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SENSITIVITIES OF CROP EVAPOTRANSPIRATION MODELS TO INPUT DATA

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ABSTRACT
Weather conditions, crop characteristics, environmental aspects and management are factors affecting evaporation and transpiration. This paper presents a sensitivity analysis of crop evapotranspiration models with regard to meteorological data and crop coefficients. The analysis of the evapotranspiration is done using two models. The first is based on the Penman-Monteith method. The second uses a procedure where the Bowen ratio is used in the computation. For both of these approaches the sensitivity analysis is applied for estimating the influences of individual observed inputs on the rate of evapotranspiration. The results of the observed data, recorded in the southern part of Czech Republic, was compared and discussed. The data was transferred from the measuring stations via the Internet browser and processed in the Matlab program environment. This paper contains several figures and tables which demonstrate the achieved results.
Keywords: sensitivity analysis, model, evapotranspiration

1. INTRODUCTION
Evapotranspiration (ET) is the term used to describe the combined process of water loss both from the soil surface by evaporation and the crops by transpiration. More than half of the water that enters the soil is returned to the atmosphere through evapotranspiration. The rate and amount of evapotranspiration is basic information needed to design irrigation projects. It is also essential for water quality management and other environmental concerns.
The principal factors affecting the rate of evapotranspiration are:
a) Weather parameters: solar radiation, air temperature, humidity, wind speed, etc.
b) Crop factors: crop height variations, crop roughness, reflection, ground cover, crop rooting, resistance to transpiration, etc.
c) Management and environmental conditions: soil salinity, land fertility, soil water content, plant density, etc.

2. ANLYSIS OF EVAPOTRANSPIRATION
There are several methods available for measuring evapotranspiration. Since vapour flux is difficult to measure directly evapotranspiration is often estimated using indirect methods [1]. Many of these indirect methods have been developed for estimating evapotranspiration from measured climatic data. In our case we used two methods for ET estimation: the Penman-Monteith method (PM method) and the method where the Bowen ratio is used (BR method) [1, 2, 4, 5]. Both of these methods are based on the fact that the evaporation of water requires relatively large amounts of energy. The energy incoming to the evaporation surface must equal the energy leaving the surface in the same time period and therefore

$$Rn = G + L \cdot E + H + Ph + Ca \qquad (1)$$

where R_n is the intensity of the net radiation $[W \cdot m^{-2}]$ i.e. the difference between incoming and outgoing radiation of both short and long wavelengths, G is the intensity of the soil heat flux $[W \cdot m^{-2}]$, L is the latent heat of vaporization $[J \cdot kg^{-1}]$, E is the intensity of evapotranspiration $[kg \cdot m^{-2} \cdot s^{-1}]$, H is the intensity of the sensible heat flux $[W \cdot m^{-2}]$, Ph is the intensity of the heat flux consumed on photosynthesis $[W \cdot m^{-2}]$ and Ca is the intensity of the biomass thermal capacitance change $[W \cdot m^{-2}]$. Since Ph and Ca are much less than the other factors they are negligible.

Net radiation (Rn) and soil heat (G) fluxes can be measured or estimated from climatic parameters. However measurements of the sensible heat (H) are complex and cannot be easily obtained. Table 1 shows the measured inputs which were used for ET estimation for both of the methods.

Table 1. Measured inputs for ET estimation with the sample interval 10 min (Y – yes, N – no)

Notation	Meaning	PM method	BR method
Rh_{zp}	relative humidity at the height z_p [%]	Y	Y
Rh_z	relative humidity at the height z [%]	Y	Y
$Rs\downarrow$	downward shortwave radiation [W.m^{-2}]	Y	Y
$Rs\uparrow$	shortwave radiation reflected by the surface [W.m^{-2}]	Y	Y
T_0	soil temperature at the depth of 0 m [^{0}C]	Y	Y
T_{01}	soil temperature at the depth of 0.1 m [^{0}C]	Y	Y
T_{02}	soil temperature at the depth of 0.2 m [^{0}C]	Y	Y
T_{zp}	air temperature at the height z_p [^{0}C]	Y	Y
T_z	air temperature at the height z [^{0}C]	Y	Y
Th	soil water content [%]	Y	Y
X_o	soil organic content in soil [%]	Y	Y
X_m	mineral content [%]	Y	Y
Z	altitude [m]	Y	Y
u_z	wind speed at z m above the ground surface [m.s^{-1}]	Y	N
z_p	crop height [m]	Y	N
z	height measurements above crops [m]	Y	Y

