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Sensitivity analysis of the evaporation module of the E-DiGOR model

Mehmet AYDIN[1,*], Suzan Filiz KEÇECİOĞLU[2]

[1]Department of Soil Science, Faculty of Agriculture, Mustafa Kemal University, TR-31040, Hatay - TURKEY

[2]Technical Training College of Antakya, Mustafa Kemal University, TR-31040, Hatay - TURKEY

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Abstract: Sensitivity analysis of the soil-water-evaporation module of the E-DiGOR (Evaporation and Drainage investigations at Ground of Ordinary Rainfed-areas) model is presented. The model outputs were generated using measured climatic data and soil properties. The first-order sensitivity formulas were derived to compute relative sensitivity coefficients.

A change in the net solar radiation significantly affected potential evaporation from bare soils estimated by the Penman-Monteith equation. The sensitivity coefficients were positive, with a mean value of 0.82. The sensitivity of potential soil evaporation to soil heat flux was lower during the summer months and higher during the winter. The gradient of saturated vapour pressure–temperature curve increased or decreased the potential evaporation rates because of the occurrence of the gradient variable in both the numerator and denominator of the equation. Increases in the vapour pressure deficit increased the evaporation and its effect was more pronounced in the winter. In the case of aerodynamic resistance, the coefficients were constantly negative, and became more negative in the winter, which means a negative correlation between the input and output.

In Aydın's equation, the dependent variable (actual soil evaporation) was initially very sensitive to a change in the water potential of a wet soil. The sensitivity decreased progressively during the drying period. The coefficients related to the absolute values of soil water potential were constantly negative, with a mean value of –0.19. The sensitivity of actual soil evaporation to air-dry water potential remained low in the wet soil and was higher in the drier soil. The sensitivity coefficient to measure the impact of potential evaporation on actual evaporation did not change during the study. According to Aydın and Uygur's equation, potential soil evaporation greatly affected the output (soil water potential) in the wet soils. In Kelvin's equation, increases in air temperature increased the absolute value of water potential at air-dryness. The sensitivity coefficients, owing to relative humidity, showed a great deal of fluctuation.

Key words: E-DiGOR model, sensitivity analysis, soil evaporation

E-DiGOR modelindeki buharlaşma modülünün duyarlılık analizi

Özet: Bu çalışmada E-DiGOR (Evaporation and Drainage investigations at Ground of Ordinary Rainfed-areas) modelinin toprak -suyunun- buharlaşması modülü için bir duyarlılık analizi sunulmaktadır. Model çıktıları, gözlemlenen iklim verileri ve toprak özellikleri kullanılarak üretilmiştir. Göreceli duyarlılık katsayılarını hesaplamak için birinci-derece duyarlılık formülleri türetilmiştir.

* E-mail: maydin@mku.edu.tr

Net solar radyasyondaki herhangi bir değişim, Penman-Monteith Eşitliği yardımıyla çıplak topraklar için tahmin edilen potansiyel buharlaşmayı önemli ölçüde etkilemiştir. Buna ilişkin duyarlılık katsayıları pozitif değerler almış ve ortalaması 0.82 bulunmuştur. Potansiyel toprak -suyu- buharlaşmasının toprak ısı akısına olan duyarlılığı yaz aylarında daha düşük, kışın daha yüksek bulunmuştur. Eşitliğin hem pay hem de paydasında yer alan bir değişken olması nedeniyle doygun buhar basıncı-sıcaklık eğrisinin eğimi, potansiyel buharlaşma oranlarını arttırabilmiş veya azaltabilmiştir. Buhar basıncı açığı, buharlaşmayı arttırmış ve bu etki kış aylarında daha çok belirginleşmiştir. Aerodinamik dirence ilişkin duyarlılık katsayıları, kış mevsiminde daha çok açılmak üzere sürekli olarak negatif değerler almış ve bu durum girdiler ile çıktılar arasında negatif bir ilişki olduğunu ortaya koymuştur.

Aydın Eşitliğindeki bağımlı değişken yani topraktan oluşan gerçek buharlaşma, ıslak bir toprağın su potansiyelindeki değişime başlangıçta çok duyarlılık göstermiştir. Toprak kurudukça, bu duyarlılık tedricen azalmıştır. Toprak su potansiyelinin mutlak niceliklerine ilişkin duyarlılık katsayıları –0.19'luk bir ortalama ile sürekli negatif değerler almışlardır. Gerçek buharlaşmanın hava-kurusu toprak su potansiyeli değişkenine olan duyarlılığı, ıslak toprak koşullarında düşük, daha kuru toprakta yüksek olmuştur. Potansiyel buharlaşmanın gerçek buharlaşma üzerindeki etkisini gösteren duyarlılık katsayısı, çalışma süresince değişmemiştir. Aydın ve Uygur Eşitliğine göre, potansiyel toprak buharlaşması ıslak topraklarda çıktı değerlerini (toprak su potansiyelini) büyük ölçüde etkilemiştir. Kelvin Eşitliğinde ise hava sıcaklığındaki artışlar, hava-kurusu toprak su potansiyelinin mutlak değerlerini arttırmıştır. Oransal neme ilişkin duyarlılık katsayıları büyük bir dalgalanma göstermişlerdir.

