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ORIGINAL PAPER

Daily reference crop evapotranspiration in the humid environments of Azores islands using reduced data sets: accuracy of FAO-PM temperature and Hargreaves-Samani methods

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Abstract Reference crop evapotranspiration (ET_o) estimations using the FAO Penman-Monteith equation (PM-ET_o) require several weather variables that are often not available. Then, ET_o may be computed with procedures proposed in FAO56, either using the PM-ET_o equation with temperature estimates of actual vapor pressure (e_a) and solar radiation (R_s), and default wind speed values (u_2), the PMT method, or using the Hargreaves-Samani equation (HS). The accuracy of estimates of daily e_a, R_s, and u_2 is provided in a companion paper (Paredes et al. 2017) applied to data of 20 locations distributed through eight islands of Azores, thus focusing on humid environments. Both estimation procedures using the PMT method ($ET_{o\ PMT}$) and the HS equation ($ET_{o\ HS}$) were assessed by statistically comparing their results with those obtained for the PM-ET_o with data of the same 20 locations. Results show that both approaches provide for accurate ET_o estimations, with RMSE for PMT ranging 0.48–0.73 mm day^{-1} and for HS varying 0.47–0.86 mm day^{-1}. It was observed that $ET_{o\ PMT}$ is linearly related with PM-ET_o, while non-linearity was observed for $ET_{o\ HS}$ in weather stations located at high elevation. Impacts of wind were not important for HS but required proper adjustments in the case of PMT. Results show that the PMT approach is more accurate than HS. Moreover, PMT allows the use of observed variables together with estimators of the missing ones, which improves the accuracy of the PMT approach. The preference for the PMT method, fully based upon the PM-ET_o equation, is therefore obvious.

1 Introduction

The reference crop evapotranspiration (ET_o) is essential for characterizing the local climate and for computing crop and vegetation evapotranspiration, water and irrigation requirements as well as for crop water management, irrigation planning and management, hydrologic and water balance studies, climate characterization, and climate change analysis. Following conceptual and computational discussions by Pereira et al. (1999, 2015), a brief review was presented in the companion paper (Paredes et al. 2017) focusing on the estimation of the actual vapor pressure (e_a, kPa), short wave radiation (R_s, MJ m^2 day^{-1}), and wind speed at 2 m height (u_2, m s^{-1}) when observations data are not available. The accuracy of using those estimates for computing ET_o replacing the respective missing variables in the PM-ET_o, as recommended by Allen et al. (1998), was assessed by comparing the respective results with those obtained with the PM-ET_o with full data

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sets. The results for accuracy were very good for all the three estimated variables, particularly considering the monthly variability of weather variables in Azores (Fig. S1 in the Supplementary Material).

The use of the referred approaches for estimating the parameters of the PM-ET$_o$ equation allows computing ET$_o$ with temperature data only as proposed in FAO56 (Allen et al. 1998). This approach to cope with missing weather data is known as reduced set PM equation or PM temperature approach (PMT) as in the current paper. As analyzed by Annandale et al. (2002), errors resulting from estimating weather parameters are "somewhat compensated for by the absence of error that would have been resident in the measurements". Hargreaves and Allen (2003) also compared the Hargreaves-Samani equation (11) with the PMT approach following that the HS equation was proposed in FAO56 as an alternative for ET$_o$ computation when only temperature data are available (Allen et al. 1998). The referred assessments evidence the need for good quality of weather data.

Researchers have generally not adhered to using the methods proposed in FAO56 (Allen et al. 1998) to estimate the missing variables and adopting the PMT approach; instead, they easily adopted the HS equation, simpler and easier to use than the PMT approach, and/or searched for alternative ET equations and numerical and heuristic methods for estimating ET$_o$ as revised by Pereira et al. (2015). Nevertheless, as stated by these authors, while using different equations and estimation methods may ease computational approaches, there is no replacement for basic Physics as it is represented in the PM-ET$_o$ formulation. Using alternative equations may induce changes in the basic Physics relationships as expressed by the non-linearity of relations between HS and PM-ET$_o$ equations shown by Raziei and Pereira (2013a), particularly for locations marked by aridity and wind speed. Differently, adopting estimated values for the missing variables, particularly R_s and e_a, has the merit of allowing explicit review of the estimates and their behavior and accuracies prior to computations, e.g., Paredes et al. (2017), as well as to approach the basic Physics represented in the PM-ET$_o$ equation (Pereira et al. 2015). Likely for this reason, trends in ET$_o$ computed with the HS equation differ of PM-ET$_o$ largely more than those computed with PMT (Ren et al. 2016). Meanwhile, using geostationary satellite imagery (De Bruin et al. 2010; Cammalleri and Ciraolo 2013) is a good alternative for reduced data sets, and using gridded data sets and reanalysis weather products consist of computational alternatives that do not require new equations or new numerical methods but just applies the PM-ET$_o$ directly and accurately (Raziei and Pereira 2013b; Martins et al. 2017).

Few attempts to assess the accuracy of the PMT method are available in literature; contrarily, the performance of the HS equation is often reported in literature, including for humid climates. Irmak et al. (2003) for Florida, Yoder et al. (2005) in humid Southeast United States, and Trajkovic and Kolakovic (2009) in Western Balkans found poor performance of HS equation for humid conditions. Differently, other authors found good results for humid climates when calibrating the Hargreaves coefficient (Sentelhas et al. 2010; Tabari et al. 2013), or the k_{Rs} coefficient (Todorovic et al. 2013; Raziei and Pereira 2013a; Almorox and Grieser 2016; Ren et al. 2016), and/or when replacing the exponent of (T_{max} − T_{min}) by a value smaller than the original 0.5 (Trajkovic 2007; Almorox and Grieser 2016). However, for an exponent different of 0.5 (Eqs. 9 and 11), the k_{Rs} coefficient varies in a much wider interval (e.g., Almorox et al. 2016) and cannot be considered anymore as to reflect the volumetric heat capacity of the atmosphere. Our approaches to compute the HS equation (Raziei et al. 2013a; Ren et al. 2016) were also applied by Almorox et al. (2016) and their results confirmed ours when calibrating k_{Rs} but not when changing the exponent. However, as discussed by Hargreaves and Allen (2003), recalibrations increase the complexity of the HS equation.

The first PMT studies closely followed the recommendations provided by Allen et al. (1998) and include those reported by Liu and Pereira (2001) and Pereira et al. (2003) for China, Popova et al. (2006) for Bulgaria, all referring to humid or sub-humid locations, and Jabloun and Sahli (2008), which also covered arid climates. All these studies have shown a better performance of the PMT approach relative to the HS equation. Moreover, those studies assessed positively the replacement of missing variables by their estimators as proposed by Allen et al. (1998): R_s computed from the T_{max} and T_{min} difference, e$_a$ computed with T_{min} replacing dew point temperature (T_{dew}), as well as assuming the world average value of $u_2 = 2$ m s^{-1}. Earlier studies by Annandale et al. (2002) were the first proposing a software to perform computations of ET$_o$ with the PM-ET$_o$ method and where missing variables were computed with those approaches. Another similar software was lately developed by Gocic and Trajkovic (2010), also including the HS equation.

ET$_o$ was estimated with the PM-ET$_o$ equation using daily weather forecast messages, i.e., R_s was estimated from the forecasted cloudiness and T_{max} and T_{min}; the actual vapor pressure, e_a, was estimated assuming $T_{dew} = T_{min}$, and u_2 was computed from the forecasted wind speed (Cai et al. 2007). This study referred to various Chinese sites with climates ranging from desert to humid. Errors of estimation of R_s and e_a were small and those for estimation of ET$_o$ were also small excepting for a hyper-arid location. Further, Cai et al. (2009) used daily weather forecast messages to estimate R_s, e_a, and u_2 for computing ET$_o$ used as input to a water balance model adopted for real time management of various field irrigation treatments of wheat. Good performances of the ET_o and of its use in modeling were obtained (Cai et al. 2009). More recent studies have demonstrated that better performance of PMT is obtained when calibrating k_{Rs} and adopting appropriate approaches to correct temperature when estimating e_a (Todorovic et al. 2013; Raziei and Pereira 2013a; Ren et al. 2016). In addition, these studies have shown that k_{Rs} varies with climate aridity. Differently, when there is no correction of T_{min} as estimator of T_{dew} and if k_{Rs} is not calibrated, e.g., Martínez and Thepadia (2010), a poor performance of the PMT method may result.

Considering the discussion above on alternative procedures to compute ET_o with reduced data sets and to estimate the missing variables as in the companion paper by Paredes et al. (2017) which provided for the first time appropriate information on estimating ET_o and related missing variables in humid islands environments, the objectives of this study consist of (a) evaluating the accuracy of estimating daily ET_o with the HS equation and the PMT approach and (b) assessing the impacts of wind speed estimation on the accuracy of the PMT approach. Computations apply to full weather data sets from 20 meteorological stations located in eight out of the nine islands of Azores.

2 Materials and methods

2.1 Study area and data

The archipelago of Azores comprises nine islands and is located in the North Atlantic at latitudes 36° 45′ N to 39° 43′ N and longitudes 24° 45′ W to 31° 17′ W (Fig. S2 in Supplementary Material). A description of the climate of the archipelago and of the weather stations was provided in the companion paper (Paredes et al. 2017).

Daily data used in the present study was collected in 20 weather stations in eight islands whose locations, basic climate characteristics and size of data sets are described in Table 1. Data included precipitation (P), maximum and minimum air temperatures (T_{max} and T_{min}, °C), relative humidity (*RH*, %), wind speed (m s^{-1}), and solar radiation (R_s, Watt m^{-2}) or sunshine duration (*n*, h). A supplemental description of weather stations is given in Table S1 (Supplementary Material).

