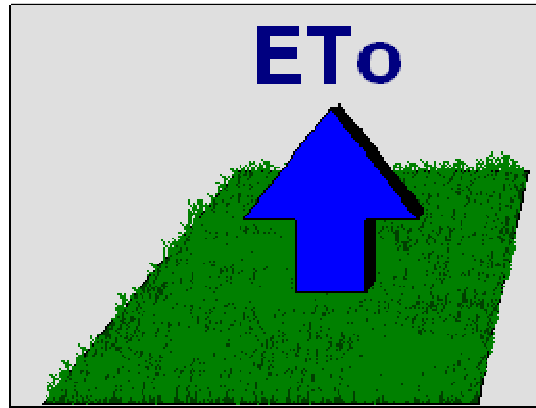


The ETo Calculator



**Evapotranspiration
from a reference surface**



Reference Manual

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Chapter 1.

Reference evapotranspiration (ET_o)

Evapotranspiration is the combination of soil evaporation and crop transpiration. Weather parameters, crop characteristics, management and environmental aspects affect evapotranspiration. The evapotranspiration rate from a reference surface is called the reference evapotranspiration and is denoted as ET_o . A large uniform grass (or alfalfa) field is considered worldwide as the reference surface. The reference grass crop completely covers the soil, is kept short, well watered and is actively growing under optimal agronomic conditions (Fig. 1).

The concept of the reference evapotranspiration was introduced to study the evaporative demand of the atmosphere independently of crop type, crop development and management practices. As water is abundantly available at the reference evapotranspiring surface, soil factors do not affect ET_o . Relating evapotranspiration to a specific surface provides a reference to which evapotranspiration from other surfaces can be related. ET_o values measured or calculated at different locations or in different seasons are comparable as they refer to the evapotranspiration from the same reference surface. The only factors affecting ET_o are climatic parameters. Consequently, ET_o is a climatic parameter and can be computed from weather data. ET_o expresses the evaporating power of the atmosphere at a specific location and time of the year and does not consider the crop characteristics and soil factors (Allen et al., 1998).

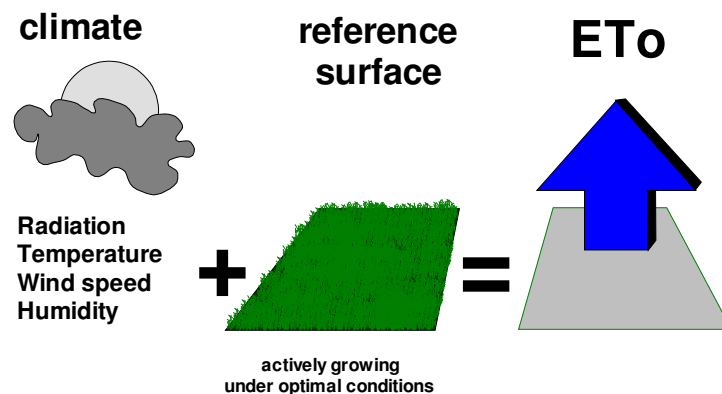


Figure 1.
Reference evapotranspiration (ET_o)

Owing to the difficulty of obtaining accurate field measurements, ET_o is commonly computed from weather data. A large number of empirical or semi-empirical equations have been developed for assessing reference evapotranspiration from meteorological data. Numerous researchers have analysed the performance of the various calculation methods for different locations. As a result of an Expert Consultation held in May 1990, the FAO Penman-Monteith method is now recommended as the standard method for the definition and computation of the reference evapotranspiration ET_o .

Chapter 2. Menu Reference

2.1 Hierarchical structure of the menus

From the *Main menu* the user has access to the various menus of the program. The hierarchical structure of the menus is plotted in Figure 2.

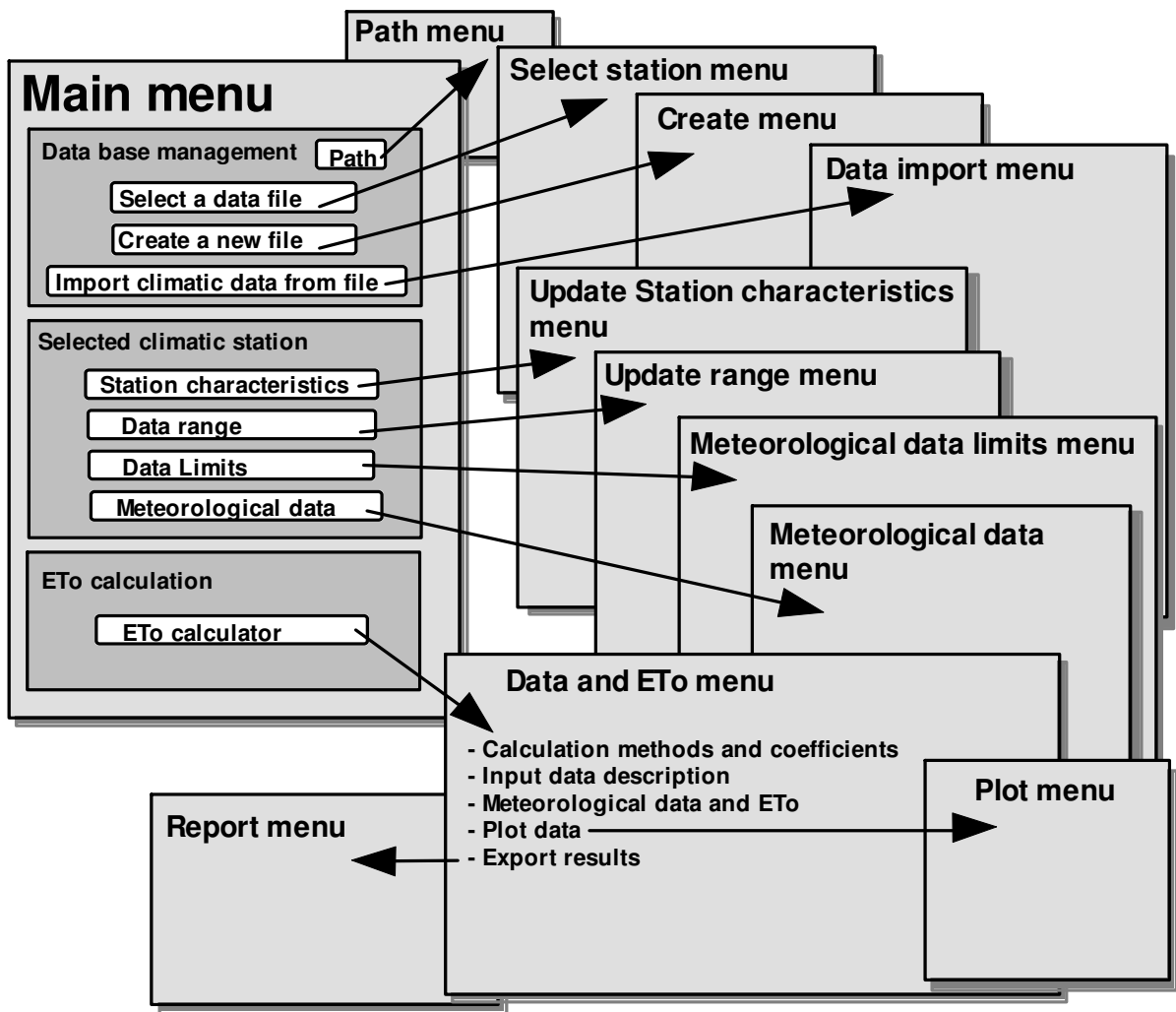


Figure 2.
Hierarchical structure of the menus

2.2 Main menu

The *Main menu* (Fig. 3) is composed of three sections:

- **Data base management** section in which:
 - the **Path** (directory and folder where data files are stored), can be changed,
 - the user can **Select a data file** or **Create a new file** in which meteorological data from climatic stations are stored,
 - the user can **Import climatic data from file**.
- **Selected climatic station.** In this section the name of the selected file and the corresponding name of the climatic Station and Country are displayed. The user can update the **Station characteristics**, expand or shorten the **Data range**, alter the thresholds of the **Data limits** and examine the available **Meteorological data**.
- **ETo calculation** section contains the **ETo Calculator**. In the corresponding *Data and ETo menu*, the climatic parameters used to calculate ETo can be selected, meteorological data can be updated, specified and plotted, and results can be exported as reports or as climate files to the Data base of AquaCrop.

