PARAMETERIZATION AND VERIFICATION OF SOIL WATER POTENTIAL MICROCLIMATIC MODEL. CASE STUDY AT SOFIA AND PLANA STATIONS

V. C. Danchovski, D. M. Ivanov, A. P. Blagoev, E. H. Donev

Department of Meteorology and Geophysics, Faculty of Physics, Sofia University, Blvd. James Boucher No 5, Sofia1164, Bulgaria

Abstract. The purpose of present work is to model the behavior of soil water potential (SWP). The model is constructed as a nonlinear combination of precipitation and evapotranspiration (ET). It is designed and tested with simulations of SWP with a time step of one hour. Investigation is done over data from two stations located in Borisova Garden, Sofia and Plana Mountain area for a period over one year. Verification is performed over obtained and actually measured values at both meteorological stations. It is concluded that the model adequately describes the course of SWP except in periods of drought where some deviation from measured data is observed. The designed mathematical model can be used as a tool for simulations of local soil water potential and hence for periods for which SWP values are not measured. Also SWP is important parameter controlling ozone flow through the stomata of the leaves and can be used to assess the risk of damage of vegetation caused by ground-level ozone.

Key words: soil water potential, soil water budget, evapotranspiration

Introduction

Soil water content has an important role in soil-plant-atmosphere continuum. The actual content can be determined by using soil water budget (Košková et al., 2008, Gusev et al., 1998, Schulte et al., 2005, see fig.1), but the lack of information about some of the components of soil water budget like runoff and drainage makes this task difficult.

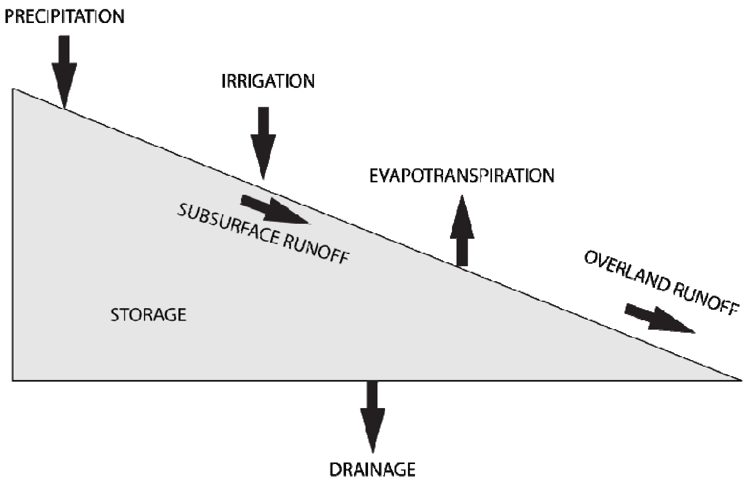

Fig. 1. Soil water budget: INPUT (Precipitation + Irrigation) = OUTPUT (Evapotranspiration +/- Drainage + Overland Runoff + Subsurface Runoff) +/- STORAGE

At the viewpoint of plant physiology, soil water potential is a more descriptive parameter, and drought stress plays a significant role in net ecosystem exchange (Baldocchi, 1997). There are many empirical relationships between *SWP* and soil water content at fixed soil water conditions and soil type (Fredlund and Xing, 1994, Mintz and Walker, 1993). Zweifel and Stampli (2008) proposed simpler model, which describes *SWP* changes as a function of precipitation rain and evapotranspiration.

ET has been frequently a subject of theoretical and experimental research and there are different models that describe it (Priestley and Taylor, 1972, McNaughton and Black, 1973, Penman, 1948, Fisher et al., 2005, Monteith, 1965, 1981). Recent *ET* models calculate potential evapotranspiration by using methods driven by meteorological data and/or vegetation characteristics and scale this estimate down to actual evapotranspiration based on limitations in available water (Stannard, 1993)

The purpose of this study is to obtain *SWP* series for periods prior measurements were carried out and to use them in stomata flux model. A satisfactory overlap with the actual measured *SWP* values is looked mainly for the plant’s activity period, i.e. without winter. It is clear that during winter soil water potential is constantly high and depends mainly on soil characteristics, geographical and climatic characteristics of site location.

