ESTIMATION OF THE REFERENCE CROP
EVAPOTRANSPIRATION: PRACTICAL APPLICATION OF THE
FAO PENMAN-MONTEITH METHOD

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1 THE PENMAN MONTEITH FORMULA

The main reference for computing evapotranspiration is the report by Allen et al. (1998), in which the Penman-Monteith method, based on the formula:

\[
ET_0 = \frac{0.408 \Delta (R_n - G) + \gamma \frac{900 u_2 (e_s - e_a)}{T + 273}}{\Delta + \gamma(1 + 0.34 u_2)}
\]  

is thoroughly treated.

To make feasible the computation of this formula, a feasible approach is presented here, with some special cases of application in the appendix.

In the formula (1) involved variables are:

- \(ET_0\): reference evapotranspiration [mm day\(^{-1}\)];
- \(G\): soil heat flux density [MJ m\(^{-2}\) day\(^{-1}\)];
- \(T\): mean daily air temperature at 2 m height [\(^\circ\)C];
- \(u_2\): wind speed at 2 m height [m s\(^{-1}\)];
- \(e_s\): mean saturation vapour pressure [kPa];
- \(e_a\): actual vapour pressure [kPa];
- \(e_s - e_a\): saturation vapour pressure deficit [kPa];
- \(\Delta\): slope of the vapour pressure curve [kPa \(^\circ\)C\(^{-1}\)]; and
- \(\gamma\): psychrometric constant [kPa \(^\circ\)C\(^{-1}\)].

The sections in the following will quickly describe the approaches to the evaluation of all those variables.

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2 CALCULATION PROCEDURE

2.1 The psychrometric constant \((\gamma)\)

The psychrometric constant, \(\gamma\), expressed in \([\text{kPa} \, ^\circ\text{C}^{-1}]\), is given by:

\[
\gamma = \frac{c_p P}{\varepsilon \lambda} = 0.665 \times 10^{-3} P
\]

(2)

where \(P\): atmospheric pressure \([\text{kPa}]\), \(\lambda\): latent heat of vaporization, 2.45 \([\text{MJ kg}^{-1}]\), \(c_p\): specific heat at constant pressure, 1.013 \(10^{-3} \text{[MJ kg}^{-1} \, ^\circ\text{C}^{-1}]\), and \(\varepsilon\): ratio molecular weight of water vapour/dry air = 0.622.

The atmospheric pressure, \(P\), is the pressure exerted by the weight of the earth's atmosphere, given by.

\[
P = 101.3 \left( \frac{293 - 0.0065 z}{293} \right)^{5.26}
\]

(3)

where \(z\): elevation above sea level \([\text{m}]\),

2.2 Saturation vapour pressure \(e^\circ(T)\)

The higher the air temperature, the higher the storage capacity, the higher its saturation vapour pressure (Fig. 1). It is expressed as follow:

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

(4)

where \(e^\circ(T)\): saturation vapour pressure at the air temperature \(T \text{ [kPa]}\), and \(T\): air temperature \([^\circ\text{C}]\),
2.3 Mean saturation vapour pressure ($e_s$)

The mean saturation vapour pressure ($e_s$) for a day, week, decade or month should be computed as the mean between the saturation vapour pressure at the mean daily maximum and minimum air temperatures for that period:

$$ e_s = \frac{e^o(T_{\text{max}}) + e^o(T_{\text{min}})}{2} \quad (5) $$

$T_{\text{max}}$: maximum air temperature  and $T_{\text{min}}$: minimum air temperature

2.4 Actual vapour pressure ($e_a$)

The actual vapour pressure ($e_a$) is the vapour pressure exerted by the water in the air. When the air is not saturated, the actual vapour pressure will be lower than the saturation vapour pressure.
2.4.1 derived from dewpoint temperature

The actual vapour pressure \( (e_a) \) is the saturation vapour pressure at the dewpoint temperature \( (T_{dew}) \) \(^\circ\text{C}\), it is given by:

\[
e_a = e^o(T_{dew}) = 0.6108 \exp\left(\frac{17.27T_{dew}}{T_{dew} + 237.3}\right) \tag{6}
\]

The \( T_{dew} \): is the temperature to which the air needs to be cooled to make the air saturated.