The Azorean climate is strongly influenced by its location in the middle of the North Atlantic Ocean, in a transition region between the sub-tropical Azores high pressure system and the mid-latitude storm track, and shows two clear seasons, winter when Azores are frequently crossed by the North Atlantic storm track (October to March concentrates 75% of the precipitation and two thirds of rainy days) and summer when climate is particularly influenced by the Azores anticyclone (Santos et al. 2004). Main characteristics of weather variables used in this study were analyzed in the companion paper and are available in Fig. S1 (Supplementary Material). Considering the focus of this paper and the importance of knowing ET_o for crop and vegetation studies, namely when looking to climate change impacts and adaptation (e.g., Santos et al. 2004; Miranda et al. 2006), Fig. 1 shows the box-and-whisker plots of monthly PM-ET_o for selected stations and the period of observations used in this study. Stations were selected to represent most of islands and related effects of longitude, and low and high altitude. The importance given to altitude relates to the type of pasture land use. Data show a clear distinction between summer and winter months, that ET_o is much smaller in stations at medium to high elevation (S. Caetano, S. Bárbara, Lagoa do Fogo, and Fontinhas), and that ET_o has a great variability in every month, particularly during summer, which is due to the frequent occurrence of cloud cover and precipitation.

2.2 Reference evapotranspiration computations

Grass reference ET_o was defined by FAO after parameterizing the Penman-Monteith equation for a cool season grass (FAO56, Allen et al. 1998). Following Allen et al. 1998, daily PM-ET_o (mm day^{-1}) is given as

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \dfrac{900}{T_{mean} + 273} u_2(e_s - e_a)}{\Delta + \gamma\,(1 + 0.34\,u_2)} \qquad (1)$$

where R_n is the net radiation at the crop surface (MJ m^{-2} day^{-1}), G is the soil heat flux density (MJ m^{-2} day^{-1}), T_{mean} is the mean daily air temperature at 2 m height (°C), u_2 is the wind speed at 2 m height (m s^{-1}), e_s is the saturation vapor pressure (kPa), e_a is the actual vapor pressure (kPa), VPD or e_s-e_a is the saturation vapor pressure deficit (kPa), Δ is the slope vapor pressure curve (kPa $°C^{-1}$), and γ is the psychrometric constant (kPa $°C^{-1}$). For daily computations, G equals zero as the magnitude of daily soil heat flux beneath the grass reference surface is very small (Allen et al. 1998). Hence, computations of PM-ET_o require observed data on T_{max} and T_{min}, R_s or sunshine duration (n), *RH* or psychrometric data, and wind speed at 2 m height (u_2). Although T_{max} and T_{min} are commonly well observed in many locations, the other variables are often not observed with good quality, or data sets are short and/or have frequent gaps, and their acquisition may be very expensive.

Computations require the adoption of the standard methods proposed by Allen et al. (1998) for computing the various parameters of Eq. (1). The vapor pressure deficit (VPD,

Table 1 Weather stations characteristics and date ranges of the weather data series

Weather stations	Island	Latitude (N)	Longitude (W)	Elevation (m)	P/PET*	Köppen classe	Observations	
							Dates	Number of days
Santa Cruz das Flores**	Flores	39° 27′ 31.11″	31° 07′ 49.65″	28	4.9	Cfb	2003–2013	3539
Horta**	Faial	38° 31′ 45.31″	28° 37′ 43.20″	40	3.4	Cfb	2006–2010	3349
São Caetano	Pico	38° 27′ 0.32″	28° 26′ 2.42″	770	8.6	Csb	2011–2014	936
Velas**	São Jorge	38° 39′ 51.08″	28° 10′ 14.94″	99	4.1	Csa	2012–2013	283
Santa Cruz da Graciosa**	Graciosa	39° 5′ 29.76″	28° 1′ 32.52″	30	2.0	Csa	2013–2017	1307
Angra do Heroísmo	Terceira	38° 39′ 31.68″	27° 13′ 22.8″	74	2.9	Csb	2003–2013	2607
Granja	Terceira	38° 41′ 45.88″	27° 10′ 14.51″	370	4.8	Csb	1996–1998 and 2002–2011	4619
Lajes**	Terceira	38° 45′ 21.68″	27° 04′ 59.86″	54	3.3	Csb	2000–2014	5478
Ribeirinha	Terceira	38° 40′ 24.16″	27° 10′ 43.27″	390	5.1	Csb	1996–1997 and 2002–2010	3780
Santa Bárbara	Terceira	38° 43′ 38.85″	27° 19′ 47.81″	800	7.1	Csb	2002–2011	3594
Chã Macela	S. Miguel	37° 45′ 52.49″	25° 31′ 55.24″	310	3.4	Csa	2010–2014	1095
Lagoa do Fogo	S. Miguel	37° 45′ 50.03″	25° 29′ 43.98″	890	7.5	Csb	2007–2012	1612
Furnas	S. Miguel	37° 45′ 42.56″	25° 19′ 44.05″	289	5.9	Csb	2006–2014	3922
Ponta Delgada	S. Miguel	37° 44′ 38.76″	25° 42′ 28.80″	71	2.9	Csa	2002–2014	3348
Santana	S. Miguel	37° 48′ 17.62″	25° 33′ 42.65″	70	4.0	Csa	2000–2012	3376
Sete Cidades	S. Miguel	37° 52′ 4.60″	25° 46′ 19.37″	260	6.1	Csa	2002–2009	2167
Tronqueira	S. Miguel	37° 46′ 9.91″	25° 11′ 51.14″	500	5.9	Csb	2010–2014	1332
Maia	Santa Maria	36° 56′ 25.38″	25° 1′ 3.18″	200	3.7	Csa	2011–2017	2249
Praia Formosa	Santa Maria	36° 57′ 9.79″	25° 5′ 35.81″	180	2.8	Csa	2011–2014	1183
Fontinhas	Santa Maria	36° 57′ 45.52″	25° 4′ 34.27″	420	3.6	Csa	2010–2014	1282

*Potential evapotranspiration (PET) computed with Thornthwaite equation

**Weather stations located at airports but on grass

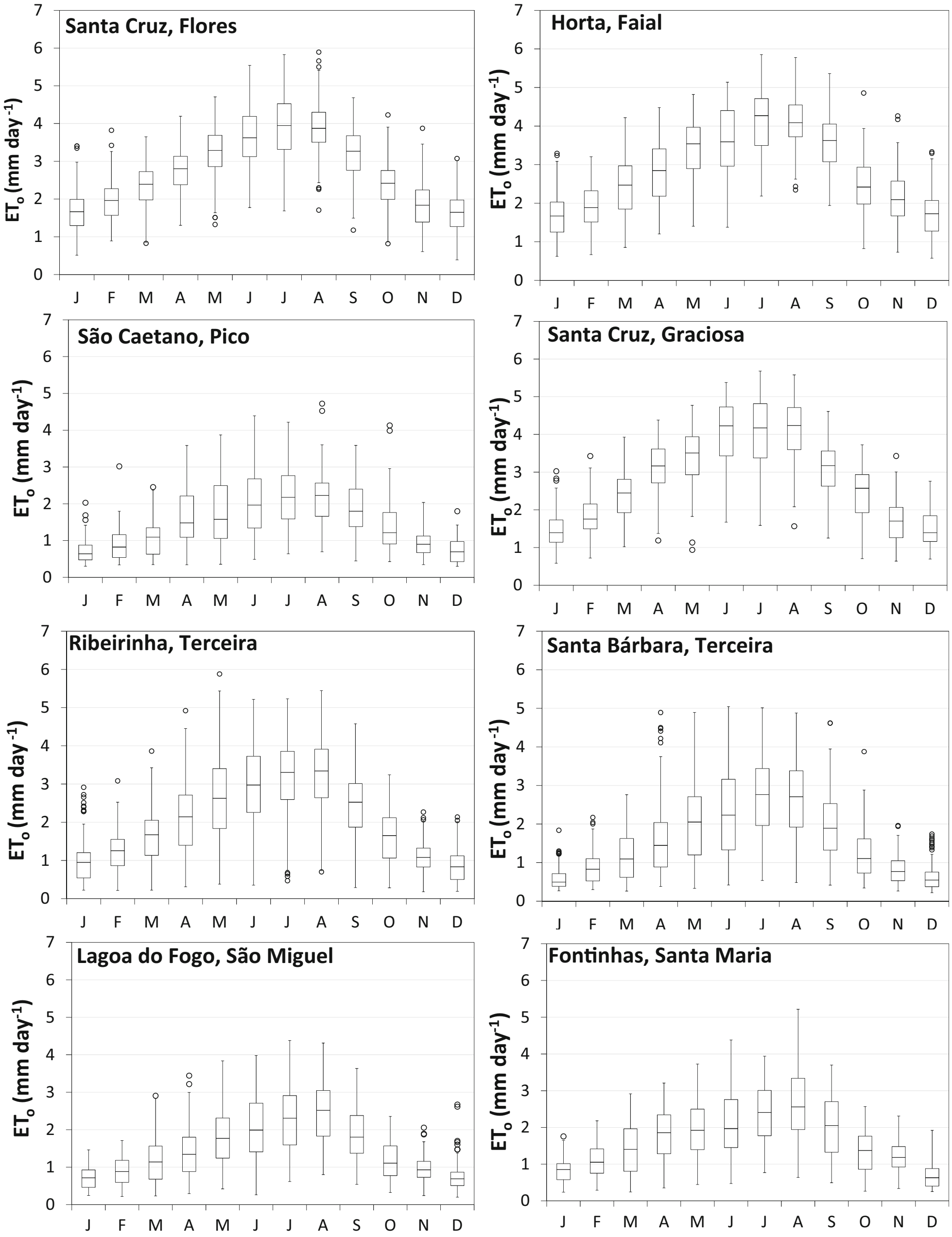

Fig. 1 The box-and-whisker plots including outliers (○) of monthly PM-ET_o for selected stations. **a** Santa Cruz, Flores Island. **b** Horta, Faial Island. **c** São Caetano, Pico island. **d** Santa Cruz, Graciosa Island. **e** Ribeirinha, Terceira Island. **f** Santa Bárbara, Terceira Island. **g** Lagoa do Fogo, São Miguel Island. **h** Fontinhas, Santa Maria Island. The periods of observations are those in Table 1

kPa), difference between the saturation vapor pressure (e_s, kPa) and the actual vapor pressure (e_a, kPa), is computed with e_s given as

$$e_s = \frac{e^o(T_{max}) + e^o(T_{min})}{2} \tag{2}$$

where $e^o(T_{max})$ and $e^o(T_{min})$ are the saturation vapor pressure at respectively the maximum and minimum daily temperatures (kPa), and e_a computed as

$$e_a = \frac{e^o(T_{min})\frac{RH_{max}}{100} + e^o(T_{max})\frac{RH_{min}}{100}}{2} \tag{3}$$

when there are observations of maximum and minimum relative humidity, RH_{max} and RH_{min} (%), or as

$$e_a = \frac{RH_{mean}}{100}\left[\frac{e^o(T_{max}) + e^o(T_{min})}{2}\right] \tag{4}$$

when only the mean daily relative humidity (RH_{mean}, %) was available.