Study sites and measurements

The first station referred as Station Sofia is part of a typical urban ecosystem located in Sofia Central Park which is the largest forest area in the city (latitude 42° 40' 34.8" N, longitude 23° 20' 41.83" E; altitude 577m). The other is a mountain station (latitude 42° 28' 34.65" N, longitude 23° 25' 39" E; altitude 1 234m) referred as Station Plana.

Station Sofia is in the area of Astronomical Observatory of Sofia University “St.

Kliment Ohridski” located in the northeastern part of the park far from buildings. Near the station at about 100m distance there is a relatively busy thoroughfare. Station Plana is located in the central part of Plana Mountain which is about 25km south from Sofia. The station is on a plateau and is close to the border of a forest at northeast. It is on the territory of Bulgarian Central Geodesy Observatory and about 5km west from the site there is a highway.

The time-series are collected from August 2009 to November 2010 at station Plana and from October 2009 to November 2010 at station Sofia. Soil water potential is measured together with soil heat flux, wind speed, wind direction, temperature, relative humidity, atmospheric pressure and total solar radiation. Radiation balance is measured only in station Plana. The sensors and units of measurement are detailed in Table 1. For the scope of present study *SWP* is measured at 0.15m depth. Solar radiation, radiation balance, temperature and relative humidity are collected at 2 m height and wind speed and direction at 10 m height. Hourly means and standard deviations of quantities measured are recorded at 0.1 Hz sampling rate with Campbell Scientific CR10X data logger.

Table 1. Information about the equipment used and the parameters measured at the stations

Sensor	Parameter	units
257 Soil Moisture sensor	Soil Water Potential	bars
HFT –3 Soil Heat Flux sensor	Soil Heat Flux	$W\,m^{-2}$
05103 YOUNG wind monitor	Wind Speed and Wind Direction	ms^{-1}
SP1110 Skye Pyranometer	Total Solar Radiation	$W\,m^{-2}$
Q – 7 Net Radiometer	Radiation Balance*	$W\,m^{-2}$
MRI	Precipitation	mm
Vaisala HMP45C	Temperature	^oC
Vaisala HMP45C	Relative Humidity	%
PTB101B Atmospheric Pressure sensor	Atmospheric Pressure	mb

Model description

SWP alteration (Ψ_{soil} - $\Psi_{soil,old}$) is considered as a function of soil wetting by precipitation (*P*) and the soil drying by evapotranspiration (*ET*). The processes of wetting and drying depend on soil resistance, which itself is changing with Ψ_{soil}. The recursive model couples these two processes within Ψ_{soil} (Zweifel and Stampli , 2008):

$$\Psi_{soil} = \Psi_{soil,old} - \frac{f_1 * ET}{R_{ET}} + \frac{f_2 * P}{R_P} , \qquad (1)$$

where R_P is the wetting resistance, R_{ET} is the evaporating resistance and f_1 , f_2 are soil-specific weighting parameters.

Allen et al. (1998) state that there is a threshold value for precipitation where changes in the *SWP* does not occur. When daily precipitation is less than about 0.2 *ET*

water is entirely evaporated and can be ignored in water balance calculations. The criterion used is the amount of rain for the last 3 hours to be more than 1.5mm.
In a feedback loop, Ψ_{soil} determines R_{ET} : the drier the soil is the bigger is the resistance to the withdrawal of water:

$$R_{ET} = \left(-\Psi_{soil}\right)^{f_3} + const_{ET} \quad (2)$$

where f_3 is soil-specific dehydration resistance parameter for each station. The constant $const_{ET}$ is added in this paper for greater consistence of the model with the observed data. The penetration of precipitation water into soil is determined by the dynamic resistance R_P, which proportionally changes with the sum of precipitated rain over the last twelve hours (P_{12}):

$$R_P = P_{12} * f_4 * \left(-\Psi_{soil}\right)^{f_5} + const_P \quad (3)$$

where f_4 and $const_P$ are specific soil resistance parameters for the process of wetting and specific for each station constant f_5 is added for natural limitation of model results near saturation and for greater consistence of the model with the observed data.