Example (Fig. 2):

The air temperature is \( T = 30\,^\circ\text{C} \)

The saturated (maximum) vapor pressure at this temperature is \( e_s = 42.6 \) millibars.

The actual vapor pressure is \( e_a = 17.1 \) millibars.

The relative humidity is \( \text{RH} = e_a / e_s = 17.1 / 42.6 = 40\% \)

The dewpoint temperature is where \( \text{RH} = 100\% \), or when \( e_a = e_s \), which is at 15\(^\circ\text{C}\).

![Figure 2. Relationship between Saturation Vapor Pressure and Temperature](image)
2.4.2 Derivation of $e_a$ from relative humidity data

The actual vapour pressure ($e_a$) is also related to the Relative Humidity (RH)

- For RH$_{\text{max}}$ and RH$_{\text{min}}$:

\[
e_a = \frac{e^\circ(T_{\text{min}}) \cdot RH_{\text{max}}}{100} + \frac{e^\circ(T_{\text{max}}) \cdot RH_{\text{min}}}{100} \div 2
\]  

(7)

where $e_a$: actual vapour pressure [kPa]; $e^\circ(T_{\text{min}})$: saturation vapour pressure at daily minimum temperature [kPa]; $e^\circ(T_{\text{max}})$: saturation vapour pressure at daily maximum temperature [kPa]; RH$_{\text{max}}$: maximum relative humidity [%]; and RH$_{\text{min}}$: minimum relative humidity [%].

When using equipment where errors in estimating RH$_{\text{min}}$ can be large, or when RH data integrity are in doubt, one should use only RH$_{\text{max}}$:

\[
e_a = e^\circ(T_{\text{min}}) \cdot \frac{RH_{\text{max}}}{100}
\]  

(8)

- For RH$_{\text{mean}}$:

In the absence of RH$_{\text{max}}$ and RH$_{\text{min}}$, another equation can be used to estimate $e_a$:

\[
e_a = \frac{RH_{\text{mean}}}{100} \left[ \frac{e^\circ(T_{\text{max}}) + e^\circ(T_{\text{min}})}{2} \right]
\]  

(9)

where

\[
RH_{\text{mean}} = \frac{RH_{\text{min}} + RH_{\text{max}}}{2}
\]  

(10)

However, Equation 9 is less desirable than are Equation 7 and 8.

If RH data is not available, $e_a$ can be estimated by assuming that the dewpoint temperature is quasi equal to the minimum daily temperature, Thus:
\[ e_a = e(T_{dew} \approx T_{\text{min}}) = 0.611\exp\left[\frac{17.27T_{\text{min}}}{T_{\text{min}} + 237.3}\right] \]  \hfill (11)

where \( T_{\text{min}} \) is in °C.

In Arid zones the air can be saturated at a temperature different from the minimum one, therefore it should be taken into account that \( T_{\text{dew}} < T_{\text{min}} \) [Allen et al. 1998].

### 2.5 Slope of the vapour pressure curve (\( \Delta \))

The slope of the vapour pressure curve (Fig.1) at a given temperature is given by:

\[ \Delta = \frac{4098 \left[ 0.6108 \exp\left(\frac{17.27T}{T + 237.3}\right)\right]}{(T + 237.3)^2} \]  \hfill (12)

where \( \Delta \): slope of saturation vapour pressure curve at air temperature \( T \) [kPa °C\(^{-1}\)], and \( T \): the mean air temperature [°C],

### 2.6 The soil heat flux (\( G \))

The soil heat flux, \( G \), is the energy that is utilized in heating the soil. It is presented here for a long time steps (monthly), based on the idea that the soil temperature follows air temperature:

\[ G = c_s \frac{T_j + T_{j-1}}{\Delta t} \Delta z \]  \hfill (13)

where \( G \): soil heat flux [MJ m\(^{-2}\) day\(^{-1}\)], \( c_s \): soil heat capacity [MJ m\(^{-3}\) °C\(^{-1}\)], \( T_j \): air temperature at time \( j \) [°C], \( T_{j-1} \): air temperature at time \( j - 1 \) [°C], \( \Delta t \): length of time interval [day], and \( \Delta z \): effective soil depth [m].