Anahtar sözcükler: E-DiGOR modeli, duyarlılık analizi, topraktan buharlaşma

Introduction

Loss of water from the soil surface through evaporation is often a major component in the soil-water balance of agricultural systems in semi-arid regions. Therefore, soil-water loss by evaporation should be assessed. In the assessment of soil-water balance in a bare soil, how to account the evaporation rates in modelling often poses a dilemma (Önder et al. 2009). The models usually use potential evaporation (E_p), mainly a physical concept that lacks a clear definition for soil conditions. In other words, soil evaporation is modelled by limiting potential evaporation (e.g., from Penman–Monteith) with soil and/or aerodynamic resistances, although newer approaches (e.g., Aydın's equation) derive soil evaporation successfully from soil water potential (Aydın et al. 2005; Falge et al. 2005). Aydın's approach is based on energy fluxes and soil properties, and experimental data are used to define a threshold separating the potential-rate and falling-rate stages of evaporation (Quevedo and Frances 2007; Romano and Giudici 2007). More recently, Aydın (2008) presented an interactive way (called the E-DiGOR model by the author) for predicting daily actual soil evaporation (E_a), soil water storage, and drainage rates, if any (Önder et al. 2009).

In models involving many input variables, sensitivity analysis (SA) is an essential ingredient of model building and quality assurance. It is a valuable tool for identifying important model parameters, testing the model conceptualisation, and improving the model structure (Sieber and Uhlenbrook 2005). In other words, SA is the study of how the variation in the output of a model (numerical or otherwise) can be apportioned, qualitatively or quantitatively, to different sources of variation. There are several possible procedures to perform uncertainty and sensitivity analyses. The most common SA is sampling-based (http://www.wikipedia.org/). In general, the sensitivity of a model depends on the quality of input variables and parameter values of interest in the standard calculation. First, the model and the standard parameter values should be described. Second, the ranges of parameters values are selected and sensitivity to the various parameters is demonstrated (Boesten 1991). For example, Alvenas and Jansson (1997) performed a sensitivity analysis of a model for soil evaporation, and selected 3 variables affecting soil surface moisture and temperature. In this study, sensitivity analyses for the soil evaporation module of the E-DiGOR (Evaporation and Drainage investigations at Ground of Ordinary Rainfed-areas) model were carried out to explore the changes in output due changes in any inputs.

Underlying theoretical background

Beven (1979) made a sensitivity analysis of the Penman-Monteith equation for cropped surfaces. For example, the sensitivity of actual evapotranspiration,

E_t, calculated by the Penman-Monteith equation to changes in a parameter value or input variable, p_i, is expressed as follows:

$E_t = f(p_1, p_2, p_3, \ldots, p_N)$,

where N is the number of parameters and input variables. Then:

$E_t + \Delta E_t = f(p_1 + \Delta p_1, p_2 + \Delta p_2, p_3 + \Delta p_3, \ldots, p_N + \Delta p_N)$

Expanding on the above equation in a Taylor series and ignoring the second-order terms and above leads to the following equation (Beven 1979):

$$\Delta E_t = \frac{\partial E_t}{\partial p_1}\Delta p_1 + \frac{\partial E_t}{\partial p_2}\Delta p_2 + \frac{\partial E_t}{\partial p_3}\Delta p_3 + \ldots\ldots\ldots + \frac{\partial E_t}{\partial p_N}\Delta p_N$$

where the differentials ($\partial E_t/\partial p_i$) define the sensitivity of the estimate to each parameter or variable. A sensitivity index can be calculated for a small change in any variable, while the other parameters are held constant (van Griensven et al. 2006). These sensitivity coefficients are, in themselves, sensitive to the relative magnitudes of E_t and p_i. According to most of the related literature on SA, the way to do this is by computing derivatives (Saltelli et al. 2004; Cariboni et al. 2007; Huang and Yeh 2007; Masada and Carmel 2008). Then normalised, local, and first-order sensitivity of E_t to p_i may be determined, and a non-dimensional relative sensitivity is defined as follows (McCuen 1974; Beven 1979; Ginot et al. 2006; Norton 2008):

$$S_i = \frac{\partial E_t}{\partial p_i} \times \frac{p_i}{E_t}$$

S_i now represents that fraction of the change in p_i that is transmitted to change in E_t, i.e. an S_i value of 0.1 would suggest that a 10% increase in p_i may be expected to increase E_t by 1%. Negative coefficients would indicate that a reduction in E_t will result from an increase in p_i. The sensitivity coefficients may vary with differential time steps depending on the current value of all p_i and the value of E_t. The last equation remains sensitive to the magnitudes of E_t and p_i, in particular, the relative sensitivity coefficients (S_i) may not be a good indicator of the significance of the p_i if either E_t or p_i tend to zero independently, or if the range of values taken by p_i is small in relation to its magnitude (Beven 1979).

