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Number **20**

IAM_ETo

Software program & User's Guide

1998

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CIHEAM

Centre International de Hautes Etudes Agronomiques Méditerranéennes

International Centre for Advanced Mediterranean Agronomic Studies

Président /*Chairman:* José Jéronimo GODINHO AVO

Secrétaire Général /*Secretary General:* Enzo CHIOCCIOLI

11, rue Newton
75116 PARIS (FRANCE)
Tel.: (33-1) 53 23 91 00 – Fax: (33-1) 53 23 91 01
e-mail: secretariat@ciheam.org

IAM

Instituts Agronomiques Méditerranéens
Mediterranean Agronomic Institutes

Bari – Chania – Montpellier – Zaragoza

IAM – Bari
Dir.: Cosimo LACIRIGNOLA
Via Ceglie 9
70010 Valenzano, Bari, Italy
Tel.: +39 080 46 06 111 – Fax: +39 080 46 06 206
e-mail: iamdir@iamb.it

IAM – Chania
Dir.: Alkinoos NIKOLAIDIS
P.O. Box 85
73100 Chania, Crete, Greece
Tel.: (30) 821 81 151 – Fax: (30) 821 81 154
e-mail: alkinoos@maich.gr

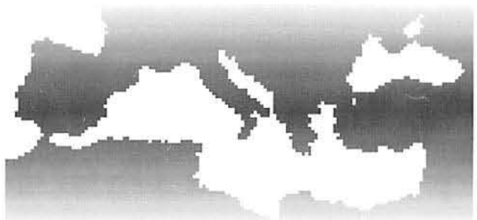
IAM – Montpellier
Dir.: Gérard GHERSI
3191, route de Mende
BP 5056
34033 Montpellier Cedex 1, France
Tel.: (33-4) 67 04 60 00 – Fax: (33-4) 67 54 25 27
e-mail: gaforg@iamm.fr

IAM – Zaragoza
Dir.: Miguel VALLS ORTIZ
Apdo. 202
50080 Zaragoza, Spain
Tel.: (34) 76 57 60 13 – Fax: (34) 76 57 63 77
e-mail: iamz@iamz.ciheam.org

IAM_ETo

CIHEAM
Centre International de Hautes Etudes Agronomiques Méditerranéennes

Options Méditerranéennes
Directeur de la publication : Enzo Chioccioli



Series B n° 20

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Scientific authors
P. Steduto, R.L. Snyder

Edited by
The Water Use Efficiency Network
(WUE_Net)

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contributing partners:

P. Steduto, A. Caliandro, P. Rubino, N. Ben Mechlia, Z. Nasr, A. Martinez-Cob, M. Jose Faci, E. Fereres, J. Berengena, G. Rana, M. Mastrorilli, M. El Mourid, M. Karrou, K. Belabbes, R. Kamber, C. Kirda, D. El-Quosy, K. El-Askari, M. Ait Ali, D. Zareb, R.L. Snyder*

* Autors in the order are: Crop-ecophysiologist at CIHEAM/IAM-Bari, Italy; Agronomist and Irrigation Scientist at Bari University, Italy; Climatologist at INAT and micrometeorologist at INRAT, Tunis, Tunisia; two Agronomic Engineers at SIA, Zaragoza, Spain; two Agronomic Engineers at Cordoba University, Cordoba, Spain; Physicist and Agronomist at SIA, Bari, Italy; two Crop physiologist at INRA, Settat, Morocco; Agrometeorologist at IAV Assan II, Rabat, Morocco; Irrigation and Soil Scientist at Çukurova University, Adana, Turkey; Irrigation Scientist and Hydrologist at NWRC, Cairo, Egypt; two Irrigation Scientist at INSID, Alger, Algeria; Biometeorologist at University of California, Davis, USA.

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FOREWORD

Undoubtedly, water represents the most critical resource for economic growth in the Mediterranean, Arid and Semi-arid Regions.

Since agriculture in these Regions is the most water demanding socio-economic sector, accurate determination of water consumption of agricultural crops, under the different climates, is a fundamental step for any water budget analysis. However, the knowledge of the so-called *evaporative demand of the atmosphere*, referred to as *reference evapotranspiration* (ET_O), still remains the starting point for such a water budget.

The present publication, with its associated software, is a simple though effective tool addressed to professional agriculturists to facilitate processing of data taken from the agro-meteorological stations to calculate ET_O by different standard equations.

It is our hope that through this issue of Options Méditerranéennes, the CIHEAM is further contributing to the development and application of scientific knowledge in the Mediterranean Agriculture.

Enzo Chioccioli
(Secretary General CIHEAM)

Cosimo Lacirignola
(Director CIHEAM-IAM-Bari)

IAM_ETo

Software Program & User's Guide

1. INTRODUCTION

IAM_ETo is a user-friendly software program for processing weather data files, usually obtained from agro-meteo stations. IAM_ETo calculates *reference evapotranspiration* (ET_O) and, for long time series, the *climatic*, or potential, *water deficit* (CWD), in addition to some related statistics. It is addressed to researchers, government agencies, engineers and extension officers.

The *reference evapotranspiration* (ET_O) is calculated from daily to monthly time intervals, according to the following equations well recognized and reported as standards in the literature:

- Penman-Monteith (FAO*)
- Penman (original)
- Penman (FAO)
- Priestley-Taylor
- Radiation (FAO)
- Blaney-Criddle (FAO)
- Blaney-Criddle (SCS**)
- Hargreaves
- Class "A" Pan (FAO)

Moreover, IAM_ETo also calculates

- ET_O with the Penman-Monteith equation using the day-time wind speed in place of the 24 hr mean wind speed;
- the evapotranspiration equivalent to the net radiation.

The procedure employed to calculate the basic variables, the equations and the units for obtaining ET_O are provided in **APPENDIX (A, B, C, D, E)**.

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* FAO - Food and Agricultural Organization of United Nations (Rome, Italy)

** SCS - Soil Conservation Service of United States Department of Agriculture (USA)

The *climatic water deficit* (CWD) is calculated as simple difference between monthly ET_O and monthly *usable rainfall* (P_O). See section 5 for further explanation.

The following statistics related to ET_O and CWD are calculated as well:

(i) if the input weather data are on daily basis, IAM_ETo calculates, in addition to daily ET_O, the mean ET_O on weekly, 10-day and monthly basis. Furthermore, it calculates the daily ET_O *standard deviation* (STD) for each of these time intervals;

(ii) where lysimeter data are available, IAM_ETo uses them to calculate the root mean square error (RMS) of the ET_O estimates by each equation and for each of the time intervals;

(iii) when evaluating the *climatic water deficit* (CWD), IAM_ETo also calculates monthly mean and standard deviation of ET_O, precipitation (Pr), usable rainfall (P_O) and the CWD itself.

2. The IAM_ETo PROGRAM

Software/Hardware Specifications

The IAM_ETo software is written in QuickBasic[1] and consists of six programs:

IAM_ETO.EXE,		IAMMAIN.EXE,
IAMDATA.EXE,		IAMDAILY.EXE,
IAMMEAN.EXE	and	IAMSTAT.EXE.

These files are not compressed and do not require any particular installation procedure. IAM_ETo is simple in its structure and design, has very low memory requirement, and runs under any *Personal Computer* (PC) MS-DOS[1] or WINDOWS[1] operated.

Although IAM_ETo can run also from the 3.5" diskette, it is recommended to run it from the Hard Disk (HD).

The weather input data for IAM_ETo are read directly from a computer file and not entered through the computer keyboard.

Getting Ready to Run IAM_ETo

Few preliminary arrangements need to be accomplished before running IAM_ETo

- Generate a Directory

Generate on your PC a *Directory* dedicated to process the weather data. In such a *Directory*, COPY both the content of the IAM_ETo diskette (i.e., the six *.EXE files) and your data file

- Prepare the Input Data Files

A typical weather data file of daily variables, coming from an agro-meteorological station, may look like the one shown in Table 1.

[1] Trade Mark of Microsoft

Table 1. *Typical weather data file coming from an agro-meteorological station*

Day #	Month #	Year #	U_day Km d^{-1}	U_night Km d^{-1}	Tmax °C	Tmin °C	RHmax %	RHmin %	Sunshine hrs	Epan mm	Rain mm
16	11	81	320	220	10.6	6.2	71	54	0.00	2.96	5.0
17	11	81	250	130	13.5	4.2	83	47	5.40	3.13	0.0
18	11	81	150	180	14.5	3.2	84	46	6.45	2.77	0.0
19	11	81	100	130	17.4	3.4	93	34	6.50	0.80	0.0
20	11	81	80	160	18.6	4.0	96	35	6.45	2.55	0.0
...	...	...	...	...	...	...	...	...	...	...	...

Of course, not all types of variables are always available. Sometimes you may have no information on maximum and minimum temperature and humidity, or no information on the dew-point temperature. Instead of solar radiation measurements there may be the bright sunshine hours, or the ratio of actual bright sunshine hours to potential sunshine hours in clear-sky condition for that same day, and so on.

Depending on the weather variables available, some equations may be used while others cannot. The input variables required by each equation are given in **APPENDIX**.

Whatever the weather data file looks like, there is no need to modify it. Similarly, absolutely no matter how variables are ranked in a row and their units. IAM_ETo, in fact, can handle the different cases. Most important is that the file must have the date in numerical format and not in text format. As an example, the date 15th of July 1990 (or 7/15/90) needs to be reported as

day # of the month (*d*), month # of the year (*m*), and the year (*y*); that is: 15 7 1990
or also 15 7 90

As for the weather variables, the order (*m,d,y* or *d,m,y* or *y,m,d* or *d,y,m*) is not important. Remember that the month and the day number are crucial for calculating the extra terrestrial solar radiation.

IAM_ETo works with ASCII files. Then, make sure your input data files are true ASCII files.

Make also sure to name your input data file with the extension "DAT" (e.g., IAM_BARI.DAT).

All variables in the data file should have no more than three decimals and must be separated by a delimiter. Although any type of delimiter is accepted by IAM_ETo, the most common and most recommended are: *tab*, *space*, *comma* (,) or *semicolon* (;).

Of course, there must be the same number of variables in each row. Consequently, a missing value must be reported as a *space* separated by a delimiter and IAM_ETo will recognize it as a missing value.

It is clear, then, that the numerical variables must be expressed in *English notation* (i.e., the decimal numbers are separated by the integer numbers with a dot; e.g., 28.5). Consequently, where needed, French or Italian notations (e.g., 25,8) must be converted into English notation. This is not a problem since any *Electronic Spreadsheet* (Lotus(2), QuattroPro(3), Excel(4), etc.) can operate the conversion of the numerical notation, as well as the conversion of the file into an ASCII file with the variables *comma* or *semicolon* delimited. As an example, if you have your weather data stored as Excel(4) file (e.g., IAM_BARI.XLS), you can *save* such a file *as* *.CSV (e.g., IAM_BARI.CSV), which is an ASCII file comma delimited, and then *rename* it as *.DAT (e.g., IAM_BARI.DAT) to be ready for IAM_ETo.

Once your input data file is ready, you need to know the Latitude and Elevation of the site where the weather data are derived from, along with the height of the wind anemometer. With this information, you are ready to run IAM_ETo.

