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Assumptions for Fourier-based modelling of diurnal temperature variations in the top soil layer under Istebna spruce stands

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ABSTRACT

Soil temperature is a key factor which affects both soil-forming processes and the hydrological balance of water exchange between the atmosphere and the ground. The measured temperature waveforms in the top layer of forest soils demonstrate very characteristic diurnal variations. This paper presents a method of determining the amplitude of the diurnal temperature variation using the Fourier transform. Temperature measurements were carried out in the top layer of soil at a depth of approx. 0.08 m within 4 homogeneous, even-aged stands of different age-classes (from a 12-year-old thicket to a 117-year-old mature stand) and at 3 inter-forest meadows. The main aim of this paper was to relate all parameters in a simple empirical model of diurnal temperature variations in the top layer of soil under a stand to biometric features of stands. The parameters describing the model depend to a large extent on the soil exposure factor and the total biomass of above-ground tree parts. The soil exposure factor and the total biomass of a stand depend solely on the number of trees per hectare, the mean height of a stand, and the mean tree diameter measured at breast height (i.e. at a height of 130 cm), all of which are very easy to measure from the ground. The analyses also show that the amplitude values, particularly in an open field, also depend on the mass of organic matter accumulated in soil. The presented model was verified using measurement results in spruce stands of the Istebna ecotype (the Silesian Beskid Mts.).

The model and parametrisation proposed for spruce stands depends solely on easily measurable biometric features and should be readily adaptable to stands composed of other tree species, using appropriate coefficients that differentiate these stands from spruce stands. The necessary improvements to the presented empirical model will be possible after a series of measurements taken within various types of stands. A thorough understanding of the factors determining temperature variation in woodlands may considerably expand the knowledge of the water exchange balance within forest complexes, as well as the estimation of site productivity.

1. Introduction

Proper approximation of soil temperature is a fundamental issue in climate monitoring and various hydrological and ecological applications. Besides wind velocity and solar radiation, soil temperature in forests is the main factor influencing the volume of water evaporating from inter-particle spaces in the soil. Evapotranspiration from soil is also a fundamental factor affecting water exchange between the atmosphere, stands, and the soil (Galicia et al., 1999; Bouchter et al., 2001). Variations in soil temperature (diurnal and seasonal) have an impact on various biological and chemical processes, such as decomposition and mineralisation of soil organic matter or release of CO_2 (Paul et al., 2002). Soil temperature is determined by many factors, for example meteorological conditions (i.e. solar radiation, wind velocity, air temperature), site topography (aspect and tilt angles, the topographic relief of the surrounding terrain and the outline of adjacent stands), water content, biomass, and spatial arrangement of plants. Furthermore, in forest complexes, the structure of the canopy, understorey and flora at the litter level change during stand growth. Roots and stems supply water to leaves, carrying energy to higher parts of plants, thus affecting soil moisture and evaporation (Eagleson, 1970; Czarnowski, 1989). In addition, the canopy, understorey and the forest floor may reduce diurnal downward heat transfer from the atmosphere to the soil or nocturnal upward long-wave thermal radiation from the soil to the atmosphere.

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Due to technical and organisational constraints of field research, air or soil temperature can only be measured at a few carefully chosen points at different heights (depths). The ongoing development of measurement methods and the automated recording of results create greater opportunities for the gathering and processing of a large amount of data. The well-understood techniques previously used to verify and analyse data have become inadequate. Therefore, new efficient methods and numerical algorithms for solving the aforementioned tasks should be found and signal processing techniques are worth considering. An adequate theory would suggest several methods that should be capable of fulfilling the arising needs and expectations (Korohoda et al., 2001; Sypka, 2003; Elias et al., 2004; Paul et al., 2004; Weiss and Hays, 2005; Graham et al., 2010). Still, the problem of the proper choice of measurement points, essential for identification of theoretical models, and improvement of the methods of extrapolating the measurement results remains to be solved on a large spatial scale.

In contrast to farmland, forest soils are characterised by specific soil profiles and their top layer is composed of organic levels formed by dead needles, seeds, cones, pieces of bark, dry branches of trees, dead organic undergrowth remains, and material of animal and microbial origin. However, the majority of the organic matter comes from the stands (Kowaliński and Gonet, 1999; Dziadowiec et al., 2004). Accumulated in soil, the organic matter is in various states of decomposition and is constantly subject to further disintegration (Pepper and Josephson, 1996) by way of mineralisation, which consists of hydrolysis and oxidation of organic molecules in the initial phase, crushing by macro and mezofauna, and rotting due to microflora and microfauna in the microbiological phase (Dziadowiec et al., 2004). Humification of organic compounds occurs simultaneously, which in the deeper organic layers is the last stage of decomposition (Kowalik, 2001). All of the processes associated with the decomposition of organic matter are among the most important soil-forming factors and are dependent, among others, on hydrothermal conditions (Kowaliński and Gonet, 1999; Zawadzki, 1999). As a result of these changes the top layer of soil consists of ecto- and endohumus layers. It may be expected that temperature dynamics in the top layer of soil (to a depth of approx. 0.08 m) are affected both by the thickness and the physico-chemical properties of the ecto- and endohumus on the temperature sensor. An additional factor that may influence the thermal conditions of the top layer of soil is the exothermic mineralisation (rotting) that occurs under aerobic conditions (Puchalski and Prusinkiewicz, 1990; Kowaliński and Gonet, 1999).