Zweifel and Stampli (2008) state that the speed of soil wetting depends mainly on the dryness of the uppermost soil layer between surface and measurement sensor and less on the absolute value of Ψ_{soil} at the measurement depth. In this work a multiplier $\left(-\Psi_{soil}\right)^{f_5}$ is added to reduce the weight of the second addend when soil is saturated. For this adjustment the type of characteristic curves is used from Fredlund and Xing (1994). Its structure shows that close to saturation changes in *SWP* are too small compared to the rest of the range if the same change in soil water content is applied. It can be observed that the wetting resistance depends less on *SWP* at the point of measurement but rather on the condition of the soil located above this point. *SWP* is measured at depth of 10 - 15 cm while this is observed at greater depths.

As it was noted *SWP* series represents precipitation well. This can be considered due to introduction of water into soil which leads to increase of *SWP*. During dry periods soil water potential decreases and the amount of decrease depends on evapotranspiration (*ET*). *ET* is determined by *VPD* (vapor pressure deficit of the air) and the incoming shortwave radiation which is the main component in the radiation balance (Crawford et al., 2000). As a result, the driest periods should be observed when solar radiation and *VPD* have high values. For that reason, *SWP* reaches its minimum values at the end of summer. It is due to lower values of summer precipitation and higher evapotranspiration. The measured values of *SWP* confirmed these assumptions and such behavior should be implied in the *SWP* model.

The course of soil temperature (T_{soil}) showed falls dictated by the amount of precipitated water which cools the soil. The periods of minimum daily variations of T_{soil} are during wet periods. This is because water is a good heat conductor and the temperature of soil easily equilibrates with the temperature of lower layers, and also because soil water contributes to increase in soil heat capacity. This leads to decrease in soil temperature contrasts during the day. On the other hand, periods with a significant positive trend in T_{soil} should have periods of drought.

Following Walter et al. (2002) the standardized reference evapotranspiration equation is calculated with one hour time step:

$$ET_0 = \frac{\dfrac{\sigma * (R_n - G_{soil})}{\lambda} + \gamma * \dfrac{C_n}{T + 273.15} * U * VPD}{\sigma + \gamma * (1 + C_d * U)}, \quad (4)$$

Where λ is latent heat of vaporization, R_n is the net radiation (estimated following Allen et al., 1998), G_{soil} is the soil heat flux, σ represents the slope of the saturation vapor pressure temperature relationship, γ is the psychrometric constant T is air temperature, U is wind speed, C_n and C_d are numerator and denominator constants for short reference vegetation.

When the surface is different from the reference surface it is necessary to use a correction factor - crop coefficient (K_c). It is defined as the ratio of crop evapotranspiration under standard conditions and the evapotranspiration of the reference surface. In this paper the reference surface is used, so it does not multiply with the crop coefficient K_c nor with the dual crop coefficient, because the evapotranspiration is multiplied in the equation for *SWP* by factor f_1, which is assumed to contain K_c. The parameters that are modified in this work concern the non-growing plant period, i.e. November, December, January and February. By analogy with K_c in Allen et al. (1998) a factor 0.4 is used and is multiplied with the reference evapotranspiration for these months. The aimed not to obtain accurate values of evapotranspiration, but satisfactory results for soil water potential, which could be used in vegetation grown parameterization scheme.

The standard conditions of crop evapotranspiration refer to crops grown in large fields under ideal agronomic and soil water conditions. A correction on the evapotranspiration is required where the growth conditions differ from standard unstressed conditions (Wetzel, 1986). Soil water shortage may reduce soil water uptake and limit crop evapotranspiration and the water stress coefficient K_s may be derived from a water balance of the root zone (Jensen et al., 1991). When *SWP* is over -0.5 MPa water stress is not observed (Rana et al., 1997), i.e. K_s=1. In interval from -0.5 to -1.5 MPa (the so-called permanent wilting point), K_s decreases linearly to 0.

Combining equations 1 and 4 gives the equations for the model. Its verification is done for two separate stations. Model's parameters are strongly dependent on local microclimate at the stations. At other stations the behavior of this model may be different.

