

# A comparative evaluation of four evapotranspiration models based on Eddy Covariance measurement over a grass covered surface in Ile-Ife, Southwestern Nigeria

O. A. Babatunde<sup>1</sup> · O. E. Abiye<sup>2</sup> · L. A. Sunmonu<sup>1</sup> · A. P. Olufemi<sup>3</sup> · M. A. Ayoola<sup>1</sup> · O. E. Akinola<sup>1</sup> · E. O. Ogolo<sup>4</sup>

Received: 9 September 2017 / Accepted: 14 October 2017 / Published online: 2 November 2017  
© Springer International Publishing AG 2017

**Abstract** An Eddy Covariance (EC) system was set up to measure vertical transport of water vapour fluxes over a grass covered surface at a site located within Obafemi Awolowo university campus (7°33'N, 4°35'E) southwestern Nigeria between 31st of May and 14th of June, 2013. The EC measurement was used as a benchmark to evaluate the performances of four evapotranspiration models (the standardized FAO-56 Penman–Monteith (PM), Priestly-Taylor (PT), Makkink (MK) and Turc) which were employed to estimate evapotranspiration in the study area. The ET estimates from the models showed similar diurnal variation with the direct measurement from EC technique with daytime mean (mm/day) ranging between 0.79 and 2.37 for EC, 1.02–3.75 for PM, 1.58–5.46 for PT, 1.13–4.02 for MK and 1.21–4.27 for Turc. Based on regression analysis and standard error of estimates (SEE), the performances of the models ranked from PM ( $R = 0.96$ , slope,  $b = 0.687$ ,  $SEE = 0.049$ ), MK ( $R = 0.97$ ,  $b = 0.569$ ,  $SEE = 0.395$ ), Turc ( $R = 0.97$ ,  $b = 0.539$ ,  $SEE = 0.553$ ) to PT ( $R = 0.97$ ,  $b = 0.386$ ,  $SEE = 1.32$ ). Recalibration of models coefficients using least square method showed significant improvement in their estimates and thus, the models were found very

reliable for predicting ET which is a relevant parameter for irrigation scheduling.

**Keywords** Evapotranspiration · Eddy covariance · FAO-56 Penman–Monteith · Irrigation

## Introduction

Evapotranspiration (ET) is an important parameter needed for the investigation of water and energy balances over naturally occurring vegetative surfaces, with applications in agrometeorology and climatology (Martano 2015). Accurate estimation of ET has an important significance to study the ecosystem productivity and water balance in order to guide irrigation, agricultural drainage and to improve agricultural water use. In general, several approaches have been undertaken to define the concept of ET which at best distinguished between potential, actual and reference ET (Thornthwaite 1948; Allen et al. 1998; Hansen et al. 1980; Dingman 1994; Watson and Burnett 1995; Jensen et al. 1990). Direct techniques for measuring ET includes lysimetry (Howell et al. 1991; Zhang et al. 2016), pan evaporimeter (Irmak et al. 2002), scintillometry (Daoo et al. 2004) and eddy covariance (Baldocchi et al. 2001). However, the direct methods have been found to be highly capital intensive, laborious to setup and requires intensive maintenance (Watson and Burnett 1995; Odi-Lara et al. 2016) in addition to certain drawbacks in their operation mechanism. For instance, the lysimetry technique does not maintain original soil profile characteristics including density during and after construction (Allen et al. 2011). Evaporation pans measure the loss of a known quantity of water through evaporation using a vernier caliper to identify changes in the

✉ O. A. Babatunde  
oae.babatunde@gmail.com

<sup>1</sup> Department of Physics and Engineering Physics, Obafemi Awolowo University, Ile-Ife, Nigeria

<sup>2</sup> Centre for Energy Research and Development (CERD), Obafemi Awolowo University, Ile-Ife, Nigeria

<sup>3</sup> Department of Physics, University of Medical Sciences, Ondo, Ondo State, Nigeria

<sup>4</sup> Department of Physics, Federal University of Technology, Akure, Nigeria

precise water level, but they do not measure transpiration. To compensate, pan evaporation data must be adjusted downward using a pan coefficient. Pan evaporation data typically overestimates ET due to the nature of the pan. Evaporation pans often will still evaporate at night due to the residual heat that is stored in the water of the pan. Hence, researchers have developed empirical models which require measurements of routine meteorological parameters as in-data to estimate ET over the years (Martano 2015). These routinely measured parameters tend to be relatively easy to collect, they include; temperature, relative humidity, rainfall, wind, and solar radiation (Maselli et al. 2014). ET models have been categorized into three basic types: temperature, radiation, and combination (Jensen et al. 1990; Watson and Burnett 1995). Temperature models generally require only measurements of air temperature as the sole meteorological input to the model (e.g., Thornthwaite 1948; Doorenbos and Pruitt 1977; Jensen et al. 1990). Radiation models (e.g., Doorenbos and Pruitt 1977; Hargreaves and Samani 1985) are typically designed to use some component of the energy budget concept and usually require some form of radiation measurement. Finally, combination models combine elements from both the energy budget and mass transfer models to give very accurate results (Jensen et al. 1990). The Penman family of models is the most common

combination model in use today (Jensen et al. 1990; Allen et al. 1998).

This study thus compares direct measurement of ET from eddy covariance technique to ET estimates obtained from four standardized models namely; FAO-56 Penman–Monteith, Priestly–Taylor, Makkink and Turc at Ile-Ife, a tropical location. These are with a view to evaluating the performance of the empirical models and validate their suitability for agro-meteorological purposes in Nigeria.

## Materials and methods

### Site description

The experimental site for this study was located at the Sports Complex (7°33'N, 4°35'E), Obafemi Awolowo university campus, Ile-Ife, southwestern Nigeria (Fig. 1). The climate of the study area is generally characterized with two seasons: namely the wet and dry season, the wet season spans between March to October and the dry season lasts from November to February. The variation of this season is a function of the meridional movement of the Inter-Tropical Discontinuity (ITD) which demarcates the warm and moist South-Westerly trade wind at the surface from the hot and dry North-Easterly trade winds (Jegade

**Fig. 1** Map showing the evapotranspiration measurement site within Obafemi Awolowo University, Ile-Ife (insert is the map of Nigeria indicating the location of Ile-Ife)



et al. 2006). The onset months of the wet season falls within the weather zone B (extends 200–400 km south of the surface position of the ITD). The zone is characterized by suppressed convection resulting into cumulus clouds and precipitation is limited to light showers, whereas in August/September, which is at the peak of wet season in the area, Ile-Ife falls within the weather zone D characterized by stratus cloud and is accompanied by light rains and drizzles with occasional moderate thunderstorm activities (Ayoola et al. 2014). The field measurements for this study took place between 31st of May and 14th of June, 2013.