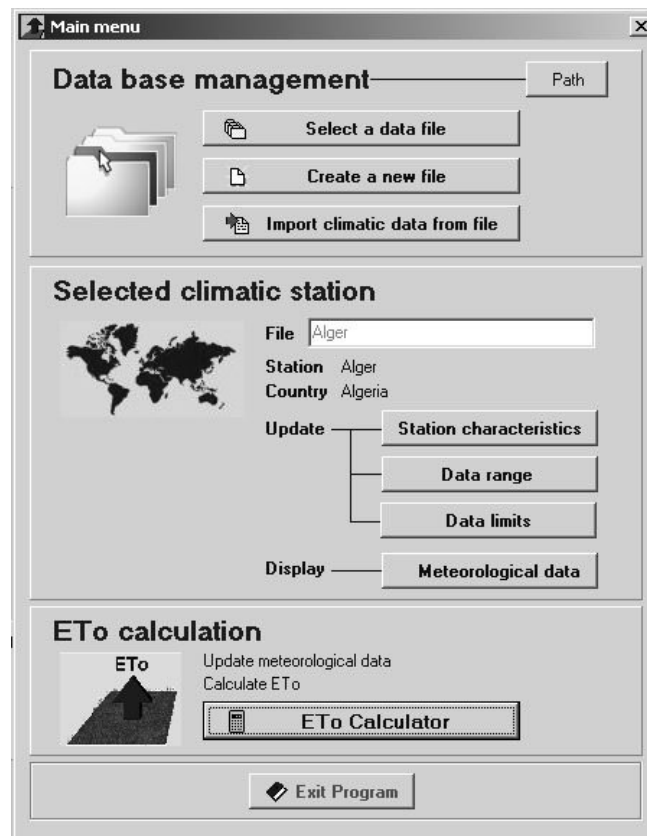


Figure 3.
Main menu of the ETo calculator

2.3 Data base management

In the Data base management section of the *Main menu* (Fig. 3), existing data files can be selected and new ones can be created.

- **Path**

By means of the Path button in the *Main menu*, the user can specify the folder where existing files can be retrieved or new ones should be stored.

- **Create a new file**

In the *Create menu* (Fig. 4), the user specifies:

The 'Create menu' dialog box is a standard Windows-style window with a title bar. It contains the following elements:

- File name:** A text input field at the top.
- Station description:** A section containing:
 - Station:** A text input field.
 - Country:** A text input field.
 - Location:** A group box containing two radio buttons: 'Degrees and Minutes' (selected) and 'Decimal degrees'.
 - Latitude:** A group box containing a text input field (22), a dropdown for 'degrees', a text input field (22), a dropdown for 'minutes', and a dropdown for 'North'.
 - Longitude:** A group box containing a text input field (22), a dropdown for 'degrees', a text input field (22), a dropdown for 'minutes', and a dropdown for 'East'.
 - Altitude:** A group box containing a text input field (222) and a label 'meter above sea level'.
- Meteorological Data:** A section containing:
 - Type:** A group box with three radio buttons: 'Daily' (selected), '10-daily', and 'Monthly'.
 - Location:** A group box with five radio buttons: 'at the coast', 'interior location' (selected), 'in arid or semi-arid area', 'in semi-humid or humid area', and 'light winds in area'.
 - Time range:** A group box containing a checkbox 'not linked to a specific year' (unchecked) and six dropdown fields: 'First Day' (1), 'First Month' (January), 'First Year' (2005), 'Last Day' (31), 'Last Month' (December), and 'Last Year' (2005).
- Buttons:** 'Cancel' and 'Create' buttons at the bottom.

Figure 4.
Create menu in the ETo Calculator

- the File name,
- information of the climatic station (the Name and Country of the climatic station, the Latitude (North or South), the Longitude (East or West), the Altitude in meters above sea level and a description of its location (the information is used to estimate missing climatic data),
- information of the Meteorological data (Type of data (daily, 10-daily or monthly), and the time range (from date - to date). If the meteorological data consists of

averages of several years, the data should not be linked to a specific year and the year has not to be specified.
If a new file is created successfully, it is stored in the specified folder (Path as specified in the *Main menu*).

- **Select a data file**

In the *Select station menu*, the user selects a data file from a list. The list displays the names of the existing files in the specified folder (Path as specified in the *Main menu*). The user can display the station characteristics and features of the available meteorological data linked with the data file.

- **Type of Data files (*.DSC and *.DTA files)**

The characteristics of the climatic station and the meteorological data linked to a station are stored in two separate data files which have the same file name but another file extension. Distinction is made between:

- files describing the station (files with extension DSC), and
- files containing the meteorological data (files with extension DTA).

The contents of the 2 data file are presented in Annex 2.

2.4 Importing climatic data from text files

Climatic data, stored in text files, can be imported by the software. The program can handle text files of daily, 10-daily or monthly climatic data created by the user, or files with monthly data exported from FaoClim 2.0 and CLIMWAT 2.0 software.

The *Data import menu* (Fig. 5) contains 5 tabular sheets, where the user specifies:

- **File type:** the type of file that needs to be imported. Distinction is made between:
 - Free format text files (files with extension CXT);
 - FAO Clim 2 files (files with extension DAT);
 - CLIMWAT files (files with extension PEN).
- **Climatic station:** the characteristics of the climatic station;
- **Meteorological data:** the type of meteorological data and time range (from-to);
- **Climatic parameters:** the climatic parameters;
- **Status Report:** The status report lists the missing information. In this tabular sheet, the user specifies the name of the file that will contain the characteristics of the station and the imported meteorological data.

If everything is properly specified, the data can be imported by means of the **<Import>** button.

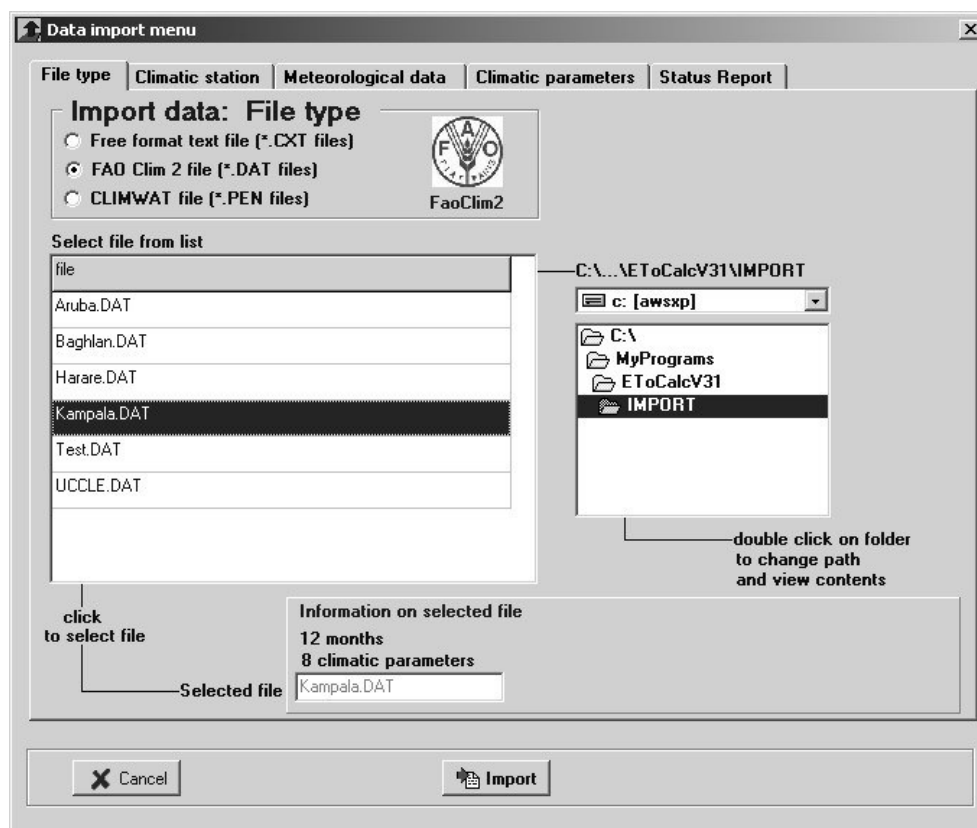


Figure 5.
Data import menu of the ETo Calculator

- **Free format text files with climatic data (*.CXT)**

A text file is a file with extension CXT in which climatic data for a specific period is saved in columns (Table 1). It is typically a copy from a spreadsheet.

In the tab sheet 'File type' (Fig. 5) the user selects from a list the text file containing the meteorological data. All files with extension CXT stored in the IMPORT sub directory of the program are listed. By altering the path, the user can retrieve 'CXT' text files stored in other directories.

Once a text file has been selected, the program displays:

- the number of data lines (rows) which should correspond with the specified time range (from-to),
- the number of climatic parameters which corresponds with the number of columns of the text file (Table 1).

Table 1. Example of a text file containing climatic data.

Daily climatic data of Irpani (Bolivia) from 3 to 16 October 2005 is saved in the text file. The file contains the maximum air temperature in degree Celsius (Column 1), the minimum air temperature in degree Celsius (Column 2), the maximum Relative Humidity in percentage (Column 3), the minimum Relative Humidity in percentage (Column 4), the wind speed in meter per second measured at 2 m above soil surface (Column 5), and the solar or shortwave radiation in W/m^2 (Column 6).

24.5	5.5	12	5	5.8	391.7
25.7	-0.1	22.9	3.5	3.8	310.6
24.8	-6.5	14.5	3.4	4.2	359.2
24.1	-9.4	16.3	3.2	3.5	361
24.6	-7.5	15.4	2.1	3.9	358
23.6	-5.4	72.2	7.9	3.2	341.7
19.6	4.4	77.4	23.7	3.7	209.9
21.1	2.9	82.8	4.1	3.9	291.4
21.4	-6.3	12.9	4.7	3.4	367.4
23.6	-5.7	54	6.1	3.2	365
24.5	-6.9	21.6	5.2	3.9	367.7
23.9	-4.1	18.8	4.9	3.7	371.81
23.5	-3.3	25.7	9.1	4.5	362.8
24.1	-4	34.7	10	4.2	366
23.9	-0.2	59.1	8	4.6	365.69
24.1	-5.3	26.1	4.9	3.4	368.19

Climatic station

The user specifies:

- the Name and Country of the climatic station,
- the Longitude (East or West),
- the Latitude (North or South),
- the Altitude in meters above sea level,
- a description of its location (the information is used to estimate missing climatic data).