In practice, the partial derivatives are calculated as the differences between original (reference) and new parameters and state variables, in incremental ratios (Masada and Carmel 2008). However, sensitivity methods based on local derivatives do not reflect model behaviour over the whole range of input variables, whereas methods based on standardised regression or correlation coefficients cannot detect non-linear and non-monotonic relationships between model input and output (Hamm et al. 2006). In the OAT (One factor-At-a-Time) approach proposed by Morris (1991), local sensitivities get integrated to a global sensitivity measure. On the other hand, Monte Carlo methods have been widely used in sensitivity analyses of environmental models, but may require a large number of simulations and consequently large computational resources (Lim et al. 1989; Sieber and Uhlenbrook 2005; van Griensven et al. 2006). In deterministic models, the outcome of a specific set of parameters is essentially the same for the same initial conditions. In contrast, in stochastic models, the computation of sensitivity involves the comparison of 2 distributions rather than 2 single values (Masada and Carmel 2008).

Materials and methods

Derivation of formulas for relative sensitivity

Potential evaporation rates from bare soils were calculated by the Penman-Monteith equation with a surface resistance of zero (Allen et al. 1994; Wallace et al. 1999; Aydın et al. 2005) using standard data of the meteorological stations:

$$E_p = \frac{\nabla \times (R_n - G_s) + \dfrac{(86.4 \times \rho \times c_p \times \delta)}{r_a}}{\lambda \times (\nabla + \gamma)} \quad (1)$$

where E_p is potential soil evaporation (kg m^{-2} day^{-1} ≅ mm day^{-1}), ∇ is the gradient of the saturated vapour pressure-temperature curve (kPa °C^{-1}), R_n is the net radiation (MJ m^{-2} day^{-1}), G_s is the soil heat flux (MJ m^{-2} day^{-1}), ρ is the air density (kg m^{-3}), c_p is the specific heat of air (kJ kg^{-1} °C^{-1} = 1.013), δ is the vapour pressure deficit of the air (kPa), r_a is the aerodynamic resistance (s m^{-1}), λ is the latent heat of vaporisation (MJ kg^{-1}), γ is the psychrometric constant (kPa °C^{-1}), and 86.4 is the factor for conversion from kJ s^{-1} to MJ day^{-1}.

The formulas calculating the relative sensitivity coefficients of the variables in Equation (1) are as follows:

$$a)\ S_{\nabla} = \frac{\partial E_p}{\partial \nabla} \times \frac{\nabla}{E_p} = \frac{1}{1 + \frac{86.4 \times \rho \times c_p \times \delta / r_a}{\nabla \times (R_n - G_s)}} - \frac{1}{1 + \frac{\gamma}{\nabla}}$$

$$b)\ S_{R_n} = \frac{\partial E_p}{\partial R_n} \times \frac{R_n}{E_p} = \frac{\nabla \times R_n}{\nabla \times (R_n - G_s) + 86.4 \times \rho \times c_p \times \delta / r_a}$$

$$c)\ S_{G_s} = \frac{\partial E_p}{\partial G_s} \times \frac{G_s}{E_p} = \frac{-\nabla \times G_s}{\nabla \times (R_n - G_s) + 86.4 \times \rho \times c_p \times \delta / r_a}$$

$$d)\ S_{\partial} = \frac{\partial E_p}{\partial \delta} \times \frac{\delta}{E_p} = \frac{1}{\frac{\nabla \times (R_n - G_s)\, r_a}{86.4 \times \rho \times c_p \times \delta} + 1}$$

$$e)\ S_{r_a} = \frac{\partial E_p}{\partial r_a} \times \frac{r_a}{E_p} = \frac{-1}{\frac{\nabla \times (R_n - G_s) \times r_a}{86.4 \times \rho \times c_p \times \delta} + 1}$$

Actual evaporation rates were computed using Aydın's equation (Aydın et al. 2008):

$$E_a = \frac{\mathrm{Log}|\psi| - \mathrm{Log}|\psi_{ad}|}{\mathrm{Log}|\psi_{tp}| - \mathrm{Log}|\psi_{ad}|} \times E_p \qquad (2)$$

where E_a and E_p are actual and potential evaporation rates (mm day^{-1}), respectively, $|\psi_{tp}|$ is the absolute value of soil water potential (matric potential) at which actual evaporation starts to drop below potential one, $|\psi_{ad}|$ is the absolute values of soil water potential at air-dryness, and $|\psi|$ is the absolute values of soil water potential. The values of all ψ are in centimetres of water.