The intensity of the latent heat flux LE $[W.m^{-2}]$

$$LE = L \cdot E \tag{2}$$

was calculated using

a) the BR method

$$LE_{BR} = \frac{Rn - G}{1 + \beta}, \tag{3}$$

where for the Bowen ratio β holds

$$\beta = \frac{H}{LE} = \gamma \cdot \frac{\Delta T}{\Delta e}, \tag{4}$$

where γ is the psychrometric constant, ΔT is the difference in air temperature between two levels, Δe is the difference in specific humidity between two levels.

b) the PM method

$$LE_{PM} = \frac{\Delta \cdot (Rn - G) + \dfrac{\rho_a \cdot c_p \cdot (e_s - e_a)}{r_a}}{\Delta + \gamma \cdot \left(1 + \dfrac{r_s}{r_a}\right)} \tag{5}$$

where Rn is the intensity of the net radiation, G is the intensity of the soil heat flux, $(e_s - e_a)$ is the saturation vapour pressure deficit, r_a is the aerodynamic resistance, r_s is the surface resistance, c_p is

the specific heat of the air, ρ_a is the air density, Δ represents the slope of the saturation vapour pressure temperature relationship.
For both methods the intensity of evapotranspiration E was calculated using

$$E = \frac{LE}{L} \tag{6}$$

Figure 1 shows the course intensities of net radiation flux (Rn), heat flux (G) and latent heat fluxes (LE_{BR}, LE_{PM}), which were estimated using the both methods on the basis of the measured inputs (see Tab.1) and with the help of direct or empirical relationships. The input data was obtained by a Internet browser from Fiedler-Magr database. The data was measured from 16th to 18th September 2007 in a meadow called "Cirkvičná", which is located near the town of Třeboň in southern Bohemia. Figure 3 shows the meteostation, which was used for reliable retrieval of agro-meteorological data.

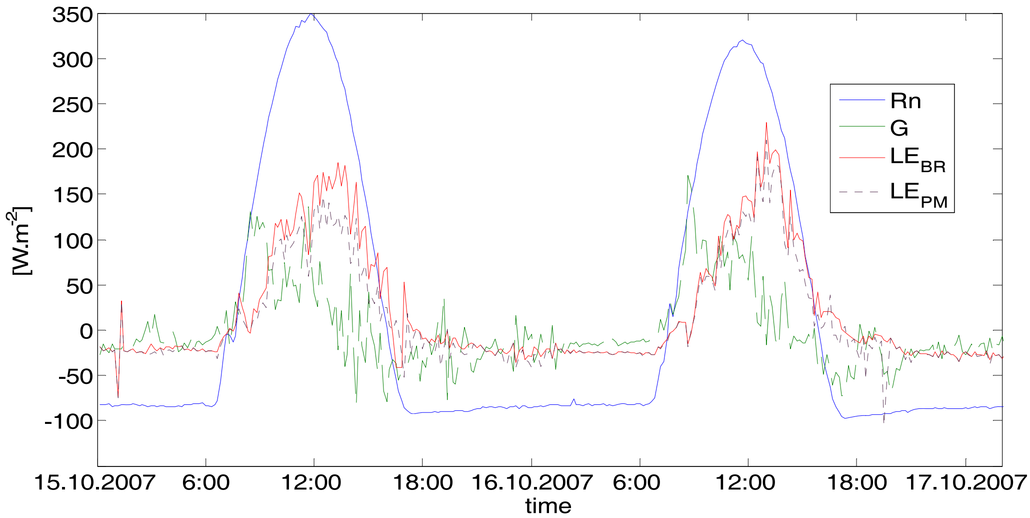

Figure 1. The course intensities of net radiation flux (Rn), heat flux (G) and latent heat fluxes (LE_{BR}, LE_{PM})

