The importance of meteorological variables in the bias of Potential evapotranspiration estimates in Crete, southern Greece

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Abstract

Aim of the present study is to identify the importance of various meteorological variables in the absolute values of positive and negative bias of the estimates of the reference potential evapotranspiration (PET_{ref}) rates from two empirical equations in Crete, southern Greece. Daily values of PET_{ref} calculated by means of the standardised FAO Penman-Monteith equation in the meteorological station of Iraklio were used as a basis for the comparison between different methods. Wind velocity was detected as an important factor, yet it is the combination of various meteorological parameters that actually controls the magnitude of bias.

1. Introduction

Estimates of reference potential evapotranspiration (PET_{ref}) are important for a number of applications in biometeorology and especially in agricultural and forest meteorology. Since there are many difficulties for the direct measurement of PET_{ref}, it is usually estimated using the standardised, physically based equation of FAO Penman-Monteith (PET_{FAO}) (Allen *et al.*, 1998) which is widely accepted to provide the best estimates of PET_{ref} over various climatic types (Droogers and Allen, 2002; Gavilán *et al.*, 2006). This equation, nevertheless, is demanding in terms of input data (among others requires input of net radiation, wind speed, air humidity) which are not measured in the majority of the weather stations. To overcome this deficiency, a number of empirical equations, less demanding in terms of input data, has been proposed for the estimation of PET_{ref}.
Yet, due to the fact that the empirical equations are developed for specific regions and climatic types it is possible that their estimates will be deemed by source of bias deriving from site-specific conditions (Allen *et al.*, 1998; Grismer *et al.*, 2002). To exemplify, it has been observed that although the Hargreave's equation (PET_{Har}), results in adequate estimates for many regions (Temesgen *et al.*, 1999; DehghaniSanij *et al.*, 2004), it has a tendency to over-estimate PET_{ref} rates in high advection phenomena of semi-arid environments (Martínez-Cob, 1996; Berengena and Gávilan, 2005). It is important therefore, besides the general evaluation of the empirical equation prior to their use, to detect and identify the specific parameters that lead in partial failure of the empirical equations even when they overall perform well.
Within this concept, in the semi arid region of Crete, the performance of thirteen empirical equations was evaluated with respect to the PET_{ref} estimates obtained by the PET_{FAO} in seven meteorological stations. The evaluation has shown that two empirical equations (Hamon's and Turc's) perform considerably well (Xystrakis and Matzarakis, submitted). For the aforementioned equations, statistical analyses were used in order to identify the meteorological parameters that have a large impact in their over- or underestimations with respect to the PET_{FAO} using data from the weather station situated in Iraklio.

2. Data and methods

Daily values (17155 days) of meteorological data, required for the calculation of PET_{FAO}, were obtained from one climate station (Irakleio – Lon: 25°10'0"; Lat: 35°19'0"; Alt: 39 m a.s.l.) on the island of Crete, southern Greece. The data included observations of mean air temperature, T_{mean} (°C); minimum air temperature, T_{min} (°C); Maximum air temperature, T_{max} (°C); Dew point temperature, T_{dew} (°C); relative humidity, RH (%); wind velocity, U_2 (m/s) and cloud cover, CL (octas).
The global (total) solar radiation data which are required for estimation of PET_{ref} by means of Turc's equation and not measured by the meteorological station of Irakleio, were estimated using the RayMan® model (Matzarakis and Rutz, 2007; Matzarakis *et al.*, 2007), taking into consideration the cloud cover, the latitude and the elevation of the meteorological station. To estimate the extraterrestrial radiation (R_a) and net radiation (R_n), required for the application of the PET_{FAO} equation, the method described by Allen *et al.* (1998) was followed. An albedo value of 0.23 was used (Allen *et al.*, 1998) in the calculation of R_n for the reference crop. The performance of the empirical equation was tested using the daily bias error (BE) measure, defined as:
$BE = E_i - O_i$
with E_i: Estimates from empirical equations and O_i: respective values from PET_{FAO} equation for day i
The empirical equations that, based on out unpublished data, show a generally good performance in Crete were these of Turc's (PET_{Tur}) described in Jacobs and Satti (2001) and Lu *et al*. (2005) and Hammon's (PET_{Ham}) described in Oudin *et al*. (2005). For these equations therefore, the meteorological factors that contribute to over- or under-estimation of PET_{ref} will be assessed.
To detect structure in the relationships between variables, factor analysis was performed (StatSoft, 2007) with the daily meteorological observations as the input variables. The principal component method was used as extraction method, the number of factors (axes) extracted was four and varimax rotation was applied for the estimation of sample scores. Stepwise multiple linear regressions were then performed using the absolute values of positive and negative values of BE and the scores of the axes of the factor analysis as the dependent and independent variables respectively. The load (importance) of each of the factors in the BE was estimated by their standardised beta coefficients in the regression models. Interception was forced to zero. The use of the negative and values of BE allowed us to account for the direction of bias (under- or over-estimation respectively). Both factor and regression analyses were performed in Statistica (StatSoft, 2007).

3. Results

The results of the factor analysis are summarised in table 1.
From the above table, and based on the correlation coefficients between the daily meteorological observations and the factors (axes), it can be concluded that the relative position of the days along the axes, indicates their meteorological conditions as described hereafter: Days that are characterised by high air temperatures are positively correlated with the first factor. Days with high RH are negatively correlated with the second factor. Days with high wind speed are negatively correlated with third factor and finally, days with high incoming radiation are positively correlated with the fourth factor. To exemplify, a day that is situated on the positive part of the first axis, on the nega-

tive part of the second axis, on the positive part of the third axis and on the negative part of the fourth axis of the factor analysis, is considered to be a warm, wet, with low wind velocity and low incoming radiation (cloudy) day.

