewski 2005]. The observed deviation from the consistence of the course of air and soil temperature at various depths may result, among others, from the occurrence of negative temperature (water freezing and unfreezing in the steam area of the soil), or also from other weather factors, such as snow cover, precipitation, or even air pressure [Koźmiński

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and Michalska 1987, Michalska and Nidzgorska-Lencewicz 2005, Szewczyk 2005]. Kossowski [2003] by studying the possibility of the estimation of heat stream in the soil with the use of standard meteorological data, stated that the strongest relation with the quantity of heat that penetrates into the soil during the day had the values of daily air temperature, so daily heat streams in the soil may be estimated on the basis of maximum and minimum air temperature, and in order to obtain the smallest possible error, also regarding real insolation. Michalska and Nidzgorska-Lencewicz [2005] stated that the closest relations of bare soil temperature at the depth of 5 cm occurred with air temperature measured on the day of the measurement, at greater depths (10 and 20 cm) the relations were best described by air temperature from the day preceding the measurement, and at the depth of 50 cm – air temperature measured two days before soil measurement.

Attempts of forecasting soil temperature were made by various scholars [Koźmiński 1983, 1991, Kang et al. 2000, Mihalakakou 2002, Plaubourg 2002] and it states from them that the greatest role in shaping bare soil temperature is played by air temperature measured at the standard level of 200 cm above the ground level.

Aim of the work was the evaluation of the possibility of soil temperature estimation at different depths in a daily course on the basis of air temperature formulated in different variants.

## MATERIAL AND METHODS

Initial data was made up of hourly (according to UTC) results of automatic air temperature measurements from 200 cm above the ground level and bare soil temperature from years 2001-2005. Measurements were taken at the agrometeorological station in Lipnik near Stargard Szczeciński, which is situated in the central part of the Szczecińska Lowland (53$^o$21' N; 14$^o$58' E, Hs 30 m AMSL) on light acid brown earth formed from boulder sand with clay insertions at the depth of 70 cm, with no ground-water wet soil. The installed thermistor sensors of type ST1 by DELTA-T of the size equal to 125 per 4.8 cm and with the measurement accuracy of ±0.2$^o$C within the temperature range of -20$^o$C to +80$^o$C were placed horizontally in the soil at four standard depths: 5, 10, 20, and 50 cm.

In the analysis, air temperature in 7 variants was taken into account as:

1) daily mean from 24 hourly measurements,
2) daily mean from hours: 3$^{00}$ a.m., 6$^{00}$ a.m., 9$^{00}$ a.m., 12$^{00}$ p.m., 3$^{00}$ p.m., 6$^{00}$ p.m., 9$^{00}$ p.m., and 12$^{00}$ a.m.,
3) daily mean from maximum temperature, minimum temperature, and measurements from 6$^{00}$ a.m. and 6$^{00}$ p.m.,
4) daily mean from maximum and minimum temperatures,
5) daily maximum,
6) daily minimum,
7) daily amplitude.

Daily air temperature set in different combinations is graphically presented in the form of monthly means and monthly mean standard deviation. Using the t-Student's test for independent variables, the significance of daily differences between air temperatures calculated with the use of various methods was also determined.

Relation between daily soil temperatures at 4 depths and air temperature set in the above variants was determined with the help of linear regression. Significance of determination coefficients $R^2$ was estimated at the level of P = 0.01 and P = 0.05, and the significance of regression equations was verified by F-Snedecor's test with the same reliability. Calculations were done with the use of the Statistica 8.0 program.

## RESULTS AND DISCUSSION

Values of the t-Student's test for the daily differences between air temperatures calculated using different methods (Table 1) indicate that in the case of the four first calculation methods of daily air temperature, so calculated as a mean from 24, 8, 4, and 2 measurements, in no month were the differences statistically significant. Significant differences appear, however, in the comparison of daily air temperature with extreme values (maximum and minimum) and air temperature amplitude. They are particularly great in summer months (July, August).

Table 1. Values of the t-Student's test for the daily differences between air temperatures calculated in different variants (2001-2005)
Tabela 1. Wartości testu t-Studenta dla dobowych różnic pomiędzy temperaturami powietrza obliczonymi w różnych wariantach (lata 2001-2005)

