# Method of completing missing data of soil temperature

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A b s t r a c t : Requisite of soil temperature knowledge for the areas where default measurement is not realized, and also the necessity of completing the missing data during the period of hardware failure lead us to the judgement of the relation between the daily average soil temperature measured at different depths at agroclimatological stations. The completing of time series scale 1962 to 2006 of soil temperatures was processed for agrometeorological station Vizovice. For the data processing, daily average soil temperature computed based on 7, 14, 21 h measurements during the years 1962 to 2006 were used. On the basis of the correlation relation between soil temperature data measured at depth 5 and 10 cm; 10 and 20 cm; 20 and 50 cm; and 50 and 100 cm, missing data of the time series were completed. Complete time data series can be used for evaluation of soil temperature regime under different conditions of soil and climate.

**Key words:** soil temperature, soil profile, correlation coefficient, regression equation

## 1. Introduction

The soil temperature is one of the most important environment characteristics and is basic element of soil climate. Understanding the spatial and temporal variation in soil temperatures is important to classification, land use, and management (*Schaetzl et al., 2005*).

Soil temperature values affect the development of soil organisms and consequently soil fertility (*Petr, 1987*). Soil temperature affects field crops and all plants. Knowledge of the level of soil temperatures is detrimental for shoot and root growth for cool-season grasses and may help develop heat-tolerant plants and effective management practices to improve the summer performance (*Pote et al., 2006*). High temperatures limit the wheat

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(Triticum aestivum L.) production in many areas around the world. Soil temperatures near the root zone could be as high as the air temperature during the wheat grain filling (*Tahir et al., 2005*). Soil temperature has significant influence also on insects and soil organisms developing in soil.

Due to difficultness of soil temperature measurement the number of meteorological stations with soil temperature measurement is relatively low. The measurement methods of the Czech Hydrometeorological Institute (CHMI) are described in "Instruction for observers of meteorological stations CSSR" (*Slabá, 1972; Fišák, 1994*). Contrary to that, the complex study of agroclimatological conditions of our territory "Agrocilotological conditions of CSSR" (1975) does not involve soil temperature. Soil conditions of our country are very variable and the expression of their spatial distribution is really difficult. "Climatic Atlas of Czechia" (*Tolasz et al., 2007*) contains tables and graphic soil temperature bases. Climatological bases of soil temperature are processed in the "Climate of CSSR, Tables" (1960), here we can also find average monthly temperatures at depths of 10, 20, 50 and 100 cm for the period of 1924-1953, or shorter for 17 stations, and maximum and minimum temperatures from 11 stations on the territories of the Czech Republic (CR) and the Slovak Republic (SR) with similar data for depths of 15, 30, 60 and 100 cm. In the "Climate of CSSR, Collective Study" (1969), in the chapter "Soil temperature" are average monthly soil temperatures and periods with temperatures equal to or lower than 0°C quoted for the stations of Čáslav-Filipov, Havlíčkův Brod, Klatovy, Rožnov pod Radhoštěm, Hurbanovo and Starý Smokovec.

Requisite of soil temperature knowledge for the areas where default measurement is not realized, and also the necessity of fulfilling the missing data during the period of hardware failure, lead us to assessing the relation between daily average soil temperature measured in different depths at climatological stations.

## 2. Material and methods

The completing of time series scale 1962 to 2006 of soil temperature was processed for agrometeorological station Vizovice. Agroclimatic characterization of this area is the following: warm macro-area, warmish area, moderately dry sub-area and district of mild cold winter *(Kurpelová et al., 1975)*. The station is situated in slope with eastern exposition 315 m a.s.l. (Fig. 1).


Fig. 1. Map of agrometeorological station (Vizovice marked by black point)

The Vizovice site has a mean annual temperature of approximately 8°C and a total annual precipitation of approximately 720 mm. Inclination is to the East.

The soil Type is Calcic gleyic-Leptosols (WRB 2006) being a clay soil (content of particles < 0.01 mm is from 67% to 80%). Properties in top-soil are affected by grass-roots. Content of particles < 0.01 mm is 74%. Its structure is polyedric. The color is 10YR 7/6.

Under top-soil the horizon is affected by water. In this horizon Fe-Mn concretions are present, and content of particles < 0.01 mm in this horizon is higher – approximately 80%. It means that water holder capacity is relatively low and lento-capillary point is relatively high. Its color is 10YR 6/3. From 30 cm and lower there is parent material (here it is geest of claystone/sandstone). Content of particles < 0.01 mm in this horizon is 67%. Color is 10YR 6/2. Soil porosity in Soil-pit Vizovice is good – it means that soil is not physically disturbed. Pedological characterization of soil profile is given in Table 1 and 2.