Meteorological data

The user specifies:

- the type of data (daily, 10-daily or monthly),
- the time range (from date - to date). If the meteorological data consists of averages of several years, the data should not be linked to a specific year and the year has not to be specified.

Once the time range is set, the program displays the corresponding number of data records within this range. The number of records should match with the number of rows of the text file containing the meteorological data.

Climatic parameters

By clicking in the cell where the code of the climatic parameter has to be specified, a list pops up containing the code for the different climatic parameters the program can handle (Fig. 6). Codes are stored in 4 folders grouping them in Temperature codes, Humidity codes, Wind speed codes, and Sunshine and Radiation codes. When a code is selected from the list for a specific climatic parameter, the program displays:

- the symbol and unit of the selected climatic parameter,
- the minimum and maximum value for the selected climatic parameter as found in the text file. The default value (-999.000) for missing data (undefined value) can be altered,
- the upper and the lower limit for the selected climatic parameter used by the program. This option allows for a range check of the imported data. If the program limits are smaller than the detected data range an error is reported in the status report and the data cannot be imported by the program. If the user believes that the program limits are too narrowly set, the user can alter the limits by hitting the **<Update Data Range>** button.

Data import menu

File type | Climatic station | Meteorological data | **Climatic parameters** | Status Report

Column..... 1 2 3 4 5 6

Climatic parameters.....

Symbol.....	Tmax	Tmin	RHmax	RHmin
Unit.....	°C	°C	%	%
Code.....	101	103	201	203

<< click in cell to select code >>

Data range.....

Data Undefined Value -999.000

Column Max.....	28.4	12.8	98.8	67.4
Column Min.....	14.1	-12.7	8.8	1.0

Program limits (Data Range)

Upper limit.....	45.0	45.0	100.0	100.0
Lower limit.....	-15.0	-15.0	15.0	15.0

>>> **Update Data Range**

List of codes

Temperature | Humidity | **Wind speed** | Sunshine and Radiation

Code	Symbol	Unit	Description
301	u(x)	m/sec	wind speed (x m above soil surface)
302	u(x)	km/day	wind speed (x m above soil surface)
303	u(x)	knot	wind speed (x m above soil surface)
304	u(x)	ft/sec	wind speed (x m above soil surface)

Height wind speed measurement
2.0 meter above ground level

click to select code

Close

Cancel Import

Figure 6.
Specifying the code for the climatic parameters for each column of the text file
in the *Data import menu*

- **FAO Clim 2.0 exported files (*.DAT files)**

A file exported from the FAOClim 2.0 software contains the characteristics of a climatic station and its mean monthly climatic data (Annex 4). When importing such a file, the program copies the relevant information in the various tabular sheets, and the user has only to specify in the 'Status report' sheet the File name that will contain the characteristics of the station and the imported meteorological data.

- **CLIMWAT 2.0 files (*.PEN files)**

A file exported from the CLIMWAT 2.0 software contains the characteristics of a climatic station and its mean monthly climatic data (Annex 5). When importing such a file, the program copies the relevant information in the various tabular sheets, and the user has only to specify in the 'Status report' sheet the File name that will contain the characteristics of the station and the imported meteorological data.

- **Status report**

The status report keeps track of errors (red bullets). An error is displayed when:

- there is a difference between the specified data range (from-to) and the number of rows (data lines) in the text file (ERROR: number of records DIFFERENT FROM lines in file),
- the text file is not yet selected (ERROR: Select file with climatic data),
- the text file is not in the correct format (ERROR: CAN NOT import data from requested file). Possible errors might be:
 - empty file (no data),
 - (some) lines might contain text, or are empty,
 - not all lines have the same number of columns.
- not all the codes of the climatic parameters are specified (ERROR: Climatic parameter not yet specified),
- the data range for the imported climatic parameter exceeds the program limits (ERROR: Range of climatic data exceeds limits).

If there are no errors listed in the status report, the user specifies the File name that will contain the characteristics of the station and the imported meteorological data, and the data is stored in the Data Base of the program when clicking on the **<Import>** button.

2.5 Information concerning the selected climatic station

When a file is created, selected from the Data base or climatic data has been imported, the file name and the name of the Climatic Station and Country are displayed. The user can display features of the available meteorological data and examine the Station characteristics, expand or shorten the Data range, and alter the thresholds of the Data limits.

- **Meteorological data**

In the *Meteorological data menu*, information of the available meteorological data is displayed: the unit, the minimal and maximal value, and the number of available records for each of the existing climatic parameters. In the 'Plot meteorological data' tabular sheet, the values throughout the total time range for each of the climatic parameter are plotted.

- **Station characteristics**

In the *Update Station characteristics menu*, the Name, Country, Altitude and Coordinates of the climatic station are displayed, as well as a description of its location. The user can update the displayed information.

- **Data range**

In the *Update range menu*, the type of the meteorological data (daily, 10-daily or monthly), and the time range (from-to) are displayed. The user can expand or shrink the range. When the data range is expanded, the extra data can be specified in the *Data and ETo menu*.

- **Data limits**

By specifying lower and upper limits for meteorological data in the *Meteorological data limits menu* (Fig. 7), only data within the specific range is accepted when entering data in the *Data and ETo menu* or when importing data from a text file. If the limits are properly set, the program provides as such a quality check for the data. Since data limits are part of the description of the station (and saved in the DSC file of that station), sharp limits valid for the region can be specified for each climatic station individually.

Since certain limits for climatic data can never be exceeded, restrictions are built in for the upper and/or lower limits:

- Limits for air temperature, relative humidity and vapour pressure are linked. Changing the limits for one parameter will alter the limits for the linked climatic parameters:

$$\text{Lower limit for } e_a \geq e^o(T_{\min}) \frac{RH_{\min}}{100}$$

Upper limit for $e_a \leq e^\circ(T_{\max})$

where e_a actual vapour pressure [kPa],
 $e^\circ(T_{\min})$ saturation vapour pressure at daily minimum temperature [kPa],
 $e^\circ(T_{\max})$ saturation vapour pressure at daily maximum temperature [kPa],
 RH_{\min} minimum relative humidity [%].

- The latitude of the station and the time of the year determine the maximum hours of bright sunshine (N) and the extraterrestrial radiation (Ra). This put a limit on the maximum value one can observe on a particular day for the actual hours of bright sunshine (n), the solar (Rs) and (Rn) radiation (see Chapter 3, Eq. 3.14, 3.19, and 3.20). However a degree of over-estimation, that the user still finds acceptable, is allowed.

Meteorological data limits menu

Station: Alger
Country: Algeria

Limits

Parameter	Lower limit	Upper limit
Temperature (degrees Celsius)	-10	35
Temperature (degrees Fahrenheit)	14.0	95.0
Relative humidity (percent)	20	100
Vapour pressure (kPa)	0.0571	5.6227
Vapour pressure (mbar)	0.5714	56.2268
Wind speed (m/sec)	0	4
Wind speed (km/day)	0	345.6
Hours of bright sunshine (hours/day)	0	11.9
Radiation (MJ/m2 day)	0	14.6
Radiation (mm/day)	0	5.9

Hours of bright sunshine (N) graph: January to December, 0 to 24 hours.

Radiation (Ra) graph: January to December, 0 to 45 MJ/m2 day.

Accepted deviation: 25%

Angstrom equation:
 $a = 0.25$
 $b = 0.50$
 $R_s = a + b (n/N=1) R_a$
 correction for altitude (60m)

Latitude station: 36° 46' North

Buttons: Cancel, Save and Close

Figure 7.
Meteorological data limits menu of the ETo Calculator

2.6 Meteorological data and ETo calculation

When a file is created or selected in the Data Base management or climatic data has been imported, the user can access the *Data and ETo menu*. In the menu the user can:

- alter the description of the input data,
- specify or update the meteorological data and view the corresponding ETo,
- plot data,
- export results.

• Calculation method

The reference evapotranspiration from meteorological data is assessed in the ETo calculator software by means of the FAO Penman-Monteith equation. This method has been selected by FAO as the reference because it closely approximates grass ETo at the location evaluated, is physically based, and explicitly incorporates both physiological and aerodynamic parameters.

• Input data description

The screenshot shows the 'Data and ETo menu' window. At the top, there are fields for 'Station' (Alger), 'Country' (Algeria), and 'File' (Alger.DTA). Below these are four tabs: 'Input data description' (selected), 'Meteorological data and ETo', 'Plot data', and 'Export results'.