**Data acquisition**

A measurement complex consisting of two but closely located masts (2.5 and 2.8 m) were setup over a plane grass-covered surface. An eddy covariance (EC) system comprising of a CSAT3 sonic anemometer and a LI-7500 (fast response) open path infrared gas analyzer was installed on the 2.5 m mast to measure the vertical transport of water vapour flux over the grass covered surface (Fig. 1). The 2.8 m mast was instrumented with an array of slow-response and well calibrated sensors (NRLITE, CS300, HMP45, ML101) deployed for routine observation of meteorological parameters such as net radiation, global radiation, air temperature, relative humidity, wind speed (Fig. 2). The EC system measures the latent heat (LE) and water exchange between the ground surface and the atmosphere. The rate of

evapotranspiration is then determined by converting measured latent heat flux from the EC as follows

$$ET = \frac{LE}{\rho_w \times \lambda}, \tag{1}$$

where  $LE$  is the Latent heat flux ( $W/m^2$ ),  $\rho_w$  is the density of water ( $Kgm^{-3}$ ) and  $\lambda$  is the latent heat of vaporization ( $MJkg^{-1}$ ).

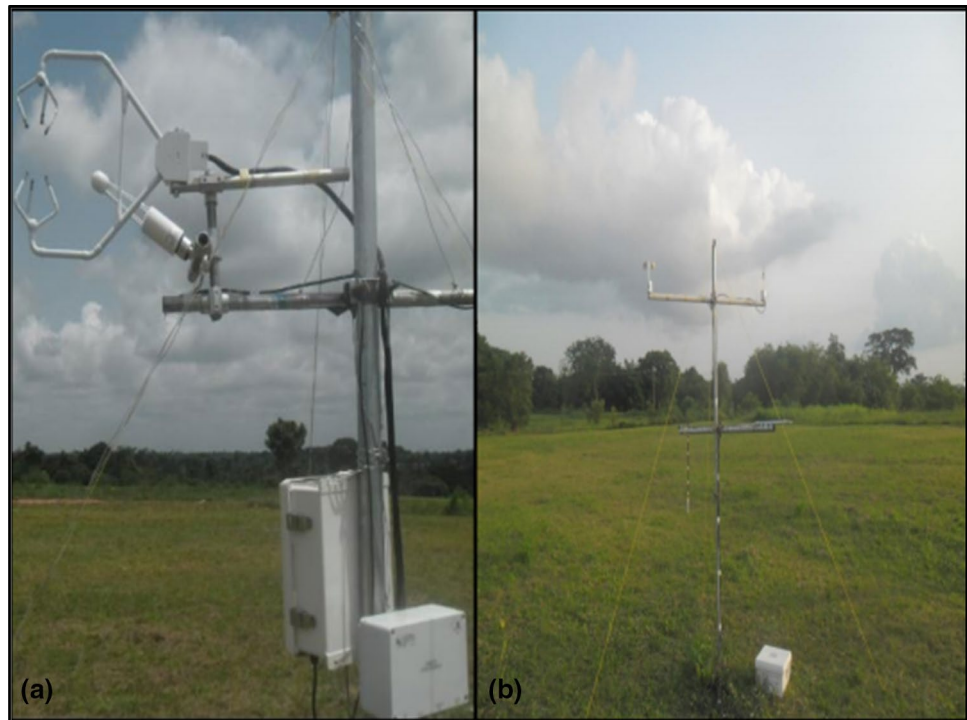
**The ET models employed**

- i. The FAO-56 Penman–Monteith employed in this study is given

$$ET = \frac{0.408\Delta(R_n - G) + \frac{\gamma 600U_2(e_s - e_a)}{T_a + 273}}{\Delta + \gamma(1 + 0.56U_2)}, \tag{2}$$

where  $R_N$  is net radiation,  $G$  is ground heat flux,  $U_2$  is wind speed at 2 m/s,  $e_s - e_a$  is vapour pressure deficit,  $T_a$  is air temperature,  $\gamma$  is the psychrometric constant and  $\Delta$  is the slope of saturation vapour pressure curve. The FAO-56 PM was adjusted so as to locally account for the influence of the bulk and aerodynamic resistances which are weather dependent parameters and as a result they vary for different climatic conditions (See Allen et al. 1998).

**Fig. 2** Setup of **a** the Eddy Covariance system comprising of a CSAT 3 sonic anemometer and a Li-7500 infrared gas analyzer **b** slow response measurement complex for microclimatic data acquisition at the experimental site in Ile-Ife



## ii. The Priestly Taylor Model

The Priestly and Taylor (1972) model used in this study is given as

$$ET = \alpha \frac{\Delta}{\Delta + \gamma} (R_n - G),$$

$\alpha = 1.26$ , and all other terms are as defined previously.

## iii. The Makkink Model:

The Makkink model (1957) developed in the Netherlands was also used, and the model is given by

$$ET = 0.61 \frac{\Delta}{\Delta + \gamma} \frac{R_s}{2.45} - 0.12, \quad (4)$$

where  $R_s$  is the incoming solar radiation,  $\gamma$  is the psychrometric constant and  $\Delta$  is the slope of saturation vapour pressure curve.

## iv. The Turc Model:

The Turc model (Turc 1961) has two forms depending on the consistent value of the relative humidity. Since  $RH > 50\%$  for this study area, the form of the model used in this work is

$$ET = 0.013T_a \times (23.9R_s + 50) / (T_a + 15). \quad (5)$$

All the terms and variables are as earlier mentioned.

## Models' performance evaluation

Comparative evaluation of model performance was done using both statistical criteria (quantitative) and graphical

display (qualitative) (Loague and Green 1991). The combined approach is useful in making comparative evaluations of model performance between alternative or competing models. In this work; the correlation measure  $R$ , the Mean biased error (MBE), the Root mean square error (RMSE) and the index of agreement ( $d$ ) were calculated and reported. It was pointed out (Fox 1981; Willmott 1982) that the commonly used correlation measure such as  $R$  and  $R^2$  are often inadequate when used to compare model predicted and observed variables. This is because the magnitude of  $R$  is not related to the accuracy of model prediction (Willmott et al. 1985). As a result of this, recommendations have been made to use other sum and difference measures to confirm the accuracy of the predictions (which consequently influence the decision to use MBE, RMSE and  $d$  in this study Krause et al. 2005; Licciardello et al. 2007; Carrillo-Rojas et al. 2016; Odi-Lara et al. 2016). Normally, the coefficient  $R$  has values ranging from 0 to 1; the closer to 1 the stronger the correlation and vice versa, a value of zero indicates no correlation between the observed and predicted values. Moreover, the MBE describe biases between the observed and the predicted values, the RMSE expresses the average difference between observed and predicted values both have values ranging from  $-\infty$  to  $\infty$ . Positive values of these statistical measures indicate overestimation while their negative values signify underestimation. The lower the error estimate the better the prediction by the models.

