Modeling evapotranspiration and soil hydro-physical characteristics: case studies in Hungary

Ph. D. Thesis

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1 Introduction

Evapotranspiration is one of the most important components of surface energy- and water balances. It cannot be measured directly; therefore different models are used. Evapotranspiration is usually modeled on both micro- and macroscale. Evapotranspiration on microscale can be estimated on a physical basis by modeling land surface energy and mass transport processes. These microscale treatments have to be combined with complex upscaling procedures for estimating evapotranspiration on larger scales. However, upscaling procedures are not always applicable due to the lack of data in high spatial resolution.

Applications of modeling evapotranspiration on macroscale are also common. In these applications evapotranspiration is frequently modeled by empirical approaches which are not always physically based. In the dissertation the relationship between evapotranspiration and soil hydro-physical characteristics is analyzed on both micro- and macroscale.

Soil water retention functions ($\Psi(\theta)$-function, Ψ is the soil moisture pressure head, θ is the volumetric soil moisture content) are usually incorporated in micrometeorological models. In Hungary, *Clapp* and *Hornberger*'s (1978) $\Psi(\theta)$-parameterization is used in the meteorological applications despite the fact that the fitting parameters of the curves have been determined by using data measured in the United States of America. In the soil physical applications *Rajkai*'s (1988) parameterization is used. Up till now these parameterizations have not been compared. Therefore in the first case study of the dissertation soil water retention functions of *Clapp* and *Hornberger* (1978) and *Rajkai* (1988) were compared for homogeneous and inhomogeneous areal distribution of soil moisture content.

Soil moisture content is one of the key factors regulating evapotranspiration. Direct and systematic measurement of soil moisture content is a time consuming and problematic task. Therefore soil moisture content is frequently estimated by models. These models are commonly based on the surface energy balance equation and use surface skin temperature as input. Surface skin temperature is usually estimated by remote sensing techniques. On the other hand, soil temperatures in the surface layer are also measured in the Hungarian Agrometeorological Observatories and Climate Stations. These data can be also used for estimating surface skin temperature. Up to this time estimation of soil moisture content by applying the energy balance approach has not been performed using measurements of the Hungarian Agrometeorological Observatories or Climate Stations.

Therefore, in the second case study of the dissertation we investigated the applicability of a micrometeorological model for estimating soil moisture content using agroclimatological observations.

Most of the studies referring to near-surface climate in Hungary did not evaluate or did not even take into consideration the effect of soil texture. Up to the present no comprehensive analyzes have been carried out about the effect of soil texture on surface energy- and water balance components in Hungary. Moreover, the effect of global climate change on the hydro-climate of Hungary - taking into consideration the soil texture - is lesser-known. We would like to fill these gaps with the third case study. Thornthwaite's climate classification method is adopted and extended for the purposes of this study. The objectives were as follows:

- Determining Thornthwaite's hydro-climate regions in Hungary,
- estimating the annual and monthly mean values of surface energy- and water balance components in Hungary,
- analyzing the correspondence between the hydro-climate types and the energy- and water balance components,
- evaluating the effect of soil texture on the hydro-climate regions and the energy- and water balance components,
- estimating and predicting the changes of the hydro-climate regions and the water balance components in the XX. and the XXI. century.

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2 Data and model

Soil water retention curves of *Clapp* and *Hornberger* (1978) and *Rajkai* (1988) were compared for homogeneous and inhomogeneous areal distribution of soil moisture content. Inhomogeneous areal distribution of θ (hereafter briefly inhomogeneous θ) was simulated supposing normal distribution. The $\Psi(\theta)$-curves for inhomogeneous θ were calculated by the probability density functions of Ψ. The relationship between the inhomogeneous and the homogeneous $\Psi(\theta)$-curves were quantified. Since these functions are determined separately for each soil textural classes, textural classes used in Hungary and in the United States of America were compared. The main objective was not to evaluate the correctness of the two parameterizations, but to examine the deviations between them.

The soil moisture content of a grass covered surface was estimated by an inverse application of the model DMPROG (*D*iagnostic *M*odel of *Prog*surf) (*Ács et al.*, 2000). The model is based on the surface energy balance equation. Surface temperature is estimated in the so called "inverse application" of the model. Surface temperature strongly depends on soil moisture content. Therefore that θ is used as the output of the inverse model ("simulated θ") for which simulated and measured surface skin temperatures were equal. Data measured at the Agrometeorological Observatory of the University of Debrecen were used. Measurements were made at 12 UTC in the period 1974-1986 above grass surface. Surface skin temperature values were estimated by extrapolating soil temperatures measured at the surface layer. The estimated θ values were validated against the volumetric soil moisture content values measured at 0-20 cm depth. Daily values of the measured θ were obtained by a linear interpolation from weekly measurements. We tested whether the method could be successfully applied for estimating soil moisture content. Finally, instantaneous and 12 year monthly mean values of θ were estimated.