| Variant Wariant | Jan Styczeń | Feb Luty | Mar Marzec | Apr Kwiecień | May Maj | Jun Czerwiec | Jul Lipiec | Aug Sierpień | Sep Wrzesień | Oct Październik | Nov Listopad | Dec Grudzień |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 vs – a 2 | 0.5 | 0.5 | -1.0 | -0.5 | -0.5 | -0.3 | -1.1 | 1.0 | 1.1 | 0.8 | 1.7 | 0.8 |
| 1 vs – a 3 | 0.7 | 0.7 | -0.8 | 0.3 | 0.0 | 0.1 | -0.8 | 1.6 | 1.9 | 1.6 | 2.1 | 0.9 |
| 1 vs – a 4 | 0.7 | 0.5 | -1.1 | -0.1 | 0.2 | 0.9 | -0.7 | 0.9 | 0.9 | 0.6 | 1.8 | 0.8 |
| 1 vs – a 5 | -4.7 | -9.2 | -7.9 | -3.4 | 8.1 | 16.1 | 20.1 | 23.0 | 12.2 | 7.0 | 1.0 | -7.1 |
| 1 vs – a 6 | -2.6 | -4.7 | -7.4 | -9.2 | -12.2 | -11.9 | -13.0 | -14.0 | -11.3 | -8.4 | -4.3 | -3.6 |
| 1 vs – a 7 | 3.7 | 5.5 | 6.0 | 10.8 | 14.5 | 16.8 | 16.1 | 18.8 | 16.2 | 9.6 | 7.6 | 4.8 |
| 2 vs – a 3 | 0.2 | 0.2 | 0.2 | 0.8 | 0.5 | 0.4 | 0.3 | 0.6 | 0.8 | 0.7 | 0.4 | 0.2 |
| 2 vs – a 4 | 0.2 | 0.0 | -0.1 | 0.4 | 0.7 | 1.1 | 0.4 | -0.1 | -0.2 | -0.2 | 0.1 | 0.1 |
| 2 vs – a 5 | -5.2 | -10.1 | -6.6 | -2.8 | 8.1 | 15.6 | 20.2 | 21.3 | 10.9 | 5.8 | -0.9 | -7.8 |
| 2 vs – a 6 | -3.0 | -5.3 | -6.2 | -8.3 | -11.2 | -11.0 | -11.6 | -14.2 | -11.7 | -8.7 | -6.2 | -4.2 |
| 2 vs – a 7 | 3.2 | 5.0 | 6.8 | 10.8 | 14.3 | 16.4 | 17.0 | 17.4 | 14.7 | 8.3 | 6.1 | 3.9 |
| 3 vs – a 4 | 0.0 | -0.2 | -0.3 | -0.4 | 0.2 | 0.7 | 0.1 | -0.7 | -0.9 | -0.9 | -0.3 | -0.1 |
| 3 vs – a 5 | -5.4 | -10.2 | -6.8 | -3.6 | 7.8 | 15.5 | 20.3 | 20.8 | 10.3 | 5.0 | -1.4 | -8.0 |
| 3 vs – a 6 | -3.2 | -5.5 | -6.4 | -9.1 | -11.7 | -11.6 | -12.0 | -14.6 | -12.3 | -9.2 | -6.6 | -4.4 |
| 3 vs – a 7 | 2.9 | 4.8 | 6.5 | 10.1 | 14.0 | 16.5 | 17.2 | 16.8 | 14.0 | 7.6 | 5.6 | 3.8 |
| 4 vs – a 5 | -5.3 | -9.9 | -6.4 | -3.2 | 7.5 | 15.0 | 20.3 | 21.3 | 10.9 | 5.9 | -1.1 | -8.0 |
| 4 vs – a 6 | -3.1 | -5.2 | -6.0 | -8.7 | -11.8 | -12.2 | -12.1 | -14.0 | -11.4 | -8.3 | -6.3 | -4.3 |
| 4 vs – a 7 | 2.9 | 4.9 | 6.8 | 10.4 | 13.6 | 15.8 | 17.2 | 17.3 | 14.7 | 8.4 | 5.9 | 3.9 |
| 5 vs – a 6 | 1.4 | 3.8 | -0.9 | -5.8 | -17.4 | -23.8 | -27.4 | -30.8 | -19.3 | -14.4 | -6.1 | 2.9 |
| 5 vs – a 7 | 8.5 | 14.8 | 14.3 | 13.5 | 4.7 | -2.0 | -8.1 | -6.9 | 0.8 | 3.2 | 7.6 | 11.9 |
| 6 vs – a 7 | 5.9 | 9.8 | 12.4 | 17.9 | 23.4 | 25.3 | 25.5 | 28.3 | 23.4 | 16.1 | 11.8 | 8.0 |

Daily air temperature calculated on the basis of – Dobowa temperatura powietrza obliczona na podstawie:
1 – daily mean from 24 measurements – średniej z 24 pomiarów
2 – daily mean from hours: $3^{00}$ a.m., $6^{00}$ a.m., $9^{00}$ a.m., $12^{00}$ p.m., $3^{00}$ p.m., $6^{00}$ p.m., $9^{00}$ p.m., and $12^{00}$ a.m. – średniej z godz.: $3^{00}$, $6^{00}$, $9^{00}$, $12^{00}$, $15^{00}$, $18^{00}$, $21^{00}$ i $24^{00}$
3 – daily mean from maximum temperature, minimum temperature, and measurements from $6^{00}$ a.m. and $6^{00}$ p.m. – średniej z temperatury maksymalnej, minimalnej oraz pomiarów z godz. $6^{00}$ i $18^{00}$
4 – daily mean from maximum and minimum temperatures – średniej dobowej z temperatury maksymalnej i minimalnej
5 – daily maximum – maksymalnej w ciągu doby
6 – daily minimum – minimalnej w ciągu doby
7 – dobowej amplitudy – daily amplitude