## Models' recalibration

The empirical models employed to estimate ET were developed in regions with differing climatic regimes. Tabari and Talaei (2011) reported that numerous scientists working on ET under different climates have shown that the models vary in their performance spatially and temporally. The

**Table 1** Daily values of ET from direct measurement (EC) and Models

DOY	EC (mm/day)	FAO-56 PM (mm/day)	PT (mm/day)	MK (mm/day)	TURC (mm/day)
151	1.05 (2.29) <sup>a</sup>	1.06 (2.65)	1.76 (4.39)	1.41 (3.19)	1.51 (3.39)
152	0.72 (1.39)	0.77 (1.96)	1.27 (3.18)	1.05 (2.31)	1.12 (2.45)
154	0.79 (1.72)	1.01 (2.44)	1.82 (4.43)	1.32 (3.14)	1.42 (3.37)
155	0.72 (1.61)	0.94 (2.41)	1.78 (4.49)	1.37 (3.18)	1.47 (3.38)
156	0.84 (1.82)	0.94 (2.48)	1.83 (4.39)	1.28 (3.05)	1.37 (3.24)
157	0.98 (2.18)	1.27 (3.03)	2.14 (5.10)	1.57 (3.59)	1.68 (3.82)
158	0.94 (1.92)	1.57 (3.75)	1.93 (4.63)	1.47 (3.31)	1.57 (3.52)
159	0.45 (0.94)	0.49 (1.25)	0.91 (2.29)	0.74 (1.69)	0.79 (1.81)
160	0.46 (0.89)	0.52 (1.33)	1.00 (2.52)	0.74 (1.74)	0.80 (1.86)
162	0.39 (0.79)	0.43 (1.02)	0.68 (1.58)	0.54 (1.13)	0.59 (1.21)
163	1.04 (2.37)	1.19 (2.95)	2.22 (5.46)	1.76 (4.02)	1.88 (4.27)
164	0.87 (1.91)	0.95 (2.26)	1.76 (4.18)	1.75 (3.99)	1.86 (4.23)

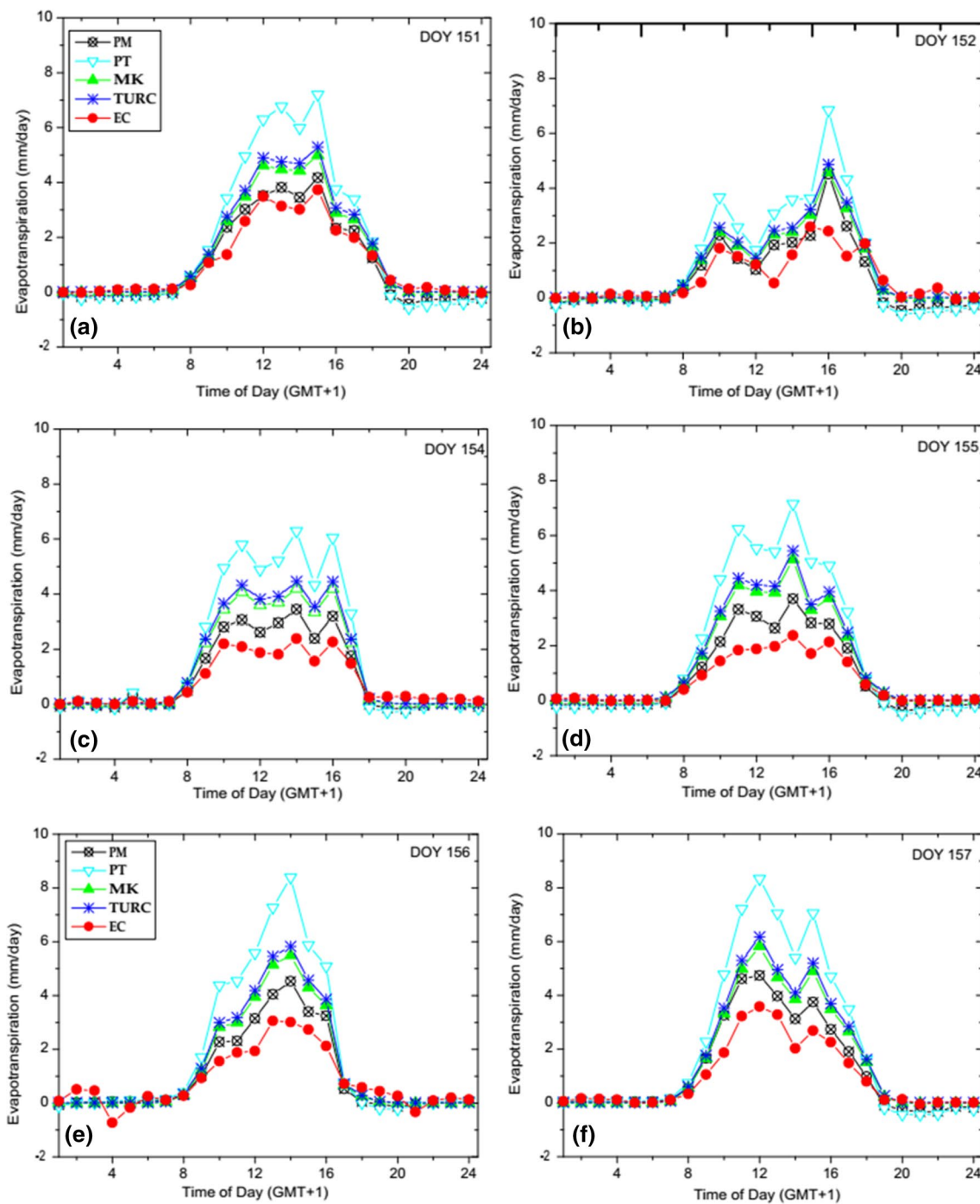
<sup>a</sup>Values in parenthesis are for daytime averages (08:00–18:00 GMT + 1)