Near-surface climate of Hungary was analyzed adopting the *Thornthwaite* (1948) approach. Thornthwaite's climate classification is based on the estimation of water balance components on land surface. Water balance was calculated by a simple bucket model for 1 m deep soil surface layer. Areal distribution of soil water holding capacity values was taken into account by using soil textural data. Soil texture was assumed to be homogeneous for the upper 1 m deep soil layer. The most important energy balance components: global radiation, net radiation, sensible heat flux, and soil heat flux were also estimated. Sensible heat flux was obtained as the residual term of the energy balance equation. The estimated water- and energy balance components are valid for climatic reference surface (short cut grass). Temperature and precipitation data measured in periods 1901-1950 and 1951-1990 were used. Sunshine duration data were also used from the period 1901-1950. The effect of the global climate change on hydro-climate of Hungary was analyzed by using the regional climate scenarios (*Bartholy et al.*, 2004). Predicted changes of seasonal mean values of temperature and precipitation for 2050 and 2100 are given in the regional climate scenarios based on 16 Global Circular Models (GCM) and the four main emission scenarios of IPCC (*IPCC*, 2001). We assumed that the areal distributions of the predicted temperature and precipitation changes are homogeneous in Hungary, and the potential evapotranspiration model of Thornthwaite can be used also in case of the changed climate.

3 Results and Conclusions

The results are summarized separately for the three case studies of the dissertation.

Case study 1: Comparison of soil water retention models

1. The water retention curves of *Clapp* and *Hornberger* (1978) and *Rajkai* (1988) significantly differ for clay soil texture in the dry water regime.

2. Clapp and Hornberger's parameterization is sensitive to the areal distribution of θ. Differences between the homogeneous and inhomogeneous $\Psi(\theta)$-curves of Clapp and Hornberger are largest in the dry and moderately moist water regimes. Rajkai's parameterization is insensitive to the areal distribution of soil moisture content.

3. Relationships between homogeneous and inhomogeneous $\Psi(\theta)$-curves are quantified for the two parameterizations and the three main soil textural classes. Results can be utilized in estimating soil water balance and modeling soil atmosphere interactions.

Case study 2: Estimating soil moisture content using the energy balance approach

1. Meteorological conditions required for a successful application of the micrometeorological model for estimating soil moisture content rarely prevail. The method is applicable for clear sky (0/8 and 1/8 cloud fraction) and strong unstable conditions, in case of strong incoming radiation, when soil moisture content is between field capacity and wilting point.

2. The estimated instantaneous values show significant scattering, but the 12 year monthly mean values of the estimated and the measured soil moisture content values agree well.

3. The method can successfully be applied in the analyzes of climate characteristics - like soil moisture content, evapotranspiration and sensible heat flux - of the Agrometeorological Observatories after performing validation on the local data set.

Case study 3: Relationship between soil texture and near-surface climate in Hungary

1. The areal distribution of actual evapotranspiration as obtained by the modified Thornthwaite's method significantly differs from the results shown in the former studies, mainly because the areal distribution of soil texture is incorporated in our model.

2. The areal distribution of the actual evapotranspiration in July is very similar to the areal distribution of soil texture. The effect of soil texture on the monthly mean values of soil moisture content is most pronounced in spring and summer. In these seasons sandy regions are significantly dryer than the surrounding areas.

3. The effect of soil texture on the water- and energy balance components is most pronounced in case of the sensible heat flux. In summer, the sensible heat flux values estimated for the sandy regions between the rivers Danube and Tisza are much higher than the ones in the surrounding areas.

4. The effect of soil texture on the areal distribution of energy- and water balance components as estimated by the modified Thornthwaite model is most pronounced in case of sandy soils, where extreme large sensible heat flux and small evapotranspiration and soil moisture content values prevail in summer.

5. Hydro-climate regions have shifted towards the drier types in some parts of the country in the XX. century.

6. Thornthwaite's approach has been applied also in the analysis of the effect of global climate change on the hydro-climate of Hungary. This is the first application of the Thornthwaite's model for this purpose in Hungary. It has to be emphasized that the results referring to the future climate of Hungary are only 'estimates'; it is not possible to validate and check their reliability at present. The results show in case of climate scenario A2 (that predicts the most marked changes) that the humid ($B1$) hydro-climate of Thornthwaite will disappear from the flatlands and hilly regions

in Hungary by 2050. At the same time, the semiarid (D) hydro-climate type will probably appear, and it will be the dominant type at the central regions of the country in 2100.

7. Hydro-climate predicted for the mid and the end of XXI. century in Hungary is significantly dryer than the hydro-climate in the XX. century. Significant increase of the annual sum of potential evapotranspiration (PET) and water deficiency (D) as well as significant decrease of the annual mean value of the soil moisture content (θ) and the annual sum of water surplus (S) is predicted. Actual evapotranspiration (ET) probably will slightly increase, however the direction of the change of ET obtained by different GCMs, soil textures and emission scenarios is not consistent. Predicted changes for 2100 are 11-21 % for PET, 4-6% for ET, 37-73% for D, -28 - -43% for S, and -8 - -15 for θ depending on the emission scenarios. Each value represents an average of change in the corresponding water balance components calculated by the results of 16 GCMs and the data of 37 climate stations in Hungary.

Analysis of near surface climate in Hungary was originally planned by using the micrometeorological approach. But the results of the second case study have shown that the micrometeorological method is not suitable for estimating the areal distribution of soil moisture content in Hungary due to the lack of input data and the limited applicability of the method. Therefore we adopted Thornthwaite's climate classification approach for the analysis of near surface climate in Hungary. Results of this study reveal that it is essential to take into consideration the soil hydro-physical properties in analyzes of near surface climate in Hungary. The importance of these properties is commensurable with the importance of atmosphere and relief in both micro- and mezoscale.

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