The 'Input data description' tab contains several sections:

- Air temperature:** Radio buttons for '* Celsius' (selected) and '* Fahrenheit'. Checkboxes for 'Mean temperature' (unchecked) and 'Minimum and Maximum temperature' (checked).
- Air humidity:** Checkboxes for 'Mean Relative Humidity' (unchecked), 'Minimum and Maximum Relative Humidity' (unchecked), 'Mean dew point temperature' (unchecked), and 'Mean actual vapour pressure' (checked). A dropdown menu shows 'mbar'.
- Psychrometric data:** Checkboxes for 'Mean dry and wet bulb temperature' (unchecked), 'Ventilated' (unchecked), 'Natural ventilated' (checked), and 'Indoors' (unchecked). A text field for 'Coefficient psychrometer' contains '0.000800'.
- IF missing air humidity:** A text field for 'T dew = T min + subtract' contains '2.0' and a dropdown menu shows '(semi)arid'.
- Wind speed:** Checkboxes for 'Mean wind speed' (checked) and 'height of measurement' (2.0 meter). A dropdown menu shows 'm/sec'. Below, 'IF missing wind speed' has a text field for 'U2 = 2.0' and a dropdown menu showing 'light to moderate wind'.
- Sunshine and Radiation:** Checkboxes for 'Hours of bright sunshine (n)' (unchecked), 'Relative sunshine hours (n/N)' (checked), 'Solar radiation (Rs)' (unchecked), and 'Net radiation (Rn)' (unchecked). Dropdown menus show 'MJ/m2.day'. A button 'Coefficients Angstrom equation' is present.
- IF missing radiation:** A text field for 'Rs =' contains '0.19' and a dropdown menu shows '< ... 0.16 (interior) ... 0.19 (coastal) ... >'.

At the bottom, there are buttons for 'Cancel' and 'Main menu'.

Figure 8.
Climatic parameters that can be used to calculate ETo

In the Input data description sheet, the climatic parameters used to calculate ETo are displayed (Fig. 8). The data is classified in 4 groups: Air temperature, Air humidity, Wind speed and Sunshine and Radiation. All climatic parameters (with their corresponding units) available in the selected or imported data file are by default checked. By removing a 'check', the specified values for the corresponding climatic parameter will not be used to calculate ETo and will be removed from the data file when the user returns to the **Main menu**. When a file is created, the user specifies in this menu the climatic parameters (with the corresponding units) that will be used to calculate ETo.

In case humidity data, wind speed data or radiation data is not available for a particular day, 10-day or month, the program will make use of the information specified in the corresponding boxes (Missing air humidity, wind speed or radiation data) to estimate the missing meteorological data (Fig. 8).

Values for the a and b coefficients of the Angstrom equation can be adjusted if actual solar radiation data are available and calibration has been carried out. By clicking on the **<Defaults>** button, the program reset the values of the coefficients to their default value as specified in the literature (Chapter 3).

• **Meteorological data and ETo**

In the meteorological data and ETo sheet, values for the selected climatic parameters are specified. Climatic data exceeding an upper or lower limit cannot be entered. If nothing is wrong with the data and the selected unit is correct, the user can expand the limits set by the program for the particular data file, by clicking on **<Data Limits>**.

If values are missing or data for more than one climatic parameter in a particular group (Air temperature, Air humidity, Wind speed or Sunshine and Radiation) are available, the program will apply the specific calculation rules as outlined in Chapter 3.

With the FAO Penman-Monteith method and the available climatic data, ETo is calculated and the results are displayed in the corresponding cells. If key climatic data is missing, ETo cannot be calculated and the ETo cell remains blank.

• **Plot data**

Specified and derived climatic data can be plotted in the Plot data sheet (Fig. 9). By clicking on the **<Plot options>** the user has access to the **Plot Menu**. In this menu the user specifies (i) the climatic data that needs to be plotted, (ii) the plot range (Maximum/Minimum), and (iii) the plot style (bar or line).

Specified and derived climatic data from the following groups can be plotted:

- Temperature: mean (Tmean), maximum (Tmax), minimum (Tmin), dew point (Tdew), dry bulb (Tdry) and wet bulb (Twet) temperature;
- Relative humidity: mean (RHmean), maximum (RHmax) and minimum (RHmin) relative humidity;

- Vapour pressure: Actual ($e(\text{act})$) and saturation ($e(\text{s})$) vapour pressure, and the vapour pressure difference ($e(\text{act}) - e(\text{s})$);
- Wind speed;
- Sunshine duration: actual duration of sunshine in a day (n) and the maximum possible duration of sunshine hours (N);
- Energy fluxes: extraterrestrial (R_a), clear sky solar (R_{so}), solar or shortwave (R_s), net solar (R_{ns}), net longwave (R_{nl}), and net (R_n) radiation, and the latent heat flux ($L(\text{ET})$);
- Relative radiation: relative sunshine duration (n/N) and relative shortwave radiation (R_s/R_{so});
- Reference evapotranspiration (ET_0).

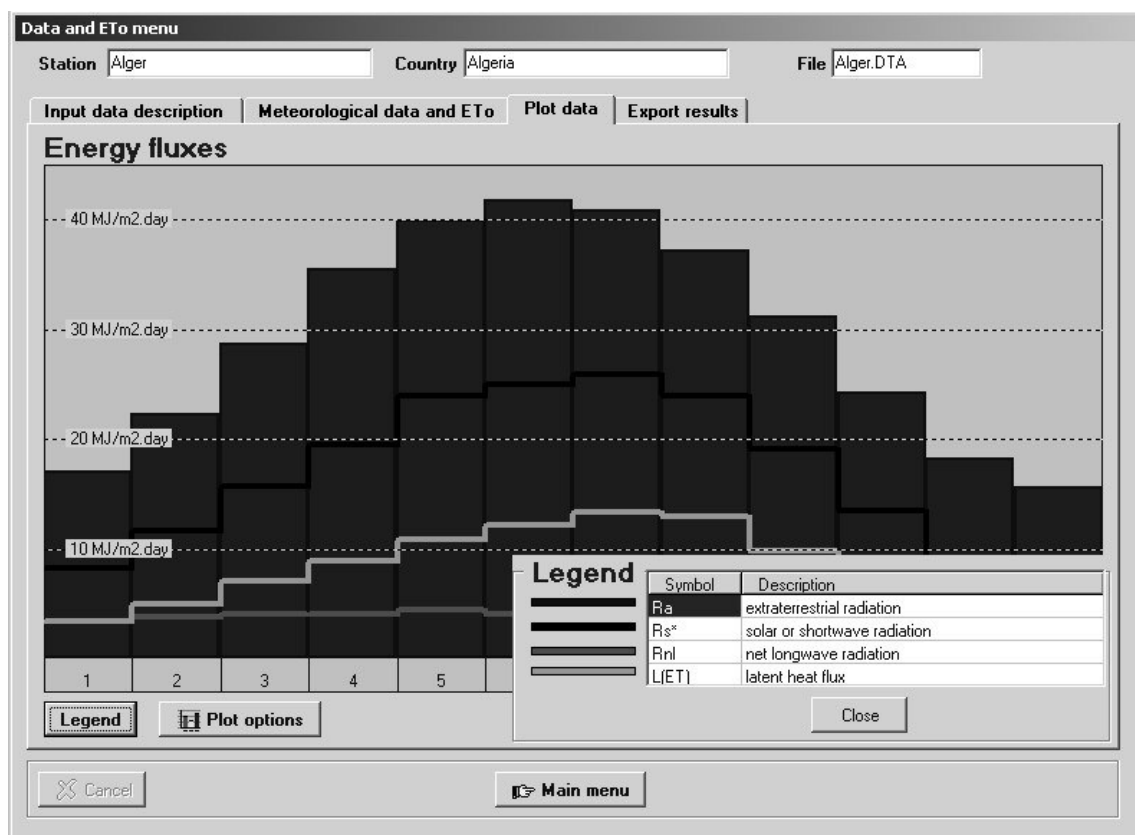


Figure 9.
Plot of energy fluxes
Extraterrestrial (bars), solar and net longwave radiation and latent heat flux

- **Export results**

Specified and derived climatic data can be exported in the Export results sheet (Fig. 10). The user selects if either an 'ETo report' has to be composed (which will be saved by default in the REPORT directory of the ETo calculator), or 'climate files' have to be exported to the data base of AquaCrop. The climate files consist of (i) an ETo file and (ii) an Air temperature file (Annex 6). The user can alter:

- the path where the report or files have to be saved,
- the file names, and
- the file descriptions.