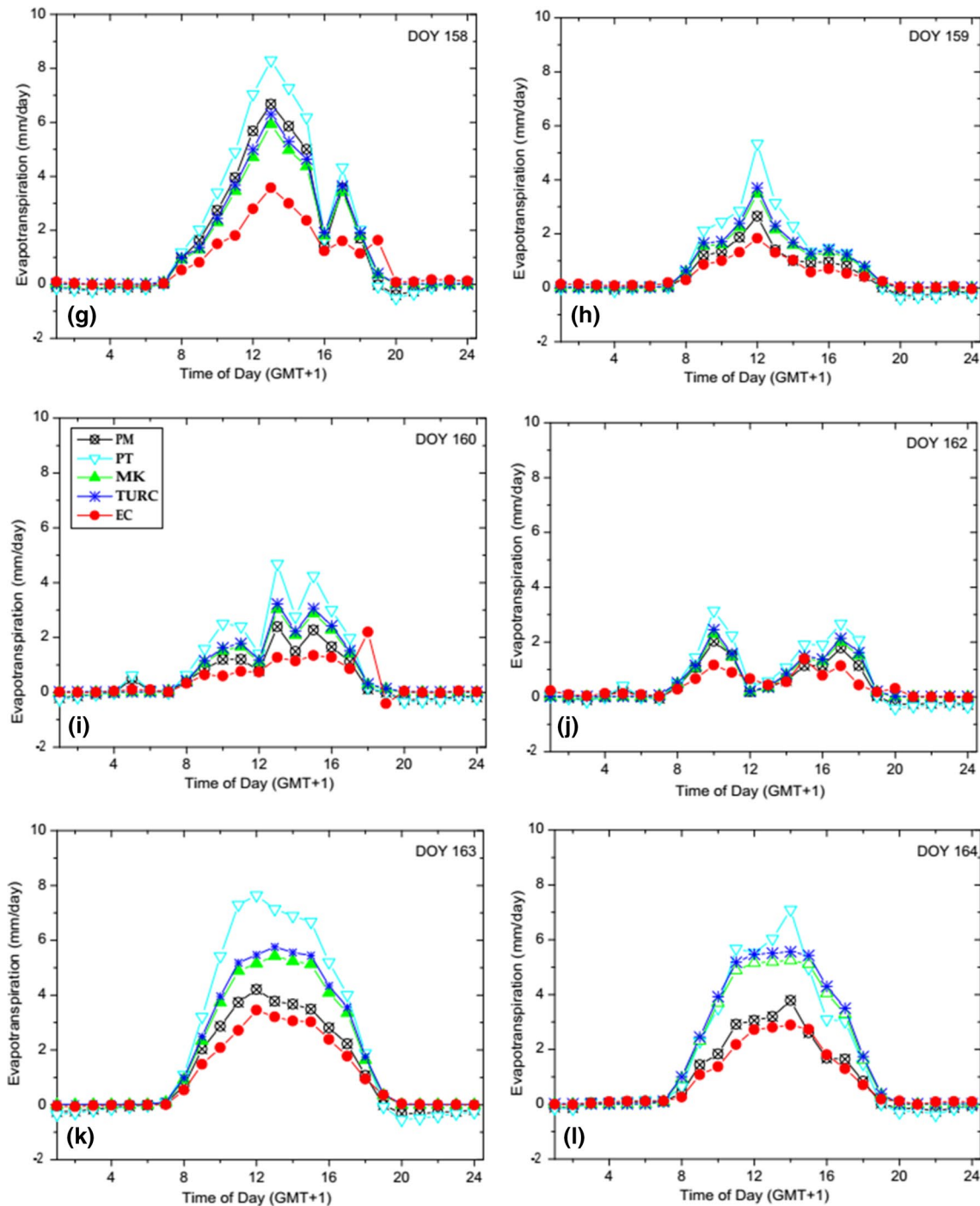
implication of this is that these models require local calibration for effective ET estimation when adapted to other locations (Allen et al. 1998; Pereira et al. 1999). ET models are therefore often calibrated against a more reliable method of estimation with a view to improving their accuracy in estimating ET (Fontenot 2004). In this study, the adopted models namely the PM, the PT, the MK and the TURC

models were calibrated on the basis of the EC method. The main approach for calibration of the models used in this study is linear regression with EC measurement. According to Houshang et al. (2012), the intercept, *a*, and slope, *b*, of the best fit regression line is then used as regional calibration coefficients:

$$ET_{cal} = a + b(ET_{model}). \tag{6}$$



**Fig. 3** a–f Diurnal variation of measured and estimated ET over grass at Ile-Ife



**Fig. 3** (continued)

## Results and discussion

The results of the mean daytime evapotranspiration measured by the eddy covariance technique and the estimation of reference evapotranspiration models over the research site for this study are presented in the Table 1. 12 fair-weather days were presented for discussion as other days

were considered spurious due to precipitation and condensations which were the prevalent weather conditions of those days. From the Table 1, the daily EC measurement range between 0.45 and 1.05 mm/day, the ET as estimated by PM range between 0.49 and 1.27 mm/day, the PT model give a range of value between 0.91 and 2.22 mm/day, while the MK model range between 0.74 and

1.76 mm/day and the TURC model give a range of value between 0.79 and 1.88 mm/day. Figure 3(a–l) showed the diurnal variation of measures and estimated ET as given by each of the model. Significant evapotranspiration does not occur in the nocturnal periods due to the fact that there is no sufficient energy from the incoming solar radiation and wind to drive the process. An observation of the range of values of ET estimate presented in Table 1 gave a clear indication that the PM model provided the closest values to those of the EC measurement chosen as the reference method while the PT model gave the farthest estimates. It is also obvious that the MK model and the TURC model estimated closer to the EC in that order. The excellent performance of the PM model can be attributed to the fact that it requires many meteorological data such as radiation, wind speed, air temperature and humidity (Tabari and Talaee 2011). These weather parameters were so fundamental to the occurrence of evapotranspiration process. The observed overestimating performance of the PT model has been well reported in literatures (Panda and Kashyap 2001; Fontenot 2004). In order to investigate the relationship between the ET models and the directly measured evapotranspiration data, a regression analysis was carried out and the standard error of estimate (SEE) was obtained. The result is presented in Table 2. All the models show strong correlation with the EC measurement on the account of the coefficient of determination ( $R^2 > 0.9$ ) which describes colinearity between observed (O) and predicted (P) variates where