Due to almost identical monthly average air temperature calculated with the use of methods 1, 2, 3, and 4, in Figure 1 only the course of average air temperature calculated with the use of four methods is presented, namely: 1, 5, 6, and 7. The smallest differences between air temperatures calculated with the use of the above variants occur in winter, start to increase significantly on the turn of March, and stay that high still in September. Yet, the highest negative deviation from daily mean air temperature calculated form 24 measurements is shown in the summer by daily temperature amplitude. Similarly to maximum air temperature, daily amplitude is characterised in the summer by the highest variability (Fig. 2), although this variability decreases significantly in winter (which is indicated by the values of standard deviation), and it results probably from positive amplitude values in all the months of the year. Very similar variability is characteristic for daily air temperatures calculated as means from 24, 8, and 4 measurements.

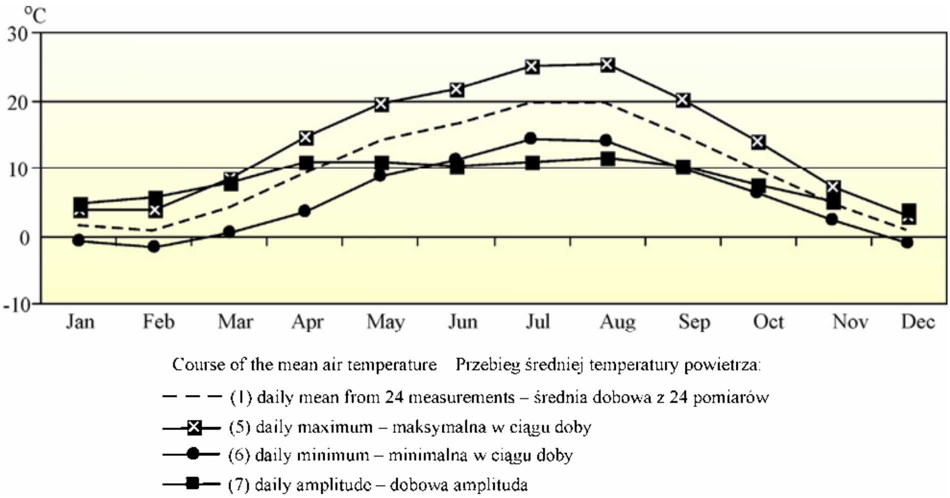


Fig. 1. Course of the mean – calculated from 24 measurements (1), maximum (5), minimum (6), and amplitude (7) air temperature in particular months (2001-2005)
Rys. 1. Przebieg średniej – obliczonej z 24 pomiarów (1), maksymalnej (5), minimalnej (6) oraz amplitudy (7) temperatury powietrza w poszczególnych miesiącach (lata 2001- -2005)

In the next stage of the work, relation between soil temperature at four depths and air temperature from 200 cm above the ground level set in different variants was studied. Figure 3 presents the distribution of the percentage values of determination coefficients $R^2$, according to consecutive months. Due to low, significantly different from other variants $R^2$ values, reflecting the relations between soil temperature and daily air temperature amplitude, the diagrams skip the values of determination coefficients, which describe this relation. Therefore, the results obtained by Kossowski [2003] were not confirmed, who, taking into account the effect of various meteorological elements on the amount of heat penetrating into the soil stated that the least significant turned out to be daily mean air temperature, and daily amplitudes were statistically significant. The closest relations soil temperature has with air temperature determined as a daily value calculated from: 24, 8, 4, and 2 measurements. In the layer situated the closest to the soil surface, $R^2$ values oscillated between ca. 48% in January and ca. 86% in October. Such a significant difference in the effect of independent variables on soil temperature in different seasons may result from weather conditions. In winter, the snow cover, which suppresses the fall of temperature in the soil, particularly during severe frost, as well as atmospheric and soil thaws may be the cause of a less precise soil temperature description with the use of air temperature, which was also mentioned by Szewczyk (2005) in his work. In autumn, on the other hand, especially in October and November, good description of soil temperature with the use of air temperature results probably from very similar in those months values of soil temperature at the depth of 5 cm with air temperature from 200 cm above the ground level, since in the period of 2001-2005, the differences in temperatures in both months did not exceed 0.2$^{o}$C.