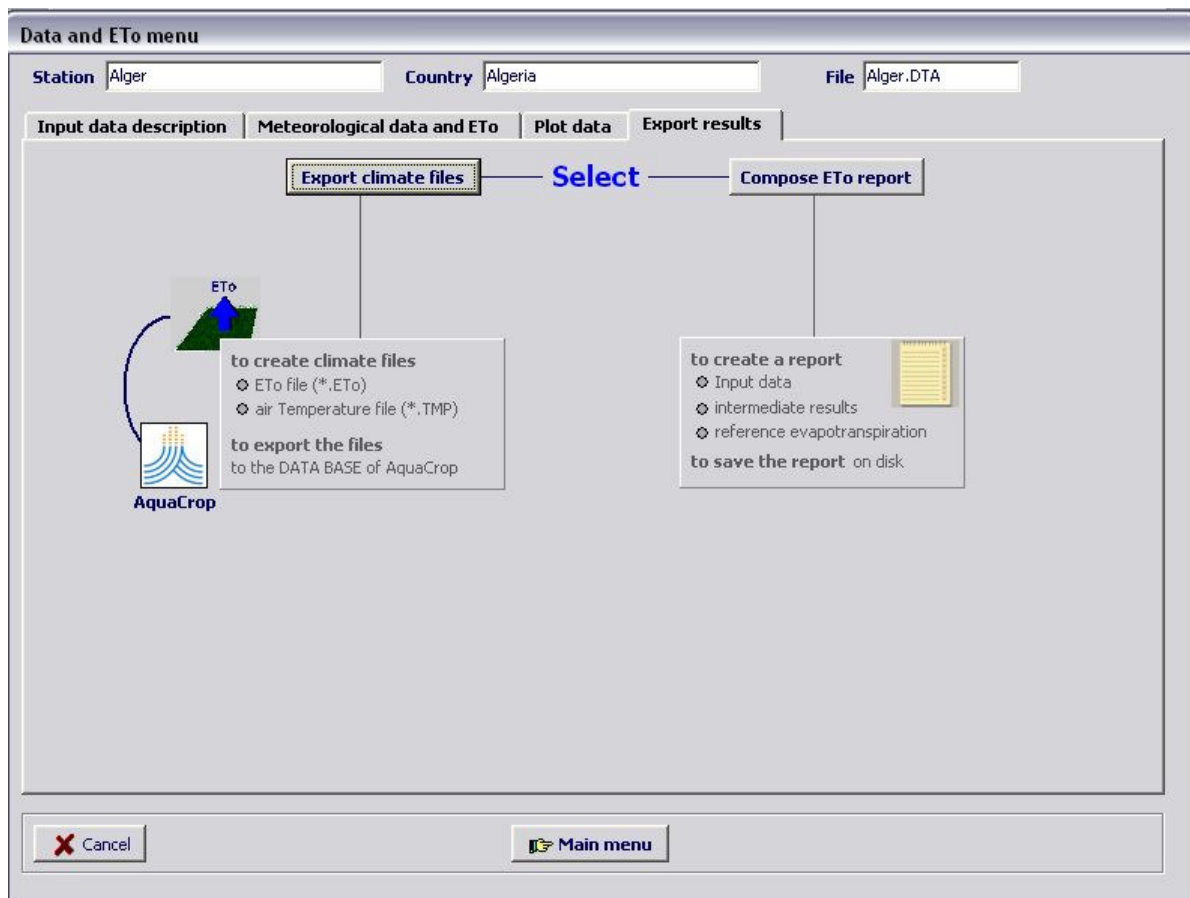


Figure 10.
Options for exporting results available in the *Data and ETo menu*

Chapter 3.

Calculation procedures

Calculation methods listed in this chapter are outlined in the FAO Irrigation and Drainage Paper n° 56 (Allen et al., 1998).

3.1 Atmospheric parameters

- **Atmospheric pressure (P)**

The atmospheric pressure, P, is the pressure exerted by the weight of the earth's atmosphere:

$$P = 101.3 \left(\frac{293 - 0.0065z}{293} \right)^{5.26} \quad (3.1)$$

where P atmospheric pressure [kPa],
 z elevation above sea level [m].

- **Psychrometric constant (γ)**

The psychrometric constant, γ , is given by:

$$\gamma = \frac{c_p P}{\epsilon \lambda} = 0.664742 \times 10^{-3} P \quad (3.2)$$

where γ psychrometric constant [kPa °C⁻¹],
 P atmospheric pressure [kPa],
 λ latent heat of vaporization, 2.45 [MJ kg⁻¹],
 c_p specific heat at constant pressure, 1.013 10⁻³ [MJ kg⁻¹ °C⁻¹],
 ϵ ratio molecular weight of water vapour/dry air = 0.622.

The value of the latent heat varies as a function of temperature. As λ varies only slightly over normal temperature ranges a single value of 2.45 MJ kg⁻¹ is considered in the program. This corresponds with the calculation procedure for the FAO Penman-Monteith equation. The fixed value for λ is the latent heat for an air temperature of about 20°C.

3.2 Air temperature

- **Mean air temperature (T_{mean})**

The mean air temperature is given by:

$$T_{\text{mean}} = \frac{T_{\text{max}} + T_{\text{min}}}{2} \quad (3.3)$$

where T_{mean} mean air temperature [$^{\circ}\text{C}$],
 T_{min} minimum air temperature [$^{\circ}\text{C}$],
 T_{max} maximum air temperature [$^{\circ}\text{C}$].

• Calculation rules

- if T_{max} and T_{min} are available, the mean air temperature (T_{mean}) is calculated by Eq. 3.3 and the specified mean air temperature is disregarded,
- if T_{mean} and only T_{max} or T_{min} are available, the missing minimum or maximum air temperature is estimated by rearranging Eq. 3.3,
- if T_{max} or T_{min} is missing and cannot be derived, ET_o cannot be calculated,
- if no temperature data is available, ET_o can not be calculated.

3.3 Air humidity

• Saturation vapour pressure as a function of air temperature ($e^{\circ}(T)$)

$$e^{\circ}(T) = 0.6108 \exp \left[\frac{17.27 T}{T + 237.3} \right] \quad (3.4)$$

where $e^{\circ}(T)$ saturation vapour pressure at the air temperature T [kPa],
 T air temperature [$^{\circ}\text{C}$],
 $\exp[.]$ 2.7183 (base of natural logarithm) raised to the power [..].

• Mean saturation vapour pressure for a day, 10-day, or month (e_s)

Due to the non-linearity of Eq. 3.4, the mean saturation vapour pressure for a day, 10-day or month is computed as the mean between the saturation vapour pressure at the mean daily maximum and minimum air temperatures for that period:

$$e_s = \frac{e^{\circ}(T_{\text{max}}) + e^{\circ}(T_{\text{min}})}{2} \quad (3.5)$$

where e_s saturation vapour pressure [kPa],
 $e^{\circ}(T_{\text{max}})$ saturation vapour pressure at the mean daily maximum air temperature [kPa],
 $e^{\circ}(T_{\text{min}})$ saturation vapour pressure at the mean daily minimum air temperature [kPa].

- **Slope of saturation vapour pressure curve (Δ)**

For the calculation of the reference evapotranspiration, the slope of the relationship between saturation vapour pressure and temperature, Δ , is required. The slope of the curve at a given temperature is given by:

$$\Delta = \frac{4098 \left[0.6108 \exp \left(\frac{17.27 T}{T + 237.3} \right) \right]}{(T + 237.3)^2} \quad (3.6)$$

where Δ slope of saturation vapour pressure curve at air temperature T [kPa °C⁻¹],
T air temperature [°C],
exp[.] 2.7183 (base of natural logarithm) raised to the power [..].

- **Actual vapour pressure (e_a) derived from dewpoint temperature**

$$e_a = e^o(T_{\text{dew}}) = 0.6108 \exp \left[\frac{17.27 T_{\text{dew}}}{T_{\text{dew}} + 237.3} \right] \quad (3.7)$$

where e_a actual vapour pressure [kPa],
 T_{dew} dew point temperature [°C].

- **Actual vapour pressure (e_a) derived from psychrometric data**

$$e_a = e^o(T_{\text{wet}}) - \gamma_{\text{psy}} (T_{\text{dry}} - T_{\text{wet}}) \quad (3.8)$$

where e_a actual vapour pressure [kPa],
 $e^o(T_{\text{wet}})$ saturation vapour pressure at wet bulb temperature [kPa],
 γ_{psy} psychrometric constant of the instrument [kPa °C⁻¹],
 $T_{\text{dry}} - T_{\text{wet}}$ wet bulb depression, with T_{dry} the dry bulb and T_{wet} the wet bulb temperature [°C].

The psychrometric constant of the instrument is given by:

$$\gamma_{\text{psy}} = a_{\text{psy}} P \quad (3.9)$$

where a_{psy} is a coefficient depending on the type of ventilation of the wet bulb [°C⁻¹], and P is the atmospheric pressure [kPa].

- **Actual vapour pressure (e_a) derived from relative humidity data**

The actual vapour pressure can also be calculated from the relative humidity. Depending on the availability of the humidity data, different equations are used:

For RH_{\max} and RH_{\min} :

$$e_a = \frac{e^o(T_{\min}) \frac{RH_{\max}}{100} + e^o(T_{\max}) \frac{RH_{\min}}{100}}{2} \quad (3.10)$$

where e_a actual vapour pressure [kPa],
 $e^o(T_{\min})$ saturation vapour pressure at daily minimum temperature [kPa],
 $e^o(T_{\max})$ saturation vapour pressure at daily maximum temperature [kPa],
 RH_{\max} maximum relative humidity [%],
 RH_{\min} minimum relative humidity [%].

For RH_{\max} :

$$e_a = e^o(T_{\min}) \frac{RH_{\max}}{100} \quad (3.11)$$

For RH_{mean} (Smith, 1992):

$$e_a = e^o(T_{\text{mean}}) \frac{RH_{\text{mean}}}{100} \quad (3.12)$$

Eq. 3.12 differs from the one presented in the FAO Irrigation and Drainage Paper N° 56. Analysis with several climatic data sets proved that more accurate estimates of e_a can be obtained with Eq. 3.12 than with the equation reported in the FAO paper if only mean relative humidity is available (G. Van Halsema and G. Muñoz, Personal communication).