Table 1 and 2. Pedological characteristic of Vizovice agroclimatological station

| Depth (cm) Index of genetic horizon | Dry color / wet color | Structure | Moisture | Others |
|---|---|---|---|---|
| 0-10 Ad | light brown | polyedric | wet | high rooting |
| 10-30 Bvm | yellow-brown | polyedric | wet | a great deal of Fe and Mn concretions |
| 30-100 C | green-brown with mold | nonstructural | wet | foxiness layers in 50 and 90-100 cm |

| Depth | Content of soil particles < 0.01 / Porosity | Water bearing capacity | Lento-capillary point | Efficient water capacity |
|---|---|---|---|---|
| cm | % vol. | | | mm |
| **10** | 74 / 52 | 37 | 26.2 | 10.8 |
| **20** | 80 / 50 | 37 | 28.0 | 9.0 |
| **30** | 80 / 50 | 37 | 28.0 | 9.0 |
| **40** | 67 / 48 | 37 | 24.1 | 12.9 |
| **50** | 67 / 48 | 37 | 24.1 | 12.9 |
| **60** | 67 / 48 | 37 | 24.1 | 12.9 |
| **70** | 67 / 48 | 37 | 24.1 | 12.9 |
| **80** | 67 / 48 | 37 | 24.1 | 12.9 |
| **90** | 67 / 48 | 37 | 24.1 | 12.9 |
| **100** | 67 / 48 | 37 | 24.1 | 12.9 |

Since 1999 the agroclimatological station Vizovice is one of the automatic stations of the Czech Hydrometeorological Institute network, where the soil temperature has been measured at depths of 5, 10, 20, 50, 100 cm in 15 minute step by electric resistance thermometers: Detectors Pt 100, maker EKOREG, type 11281. The detector consists of brash headless bushing with closed butt (graded diameter 5 and 6 mm, overall length 60 mm). Before 1999, the soil temperature was measured by mercurial thermometers. Mercurial soil thermometers have been sorted out to two types: Bent thermometers with range from −30°C to +45°C for low depth are permanently placed in the soil. They were constructed mainly for depths of 5, 10 and 20 cm. In-depth mercurial thermometers with range of −25°C to +35°C were used for measuring soil temperature at 50 cm and 100 cm at CHMI stations. Hours of observation were 7, 14, 21 h of local time.

## 3. Results and discussion

For the data processing in this paper daily average soil temperature computed on the basis of 7, 14, 21 h measurements during the years 1962 to 2006 were used. On the basis of the correlation relation between soil temperature data measured at depth 5 and 10 cm; 10 and 20 cm; 20 and 50 cm; 50 and 100 cm and 10 and 5 cm missing data were completed of time series. The data were sorted out according to single months to find the correlation equations for different weather conditions. The correlation coefficient between measured depths is presented in Table 3.

Table 3. Correlation coefficient (r) for different depths soil temperature at Vizovice station

| | r | | | |
|---|---|---|---|---|
| | 5 - 10 cm | 10 - 20 cm | 20 - 50 cm | 50 - 100 cm |
| year | 0.998 | 0.998 | 0.977 | 0.969 |
| January | 0.977 | 0.970 | 0.800 | 0.843 |
| Ferbuary | 0.981 | 0.982 | 0.892 | 0.784 |
| March | 0.984 | 0.987 | 0.925 | 0.923 |
| April | 0.986 | 0.983 | 0.882 | 0.910 |
| May | 0.976 | 0.979 | 0.869 | 0.919 |
| June | 0.973 | 0.973 | 0.777 | 0.875 |
| July | 0.973 | 0.973 | 0.685 | 0.832 |
| August | 0.977 | 0.977 | 0.713 | 0.814 |
| September | 0.987 | 0.982 | 0.870 | 0.890 |
| October | 0.992 | 0.988 | 0.935 | 0.901 |
| November | 0.990 | 0.984 | 0.915 | 0.914 |
| December | 0.974 | 0.965 | 0.868 | 0.911 |

For the depths of 5 and 10, 10 and 20, 20 and 50 cm the maximum value of the correlation coefficient (r) was reached in October, for the depths of 50 and 100 it was in March. The month with minimal value of the correlation coefficient for the depths of 5 and 10 cm and 20 and 50 cm was July, for depths 10 and 20 cm December, and for 50 and 100 cm February. The highest correlation relation was found between 5 and 10 cm, lowest between 20 and 50 cm (Table 3). At depths 20 to 30 cm the characteristics of soil profile are changing (Table 2). At this depth the layer with higher content of clay particles was found.