(2) Lotus is a trademark of Lotus Corporation
(3) QuattroPro is a trademark of Borland
(4) Excel is a trademark of Microsoft

3. Running IAM_ETo

Once IAM_ETo and the input data files are in the same directory, you can start your data processing by IAM_ETo.

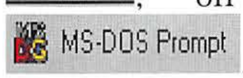
Note that the "O" in the IAM_ETO.EXE file is a letter and not a "zero" number.

To run the IAM_ETo, you have the following options:

(a) under MS-DOS operating system, move to the working directory and at the DOS prompt, just enter `C:\<working directory>\IAM_ETo ↵`

(b) under WINDOWS operating system, click on 

, on 

, and then on 

. At this point, you just enter

`C: :\<working directory>\IAM_ETo ↵`

(c) under WINDOWS operating system, click on 

and then on 

. At this point, you just enter `C: :\<working directory>\IAM_ETo ↵`

Choose the one more convenient to you.

Depending on the settings of your operating system, though, one option or the other may not work properly. In this case, you may use the remaining working options or revise the settings of the operating system. Working under Windows[4] operating system, one might also *Shut Down* the system and *restart the computer in MS-DOS mode*. In this case you end up like the option **(a)** and **(b)**.

If IAM_ETo starts properly, the *home page* of IAM_ETo will appear on the screen, as shown in Fig. 1.

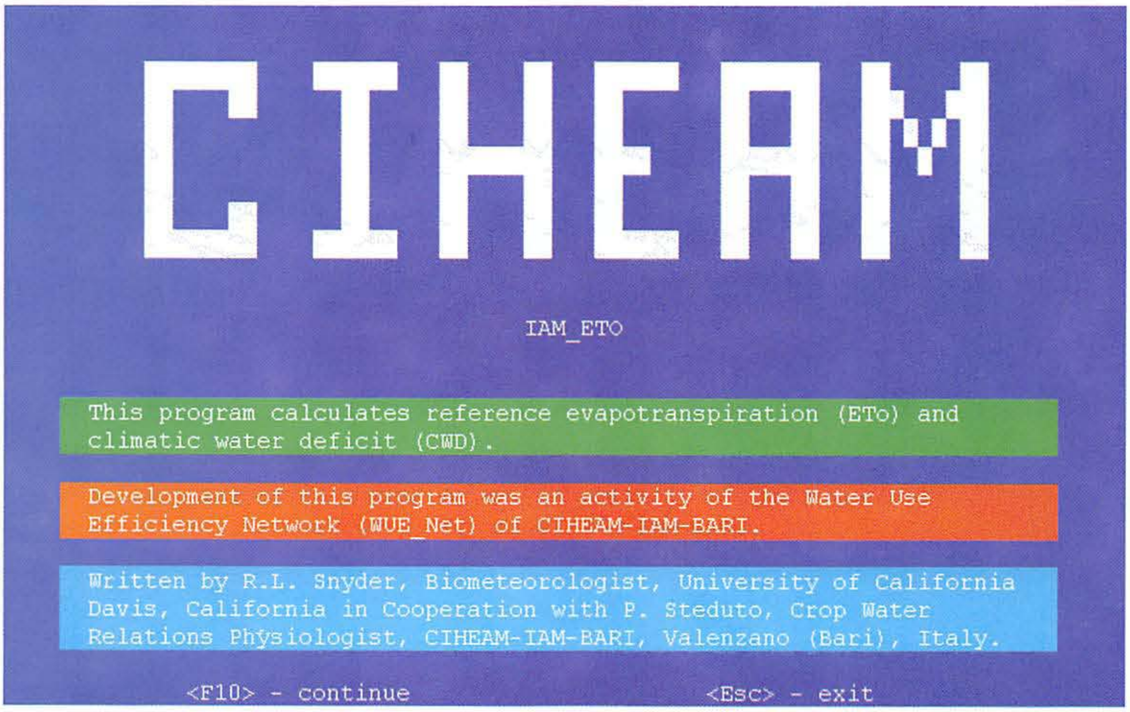


Fig. 1 - The *home* page of IAM_ETo

At the bottom of the *home page*, two function keys are highlighted: the <F10> key to continue and the <Esc> key to exit. These two keys are the most relevant keys to run IAM_ETo. In more advanced steps of the IAM_ETo running, the <Esc> key is also used to go back to previous pages.

<F5>, *space bar* and the *arrow* keys are the only additional keys needed to operate IAM_ETo. These keys will be described as encountered during the program operation.

Press <F10> to continue. The *station description page* will appear, as shown in Fig. 2.

On this page, it is required to insert the *Filename* of the input data file, the *Latitude* and *Elevation* of the station, and the height of the wind sensor (i.e., the anemometer height from the ground). The *Filename* will be entered without extension (*.DAT) since it is already a default for IAM_ETo. If the input data file has no DAT extension and you enter anyway its *Filename*, IAM_ETo would automatically quit, displaying an error message.

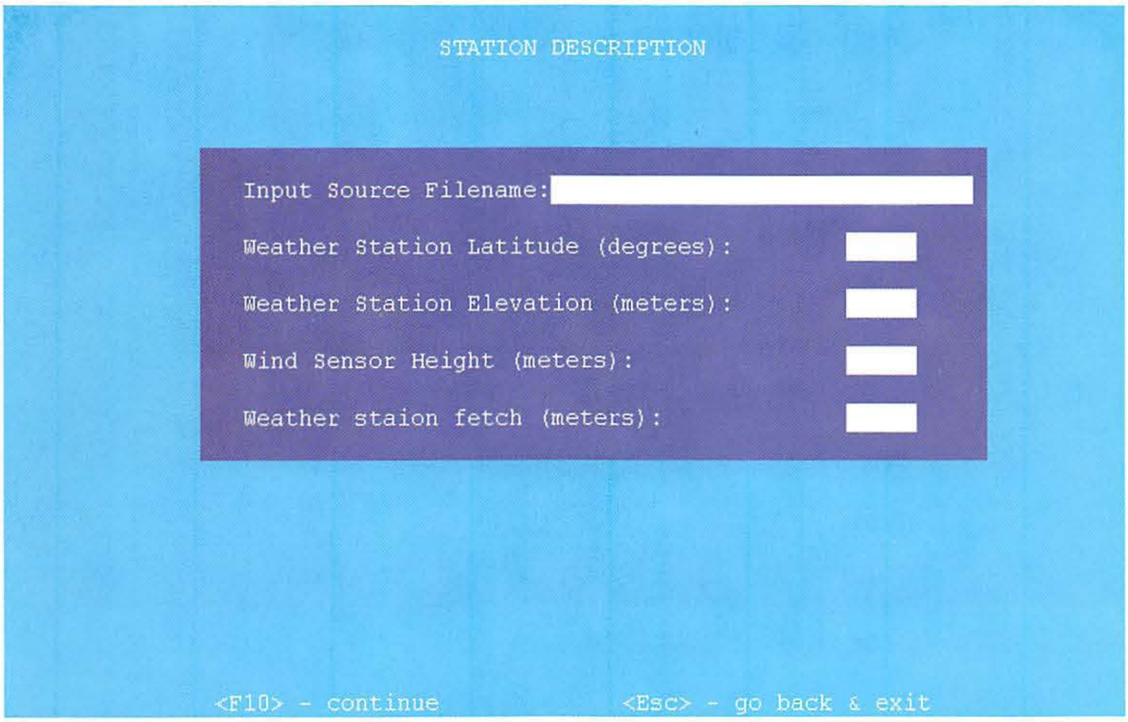


Fig. 2 - The *station description* page

The *Latitude* must be entered in 100s of a degree and not in 60s, with the value rounded to the nearest 10th of a degree. For instance, if the L*atitude* is 38° 45', it must be converted into degrees considering that $X^{o} = \frac{X'}{60} \times 100$, so that 38° 45' = 38.75°. This value should then be entered as 38.8 (the nearest 10th of a degree).

At any entry, the highlight cursor moves automatically to the next entry. If you make mistakes, just delete completely the entered number (by the *Del* key) and enter the correct value. You can use *Enter* (↵) or the *up* (↑) and *down* (↓) arrow keys to move between entries.

Once the *station description page* has been completed, press <F10> to continue.

The *data sample page* will appear as the example shown in Fig. 3 (input data file of Table 1).

On this page, IAM_ETo displays the first seven rows from the input data file and requires two basic pieces of information: (i) the number of variables per row and (ii) the type of delimiter used to separate the variables. The number of variables per row corresponds to the number of columns of the input data file.

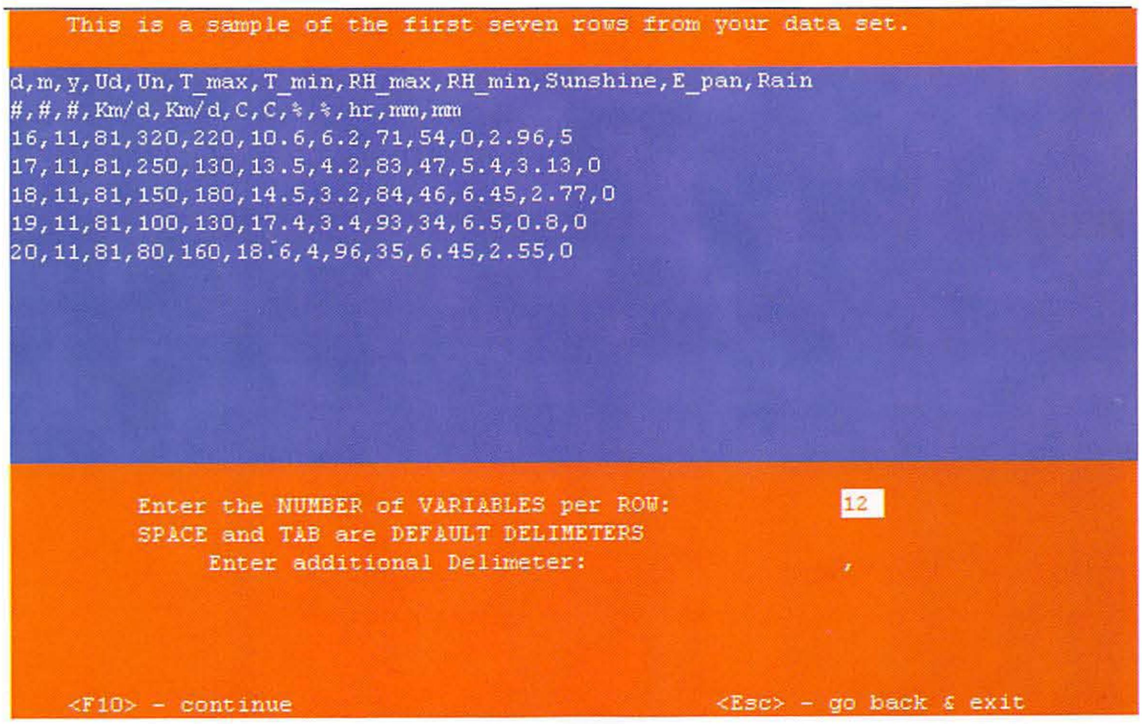


Fig. 3 - The *data sample* page

As mentioned earlier, make sure that the number of variables per row is the same for all the rows. If this is not the case, IAM_ETo will read the values out of the right sequence and sooner or later will warn you that something is wrong with the data or even quit automatically, sending an error message.