• Vapour pressure deficit ($e_s - e_a$)

The vapour pressure deficit is the difference between the saturation (e_s) and actual vapour pressure (e_a) for a given time period.

• Calculation rules

If air humidity data are missing or if several climatic parameters are available with which the air humidity can be estimated, the following calculation rules exist:

- If the mean actual vapour pressure (e_a) is missing and air humidity is specified by means of another climatic parameter, e_a is estimated from (in descending order):
 - the specified mean dew point temperature T_{dew} (Eq. 3.7),
 - the specified mean dry (T_{dry}) and wet bulb (T_{wet}) temperature (Eq. 3.8),
 - the specified maximum (RH_{\max}) and minimum (RH_{\min}) relative humidity, and the specified maximum (T_{\max}) and minimum (T_{\min}) air temperature (Eq. 3.10). In case RH_{mean} and only RH_{\max} or RH_{\min} are available, the program estimates the missing minimum or maximum relative humidity by rearranging Eq. 3.13:

$$RH_{\text{mean}} = \frac{RH_{\max} + RH_{\min}}{2} \quad (3.13)$$

- the specified maximum (RH_{\max}) and minimum (T_{\min}) air temperature (Eq. 3.11),
- the specified mean (RH_{mean}) and mean (T_{mean}) air temperature (Eq. 3.12).
- If no air humidity data are available, e_a is estimated by assuming that the minimum air temperature (T_{\min}) is a good estimate for the mean dew point temperature (T_{dew}). Before using T_{\min} in Eq. 3.7, the number of degrees specified in the **Data and ETo menu** (Missing air humidity in the Input data description sheet) will be subtracted from T_{\min} .

3.4 Radiation

• Extraterrestrial radiation (R_a)

The extraterrestrial radiation, R_a , for each day of the year and for different latitudes is estimated from the solar constant, the solar declination and the time of the year by:

$$R_a = \frac{24 (60)}{\pi} G_{\text{sc}} d_r [\omega_s \sin(\varphi) \sin(\delta) + \cos(\varphi) \cos(\delta) \sin(\omega_s)] \quad (3.14)$$

where

R_a	extraterrestrial radiation [$\text{MJ m}^{-2} \text{day}^{-1}$],
G_{sc}	solar constant = $0.0820 \text{ MJ m}^{-2} \text{min}^{-1}$,
d_r	inverse relative distance Earth-Sun (Equation 3.16),
ω_s	sunset hour angle (Equation 3.18) [rad],
φ	latitude [rad] (Equation 3.15),
δ	solar declination (Equation 3.17) [rad].

The latitude, φ , expressed in radians is positive for the northern hemisphere and negative for the southern hemisphere. The conversion from decimal degrees to radians is given by:

$$[\text{Radians}] = \frac{\pi}{180} [\text{decimal degrees}] \quad (3.15)$$

The inverse relative distance Earth-Sun, d_r , and the solar declination, δ , are given by:

$$d_r = 1 + 0.033 \cos\left(\frac{2\pi}{365} J\right) \quad (3.16)$$

$$\delta = 0.409 \sin\left(\frac{2\pi}{365} J - 1.39\right) \quad (3.17)$$

where J is the number of the day in the year between 1 (1 January) and 365 or 366 (31 December).

The sunset hour angle, ω_s , is given by:

$$\omega_s = \arccos \left[-\tan (\varphi) \tan (\delta) \right] \quad (3.18)$$

- **Daylight hours (N)**

The daylight hours, N, are given by:

$$N = \frac{24}{\pi} \omega_s \quad (3.19)$$

where ω_s sunset hour angle in radians given by Equation 3.18.

- **Solar radiation (R_s)**

If the solar radiation, R_s , is not measured, it can be calculated with the Angstrom formula, which relates solar radiation to extraterrestrial radiation and relative sunshine duration:

$$R_s = \left(a_s + b_s \frac{n}{N} \right) R_a \quad (3.20)$$

where

R_s	solar or shortwave radiation [$\text{MJ m}^{-2} \text{ day}^{-1}$],
n	actual duration of sunshine [hour],
N	maximum possible duration of sunshine or daylight hours [hour],
n/N	relative sunshine duration [-],
R_a	extraterrestrial radiation [$\text{MJ m}^{-2} \text{ day}^{-1}$],
a_s	regression constant, expressing the fraction of extraterrestrial radiation reaching the earth on overcast days ($n = 0$),
$a_s + b_s$	fraction of extraterrestrial radiation reaching the earth on clear days ($n = N$).

The default values for a_s and b_s are 0.25 and 0.50. If the user has site specific information, calibrated values for a_s and b_s can be specified in the **Data and ETo menu** (Calculation method and coefficients).

- **Clear-sky solar radiation (R_{so})**

The calculation of the clear-sky radiation, R_{so} , when $n = N$, is required for computing net longwave radiation. Depending on the option selected in the **Data and ETo menu** (Calculation method and coefficients) Eq. 3.21 or 3.22 is used

When adjustment for station elevation is requested:

$$R_{so} = \left(0.75 + 2 \cdot 10^{-5} z \right) R_a \quad (3.21)$$

where

R_{so}	clear-sky solar radiation [$\text{MJ m}^{-2} \text{ day}^{-1}$],
z	station elevation above sea level [m],
R_a	extraterrestrial radiation [$\text{MJ m}^{-2} \text{ day}^{-1}$].

When no adjustment for station elevation is requested (calibrated values for a_s and b_s are available):

$$R_{so} = (a_s + b_s) R_a \quad (3.22)$$

where $a_s + b_s$ fraction of extraterrestrial radiation reaching the earth on clear-sky days ($n = N$).

• **Net solar or net shortwave radiation (R_{ns})**

The net shortwave radiation resulting from the balance between incoming and reflected solar radiation is given by:

$$R_{ns} = (1 - \alpha) R_s \quad (3.23)$$

where R_{ns} net solar or shortwave radiation [$\text{MJ m}^{-2} \text{ day}^{-1}$],
 α albedo or canopy reflection coefficient for the reference crop [dimensionless],
 R_s the incoming solar radiation [$\text{MJ m}^{-2} \text{ day}^{-1}$].

If net solar radiation needs to be calculated when computing ET_o , the fixed value of 0.23 is used for the albedo in Eq. 3.23.

• **Net longwave radiation (R_{nl})**

$$R_{nl} = \sigma \left[\frac{T_{\max,K}^4 + T_{\min,K}^4}{2} \right] \left(0.34 - 0.14 \sqrt{e_a} \right) \left(1.35 \frac{R_s}{R_{so}} - 0.35 \right) \quad (3.24)$$

where R_{nl} net outgoing longwave radiation [$\text{MJ m}^{-2} \text{ day}^{-1}$],
 σ Stefan-Boltzmann constant [$4.903 \cdot 10^{-9} \text{ MJ K}^{-4} \text{ m}^{-2} \text{ day}^{-1}$],
 $T_{\max,K}$ maximum absolute temperature during the 24-hour period [$K = ^\circ\text{C} + 273.16$],
 $T_{\min,K}$ minimum absolute temperature during the 24-hour period [$K = ^\circ\text{C} + 273.16$],
 e_a actual vapour pressure [kPa],
 R_s/R_{so} relative shortwave radiation (limited to ≤ 1.0),
 R_s measured or calculated (Equation 3.20) solar radiation [$\text{MJ m}^{-2} \text{ day}^{-1}$],
 R_{so} calculated (Equation 3.21, 3.22) clear-sky radiation [$\text{MJ m}^{-2} \text{ day}^{-1}$].

When maximum and minimum air temperature are missing, $\left[\frac{T_{\max,K}^4 + T_{\min,K}^4}{2} \right]$ in Eq. 3.24 is replaced by $[T_{\text{mean},K}^4]$.

- **Net radiation (R_n)**

The net radiation (R_n) is the difference between the incoming net shortwave radiation (R_{ns}) and the outgoing net longwave radiation (R_{nl}):

$$R_n = R_{ns} - R_{nl} \quad (3.25)$$

- **Calculation rules**

If sunshine or radiation data are missing or if several climatic parameters are available with which radiation can be estimated, the following calculation rules exist:

- If net radiation (R_n) is missing, R_n is calculated by Eq. 3.25,
- If R_n and solar radiation (R_s) are missing, R_s is derived from (in descending order):
 - the specified hours of bright sunshine n (Eq. 3.20),
 - the specified relative sunshine hours n/N (Eq. 3.20),
 - the maximum (T_{\max}) and minimum (T_{\min}) air temperature by means of the adjusted Hargreaves' radiation formula:

$$R_s = k_{Rs} \sqrt{(T_{\max} - T_{\min})} R_a \quad (3.26)$$

where R_a extraterrestrial radiation [$\text{MJ m}^{-2} \text{d}^{-1}$],
 T_{\max} maximum air temperature [$^{\circ}\text{C}$],
 T_{\min} minimum air temperature [$^{\circ}\text{C}$],
 k_{Rs} adjustment coefficient [$^{\circ}\text{C}^{-0.5}$].

The value for the adjustment coefficient k_{Rs} is specified in the **Data and ETo menu** (Missing radiation data in the Input data description sheet). Indicative default values are 0.16 for interior locations and 0.19 for coastal locations.