The sensitivity coefficients based on the partial derivatives for Equation (2) are as follows:

$$a)\ S_{\psi} = \frac{\partial E_a}{\partial \psi} \times \frac{\psi}{E_a} = \frac{\psi}{\ln 10 \times |\psi| \times (\mathrm{Log}|\psi| - \mathrm{Log}|\psi_{tp}|)}$$

$$b)\ S_{\psi_{ad}} = \frac{\partial E_a}{\partial \psi_{ad}} \times \frac{\psi_{ad}}{E_a} = \frac{1}{\ln 10} \times \left(\frac{-1}{\mathrm{Log}|\psi| - \mathrm{Log}|\psi_{ad}|} + \frac{1}{\mathrm{Log}|\psi_{tp}| - \mathrm{Log}|\psi_{ad}|} \right)$$

$$c)\ S_{E_p} = \frac{\partial E_a}{\partial E_p} \times \frac{E_p}{E_a} = 1$$

$$d)\ S_{\psi_{tp}} = \frac{\partial E_a}{\partial \psi_{tp}} \times \frac{\psi_{tp}}{E_a} = \frac{-1}{\ln 10 \times \left(\mathrm{Log}|\psi_{tp}| - \mathrm{Log}|\psi_{ad}|\right)}$$

To estimate $|\psi|$, Aydın and Uygur's equation can be used (Aydın 2008; Aydın et al. 2008):

$$\psi = -[(1/\alpha)\ (10\Sigma E_p)^3 / 2(\theta_{fc} - \theta_{ad})\ (D_{av}\ t/\pi)^{1/2}] \qquad (3)$$

where ψ is soil water potential (cm of water) at the top surface layer, α is a soil-specific parameter (cm) related to flow path tortuosity in the soil, ΣE_p is cumulative potential soil evaporation (cm), and θ_{fc} and θ_{ad} are average-volumetric water content (cm^3 cm^{-3}) at field capacity and air-dryness, respectively. D_{av} is average hydraulic diffusivity (cm^2 day^{-1}), t is the time since the start of evaporation (days), and π is 3.1416.

The relative sensitivity of $|\psi|$ to input variables in Equation (3) is as follows:

$$a)\ S_{E_p} = \frac{\partial \psi}{\partial E_p} \times \frac{E_p}{\psi} = \frac{30E_p}{10\Sigma E_p}$$

$$b)\ S_{D_{av}} = \frac{\partial \psi}{\partial D_{av}} \times \frac{D_{av}}{\psi} = -1/2$$

c) $S_{\theta_{fc}} = \frac{\partial \psi}{\partial \theta_{fc}} \times \frac{\theta_{fc}}{\psi} = - \frac{\theta_{fc}}{(\theta_{fc} - \theta_{ad})}$

d) $S_{\theta_{ad}} = \frac{\partial \psi}{\partial \theta_{ad}} \times \frac{\theta_{ad}}{\psi} = \frac{\theta_{ad}}{(\theta_{fc} - \theta_{ad})}$

e) $S_{\alpha} = \frac{\partial \psi}{\partial \alpha} \times \frac{\alpha}{\psi} = - 1$

For $|\psi_{ad}|$, Kelvin's equation can be employed (Brown and Oosterhuis 1992; Aydın 2008):

$$\psi_{ad} = \frac{R_g T}{mg} \ln H_r \quad (4)$$

where ψ_{ad} is the water potential for air-dry conditions (cm of water), T is the absolute temperature (K), g is the acceleration due to gravity (981 cm s^{-2}), m is the molecular weight of water (0.01802 kg mol^{-1}), H_r is the relative humidity of the air (fraction), and R_g is the universal gas constant (8.3143×10^4 kg cm^2 s^{-2} mol^{-1} K^{-1}).

The relative sensitivity of $|\psi_{ad}|$ to input variables in Equation (4) are as follows:

a) $S_T = \frac{\partial \psi_{ad}}{\partial T} \times \frac{T}{\psi_{ad}} = 1$

b) $S_{H_r} = \frac{\partial \psi_{ad}}{\partial H_r} \times \frac{H_r}{\psi_{ad}} = \frac{1}{\ln H_r}$

Climate data and soil properties

The climate data were obtained from Adana Meteorological Station (Turkey) for the study year of 2006 (Table 1). The soil properties used in the model were as described by Aydın (2008). The soil texture is fine with sand of 331, silt 122, and clay 547 g kg^{-1} of soil mass at the layer of 0-40 cm. Dry bulk density varies between 1.20 and 1.27 g cm^{-3}. On average, volumetric water content at field capacity is 0.35 cm^3 cm^{-3}. In this study, albedo of the bare soil was assumed to be 0.15 (van Dam et al. 1997; Ács 2003). In the calculations of soil water potential, tortuosity parameter (α), which can be defined as the actual round about flow path, for the clay soil was taken as 1.1 cm. The volumetric water content at air-dry condition and hydraulic diffusivity were assumed to be 0.05 cm^3 cm^{-3} and 95 cm^2 day^{-1}, respectively. As suggested by Aydın (2008), ψ_{tp} for the clay soil was taken as 60.0 cm of water.