Considering that $e_a = e^o(T_{dew})$, T_{dew} is computed from e_a as

$$T_{dew} = \frac{116.91 + 237.3 \ln(e_a)}{16.78 - \ln(e_a)} \tag{5}$$

When RH data are missing, considering the relations for T_{dew}

in moist air (Lawrence 2005), for humid climates T_{dew} is above T_{min} and can be approximated using an empirical temperature adjustment coefficient a_d (°C) that was locally calibrated for Azores as described in the companion paper (Paredes et al. 2017). Thus, T_{dew} is estimated as

$$T_{dew} = \left(\frac{T_{max} + T_{min}}{2}\right) - a_d \tag{6}$$

resulting that the actual vapor pressure is estimated from T_{dew} ($e_{a\ Tdew}$) adjusted with the calibrated parameter a_d as

$$e_{a\ Tdew} = e^o(T_{dew}) = 0.611 \exp\left[\frac{17.27\,(T_{mean} - a_d)}{(T_{mean} - a_d) + 237.3}\right] \tag{7}$$

where T_{dew} is replaced by its value given by Eq. 6. As described in the companion paper, that estimation procedure was performed with very good accuracy.

Solar radiation, R_s, was observed in all but one weather stations, Lajes, where sunshine duration (n, h) was observed; hence, R_s was calculated as

$$R_s = \left(a_s + b_s \frac{n}{N}\right) R_a \tag{8}$$

where, in addition to variables previously defined, N is the maximum possible daylight hours [h], n/N is the relative sunshine duration [−], R_a is the extraterrestrial radiation [MJ m^{-2} day^{-1}], a_s is the fraction of extraterrestrial radiation reaching the earth on overcast days ($n = 0$), and $a_s + b_s$ is the fraction of extraterrestrial radiation reaching the earth on clear sky days ($n = N$). Despite knowing that a greater accuracy of calculations with Eq. 8 is obtained when parameters a_s and b_s are locally calibrated, the default parameters $a_s = 0.25$ and $b_s = 0.50$ were used as recommended by Allen et al. (1998).

In the absence of observations, Allen (1997) and Allen et al. (1998) proposed to estimate R_s for use with the PM-ET_o equation using the Hargreaves and Samani (1982) equation that expresses R_s as a linear function of the square root of the temperature difference $T_{max} - T_{min}$:

$$R_{s\ TD} = k_{R_s}(T_{max} - T_{min})^{0.5} R_a \tag{9}$$

where k_{Rs} is an empirical radiation adjustment coefficient (°$C^{-0.5}$) and R_a is the extraterrestrial radiation (MJ m^2 day^{-1}). In this study, as described in the companion paper, the ET_o estimates using Eq. 9 have shown a very good accuracy when k_{Rs} were calibrated for all locations used in this study (Paredes et al. 2017).

Allen et al. (1998) proposed the use of the world average wind speed value $u_2 = 2$ m s^{-1} as default value ($u_{2\ def}$) when wind speed data are missing. This default value was adopted for all stations except those located in airports but over grass, where $u_{2\ def} = 3$ m s^{-1} was adopted due to high exposure to winds of all directions. Another studied alternative refers to the average wind speed data ($u_{2\ avg}$) as considered by Popova et al. (2006) and Jabloun and Sahli (2008). To adjust wind speed data obtained from instruments placed at heights other than the standard height of 2 m, the following logarithmic wind speed profile (Allen et al. 1998) was used:

$$u_2 = u_z \frac{4.87}{\ln(67.8\ z\ -\ 5.42)} \tag{10}$$

where u_2 is the wind speed at 2 m above ground surface [m s^{-1}], u_z is the measured wind speed at z m height [m s^{-1}], and z is the height of measurement above ground surface [m].

The use of the above referred approaches for estimating the parameters of the PM-ET_o equation allows computing ET_o with temperature data only as proposed in FAO56 (Allen et al. 1998). This approach is known as reduced set PM equation or PM-ET_o temperature approach (PMT) as in the current paper.

The Hargreaves-Samani equation (HS, Hargreaves and Samani 1985) is also used in the current study. The HS equation estimates ET_o ($ET_{o\text{-}HS}$, mm d^{-1}) from $T_{max} - T_{min}$ and is written (Todorovic et al. 2013) as

$$ET_{o-HS} = 0.0135\ k_{Rs} \frac{R_a}{\lambda} (T_{max} - T_{min})^{0.5} (T_{mean} + 17.8) \tag{11}$$

where λ is the latent heat of vaporization (MJ kg^{-1}) for the mean air temperature T_{mean} (°C) and assumed to be 2.45 MJ kg^{-1}, and k_{Rs} (°$C^{-0.5}$) and R_a (MJ m^2 d^{-1}) as defined for Eq. 9. The constant 0.0135 is a factor for conversion from American to the International system of units. k_{Rs} was calibrated for all locations and for two seasons, winter and summer as reported by Paredes et al. (2017). The calibrated k_{Rs} values are used with the PMT approach but a distinct calibration was performed for the HS equation.

Results of both ET_o temperature estimation approaches were compared with the PM-ET_o using full data sets as described in the next section.

2.3 Accuracy indicators

The accuracy of ET_o computations with the PMT method ($ET_{o\text{-}PMT}$) and the HS equation ($ET_{o\ HS}$) was evaluated by comparing their results with those of the PM-ET_o equation using full data sets. As per previous applications to ET_o studies, namely by Martins et al. (2017) and similarly to assessments reported in the companion paper (Paredes et al. 2017), accuracy was measured with several statistical indicators:

1. The regression coefficient (b_0) of the regression forced to the origin (FTO) between daily PM-ET_o computed with

observed data, O_i, and daily ET_o computed with predicted variables, P_i. Values of b_0 near 1 indicates that O_i and P_i are statistically close while $b_0 > 1$ suggests overestimation and $b_0 < 1$ underestimation.

2. The determination coefficient (R^2) of the ordinary least squares (OLS) regression between O_i and P_i, where a value close to 1.0 indicates that most of the variation of the PM-ET_o values is explained by the simplified computation approach.
3. The root mean square error (RMSE, mm day^{-1}) measures overall discrepancies between observed and estimated values, thus should be as small as possible.
4. The percent bias (PBIAS, %), which is a normalized difference between the means of both sets O_i and P_i, that indicates the average tendency for P_i under- or overestimate O_i.
5. The Nash and Sutcliffe (1970) modeling efficiency (EF, non-dimensional) that provides an indication of the relative magnitude of the mean square error ($MSE = RMSE^2$) relative to the observed data variance (Legates and McCabe Jr. 1999). The best value is EF = 1.0 that represents a perfect match between P_i and O_i and EF close to 1 means that the "noise" is negligible relative to the "information', implying that alternative-based values of ET_o are good estimators of PM-ET_o values.

The joint assessment of this set of indicators provides a good evaluation of the quality of ET_o computed with the PMT and HS approaches as in previous applications (Martins et al. 2017).

3 Results and discussion

3.1 Accuracy of the FAO-PMT method for ET_o estimations

As previously analyzed in Section 2.2, the PMT computations included the use of T_{mean} for T_{dew} and e_a estimation ($e_{a\ Tdew}$, Eqs. 6 and 7), of the squared root of the temperature difference $T_{max} - T_{min}$ for R_s calculations ($R_{s\ TD}$, Eq. 8), and of the $u_{2\ avg}$ and $u_{2\ def}$, referring respectively to the local average and to the default wind speed. Both the temperature adjustment coefficient a_d (Eq. 6) and the radiation adjustment factor k_{Rs} (Eq. 8) were calibrated for all locations and both the winter and summer seasons (Paredes et al. 2017) and are used herein for $ET_{o\text{-}PMT}$ calculations.

$ET_{o\text{-}PMT}$ estimations using the winter and summer calibrated a_d (Eq. 6) and k_{Rs} (Eq. 8) and both wind speed estimators $u_{2\ avg}$ and $u_{2\ def}$ yielded very good accuracy indicators as shown in Table 2. When winter and summer calibrated a_d and/or k_{Rs} were different, computations were performed assigning those different values to the corresponding winter and summer months. Indicators in Table 2 are somewhat different due to using both $u_{2\ avg}$ and $u_{2\ def}$. A detailed analysis by location may be performed using Table 2 but a global analysis is easier when considering the frequency of the various indicators as depicted in Fig. 2.

