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Technical Note

Simplified limited data Penman's ET_0 formulas adapted for humid locations

John D. Valiantzas

Agricultural University of Athens, Division of Water Resource Management, Department of Natural Resources and Agricultural Engineering, 75 Iera Odos, 11855 Athens, Greece

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SUMMARY

New reference evapotranspiration formulas based on simplifications of Penman's equation were developed applicable to humid areas, where wind speed and/or relative humidity data are missing. The new formulas were obtained by empirical calibration adjustments using meteorological data obtained from the humid locations of the CLIMWAT global data base. The performance of the new derived formulas was tested under various climatic conditions using data set monthly and daily data obtained from 16 weather stations at humid locations of California, Florida, and Greece. Comparisons indicated that the suggested formulas performed better than other empirical methods not requiring wind and/or humidity data for the majority of humid locations.

1. Introduction

Penman (1948, 1963) published the radiation-aerodynamic combination equation to predict evaporation from open water, bare soil, and grass. Recently Valiantzas (2006, 2013a,b) derived simple formulas – equivalent in accuracy to the Penman equation – for computing reference evapotranspiration (ET_0) from full-set of routinely measured meteorological variables (e.g. solar radiation, R_S (MJ/m^2/d); relative humidity, RH (%); wind speed, u (m/s); and average temperature, T (°C)).

For places where wind and/or humidity data are not available, Valiantzas (2006, 2013a,b,c) suggested simplifications to the full-set of data formulas. The suggested simplified formulas were recommended, validated and successfully applied by various researches as Lewis and Lamoureux (2010), MacDonald et al. (2009), Rimmer et al. (2009), McMahon et al. (2013), D'Agostino (2013), Kisi and Zounemat-Kermani (2014), Kisi (2013), Valipour (2014), and others.

The FAO-56 methodology (Allen et al., 1998) (hereinafter referred to as "FAO56-PM") for estimating reference crop evapotranspiration, ET_0, (daily or monthly data), recommends the sole use of the Penman–Monteith equation. The FAO56-PM scheme is considered as the "standard" method in hydrological and irrigation applications at well-watered meteorological stations under varying locations and climatic conditions. The main shortcoming of the standardized Penman–Monteith procedure is the relatively high data demand requiring measurements of T, RH, R_S, and u that are not always available for many locations. Furthermore, the installation and maintenance of full-set of data weather station equipment can be expensive and complicate (Valiantzas, 2012; Exner-Kittridge, 2012; and Valiantzas, 2013d).

Numerous empirical equations have been developed for estimating ET_0 from limited data, but their performances in different climatic conditions vary. When only humid location were considered, the wind-data reduced formula of Turc (1961) (radiation-type method) is commonly considered as the most efficient (Jensen et al., 1990; Yoder et al., 2005; Nandagiri and Kovoor, 2006; Trajkovic and Kolakovic, 2009; Martinez and Thepadia, 2009; Tabari et al., 2013 and others). In a recent paper, Gao et al. (2014) concluded that both the Turc (1961) and Valiantzas (2013a) methods requiring only T, RH, and R_S performed acceptably at humid locations in Southwestern China.

In this study the focus is on new, simplified ET_0 formulas applicable to humid locations, where wind and/or humidity data are missing.

2. Methodology

Humid locations are defined as the locations where monthly relative humidity is greater than 60% in the month having peak evaporation (Shuttleworth, 1993).

E-mail address: ival@aua.gr

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In this section improved simplified ET_0 formulas were derived applicable to humid areas. The new formulas were based on empirical calibration adjustments made on recently developed by the author simplified Penman's expressions, using monthly data obtained from the humid stations of the CLIMWAT global data base.

2.1. Data bases

A global climatic data set, the FAO-CLIMWAT (Smith, 1993), including monthly data, was used for the empirical calibration adjustments. High quality records of climatic data from meteorological stations in thirteen countries (Temesgen et al., 1999), that essentially cover all the typical range of variation of the input weather variables were selected: Spain, France, Italy, Greece, and Cyprus in Europe; Pakistan, Lebanon and some stations in India in Asia; Egypt, Tunisia, Algeria, Ethiopia, and Sudan in Africa. All the stations are located in the northern hemisphere. From the total number of 535 stations in these countries, 234 stations (corresponding to $n_o = 2808$ data from the database) characterized by humid climate ($RH > 60\%$ in the peak month, Shuttleworth, 1993), were retained and selected to be used for calibration purpose.

The new derived formulas are tested using daily data set obtained from 16 weather stations at humid locations. Six stations characterized by a humid climate were selected from across California for this study. A series of high quality data sets used in this analysis for the validation and comparisons was obtained from the CIMIS database (http://wwwcimis.water.ca.gov).

Eight stations characterized by a humid climate were also selected from across Florida. The data sets used was obtained from the Florida Automated Weather Network (FAWN) that can be found online at http://fawn.ifas.ufl.edu. Finally, data sets from two stations characterized by a humid climate at Greece, the Naxos island, and the Araxos station were also included in this analysis.

An effort was made to select stations covering a wide range of weather parameters. The long term average wind ranged approximately from 1.0 to 4.0 m/s. Table 1 lists the station number, station name, elevation, latitude, long term average wind values, and period of data used of the selected stations.

Table 1
Station name, elevation (m), latitude (deg), average wind speed (m/s) and period of data used of the 16 humid stations selected for comparisons.

