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ET_CSDLL: A DLL for the Computation of Reference and Crop Evapotranspiration

Marcello Donatelli*, Claudio O. Stöckle, Roger L. Nelson, Gianni Bellocchi

M. Donatelli, and G. Bellocchi, Research Institute for Industrial Crops, Bologna, Italy; C.O. Stöckle, and R.L. Nelson, Biological Systems Engineering Department, Pullman, WA, USA

*Corresponding author (m.donatelli@isci.it)

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ETCS_DLL: A DLL for the Computation of Reference and Crop Evapotranspiration

ABSTRACT

ET_CSDLL is a MS Windows library containing routines to estimate reference crop evapotranspiration (ET_0) following the guidelines of the FAO Irrigation and Drainage Paper No. 56 for implementing the Penman-Monteith (P-M) equation. In addition, the Priestley-Taylor equation is also included for calculating ET_0 for conditions where meteorological data are insufficient to apply the P-M equation. The DLL (dynamic link library) can be used in MS Excel spreadsheets and in code developed using a visual MS Windows programming language. Examples are shown to illustrate the use of the DLL in MS Excel and MS Visual Basic applications.

One of the main goals of modelers in the area of agro-ecology is to advance in the development and application of models that represent the systems under study. To help reaching that goal, modular approaches are recommended (Jones et al., 2001), thus facilitating more systematic model development, documentation, maintenance, and sharing.

Evapotranspiration (*ET*) – i.e. the water removed as vapor from the soil-plant system by direct evaporation and plant transpiration - is a major variable in irrigation design and scheduling, watershed hydrology, mechanistic crop growth models and other models that attempt to simulate the soil water budget.

Reference crop evapotranspiration (ET_0) refers to water evaporation from a unit ground area completely covered by a 0.12-m grass, healthy and unstressed, and with ample water supply. Evaporation from such a surface can be partitioned into soil evaporation and plant transpiration from a unit ground area occupied by a crop of interest.

One-dimensional equations based on aerodynamic theory and energy balance, the so-called combination equations, have proved useful for *ET* estimation because they take into account both the canopy properties and meteorological conditions. The Penman-Monteith (P-M) equation (Monteith, 1965) is a biophysically-based combination equation that has become popular and shown to be a good estimator of *ET* for a wide variety of climatic conditions (Allen et al., 1998).

The Priestley-Taylor (P-T) equation for the calculation of ET_0 (Priestley and Taylor, 1972) is a simpler, semi-empirical model that has been successfully applied in many areas (e.g., Jamieson, 1982; Steiner et al. 1991; Rana, 1998; German, 1999). The P-T model is useful for conditions where P-M cannot be applied due to the lack of required weather data.

Routines for ET_0 calculation using both P-M and P-T have been implemented in several crop growth and hydrologic models, generally with minor attention to code transparency. The consequence is the re-implementation of the approach every time an estimate of ET_0 is needed in one application. Therefore, we chose to develop ET_CSDLL, a public DLL (dynamic link library) that incorporates all relevant aspects of daily *ET* computation, and which can be plugged into existing application software running on a Microsoft Windows-based operating system.

BACKGROUND

The set of equations coded in the DLL are intended to calculate ET_0 (mm day^{-1}) using the P-M equation as implemented in the FAO Irrigation and Drainage Paper No. 56 (Allen et al., 1998). ET_0 is also calculated using the P-T equation, following the implementation of Steiner et al. (1991).