Results and discussion

As noted factors that influence the course of *SWP* are the amount of precipitation (*P*) and evapotranspiration (*ET*) (see equation 1). The latter depends on radiation balance at soil surface (R_n – G_{soil}) and the vapor pressure deficit in the air above (see equation 4). Comparison of these two factors showed that the first addend (the energy balance) is much larger than the second term (the deficit of water vapor), which has a significant impact at night. The contribution of the *VPD* term is 21.9% at station Plana and 9.8% at station Sofia. During daylight hours, this it is 12.6% at station Plana and 6.1% at station Sofia. The night values are respectively 41.4% and 15.8%. During night, the radiation term is negative but much smaller in module than during day. This is due to negative evaporation, which some authors like Walter et al. (2002) recommend to be left in the equations because it is much less than the daily component, but it explains the phenomena like morning dew (table 2).

Table 2. *ET* components in daytime, nighttime and daily [mm]

Periods	Daytime		Nighttime		Daily	
Station / Component	Plana	Sofia	Plana	Sofia	Plana	Sofia
Radiation balance	758	658	-111	-95	647	563
Vapor Pressure Deficit	96	40	46	15	142	55

The difference in *VPD* term for both stations can be explained by the weaker wind at station Sofia. Slowing of the wind is caused by the closeness of tall trees at station Sofia, which distorts wind profile and reduces wind velocity.

Because of the significant contribution of the radiation term in equation 4 at Plana Station during the period 4 August 2009 – 4 November 2010 the total radiation balance was also measured. The data obtained showed increase in the modeled radiation balance (Allen et al., 1998). However, 23% overestimation in R_n causes only 16% increase in estimated ET_0.This contributes between 10-th and 16-th hour of the day and leads to more pronounced peaks in evaporation diurnal course. Therefore, *SWP* should be overestimated during the afternoon. The increase of reference evapotranspiration, however, is inhibited by parameters in the equation 1 and significant difference in the *SWP* model is not observed.

The data show that at Plana Station after 10 August 2010 there is a 20 day period of drought in which short-wave solar radiation, a major component in the radiation balance and the deficit of water vapor have high values, therefore, in this period the water in the soil should have its lowest values and *SWP* reached its minimum values. For this same period of drought, there is gradually increasing daily average soil temperature, and this trend is interrupted by precipitated rain. At Sofia Station, which is about 25 km far from Plana Station there, measurements have similar structure. The *SWP* reaches its minimum values at the end of summer, which is due to lower values of summer precipitation and higher evapotranspiration. The measured values of the *SWP* confirm these assumptions. Such behavior should be regarded in the *SWP* model as well. In the station Sofia the period of drought is late August and early September. It is due to period of about a month without rain with high levels of solar radiation and water vapor deficit. There are very clear streaks of T_{soil}'s plunging, when there was rain.

Model verification

The constructed model is verificated with measured data from August 2009 to November 2010(Plana Station) and from October 2009 to November 2010(Sofia Station). Determination of the parameters in the models is done by minimizing the mean squared deviation of the measured data. Parameters used in the model for both stations are presented in Table 3.

Table 3. Parameters of the model

	f_1	f_2	f_3	f_4	f_5	$const_{ET}$	$const_P$
Plana	0.0151	2.70	-0.60	2.1	-1.2	2	10
Sofia	0.0122	3.50	-0.50	2.1	-1.3	2	10

It is clear that evaporation described by the second term in the equation is highly dependent on upstream water in the soil. It provides enough water to leave the top layer of soil by evapotranspiration. This flow is greater, when the difference in potential between that point and the levels below it is greater. For this reason *SWP* decreases faster when the soil is dry. Yet the process of evapotranspiration reduces when the soil dries. When the soil is wet, the water has high potential energy, and is relatively free to move and is easily taken up by plant roots. In dry soils, the water has low potential energy and is strongly bound by capillary and absorptive forces to the soil matrix, and is less easily extracted by the crop (Allen et al., 1998). Such behavior can be implied with negative f_3. In order to limit the contribution of the second term in equation 1 near saturation f_5 is assumed to be negative. In this state excess water is drained and / or absorbed in the lower layers.

The simulated and observed daily soil water potential for Sofia and Plana Stations are compared on figure 2 and figure 3.