the observations are interval or ratio in scale (Willmott 1981). However, Variance in their SEE and slope can be used to evaluate their respective performances. The result in Table 2 show that the PM model has the lowest error of estimate of 0.049 and a slope closest to unity of 0.687 hence it has the strongest performance correlation with the benchmark measurements. The MK model followed the PM model in performance with the second lowest SEE of 0.395 and a slope of 0.569. The TURC model rated 3rd in the correlation performance with SEE of 0.553 and a slope of 0.539. The PT model has the highest error of estimate (1.32) and the lowest slope (0.386). Table 3 showed the percentage departure of ET values obtained by the model from the EC measurement. From the table the FAO-56 Penman–Monteith (PM) model has the least departure from the benchmark measurement with an average overestimation of 14.7%. The Makkink (MK), Turc and Priestly-Taylor (PT) models overestimated the EC measurement by 51.1, 60.7 and 94.1% respectively. Figures 4 and 5 were presented to examine the influence of surface radiative fluxes on the performances of the ET methods. As can be seen from the time series, the fluxes were the major determinant of the variation and rate of ET occurrence. The peaks, dips and the fluctuations in the fluxes over a diurnal course were quite identical. The Julian days 159, 160 and 162 were of particular interest as dips in net and global radiation fluxes occasioned low estimates of evapotranspiration rates. In order to improve the performances of the models, 10 days estimate were used to obtain recalibrated coefficients. The result of the ET estimate for Julian days 163 and 164 were then used to validate the procedure and examine the performance of the adjustment. The result is presented in Fig. 6. The results of coefficient adjustment presented graphically above show an improvement in the performances of these models. It can be seen that the PM model does improve after recalibration and similarly the other models. The adjustment almost brought the MK and TURC model to the exact estimates of the EC measurement, this implies

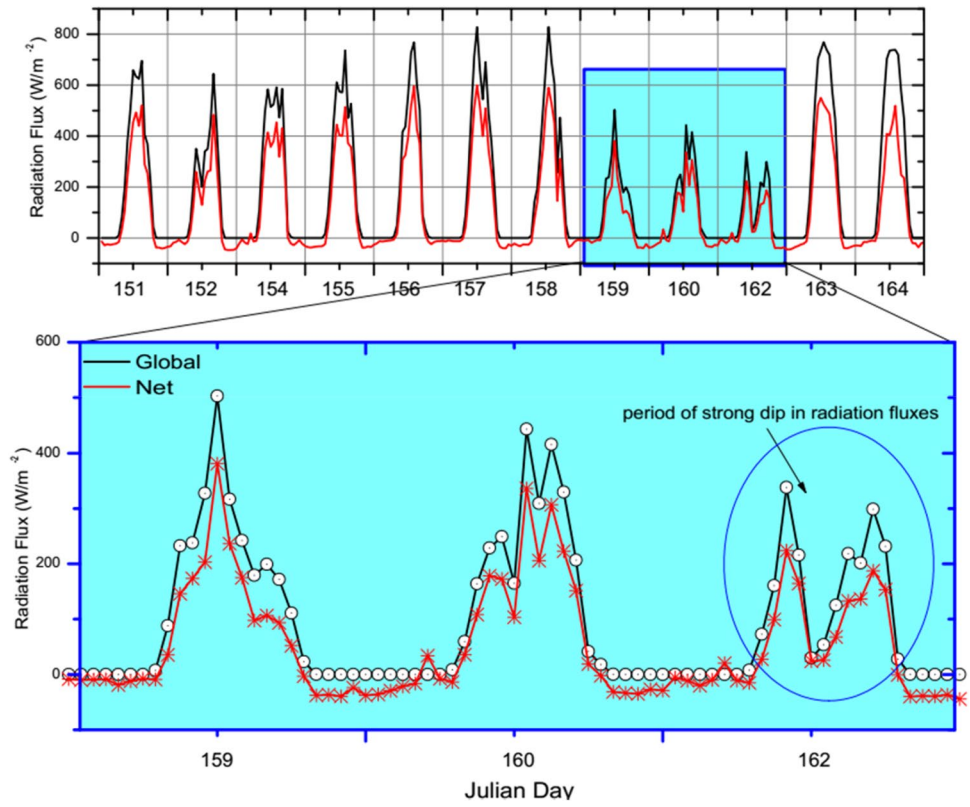
**Table 2** Coefficient of linear regression and error estimate for the performances evaluation of the models

Models	R <sup>2</sup>	Slope (b)	Intercept(a)	SEE
PM	0.96	0.617	0.181	0.049
PT	0.97	0.379	0.153	1.32
MK	0.97	0.565	0.092	0.395
TURC	0.97	0.534	0.082	0.553

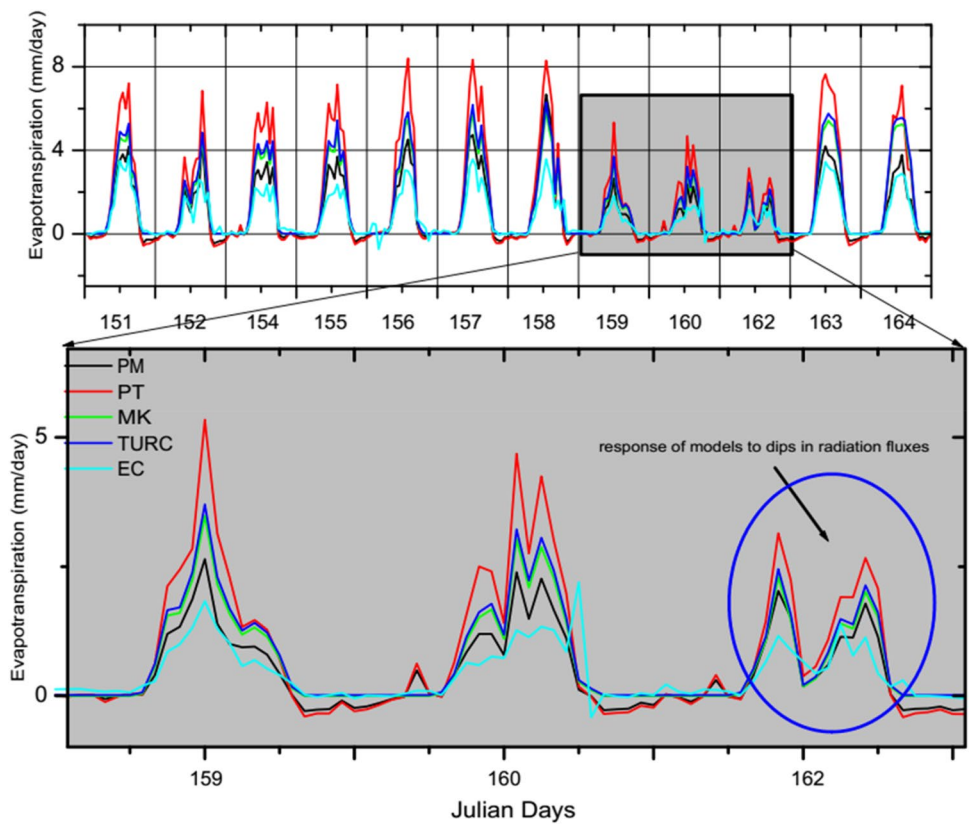
**Table 3** Percentage departure of ET estimate by models from ET obtained from Eddy covariance measurement