Computation of relative sensitivity coefficients

In the simplest form, a first-order Taylor series approximation requires computing the model output at a single point and determining the derivative (van Griensven et al. 2006). Therefore, the daily model outputs were calculated by using measured climatic data and soil properties for the entire year of 2006. Then the relative sensitivity coefficients for the selected variables were determined based on partial

Table 1. Some monthly climatic data of Adana for the study year of 2006.

Month	Mean temperature (°C)	Mean relative humidity (%)	Mean duration of sunshine (h day^{-1})	Mean wind speed (m s^{-1})	Rainfall (mm)
January	8.8	62.9	4.4	1.6	36.3
February	10.5	63	3.4	1.6	131.6
March	14.1	76.4	5.1	1.3	46.2
April	18.5	76.2	4.3	1.2	9.3
May	22.4	69	10.4	1.1	19.7
June	26	73.2	10.6	1.2	4.5
July	27.9	78.8	10	1.1	41.3
August	29.1	78.9	9.5	1.1	5.7
September	26.2	67.7	8.7	1	37.4
October	21.5	70.8	6.7	0.9	156.3
November	13.2	65.1	6.5	0.9	91.5
December	9.3	57.7	6.9	1.2	0

derivatives. In other words, sensitivity coefficients, as defined by equations given in the sub-section "Derivation of formulas for relative sensitivity", were calculated on a daily basis for the study periods to cover the entire possible range of the input variable values. However, the magnitude of this measure of sensitivity is only relative (i.e. change in model output due a change in model input). In order to give the readers an idea of the importance of input variables, the relative sensitivity coefficients were pooled for each variable and the average values of the coefficients and their confidence limits were determined (Spiegel 1961).

Results

The values of potential soil evaporation estimated by the Penman-Monteith equation for the bare soil surface throughout the study period are plotted in Figure 1 together with the relative sensitivity coefficients. The daily sensitivity coefficients exhibited a seasonal variation. Actual soil evaporation estimated by Aydın's equation for the bare soil during a period of 34 days and the sensitivity coefficients are given in Figure 2. Predicted soil water potential and its relative sensitivity to potential soil evaporation are presented in Figure 3. Water potential at air-dryness and its sensitivity to air-humidity during the first-half of the year are depicted in Figure 4. It can be seen from the figures that the coefficients varied daily depending on the values of all input variables and outputs. The mean values of the coefficients together with their confidence limits (Spiegel 1961) are given in Table 2.

Discussion

According to the Penman-Monteith equation, all the sensitivity coefficients were relatively stable when potential soil evaporation was the highest (Figure 1). As indicated by van Griensven et al. (2006), local techniques concentrate on estimating the local impact of a parameter on the model output. This means that the analysis focuses on the impact of changes in a certain parameter value. A change in net radiation (R_n) significantly affected the output (E_p) of the Penman-Monteith model used for bare soil. In other words, the E_p estimates were very sensitive to R_n, with a mean value of 0.82 (Table 2). This confirms that the radiation term is generally dominant over the aerodynamic term in the prediction equation as reported by Beven (1979). The sensitivity to G_s was small during the summer season. However, G_s had a significant impact during the winter months when net radiation was low. The slope of saturated vapour pressure–temperature curve (∇) increased or decreased the value of E_p. The changes in S_∇ between positive and negative values were the result of the occurrence of ∇ in both the numerator and denominator of the Penman-Monteith equation. The effects of the vapour pressure deficit (δ), which increases the evaporation, reached higher levels during the winter months. In the case of Sr_a, the values constantly had a negative sign. However, the pattern of yearly change in Sr_a was becoming more negative during the winter days. Our results are not directly comparable to those of other sensitivity analyses since the predictions for vegetation surfaces (Beven 1979; Saxton 1975) or open-water surfaces (McCuen 1974) were considered in the other available papers. However, all studies (McCuen 1974; Saxton 1975; Coleman and DeCoursey 1976; Beven 1979) showed that potential evaporation/evapotranspiration was much more sensitive to radiation, humidity, and temperature. In addition, Piper (1989) emphasised that the sensitivity of Penman estimates of evaporation to input variables could have seasonal fluctuations.