After entering the number of variables per row and the delimiter, press <F10> to continue.

The *variables description page* will appear, as shown in Fig. 4.

On this page, IAM_ETo displays a list of the most common variables that will most likely be present in your input data file.

On the upper and left-side of this page, there is a heading labeled <NUMBER> and on the upper and right-side there is a heading labeled <UNITS>.
Under the <NUMBER> heading, the order (from left to right on the row) corresponding to each variable in the input data file has to be entered. Under the <UNIT> heading, the proper unit of the corresponding variable has to be entered.

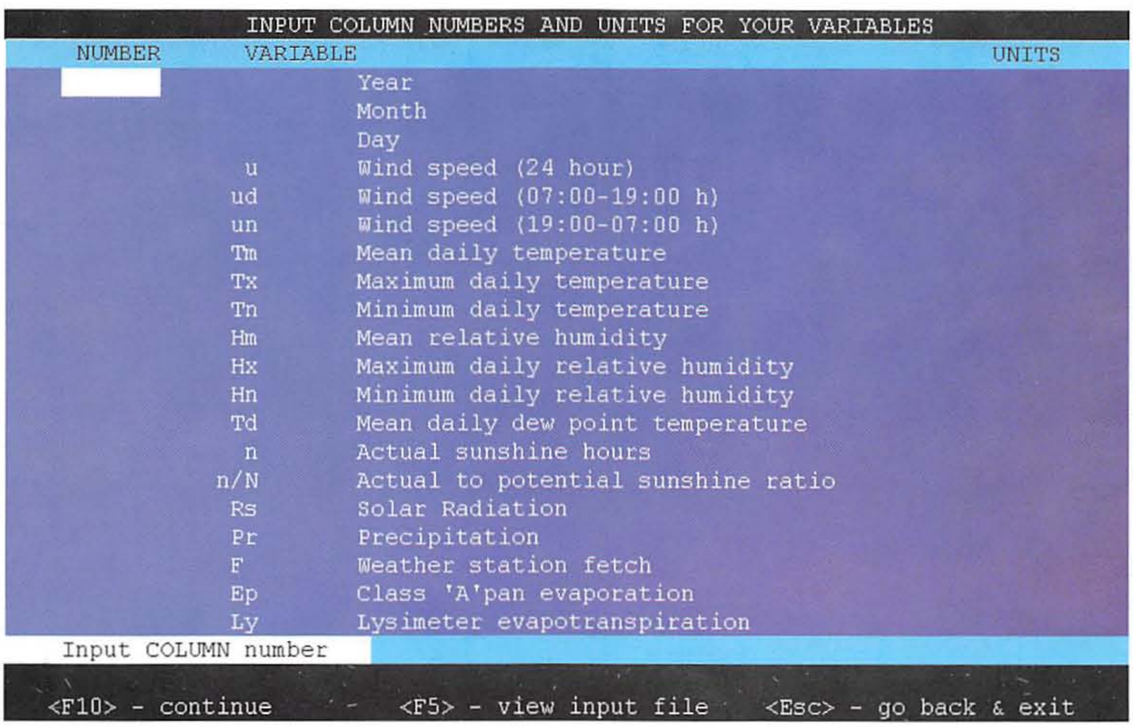


Fig. 4 - The *variables description* page

For the sake of clarity, in Fig. 5, as an example, the order and the units for each variable of the input data file of Table 1 are reported.

The highlighted cursor of IAM_ETo can be moved back and forth from the left side (the NUMBER column) to the right side (the UNIT column) of the VARIABLE list using the *left* and *right* arrow keys (← and →). Using the *up* and *down* arrow keys (↑ and ↓), the highlighted cursor can be located next to each variable present in the input data file, so that the corresponding order number can be entered. In the example reported in Fig. 5, the *Year* is 3rd in the order of variables, always from left to right of each arrow of the input data file (see Table 1). Similarly, the *Month* is 2nd, the *Day* is 1st and so on.

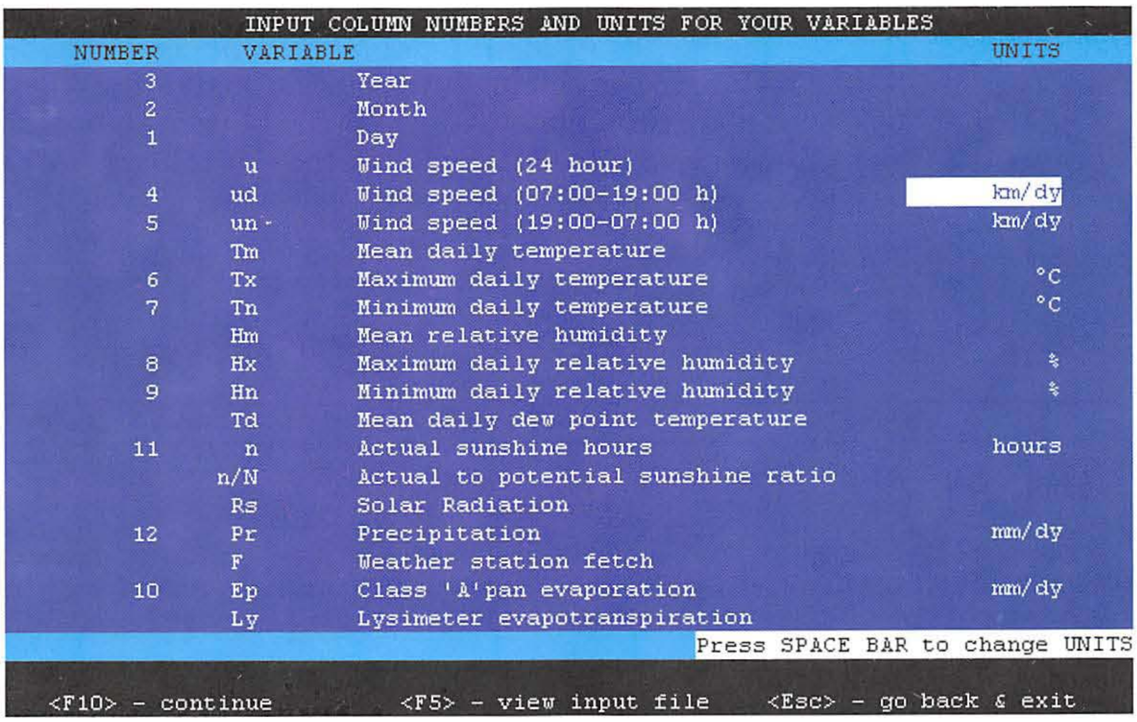


Fig. 5 - Example of a compiled *variables description* page

When the order number of a weather variable is entered, on the right side of the variable (under the UNITS column) a default unit appears. If the default unit is not the correct one for the variable of the input data file, move the highlighted cursor to the right side using the arrow key and press the space-bar to switch to a different unit. IAM_ETo has a set of most common units for each weather variable. Pressing several times the space-bar, all the units included in the set will appear in sequence. The full set of units available in IAM_ETo is listed in Table 2 for each of the variables included.

Once the correct unit appears, you can go back to the left side of the variable list (always with the arrow key) and continue to insert the order number, and change the units if needed, for each of the remaining variable of your input data file. Note that when the highlighted cursor is on the left side of the variable description page, a highlighted row on the bottom left-side indicates to *Input COLUMN number* (see Fig. 4). When the highlighted cursor is on the right side, a highlighted row on the bottom right-side indicates to *Press SPACE BAR to change UNITS* (see Fig. 5).

Table 2. Variable name, symbol and list of possible units included in IAM_ETo

Variable	symbol	unit 1	unit 2	unit 3	unit 4
Year					
Month					
Day					
Wind speed (24 hours)	u	km d^{-1}	m s^{-1}	mph	km hr^{-1}
Wind speed (07:00-19:00 hr)	ud	km d^{-1}	m s^{-1}	mph	km hr^{-1}
Wind speed (19:00-07:00 hr)	un	km d^{-1}	m s^{-1}	mph	km hr^{-1}
Mean daily temperature	Tm	°C	°F		
Maximum daily temperature	Tx	°C	°F		
Minimum daily temperature	Tn	°C	°F		
Mean daily relative humidity	Hm	%			
Maximum daily relative humidity	Hx	%			
Minimum daily relative humidity	Hn	%			
Mean daily dew-point temperature	Td	°C	°F		
Actual sunshine hours	n	hr			
Actual to potential sunshine ratio	n/N				
Solar radiation	Rs	MJ m^{-2} d^{-1}	W m^{-2}	ly d^{-1}	
Precipitation	Pr	mm d^{-1}	mm mo^{-1}	in d^{-1}	in mo^{-1}
Weather station fetch	F	m	feet		
Class 'A' pan evaporation	Ep	mm d^{-1}	mm mo^{-1}	in d^{-1}	in mo^{-1}
Lysimeter evapotranspiration	Ly	mm d^{-1}	in d^{-1}		

note: mo=month

At the bottom of the *variables description page*, notice that a new function key <F5> is displayed along with the <F10> and <Esc> keys. The <F5> key is used to go back to the *data sample page* (Fig. 3) to view or check the order and the units of the variables of the input data file. To be more effective, however, it is suggested to print a sample page (or take a hand note) of the input data file, including the heading with the units, to keep in front of you when compiling the *variables description page*.

Once also the *variables description page* has been completed, IAM_ETo is finally ready to run all the calculations it was programmed for.

4. Calculating ETo

Pressing <F10> to continue, IAM_ETo will start reading sequentially each row of the input data file and will display on the screen the row number being read. The screen will appear as shown in Fig. 6, where the numbers of the rows scroll rapidly.