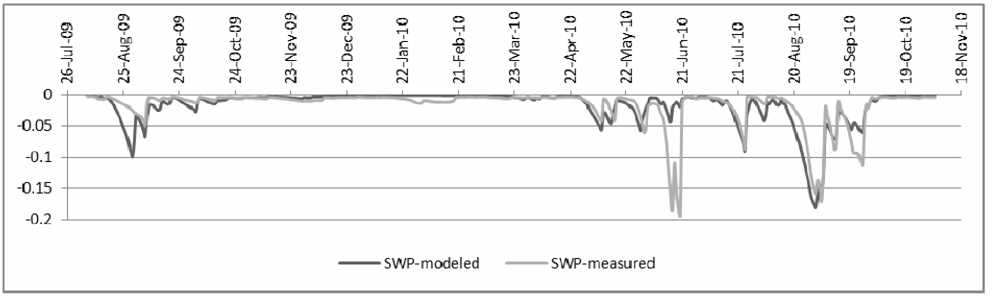

Fig. 2. *SWP* [MPa] - measured and modeled at station Plana

An agreement of the model with measured data at Station Plana is observed during wet seasons. The data shows a gap around mid-June. It is because the *SWP* sensor's readings fall below the range for which it is calibrated to work. An approach to the series during such periods is made as two sixteen days' period series were taken - one of them is during the drought, correctly registered by the sensor from 15 to 31 May 2010 and the other is the one mentioned above - from 4 to 20 June 2010. These periods were selected because they have similarity in microclimatic parameters, especially in precipitated rain. Table 4 gives the average and total amounts for the parameters related to *SWP*. It can be noted that actually evaporated water is about 77% more in the second period. Also, diurnal variations of T_{soil} are significant, and in accordance with the assumptions made before soil should be dry and T_{soil} should have positive trend for the period. Though the amount of rain precipitated is about 43% more, this period is characterized by drought as the average soil temperature shows.

Table 4. Case study of *SWP* at Station Plana

Period	Average Soil Temperature [°C]	Amount Evapotranspiration [mm]	Amount Precipitation [mm]
15May2010-31May2010	11.08	46.71	29.72
04June2010-20June2010	16.25	82.65	42.42

When obtaining values for *SWP* soil temperature is used. For the second interval it is higher, and this may further distort the obtained values. This is especially notable near the boundaries of the scope for which the sensor is calibrated.

As in station Plana, in station Sofia greater diversion of the model with measured data is during the dry periods (figure 3).

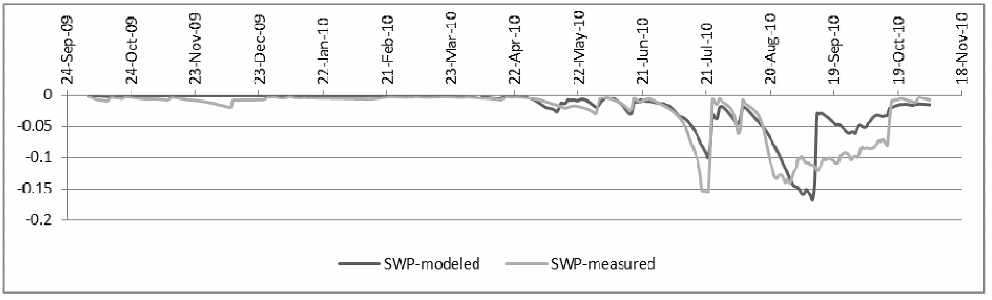

Fig. 3. *SWP* [MPa] – measured and modeled at station Sofia

During the period from end of August until early October there are the most significant differences of modeled and measured values. A detailed look at the two segments of the chart (figure 3) - shows that the match between modeled and measured *SWP* is very good for the first series from 15 June to 22 July 2010, ending with the fall of 1.65 liters rain, and in the second from 05 August to 09 September 2010, ends with a fall of 2.79 liters rain there are significant differences. The main meteorological parameters affecting *SWP* for these periods are shown in table 5.