In Aydın's equation, the dependent variable (E_a), was initially very sensitive to a change in the $|\psi|$ value; hence a change in $|\psi|$ significantly affected the E_a rate in the wet soil (Figure 2). The sensitivity decreased progressively during the drying period. The coefficients were constantly negative, with a mean value of −0.19 (Table 2), and exhibited a regular pattern during the study period. In contrast, the values of $S|\psi_{ad}|$ remained small in the wet soil and became higher in the drier soil. The sensitivity coefficient used to measure the effect of potential (E_p) on actual evaporation (E_a) was observed to be a constant value. From the equation of Aydın and Uygur (Aydın et al. 2008), it was clear that in the wet soils E_p greatly affected the output of the model, ψ (Figure 3). However, in Kelvin's equation, it was observed that an increase in the absolute temperature

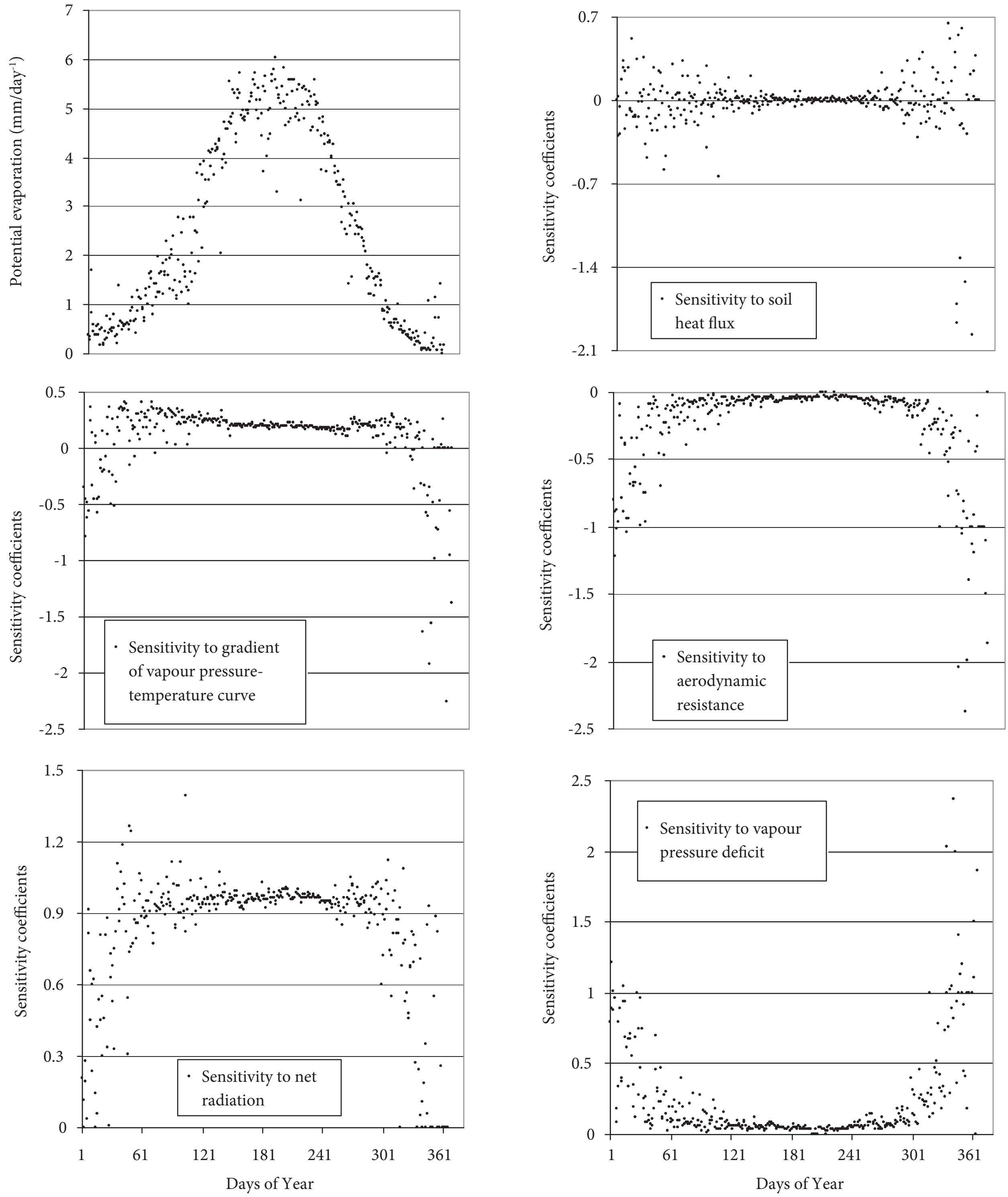

Figure 1. Predicted potential evaporation from bare soil and its relative sensitivity to input variables in Adana during the year of 2006.