For the figure construction the layer of lower depth was always determined as an independent variable. In the case of gaps in 5 cm data series analogical procedure was used, but soil temperature of 10 cm was taken as an independent variable (Fig. 6). Figures 2, 3, 4, 5 and 6 present months with highest correlation coefficient values.

By the use of this method the set of regression equation was obtained (Table 4). According to these equations it was possible to complete the missing data of soil temperature on the basis of others depths. For the 5 cm data gaps the same equation were computed set on the basis of soil temperature measured at 10 cm depth (Table 5).

Table 4. Regression equations for different depths soil temperature at Vizovice station

| | regression eguation | | | |
|---|---|---|---|---|
| | **5 - 10 cm** | **10 - 20 cm** | **20 - 50 cm** | **50 - 100 cm** |
| **year** | y = 0.958x + 0.311 | y = 0.946x + 0.355 | y = 0.820x + 1.783 | y = 0.756x + 2.180 |
| **January** | y = 0.921x + 0.260 | y = 0.843x + 0.356 | y = 0.538x + 1.933 | y = 0.760x + 2.405 |
| **Ferbuary** | y = 0.915x + 0.134 | y = 0.871x + 0.254 | y = 0.602x + 1.471 | y = 0.583x + 2.162 |
| **March** | y = 0.916x + 0.032 | y = 0.897x + 0.134 | y = 0.655x + 1.148 | y = 0.579x + 1.834 |
| **April** | y = 0.894x + 0.512 | y = 0.901x + 0.321 | y = 0.721x + 1.216 | y = 0.668x + 1.377 |
| **May** | y = 0.857x + 1.523 | y = 0.910x + 0.5405 | y = 0.706x + 2.104 | y = 0.705x + 1.397 |
| **June** | y = 0.863x + 1.906 | y = 0.853x + 1.837 | y = 0.631x + 4.321 | y = 0.644x + 2.949 |
| **July** | y = 0.827x + 2.914 | y = 0.853x + 2.176 | y = 0.517x + 7.327 | y = 0.609x + 4.369 |
| **August** | y = 0.856x + 2.431 | y = 0.866x + 2.055 | y = 0.549x + 7.345 | y = 0.481x + 7.263 |
| **September** | y = 0.891x + 1.651 | y = 0.903x + 1.325 | y = 0.650x + 5.446 | y = 0.569x + 6.083 |
| **October** | y = 0.928x + 0.968 | y = 0.915x + 1.010 | y = 0.670x + 4.644 | y = 0.602x + 5.441 |
| **November** | y = 0.930x + 0.682 | y = 0.914x + 0.795 | y = 0.681x + 3.625 | y = 0.695x + 4.046 |
| **December** | y = 0.923x + 0.481 | y = 0.886x + 0.591 | y = 0.725x + 2.528 | y = 0.829x + 2.826 |

Table 5. Regression equations for soil temperature at 10 and 5 cm depths at Vizovice station

| | **regression eguation** |
|---|---|
| | **10 - 5 cm** |
| **year** | y = 1.039x - 0.277 |
| **January** | y = 1.036x - 0.280 |
| **Ferbuary** | y = 1.052x - 0.135 |
| **March** | y = 1.057x + 0.059 |
| **April** | y = 1.087x - 0.309 |
| **May** | y = 1.112x - 1.011 |
| **June** | y = 1.096x - 1.126 |
| **July** | y = 1.144x - 2.285 |
| **August** | y = 1.115x - 1.847 |
| **September** | y = 1.092x - 1.408 |
| **October** | y = 1.060x - 0.865 |
| **November** | y = 1.053x - 0.619 |
| **December** | y = 1.029x - 0.442 |