DOY	ET values from methods (mm/day)					% Departure from reference EC measurement			
	EC	PM	PT	MK	TURC	PM	PT	MK	TURC
151	1.05	1.06	1.76	1.41	1.51	1	71	36	46
154	0.79	1.01	1.82	1.32	1.42	22	103	53	63
155	0.72	0.94	1.78	1.37	1.47	22	106	65	75
156	0.84	0.94	1.83	1.28	1.37	10	99	44	53
157	0.98	1.27	2.14	1.57	1.68	29	116	59	70
159	0.45	0.49	0.91	0.74	0.79	4	46	29	34
163	1.04	1.19	2.22	1.76	1.88	15	118	72	84
Average						15	94	51	61

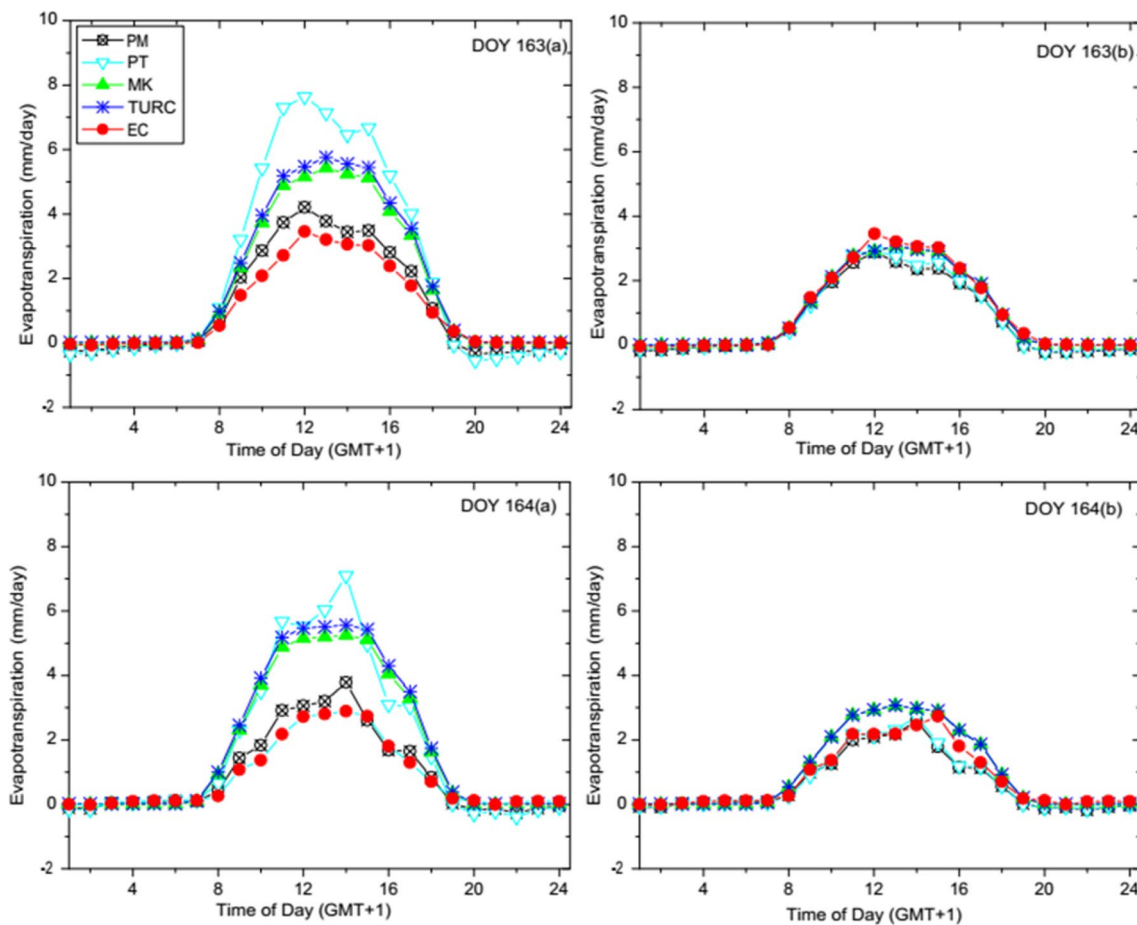
**Fig. 4** Period of observable strong dip in net and global radiation fluxes