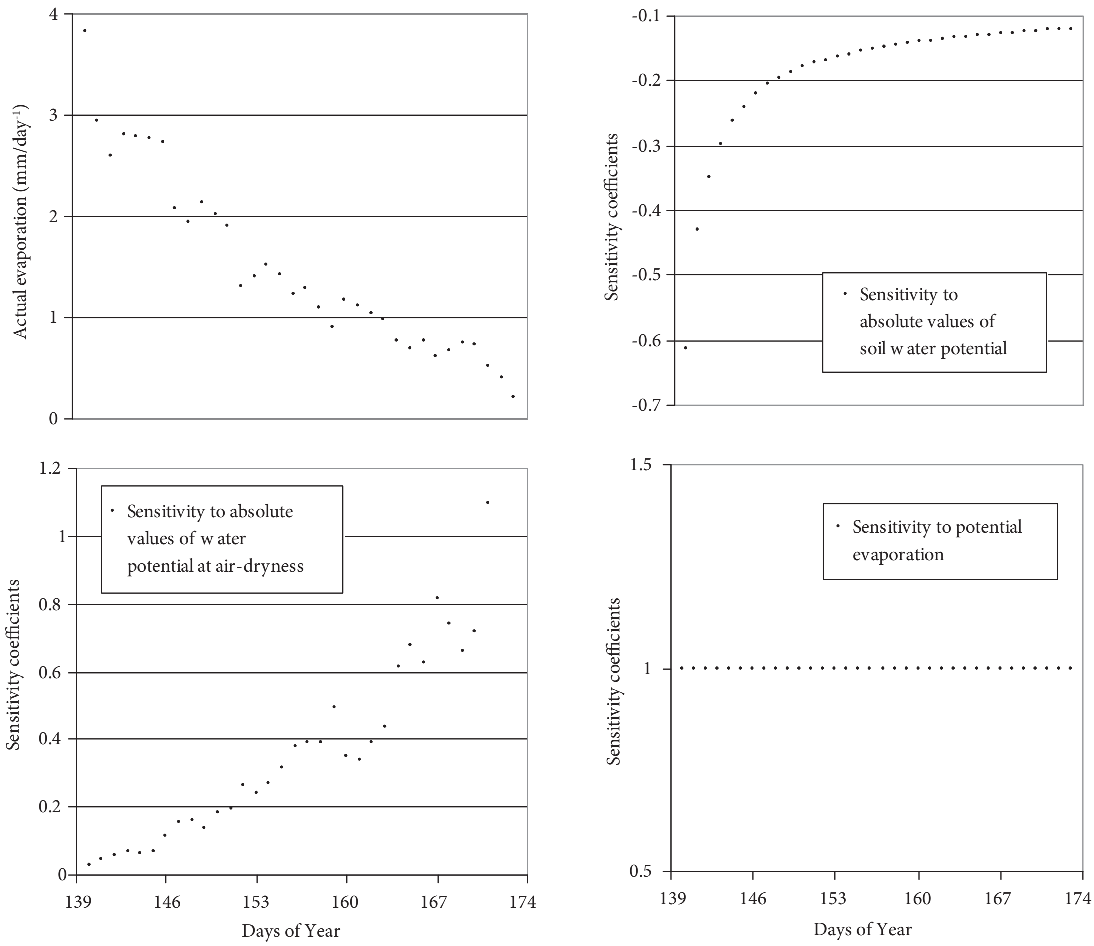

Figure 2. Predicted actual evaporation from bare soil and its relative sensitivity to input variables during a drying period in Adana.