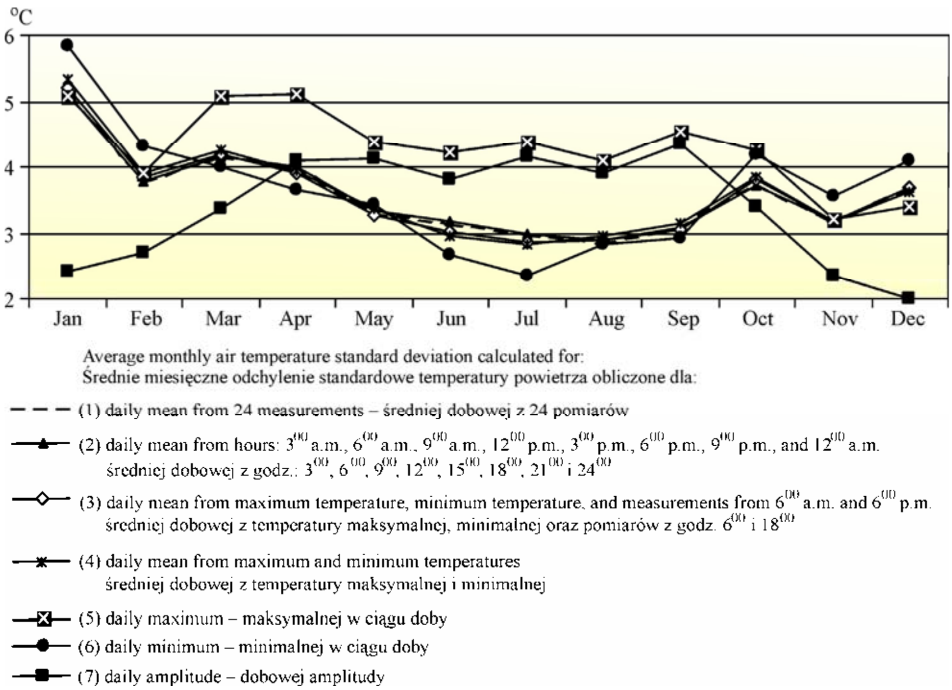


Fig. 2. Air temperature standard deviation in particular months (2001-2005)
Rys. 2. Odchylenie standardowe temperatury powietrza w poszczególnych miesiącach (lata 2001-2005)