- For day and ten-day periods

For the period of a day and ten-day periods it can be assumed that: \( G_{\text{day}} = 0 \)
• For monthly period
- The soil heat capacity $c_s$ assumed to be constant equal to 2.1 MJ m$^{-3}$ °C$^{-1}$
- The effective soil depth might be 2 m or more.

So the G is expressed as:

$$G_{\text{month, } j} = 0.14(T_{\text{month, } j} - T_{\text{month, } j-1})$$  \hspace{1cm} (14)

where $T_{\text{month, } j}$ mean air temperature of month $j$ [°C], and $T_{\text{month, } j-1}$ mean air temperature of previous month [°C].

2.7 Wind speed $u_2$

To adjust wind speed data obtained from instruments placed at elevations other than the standard height of 2m, a logarithmic wind speed profile may be used for measurements above a short grassed surface:

$$u_2 = \frac{u_z 4.87}{\ln(67.8z - 5.42)}$$  \hspace{1cm} (15)

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$^{-1}$], and $z$ : height of measurement above ground surface [m].

2.8 Calculation Procedure of the Net Radiation ($R_a$)

2.8.1 Extraterrestrial radiation for daily periods ($R_a$)

$$R_a = f(\text{Latitude, solar declination, time of the year})$$

$$R_a = \frac{24 \times 60}{\pi} G_{sc} d_r \omega_s \sin \phi \sin \delta + \cos \phi \cos \delta \sin \omega_s$$  \hspace{1cm} (16)

where $R_a$ : extraterrestrial radiation [MJ m$^{-2}$ day$^{-1}$], $G_{sc}$ : solar constant = 0.0820 MJ m$^{-2}$ min$^{-1}$, $d_r$ : inverse relative distance Earth-Sun, $\omega_s$ : sunset hour angle [rad], $\phi$ : latitude [rad], and $\delta$ : solar declination [rad].
The inverse relative distance Earth-Sun, $d_r$, and the solar declination, $\delta$, are given by:

$$d_r = 1 + 0.033 \cdot \cos \left( \frac{2\pi}{365} J \right) = 1 + 0.033 \cdot \cos(0.0172J)$$

(17)

$$\delta = 0.409 \cdot \sin \left( \frac{2\pi}{365} J - 1.39 \right) = 0.409 \cdot \sin(0.0172J - 1.39)$$

(18)

where $J$ is the number of the day in the year between 1 (1 January) and 365 or 366 (31 December), it can be estimated by:

$$J = \text{int}(30.42M - 15.23)$$

(19)

$J$: average day of the month and $M$: month of the year

The sunset hour angle, $\omega_s$, is given by:

$$\omega_s = \arctan(\tan \varphi \cdot \tan \delta)$$

(20)

2.8.2 Solar radiation ($R_{s}$)

2.8.2.1 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.

- For near sea level or when calibrated values for $a_s$ and $b_s$ are available

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

(21)

where $R_{so}$: clear-sky solar radiation [MJ m$^{-2}$ day$^{-1}$]; and $a_s+b_s$: fraction of extraterrestrial radiation reaching the earth on clear-sky days ($n = N$).

- When calibrated values for $a_s$ and $b_s$ are not available

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

(22)

where $z$ station elevation above sea level [m].
In alternative one may use simply the FAO recommended values, \(a_s = 0.25\) and \(b_s = 0.50\), obtaining:

\[
R_{s0} = 0.75 \cdot R_a
\]  

(23)

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:

\[
R_s = \left( a_s + b_s \frac{n}{N} \right) R_a
\]  

(24)

where \(R_s\) : solar or shortwave radiation [MJ m\(^{-2}\) day\(^{-1}\)]; \(n\) : actual duration of sunshine [hour]; \(N\) : maximum possible duration of sunshine or daylight hours [hour], estimated from the sunset hour angle, \(\omega_s\), it’s given as:

\[
N = \frac{24}{\pi} \omega_s
\]  

(25)

\(n\) : relative sunshine duration [-], \(R_a\) : extraterrestrial radiation [MJ m\(^{-2}\) day\(^{-1}\)], \(a_s\) : regression constant, expressing the fraction of extraterrestrial radiation reaching the earth on overcast days \((n = 0)\), and \(a_s + b_s\) : fraction of extraterrestrial radiation reaching the earth on clear days \((n = N)\).