3.5 Wind speed

- **Adjustment of wind speed to standard height**

To adjust wind speed data obtained from instruments placed at elevations other than the standard height of 2 m:

$$u_2 = u_z \frac{4.87}{\ln(67.8 z - 5.42)} \quad (3.27)$$

where

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

• Missing wind speed data

If wind speed data is missing, the default value for u_2 specified in the **Data and ETo menu** (Missing wind speed in the Input data description sheet) is used.

3.6 Reference evapotranspiration (FAO Penman-Monteith)

The relatively accurate and consistent performance of the Penman-Monteith approach in both arid and humid climates has been indicated in both the ASCE and European studies. The FAO Penman-Monteith equation (Allen et al., 1998) is given by:

$$ET_o = \frac{0.408 \Delta (R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma (1 + 0.34 u_2)} \quad (3.28)$$

where

ET_o	reference evapotranspiration [mm day^{-1}],
R_n	net radiation at the crop surface [$\text{MJ m}^{-2} \text{day}^{-1}$],
G	soil heat flux density [$\text{MJ m}^{-2} \text{day}^{-1}$],
T	mean daily air temperature at 2 m height [$^{\circ}\text{C}$],
u_2	wind speed at 2 m height [m s^{-1}],
e_s	saturation vapour pressure [kPa],
e_a	actual vapour pressure [kPa],
$e_s - e_a$	saturation vapour pressure deficit [kPa],
Δ	slope vapour pressure curve [$\text{kPa } ^{\circ}\text{C}^{-1}$],
γ	psychrometric constant [$\text{kPa } ^{\circ}\text{C}^{-1}$].

In Eq. 3.28, the value 0.408 converts the net radiation R_n expressed in $\text{MJ/m}^2 \cdot \text{day}$ to equivalent evaporation expressed in mm/day . Because soil heat flux is small compared to R_n , particularly when the surface is covered by vegetation and calculation time steps are 24 hours or longer, the estimation of G is ignored in the ET_o calculator and assumed to be zero. This corresponds with the assumptions reported in the FAO Irrigation and Drainage Paper n° 56 for daily and 10-daily time periods. Allen et al. (1989) state that the soil heat flux beneath the grass reference surface is relatively small for that time period.

3.7 Conversion to standard metric unit

To convert a value (*A*) expressed in a non-standard unit to a value (*Y*) expressed in the standard metric unit, the following equations are used in the software:

- Temperature: standard unit is degree Celsius**

Temperature unit	Equation to convert to standard unit (°C)
degree Fahrenheit (°F)	$Y\text{ °C} = (A\text{ °F} - 32) 5/9$

- Vapour pressure: standard unit is kilo Pascal**

Vapour pressure unit	Equation to convert to standard unit (kPa)
millibar	$Y\text{ kPa} = 0.1 A\text{ mbar}$
pound per square inch (psi)	$Y\text{ kPa} = 6.89476 A\text{ psi}$
atmospheres (atm)	$Y\text{ kPa} = 101.325 A\text{ atm}$
millimetre of mercury (mmHg)	$Y\text{ kPa} = 0.133322 A\text{ mmHg}$

- Wind speed: standard unit is meter per second (m/s)**

Wind speed unit	Equation to convert to standard unit (m/s)
kilometre per day (km/day)	$Y\text{ m/s} = (A / 86.40)\text{ km/day}$
nautical mile/hour (knot)	$Y\text{ m/s} = 0.5144 A\text{ knot}$
foot per second (ft/s)	$Y\text{ m/s} = 0.3048 A\text{ ft/sec}$

- Radiation: standard unit is megajoules per square meter per day (MJ/m².day)**

Radiation unit	Equation to convert to standard unit (MJ/m ² .day)
watt per m ² (W/m ²)	$Y\text{ MJ/m}^2.\text{day} = 0.0864 A\text{ W/m}^2$
joule per cm ² per day (J/cm ² .day)	$Y\text{ MJ/m}^2.\text{day} = 0.01 A\text{ J/cm}^2.\text{day}$
equivalent evaporation (mm/day)	$Y\text{ MJ/m}^2.\text{day} = 2.45 A\text{ mm/day}$
calorie per cm ² per day (cal/cm ² .day)	$Y\text{ MJ/m}^2.\text{day} = 4.1868 \cdot 10^{-2} A\text{ cal/cm}^2.\text{day}$

- Evapotranspiration: standard unit is millimeter per day (mm/day)**

Evaporation unit	Equation to convert to standard unit (mm/day)
equivalent radiation in megajoules per square metre per day (MJ/m ² .day)	$Y\text{ mm/day} = 0.408 A\text{ MJ/m}^2.\text{day}$

References

Allen, R., L.S. Pereira, D. Raes, and M. Smith. 1998. Crop evapotranspiration – Guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper N° 56. Rome, Italy.

Hargreaves, G.H. 1994. Defining and using reference evapotranspiration. Journal of Irrigation and Drainage Engineering. Vol 120 (6): 1132 - 1139.

Smith, M. 1992. CROPWAT - a computer program for irrigation planning and management. FAO Irrigation and Drainage Paper N°46. Rome, Italy.

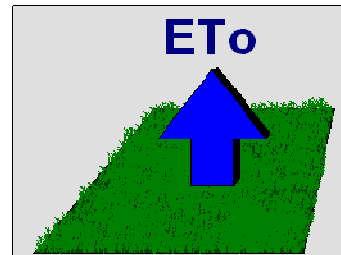
Annex 1. - The ETo calculator

The reference evapotranspiration is assessed in the ETo calculator software from meteorological data by means of the FAO Penman-Monteith equation (Allen et al., 1998). The program can handle daily, ten-day and monthly climatic data. The data can be given in a wide variety of units and data specified in commonly used climatic parameters can be processed.

The ETo Calculator is public domain software, and an installation disk (1.5 Mb) and a software copy of the Reference Manual can be obtained from:

<http://www.fao.org/nr/water/eto.html>

Contact dirk.raes@ees.kuleuven.be for further information



If the ETo calculator software is correctly installed, it occupies less than 2 Mb on disk. The main directory (default “C:\FAO\EToCalc”) contains:

- the executable file (EToCalc.EXE), and
- three subdirectories:
 - DATA (containing ‘DSC’ (station description), and ‘DTA’ (data) files),
 - IMPORT (containing text files with climatic data that can be imported),
 - REPORT (containing exported files).

Reference:

FAO 2009. ETo Calculator. Land and Water Digital Media Series, N° 36. FAO, Rome, Italy.

Annex 2. Data files

The characteristics of the climatic station and the meteorological data linked to that station are stored in two separate data files which have the same file name but a different file extension. Distinction is made between files describing the station (files with extension DSC) and files containing the meteorological data (files with extension DTA).

• DSC file (description)

The DSC file contains information of the characteristics of the climatic station (Name, location and coordinates), type and range of meteorological data, coefficients, and options required for the estimation of ETo from meteorological data. The DSC file consists of the following lines:

Line number	Description
1	Name of the station
2	Country
3	Latitude (degrees); Positive values for the Northern hemisphere and Negative values for Southern locations
4	Longitude (degrees); Positive values for Eastern locations and negative values for Western locations
5	Altitude (meters above sea level)
6	Type of data (1 to 3) 1 = daily, 2 = 10-daily, and 3 = monthly data
7	Time range: from Date (Day/Dec - Month - Year)
8	Time range: to Date (Day/Dec - Month - Year)
9	Coefficient for psychrometer (depending on type of ventilation)
10	Height (meter) of wind speed measurement
11	Average difference between Tmin and Tdew (missing humidity data)
12	Coefficient for Hargreaves Equation (missing radiation data)
13	Estimate (m/sec) of wind speed in location (missing wind speed)
14	'a' coefficient of the Angstrom formula
15	'b' coefficient of the Angstrom formula
16	Adjustment for station elevation (Angstrom formula) 0 = no adjustment 1 = adjust for station elevation
17	Climatic data range: lower limit for air temperature (°C)
18	Climatic data range: upper limit for air temperature (°C)
19	Climatic data range: lower limit for Relative Humidity (%)
20	Climatic data range: upper limit for wind speed (m/sec)
21	Climatic data range: Allowable deviation (%) from maximum expected radiation
22	Empty line
23-62	List of the Codes, Symbols, Descriptions and Units of climatic parameters

Example: 'Alger.DSC' file

Line number	Example
1	Alger
2	Algeria
3	36.77 : Latitude (degrees)
4	3.05 : Longitude (degrees)
5	60 : Altitude (meters above sea level)
6	3 : monthly data
7	1 1 1901 : From Date (Day/Dec - Month - Year)
8	31 12 1901 : To Date (Day/Dec - Month - Year)
9	0.000800 : coefficient psychrometer (depending on type of ventilation)
10	2.0 : height wind speed measurement (meter)
11	0.0 : Missing Tdew: negative adjustment Tmin (°C)
12	0.19 : Missing Rs: Coefficient Hargreaves Equation (MJ/m2.day)
13	2.0 : Missing wind speed: estimate U2 (m/sec)
14	0.25 : Coefficient: a Angstrom formula
15	0.50 : Coefficient: b Angstrom formula
16	1 : Option: Adjustment for station elevation (Angstrom formula)
17	-10 : Climatic data range: Minimal temperature (°C)
18	35 : Climatic data range: Maximal temperature (°C)
19	20 : Climatic data range: Minimal Relative Humidity (%)
20	4 : Climatic data range: Maximal wind speed (m/sec)
21	5 : Climatic data range: Allowable deviation (%) from theoretical maximum radiation
22	
23	List of CLIMATIC PARAMETERS=====
24	Code Symbol Description Unit
25	101 Tmax maximum air temperature °C
26	102 Tmean mean air temperature °C
...
60	435 Rn net radiation cal/cm2.day
61	501 ETo reference crop evapotranspiration mm/day
62	=====

- **DTA file (meteorological data)**

The DTA file contains the meteorological data linked with the climatic station.