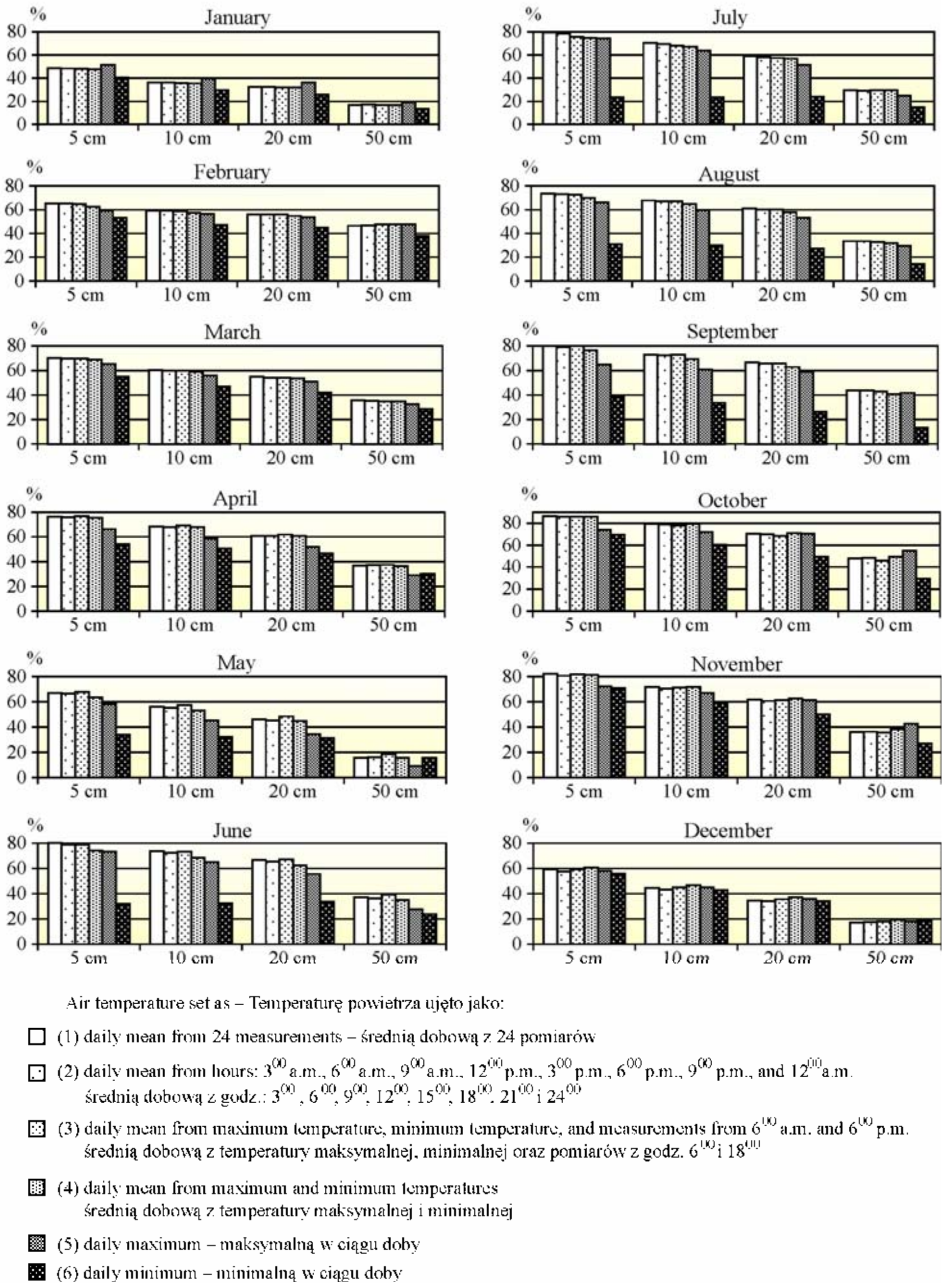


Fig. 3. Coefficients of determination $R^2$ (%) for the daily dependency of bare soil temperature at the depths of: 5, 10, 20, and 50 cm from air temperature (2001-2005)

Rys. 3. Współczynniki determinacji $R^2$ (%) dla dobowej zależności temperatury gleby nieporośniętej na głębokościach: 5, 10, 20 i 50 cm od temperatury powietrza (lata 2001--2005)

As the depth increases, the values of determination coefficients $R^2$ decrease and are the lowest for the relation of soil temperature at a half a meter depth, which results from temporary shift of the values registered in the soil in relation to the value of the temperature registered in the air [Koźmiński and Michalska 1987, Szewczyk 2005]. At the depth of 50 cm, the amplitude of bare soil temperature decreases significantly in relation to more shallow layers, regardless of the averaged period (month, season, year), and the daily amplitude of soil temperature at this depth disappears almost completely [Michalska and Nidzgorska-Lencewicz 2005]. As resulted from the studies by the authors, the closest relations between soil temperature at the depth of 50 cm occurred with air temperature measured two days before the measurement of soil temperature.

Figure 4 presents an example of a daily relation between bare soil temperature at four depths and air temperature (calculated from 24 measurements) in July in years 2001-2005. The smallest dispersion of points around the regression line occurs for soil temperature at the depths of 5 cm and 10 cm. In the deepest layer, soil temperature variability is described by air temperature only in 30%.

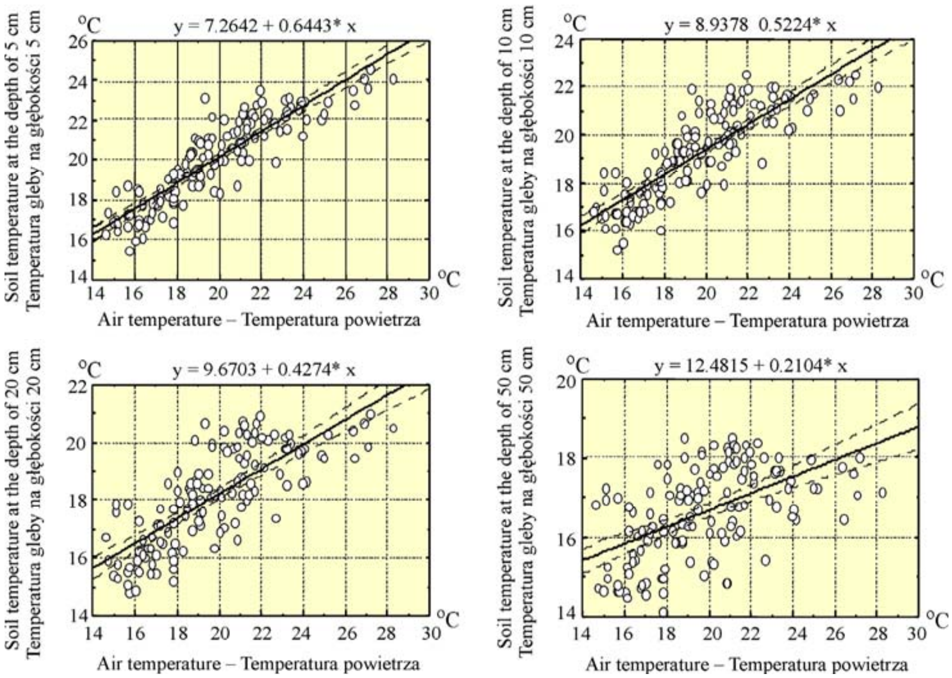


Fig. 4. Daily dependency of bare soil temperature at the depths of: 5, 10, 20, and 50 cm from air temperature (calculated from 24 measurements) in July (2001-2005)