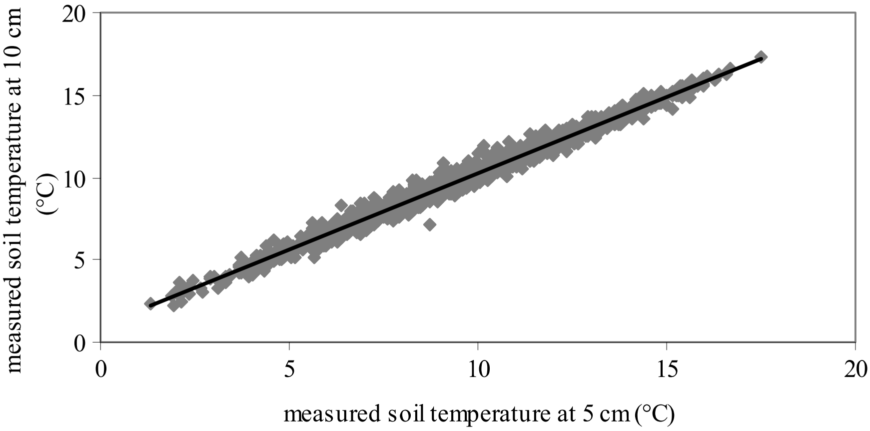


Fig. 2. Relationship between soil temperature measured at the depth 5 and 10 cm, Octobers 1962 – 2006; y = 0.928x + 0.968, r = 0.992.

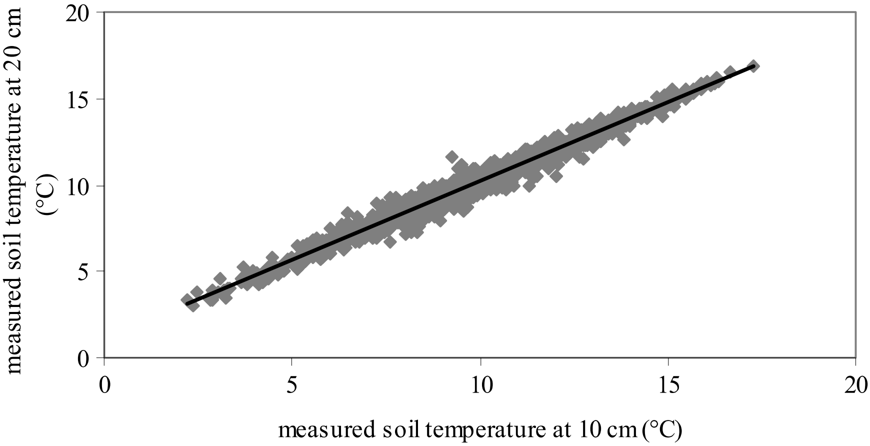


Fig. 3. Relationship between soil temperature measured at the depth 10 and 20 cm, Octobers 1962 – 2006; y = 0.915x + 1.030, r = 0.988.

Differences between soil temperature computed based on these equations and measured data are presented in Table 6. For example the difference lower or equal to ±1.0°C at depth 5 cm was ascertained in 96.1% cases.

The maximal deviation of computed and measured values at depth 5 cm reached 3.6°C, at depth 10 cm it was 3.1°C, at depth 20 cm it was 2.6°C.

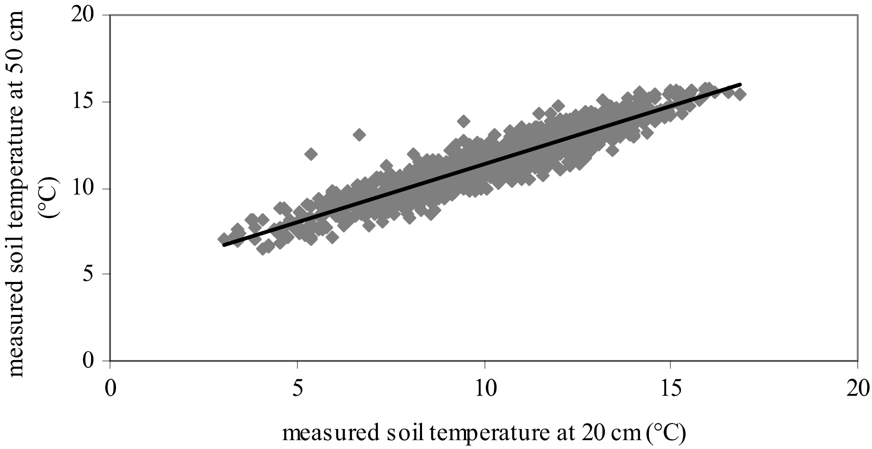


Fig. 4. Relationship between soil temperature measured at the depth 20 and 50 cm, Octobers 1962 – 2006; y = 0.674x + 4.620, r= 0.935.