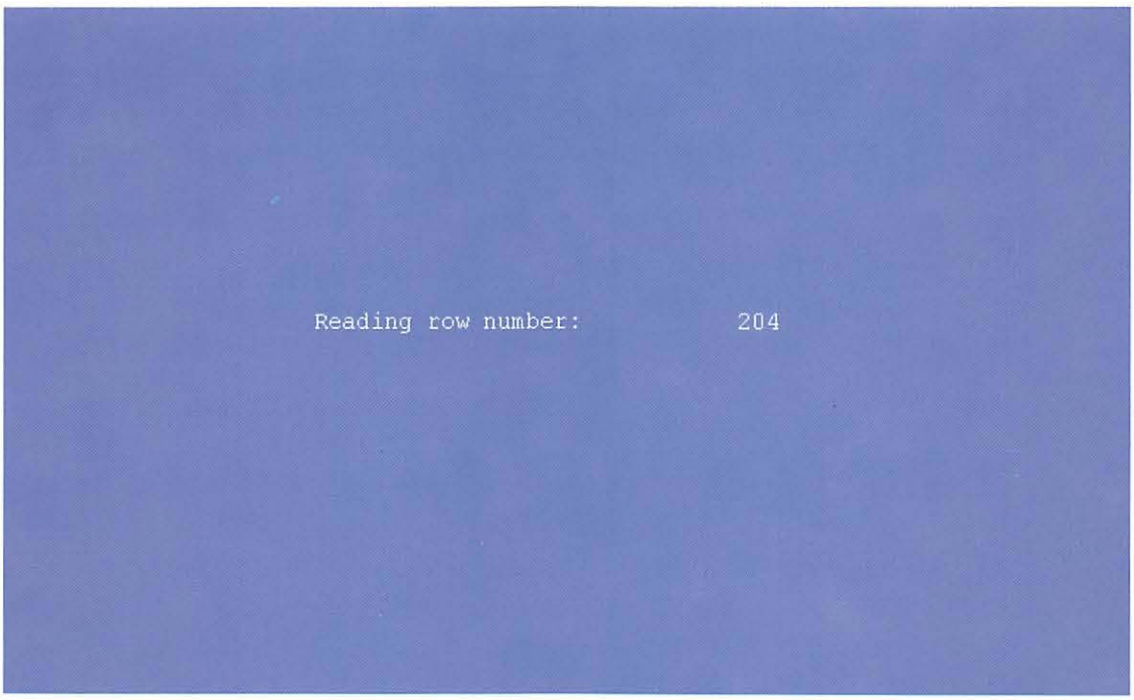


Fig. 6 - The *running* page of IAM_ETo while reading the input data file, row by row

During the reading procedure, IAM_ETo operates a sort of consistency control on the data to check whether the input data are properly entered. A typical case is represented by the switch between maximum and minimum temperature, or between maximum and minimum relative humidity, that may occur while constructing the input data file. In such cases, IAM_ETo will warn you displaying the row number and the variable where the inconsistency occurred. In Fig. 7, an example of warning for a relative humidity inconsistency is reported where maximum relative humidity (Hx) happens to be less than the minimum relative humidity (Hn). The abbreviations used to describe the variables correspond to the symbols reported in Table 2.

Pressing <Esc> to go back and exit, one can enter the original input data file to correct the inconsistency and then run IAM_ETo again. Pressing <F10> to continue, IAM_ETo will skip the inconsistent row and will continue the reading of the other rows.

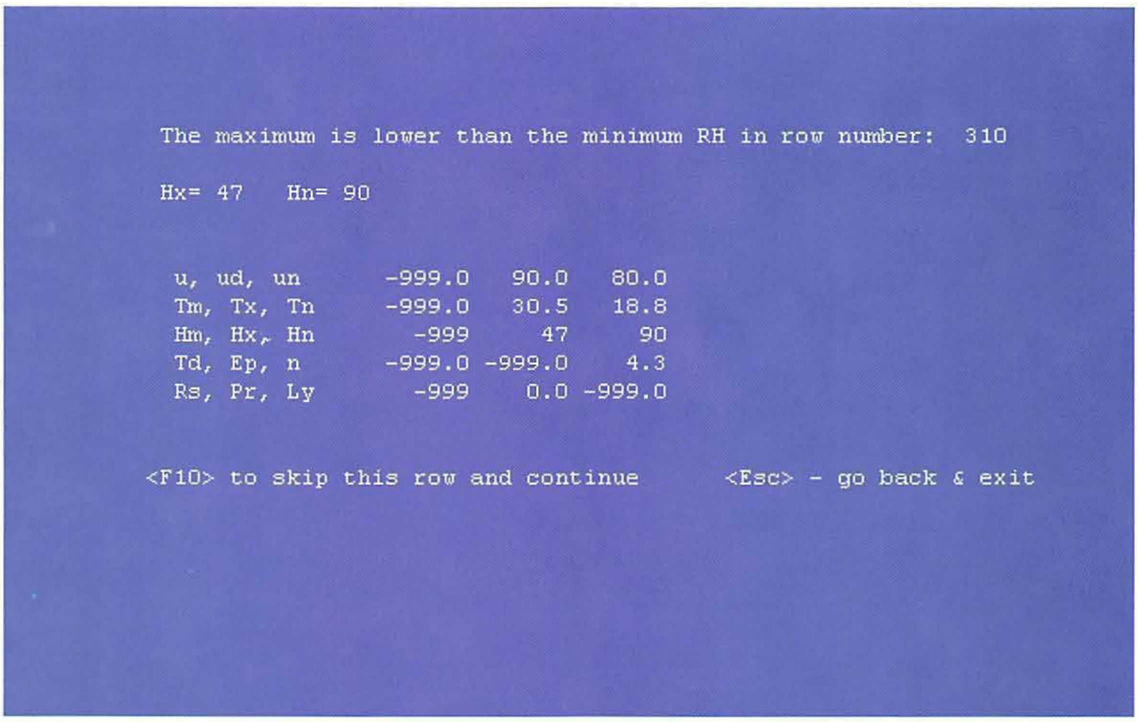


Fig. 7 - Example of warning by IAM_ETo for the case of an inconsistent variable declaration (Hx<Hn)

Another example of inconsistency are the relative humidity values higher than 100%. In Fig. 8, for instance, a warning is reported for an inconsistency in raw n° 704 of the input data file, where the maximum relative humidity is 102%. It is important, however, to realize that sometimes relative humidity sensors may in fact record values slightly higher than 100%, as simple consequence of the sensor offset at very high values. If this is the case (as the one reported in Fig. 8), it is better to prepare the input data file in such a way that all relative humidity values fall within the 0-100% range. This will avoid unwanted and tedious warnings from IAM_ETo.

When all the rows in the input data-file are read, IAM_ETo continues to run calculating first the daily and then the monthly ET_O values. While calculating the daily ET_O, IAM_ETo displays on the screen the row number being processed, which scrolls very quickly. An example of this running-page is shown in Fig. 9. The file name where the results of the processing will be output is displayed as well.

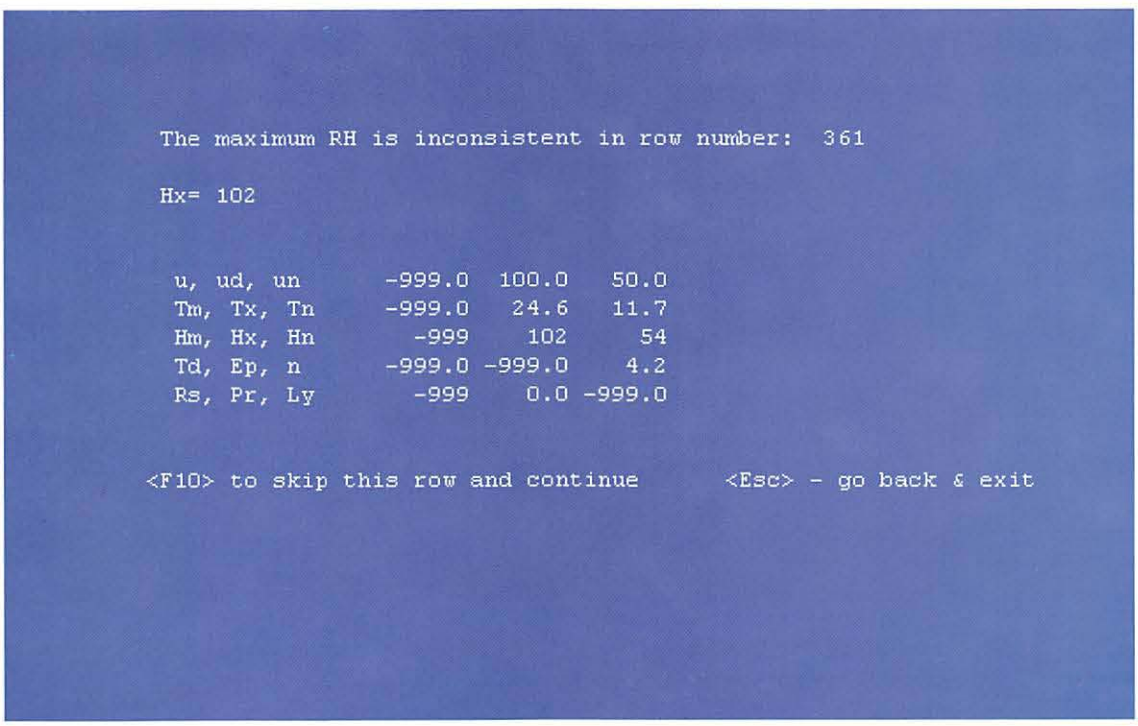


Fig. 8 - Example of warning by IAM_ETo for the case of an inconsistent, though acceptable, maximum relative humidity value (Hx)

The output file containing the daily ET_O values for each equation, along with the precipitation, is the one having the extension *.IA2.
Once the daily ET_O values are calculated, IAM_ETo calculates the monthly ET_O, displaying the corresponding running-page on the screen, as shown in Fig. 10.

