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PECULIARITIES OF SOIL MOISTURE AND TEMPERATURE DYNAMICS BASED ON TDR-MEASUREMENT RESULTS FOR 2008-2012 IN THE WESTERN POLESIE TERRITORY OF UKRAINE

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A b s t r a c t. The paper presents the results of an investigation which took place over the years 2008-2012 in the Shatsk National Natural Park. For the investigation four genetically different soils in that area were selected. Those were a soddy-podzolic soil (*S*01) under grass vegetation, lowland peat bog (*S*02), anthropogenic lowland peat bog (*S*03) with mineralised upper layer and a soddy-gley loamy soil (*S*04). The TDR device developed and created in the Institute of Agrophysics PAS in Lublin, and probes for measurement soil moisture, temperature and salinity were used in the study. The eight probes of the TDR-measuring system were installed at different depths, from 10 to 80 cm, at 10 cm intervals, for soils *S*02, *S*03 and *S*04, and at the depths of 10 cm and 50 cm for soil *S*01. The dynamics of soil temperature and soil moisture at different depths and the speed of response to changes in subsequent uncured layers are presented. Hourly TDR data have been diurnal-averaged and used for the calculation of correlation coefficients between soil temperature at different depths, air temperature, precipitation, solar activity parameter, Wolf number and total solar radiation. The study included also the effect of changes in solar radiation in the soil with the seasons

K e y w o r d s : soil parameters, TDR-metering, correlation, climatic conditions, solar activity

LIST OF SYMBOLS

T_{soil} – Soil temperature (^{o}C),
θ_{soil} – Soil moisture (% Vol.),
T_{air} – Air temperature (°C),

V – Precipitations (mm day^{-1}),
W – Wolf number (Sun spot index to characterise solar activity),
*TS*I – Total Solar Irradiance (kcal cm^{-2}),
*S*01 – Soddy-podzolic soil under grass vegetation,
*S*02 – Lowland peat bog,
*S*03 – Anthropogenic lowland peat bog with mineralised upper layer,
*S*04 – Soddy-gley loamy soil,
r – correlation coefficient.

INTRODUCTION

The protected territory of the Shatsk National Natural Park forms a part of the Transboundary Biosphere Reserve in Ukrainian Western Polesie. The soil ecosystems of the Shatsk National Natural Park are typical for the western Polesie region (Shevchuk 1999). Soil water temperature is the main co-factor of the soil formation process. It is always changing, especially within the protected territory, under the influence of such factors as melioration, renaturalisation, intensive man-made loadings, as well as solar activity and global climate changes, all of which lead to changes in the soil properties as well as general soil transformation.

The TDR-based monitoring system created at the Institute of Agrophysics of PAS in Lublin was installed in 2007 in both the Shatsk National Natural Park (Ukraine) and the Poleski National Park (Poland) (Fig. 1), within the Neighbourhood Program Poland-Belarus-Ukraine project. Such physical parameters as soil temperature, moisture and bulk electrical conductivity which can be easy transformed to soil salinity (Malicki, Walczak 1999) at different soil depths (from 10 cm up to 80 cm in 10 cm steps) and for different soil types were monitored during the years 2008-2012. Experimental dependencies describing the soil temperature and soil moisture time change dynamics were obtained. The basic task of the study was to estimate the peculiarities of physical parameters time changes (diurnal, seasonal and annual) of different soil types, and the influence on the physical parameters by external factors, such as climate and solar activity.

METHOD

The monitoring system consisted of a TDR/MUX/mts device for soil temperature, moisture and salinity measurements, and a MIDL-2 data logger to store and deliver the monitoring data to a server (Fig. 2) (Skierucha 2006, Skierucha *et al*. 2012). The system allows the measurement of soil physical parameters at different depths using 8 probes (each probe measures soil temperature, moisture and salinity (Skierucha *et al*. 2010, Wilczek *et. al.* 2011, Janik *et. al.* 2011). The TDR system is characterised by low energy consumption, large memory volume and the possibility to control the device remotely for measuring and sending data over the Internet. All of this is especially important when the studied object is at a considerable distance from the server or is difficult to access.

Data on the nature of regularities in the time changeability of the physical parameters of soil mentioned in the literature tend to be fragmentary, sometimes contradictory, and often conditioned by the irregularity and short duration of the measurements. In addition, conclusions have been made solely on the basis of such measurements. In this work, the complex random nature of the experimental data is taken into account during the analysis in order to model the probabilistic random processes effectively. In particular, these include models of periodically correlated random processes for the evaluation of annual soil temperature and soil moisture data from different soil types taken at different depths.

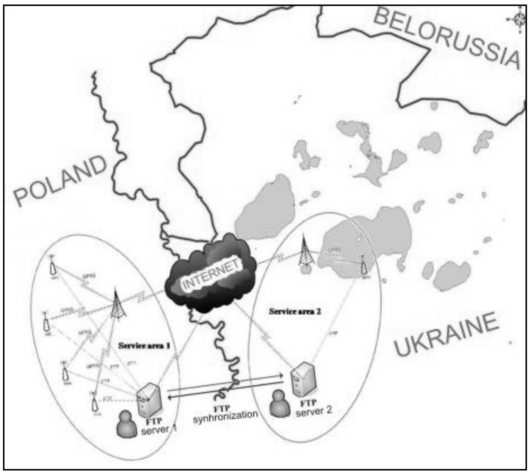


Fig. 1. Transboundary Polish-Ukrainian soil

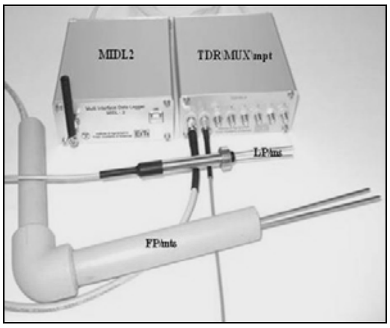


Fig. 2. TDR/MUX/mts ecosystem monitoring network

MATERIALS

The choice of measuring points in the Shatsk National Natural Park territory was conditioned by the following criteria:

1) measured objects should include genetically different soil types;

2) selected soil types should have a different degree of anthropogenic transformation.