Table 5. Case study of *SWP* at Station Sofia

Period	Average Soil Temperature [°C]	Amount Evapotranspiration [mm]	Amount Precipitation [mm]
15 June - 22 July 2010	18.73	93.71	46.23
5 August - 9 September 2010	18.72	91.27	8.85

Although both periods start at approximately same conditions (values of *SWP* are approximately -0.01MPa) and have almost the same *ET*, they end at a different conditions. It is due to the different amount of rain for the two periods, and especially its irregularity for the latter. *SWP* as a function of water content has hysteresis, i.e. at the same water content, *SWP* values are different depending on whether the soil is wetting or drying (Childs, 1940; Braddock et al., 2001) and it can be suggested that the behavior of the sensor in the second period is influenced by such effects. Also, the 46.22 mm rain precipitation is scattered in a few periods of rainfall, most of them about 1 mm, which the rain sensor for *SWP* did not detected. This suggests that there is a threshold value for rain precipitation below which that amount precipitated does not lead to wetting of soil and evaporates quickly without penetrating in depth. Almost 3 liters of rain on 09 September 2010 did not change the values of *SWP*. It may be caused by residual effects in the response of the sensor caused by excessive drying or difficulty in releasing the air from soil pores and replacing it with water. The sensor shows an ordinary state with small but regular precipitation in mid-October.

As from the discussion made above, it can be concluded that the built model describes satisfactorily the behavior of the studied characteristic. This is confirmed by the high values of correlation between measured and calculated value of the *SWP* for both stations. Correlation for station Sofia is 0.85 and 0.72 for Station Plana.

Conclusion

Present work combined a classical approach to describe evaporation from underlying surface with water balance in the soil in order to obtain simple parametric model describing the behavior of *SWP*. It depends on the amount of precipitated rain and on incoming short wave solar radiation by means of evapotranspiration. The parameters are set and the model is verified for two different polygons with different soil and microclimate characteristics.

Preliminary analysis of the behavior of *SWP* based microclimatic parameters (mainly T_{soil} and G_{soil}) for both stations is confirmed by the measurements of the *SWP*. Such behavior has the constructed model. The verification showed that it correctly describes the periods when the vegetation is not subjected to water stress and thus the leaves stomata are most open. These are the periods in which there is potential for damage of vegetation following the entry of tropospheric ozone in the leaf tissue according to the contemporary understanding on this matter. For this the model can be used to assess potential hazards to plants through a stomatal flux index. Also, it can be used to determine periods of sustained drought and the consequent limitation in the growth and development of vegetation. For that purpose it should be verified with data from a sensor running around and below the permanent wilting point.

The results satisfactorily describe synoptic scale processes, except during summer when the model is unable to represent daily fluctuations of *SWP* due to the simple form of the model, which smoothes the daily course of estimated *SWP*.

Another confirmation of the good match of modeled to measured data is the high value of correlation coefficient between the two series.

Acknowledgments. This work was carried out within the frame of the contract: “City versus Mountain Tropospheric Ozone: The Sofia-Plana region in an air quality and ecological sustainability perspective” - contract DO 02-127/08, National Science Fund at the Ministry of Science and Education, Bulgaria.

References

Allen R.G., Pereira L.S., Raes D., Smith M. (1998) Crop evaporation. Guidelines for computing crop water requirements. *Irrigation and Drainage Paper 56*, FAO, Rome, Italy

Baldocchi, D. (1997) Measuring and modelling carbon dioxide and water vapour exchange over a temperate broad-leaved forest during the 1995 summer drought. *Plant, Cell and Environment*, 20: 1108–1122

Braddock R.D., Parlange J.Y., Lee H. (2001) Application of a Soil Water Hysteresis Model to Simple Water Retention Curves. *Transport in Porous Medi*a, 44: 407–420

Childs E.C. (1940) The use of soil moisture characteristics in soil studies. *Soil Science:October 1940* 50(4): 239-252

Crawford T. M., Bluestein H. B. (2000) An Operational, Diagnostic Surface Energy Budget Model. *Journal of Applied Meteorology*, 39: 1196-1217

Fisher J. B., DeBiase T.A., Ye Qi, Ming Xu, Goldstein A.H. (2005) Evapotranspiration models compared on a Sierra Nevada forest ecosystem. *Environmental Modelling & Software,* 20 783-796

Fredlund D.G., Xing A. (1994) Equations for soil-water characteristics curve. *Canadian Geotechnical Journal*, 31(3): 521-532