This paper presents variations of temperature in the top layer of soil at a depth of approx. 0.08 m inside a densely forested mountain valley (49°35′N, 18°50′E) which covers an area of 1.68 km^2 (0.649 mi^2). In such a small investigated area, varying temperature values may be only a result of topographic factors (aspect and slope angles, altitude) and the structure of the neighbouring tree stands, with negligible differences arising from the geographical position or climate. The aim of the study was to compare the amplitudes of diurnal variation of soil at a depth of approx. 0.08 m under spruce stands of different age classes and on an inter-forest meadow, as well as to attempt to describe this variation by empirical equations. An additional objective is the expression of relations that describe dependencies between the amplitudes of the diurnal temperature cycle in the top layer of soil by means of stand characteristics, as well as an attempt at ecological interpretation of the obtained coefficients of the model. It will be possible to use models which express general relationships in extrapolation of results from single measurements to large areas. Models which describe general relationships may be important in forest practice for predicting natural changes in stands due to stand development and the consequences of management measures (weeding and thinning). It should also be noted that the research object is an element of soil climate. For that reason, the relationships described may also be useful for forest soil science, especially for processes related to organic matter decomposition and the circulation of elements in the forest ecosystem (Puchalski and Prusinkiewicz, 1990; Blum, 1999; Dziadowiec et al., 2004).

2. Sites, measurements and methods

In hydro-meteorological research, all measurements can be taken at only a few carefully chosen points, meaning the obtained results have to be extrapolated over a large spatial scale. Therefore, the investigated sites should be typical and have properties representative of all study regions.

2.1. Research sites

The research sites were located within the Dupniański Stream experimental catchment area (49°35′N, 18°50′E) in the Silesian Beskid Mountain Range (Poland). The experimental catchment was arranged by the Department of Forest Engineering at the University of Agriculture in Krakow. This small mountain catchment (average height: 680 m AMSL, total area: 1.68 km^2, maximum length: 2.09 km, maximum width: 1.47 km, circuit: 5.39 km, valley prominence: 404.4 m, geology: Istebna series sandstone) was 95% covered by a Norway spruce stand (*Picea abies* (L) *Karst., ecotype—the Istebna spruce*). The Istebna spruce is characterised by very fast growth up to a height of 50 m, productivity up to 1500 cubic meters per hectare, extraordinary stem quality, and high resistance to disease. Spruce stands in this region of the Silesian Beskid Mountains have been rated among the best seed forest stands in Europe (Giertych, 1996; Janson, 1996; Pacalaj et al., 2002; Małek and Gawęda, 2005; Liesebach et al., 2010). Seven research sites with automatic data recording were deliberately located inside the experimental basin area: 3 at inter-forest meadows (sites S5, M1 and M2); 4 within homogeneous, even-aged stands of different age classes, from a 12-year-old natural thicket (site S1) to a 117-year-old mature stand (site S4). The spatial arrangement of all research sites within the Dupniański Stream catchment is presented in Fig. 1. Table 1 presents selected characteristics of the experimental sites in the investigated area. The homogeneous, even-aged spruce stands on the research site consisted only of a canopy and stem layer; there was no forest vegetal cover in the vicinity of the selected measurement points. The biometric features of the investigated stands were measured *in-situ* on circular sites with an area of 10 ares around the measuring profiles. The diameters at breast height (i.e. 1.30 m above ground, *DBH*) were recorded with precision callipers. The heights of trees (*H*) in the experimental stands were determined trigonometrically using a Zeiss Dahlta 010B tacheometer. The obtained data was used to calculate the mean diameter at breast height and the mean tree height by applying Lorey's formula, which gives slightly higher values than the traditional arithmetic average because of a correction to the basal area. Thereafter, the biomass of leaves (needles) and the volume of the stem and small-sized branch wood were estimated for the model mean tree by the method proposed by Suliński (1993, 2007). The empirical equations used in this procedure were identified using data included in yields tables (Schwappach, 1943) and in volumetric tables (Czuraj et al., 1966). The total biomass of fresh timber (stem and branches, [tonne per hectare]) was approximated by multiplying the model mean tree volume by the green spruce wood density of 0.75 [tonne per cubic meter] (Suliński, 1993, 2007), and the total number of trees per hectare (*N*). The total biomass of the stand was the sum of the total biomass of fresh timber and the total biomass of leaves. The results (standardised for 1 ha) are shown in Table 2. The detailed