Measurements were made over a year for each of the selected soil types (Tab. 1). During the TDR monitoring system installation process, vertical soil sections were examined in detail.

Soil *S*01 – the most widespread on Polesie (> 60%), located mainly under the crown layer of coniferous and mixed forests with grassy vegetation. Content of humus in the arable layer is low (0.7-1.0%) in sandy and sandy-loam types and (1.5-2.0%) in loamy types. It holds little moisture, with high water permeability, and low capacity for nutriment absorption.

Soil *S*02 – is found in lowland peat bogs (peat thickness >50 cm), formed in deep cavities, rich in nitrogen and poor in phosphorus and potassium.

Table 1. Characteristics of the TDR monitoring system locations

Soil type	*S*01	*S*02	*S*03	*S*04
Soil description	Soddy-podzolic soil under grass vegetation	Lowland peat bog	Anthropogenic lowland peat bog with mineralised upper layer	Soddy-gley loamy soil
Period (years)	2008-2009	2009-2010	2010-2011	2011-2012
Measurement depth (cm)	10 cm 50 cm	From 10cm up to 80 cm, in 10 cm steps	From 10 cm up to 80 cm, in 10 cm steps	From 10 cm up to 80 cm, in 10 cm steps
Forest habitat type	–	–	–	Alder forest

Soil *S*03 – is an anthropogenic lowland peat bog with a mineralised upper layer, differing from *S*02 in that over a several-year period it has been cultivated, enriched by mineral fertilisers and converted into a cultivated soil. Its fertility varies considerably and is heavily managed due to the high level of organic matter decomposition and high soil water level which, over-damping the arable layer, cools the soil and washes away the nutrients accumulated in the arable layer. This overdrying results in the fall-off of productivity.

Soil *S*04 – soddy-gley loamy soil located in areas of weakly lowered relief. Alder forests form on it as a result of the overgrowing of former eutrophic grass bogs.

RESULTS AND DISCUSSION

The eight probes of the TDR-measuring system were installed at different depths from 10 to 80 cm, at 10 cm intervals, for soils *S*02, *S*03 and *S*04, and at the depths 10 cm and 50 cm for soil *S*01.

Regularities of time changeability of the physical parameters of soil

The dynamics of the changes of soil moisture, temperature and salinity are determined by many natural and anthropogenic factors, directly related to the climate and solar activity, including Wolf number and Total Solar Radiation. The soil thermal regime is determined by the relation between solar radiation and physical properties of soil, forming the spatial-temporal dynamics of the thermal field, which should have a periodic character due to the solar radiation and decrease in temperature with depth. Therefore, the experimental data were analysed from the hourly measurement data taken over a five year period for temperature, moisture and salinity at different depths.

The soil thermal regime is determined mainly by the ratio between the absorption of solar radiation and soil thermal radiation. Therefore, the time changeability temperature of the soil characteristic is a long-term, annual and diurnal periodic, conditioned by the cyclical nature of the reception of the sun energy. Delays in temperature changes and different oscillation ranges are characteristic of increasing depth. Water appears in the soil from atmospheric precipitation, subsoil water sources, and condensate from the soil-air-water stream. It stipulates the practical absence of long periodic trends in soil moisture changes over a year. However, in a mild season, peat soil moisture levels have a stable diurnal period. The time changeability of soil salinity is characterised by annual and oscillating trends peculiar to the soil temperature changes (Skierucha 2006), and also features a stable diurnal period during the year. The soil temperature essentially influences the soil moisture and, especially, the bulk electrical conductivity (salinity) of the soil. The physical parameters of soil oscillations differ in both the regularity of the changes and the presence of noticeable random deviations. As an example, the experimental dependences of the time changeability of soil temperature for soil *S*02 (lowland peat bog) are presented in Figures 3-5.

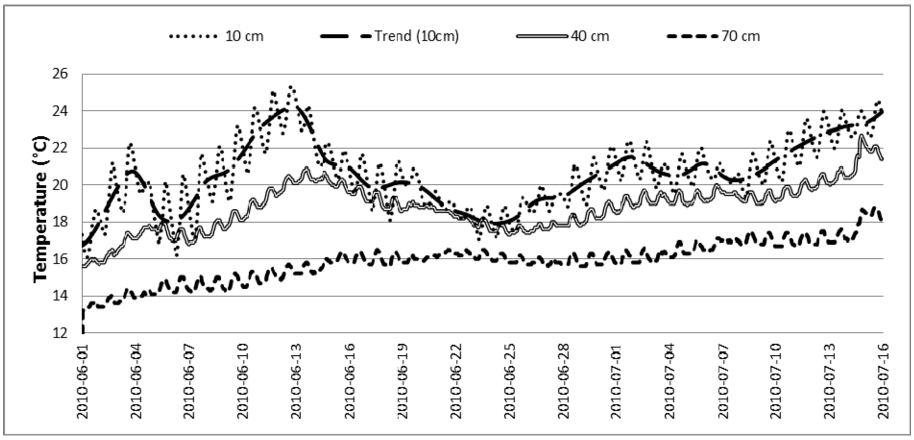
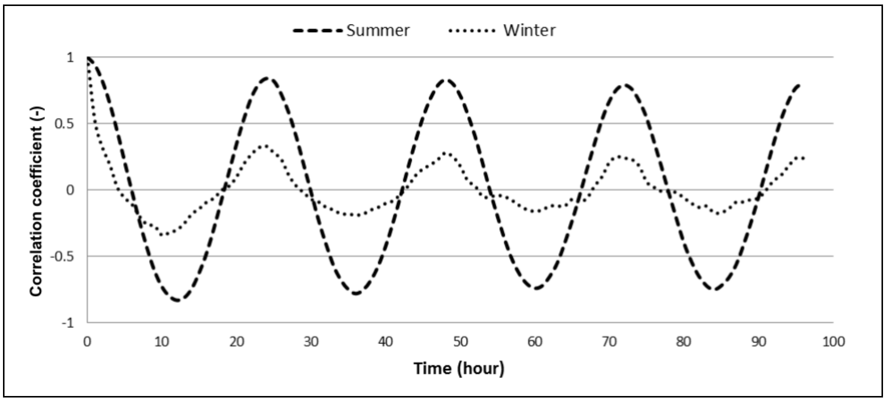
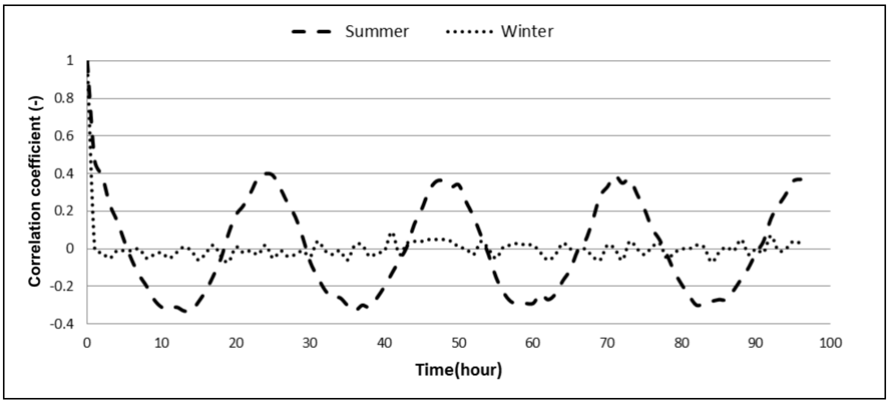


