ON ESTIMATION OF THE CLIMATIC WETNESS BY USING THE EVAPOTRANSPIRATION DATA

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Climate conditions, thermal and moisture are crucial for cultivated crops. Before to plan about what we could get as crop yield, it is rather to obtain a data on currently existing wetness. It can be used directly observed soil moisture content, but the measurements are difficult and mostly troublesome. Therefore, the agrarian service try to operate with any indices of wetness, often defined by a remote sensing technique. Satellite sensors existed by the time allow to image the radiation budget components (visual or infra-red), the "skin" moisture (micro-wave spectral band) and the VI (vegetation index) for a large area.

Evapotranspiration activity of vegetated crops is a good, integral (and more stable than highly variable soil moisture) index of their growth. Hence, to monitor it based upon remotely sensed data is particularly important for crop agriculture. The same is to be said about the improvement of the technique for evaluating evapotranspiration, that we can be able to do by having obtained the long-term data of special observation (Shutov, 2000).

The radiative wetness index

The so-called radiative wetness index (RWI) has been offered by M. Budyko (1971). It is defined as RWI = R/LP, i.e. as a ratio of the net radiation R and that energy flux LP allowed to evaporate all the precipitation amount (L = 2.51 MJ/kg). There are works (Fedorov, 1978) used this approach to evaluate evaporation for a wide time intervals (months of a growing season). Several observation data (e.g. shown in the **Fig. 1**) compiled long since (Kuz'min *et al*., 1968) enables to estimate evaporation through the following:

$$E/E_0 = A\,(R/LP)^n \qquad (1)$$

where A and n are empirical parameters appropriated to a month: for July A = 0.78 and n = -0.50 (grassland) n = -0.76 (bare soil surface).

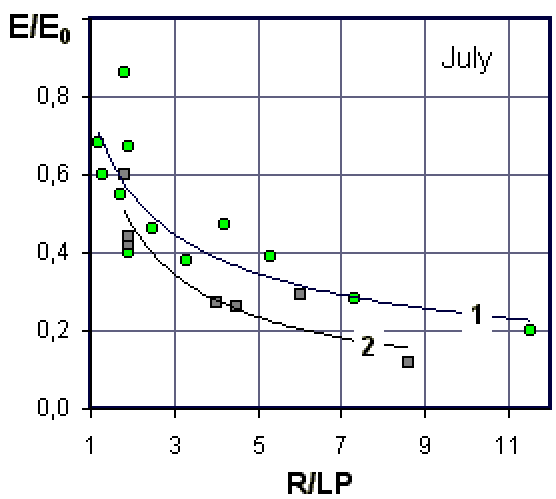

Figure 1. Empirical correlation plot between relative evaporation (E/E_0) and the radiative wetness index (R/LP) for grassland (1) and bare soil (2)

Now the approach may ground a new technique since the RWI would be determined by remote sensing from satellites. The problems of detecting the radiation from satellites are beyond the scope as discussed in a lot of special papers and reports.

The Pristley-Taylor approach

The method of evaluating evaporation is based upon the well know Penman's equation which can be simplified and reduced to the following (Pristley and Taylor, 1972):

$$E_e = \Phi_e R \delta / (\delta + \gamma) \quad (2)$$

where R – net radiation, Φ_e – an empirical factor, δ – derivative of the vapor pressure by air temperature, γ – the psychrometric constant.

Originally, by Pristley and Taylor $\Phi_e = 1.26$. Other estimates vary from 1.08 to 1.42. For the last two decades, the method have become of a great usage (Kane *et al.*, 1990) as required no detailed profile measurements but allowing to apply the remotely sensed net radiation income.

The heat-and-water balance (HWB) method

The HWB-method of evaluating evapotranspiration implies all the basic factors affecting: weather conditions, which are indicated by the potential evaporation E_0, the soil moisture content and the plant cover (bio-physical) features. Accepted is the following equation:

$$E = a \beta E_0 f(W) + kP \quad (3)$$

where a – dimensionless scaling factor, β - ratio of evaporation from a plant cover to that from bare soil determined by long-term studies at Valday, E_0 – potential evaporation, kP – that part of precipitation (P) which is evaporated from plant leaves immediately.