Rys. 4. Dobowa zależność temperatury gleby nieporośniętej na głębokościach: 5, 10, 20 i 50 cm od temperatury powietrza (obliczonej z 24 pomiarów) w lipcu (lata 2001-2005)

In Table 2, regression equations are presented for the determination of daily soil temperature at four depths from air temperature. Due to the fact that the differences between air temperature calculated as a mean from 24, 8, and 4 measurements are statistically insignificant, in the table only three variants of the equations are placed (which take into account data availability), namely the average daily air temperature calculated from 24 measurements (a), daily mean from minimum and maximum temperatures (b), and maximum temperature (c). Using linear regression equations it is possible to estimate daily soil temperature on a chosen day of the month.

Table 2. Regression equations for the daily dependency of bare soil temperature at the depths of 5, 10, 20, and 50 cm on air temperature set as: mean from 24 measurements (a), mean from maximum and minimum temperatures (b), and maximum temperature (c), in the period from January to December (years 2001-2005)

Tabela 2. Równania regresji dla dobowej zależności temperatury gleby nieporośniętej na głębokościach: 5, 10, 20 i 50 cm od temperatury powietrza ujętej jako: średnia z 24 pomiarów (a), średnia z temperatury maksymalnej i minimalnej (b) oraz temperatura maksymalna (c), w okresie od stycznia do grudnia (lata 2001-2005)

| Month<br>Miesiąc | Depth<br>Głębokość<br>cm | a | b | c |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |
| January<br>Styczeń | 5 | y = 1.0132 + 0.2806·x | y = 1.0895 + 0.2641·x | y = 0.3688 + 0.2881·x |
| | 10 | y = 1.4752 + 0.2204·x | y = 1.5354 + 0.2073·x | y = 0.9568 + 0.2294·x |
| | 20 | y = 1.6263 + 0.1964·x | y = 1.6809 + 0.1841·x | y = 1.1608 + 0.2053·x |
| | 50 | y = 2.9130 + 0.1098·x | y = 2.9447 + 0.1021·x | y = 2.6546 + 0.1143·x |
| February<br>Luty | 5 | y = 0.9113 + 0.4057·x | y = 0.9365 + 0.3852·x | y = -0.1191 + 0.3739·x |
| | 10 | y = 1.4602 + 0.3517·x | y = 1.4797 + 0.3362·x | y = 0.5352 + 0.3322·x |
| | 20 | y = 1.6131 + 0.3147·x | y = 1.6293 + 0.3019·x | y = 0.7795 + 0.2988·x |
| | 50 | y = 2.8040 + 0.2294·x | y = 2.8120 + 0.2238·x | y = 2.1740 + 0.2236·x |
| March<br>Marzec | 5 | y = 0.8613 + 0.5477·x | y = 0.8996 + 0.5292·x | y = -0.3394 + 0.4303·x |
| | 10 | y = 1.3804 + 0.4518·x | y = 1.4154 + 0.4357·x | y = 0.3925 + 0.3546·x |
| | 20 | y = 1.6118 + 0.3783·x | y = 1.6433 + 0.3643·x | y = 0.7786 + 0.2977·x |
| | 50 | y = 2.6420 + 0.2158·x | y = 2.6593 + 0.2080·x | y = 2.1851 + 0.1676·x |
| April<br>Kwiecień | 5 | y = 3.2731 + 0.5655·x | y = 3.3498 + 0.5693·x | y = 2.5388 + 0.4127·x |
| | 10 | y = 3.8471 + 0.4724·x | y = 3.9008 + 0.4768·x | y = 3.2807 + 0.3416·x |
| | 20 | y = 4.0069 + 0.3999·x | y = 4.0462 + 0.4043·x | y = 3.5456 + 0.2879·x |
| | 50 | y = 5.1791 + 0.2234·x | y = 5.2225 + 0.2234·x | y = 5.0134 + 0.1544·x |
| May<br>Maj | 5 | y = 6.7651 + 0.5490·x | y = 7.2504 + 0.5251·x | y = 7.1454 + 0.3851·x |
| | 10 | y = 7.6670 + 0.4426·x | y = 8.0478 + 0.4240·x | y = 8.1962 + 0.2990·x |
| | 20 | y = 7.6845 + 0.3779·x | y = 7.9682 + 0.3650·x | y = 8.3605 + 0.2438·x |
| | 50 | y = 9.3966 + 0.1666·x | y = 9.5098 + 0.1617·x | y = 9.9668 + 0.0935·x |
| June<br>Czerwiec | 5 | y = 6.1626 + 0.6870·x | y = 6.2376 + 0.6992·x | y = 7.1583 + 0.4882·x |
| | 10 | y = 7.7150 + 0.5538·x | y = 7.7659 + 0.5642·x | y = 8.6734 + 0.3864·x |
| | 20 | y = 8.1979 + 0.4635·x | y = 8.1992 + 0.4747·x | y = 9.1862 + 0.3147·x |
| | 50 | y = 10.5246 + 0.2444·x | y = 10.5191 + 0.2508·x | y = 11.2532 + 0.1564·x |
| July<br>Lipiec | 5 | y = 7.2642 + 0.6443·x | y = 7.0979 + 0.6571·x | y = 9.3545 + 0.4243·x |
| | 10 | y = 8.9378 + 0.5224·x | y = 8.7692 + 0.5344·x | y = 10.7734 + 0.3384·x |
| | 20 | y = 9.6703 + 0.4274·x | y = 9.4932 + 0.4393·x | y = 11.3447 + 0.2700·x |
| | 50 | y = 12.4815 + 0.2104·x | y = 12.3445 + 0.2188·x | y = 13.3792 + 0.1300·x |
| August<br>Sierpień | 5 | y = 7.6855 + 0.6090·x | y = 8.3092 + 0.5779·x | y = 9.4998 + 0.4018·x |
| | 10 | y = 95700 + 0.4905·x | y = 10.0805 + 0.4650·x | y = 11.1388 + 0.3194·x |
| | 20 | y = 10.4320 + 0.4089·x | y = 10.8939 + 0.3858·x | y = 11.7752 + 0.2649·x |
| | 50 | y = 14.0662 + 0.1761·x | y = 14.0626 + 0.1761·x | y = 14.6365 + 0.1143·x |
| September<br>Wrzesień | 5 | y = 4.7491 + 0.6817·x | y = 5.1742 + 0.6510·x | y = 6.6178 + 0.4140·x |
| | 10 | y = 6.4041 + 0.5801·x | y = 6.7930 + 0.5522·x | y = 7.9045 + 0.3568·x |
| | 20 | y = 7.3229 + 0.5119·x | y = 7.6987 + 0.4851·x | y = 8.4595 + 0.3241·x |
| | 50 | y = 10.6557 + 0.3057·x | y = 10.9410 + 0.2856·x | y = 11.2019 + 0.2001·x |