Fig. 3. Temperature time indications at different depths (10, 40, 70 cm) for lowland peat bogs and their low-frequency trend

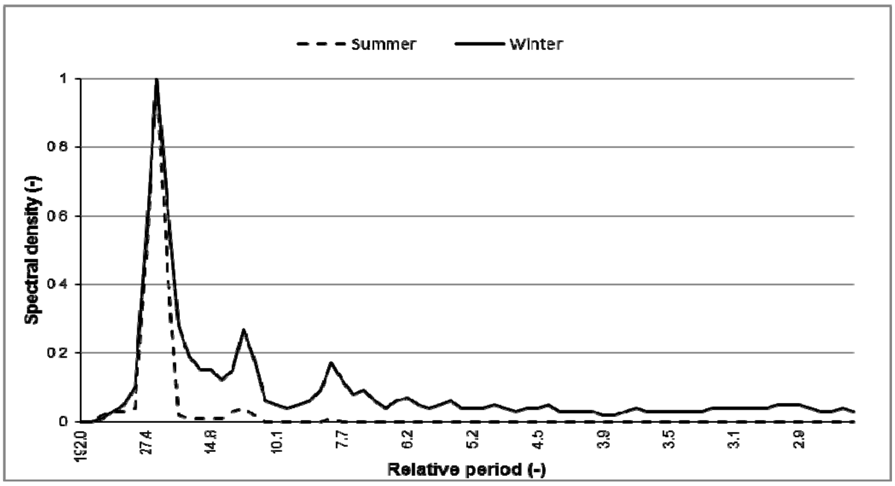
a)


Summer
Winter
Correlation coefficient (-)
1
0.5
0
-0.5
-1
0 10 20 30 40 50 60 70 80 90 100
Time (hour)

b)


Summer
Winter
Correlation coefficient (-)
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
0 10 20 30 40 50 60 70 80 90 100
Time(hour)

c)


Summer
Winter
Spectral density (-)
Relative period (-)

d)

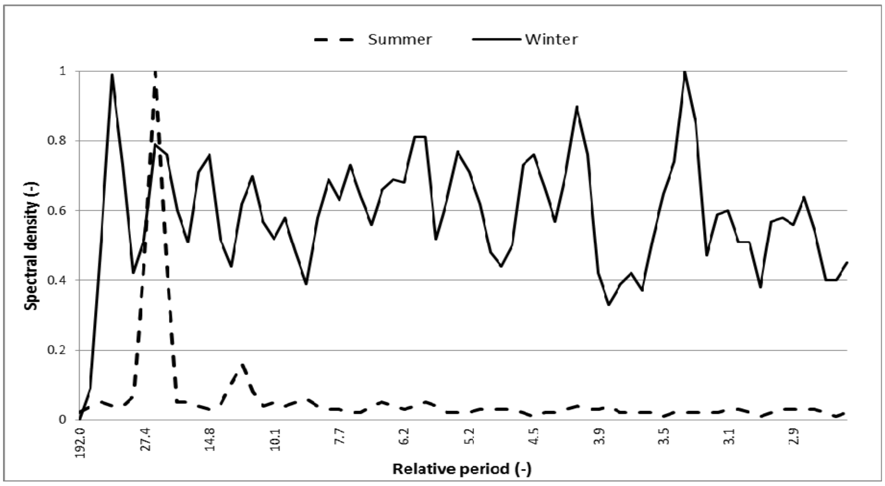


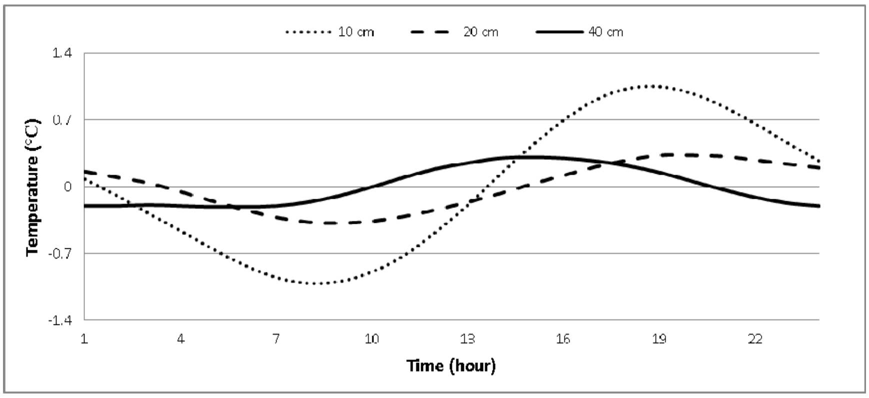
Fig. 4. Estimations of the correlation functions (a, b) and spectral density (c, d) of the stationary random process of T_{soil} diurnal changes at a depth of 10 cm