Tab. 1: Factor analysis outputs. Correlation coefficients which are higher than 0.7 are bolded and underlined

Variables	Factor 1	Factor 2	Factor 3	Factor 4
T_{mean}	**0.891091**	0.256722	0.039950	0.357928
RH	-0.157786	**-0.951404**	0.169836	-0.190822
U2	-0.040839	0.145534	**-0.980987**	-0.108822
CL	-0.322499	-0.121923	-0.110805	**-0.909969**
T_{max}	**0.859845**	0.296496	0.110251	0.338196
T_{min}	**0.914387**	0.171401	-0.106921	0.252498
T_{dew}	**0.876975**	-0.324674	0.130110	0.311544
R_s	0.483314	0.177272	0.069425	**0.818468**

The results of the regression analysis between the absolute values of bias error of the empirical equations are presented in table 2

Tab. 2: Beta coefficients and their standard errors of the regression analyses. All but the underline factors are statistically significant at 0.01 level

Hammon's equation					
over-estimation (absolute values of positive BE)			Under-estimation (absolute values of negative BE)		
	beta	Std. Err.		beta	Std. Err.
Factor 1	0.529495	0.007387	**Factor 3**	-0.576253	0.005806
Factor 2	-0.007092	0.007474	**Factor 2**	0.493862	0.005820
Factor 3	0.467052	0.007648	**Factor 1**	-0.230526	0.005773
Factor 4	-0.243960	0.007635	**Factor 4**	0.167189	0.005837
Turc's equation					
over-estimation (absolute values of positive BE)			Under-estimation (absolute values of negative BE)		
	beta	Std. Err.		beta	Std. Err.
Factor 3	0.628697	0.006736	**Factor 3**	-0.647237	0.004399
Factor 4	0.452673	0.006794	**Factor 2**	0.486130	0.004380
Factor 1	0.126237	0.006650	**Factor 4**	-0.441899	0.004409
Factor 2	-0.041261	0.006576	**Factor 1**	0.095315	0.004389

The above table, combined with the results presented in table 1, shows that the over-estimation of Hammon's equation mostly depends on air temperatures as the absolute values of positive bias increase when values of factor one increase. The absolute values of positive bias also increase with an increase of the factor three, which is related with a decrease in wind velocity. Finally, the absolute values of positive bias decrease as sample scores along factor four increase with the latest signifying an increase in incoming radiation values. The relative humidity has not effect over the overestimation from Hammon's equations.

Table 2 also shows that under-estimation of PET_{ref} from the same empirical equation mostly depends on the factor related with wind speed. The absolute value of under-

estimation increases with decrease in the values of factor three (increase in U_2). The absolute values of under-estimation also increase with increasing values of factor two (decrease in RH). Additionally, increase in over-estimation is observed for decrease in factor's one values (decrease in air temperatures). Finally, the absolute values of under-estimation slightly increase with a respective increase in the values of factor four (increase in radiation intensity).
Summarising for Hammon's equation, large over-estimations are expected during warm, with low wind velocity and incoming radiation days, while large under-estimations are expected to occur during days with high wind velocity which are dry, cold and sunny.
Concerning the over-estimation of Turc's equation, the factor three, which is related to wind velocity, is identified to has the greater importance. As values of factor three increase (U_2 decreases), the absolute error of over-estimation increases. Similarly, when values of factor four increase (increased incoming radiation), the overestimation increases. When values of factor one increase (increase in air temperatures), the over-estimation decreases and finally, when values of factor two increase (decrease in relative humidity).
The factor with the greatest importance concerning the under-estimation of Turc's equation is identified as to be the factor three (related to wind speed). High values of factor three (low wind velocity) result in low under-estimations. Additionally, high values of factor two (low values of relative humidity) result in large under-estimations. Respectively, low values of factor four (low incoming radiation) result in large under-estimations. Finally, high values of factor one (high air temperatures) result in a slight increase in under-estimation of PET_{ref}.
Summarising for Turc's equation, high over-estimation bias is expected for days with low wind speed which are sunny, warm and dry. High underestimations are expected during days with high wind speed which are dry, cloudy and cold.

4. Discussion

The under-or over-estimation of these two empirical equations for the prevailing meteorological conditions in Irakleio, largely depends on wind velocity, as the factor three, which is related to this meteorological variable, has been identified as having the greatest relative importance in three of the four regression models. That can be explained from the fact that both of the empirical equations, unlike the PET_{FAO} do not account for wind velocity for the estimation of PET_{ref}.
Additionally, it is interesting to observe that the equations show a consistent pattern in terms of the effect that the meteorological variables have in over- or under-estimation of PET_{ref}. The regression coefficients of the independent variables (factors) have the opposite sign, for high over- and under-estimations (with the exception of air temperatures for Turc's equation). Fore example, high relative humidity is related with high over-estimations and with low underestimations. Nevertheless, it is obvious that the over- or underestimation form the empirical PET_{ref} equations does not depend in a single parameter but to their combination. Further research is required in order to be able to detect the important parameters that lead to deviation of estimates from PET_{ref} values and make use of this knowledge for an optimum calibration of the empirical equations at local conditions, taking into consideration the prevailing meteorological conditions.

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