Originally, the method has been proposed by S.I. Kharchenko (1975) to use in agriculture irrigation studies. We only improve it by specifying the relationship between evaporation and soil moisture $f(W)$ and providing with the β-values for several crops (Shutov, 2000).

On the potential evaporation

There are a number of methods of how to evaluate the potential evaporation. One of the widely accepted is so well known Penman's, that is not needed in a formal description. Quite another is the Budyko's (Budyko, 1971) method accepted in Russia, it is based upon that the evaporation from highly wet surface is closely correlates with the R_w/L ratio, where R_w is the radiation budget of the wet surface (open water, soil, grassland and so on).

By examining the water evaporation E_w measured using the pan evaporimeters GGI-3000TM, we have recently found (Shutov, 2003) that $E_w = 0.61R/L$. If so, we can choose either use Penman's or the simplest, ratio of R/L which might be detected by satellite sensors.

The "evaporation – soil moisture" inter-dependence

This relationship, $E/E_0 = f(W)$ grounds many of the calculation procedures such, for instance, as that developed by Budyko (1971), where the $f(W)$-function is accepted linear. Some later multiple evidences have appeared of the non-linear shape of the function. The variances were found divergent so one could tangibly be mistaken of using that unfitted (Jensen, 1986). By the long-term observation at Valday, we have specified the $f(W)$ as follows (Shutov, 2000):

$$f(W) = W^*_{cr}\{1 - [1 - (W^*)^{1/m}]^m\}^2 \quad (4)$$

where $W^* = W/\text{FC}$ and W^*_{cr} is close to the FC ("field capacity" of the soil, that moisture content by which all the movable water has been percolated off the soil layer examined).

Of a great concern are the following: first, the equation (4) quite corresponds to the equation described the soil hydraulic conductivity by R. van Genuchten (1980) with the necessary exponent n = 0.88, second, non-linear shape of the $f(W)$-function as it is shown in the **Fig. 2** may have resulted in an unexpected error in evaluating evaporation by drought.

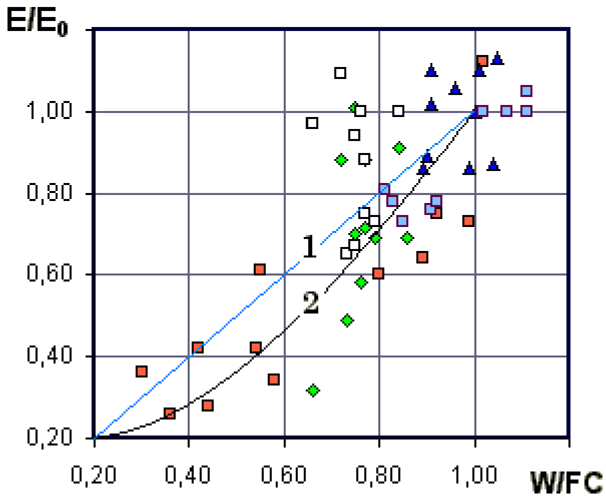

Figure 2. Empirical "evaporation – soil moisture" relationship by observation at Valday, Russia

1 – linear shape accepted in manuals,
2 – the approximation by Eq. (4) captured a non-linear shape of the $f(W)$-function

Simulation results

The HWB-method (Eqs. 3,4) allows to simulate soil moisture content when its initial value is obtained or assumed equal to the field capacity (FC). To evaluate that vertical flux G from saturated zone an empirical correlation between G and ground water level Z was accepted found by (Rogotsky, 1979) as $G = A$ exp (- Z) where A = 1.15 – 1.37 for different vegetation and b = 0.025.