Station name	Elevation (m)	Latitude (deg)	Average wind (m/s)	Data period
1. Orland/CA	60.4	39.69	2.4	1995–1999
2. De Laveaga/CA	91.4	37	1.3	1995–1999
3. Suisun-Valley/CA	10.7	38.23	2.4	1995–1999
4. Petaluma East/CA	29.6	38.27	2.0	2000–2001
5. Lodi West/CA	7.6	38.13	1.1	2000–2004
6. Novato/CA	7.6	38.12	1.0	1998–2001
7. Naxos/GR	3	37.06	4.9	1982–2000
8. Araxos/GR	15	37.15	1.7	1995–1999
9. Fort-Pierce/FL	8	27.4	2.1	2000
10. Alachua/FL	56	29.7	1.7	2000
11. Okahumpka/FL	31.5	28.7	1.5	2000
12. Avalon/FL	69	28.5	1.7	2000
13. Hastings/FL	7.6	29.7	2.2	2000
14. Ocklawaha/FL	24	29.05	1.1	2000
15. Dover/FL	21	28.05	1.2	2000
16. Ona/FL	23	27.4	1.3	2000

2.2. Development of formulas adjusted for humid locations

2.2.1. Formulas requiring R_S, T and RH data alone

2.2.1.1. Previous simplified formula: – referred to in this paper as "Fo-$_{CLASSIC}$(R_S,T, RH)". In a recent paper Valiantzas (2013a) has developed an improved formula for estimating ET_0 based on the reasonable assumption that the impact of the aerodynamic component on Penman's equation is rather small for days with high relative humidity values compared to days with low level of relative humidity. Therefore a purely empirical weighted factor, W_{aero}, accounting for the impact of the aerodynamic term depending on RH values was introduced. Valiantzas (2013a) when the wind speed data are missing suggested the following formula applicable to humid and arid locations

$$\begin{aligned} &ET_0 \approx 0.0393 R_S\sqrt{T+9.5} - 2.4\left(\tfrac{R_S}{R_A}\right)^2 + C_u(T+20)\left(1-\tfrac{RH}{100}\right) \\ &C_u = 0.054 \quad when \quad RH > RH_0 \\ &C_u = 0.083 \quad when \quad RH \leqslant RH_0 \end{aligned} \tag{1}$$

where R_A is the extraterrestrial radiation (MJ/m^2/d), $C_u = W_{aero}\times 0.066 \times 2^{0.6} - 0.024$ is an empirical adjustment coefficient, and the separation value is $RH_0 = 65\%$.

2.2.1.2. New simplified formula applicable to humid areas: – referred to in this paper as "Fo-HUMID(R_S, T, RH)". In this paper an improved modification of the formula Eq. (1) is proposed adjusted for humid locations only. Initially, the limited value RH_0 is considered as a variable to be adjusted. Then, the purely empirical weighted factor, W_{aero}, is assumed as a continuous function of RH of the following simple purely empirical power function form

$$\begin{aligned} &when \quad RH > RH_0 \qquad W_{aero} = 1 - C_1(RH/100 - RH_0/100)^{C_2} \\ &when \quad RH \leqslant RH_0 \qquad W_{aero} = 1 + C_3(RH_0/100 - RH/100)^{C_2} \end{aligned} \tag{2}$$

where C_1, C_2, C_3, and RH_0 are empirical coefficients that should be identified using calibration procedure.

The calibration of the $n_o = 2808$ data from the FAO-CLIMWAT database corresponding to humid climate lead to $C_1 = 0.3$, $C_2 = 0.2$, $C_3 = 0.21$, and $RH_0 = 50$.

The modified formula, not requiring wind data, and valid for humid locations takes the final form

$$\begin{aligned} &ET_0 \approx 0.0393 R_S\sqrt{T+9.5} - 2.4\left(\tfrac{R_S}{R_A}\right)^2 + C_u(T+20)\left(1-\tfrac{RH}{100}\right) \\ &C_u = 0.076 - 0.0119(RH-50)^{0.2} \quad when \quad RH > 50 \\ &C_u = 0.076 + 0.0084(50-RH)^{0.2} \quad when \quad RH \leqslant 50 \end{aligned} \tag{3}$$

2.2.1.3. Turc method-referred to in this paper as "TURC(R_S, T, RH)". The formula of Turc (1961) (radiation-type method with wind data reduced) takes the form

$$ET_0 \approx (23.89 R_S + 50)\frac{0.013T}{T+15}[1 - W_{RH}(0.71 - 1.43RH/100)] \tag{4}$$

where $W_{RH} = 1$ when $RH < 50\%$ and $W_{RH} = 0$ when $RH > 50\%$.

2.2.2. Formulas requiring R_S and T data alone

2.2.2.1. Previous simplified formula: – referred to in this paper as "Fo-$_{CLASSIC}$(R_S, T)". Since the computation of variable R_A in daily basis requires a rather complicated numerical procedure, Valiantzas (2013b) suggested an even more full-set of data simplified form of Penman's equation not requiring R_A. Valiantzas (2013b) applied further simplifications leading to a simplified version of Penman's equation in which R_S, and T are the only required weather data.

Indeed, Valiantzas (2013b) demonstrated that RH can be approximated as

$$(1 - RH/100) \approx 0.078(T - T_{dew})^{0.7} \tag{5}$$