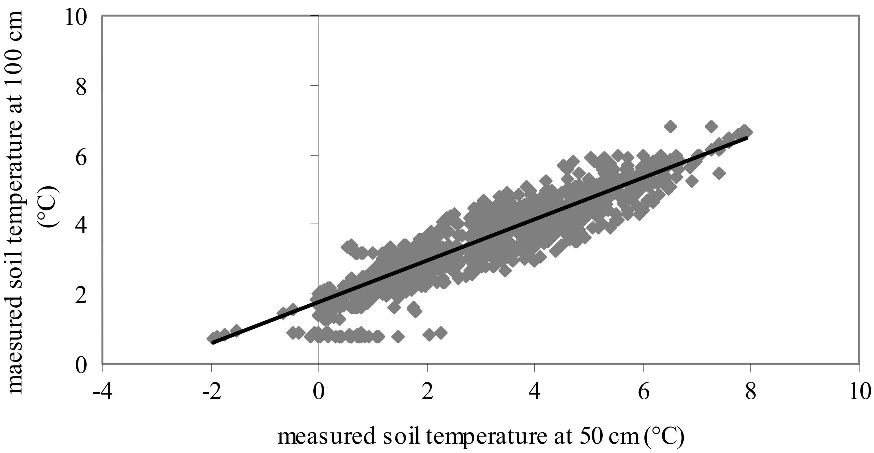


Fig. 5. Relationship between soil temperature measured at the depth 50 and 100 cm, Marches 1962 – 2006; y = 0.598x + 1.753, r = 0.923.

Computed deviation reached 5.4°C at depth 50 cm and at depth 100 cm the maximum was 2.4°C. These differences could be explained as faulty measurements, as well as a consequence of the regression equations application.

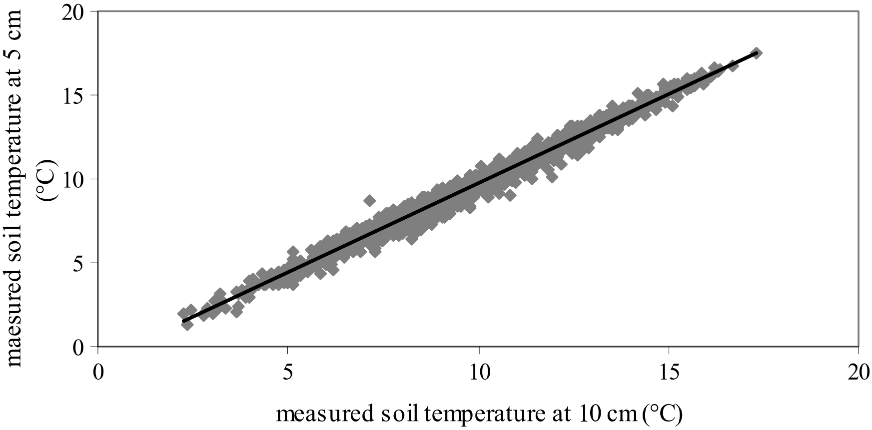


Fig. 6. Relationship between soil temperature measured at the depth 10 and 5 cm, Octobers 1962 – 2006; y = 1.060x – 0.865, r = 0.992.

Table 6. Percent occurrence of differences between measured and computed soil temperatures (%)

| Difference (°C) | Depths | | | | |
|---|---|---|---|---|---|
| | 5 cm | 10 cm | 20 cm | 50 cm | 100 cm |
| = 0.0 | 10.0 | 10.3 | 12.0 | 6.4 | 9.0 |
| ≤ 0.1 | 19.2 | 20.6 | 23.4 | 12.3 | 18.0 |
| ≤ 0.2 | 37.8 | 40.7 | 45.3 | 24.8 | 36.0 |
| ≤ 0.3 | 53.9 | 58.2 | 63.5 | 35.5 | 51.6 |
| ≤ 0.4 | 67.0 | 71.2 | 75.8 | 46.1 | 65.6 |
| ≤ 0.5 | 73.4 | 80.4 | 83.5 | 55.0 | 75.8 |
| ≤ 0.6 | 83.5 | 87.2 | 89.5 | 63.0 | 84.0 |
| ≤ 0.7 | 88.7 | 91.5 | 92.9 | 69.7 | 90.2 |
| ≤ 0.8 | 92.1 | 94.3 | 95.0 | 75.2 | 94.4 |
| ≤ 0.9 | 94.5 | 96.1 | 96.5 | 80.0 | 97.7 |
| ≤ 1.0 | 96.1 | 97.4 | 97.5 | 84.2 | 95.2 |