Accuracy indicators when $u_{2\ avg}$ was used (Table 2 and Fig. 2) were good, nevertheless with a slight tendency for underestimation of PM-ET_o values, with b_0 generally close to 1.0 but varying from 0.94 to 1.01. Coherently, PBIAS results indicate an underestimation bias ranging from − 5 to − 10.2% in 65% of the locations, and a quite low PBIAS, ranging from − 5 to 2.5%, in 35% of the locations. R^2 values are higher than 0.60 in 85% of cases, which indicates that the variance of PM-ET_o is quite well explained by the OLS regression on $ET_{o\text{-}PMT}$. Using the default wind speed $u_{2\ def}$, the underestimation tendency prevails, with b_0 ranging from 0.93 to 1.0, although PBIAS varied in a wider interval of − 10.4 to 3.1%, so including a few overestimation bias. R^2 values have a distribution similar to that relative to $u_{2\ avg}$, also with 85% of cases with $R^2 > 0.60$. Estimation errors are small for all locations, with RMSE ranging from 0.47 to 0.74 mm day^{-1} when $u_{2\ avg}$ is used, and 0.48 to 0.73 mm day^{-1} if $u_{2\ def}$ is used. EF values are good and also quite similar for both estimators, ranging from 0.49 to 0.75 and from 0.46 to 0.76 respectively when $u_{2\ avg}$ or $u_{2\ def}$ are used. It may be concluded that both wind speed estimators provide for similar accuracy indicators and therefore there is evidence that $u_{2\ def}$ may be commonly used with the PMT approach together with the estimators of actual vapor pressure and short wave radiation when both a_d and k_{Rs} are seasonally calibrated.

Similar to ours (0.48 to 0 73 mm day^{-1}), RMSE values were reported for daily ET_o computations using the PMT approaches in inland sub-humid climates (Popova et al. 2006, Jabloun and Sahli 2008; Ren et al. 2016). Poor results were reported by Sentelhas et al. (2010) with RMSE up to 1.218 mm day^{-1} likely due to absence of adjustments of T_{dew} and k_{Rs}. Differently, Almorox et al. (2016) reported lower RMSE values for humid climates when calibrating k_{Rs} for local conditions as well as when using $T_{dew} = T_{min}$ and $T_{dew} = T_{min}-2$. Also better results are reported by Raziei and Pereira (2013a) for humid climates of Iran. Using ANNs to estimate ET_o for the Basque region, northern Spain, Landeras et al. (2008) reported RMSE averages similar to our results when computations were performed with temperature data only. For the same region, Shiri et al. (2012, 2013), reported slightly better RMSE averages, also similar to ours, when using gene expressing programming or a neuro-fuzzy model with T_{max} and T_{min} only. Referred studies are, however, for less humid and windy climates than Azores islands but

Table 2 Accuracy of the $ET_{o\text{-}PMT}$ estimation using both the u_2 local average ($u_{2\ avg}$) and a default value ($u_{2\ def}$) considering the calibrated adjustment factors for T_{dew} (a_d) and for solar radiation (k_{Rs})

Weather station	a_d (°C)	k_{Rs} (°C$^{-0.5}$)	u_2 (m s^{-1})	b_0	R^2	RMSE (mm day^{-1})	PBIAS (%)	EF
Santa Cruz, Flores	$a_d = 4$	Winter: $k_{Rs} = 0.19$ Summer: $k_{Rs} = 0.21$	$u_{2\ avg} = 3.2$	0.98	0.68	0.63	− 2.7	0.67
	$a_d = 4$	Winter: $k_{Rs} = 0.19$ Summer: $k_{Rs} = 0.21$	$u_{2\ def} = 3.0$	0.98	0.68	0.63	− 1.6	0.67
Horta	$a_d = 3.5$	$k_{Rs} = 0.25$	$u_{2\ avg} = 3.8$	0.98	0.67	0.72	− 6.3	0.66
	$a_d = 3.5$	$k_{Rs} = 0.25$	$u_{2\ def} = 3.0$	0.95	0.67	0.72	1.1	0.66
São Caetano	Winter: $a_d = 1.5$ Summer: $a_d = 2$	$k_{Rs} = 0.18$	$u_{2\ avg} = 3.0$	0.95	0.58	0.56	− 8.4	0.56
	Winter: $a_d = 1.5$ Summer: $a_d = 2$	$k_{Rs} = 0.18$	$u_{2\ def} = 2.0$	0.95	0.58	0.56	− 8.1	0.56
Velas	$a_d = 3.5$	$k_{Rs} = 0.20$	$u_{2\ avg} = 3.8$	0.97	0.57	0.62	− 4.8	0.56
	$a_d = 3.5$	$k_{Rs} = 0.20$	$u_{2\ def} = 3.0$	0.96	0.58	0.61	− 2.4	0.57
Santa Cruz, Graciosa	$a_d = 3.5$	Winter: $k_{Rs} = 0.19$ Summer: $k_{Rs} = 0.22$	$u_{2\ avg} = 3.9$	0.97	0.68	0.66	− 1.8	0.68
	$a_d = 3.5$	Winter: $k_{Rs} = 0.19$ Summer: $k_{Rs} = 0.22$	$u_{2\ def} = 3.0$	0.94	0.69	0.66	2.2	0.68
Angra Heroísmo	$a_d = 3.5$	Winter: $k_{Rs} = 0.22°$ Summer: $k_{Rs} = 0.23$	$u_{2\ avg} = 2.8$	0.98	0.72	0.64	− 3.4	0.71
	$a_d = 3.5$	Winter: $k_{Rs} = 0.22$ Summer: $k_{Rs} = 0.23$	$u_{2\ def} = 2.0$	0.96	0.72	0.63	0.2	0.72
Granja	$a_d = 2$	$k_{Rs} = 0.17$	$u_{2\ avg} = 2.6$	0.97	0.77	0.57	− 5.8	0.75
	$a_d = 2$	$k_{Rs} = 0.17$	$u_{2\ def} = 2.0$	0.97	0.77	0.57	− 4.7	0.76
Lajes	Winter: $a_d = 3.5$ Summer: $a_d = 4$	Winter: $k_{Rs} = 0.20$ Summer: $k_{Rs} = 0.21$	$u_{2\ avg} = 5.1$	1.01	0.60	0.74	− 6.0	0.57
	Winter: $a_d = 3.5$ Summer: $a_d = 4$	Winter: $k_{Rs} = 0.20$ Summer: $k_{Rs} = 0.21$	$u_{2\ def} = 3.0$	0.93	0.60	0.73	3.1	0.57
Ribeirinha	Winter: $a_d = 2$ Summer: $a_d = 2.5$	$k_{Rs} = 0.20$	$u_{2\ avg} = 4.5$	0.98	0.69	0.66	− 9.0	0.67
	Winter: $a_d = 2$ Summer: $a_d = 2.5$	$k_{Rs} = 0.20$	$u_{2\ def} = 2.0$	0.97	0.70	0.64	− 5.2	0.69
S. Bárbara	Winter: $a_d = 1$ Summer: $a_d = 2$	Winter: $k_{Rs} = 0.15$ Summer: $k_{Rs} = 0.17$	$u_{2\ avg} = 2.3$	0.98	0.73	0.58	− 10.2	0.70
	Winter: $a_d = 1$ Summer: $a_d = 2$	Winter: $k_{Rs} = 0.15$ Summer: $k_{Rs} = 0.17$	$u_{2\ def} = 2.0$	0.98	0.72	0.58	− 10.4	0.70
Chã de Macela	$a_d = 2.5$	Winter: $k_{Rs} = 0.15$ Summer: $k_{Rs} = 0.17$	$u_{2\ avg} = 1.4$	0.99	0.66	0.54	− 6.4	0.64
	$a_d = 2.5$	Winter: $k_{Rs} = 0.15$ Summer: $k_{Rs} = 0.17$	$u_{2\ def} = 2.0$	1.00	0.66	0.55	− 9.4	0.63
Lagoa do Fogo	$a_d = 1.5$	Winter: $k_{Rs} = 0.20$ Summer: $k_{Rs} = 0.21$	$u_{2\ avg} = 2.1$	0.96	0.63	0.56	− 8.5	0.61
	$a_d = 1.5$	Winter: $k_{Rs} = 0.20$ Summer: $k_{Rs} = 0.21$	$u_{2\ def} = 2.0$	0.96	0.63	0.56	− 8.6	0.61

Table 2 (continued)

Weather station	a_d (°C)	k_{Rs} (°C$^{-0.5}$)	u_2 (m s^{-1})	b_0	R^2	RMSE (mm day^{-1})	PBIAS (%)	EF
Furnas	Winter: $a_d = 2.5$ Summer: $a_d = 3$	Winter: $k_{Rs} = 0.19$ Summer: $k_{Rs} = 0.20$	$u_{2\ avg} = 2.4$	1.01	0.64	0.62	− 8.5	0.60
	Winter: $a_d = 2.5$ Summer: $a_d = 3$	Winter: $k_{Rs} = 0.19$ Summer: $k_{Rs} = 0.20$	$u_{2\ def} = 2.0$	1.00	0.64	0.61	− 6.8	0.61
Ponta Delgada	$a_d = 3.5$	$k_{Rs} = 0.24$	$u_{2\ avg} = 3.8$	0.96	0.66	0.72	− 1.9	0.66
	$a_d = 3.5$	$k_{Rs} = 0.24$	$u_{2\ def} = 3.0$	0.94	0.66	0.71	1.1	0.66
Santana	$a_d = 3$	$k_{Rs} = 0.19$	$u_{2\ avg} = 1.7$	0.98	0.70	0.55	− 3.0	0.70
	$a_d = 3$	$k_{Rs} = 0.19$	$u_{2\ def} = 2.0$	0.99	0.70	0.56	− 4.6	0.69
Sete Cidades	$a_d = 2.5$	Winter: $k_{Rs} = 0.14$ Summer: $k_{Rs} = 0.15$	$u_{2\ avg} = 2.2$	0.99	0.65	0.48	− 6.6	0.63
	$a_d = 2.5$	Winter: $k_{Rs} = 0.14$ Summer: $k_{Rs} = 0.15$	$u_{2\ def} = 2.0$	0.98	0.65	0.48	− 5.5	0.64
Tronqueira	Winter: $a_d = 1.5$ Summer: $a_d = 2$	$k_{Rs} = 0.16$	$u_{2\ avg} = 1.4$	0.97	0.76	0.47	− 5.9	0.75
	Winter: $a_d = 1.5$ Summer: $a_d = 2$	$k_{Rs} = 0.16$	$u_{2\ def} = 2.0$	0.97	0.76	0.48	− 6.7	0.75
Maia	Winter: $a_d = 3$ Summer: $a_d = 3.5$	$k_{Rs} = 0.21$	$u_{2\ avg} = 2.3$	0.97	0.64	0.72	− 4.6	0.63
	Winter: $a_d = 3$ Summer: $a_d = 3.5$	$k_{Rs} = 0.21$	$u_{2\ def} = 2.0$	0.96	0.64	0.72	− 3.2	0.63
Fontinhas	$a_d = 1.5$	$k_{Rs} = 0.22$	$u_{2\ avg} = 4.7$	0.94	0.51	0.63	− 7.9	0.49
	$a_d = 1.5$	$k_{Rs} = 0.22$	$u_{2\ def} = 2.0$	0.99	0.52	0.64	− 10.4	0.46
Praia Formosa	$a_d = 3$	$k_{Rs} = 0.20$	$u_{2\ avg} = 3.3$	0.99	0.61	0.62	− 5.5	0.59
	$a_d = 3$	$k_{Rs} = 0.20$	$u_{2\ def} = 2.0$	0.95	0.61	0.62	0.3	0.60