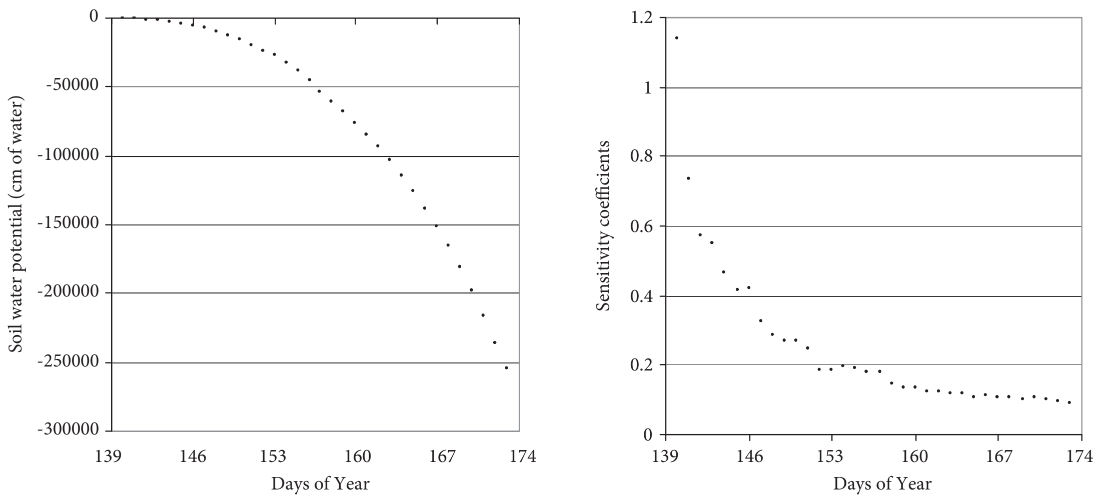

Figure 3. Predicted soil water potential, ψ, and the relative sensitivity of |ψ| to potential soil evaporation during a drying period in Adana.

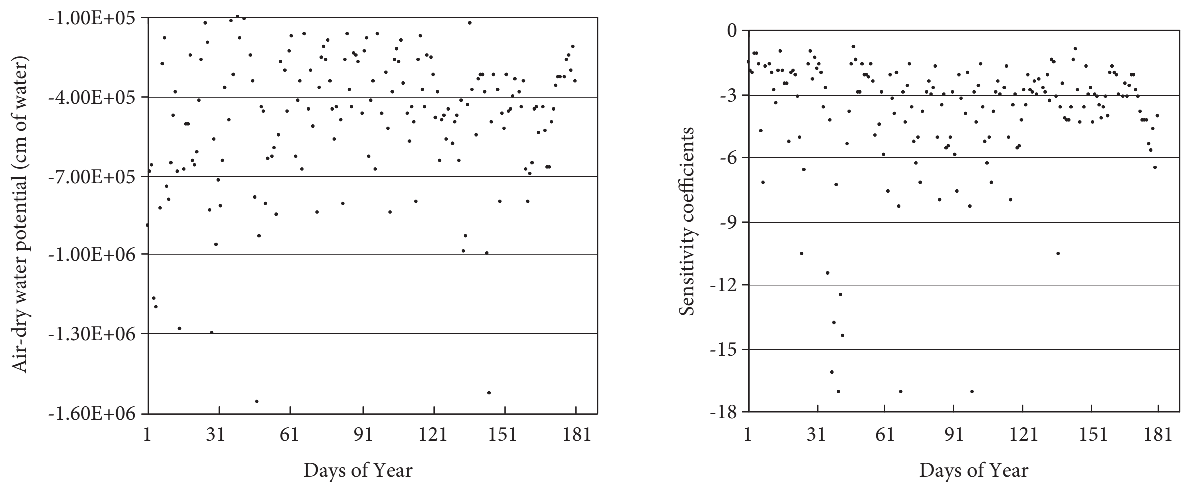

Figure 4. Predicted water potential at air-dryness, ψ_{ad}, and the relative sensitivity of $|\psi_{ad}|$ to air-humidity in Adana during the first-half of 2006.

Table 2. Relative sensitivity coefficients and their confidence limits for input variables in the equations used.

Input variables	Mean sensitivity coefficients	Confidence limits (**P < 0.01)	
		lower boundary	upper boundary
	For the output (E_p) of the Penman-Monteith equation		
R_n	0.82	0.78	0.86
G_s	−0.02	−0.05	0.01
∇	0.11	0.07	0.15
δ	0.24	0.19	0.29
r_a	−0.24	−0.29	−0.19
	For the output (E_a) of Aydın's equation		
$\lvert\psi\rvert$	−0.19	−0.23	−0.15
$\lvert\psi_{ad}\rvert$	0.46	0.25	0.67
$\lvert\psi_{tp}\rvert$	0.11		
E_p	1.0		
	For $\lvert\psi\rvert$ from Aydın and Uygur's equation		
E_p	0.25	0.16	0.34
θ_{fc}	−1.17		
θ_{ad}	1.17		
α	−1.00		
D_{av}	−0.50		
	For $\lvert\psi_{ad}\rvert$ from Kelvin's equation		
H_r	−4.11	−4.67	−3.55
T	1.00		

resulted in the same ratio of increase in the minimum water potential as an absolute value (Table 2). Since the dependent variable of equation (ψ_{ad}) was a logarithmic function (ln H_r) of relative humidity (fractional), the sensitivity coefficients of relative humidity showed a great deal of variation (Figure 4). The change pattern of ψ_{ad} was moderately consistent with the pattern of S_{Hr}. This means that the presence or absence of nonlinearities or correlative interactions with other parameters should be considered (van Griensven et al. 2006). In spite of this fact, detailed information about the success of the model or its limitations was obtained, and the effect levels of the inputs on the predicted values of the model were determined. It can be concluded that normalised, local, and first-order sensitivity analysis is sufficient to evaluate the performance of the soil evaporation module of the E-DiGOR model.

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