Table 2 continue – cd. tabeli 2

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| October<br>Październik | 5 | y = 2.9258 + 0.6829·x | y = 3.1124 + 0.6578·x | y = 2.0206 + 0.5549·x |
| | 10 | y = 4.4260 + 0.5795·x | y = 4.5609 + 0.5605·x | y = 3.4594 + 0.4851·x |
| | 20 | y = 5.5157 + 0.4896·x | y = 5.5999 + 0.4765·x | y = 4.4246 + 0.4295·x |
| | 50 | y = 8.3996 + 0.3083·x | y = 8.4261 + 0.3026·x | y = 7.4480 + 0.2894·x |
| November<br>Listopad | 5 | y = 1.9668 + 0.6579·x | y = 2.0361 + 0.6518·x | y = 0.6608 + 0.6101·x |
| | 10 | y = 3.0670 + 0.5613·x | y = 3.1118 + 0.5592·x | y = 1.8424 + 0.5356·x |
| | 20 | y = 3.6896 + 0.4899·x | y = 3.7141 + 0.4911·x | y = 2.5130 + 0.4821·x |
| | 50 | y = 6.2475 + 0.3128·x | y = 6.2312 + 0.3202·x | y = 5.3012 + 0.3343·x |
| December<br>Grudzień | 5 | y = 1.6031 + 0.3667·x | y = 1.6137 + 0.3749·x | y = 0.8415 + 0.3939·x |
| | 10 | y = 2.2876 + 0.2858·x | y = 2.2935 + 0.2948·x | y = 1.6847 + 0.3103·x |
| | 20 | y = 2.5614 + 0.2383·x | y = 2.5648 + 0.2476·x | y = 2.0516 + 0.2613·x |
| | 50 | y = 4.3178 + 0.1438·x | y = 4.3180 + 0.1515·x | y = 4.0117 + 0.1571·x |

In order to check the reliability of the equations, for consecutive months average absolute differences between the actual bare soil temperature measured at four depths and the one calculated on the basis of air temperature formulated in three above mentioned variants were calculated (Fig. 5). Taking into account the levels at which soil temperature is measured, the smallest absolute differences apply to the depth of 50 cm – from 0.5 to 1.0°C. In more shallow soil layers, ranges of the differences are similar to each other and oscillate between 0.8 and 1.3°C. The greatest differences occur in January and March. On the other hand, definitely the smallest differences were noted in February and August, which results most likely from the smallest during the year soil temperature variability precisely in those months [Michalska and Nidzgorska-Lencewicz 2008]. Taking into account the variants of air temperature on the basis of which soil temperature was determined, the smallest absolute differences applied to the first method of daily mean calculation, that is from 24 measurements, and subsequently to the mean from two measurements (maximum and minimum), and from one measurement of maximum temperature only. However, differences between the actual soil temperature and the one calculated from equations (in three formulations) during the year on average did not exceed 1°C.