The above realizations centred on the low-frequency trend, giving sufficient grounds to consider that the time changeability of a soil's physical parameters, are described by the realizations of stationary random processes, because they form homogeneous oscillations throughout the study period: they lack a systematic trend, the oscillation amplitude neither really grows nor diminishes, while the pulsation periods also lack noticeable changes (Dragan *et al*. 1987).

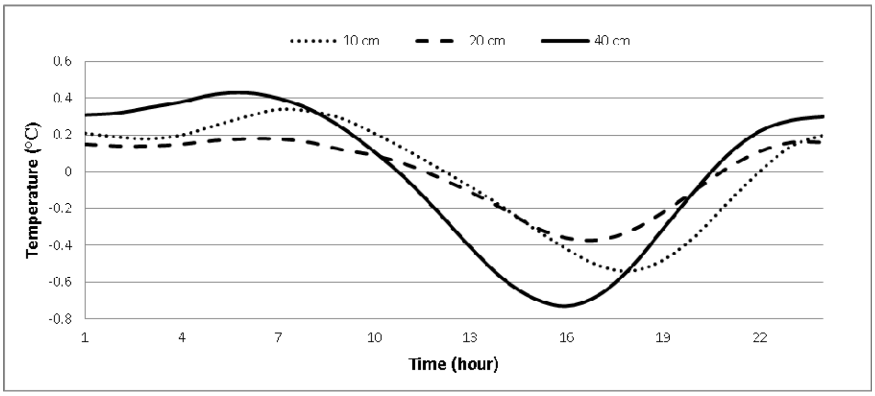
Estimations of the soil temperature change sampled for cross-correlation function and spectral density at the different depths of peat in the summer and winter periods are presented in Figure 4. They are characterised by poorly damped oscillations of the cross-correlation function, having a 24 hour period, and by significantly expressed spectral peaks over the same period (sometimes there are peaks in the periods of multiple frequencies). Such processes are rhythmic and, in this case, especially the periodic diurnal soil temperature. Because relative soil electrical conductivity differs from that of ice, soil moisture data for the winter often features an error. Analogous characteristics for periodically-correlated random processes of diurnal variations in summer soil temperatures of the peat at the depths of 10 cm (1), 20 cm (2) and 40 cm (3) are presented in Figure 5.

It has been established in the given work that, unlike literature data, the amplitude of the soil temperature diurnal at a depth of 10 cm does not exceed 5^{o}C, while at depths > 40 cm these changes are insignificant. At all depths the form of these changes remains constant. The estimates of dispersion changes with depth have confirmed that only at a depth of 10 cm does the soil temperature feature random deviations from the expected value, having the character of periodically-correlated random processes, while all other depths maintain a stationary-random process. Oscillation dispersion diminishes quickly with increasing depth.

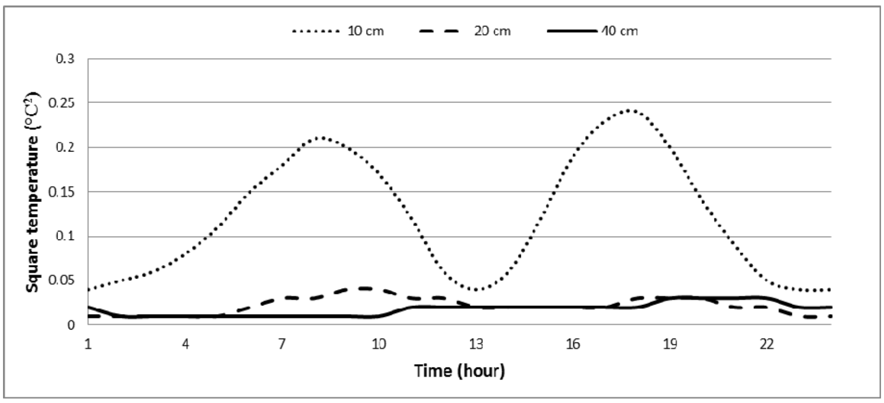
a)



b)



c)



d)

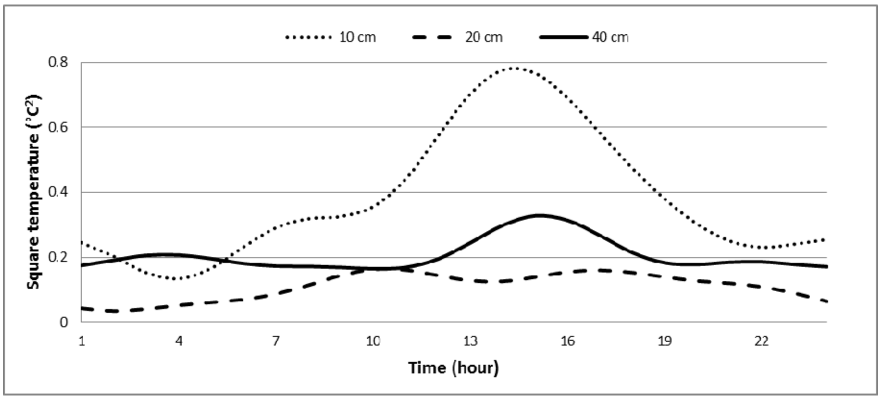


Fig. 5. Estimations of mathematical expectation (a, b) and dispersion (c, d) correlated process of soil temperature diurnal variations in summer at depths: 10 cm, 20 cm and 40 cm

Influence of external factors (climate and solar activity) on the physical parameters of soils

The change dynamics of climatic parameters such as air temperature and precipitation for the Shatsk National Natural Park for the years 2008-2012 is presented in Figure 6. This figure presents the typical temperature dynamic during the year. It shows also the seasonally increased value of precipitation.