Potential crop evapotranspiration (ET_P), assuming disease-free, well-fertilized crops, grown in large fields under optimum soil water conditions is estimated as:

$$ET_P = K_c' ET_0 \quad (1)$$

with K_c' fluctuating from a value of 1.0 at a leaf area index (*LAI*, m^2 m^{-2}) equal to zero (no crop) to a value K_c for a full grown crop with $LAI \geq 3$, as given for different crops and climate conditions by Allen et al. (1998):

$$K_c' = 1 + (K_c - 1)\frac{LAI}{3} \qquad \text{for } LAI < 3$$

$$(2)$$

$$K_c' = K_c \qquad \text{for } LAI \geq 3$$

ET_P is partitioned into potential crop transpiration (T_P) and potential soil water evaporation (E_P):

$$T_P = ET_P f \quad (3)$$

$$E_P = ET_P - T_P \quad (4)$$

where f is the fraction of incident radiation intercepted by the crop canopy:

$$f = 1 - exp(-kLAI) \quad (5)$$

where k is crop extinction coefficient for incident global solar radiation (unitless). The parameter k typically ranges from 0.35-0.40 for canopies with vertical tendencies to 0.55-0.65 for heliotropic crops.

ET_0 in MJ m^{-2} day^{-1} is computed as:

- FAO Penman-Monteith equation:

$$ET_0 = \frac{s\,(R_n - G) + \frac{VPD\,\rho\,C_p}{r_a}}{s + \gamma\left(1 + \frac{r_c}{r_a}\right)} \quad (6)$$

- Priestley-Taylor equation:

$$ET_0 = \left[1 + \left(PTc - 1\right)\ VPD\right]\frac{s\,(R_n - G)}{s + \gamma} \quad (7)$$

The value of ET_0 in MJ m^{-2} day^{-1} is converted to kg m^{-2} day^{-1} (which is equivalent to mm day^{-1}), dividing it by the latent heat of vaporization (λ, MJ kg^{-1}). Input variables required by the DLL are given in Table 1. Symbols and equations used are described in Table 2.

APPLICATIONS

Public functions are made available in ET_CSDLL. The DLL must be referenced in projects under development that are written using a visual MS Windows programming language (Visual Basic, C++, Delphi, etc.). Examples are provided in the installation package to illustrate the use of the DLL in MS Excel and MS Visual Basic 6.

MS Excel application

The public functions made available in the DLL can be accessed from MS Excel easily, without the need to declare the functions, provided that the DLL was registered. The code can be browsed by opening the VBA editor window of the MS Excel. Inputs and outputs are interfaced in the spreadsheet, as shown in Figure 1.

MS Visual Basic 6 application

MS Visual Basic 6 project allows performing the same computations done by the spreadsheet sample. Access to public functions is allowed by either providing the inputs needed or returning the values requested.

AVAILABILITY AND FEEDBACK

ETCS_DLL is made available free of charge for non commercial purposes. The installation package is available for downloading at: http://www.isci.it/tools. The system requires about 4 MB of hard disk space. Both the techniques implemented and the scientific background are fully documented by the help file. Comments about ET_CSDLL may be sent to agronomy@isci.it.

REMARKS

The DLL for computation of ET_0, T_P and E_P is a first step towards a commonly-agreed architecture for agronomic/agrometeorological modeling. It serves as a convenient means to support collaborative model development among a large, distributed network of scientists involved in creating object-oriented models. It can be used as a submodel of any model, written in any language. Code sharing of the modules significantly increases transparency of the underpinning science. Any improvement in the science can be automatically transferred into the DLL routines. ET_CSDLL is consistent with the *ET* implementation of the cropping systems model CropSyst (Stöckle at al., 2003).

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Fig. 1 – Example of MS Excel spreadsheet for calculation of evapotranspiration rate variables, where inputs are entered and a summary report output is produced.

Table 1. Input variables required by the DLL.

Input variable	Unit
R_s, incoming solar radiation	MJ m^{-2} day^{-1}
J, day number in the year	unitless
lat, latitude	deg
z, elevation above see level	m
U_z, wind speed	m s^{-1}
z_m, height wind speed measurement above ground surface	m
T_x, maximum air temperature	°C
T_n, minimum air temperature	°C
T_d, dew-point air temperature*	°C
RH_x, maximum relative air humidity	%
RH_n, minimum relative air humidity	%
a, aridity factor	kPa^{-1}
PTc, Priestley-Taylor constant	unitless

* If T_{dew} is set to zero, then $T_d = 0.52T_n + 0.67T_x - 0.009T_x^2 - 2$ (Linacre, 1992)

Table 2. Components of the Penman-Monteith and the Priestley-Taylor equations.