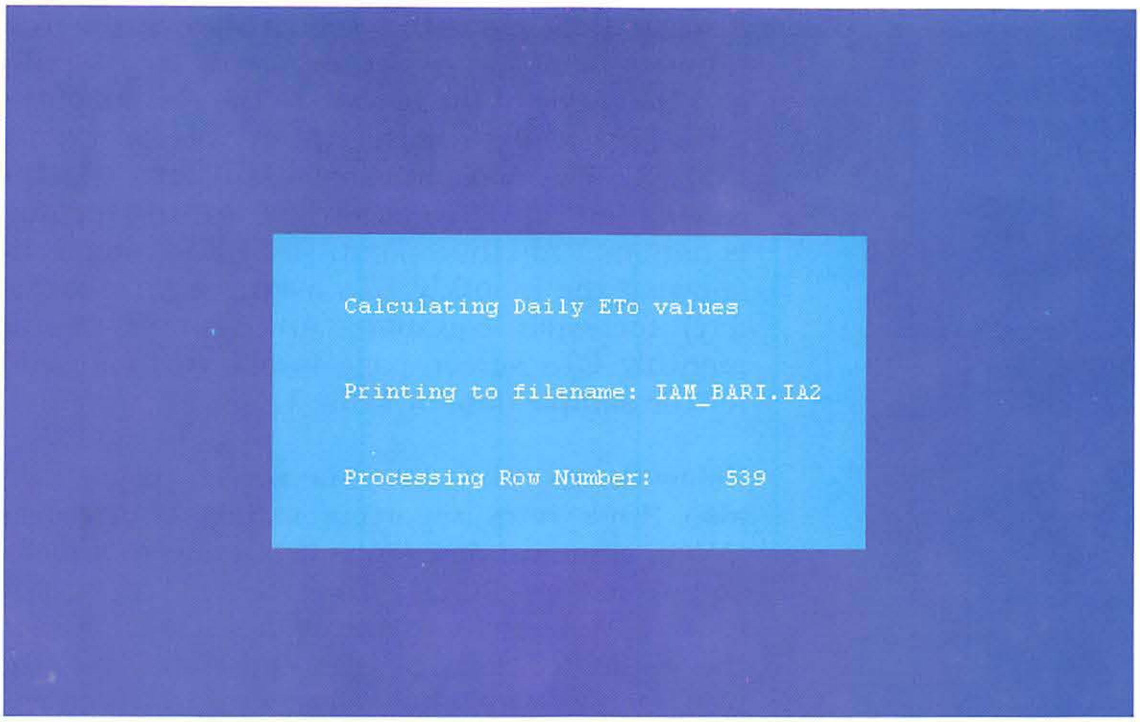


Fig. 9 - The *running* page of IAM_ETo while processing daily ET_O

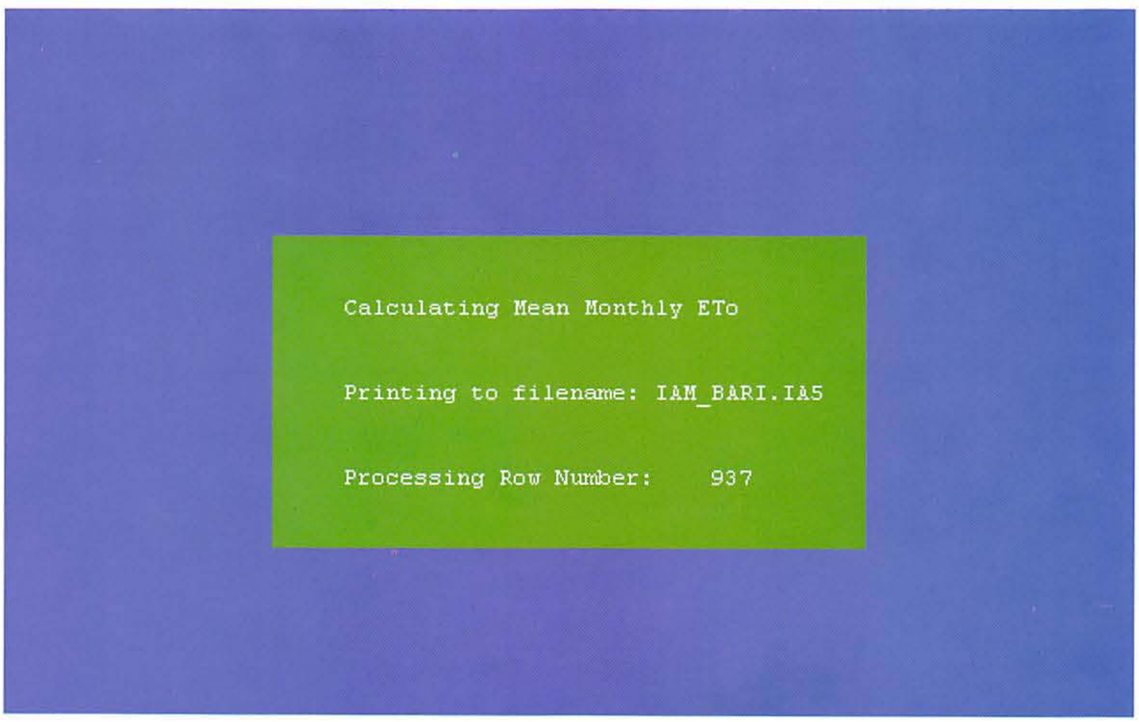


Fig. 10 - The *running* page of IAM_ETo while processing the mean monthly ET_O

Also in this case, the screen shows the row number being processed scrolling very rapidly and the name of the file where the results of the processing will be stored. After this operation, IAM_ETo has accomplished its major task: the calculation of ETo according to the default equations. At this point, IAM_ETo stops by showing the monthly ETo averages (in mm per day) for each equation. An example of the monthly ETo screen-page is shown in Fig. 11 for the sample data of Table 1.

Below the monthly data, the screen-page shows also three rows reporting values of averages (AVG), standard deviations (STD) and root mean square errors (RMS). The root mean square error (RMS) refers to the comparison between the estimated ETo by the equations and the lysimeter, or any other reference ETo which will be indicated as "lysimeter" in the variable description page (see section 6 for further explanation).

Monthly Mean ETo (mm/dy) and Mean Total Precipitation (mm/mo)

MON	LYS	PM	PEN	FAOP	PT	FAOR	FAOB	SCSB	HARG	Epan	PMD	Rn
Jan	1.3	1.4	1.4	1.5	0.6	1.1	1.1	1.3	1.2	1.2	1.5	0.9
Feb	1.6	1.6	1.8	1.9	1.1	1.6	1.3	1.4	1.5	1.5	1.8	1.7
Mar	2.3	2.3	2.5	2.8	2.0	2.4	2.1	1.9	2.4	2.1	2.5	2.8
Apr	3.5	3.2	3.5	4.2	3.3	3.7	3.2	2.8	3.5	3.3	3.6	4.2
May	4.4	4.2	4.6	5.5	4.5	4.9	4.5	4.4	4.7	4.0	4.6	5.3
Jun	5.6	5.3	5.7	6.9	5.2	5.9	6.0	5.9	5.6	4.9	5.9	5.8
Jul	6.1	5.7	6.0	7.4	5.6	6.3	6.7	6.9	6.0	5.5	6.4	6.0
Aug	5.4	5.2	5.5	6.6	4.9	5.7	6.1	6.3	5.3	4.8	5.8	5.3
Sep	4.0	3.9	4.1	4.8	3.7	4.4	4.6	5.0	4.2	3.8	4.3	4.1
Oct	2.4	2.5	2.6	2.9	2.1	2.7	2.9	3.3	2.6	2.3	2.7	2.5
Nov	1.4	1.5	1.5	1.7	0.8	1.4	1.6	1.9	1.5	1.4	1.6	1.1
Dec	1.1	1.2	1.1	1.2	0.5	1.0	1.0	1.4	1.1	1.1	1.2	0.7
AVG	3.8	3.7	3.9	4.7	3.4	4.0	4.1	4.2	3.8	3.5	4.1	3.9
STD	2.0	1.8	1.9	2.4	1.9	2.1	2.3	2.1	1.8	1.8	2.1	2.0
RMS	0.0	0.6	0.6	1.2	0.9	0.7	0.9	1.2	0.9	0.8	0.7	0.9

<F10> - continue to calculate CWD <Esc> - go back & exit

Fig. 11 - Monthly mean ETo *screen* page

RMS is calculated according to the following equation

$$RMS = \sqrt{\frac{\sum (ET_{O\_Eq} - ET_{O\_Ly})^2}{n-1}}$$

where $ETo_{\_Eq}$ is the ETo value calculated according to each equation, $ETo_{\_Ly}$ is the corresponding ETo value obtained from the lysimeter and ***n*** is the number of data included in the comparison.

The AVG, STD and RMS values are reported in the output file *.IA5 on both monthly and annual basis, if more than one year of data is available.

At the very bottom of the monthly ETo screen-page (Fig. 11), the usual <F10> and <Esc> keys are displayed. At this step of the program execution, one can continue (pressing <F10>) to make IAM_ETo to accomplish its 2nd major task, i.e., the calculation of the climatic water deficit (CWD) or go back (pressing <Esc>) to process another input data file for the calculation of ETo.
Continuing with the calculation of CWD, IAM_ETo also generates the 10-day and the 7-day ETo. The results of these calculations are reported in the output file with the extension *.IA3 and *.IA4, respectively.

5. Calculating the Climatic Water Deficit (CWD)

From the monthly ET_O screen-page, press <F10> to continue. IAM_ETo will display the *equation selection page*, as shown in Fig. 12.

The *climatic water deficit* (CWD) is calculated as difference between the water *demand* and the water *supply* represented by the *reference evapotranspiration* (ET_O) and the *usable rainfall* (P_O), respectively.

The calculation of the (CWD) is performed on a monthly basis using a specific ET_O equation selected from the screen.

The selection of the equation is made by inserting the corresponding ET_O equation number. Of course, only those equations that can be calculated with the available data can be selected. After entering the equation number, the highlighted cursor moves automatically to the 2nd information required, i.e. the minimum number of days per month to be considered in order to include a month in the analysis. This second piece of information is required because not all the days of a month are always available in the input data file. Some times, in fact, the agro-meteo stations are not functioning properly, or the quality control on the data induced to eliminate some days, or for any other reason that makes the month incomplete. The CWD calculated on a significantly reduced number of days in a month can make the results unreliable or even meaningless. The default minimum number of days per month is 25. The user is free to change this number to adjust the calculation to its data availability. To insert a different number, delete the 25 by the <Del> key and enter the new one. The user of IAM_ETo is responsible, anyway, for the interpretation of the results. Furthermore, we advice not to use the calculation of the CWD, as a climatic index, for data sets of less than 30 years.

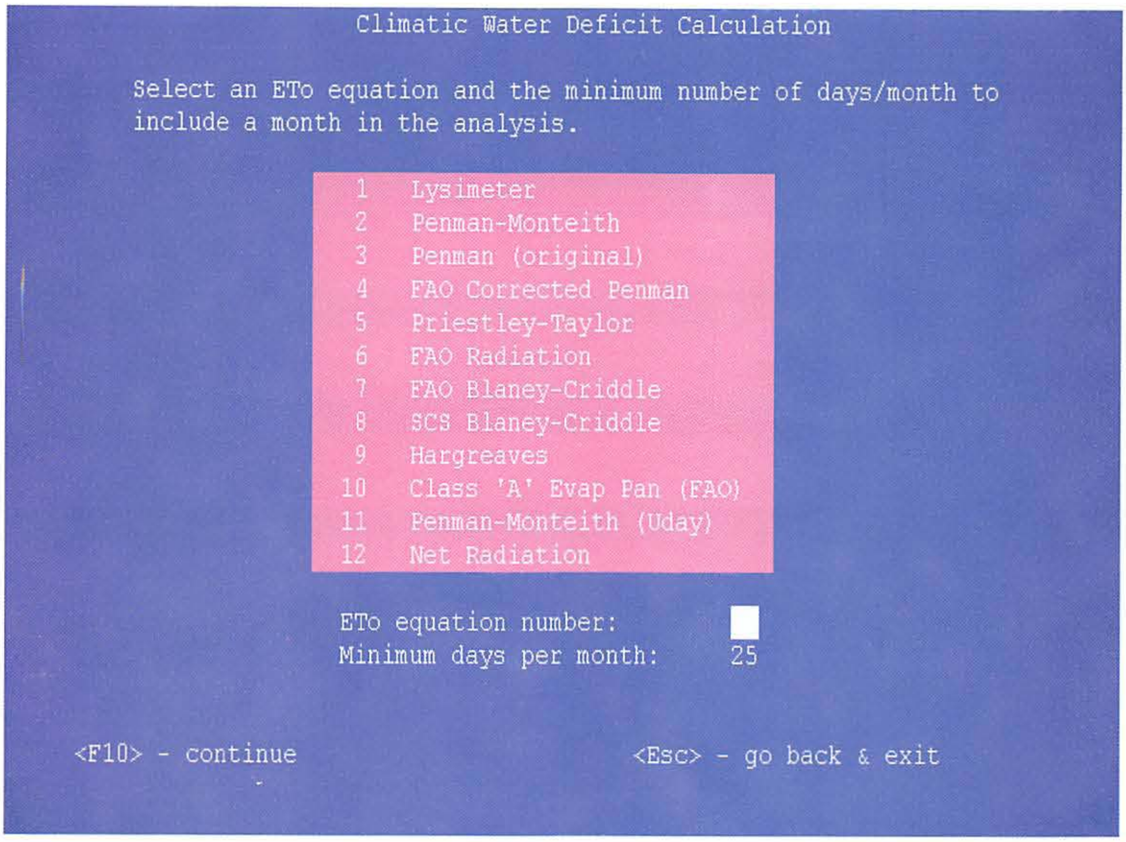


Fig. 12 - *Equation selection* page for the calculation of the CWD

After entering the required information (the equation for estimating ET_O and the minimum number of days) and pressing <F10>, IAM_ETo displays the CWD results on the last screen-page, as shown in Fig. 13.