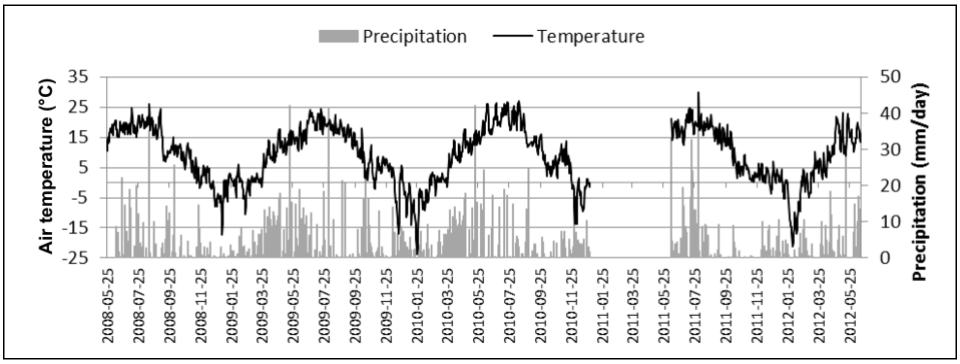


Fig. 6. Dynamics of climate parameters at the Shatsk National Natural Park during the years 2008-2012

The soil temperature and soil moisture time changes for the different soil types and the values of air temperature change are presented in Figures 7 - 10.

The lowest air temperature values were observed during winters of 2009-2010 and 2011-2012. A medium snow-cover thickness (≈ 22 cm) persisted over the winter period of 2009-2010 (for other winter periods it was approximately identical (7-9) cm). It should be taken into account that for soil temperature near 0°C the water content measurements are not accurate due to water freezing. But the periods with 0°C soil temperature are relatively small in comparison with the whole investigated period. The greatest mean air temperature values were observed in the summer period of 2010-2011.

a)

b)

Fig. 7. (a) T_{soil} and (b) θ_{soil} dynamics for *S*01 in the years 2008-2009

During investigations of the influence of external factors on soil temperature it is necessary to take into account the soil type, its structure and properties, and locations. In the summer period the upper soil layers on open terrain (*S*01, *S*02 and *S*03) respond more to climatic factors and solar activity than those of soils located in forest zones (*S*04), *w*here the rootage has a considerable influence on the soil temperature and soil moisture time changeability.

Hourly TDR data have been diurnal-averaged and used for the calculation of correlation coefficients between soil temperature at different depths, air temperature, precipitation, solar activity parameter, Wolf number and total solar radiation. The influence of solar radiation on the soil changes with the seasons. Therefore, different periods were chosen for the correlation coefficient calculations, namely three winter and three summer months, as it was considered that this better manifests the solar influence on soil temperature.

Soil *S*01: Soil temperature time changeability has a clear annual periodic at the depths of 10 cm and 50 cm (unlike humidity); mean soil moisture < 15% (it increases during the spring period due to the increase of ground water level at 50 cm).

Soil *S*02: soil temperature time changeability (Fig. 8) maintains a clear annual periodic, while soil moisture time changeability does not have such a rhythm; soil moisture mean values ≈ 80-90% for the lower soil layers and ≈ 70% for the upper ones.

a)

b)

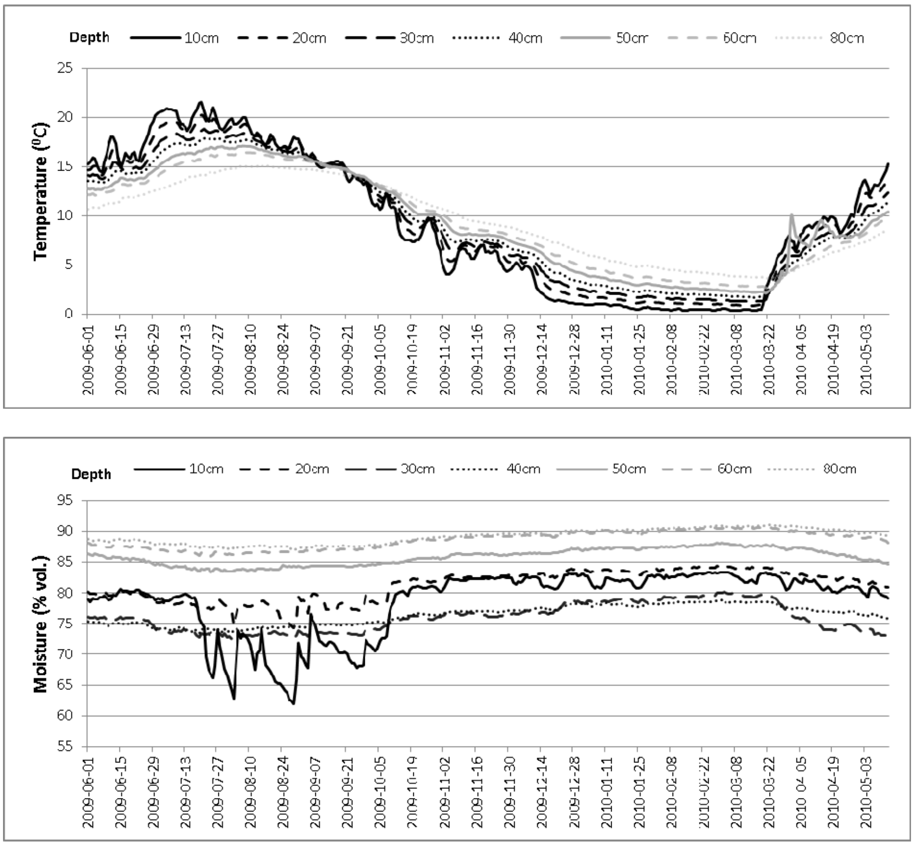
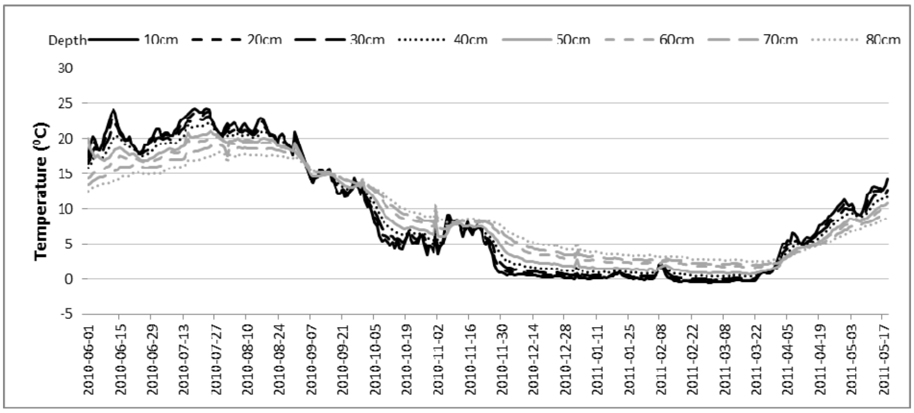