Line 1: 'Nr' and the code for each of the climatic parameters (see Annex 3)

Line 2 to end: Each line contains the number of the record line and the corresponding values for each of the climatic parameters. There are as many lines as records. If meteorological data is missing, the value '-999' is specified. Any format for the values can be used.

Example: 'Alger.DTA' file

Nr	101	103	222	301	402	501
1	14.8	9.2	10.2300	2.10	0.47	1.4
2	15.8	9.6	10.2300	2.40	0.55	2.0
3	17.5	10.8	10.7400	2.80	0.59	2.8
4	19.7	12.5	11.9600	2.40	0.60	3.5
5	22.5	15.1	14.7900	2.20	0.70	4.0
6	25.6	18.3	18.2400	2.20	0.70	4.5
7	28.5	21.0	21.4800	2.00	0.77	4.8
8	29.1	21.8	22.2900	2.40	0.79	4.6
9	27.1	20.3	20.5700	2.00	0.73	3.5
10	23.1	17.0	16.0100	2.00	0.61	2.6
11	19.0	13.1	12.5600	2.00	0.50	1.8
12	15.6	10.2	10.6400	2.10	0.49	1.4

Annex 3. Code for climatic parameters

Code	Climatic parameter (Description and Symbol)	Unit
Air temperature (100)		
101	Maximum air temperature (Tmax)	°C
102	Mean air temperature (Tmean)	°C
103	Minimum air temperature (Tmin)	°C
111	Maximum air temperature (Tmax)	°F
112	Mean air temperature (Tmean)	°F
113	Minimum air temperature (Tmin)	°F
Air Humidity (200)		
201	Maximum Relative Humidity (RHmax)	%
202	Mean Relative Humidity (RHmean)	%
203	Minimum Relative Humidity (RHmin)	%
210	Dewpoint temperature (Tdew)	°C
211	Dewpoint temperature (Tdew)	°F
221	Actual vapour pressure: e(act)	kPa
222	Actual vapour pressure: e(act)	mbar
223	Actual vapour pressure: e(act)	psi
224	Actual vapour pressure: e(act)	atm
225	Actual vapour pressure: e(act)	mmHG
231	Temperature of dry bulb (Tdry)	°C
232	Temperature of wet bulb (Twet)	°C
233	Temperature of dry bulb (Tdry)	°F
234	Temperature of wet bulb (Twet)	°F
Wind speed (300)		
301	Wind speed at x m above soil surface: u(x)	m/sec
302	Wind speed at x m above soil surface: u(x)	km/day
303	Wind speed at x m above soil surface: u(x)	knot
304	Wind speed at x m above soil surface: u(x)	ft/sec
Radiation (400)		
401	Actual duration of sunshine in a day (n)	hour
402	Relative sunshine duration (n/N)	-
421	Solar or shortwave radiation (Rs)	MJ/m ² .day
422	Solar or shortwave radiation (Rs)	W/m ²
423	Solar or shortwave radiation (Rs)	J/cm ² .day
424	Solar or shortwave radiation (Rs)	mm/day
425	Solar or shortwave radiation (Rs)	cal/cm ² .day
431	Net radiation (Rn)	MJ/m ² .day
432	Net radiation (Rn)	W/m ²

433	Net radiation (Rn)	J/cm ² .day
434	Net radiation (Rn)	mm/day
435	Net radiation (Rn)	cal/cm ² .day
ETo, Reference crop evapotranspiration (500)		
501	Reference crop evapotranspiration (ETo)	mm/day

Annex 4. FAO Clim 2.0 file (*.DAT files)

Example: ‘Harare.DAT’ file

Station_ID	Station_Name	WMO_CODE	Country_Name	Longitude	Latitude	Elevation (m)										
ZW71HRR0	HARARE-(BELVEDERE)	67774	ZIMBABWE	31.02	-17.83	1472										
Code	Element_Name	Begin_Y	Nbr_Y	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Remarks
201	Temp__mean_max	-99999	25	26	25.8	26.1	25.6	23.7	21.5	21.6	24.1	27	29	27.3	26.2	CIAT82. [FAO302]
202	Temp__mean_min	-99999	25	15.7	15.6	14.2	12.5	9.2	6.8	6.5	8.6	11.5	14.6	15.4	15.7	CIAT82. [FAO302]
203	Temp__mean_mly	1949	36	20.4	20.3	19.9	18.8	16.1	13.7	13.7	15.9	19	21.3	20.9	20.4	available data: 30(29) [FAO777]
292	Temp_Mean_Night	-99999	-99999	18.7	18.6	17.7	16.5	13.7	11.4	11.4	13.7	16.7	19.5	19.5	19.3	FAO misc. [FAO301]
293	Temp_Mean_Daytm	-99999	-99999	22.6	22.5	22.2	21.4	19	16.8	16.8	19.2	22.1	24.4	23.5	22.9	FAO misc. [FAO301]
208	Precip_Total_mly	1961	30	192	178	99	41	8	3	2	3	7	42	93	183	available data: 30(30) [FAO777]
251	Temp_dp_mea_mly	-99999	25	15.6	15.8	13.9	11.8	8	5.2	3.4	4.3	5.8	9.1	12.6	14.8	CIAT86.Estimated:CIAT44. [FAO302]
258	RH__mean_mly	-99999	30	82	83	75	62	54	55	51	49	51	59	78	83	CIAT32. [FAO302]
298	Vap_Pr__mean_mly	-99999	-99999	17.8	18.1	16	14	11	9	7.9	8.5	9.8	11.8	15	16.9	FAO misc. [FAO301]
294	PET_total__mly	-99999	-99999	126	110	120	108	99	84	107	140	176	199	147	134	FAO misc. [FAO301]
297	wind_sp_mean_mly	-99999	27	2.6	2.6	2.8	2.8	2.8	3	3.3	3.5	3.9	3.8	3.2	2.9	CIAT82.Estimated:CIAT71. [FAO302]
296	Sunsh_fract_mly	-99999	30	0.49	0.48	0.57	0.71	0.77	0.77	0.8	0.81	0.8	0.73	0.54	0.47	CIAT32.Estimated:CIAT18. [FAO302]

Annex 5. CLIMWAT 2.0 file (*.PEN files)

Example: 'Cairo.PEN' file

"Location 3", "CAIRO", 74, 30.13, "N.L.", 31.40, " 01"						
18.8	9.0	54.0	328.3	7.53	13.13	3.02
20.5	9.8	47.0	362.9	8.24	16.27	3.99
23.4	11.7	41.4	397.4	9.02	20.06	5.21
28.4	14.7	32.1	388.8	9.71	23.26	7.03
32.0	17.5	29.1	397.4	10.69	25.81	8.44
34.2	20.4	31.1	371.5	11.82	27.76	9.06
34.4	21.7	37.8	319.7	11.67	27.31	8.22
33.9	21.9	43.3	302.4	11.25	25.80	7.47
32.6	20.4	44.5	319.7	10.51	22.85	6.76
29.6	17.9	46.1	328.3	9.62	18.85	5.62
24.7	13.8	57.1	285.1	8.41	14.68	3.58
20.2	10.3	56.2	319.7	7.07	11.93	2.99

Annex 6. Exported AquaCrop files



Example: 'Brussels.ETo' file

```
Brussels (Uccle) (Belgium) - monthly data: January - December
  3 : Monthly records (1=daily, 2=10-daily and 3=monthly data)
  1 : First day of record (1, 11 or 21 for 10-day or 1 for months)
  1 : First month of record
1901 : First year of record (1901 if not linked to a specific year)
```

```
  Average ETo (mm/day)
=====
      0.1
      0.7
      1.3
      2.4
      3.0
      3.6
      3.3
      2.9
      2.1
      1.0
      0.5
      0.1
```

Example: 'Brussels.TMP' file

```
Brussels (Uccle) (Belgium) - monthly data: January - December
  3 : Monthly records (1=daily, 2=10-daily and 3=monthly data)
  1 : First day of record (1, 11 or 21 for 10-day or 1 for months)
  1 : First month of record
1901 : First year of record (1901 if not linked to a specific year)
```

```
  Tmin (C)   TMax (C)
=====
      -1.2      4.3
       0.3      6.7
       2.2     10.3
       5.1     14.2
       7.9     18.4
      10.9     22.0
      12.1     22.7
      12.2     22.3
      10.6     20.5
       7.3     15.4
       3.1      8.9
       0.2      5.6
```