**Fig. 5** Models response to dip in radiation fluxes







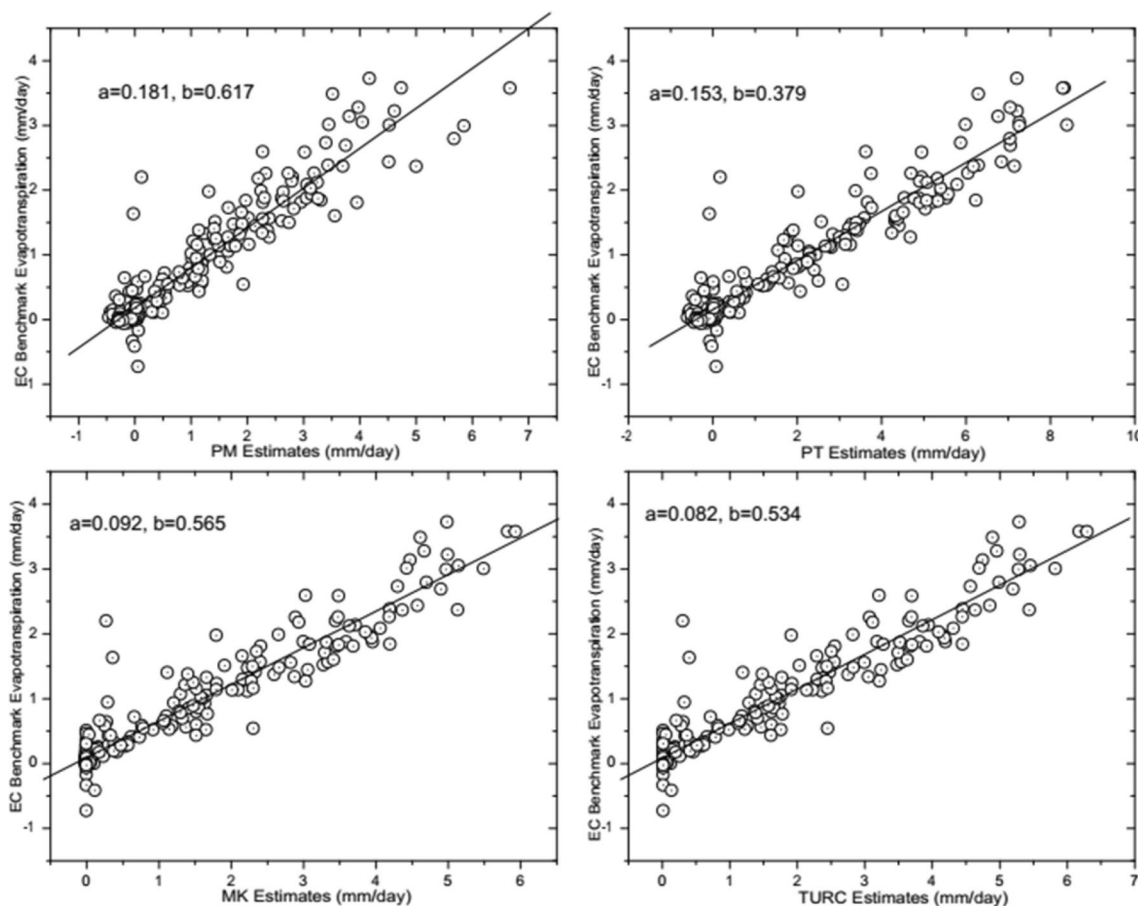
**Fig. 6** ET estimates from models before (a) and after (b) recalibration of coefficients

**Table 4** a Statistical analysis of ET models before coefficient adjustment. b Statistical analysis of ET models after coefficient adjustment

Model	MBE	RMSE	d	R <sup>2</sup>	b	a
(a) Before coefficient adjustment						
PM	0.14099	0.4225	0.99	0.99	0.774	0.124
PT	1.16843	2.1266	0.77	0.99	0.416	0.118
MK	0.72558	1.1407	0.94	0.99	0.592	-0.0075
TURC	0.84432	1.3104	0.92	0.99	0.561	-0.0174
(b) After coefficient adjustment						
PM <sub>c</sub>	-0.0625	0.1852	0.99	0.99	0.936	0.124
PT <sub>c</sub>	0.1459	0.4206	0.98	0.99	0.777	0.117
MK <sub>c</sub>	0.0989	0.1868	0.99	0.99	0.918	-0.0062
TURC <sub>c</sub>	0.0999	0.1795	0.99	0.99	0.927	-0.0174

recalibration has clearly improved the performance of both models and makes them suitable for this study location. In order to ensure a rigorous comparison of the performances of these models before and after recalibration, an extended analysis was performed using three different statistical indices for the estimated values. The result of these statistical tests is presented in Table 4a, b. Intercepts (a) and slopes (b) for the least squared regression

analysis also were obtained and reported (Fig. 7). while the adjusted versions of the ET models are presented in Table 5. These results further strengthen the investigation to see the influence of calibration on the performances of these models. As shown above all the statistical measures employed for the models performance evaluation are in agreement with the results obtained by the regression analysis. The errors reduced after adjustment for every



**Fig. 7** Least-square regression analysis of EC Benchmark values and ET model estimates

**Table 5** ET models and their corresponding adjusted versions for the study location

Original models	Adjusted model
$ET_{PM} = \frac{0.408\Delta(R_n - G) + \gamma 600U_2(e_s - e_a)}{\Delta + \gamma(1 + 0.56U_2)}$	$ET_{PM} = \frac{0.252\Delta(R_n - G) + \gamma 370.2U_2(e_s - e_a)}{\Delta + \gamma(1 + 0.56U_2)} + 0.181$
$ET_{PT} = 1.26 \frac{\Delta}{\Delta + \gamma} (R_n - G) / \lambda$	$ET_{PT} = \frac{0.478 \frac{\Delta}{\Delta + \gamma} (R_n - G)}{\lambda} + 0.153$
$ET_{MK} = 0.61 \frac{\Delta}{\Delta + \gamma} \frac{R_s}{\lambda} - 0.12$	$ET_{MK} = 0.345 \frac{\Delta}{\Delta + \gamma} \frac{R_s}{\lambda} - 0.028$
$ET_{TURC} = 0.013 \frac{T_a(23.9R_s + 50)}{T_a + 15}$	$ET_{TURC} = 0.0069 \frac{T_a(23.9R_s + 50)}{T_a + 15} + 0.082$

one of the models, the index of agreement came closer to unity though there was no much effect on intercept yet the regression analysis show an improved result in ET estimations after the models were calibrated, changing the slopes closer to unity.

**Conclusion**

The conclusions from this study were that the FAO-56 Penman–Monteith equation is suitable for Ile-Ife, a

tropical climate with or without adjustment especially if the bulk and aerodynamic resistances were calculated from local weather data. Also, the performance of the other empirical models improved once they were recalibrated by adjusting their original coefficient based on the measured ET values obtained from the EC technique. The improvement in the performance of the models requiring less input data will make irrigation scheduling less rigorous, cost effective and accessible.

**Acknowledgements** The authors acknowledge and appreciate the support in terms of meteorological sensors and guidance provided by the Atmospheric Physics Research Group (APRG, headed by Prof. O.O. Jegede), Physics and Engineering Physics Department, Obafemi Awolowo University, Ile-Ife, Nigeria.