Fig. 8. (a) T_{soil} and (b) θ_{soil} dynamics for *S*02 in the years 2009-2010

Soil *S*03: soil temperature and soil moisture time changeability (Figure 9) is similar to that for soil *S*02. Soil moisture in the upper soil layers lacks such a time changeability (soil moisture mean value < 55%); the soil temperature mean value change has a clear annual period (Fig. 9a), similar to all previous soils; soil moisture mean value < 25 %, except for the upper layers during periods of considerable precipitation.

a)



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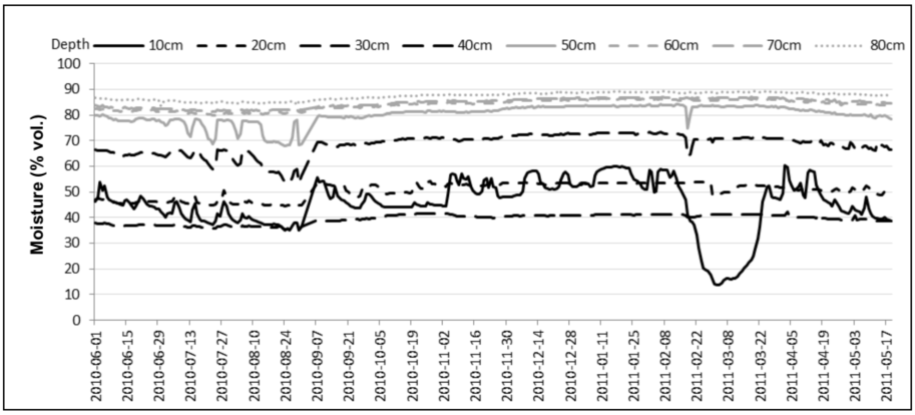
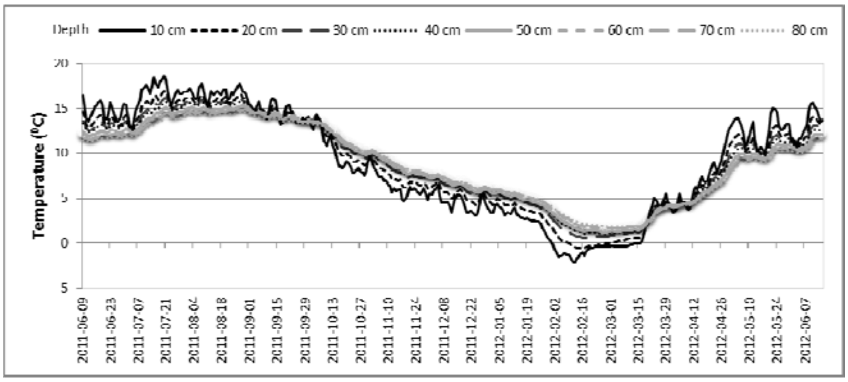


Fig. 9. (a) T_{soil} and (b) θ_{soil} dynamics for *S*03 in the years 2010-2011

Soil *S*04: Figure 10a present characteristic time changeability of soil temperature and movement in time with increase in depth. Soil moisture (Figure 10b) is most changeable in upper layers, with characteristic decreased value of moisture during soil temperature near 0°C.

a)



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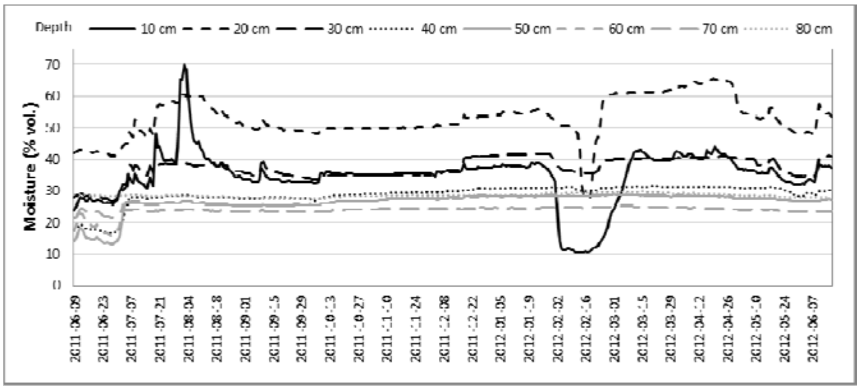

Fig. 10. (a) T_{soil} and (b) θ_{soil} dynamics for *S*04 in the years 2011-2012

RESULTS

Soil *S*01: the highest *r* value for soil temperature and air temperature ($r \approx 0.6$) was observed in the summer and winter periods (Fig. 11); the influence of precipitation on soil temperature is practically absent in the winter period; the correlation between precipitation and soil temperature in the summer period $r \approx 0.30$; substantial influence of precipitation on soil temperature was not observed in the summer as the soil is sandy ($\theta_{soil} \approx 15\%$) and water does not remain long in its upper layers; the negative values of *r* between Wolf number and Total Solar Irradiation characterise the influence of solar activity, conditioned by the presence or absence of snow cover (≈ 9 cm) and low absorption of heat by this soil type (vegetable cover is significant in summer, as it assimilates heat for photosynthesis and substantially diminishes the transmission of heat to the soil).