Figure 2. The meteostation in "Církvičná"

The both intensities of evapotranspiration estimated using the BR method (denoted by E_{BR}) and using the PM method (denoted by E_{PM}) for the same inputs are demonstrated in the Figure 2. As the Bowen ratio energy balance method often produces totally unacceptable sensible and latent heat fluxes the calculations were completed by the filter described in [5].
Sensitivity analysis is important in understanding the relative importance of climatic variables to the variation of evapotranspiration. For multi-variable models (e.g. the PM method and BR method) different variables have different dimensions and different ranges of values, which make it difficult to compare the sensitivity by partial derivatives [3]. Consequently the partial derivative is transformed into a non-dimensional form

$$c_{x_i} = \lim_{\Delta x_i \to 0} \frac{\frac{\Delta E}{E}}{\frac{\Delta x_i}{x_i}} = \frac{\partial E}{\partial x_i} \cdot \frac{x_i}{E} \quad (7)$$

where c_{x_i} is the "non-dimensional relative sensitivity coefficient" and x_i is the reference value of the i th variable. Practically the relative sensitivity coefficient is accurate enough to represent the slope of the sensitivity curve within a certain "linear range" around the reference point. From this sensitivity analysis was found out that the most important factors for the rate of transpiration are the relative humidity, the shortwave radiation, the air temperature and the wind speed. The enumeration was realized for different reference points in the Matlab program environment with the help of Symbolic Math Toolbox from the MathWorks, Inc.

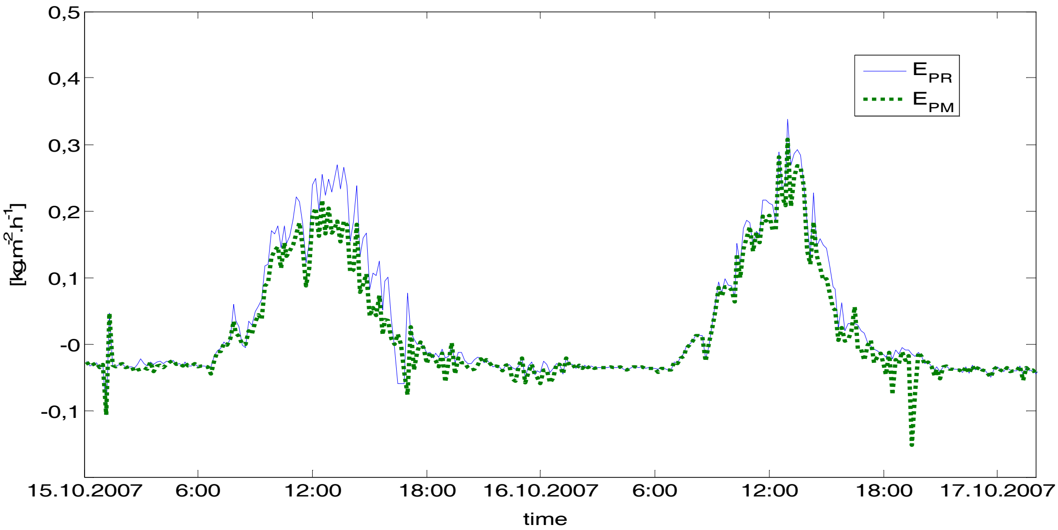

Figure 3. The rate of evapotranspiration E_{BR} and E_{PM}, i.e. using BR method and PM method

3. CONCLUSION

The inputs given in Table 1 are observed only in the limited number of localities because meteorological stations, where most of these parameters are measured, are placed very rarely. To improve the estimate of evapotranspiration in some localities the information from the meteorological stations will be completed by images from a thermocamera. The thermocamera with computer remote control will be placed on an airship. The photography scanned from the airship is possible to carry out within low altitude so that it can be ensured high resolution about 5 – 10 cm /pixel. The sensitivity analysis will be further used for the suggestion of new sensors and the reduction of measuring uncertainties.

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