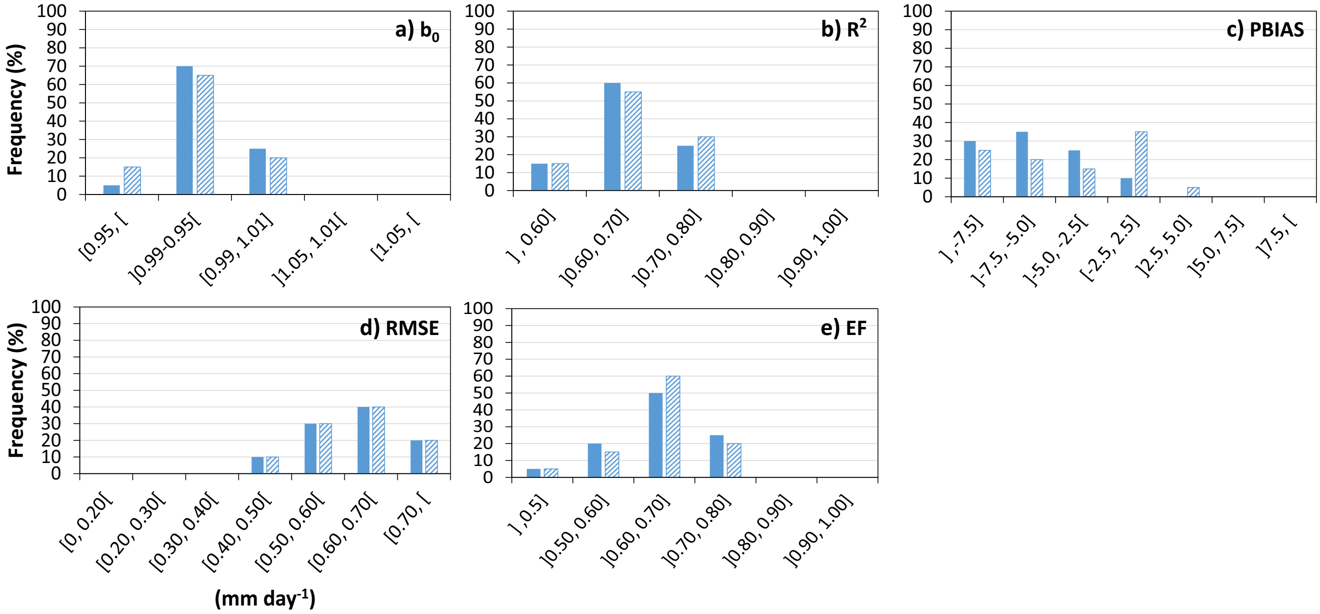

Fig. 2 Frequency distribution of the accuracy indicators relative to the computation of ET_o with the FAO-PMT approach comparing the use of the annual wind speed averages (▮) with the default wind speed value (▨)

allow to assume that our PMT results are good and may be used in Azores when only T_{max} and T_{min} data are available.

The scatter plots in Fig. 3 highlight good relationships between $ET_{o\ PMT}$ using $u_{2\ def}$ and PM-ET_o. Moreover, plots allow perceiving that slight overestimations occur for the smaller values of ET_o, and underestimations occur for the high ET_o values. However, under- and overestimations are more important for the stations located in high elevations (S. Caetano, S. Bárbara, and Lagoa do Fogo).

3.2 Accuracy of $ET_{o\ PMT}$ when reduced data sets lack two variables

The accuracy of $ET_{o\ PMT}$ when data sets lack both *RH* and u_2 was assessed comparing with PM-ET_o and $ET_{o\ PMT}$ when the latter is computed with observed solar R_s and the actual vapor pressure is estimated with Eq. 7 ($e_{a\ Tdew}$) with the parameter a_d calibrated locally and for the winter and summer seasons as referred above. Wind speed was estimated with both the local daily average $u_{2\ avg}$ and the default $u_{2\ def}$ but, confirming

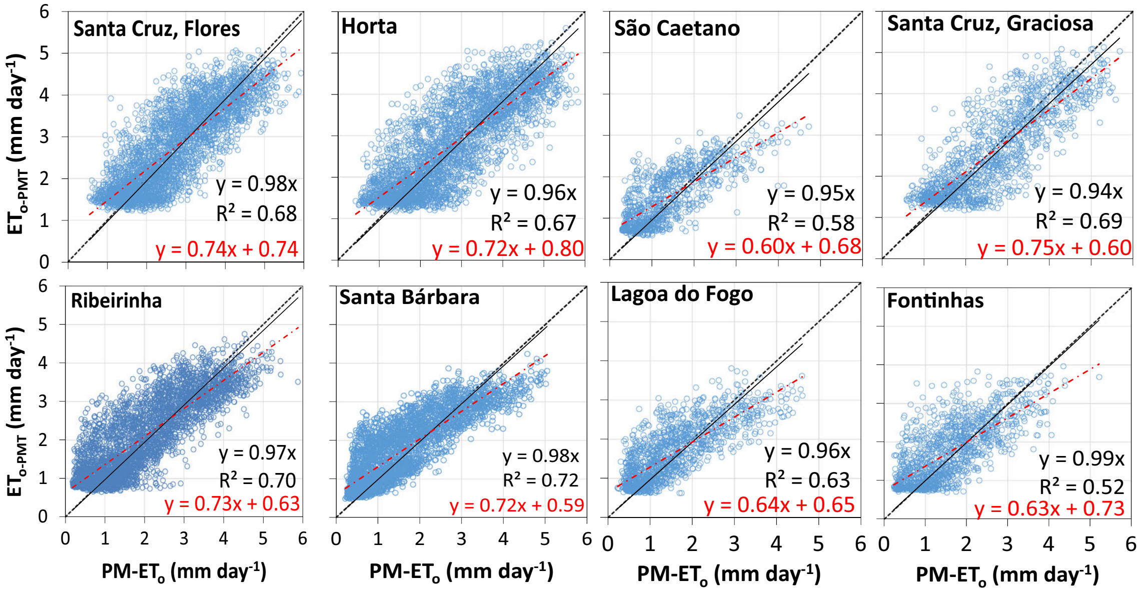

Fig. 3 Comparing $ET_{o\ PMT}$ with PM-ET_o for eight selected locations in various islands and having different environments. Included the FTO and the OLS regression equations and the OLS determination coefficient R^2

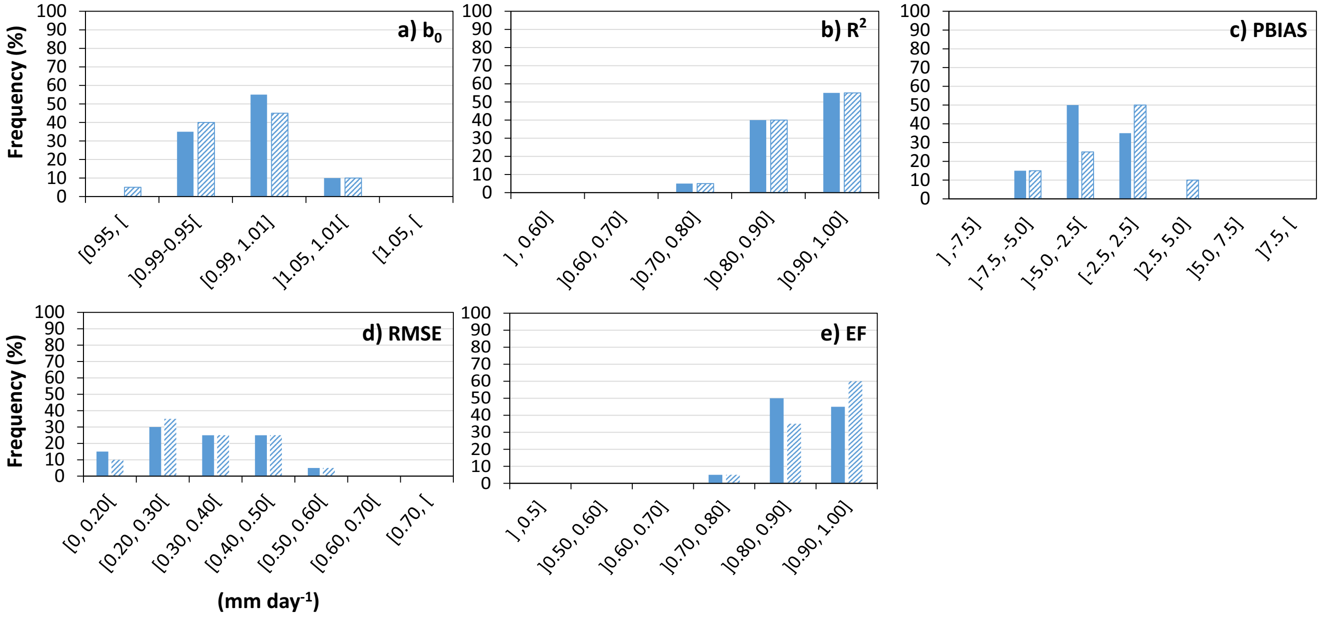

Fig. 4 Frequency distribution of accuracy indicators relative to the computation of $ET_{o\ PMT}$ with observed solar radiation and using the estimator $e_{a\ Tdew}$ for actual vapor pressure and both wind speed estimators $u_{2\ avg}$ (▮) and $u_{2\ def}$ (▨)

results above reported for $ET_{o\ PMT}$, there were no meaningful differences in accuracy relative to both u_2 estimators (Table S2 and Fig. 4). Hence, in the following, only $u_{2\ def}$ is considered. Overall indicators are reported in Table S2 (Supplementary Material) and their frequency is summarized in Fig. 4.