Soil *S*02: value of *r* for soil temperature and air temperature is $r \approx 0.55$ in summer and diminishes with depth; in winter $r \approx 0.40$ and also diminishes with depth (Fig. 12); value of r between precipitation and soil temperature is $r \approx 0.20$ (in winter) and it is higher than in the summer period because of the periodic thaw, during which rapidly melting snow causes the soil temperature to change; the value of r between the solar activity parameters and soil temperature is negative in winter and in summer, increasing with depth.

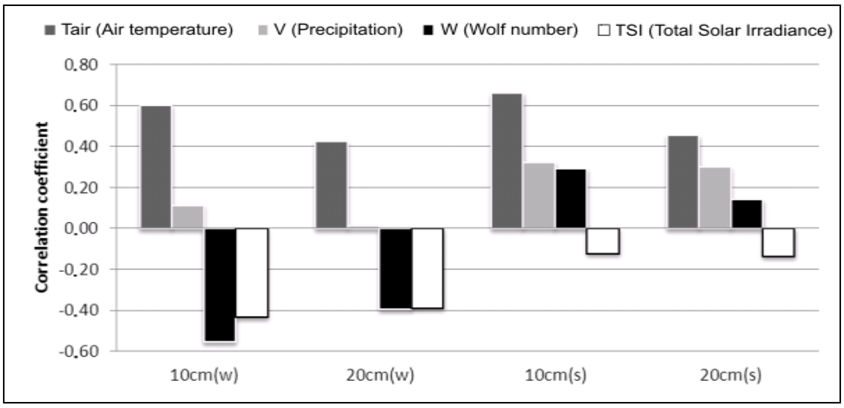

Fig. 11. Correlation coefficients for *S*01 soil temperature in winter and summer (2008-2009) at depth of 10 cm and 20 cm

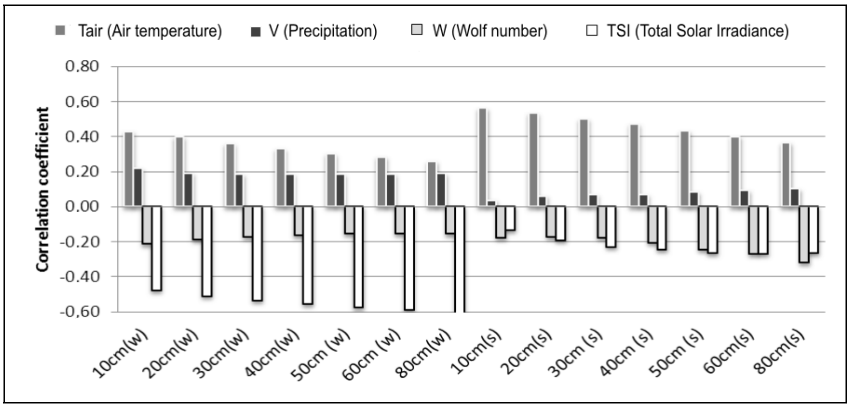

Fig. 12. Correlation coefficients for *S*02 soil temperature in winter and summer (2009-2010)

Soil *S*03: the water-temperature regime in the upper and lower layers substantially differs due to its use in agriculture (Fig. 13); $\theta_{soil} \approx$ 80-90%) for the lower layers and θ_{soil} < 30% for the upper layers; value of r between soil temperature and air temperature is $r \approx 0.60$ in summer and diminishes with depth; it becomes negative in winter (depths > 40cm) due to anthropogenic transformation of the upper layers; the value of r between the solar activity parameters and soil temperature is $r \approx 0.20$-0.40 in summer; the influence of solar activity on soil temperature is considerably less in winter.

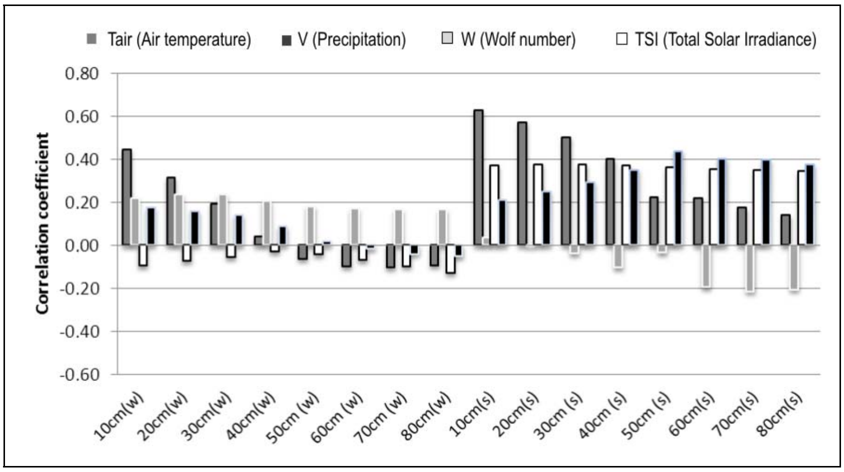

Fig. 13. Correlation coefficients for *S*03soil temperature in winter and summer (2010-2011)