On the upper part of this page, the filename of the input data file used, the equation selected for calculating ET_O and the minimum number of days per month entered are reported. For each month, *mean* and *standard deviation* (STD) of ET_O, *precipitation* (Pr), *usable rainfall* (P_O) and *climatic water deficit* (CWD) are given in mm per month, along with the number of years included in the analysis for each month.

In this page, the *precipitation* (Pr) comes from the input data file while the *usable rainfall* (P_O) is the monthly amount of precipitation not exceeding the *reference* evapotranspiration (ET_O).

Filename: IAM_BARI   Equation: Penman-Monteith

Minimum days per month: 10

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
ETo, Reference Evapotranspiration (mm/mon)												
Mean	47	47	70	89	122	155	176	154	110	73	49	30
STD	11	3	10	13	34	29	15	22	21	17	18	0
Pr, Precipitation (mm/mo)												
Mean	48	88	69	70	59	51	57	67	75	59	74	61
STD	11	12	27	63	42	42	42	49	39	34	37	13
Po, Usable Rainfall (mm/mo)												
Mean	41	47	60	59	59	51	57	67	72	57	49	30
STD	7	3	16	46	42	42	42	49	33	31	18	0
CWD, Climatic Water Deficit (mm/mo)												
Mean	6	0	10	30	64	104	119	87	38	16	0	0
STD	5	0	14	51	72	55	45	57	37	22	0	0
Years of record												
n =	3	2	4	5	7	7	6	8	6	5	5	2

<F10> - repeat CWD calculation   <Esc> - go back & exit

Fig. 13 - The *CWD screen* page results

In other words,

$$P_O=Pr \quad \text{if} \quad Pr<ET_O$$
$$P_O=ET_O \quad \text{if} \quad Pr\geq ET_O$$

then, $$CWD=ET_O - P_O$$

As example, in Fig. 13, for the month of February ET_O=47 mm and Pr=88 mm, then P_O=47 mm and CWD=0 mm. For the month of June, instead, ET_O=155 mm and Pr=51 mm, then P_O=51 mm and CWD=104 mm. The results of this calculation are stored in an output file with the extension *.IA7. Recall that the calculation of CWD is executed month by month and the overall *mean* and STD are

derived afterward, with the results given in Fig. 13, and not the other way around.
By that, IAM_ETo has completed all its jobs.
Pressing <F10>, one can run again the CWD choosing a different equation or a different n° of days per month. Pressing <Esc>, one can go back and exit.

6. Suggestions for Alternative use of IAM_ETo

IAM_ETo is typically tailored to daily data processing. Nevertheless, it can process also weather data on longer time periods (e.g., 7-day, 10-day, monthly, etc.). When processing monthly data, IAM_ETo automatically recognizes a data set as monthly if no day is inserted in the *variable declaration page* (see Fig. 4 and 5). When processing other time intervals, a simple trick needs to be adopted, i.e., to insert the middle day date of the time period considered. As an example, if you have 10-day input data, your data file will have three rows per month. Then, the 1st, the 2nd and the 3rd row will have the day 5, 15 and 25 (assuming 30 days per month). Similarly, for 7-day input data, your data file will have only four rows per month, each with the day number corresponding to the middle date of every week. This is the way to use IAM_ETo also for time periods longer than one day and shorter than a month. However, IAM_ETo cannot be used for time periods shorter than one day (e.g., hourly scale).

As mentioned earlier, IAM_ETo calculates the root mean square error (RMS) between the estimated ET_O by each equation and the lysimeter measurements (where available). If you have no lysimeter data, but need to compare the equation estimates against a different reference, such as Class A pan evaporation or one particular equation you consider more valid (e.g., PM), you just need to attribute (in the *variable description page* -see Fig. 4-) the order n° of your reference to the *variable* "lysimeter". For IAM_ETo, in fact, whatever is under the "lysimeter" variable is taken as the column to compare for the calculation of RMS.

If one wants to use any of the ET_O obtained by IAM_ETo as a reference, first run the program to get the desired ET_O, then insert the selected reference ET_O in the input data file, and then re-run IAM_ETo indicating the order number of such ET_O as a "lysimeter" variable in the *variable declaration page* (Fig. 4).

7. The Output Files

While running, IAM_ETo generates nine output files with different information stored. Three of these files support IAM_ETo itself, while the other 6 contain the results of the calculation useful for the user. Hereafter, all the output files are described in details.

CFILE
containing the input file name for possible subsequent running with IAM_ETo on the same input data file.

<Filename>.IA0
containing the descriptive entries of the weather station, order of the variables, units, etc.

<Filename>.IA1
containing the data values in standard format and proper units, needed to run the calculation routine.

<Filename>.IA2
containing the ET_o values, calculated with the various equations, at the same time scale as the input data file (e.g., if you input daily data you'll get daily ET_O; if you input monthly data you'll get monthly ET_O; etc.).

<Filename>.IA3
containing three tables with the upper one listing the *average* 7-day ET_O values, the middle one reporting the *standard deviations*, and the bottom one giving the *Root Mean Square Error* (RMSE) of the ET_O values *vs.* the lysimeter values (if available), in addition to three rows of data (at the very bottom) reporting annual ET_O AVG, STD and RMS. If -999 values are displayed, it means that there is no available information to derive the statistics.

<Filename>.IA4
containing the same data values and statistics as in <Filename>.IA3, but for a 10-day period.

<Filename>.IA5
containing the same data values and statistics as in <Filename>.IA3, but for a monthly period.

<Filename>.IA6
containing the values of the intermediate variables needed to calculate ET_o; i.e., Atmospheric pressure (B_p), psychrometric constant (γ), slope of the relationship vapor pressure *vs.* temperature (s), vapor pressure deficit (VPD), extra terrestrial radiation (R_a), astronomic day length (N), etc.

<Filename>.IA7
containing the monthly ET_o, Precipitation and Climatic Water Deficit (or CWD).

note 1: the output files of major interest are <Filename.IA2>, <Filename>.IA3, <Filename>.IA4 and <Filename>.IA5. The latter three files are meaningful only if the input data file is on a daily basis.

note 2: if one wants to retain the site description information (e.g., same latitude, elevation, variables number, order and units) to be used with a different data set, the easiest way is to copy the *.IA0 to the new file name. For example, let's say you have two data files from the same site (e.g., IAMBARI1.DAT and IAMBARI2.DAT) and you have already run IAMBARI1.DAT, then, simply copy IAMBARI1.IA0 (generated during the processing of IAMBARI1.DAT) to IAMBARI2.IA0 and run IAMBARI2.DAT. In this way, the *variable description page* (Fig. 5) will be retained also for this last data set.

APPENDIX

A. Basic Variables Calculations

- Extraterrestrial radiation (I_d), in MJ m^{-2} d^{-1}, is calculated using the methods described by Iqbal (1983). Inputs include the solar constant (I_o = 4.9212 MJ m^{-2} hr^{-1}), the day angle (Γ) for day of the year (D) in radians, the Earth-Sun distance (E_o) in radians, sunrise hour angle (ω_s) in radians, solar declination (δ) in radians, and latitude (L) expressed in radians (ϕ).

$$I_d = \frac{24}{\pi} I_o E_O [\omega_s \sin(\delta) \sin(\phi) + \cos(\delta) \cos(\phi) \sin(\omega_s)] \quad (1)$$

$$I_o = 4.9212 \quad MJ\ m^{-2}\ hr^{-1} \quad (2)$$

$$\Gamma = 2\pi \frac{D-1}{365} \quad (3)$$

$$\begin{aligned} E_o = {} & 1.00011 + 0.034221 \cos(\Gamma) + 0.00128 \sin(\Gamma) \\ & + 0.000719 \cos(2\Gamma) + 0.000077 \sin(2\Gamma) \end{aligned} \quad (4)$$

$$\begin{aligned} \delta = {} & 0.006918 - 0.399912 \cos(\Gamma) + 0.07257 \sin(\Gamma) \\ & + 0.006758 \cos(2\Gamma) + 0.000907 \sin(2\Gamma) \\ & - 0.002697 \cos(3\Gamma) + 0.00148 \sin(3\Gamma) \end{aligned} \quad (5)$$

$$\omega_s = \cos^{-1} [-\tan(\phi) \tan(\delta)] \quad (6)$$

$$\phi = L \frac{\pi}{180} \quad (7)$$

The extraterrestrial radiation expressed in mm of evaporation (R_a) is calculated by dividing I_d by the latent heat of vaporization (λ=2.45 MJ kg^{-1} at 25°C).

$$R_a = \frac{I_d}{\lambda} \qquad \mathbf{8}$$

The monthly mean maximum sunshine hours (N) are determined from the sunrise hour angle as:

$$N = \frac{24}{\pi}\omega_s \qquad \mathbf{9}$$

with ω_s calculated from the 15th day of the month. The actual bright sunshine hours (n) are input for each month and the ratio n/N is used to calculate ET_o in some methods.

- Latent heat of vaporization (λ), in MJ kg^{-1}, is computed as a function of temperature for all ET_O calculations

$$\lambda = 2.501 - (2.361\text{x}10^{-3})T_m \qquad \mathbf{10}$$

with T_m = mean air temperature in °C.

- Barometric pressure (B_p), in kPa, from Doorenbos and Pruitt (1977)

$$B_P = 101.3[(293 - 0.0065E_L)/293]^{5.26} \qquad \mathbf{11}$$

with E_L = elevation of the site in m.

- Mean air temperature (T_m), in °C

$$T_m = \frac{T_x + T_n}{2} \qquad \mathbf{12}$$

with T_x and T_n the *max* and *min* air temperature, respectively.

- Mean relative humidity (H_m), in %

$$H_m = \frac{H_x + H_n}{2} \qquad \mathbf{13}$$

with H_x and H_n the *max* and *min* relative humidity, respectively.

- Psychrometric constant (γ), in kPa °C^{-1},

$$\gamma = \frac{0.00163\, B_P}{\lambda} \quad 14$$

- Saturation vapor pressure at mean air temperature (e_{am}), in kPa

$$e_{am} = 0.6108\, e^{\left(\frac{17.27\, T_m}{T_m + 237.3}\right)} \quad 15$$

- Slope of saturation vapor pressure (Δ), in kPa °C^{-1},

$$\Delta = \frac{4099 e_{am}}{(T_m + 237.3)^2} \quad 16$$

- Wind speed at 2 m height (u_2), in m s^{-1},

$$u_2 = u\left(\frac{200}{Z_w}\right)^{0.2} \quad 17$$

where Z_w is the height from the ground of the wind sensor (cm).