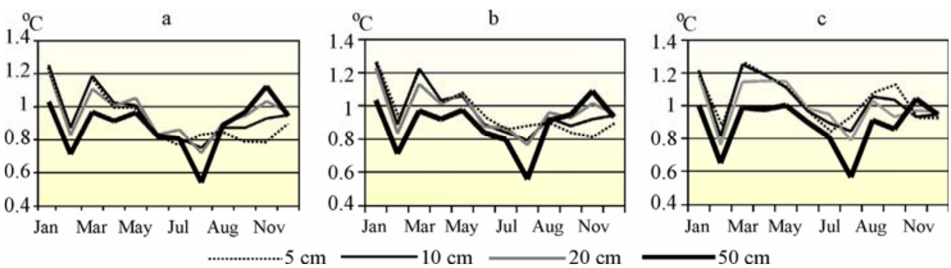


Fig. 5. Average absolute differences between bare soil temperature measured at the depths of 5, 10, 20, and 50 cm and the one calculated on the basis of air temperature set as: mean from 24 measurements (a), mean from maximum and minimum temperatures (b), and maximum temperature (c), (2001-2005)

Rys. 5. Średnie bezwzględne różnice pomiędzy temperaturą gleby nieporośniętej zmierzoną na głębokościach 5, 10, 20 i 50 cm a obliczoną na podstawie temperatury powietrza ujętej jako: średnia z 24 pomiarów (a), średnia z temperatury maksymalnej i minimalnej (b) oraz temperatura maksymalna (c), (lata 2001-2005)

## CONCLUSIONS

1. No statistically significant differences were found in all the months of the year between daily air temperatures calculated as means from: 24 (hourly), 8 (every three hours), 4 ($6^{00}$ a.m., $6^{00}$ p.m., maximum and minimum), and 2 (extreme values) measurements.

2. The best results of soil temperature estimation at different depths were obtained using in the equations daily air temperature calculated as a mean from 24 (hourly) measurements.

3. Due to low values of the determination coefficient ($R^2$) for the determination of soil temperature on the basis of air temperature in winter months, for the description of this relation, equations of single linear regression are insufficient.

4. Average absolute differences for particular months between the actual temperature and the one calculated oscillate at the depths to 20 cm between 0.7 and 1.0°C during summer and 0.8 and 1.3°C in winter months. At the depth of 50 cm, the differences are smaller.

5. Regression equations included in the work for soil temperature estimation on the basis of air temperature should be checked in other measurement places in order to determine their practical value.

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## OCENA MOŻLIWOŚCI SZACOWANIA TEMPERATURY GLEBY NIEPOROŚNIĘTEJ NA PODSTAWIE POMIARÓW TEMPERATURY POWIETRZA

**Streszczenie**. Podstawę opracowania stanowiły wyniki automatycznych, cogodzinnych pomiarów temperatury powietrza oraz temperatury gleby nieporośniętej, pochodzące ze stacji agrometeorologicznej w Lipniku (53°21' N; 14°58' E, 30 m n.p.m.) z okresu 2001--2005. W oparciu o wyniki analizy regresji liniowej oceniono związki dla poszczególnych miesięcy, pomiędzy dobową temperaturą gleby na 4 głębokościach a temperaturą powietrza ujętą w 7 różnych kombinacjach. Stwierdzono, że największymi możliwościami predykcji dobowej temperatury gleby w profilu do 50 cm odznacza się temperatura powietrza będącą średnią z 24 cogodzinnych pomiarów. Średnie bezwzględne różnice między rzeczywistą temperaturą gleby a obliczoną z równań dla tego związku wahają się w poszczególnych miesiącach od 1,3°C na głębokości 5 cm do 0,5°C na głębokości 50 cm. Przeciętnie najmniejsze różnice dotyczą ciepłej połowy roku i głębokości 50 cm. Wykazano, że zdecydowanie najmniejszymi możliwościami szacowania dobowych wartości temperatury gleby odznacza się dobowa amplituda temperatury powietrza.

**Słowa kluczowe**: temperatura gleby, temperatura powietrza, szacowanie temperatury gleby

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