## 4. Conclusions

In this contribution the possibility of missing soil temperature data completing was investigated. The method of correlation analyses and regression equation was applied. This method deals with daily average of soil temperature computed from measurements at 7, 14, 21 h of local time at five depths. Daily average values are used as input data. At Vizovice there were 80 434 values. The processing period was 16 405 days. After processing the

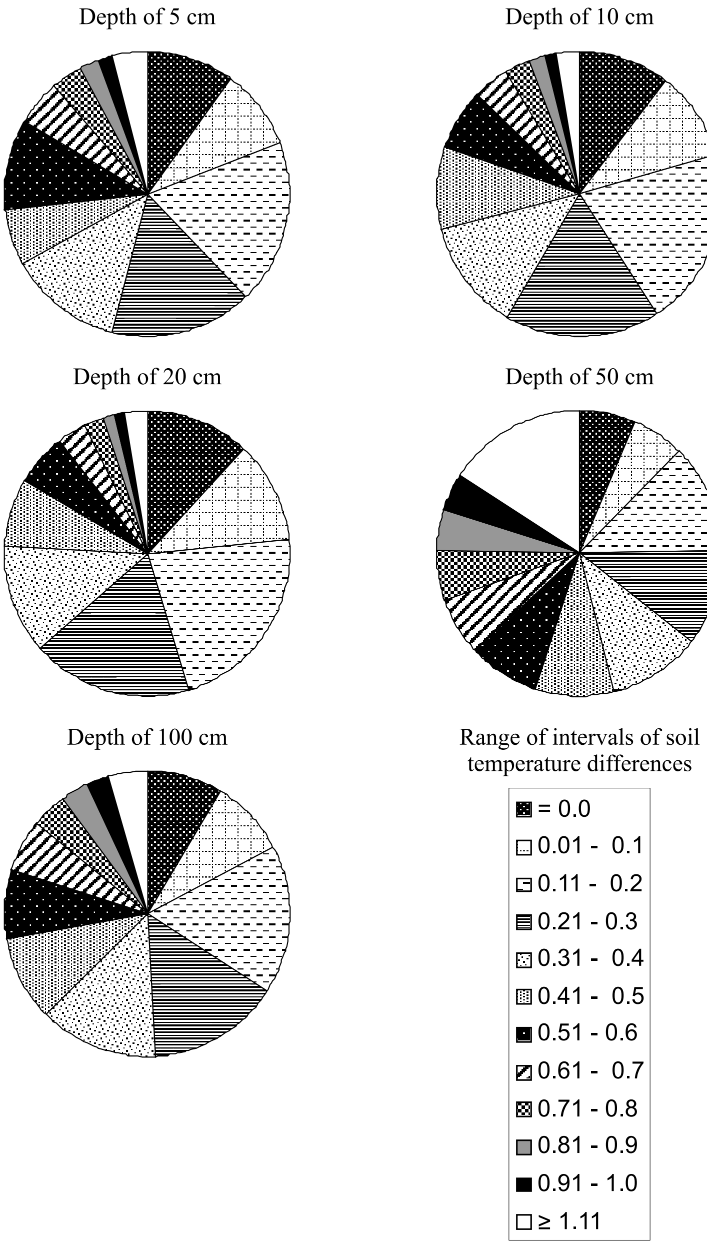


Fig. 7. Percent occurrence of measured and computed soil temperature differences sorted out according to 0.09°C intervals from 0,0 to ±1.11°C.

missing values (1591) were completed.

High correlation among soil temperature data was found at measured depths 5 and 10 cm, 10 and 20 cm, 20 and 50 cm, 50 and 100 cm (Table 3). The highest correlation relation was found between 5 and 10 cm, lowest between 20 and 50 cm. On this basis the regression equations (Table 4, 5) were used for completing the series of the measured data. The comparison of basic database of measured data and the data computed from the regression equation application are presented in Table 6 and Fig. 7. The highest percentage occurrence of differences $\leq \pm 1.0^{\circ}$C between the measured and computed soil temperatures was assessed at depth 20 cm in 97.5% of cases, the lowest at depth of 50 cm; 84.2% of cases.

This method will be also used for other agrometeorological stations of the Czech Hydrometeorological Institute network with different soil and climatological conditions. Complete time data series can be used for evaluation of soil temperature regime under different conditions of soil and climate.

***Acknowledgments***. The authors are grateful to the Ministry of the Environment of the Czech Republic (grant No. 1D/1/5/05) for the support of this work.

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