- Day-time wind speed (u_d), in m s^{-1} (Doorenbos and Pruitt, 1977). For wind calculations, daytime is from 0700-1900 hours and nighttime is from 1900-0700 hours.

$$u_d = 2\, u_2\left(\frac{R_{dn}}{R_{dn} + 1}\right) \quad 18$$

where R_{dn} is the ratio of daytime to nighttime average wind speed.

- Incident solar radiation (R_s), in MJ m^{-2} d^{-1}, when measurements are not available, is calculate as

$$R_s = \left(0.25 + 0.50\frac{n}{N}\right) I_d \quad 19$$

- Relative sunshine hours (n/N), when n is unknown, is calculated as

$$\frac{n}{N} = 2\frac{R_s}{I_d} - 0.5 \quad 20$$

NOTE:

Since the soil heat flux density (G) is not commonly measured and G≈0 on a daily basis, G=0 is used for all ET_o calculations.

B. ET_O Calculation Equations

- **PENMAN-MONTEITH FAO METHOD (Allen et al., 1994a, b; 1998)**

Saturation vapor pressure at the maximum air temperature (e_{ax})

$$e_{ax} = 0.6108\, e^{\left(\frac{17.27\, T_x}{T_x + 237.3}\right)} \qquad 21$$

Saturation vapor pressure at the minimum air temperature (e_{an})

$$e_{an} = 0.6108\, e^{\left(\frac{17.27\, T_n}{T_n + 237.3}\right)} \qquad 22$$

Mean saturation vapor pressure at the dew point temperature or the actual vapor pressure of the air (e_{dp})

$$e_{dp} = \frac{e_{ax}\frac{H_n}{100} + e_{an}\frac{H_x}{100}}{2} \qquad 23$$

Mean daily saturation vapor pressure (e_{ap})

$$e_{ap} = \frac{e_{ax} + e_{an}}{2} \qquad 24$$

Net solar radiation (R_{ns}), with albedo (α)=0.23,

$$R_{ns} = 0.77\frac{R_s}{\lambda} \qquad 25$$

Net terrestrial (longwave) radiation (R_{lp}) modified from Doorenbos and Pruitt (1977)[1]

$$R_{lp} = (-\sigma \frac{T_{kx}^4 + T_{kn}^4}{2\lambda})(0.9\frac{n}{N} + 0.1)(0.34 - 0.14\sqrt{e_{dp}}) \qquad 26$$

where σ = Stefan-Boltzman constant ($4.903x10^{-9}$ MJ K^{-4} m^{-2} d^{-1}), $T_{kx} = T_x + 273.16$ and $T_{kn} = T_n + 273.16$.

Net radiation (R_{np}) is

$$R_{np} = R_{ns} + R_{lp} \qquad 27$$

Modified psychrometric constant (γ^*)

$$\gamma^* = \gamma\left(1 + \frac{r_c}{r_a}\right) = \gamma(1 + 0.34\,u_2) \qquad 28$$

Radiation term of ET_o equation (R_{dp})

$$R_{dp} = \frac{\Delta}{\Delta + \gamma^*}(R_{np} - G) \qquad 29$$

Aerodynamic term of ET_o equation (A_{dp})

$$A_{dp} = \frac{\frac{\gamma}{\Delta + \gamma^*}(e_{ap} - e_{dp})(900)u_2}{T_m + 273} \qquad 30$$

Evapotranspiration(E_{PM})

$$E_{PM} = R_{dp} + A_{dp} \qquad 31$$

---

[1] In the FAO Paper n. 56, the term $(0.9\frac{n}{N} + 0.1)$ of eq. 26 is replaced by the term $(1.35\frac{R_S}{R_{SO}} - 0.35)$ with R_S calculated as in eq. 19 and R_{SO} (the clear-sky radiation) calculated as $(0.75 + 2x10^{-5}z)$ where z is the station elevation above sea level (in m). Strictly speaking, then, eq. 26 is not identical to what is used in the FAO Paper n. 56. Though, there is no significant difference in the numerical results.

- **ORIGINAL PENMAN METHOD (Penman, 1948)**

Net solar radiation (R_{ns})

$$R_{ns} = 0.77 \frac{R_s}{\lambda} \quad 32$$

Net terrestrial (longwave) radiation (R_L)

$$R_L = (\frac{-\sigma T_k^4}{\lambda})(0.9\frac{n}{N} + 0.1)(0.34 - 0.14\sqrt{e_d}) \quad 33$$

where $T_k = T_m + 273.16$.

Net radiation (R_{no})

$$R_{no} = R_{ns} + R_L \quad 34$$

Radiation term of ET_o equation (R_{do})

$$R_{do} = \frac{\Delta}{\Delta + \gamma}(R_{no} - G) \quad 35$$

Aerodynamic term of ET_o equation (A_{do})

$$A_{do} = \frac{\frac{\gamma}{\Delta + \gamma}(e_{am} - e_d)(6.43)(1 + 0.536u_2)}{\lambda} \quad 36$$

Evapotranspiration (E_{PEN})

$$E_{PEN} = R_{do} + A_{do} \quad 37$$

- **FAO PENMAN METHOD (Doorenbos and Pruitt, 1977)**

Net solar radiation (R_{ns})

$$R_{ns} = 0.77 \frac{R_s}{\lambda} \quad \textbf{38}$$

Net terrestrial (longwave) radiation (R_L)

$$R_L = (\frac{-\sigma T_k^4}{\lambda})(0.9 \frac{n}{N} + 0.1)(0.34 - 0.14\sqrt{e_d}) \quad \textbf{39}$$

where $T_k = T_m + 273.16$

Net radiation (R_{no})

$$R_{no} = R_{ns} + R_L \quad \textbf{40}$$

Radiation term of ET_o equation (R_{do})

$$R_{do} = \frac{\Delta}{\Delta + \gamma}(R_{no} - G) \quad \textbf{41}$$

Aerodynamic term of ET_o equation (A_{df})

$$A_{df} = \frac{\frac{\gamma}{\Delta + \gamma}(e_{am} - e_d)(6.61)(1 + 0.864 u_2)}{\lambda} \quad \textbf{42}$$

Evapotranspiration (E_P)

$$E_P = R_{do} + A_{df} \quad \textbf{43}$$

Doorenbos and Pruitt (1977) provided a correction factor (C) that is multiplied by E_P to adjust for local conditions. Recently, Allen and Pruitt (1991) reported an equation for determining this correction factor (C).

$$C = A0 + A1(U_{dy}) + A2(U_{dy} \bullet S_{rd}) + A3(RH_x \bullet S_{rd}) + A4(DN_w \bullet U_{dy} \bullet RH_x) + A5(DN_w \bullet U_{dy} \bullet RH_x \bullet S_{rd}) + A6(U_{dy}^2 \bullet RH_x \bullet S_{rd}) + A7(DN_w^2 \bullet U_{dy} \bullet RH_x) + A8(DN_w \bullet U_{dy}^2 \bullet RH_x^2 \bullet S_{rd}) + A9(RH_x \bullet S_{rd}^2) \quad \textbf{44}$$

where DN_w is the ratio of daytime (0700h-1900h) to nighttime (1900h-0700h) average wind speeds (if $DN_w>4$ then $DN_w=4$), RH_x is the maximum daily relative humidity ($30\% \leq RH_x \leq 90\%$), U_{dy} is the average daytime wind speed ($U_{dy} \leq 10$ m s^{-1}), and S_{rd} is the solar radiation (3 mm d$^{-1} \leq S_{rd} \leq 12$ mm d^{-1}). Values for the coefficients in the above equation are:

A0 = 0.892
A1 = -0.0781
A2 = 0.00219
A3 = 0.000402
A4 = 0.000196
A5 = 0.0000198
A6 = 0.00000236
A7 = -0.00000860
A8 = -0.0000000292
A9 = -0.0000161

The corrected FAO Penman ET_o (E_{FAOP}) is calculated as:

$$E_{FAOP} = C \cdot E_P \quad (45)$$

- **PRIESTLEY/TAYLOR METHOD (Priestley and Taylor, 1972)**

Net solar radiation (R_{ns})

$$R_{ns} = 0.77\frac{R_s}{\lambda} \quad (46)$$

Net terrestrial radiation (R_L)

$$R_L = (\frac{-\sigma T_k^4}{\lambda})(0.9\frac{n}{N}+0.1)(0.34-0.14\sqrt{e_d}) \quad (47)$$

where $T_k = T_m + 273.16$

Net radiation (R_{no})

$$R_{no} = R_{ns} + R_L \quad (48)$$

Evapotranspiration (E_{PT})

$$E_{PT} = 1.26 \frac{\Delta}{\Delta + \gamma} (R_{no} - G) \quad \textbf{49}$$

- **FAO RADIATION METHOD (Doorenbos and Pruitt, 1977)**

Constants

B_0=1.066; B_1=-0.0013; B_2=0.045; B_3=-0.0002; B_4=-0.0000315; B_5=-0.0011

Correction factor

$$B = B_0 + B_1 H_m + B_2 U_d + B_3 H_m U_d + B_4 H_m^2 + B_5 U_d^2 \quad \textbf{50}$$

Evapotranspiration (E_{FAOR})

$$E_{FAOR} = B \frac{\Delta}{\Delta + \gamma} \frac{R_s}{\lambda} - 0.3 \quad \textbf{51}$$

- **FAO BLANEY/CRIDDLE METHOD (Doorenbos and Pruitt, 1977)**

Constants

A_0=0.908; A_1=-0.00483; A_2=0.7949; A_3=0.00768; A_4=-0.0038; A_5=-0.000443; A_6=0.281; A_7=-0.00975

Correction factors

$$A = 0.0043 H_n - \frac{n}{N} - 1.41 \quad \textbf{52}$$

$$B = A_0 + A_1 H_n + A_2 \frac{n}{N} + A_3 (\ln(U_d + 1))^2 + A_4 H_n \frac{n}{N}$$
$$+ A_5 H_n U_d + A_6 \ln(U_d + 1) \ln(\frac{n}{N} + 1)$$
$$+ A_7 \ln(U_d + 1)(\ln(H_n + 1))^2 \ln(\frac{n}{N} + 1) \quad \textbf{53}$$

Monthly percentage of annual sunshine hours (P)

$$P = \frac{N_m}{N_a} \quad \textbf{54}$$

where N_m is the monthly total maximum sunshine hours and N_a is the annual total maximum sunshine hours.

Evapotranspiration (E_{FAOBC})

$$E_{FAOBC} = A + B(0.46\, T_m + 8.13) P \quad \textbf{55}$$

- **SCS BLANEY/CRIDDLE METHOD (Blaney and Criddle, 1950)**

$$K_c = 1.0 \quad \textbf{56}$$

Correction factors

$$K_T = 0.0173\, T_F - 0.314 \quad \textbf{57}$$

$$T_F = 1.8\, T_m + 32 \quad \textbf{58}$$

Evapotranspiration (E_{SCSB})

$$E_{SCSB} = \frac{25.4}{100} K_T K_C T_F P \qquad 59$$

where P is the monthly percentage of annual sunshine hours.