Assumed at W = FC the evaporation $E = a\beta E_0$, which rate is called "optimal" and the difference ($E_0 - E$) determines the crop water deficit or, when $E > E_0$ the water surplus. The difference "precipitation minus evaporation" ($P - E$) serves as another index of wetness. Simulating the wetness indices for several growing seasons enables to assure that both water surplus and drought have occurred for several periods of each season (**Fig. 3**).

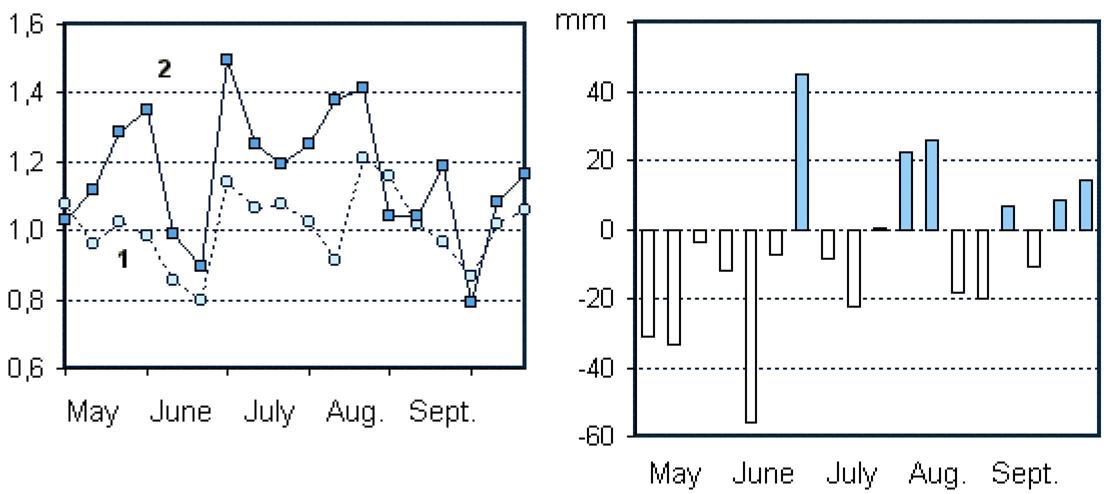

Fig. 3. Simulation of the wetness indices for the 1998 growing season at Valday
Left panel: 1 - W/FC, 2 – E/E_0; right panel: difference ($P - E$).

Discussion and conclusions

Examined the wetness indices for a decade, we can reveal that there are no quite similar years, but each season occurs peculiar. Besides, it seems not possible to wholly estimate the climatic wetness using only one index. It is rather to use all the three above indices together.

For instance, when evaluating are only differences (*P* – *E*), we may infer about a drought in May. However, a look at the soil moisture index (*W*/FC) cannot allow to decide so. Soil moisture content, slightly exceeding the FC is quite enough to vegetation, which growing leaves transpirate so actively that the actual evaporation rate greatly exceeds the potential one. In general, the atmospheric drought by early summer does not entail soil moisture deficit.

Drought due to scanty rainfalls (as in the mid June) leads to decreasing evaporation and soil moisture deficit only a week later. Rainfall abundance has an immediate effect on soil moisture.

Thermal conditions may also be proactive to wetness. So, cool 1988 summer moderates evaporation and the soil moisture deficit in spite of relatively low rainfall amount. The (*P* – *E*) totals increase so (**Table**) that allows to refer to the season as wet.

Table. Water balance components for May – September by different wetness

	P, mm	E_0, mm	E, mm	Σ(P – E), mm
1988	321	477	357	98
1991	452	456	468	57
1998	470	499	572	-101

Summarized the above table, we can assume 1988 as cool and wet by soil moisture, 1991 as wet by rainfalls and 1998 as wet by rainfalls, warm, crop productive and, as such – with the greatest transpiration and, consecutively, tending to be dry by the atmospheric wetness index. Hence, all-round assessment can be done by using three indices: atmospheric (*P* – *E*), "evaporative" (E/E_0) and soil moisture index (*W*/FC).

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