Variable	Unit	Formulation
R_n, net radiation	MJ m^{-2} day^{-1}	$R_n = 0.77R_s - \left[1.35\left(\frac{R_s}{R_{so}}\right) - 0.35\right]\left(0.34 - 0.14\sqrt{e_a}\right)\sigma\left(\frac{T_{Kx}^4 + T_{Kn}^4}{2}\right)$
R_{so}, clear sky solar radiation	MJ m^{-2} day^{-1}	$R_{so}=max(R_s, 0.75R_a)$
R_a, extraterrestrial radiation	MJ m^{-2} day^{-1}	$R_a = 0.31831 K_{sc} d_r \left(\omega_s \sin\vartheta \sin\delta + \cos\vartheta \cos\delta \sin\omega_s\right)$
K_{sc}, solar constant	MJ m^{-2} day^{-1}	K_{sc}=108.08
d_r, inverse relative distance between the earth and sun	unitless	$d_r = 1 + 0.033\cos(0.0172J)$
ω_s, summer hour angle	rad	$\omega_s = \arccos(-\tan\phi \tan\partial)$
ϕ, latitude	rad	ϕ=1.74E-02lat
δ, solar declination	rad	$\delta = 0.409\sin(0.0172J - 1.39)$
σ, Stefan-Boltzman constant	MJ m^{-2} K^{-1} day^{-1}	σ=4.903E-09
T_{Kx}, maximum air temperature	K	T_{Kx}=273.15+T_x
T_{Kn}, minimum air temperature	K	T_{Kn}=273.15+T_n
G, soil heat flux	MJ m^{-2} day^{-1}	G=0 for the 24-h period
γ, psychrometric constant	kPa °C^{-1}	$\gamma = 0.00163(P/\lambda)$
P, atmospheric pressure	kPa	$P = 101.3[(293 - 0.0065z)/293]^{5.26}$
λ, latent heat of vaporization	MJ kg^{-1}	$\lambda = 2.501 - 0.002361T_{mean}$
T_{mean}, daily mean air temperature	°C	$T_{mean}=(T_x+T_n)/2$
ρ, atmospheric density	Kg m^{-3}	$\rho = 3.486\frac{P}{1.01(T_{mean} + 273)}$
C_p, specific heat capacity of moist air	MJ kg^{-1} °C^{-1}	C_p=0.001013
r_a, aerodynamic resistance for the grass reference surface	day m^{-1}	$r_a = 208/U_2$
U_2, wind speed at 2 m above ground surface	m day^{-1}	$U_2 = U_z\frac{4.87}{\ln(67.8z_m - 5.42)}$
r_c, canopy resistance for reference grass	day m^{-1}	r_c=0.00081
s, slope of the saturation vapor pressure curve	kPa °C^{-1}	$s = 2503\frac{\exp[(17.23T_{mean})/(T_{mean} + 237.3)]}{(T_{mean} + 237.3)^2}$
VPD, vapor pressure deficit	kPa	Penman-Monteith: $VPD = e_s - e_a$ Priestley-Taylor: $VPD = 0.475VPD_x$
$e^0(T)$, saturation vapor pressure	kPa	$e^0(T) = 0.6108\exp\frac{17.27T}{T + 237.3}$
T, air temperature	°C	T_x, T_n, T_d
e_s, daily mean saturation vapor pressure	kPa	$e_s = \frac{e^0(T_x) + e^0(T_n)}{2}$
e_a, actual vapor pressure	kPa	if RH_x and RH_n available: $e_a = \frac{e^0(T_n)(RH_x/100) + e^0(T_x)(RH_n/100)}{2}$ if T_d available: $e_a = e^0(T_d)$
VPD_x, vapor pressure deficit	kPa	$VPD_x = \frac{e^0(T_x) - e^0(T_n)}{1 - a[e^0(T_x) - e^0(T_n)]}$

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Figure 1