- **HARGREAVES METHOD (Hargreaves, 1974)**

Mean temperature range by month (T_d)

$$T_d = T_x - T_n \qquad 60$$

Evapotranspiration (E_{HARG})

$$E_{HARG} = \frac{0.0023}{\lambda} I_d \sqrt{T_d} (T_m + 17.8) \qquad 61$$

- **FAO EVAPORATION PAN METHOD (Doorenbos and Pruitt, 1977)**

Variable limits for use in correcting pan evaporation:

Mean relative humidity (H_m)

$$30 \le H_m \le 84 \qquad 62$$

Daily wind run (W_R), in km d^{-1}

$$84 \le W_R \le 700 \qquad 63$$

Upwind fetch of bare ground or low-growing vegetation, in m

$$1 \leq |F| \leq 1000 \quad (64)$$

Pan evaporation correction when surrounded by vegetation (F>0)

$$P_C = 0.108 - 0.000331 W_R + 0.0422 \ln(F) + 0.1434 \ln(H_m) - 0.000631 (\ln(F))^2 \ln(H_m) \quad (65)$$

Pan evaporation correction when surrounded by bare soil (F<0)

$$P_C = 0.61 + 0.00341 H_m - 1.87x\,10^{-6} W_R H_m - 1.11x\,10^{-7} W_R F + 3.78x\,10^{-5} W_R \ln(F) - 3.32x\,10^{-5} W_R \ln(W_R) - 0.0106 \ln(W_R) \ln(F) + 0.00063 (\ln(F))^2 \ln(W_R) \quad (66)$$

Evapotranspiration (E_{PAN})

$$E_{PAN} = E_P P_C \quad (67)$$

where E_P is the measured evaporation from the pan.

C. Minimum weather variables requirement for each method

(and time scale suggested for application)

METHOD	Temperature	Humidity	Wind	Sunshine or Radiation	Evaporation	Time scale 1d	10d	M
Hargreaves	*							*
Blaney-Criddle	*							*
Radiation	*			*			*	*
Priestley-Taylor	*			*		*	*	*
Penmann	*	*	*	*		*	*	
Penman-Monteith	*	*	*	*		*		
Pan Evaporation					*		*	*

D. Additional Equations

- **PENMAN-MONTEITH using daytime wind speed**

  This equation is the same as the Penman-Monteith equation previously described (Eq. 31), except the daytime wind speed (7:00-19:00) rather than the 24-hour wind speed is used in the equations 28 and 30.

- **Net Radiation Equivalent Evaporation**

  This method simply expresses the value of R_{np} calculated in Eq. 27 as totally used in evapotranspiration. Because the soil heat flux (G) is neglected in the daily ET_O calculations, the values obtained by this method correspond to the so-called *available energy*.

E. Symbols description and units

Symbol	Description	UNITS
π	3.1415927	
σ	Stefan-Boltzman costant (4.903x10^{-9})	MJ K^{-4} m^{-2} d^{-1}
δ	Sun declination	radians
ϕ	Latitude	radians
ω_s	Sunrise hour angle	radians
Γ	Day angle	radians
I_o	Solar constant	MJ m^{-2} hr^{-1}
I_d	Extraterrestrial radiation	MJ $m^{-2}d^{-1}$
E_o	Earth-Sun distance	radians
λ	Latent heat of vaporization	mm (MJ $m^{-2}d^{-1})^{-1}$
R_a	Extraterrestrial radiation	mm d^{-1}
R_s	Solar Radiation	MJ $m^{-2}d^{-1}$
R_n	Net radiation	MJ m^{-2} d^{-1}
G	Soil heat flux	mm d^{-1}
N	Potential sunshine hours	hrs
n	Actual sunshine hours	hrs
n/N	Ratio of actual to potential sunshine hours	
P	Monthlw percent of annual sunshine hours	%
T_x	Maximum temperature	°C
T_n	Minimum temperature	°C
T_m	Mean air temperature	°C
H_x	Maximum relative humidity	%
H_n	Minimum relative humidity	%
H_m	Mean air relative humidity	°C
u_2	Wind speed at 2.0 meters height	m s^{-1}
u_d	Day time wind speed	m s^{-1}
u_n	Night time wind speed	m s^{-1}
R_{dn}	Day/night wind ratio	
W_r	Wind run adjusted to 2.0 meters height	km d^{-1}
B_p	Barometric pressure	kPa
γ	Psychometric constant	kPa °C^{-1}
γ*	Gamma star for Penman-Monteith	kPa °C^{-1}
Δ	Slope of sat. vap. press. curve	kPa °C^{-1}
e_{ax}	Sat. vap. press. at T_{max}	kPa
e_{an}	Sat. vap. press. at T_{min}	kPa
e_{dp}	Actual vapor press. for Penman-Monteith	kPa
e_{ap}	Mean sat. vapor press. for Penman-Monteith	kPa
e_{am}	Sat. vap. press. at T_m	kPa
e_d	Actual vap. press. using T_m and H_m	kPa
R_{lp}	Longwave net radiation for Penman-Monteith	mm d^{-1}
R_{ns}	Shortwave net radiation	mm d^{-1}
R_{np}	Net radiation for Penman-Monteith	mm d^{-1}
R_{dp}	Radiation term for Penman-Monteith	mm d^{-1}
R_L	Longwave net radiation for original and FAO Penman	mm d^{-1}
R_{no}	Net radiation for original Penman	mm d^{-1}
R_{do}	Radiation term for original Penman	mm d^{-1}
R_{nf}	Net radiation term for FAO Penman	mm d^{-1}
R_{df}	Radiation term for FAO Penman	mm d^{-1}
A_{do}	Aerodynamic term for original Penman	mm d^{-1}
A_{df}	Aerodynamic term for FAO Penman	mm d^{-1}
A_{dp}	Aerodynamic term for Penman-Monteith	mm d^{-1}
E_{PAN}	Evaporation pan	mm d^{-1}
E_{LYS}	Lysimeter evapotranspiration	mm d^{-1}
E_{PEN}	Original Penman ET_O estimate	mm d^{-1}
E_{FAOP}	FAO Penman ET_O estimate	mm d^{-1}
E_{PM}	Penman-Monteith ET_O estimate	mm d^{-1}
E_{FAOR}	FAO radiation estimate	mm d^{-1}
E_{FAOB}	FAO Blaney-Criddle ET_O estimate	mm d^{-1}
E_{SCSB}	SCS Blaney-Criddle ET_O estimate	mm d^{-1}
E_{HARG}	Hargreaves ET_O estimate	mm d^{-1}
E_{CPAN}	FAO corrected pan ET_O estimate	mm d^{-1}

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INTERNATIONAL CENTRE FOR ADVANCED MEDITERRANEAN AGRONOMIC STUDIES

RESUME

L'estimation des besoins en eau des cultures, le bilan hydrologique d'un couvert végétal, l'efficience d'utilisation de l'eau de la part des systèmes agricoles, et beaucoup d'autres conditions où la consommation en eau dans le continuum sol-plante-atmosphère entre en jeu, requièrent, de quelques manières, la détermination de la "demande climatique".

Une manière pour quantifier une telle "demande" est fournie par l'estimation de l'"évapotranspiration de référence", indiquée par ETo et définie en tant que "taux d'évapotranspiration à partir d'une surface étendue d'une culture de gazon vert, de hauteur uniforme de 8 à 15 cm, en bonnes conditions de croissance, ombrageant entièrement le sol et qui ne manque pas d'eau. Autrefois, la culture de référence était la luzerne. Plus récemment, on a pris comme culture de référence abstraite ayant une hauteur, une conductance du couvert et une réflectance de surface constantes. Au fil du temps, différents modèles et équations ont été développés et testés pour estimer ETo, chacun avec ses particularités, son échelle temporelle et ses besoins en termes de données.

Pour cela, ETo étant le point de départ pour un grand nombre d'applications dans la gestion de l'eau en agriculture, le Réseau d'Efficience d'Utilisation de l'Eau (WUE_Net), un Réseau de recherche formé par des Institutions scientifiques qui opèrent dans la Méditerranée, promu et appuyé par le CIHEAM, a décidé de produire ce logiciel IAM_ETo (avec documentation annexe) pour l'élaboration aisée et rapide des données météorologiques couramment obtenues à partir des stations agro-météorologiques pour calculer ETo et, pour de longues séries de données, le déficit hydrique climatique (CWD ClimaticWater Deficit).

IAM_ETo calcule ETo à différentes échelles temporelles, journalière à un mois, par les équations suivantes, qui représentent les principaux standards reportés en littérature:

- Penman-Monteith (FAO)
- Penman (originel)
- Penman (FAO)
- Priestly-Taylor
- Rayonnement (FAO)
- Blaney-Criddle (FAO)
- Blaney-Criddle (SCS)
- Hargreaves
- Bac de classe A (FAO)

IAM_ETo calcule le déficit hydrique climatique (CWD) en tant que différence entre ETo et la pluie mensuelle utilisable (à savoir, pour un mois donné, la pluie utilisable est la hauteur de pluie qui n'excède pas ETo).

Au cours de l'élaboration des données, IAM_ETo calcule aussi des données statistiques, telles les moyennes, les écarts types et les erreurs quadratiques moyennes.

De par ses particularités, IAM_ETo s'adresse aux scientifiques, aux agences gouvernementales, aux ingénieurs et aux vulgarisateurs qui s'occupent de la gestion de l'eau en agriculture et en irrigation.

SUMMARY

The estimates of crop water requirements, the hydrological balance of a vegetated surface, the efficiency in water use by agricultural systems, and many other cases where the water consumption throughout the soil-plant-atmosphere is involved, all require, at a moment or another, the determination of the "evaporative demand of the atmosphere".

One way to quantify such a "demand" is given by estimating the "reference-crop evapotranspiration", indicated as Eto and typically defined as "the rate of evapotranspiration from an extensive surface of 8 to 15 cm tall green grass cover, of uniform height, actively growing, completely shading the ground and not short in water". At times, the reference crop was alfalfa. More recently, the reference crop has been abstracted and assumed as a crop having height, canopy conductance and surface reflectance as constants. Over time, different equations or models have been developed and tested to estimate ETo, each one with its own peculiarity, time scale, and data requirements.

Thus, being Eto the starting point for many applications in agricultural water management, the Water Use Efficiency Network (WUE_Net), a research Network of scientific Institutions operating in the Mediterranean, promoted and supported by the CIHEAM, decided to yield this IAM_ETo Software Program and User's Guide to process easily and quickly weather data commonly obtained from agro-meteorological stations to calculate Eto and, for long time series of data, the climatic water deficit (CWD).

IAM_ETo calculates ET_0 at different time scales, from daily to monthly, with the following equations, representing the major standards in the literature:

- Penman-Monteith (FAO)
- Penman (original)
- Penman (FAO)
- Priestley-Taylor
- Radiation (FAO)
- Blaney-Criddle (FAO)
- Blaney-Criddle (SCS)
- Hargreaves
- Class "A" Pan (FAO)

IAM_ETo calculates the climatic water deficit (CWD) as simple difference between monthly ETo and monthly usable rainfall (i.e., for a given month, usable rainfall is the depth of rainfall not exceeding Eto).

While processing the data, IAM_ETo calculates also some useful statistics such as means, standard deviations and root mean square errors.

For its distinctive features, IAM_ETo is addressed to scientists, governmental agencies, engineers and extension officers involved in agricultural water management and irrigation.

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