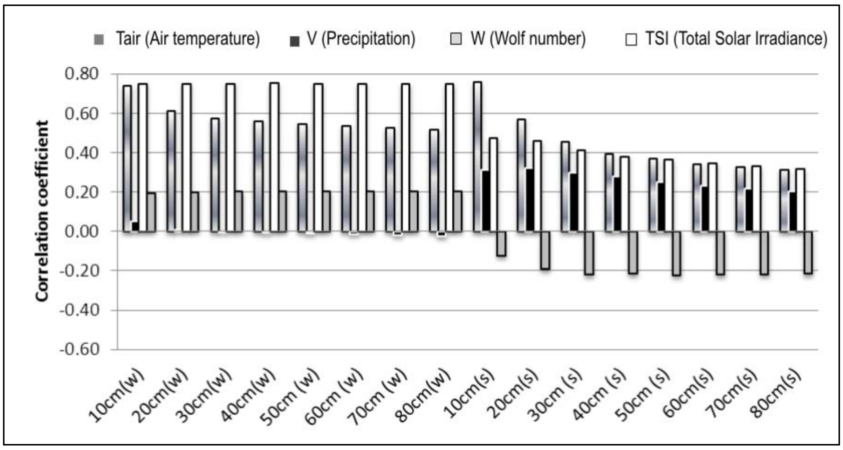

Fig. 14. Correlation coefficients for *S*04 soil temperature in winter and summer (2011-2012)

Soil *S*04: its location in alder forests fully changes the water-temperature regime and microclimate; the correlation between air temperature and soil temperature is almost identical in winter and in summer ($r \approx 0.35$-0.55 in summer and

$r \approx 0.55$-0.75 in winter) (Fig.14); the influence of precipitation and soil temperature is insignificant in winter; in summer $r \approx 0.20$-0.30, the correlation between Wolf number and soil temperature being stable in summer and in winter ($r \approx 0.30$-0.60 in summer and $r \approx 0.50$-0.75 in winter); the correlation between total solar irradiation and soil temperature is atypically negative in summer due to the forest microclimate, with the tree crowns blocking the influence of the sun's radiation.

CONCLUSIONS

1. On the basis of the experimentally derived data, the dependencies describing the dynamics of soil temperature and water content during the years 2008-2012 in the West Polesie nature-protected territory show that for natural, undisturbed soil types there are the obvious dependencies. These relationships describe the seasonal influence of the sun's radiation and climate on the soil-water-temperature regime.
2. Untypical or opposite tendencies than in natural, undisturbed soils in relation to the seasonal influence of the sun's radiation and climate on the evolutional processes occurring in soils are observed for soils disturbed by anthropogenic influences.

REFERENCES

Dragan Ya.P., Rozhkov V.A., Yavorskyi I.M., 1987. Methods of probabilistic analysis of oceanological process rhythms (in Russian). Gidrometeoizdat, Leningrad, Russia.

Janik G., Szpila M., Słowińska J., Brej G., Turkiewicz M., Skierucha W., Pastuszka T. 2011 Method of determination of sensitivity zone of TDR sensors (in Polish). Acta Agrophysica,18(2), 269-286.

Malicki M., Walczak R., 1999 Evaluating soil salinity status from bulk electrical conductivity and permittivity. European Journal of Soil Science, 50, 505-514

Shevchuk M., 1999. Soils of the Volyn Region (in Ukrainian). Volyn State University, Ukraine.

Skierucha W., 2006 Temperature influence on the reflectometric measurement of soil moisture. Acta Agrophysica, 122, 1-88.

Skierucha W., Wilczek A., Szypłowska A., 2012 Dielectric spectroscopy in agrophysics. International Agrophysics, 26(2), 187-197.

Skierucha W., Slawinski C., Wilczek A., Alokhina O., 2010. The technical implementation of a soil moisture, salinity and temperature monitoring system in Polesie National Park and Shatsk National Natural Park. In: The future of hydrogenic landscapes in European Biosphere Reserves (Eds. T. Chmielewski & D. Piasecki), 299-309.

Skierucha W., Wilczek A., Szypłowska A., Sławiński C., Lamorski K., 2012. A TDR-based soil moisture monitoring system with simultaneous measurement of soil temperature and electrical conductivity. Sensors & Actuators, 12, 544-552

Wilczek A. Skierucha W., Szypłowska A., 2011. Influence of moisture and salinity of soil on its dielectric permittivity. Acta Agrophysica Monographiae, 197, 2011(6), 1-87.

SPECYFIKA ZMIENNOŚCI WILGOTNOŚCI I TEMPERATURY GLEBY NA PODSTAWIE BADAŃ TDR W LATACH 2008-2012 NA OBSZARZE POLESIA ZACHODNIEGO NA UKRAINIE

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Streszczenie. W pracy przedstawiono wyniki badań prowadzonych w latach 2008-2012 na terytorium Szackiego Parku Narodowego. Do badań wybrane zostały cztery genetycznie różne gleby na tym terenie. Są to gleby soddy – podzolic (S01) porośnieta trawą, lowland peat bog (S02), anthropogenic lowland peat bog (S03) ze zmineralizowaną warstwą powierzchniową i soddy – gley loamy soil (S04). Badania zostały przeprowadzone przy użyciu urządzenia TDR opracowanego i wykonanego w Instytucie Agrofizyki PAN w Lublinie oraz sond polowych do pomiaru wilgotności gleby, temperatury oraz zasolenia. Praca przedstawia zmienność właściwości fizycznych gleby w czasie w różnych typach gleby i na różnych głębokościach. Osiem sond TDR zostało zainstalowane w glebach S02, S03, S04 na głębokości od 10 cm do 80 cm w odstępach 10cm oraz w glebie S01 na głębokości od 10 cm do 50 cm. Dane dobowe z pomiarów TDR zostały uśrednione i wykorzystane do wyznaczenia współczynników korelacji między temperaturą gleby na różnych głębokościach a temperaturą powietrza, opadami atmosferycznymi, parametrami aktywności słonecznej, liczbą Wolfa i całkowitym promieniowaniem słonecznym. Zbadany został również wpływ promieniowania słonecznego na zmiany badanych parametrów w glebie wraz z porami roku.

Słowa kluczowe: właściwości gleby, pomiar TDR, korelacje, warunki klimatyczne, aktywność słoneczna