Gusev Ye.M., Busarova O.Ye., Nasonova O.N. (1998) Modelling soil water dynamics and evapotranspiration for heterogeneous surfaces of the steppe and forest- steppe zones on a regional scale. *Journal of Hydrology*, 206(3-4): 281-297

Jensen H.E., Jensen K.H., Rosbjerg D. (1991) Plant Water Relationships and Evapotranspiration. Hydrological Interactions Between Atmosphere. *Soil and Vegetation*, IAHS Publ. no. 204

Košková R., Němečková S., Sitková Z. (2008) Assessment of evapotranspiration and soil water content in the Kysuca River basin (Slovakia) using a raifall-runoff model. *2008 IOP Conf. Ser.: Earth Environ*, 4 012002

McNaughton K.G., Black T.A. (1973) A study of evapotranspiration from Douglas fir forest using using the energy balance. *Water Resources Research*., 9(6): 1579-1590

Mintz Y., Walker G. K. (1993) Global Fields of Soil Moisture and Land Surface Evapotranspiration Derived from Observed Precipitation and Surface Air Temperature. *Journal of Climate and Applied Meteorology*, 32: 1305-1334

Monteith (1965) Evaporation and the environment. *XIXth Symposium Society for Experimental Biology* , Academic Press, NY: 205 – 234

Monteith (1981) Evaporation and surface temperature. *Quarterly Journal of the Royal Meteorological Society*, 107(451): 1-27

Penman H.L. (1948) Natural evaporation from open water, bare soil and grass. Proceedings of the Royal Society of London. *Series A, Mathematical and Physical Sciences*, 193(1032): 120-145

Priestley C.H.B., Taylor R.J. (1972) On the assessment of surface heat flux and evaporation using large-scale parameters. *Monthly Weather Review*, 100(2): 81-92

Rana G., Katerji N., Mastrorilli M., El Moujabber M., Brisson N. (1997) Validation of a model of actual evapotranspiration for water stressed soybeans. *Agricultural and Forest Meteorology* 86: 215-224

Schulte R.P.O., Diamond J., Finkele K., Holden N.M., Brereton A.J. (2005) Predicting the soil moisture conditions of Irish grasslands. *Irish Journal of Agricultural and Food Research* 44: 95–110

Stannard, D.I. (1997) Comparison of PenmaneMonteith, ShuttlewortheWallace, and Modified PriestleyeTaylor Evapotranspiration Models for Wildland Vegetation in Semiarid Rangeland. *Water Resources Research*, 29 (5): 1379-1392

Walter I.A., Allen R.G., Elliott R.L., Howell T.A., Itenfisu D., Jensen M.E., Snyder R.L. (2002) The ASCE Standardized Reference Evapotranspiration Equation. *ASCE-EWRI Task Committee Report*

Wetzel P. J. (1986) Concerning the Relationship between Evapotranspiration and Soil Moisture. *Journal of Climate and Applied Meteorology,* 26: 18-27

Zweifel M., Stampli A. (2008) Mechanisms of structural change derived from patterns of seedling emergence and mortality in a semi-natural meadow. *Journal of Vegetation Science* 19: 563-574

Параметризация и верификация на микроклиматичен модел за водният потенциал на почвата. Изследване за станции в София и Плана

В. Данчовски, Д. Иванов, А. Благоев, Е. Донев

Резюме: Цел на настоящата работа е моделирането на поведението на водния потенциал на почвата (ВПП). Моделът представлява нелинейна комбинация от падналия валеж и изпарението. Той е конструиран и изпробван за симулации на ВПП със стъпка по времето един час. Изследванията са извършвани с данни от две станции, разположени в Борисовата Градина в София и на Плана планина за период от над една година. Така създадения модел се верифицира с реално измерените стойности. Симулираните стойности коректно описват поведението на ВПП като известни отклонения се наблюдават само при продължителни засушавания. Създаденият математичен модел може да се използва като средство за симулиране на локалното поведение на ВПП, а от тук и за установяване на периоди на засушаване, за които няма измервания на ВПП. Също така, ВПП е ключов параметър за потока озон през устицата на листата и може да служи за оценка на риска от увреждане на растителността причинено от приземния озон.