It could be observed that the regression coefficient b_0 ranged from 0.94 to 1.02 with 45% of cases within the shortest interval of 0.99 to 1.01. Therefore, with b_0 values close to 1.0, a slightly underestimation trend occurs, with 85% of locations presenting a PBIAS ranging from − 5 to 2.5%. R^2 is generally high, ranging from 0.75 to 0.98 and most values above 0.80. In 95% of cases results have shown RMSE < 0.50 mm day^{-1} with all values ranging from 0.17 to 0.57 mm day^{-1}; hence, errors are small. The modeling efficiency was very good, varying from 0.74 to 0.97, and 95% of cases with EF > 0.80. These indicators evidence that approaches used when both *RH* and u_2 data are missing are appropriate for Azores humid and windy climate conditions.

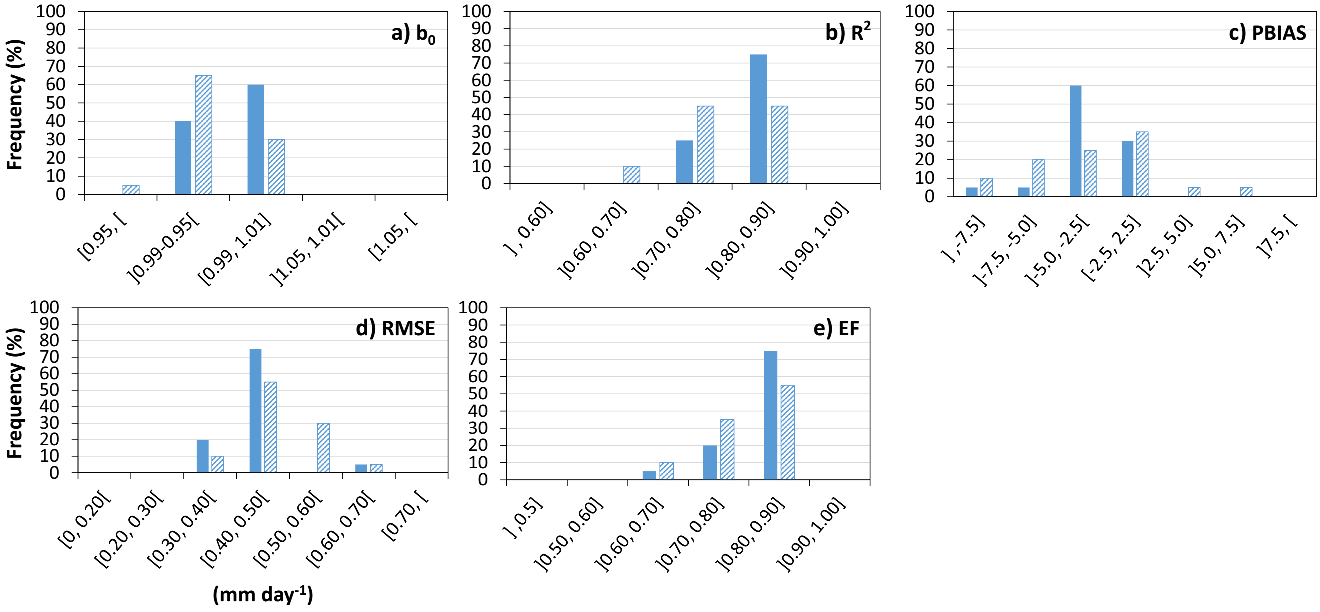

Fig. 5 Frequency distribution of accuracy indicators of $ET_{o\text{-}PMT}$ estimation with observed *RH* and using the estimators $R_{s\ TD}$ for solar radiation and both the $u_{2\ avg}$ (▮) and $u_{2\ def}$ (▨) for wind speed

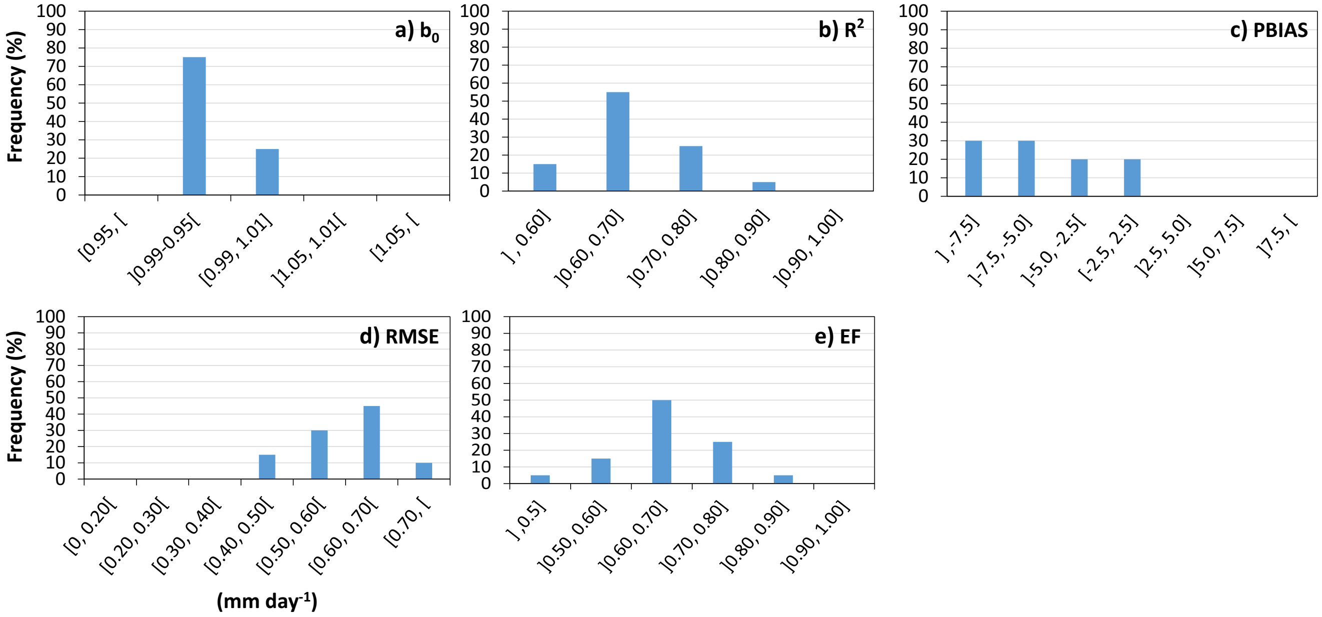

Fig. 6 Frequency distribution of the accuracy indicators relative to the computation of $ET_{o\ PMT}$ with observed wind speed, actual vapor pressure estimated with $e_{a\ Tdew}$ and solar radiation R_s estimated as $R_{s\ TD}$ using respectively a_d and k_{Rs} locally and seasonally calibrated

When observations of R_s and u_2 are missing, $ET_{o\ PMT}$ was computed with observed e_a data. R_s was estimated with the $R_{s\ TD}$ estimator (Eq. 9) with k_{Rs} calibrated for every local and for summer and winter conditions, as described before. As analyzed above, the estimator $u_{2\ def}$ was used for wind speed; nevertheless, the comparative analysis in Fig. 5 also includes $u_{2\ avg}$. Overall accuracy indicators are reported in Table S3 (Supplementary Material) and their frequency is summarized in Fig. 5.

Values of b_0 range between 0.92 and 1.01, which identifies a slight tendency for underestimation of PM-ET_o. Consequently, in 60% of cases PBIAS ranges from − 5 to 2.5%, confirming the tendency for underestimation. R^2 is quite high, varying within the interval 0.70 to 0.90 in 90% of cases. Errors are small, with RMSE within the interval 0.30 to 0.50 mm day^{-1} in 65% of locations. EF was generally high since for 90% of cases it ranged from 0.70 to 0.90. Therefore, the above referred $ET_{o\ PMT}$ approach when e_a is observed is quite accurate and appropriate for the humid and windy islands of Azores.

When only wind speed is available, the $ET_{o\text{-}PMT}$ was used with the estimators $R_{s\ TD}$ and $e_{a\ Tdew}$. The accuracy indicators are shown in Table SI-4 and their frequency is summarized in Fig. 6. In agreement with previous analysis, a slight tendency for underestimation of ET_o occurs. For 75% of locations, a $b_0 \leq 0.98$ was observed; consequently, an estimation bias higher than − 5% in 60% of locations was observed. The estimation errors are similar to those referred for ET_o estimated with temperature only (0.48 to 0 73 mm day^{-1}), however, slightly smaller, with RMSE < 0.70 for 90% of locations. The efficiency of modeling is good, ranging from 0.49 to 0.89 and with EF > 0.60 in 80% of the weather stations.