## References

- Allen RG, Pereira LS, Reas D, Smith M (1998) Crop evapotranspiration guidelines for computing requirements. (FAO irrigation and Drainage paper 56. Food and Agric Organization, Rome, p 326)
- Allen RG, Pereira LS, Howell TA, Jensen ME (2011) Evapotranspiration information reporting 1: Factors governing measurement accuracy. *Agric Water Manag* 98(6):899–920
- Ayoola MA, Sunmonu LA, Ajao IA, Jegede OO (2014) Measurement of net all-wave radiation at a tropical location, Ile-Ife, Nigeria. *Atmosfera* 27(3):305–315
- Baldocchi D, Falge E, Gu L, Olson R, Hollinger D, Running S, Anthoni P, Bernhofer C, Davis K, Evans R, Fuentes J, Goldstein A, Katul G, Law B, Lee X, Malhi Y, Meyers T, Munger W, Oechel W, Pilegaard K, Schmid P, Valentini R, Verma S, Vesala T, Wilson K, Wofsy S (2001) FLUXNET: a new tool to study the temporal and spatial variability of ecosystem-scale carbon dioxide, water vapor, and energy flux densities. *Bull Am Meteorol Soc* 82:2415–2434
- Carrillo-Rojas G, Silva B, Córdova M, Célteri R, Bendix J (2016) Dynamic mapping of evapotranspiration using an energy balance-based model over an Andean Páramo catchment of Southern Ecuador. *Remote Sens* 8:160. doi:10.3390/rs8020160
- Daoo VJ, Panchal NS, Sunny F, Raj VV (2004) Scintillometric measurements of daytime atmospheric turbulent heat and momentum fluxes and their application to atmospheric stability evaluation. *Exp Therm Fluid Sci* 28(4):337–345
- Dingman SL (1994) *Physical hydrology*. Prentice hall, Upper saddle River
- Doorenbos J, Pruitt WO (1977) Crop water requirements, irrigation and drainage paper No. 24. Food and Agriculture organization, Rome
- Fontenot R (2004) An evaluation of reference ET models in Louisiana. M.sc thesis, Baton Rouge, LA: Louisiana state University, Agricultural and Mechanical College, Dept. of Geography and Anthropology. <http://etd.lsu.edu/docs/available/etd-06302004-153939/>
- Fox DG (1981) Judging air quality model performance: A summary of the AMS workshop on Dispersion Model Performance. *Bull Am Meteorol Soc* 62:599–609
- Hansen VE, Israelsen OW, Stringham GE (1980) *Irrigation principles and practices* 4th edn. Wiley, New York
- Hargreaves GH, Samani ZA (1985) Reference crop evapotranspiration from temperature. *Appl Eng Agric* 1(2):96–99
- Houshang G, Vahid R, Erfan K, Hossein M (2012) Time and place calibration of the Hargreaves equation for estimating monthly reference evapotranspiration under different climatic conditions. *J Agric Sci* 4:3
- Howell TA, Schneider AD, Jensen ME (1991). History of Lysimeter design and use for evapotranspiration measurements. In: Howell RGTA, Pruitt WO, Walter IA, Jensen ME (eds.) *Lysimeters for evapotranspiration and environmental measurements*, pp 1–9. American Soc Civil Engineers, New York
- Irmak S, Haman DZ, Jones JW (2002) Evaluation of class A pan coefficients for estimating reference evapotranspiration in humid location. *J Irrig Drain Eng* 128(3):153–159
- Jegede OO, Ogolo EO, Aregbesola TO (2006) Estimating net radiation using routine meteorological data at a tropical location in Nigeria. *Int J Sustain Energy* 25(2):107–115
- Jensen ME, Burman RD, Allen RG (1990) *Evapotranspiration and Irrigation water requirements*. American Society of civil Engineers, Manuals and Report on Engineering practice No. 70, New York
- Krause P, Boyle DP, Base F (2005) Comparison of different efficiency for hydrological model assessment. *Adv Geosci* 5:89–97
- Licciardello F, Zema DA, Zimbone SM, Bingner RL (2007) Runoff and soil erosion evaluation by the AnnAGNPS model in a small Mediterranean Watershed. *Transac ASAE* 50(5):1585–1585
- Loague K, Green RE, 1991. Statistical and Graphical methods for evaluating solute transport models: overview and application. *J Contam Hydrol JCOHE6* 7(112): P51–73
- Makkink GF (1957) Testing the Penman Formula by means of lysimeters. *J Inst Water Eng* 11(3):277–288
- Martano P (2015) Evapotranspiration estimates over non-homogeneous mediterranean land cover by a calibrated “Critical Resistance”. *Approach Atmos* 6:255–272. doi:10.3390/atmos6030255
- Maselli F, Papale D, Chiesi M, Matteucci G, Angeli L, Raschi A, Seufert G (2014) Operational monitoring of daily evapotranspiration by the combination of modis ndvi and ground meteorological data: Application and evaluation in central italy. *Remote Sens Environ* 152:279–290
- Odi-Lara M, Campos I, Neale CMU, Ortega-Farías S, Poblete-Echeverría C, Balbontín C, Calera A (2016) Estimating Evapotranspiration of an Apple Orchard Using a Remote Sensing-Based Soil Water Balance. *Remote Sens* 8:253. doi:10.3390/rs8030253
- Panda RK, Kashyap PS (2001) Evaluation of evapotranspiration estimation methods and development of crop coefficients for potato crop in a sub-humid region. *Elsevier Agric Water Manag* 50(1):9–25
- Pereira LS, Perrier A, Allen RG, Alves I (1999) Evapotranspiration: concepts and future trends. *J Irrig Drain Eng ASCE* 131(1):37–58
- Priestly CHB, Taylor RJ (1972) On the assessment of surface heat flux and evaporation using large-scale parameters. *Monthly Weather Rev* 100(2):81–92
- Tabari H, Talaee PH (2011) Local calibration of the Hargreaves and Priestly-Taylor equations for estimating reference ET in Arid and cold climates of Iran based on the Penman-monteith. *J Hydrol Eng* 16(10):837–845
- Thornthwaite CW (1948) An approach towards a rational classification of climate. *Geogr Rev* 38:55–94
- Turc L (1961) Evaluation des besoins en eau d’irrigation évapotranspiration potentielle, formule climatique simplifiée et mise à jour. (In French). *Ann Agron* 12(1):13–49
- Watson I, Burnett AD (1995) *Hydrology, an environmental approach*. CRC press, Boca Raton
- Willmott CJ (1982) Some comments on the evaluation of model performance. *Bull Am Meteorol Soc* 63(11):1309–1313
- Willmott CJ (1981) On the Validation of Models. *Phys Geogr* 2:184–194
- Willmott CJ, Ankleson SJ, Davis RE, Feddema JJ, Klink KM, Legates DR (1985) Statistics for the evaluation and comparison of models. *J Geophys Res* 90(5):8995–9005
- Zhang H, Gorelick SM, Avise N, Tilmant A, Rajsekhar D, Yoon J (2016) A new temperature-vegetation triangle algorithm with variable edges (TAVE) for satellite-based actual evapotranspiration estimation. *Remote Sens* 8:735. doi:10.3390/rs8090735