3.3 Accuracy of ET_o estimation with the Hargreaves-Samani equation

The Hargreaves-Samani equation (HS, Eq. 11) is often used but not with very good results in humid climates as analyzed before. This fact may relate to the fact that authors do not calibrate the k_{Rs} factor or perform such calibration using a less good approach. To overcome related problems, k_{Rs} was calibrated locally without significant seasonal differences.

Accuracy indicators relative to the application of the HS equation for computing ET_o using a calibrated k_{Rs} factor are shown in Table 3 and Fig. 7. Results show a b_0 ranging from 0.96 to 1.03, however with a slight underestimation tendency and, consequently, with 70% of cases showing an underestimation bias (PBIAS < − 2.5%). R^2 range 0.60 to 0.80 in 90% of cases. RMSE are relatively small, from 0.47 to 0.86 mm day^{-1}, with 65% of the stations showing RMSE > 0.60 mm day^{-1}. EF values are acceptable to good, with 45% of cases having EF < 0.60. Results analyzed above indicate that the HS equation may be used in Azores islands as alternative to the PMT method.

To better assess the relationships, $ET_{o\ HS}$ and PM-ET_o scatter plots were used (Fig. 8). They show that those relationships are non-linear for the locations at high elevation but not exposed to strong winds (S. Caetano, S. Bárbara, and Lagoa do Fogo). For these conditions,

Table 3 Accuracy of ET_o estimations using the Hargreaves-Samani equation after calibrating the k_{Rs} factor

Weather station	k_{Rs} value (°$C^{-0.5}$)	b_0	R^2	RMSE (mm day^{-1})	PBIAS (%)	EF
Santa Cruz, Flores	$k_{Rs} = 0.21$	1.01	0.67	0.74	− 2.0	0.55
Horta	$k_{Rs} = 0.23$	1.02	0.68	0.77	− 7.6	0.61
São Caetano	$k_{Rs} = 0.16$	0.96	0.64	0.52	− 7.4	0.62
Velas	$k_{Rs} = 0.20$	0.97	0.60	0.64	0.5	0.53
Santa Cruz, Graciosa	$k_{Rs} = 0.21$	1.00	0.69	0.73	− 1.6	0.61
Angra Heroísmo	$k_{Rs} = 0.21$	1.01	0.74	0.64	− 3.5	0.71
Granja	$k_{Rs} = 0.15$	1.01	0.79	0.56	− 7.7	0.77
Lajes	$k_{Rs} = 0.21$	0.98	0.57	0.86	0.2	0.42
Ribeirinha	$k_{Rs} = 0.17$	0.98	0.74	0.60	− 5.9	0.73
Santa Bárbara	$k_{Rs} = 0.14$	0.96	0.78	0.57	− 8.4	0.75
Chã Macela	$k_{Rs} = 0.15$	0.98	0.63	0.57	− 5.8	0.60
Lagoa do Fogo	$k_{Rs} = 0.18$	0.97	0.62	0.57	− 8.3	0.59
Furnas	$k_{Rs} = 0.18$	1.01	0.63	0.65	− 6.6	0.57
Ponta Delgada	$k_{Rs} = 0.22$	0.97	0.68	0.74	− 0.1	0.64
Santana	$k_{Rs} = 0.17$	0.98	0.67	0.60	− 1.7	0.64
Sete Cidades	$k_{Rs} = 0.15$	1.00	0.62	0.53	− 4.3	0.55
Tronqueira	$k_{Rs} = 0.15$	1.03	0.79	0.47	− 11.5	0.75
Maia	$k_{Rs} = 0.19$	0.97	0.62	0.76	− 2.7	0.59
Praia Formosa	$k_{Rs} = 0.19$	0.99	0.64	0.64	− 2.6	0.57
Fontinhas	$k_{Rs} = 0.18$	0.99	0.53	0.64	− 10.4	0.47

overestimations of small ET_o values and, particularly, underestimation of high ET_o vales are greater than for other locations and when using the PMT method (Fig. 3). That non-linearity may be explained by the relatively small difference $T_{max} - T_{min}$ (Fig. SI-2). Impacts of wind speed were not detected.

A tendency for the overestimation of ET_o when using the original $ET_{o\text{-}HS}$ is reported in most studies performed in humid climates but studies relative to the use of HS after calibration of the k_{Rs} coefficient report a decrease in the estimation errors relative to the use of a default value for the Hargreaves coefficient or k_{Rs}. Estimation errors lower than those in the present study (0.47 to 0.86 mm day^{-1}) were reported for several humid locations in the north-eastern Italy (Berti et al. 2014). Ren et al. (2016) for several locations in Mongolia, China indicated

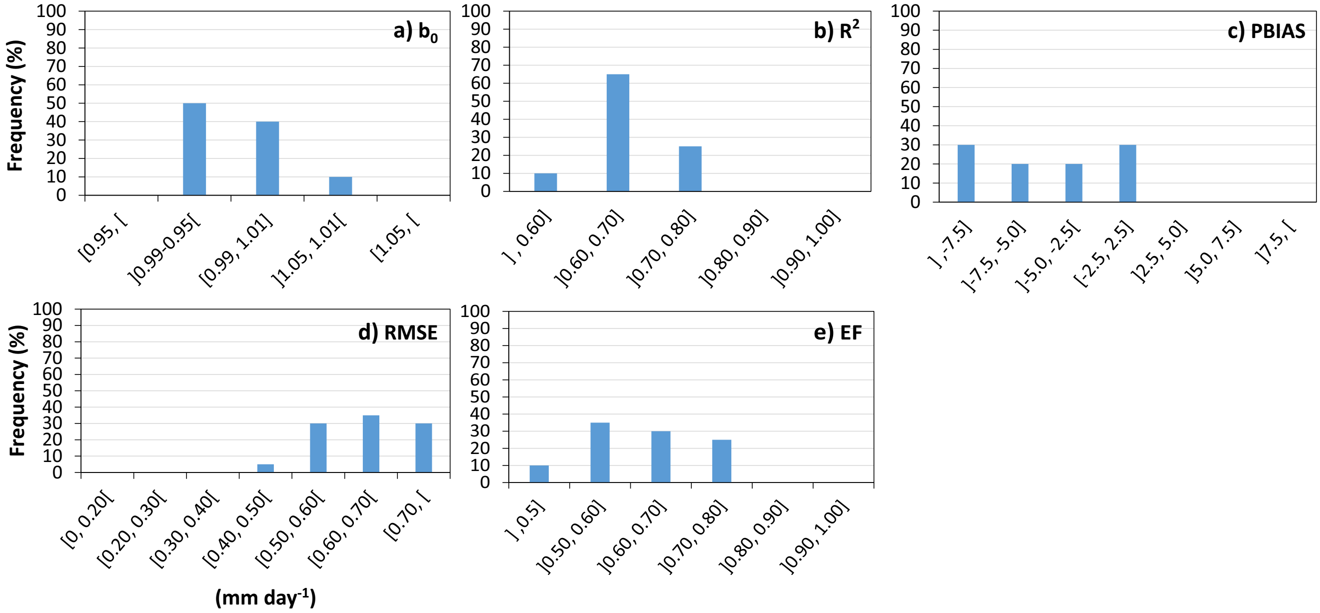

Fig. 7 Frequency distribution of the accuracy indicators relative to $ET_{o\text{-}HS}$ estimation

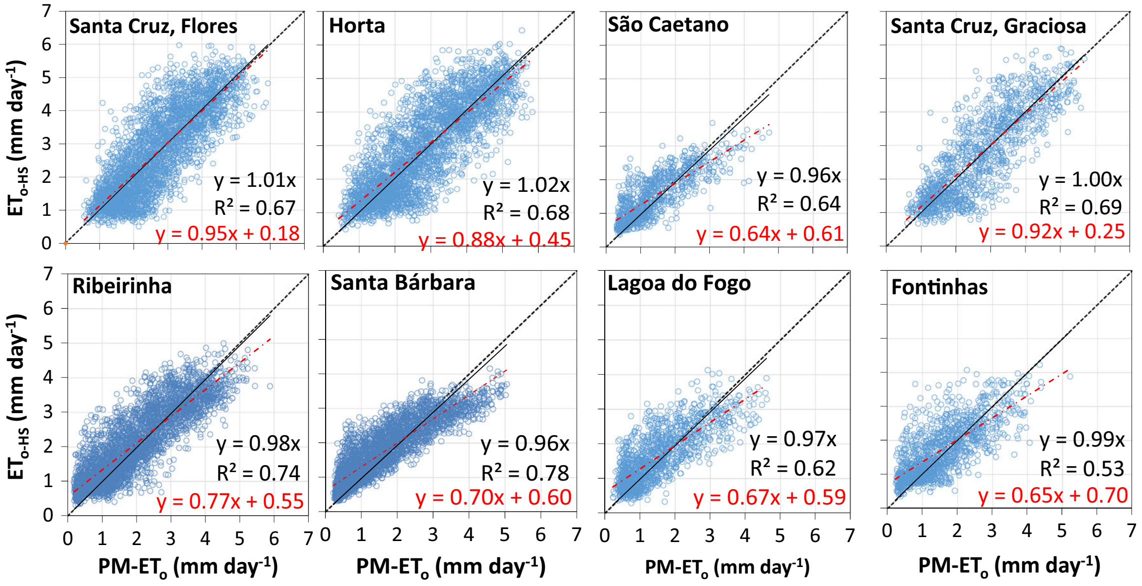

Fig. 8 Comparing $ET_{o\ HS}$ with PM-ET_o computed with full data sets for eight selected locations in various islands and having different environments. Included the FTO and the OLS regression equations and the OLS determination coefficient R^2

RMSE < 0.61 mm day^{-1} after appropriate calibration of k_{Rs}. Aladenola and Madramootoo (2014) reported very high RMSE values for humid locations in Canada. Vanderlinden et al. (2004) calibrated the product 0.0135 k_{Rs} for coastal areas and report RMSE ranging from 0.60 to 0.95 mm day^{-1}. Mendicino and Senatore (2013) also calibrated the product 0.0135 k_{Rs} and reported a mean absolute error ranging 0.32 to 1.24 mm day^{-1}. This comparison with already published errors of estimate support the quite good results obtained in the current study.

3.4 Comparing the PMT and HS approaches

Comparing the application of PMT method with HS equation in the present study (Fig. 9), results show that indicators are not very different after proper calibration of k_{Rs}. All regression coefficients relative to HS equation fall in the interval 0.95 to 1.05 while those for PMT are below 0.95 in 10% of cases. However, the PMT presents slightly lower bias of estimation. R^2 show a very similar distribution (Fig. 9). Lower RMSE, with only 20% of cases above 0.70 mm day^{-1} were observed

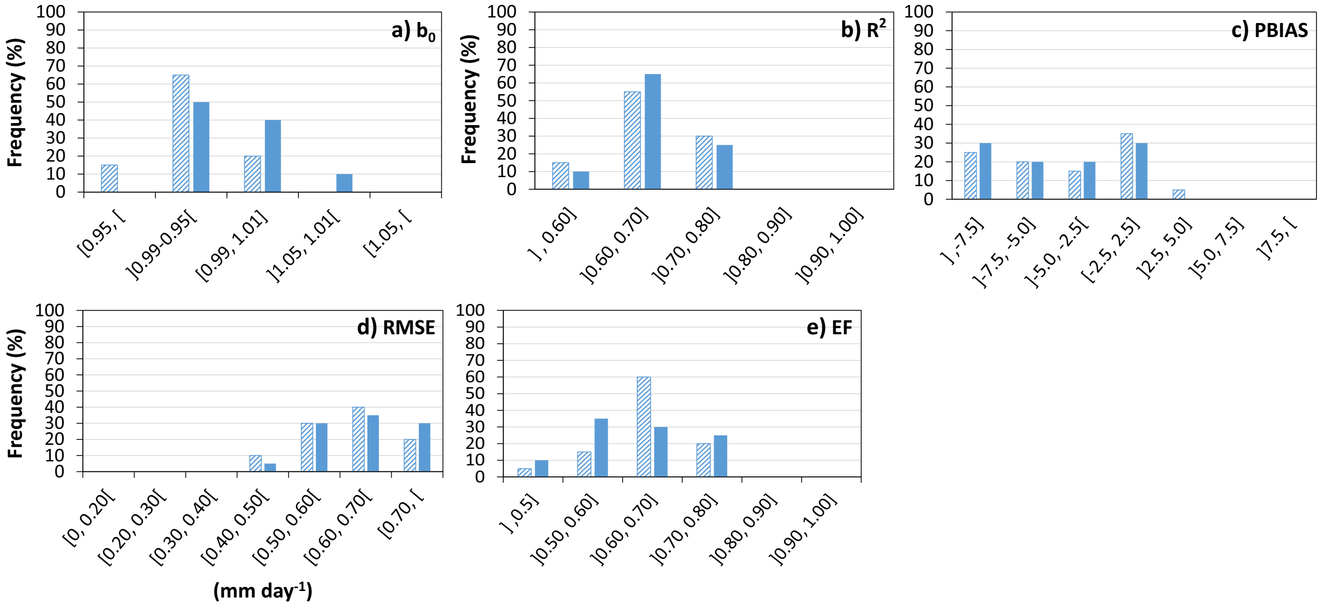

Fig. 9 Frequency distribution of the "goodness-of-fit" indicators relative to the computation of ET_o with the PMT approach with $u_{2\ def}$ (▨) and the Hargreaves-Samani equation (■)

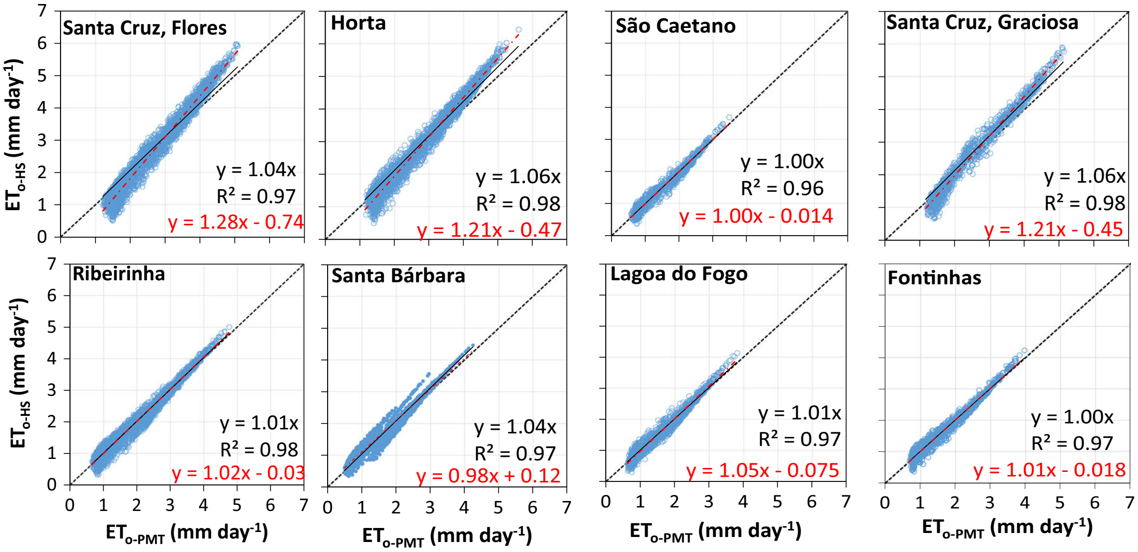

Fig. 10 Comparing $ET_{o\ HS}$ with $ET_{o\ PMT}$, for eight selected locations in various islands and having different environments. Included the FTO and the OLS regression equations and the OLS determination coefficient R^2

for PMT while that frequency increases to 30% when HS is applied. Relative to PMT, 80% of cases have EF > 0.60 while this frequency is only 55% for HS. These results indicate that the use of PMT method is more appropriate than HS in humid island environments when only temperature data are available. Similar better accuracy results of the $ET_{o\text{-}PMT}$ relative to $ET_{o\text{-}HS}$ were obtained in a monsoon climate in Northern China (Liu and Pereira 2001; Pereira et al. 2003) and in sub-humid climates of Inner Mongolia (Ren et al. 2016). Todorovic et al. (2013) and Almorox et al. (2016) found a better performance of PMT relative to HS for monthly time-step within a wide variety of climates. Martínez and Thepadia (2010) also reported that PMT performed better than HS.

For comparing HS with PMT approaches, linear FTO and OLS regressions between $ET_{o\ HS}$ and $ET_{o\ PMT}$ were developed (Fig. 10). They show a tendency for $ET_{o\ HS}$ to overestimate $ET_{o\ PMT}$ for locations at low elevation, near the sea (Santa Cruz das Flores, Horta and Santa Cruz da Graciosa). For the remaining locations, only a slight tendency for over-estimating the large ET_o values and under-estimate the small ones was detected.

4 Conclusions

The spatial variability of climatic conditions that drive evapotranspiration is a matter of special importance for local agriculture and water management purposes in small volcanic islands, as it is the case of the Azores Islands. However, in these environments, the observation of surface meteorological data required for accurate PM-ET_o computation is insufficient, with data not reflecting the high spatial variation of the climate as influenced by elevation, exposure to dominant winds and longitude. Therefore, it was of great importance to assess calculation approaches that provide for accurate ET_o estimation using reduced data sets. Their application made it evident the influence of those factors on ET_o estimation as well as the seasonality of its climatic drivers.

The approaches proposed by Allen et al. (1998) to estimate ET_o using reduced data sets were tested considering recent developments for estimation of the actual vapor pressure ($e_{a\ Tdew}$) and the short wave solar radiation ($R_{s\ TD}$) after appropriate local and seasonal calibration of the respective adjustment factors, a_d and k_{Rs}, as discussed in the companion paper (Paredes et al. 2017). Tested approaches of the PM temperature method for humid island environments referred to the use of temperature data only and to cases when, in addition to temperature, some variables are observed, thus when estimates $e_{a\ Tdew}$, $R_{s\ TD}$ or $u_{2\ def}$ are used together with observed variables. The PMT method yielded accurate results as analyzed using a set of accuracy indicators. Meanwhile, ET_o results have shown to be influenced by the altitude and exposure to dominant winds.

Both temperature methods, the PMT approach and the Hargreaves-Samani equation, also using locally calibrated k_{Rs} factors, were compared. Both approaches have shown good accuracy in representing the temporal behavior of ET_o in all locations with relatively low estimation errors: RMSE ranging from 0.48 to 0.73 mm day^{-1} for PMT and from 0.47 to 0.86 mm day^{-1} for HS. However, PMT yielded better accuracy results for most locations, namely smaller RMSE and higher EF. In addition, ET_o results of the HS equation have shown not to vary linearly with those of the PM-ET_o equation for high elevation sites and, with a lesser extent, for windy locations. Moreover, contrarily to HS equation, PMT can be used combining data on observed variables with estimators of missing ones, which is helpful when using reduced data sets. Thus, for the Atlantic islands of Azores, accuracy results indicated the appropriateness of using PMT, including because this method approaches the Physics base of the original PM-ET_o equation. Meanwhile, further and deep studies are desirable to better understand the variability of ET_o in the humid climatic environments of Azores archipelago, as well as the role of related driving factors.

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