If \(n\) is not available, \(\frac{n}{N}\) can be replaced by, \(m_c\), which is the fractional cloud cover:

\[
\frac{n}{N} = 1 - m_c
\]  

(26)

\(m_c\) represents the fractional average number of the eight part of the sky covered with clouds (Okta).

If those informations are not available \(R_s\) can be estimated with the Hargreaves-Samani formula:

\[
R_s = k_{Rs} \left( T_{max} + T_{min} \right)^{1/2} R_a
\]  

(27)

Where \(k_{Rs} = 0.16 – 0.19\) depends on the considered zone (internal or costal) \(T_{max}\) and \(T_{min}\) are expressed in °C.
2.8.2.2 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:

$$R_{ns} = (1 - \alpha) \cdot R_s$$  \hspace{1cm} (28)

where $R_{ns}$: net solar or shortwave radiation [MJ m$^{-2}$ day$^{-1}$], $\alpha$: albedo or canopy reflection coefficient, which is 0.23 for the hypothetical grass reference crop [dimensionless], $R_s$ : the incoming solar radiation [MJ m$^{-2}$ day$^{-1}$] and $R_{ns}$ : is expressed in the above equation in MJ m$^{-2}$ day$^{-1}$.

Table 1. Some values of the albedo

<table>
<thead>
<tr>
<th>Surface</th>
<th>Mean</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
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<td>0.02</td>
<td>1.00</td>
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<tr>
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<td>0.63</td>
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<td>0.95</td>
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<td>0.05</td>
<td>0.84</td>
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<tr>
<td>city</td>
<td>0.16</td>
<td>0.12</td>
<td>0.21</td>
</tr>
<tr>
<td>roads</td>
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<td>0.10</td>
<td>0.28</td>
</tr>
<tr>
<td>forest</td>
<td>0.18</td>
<td>0.10</td>
<td>0.24</td>
</tr>
<tr>
<td>grass</td>
<td>0.25</td>
<td>0.14</td>
<td>0.45</td>
</tr>
<tr>
<td>cereals</td>
<td>0.18</td>
<td>0.16</td>
<td>0.23</td>
</tr>
<tr>
<td>coton</td>
<td>0.21</td>
<td>0.20</td>
<td>0.22</td>
</tr>
<tr>
<td>tomato</td>
<td>0.19</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2.8.2.3 Net longwave radiation ($R_{nl}$)

The rate of longwave energy emission is expressed by the Stefan-Boltzmann law.

$$R_{nl} = f \cdot \varepsilon' \cdot \sigma \cdot \frac{(T_{\text{max}}^4 + T_{\text{min}}^4)}{2}$$  \hspace{1cm} (29)

where $R_{nl}$: net outgoing longwave radiation [MJ m$^{-2}$ day$^{-1}$], $\sigma$: Stefan-Boltzmann constant [4.903 $10^{-9}$ MJ K$^{-4}$ m$^{-2}$ day$^{-1}$], $T_{\text{max}}$: maximum absolute temperature during the 24-hour period [K = °C + 273.16], $T_{\text{min}}$: minimum absolute temperature during the 24-hour period [K = °C + 273.16], $f$: Cloudiness adjustment factor expresses the effect of cloudiness, and $\varepsilon'$: Net emissivity expressing a correction for air humidity.

When Solar radiation data is available, $f$ is given by:
\[ f = \left( a_c \frac{R_s}{R_{so}} + b_c \right) \]  

(30)

Where \( a_c \) and \( b_c \) are cloudiness factors; \( R_s \): Solar radiation for measured short wave [MJ m\(^{-2}\) day\(^{-1}\)], \( R_{so} \): Clear-sky shortwave Solar radiation [MJ m\(^{-2}\) day\(^{-1}\)]. \( a_c = 1.35 \) and \( b_c = -0.35 \) for arid areas \( a_c = 1 \) and \( b_c = 0 \) for humid areas. Those values are recommended by FAO (1977).

The net emissivity is expressed by:

\[ \varepsilon' = (a_l + b_l \sqrt{e_a}) \]  

(31)

\( e_a \) = actual vapour pressure [kPa], \( a_l \) = calibration coefficient \([0.34;0.44]\); \( b_l \) = calibration coefficient \([-0.25;-0.14]\); \( a_l = 0.34 \) and \( b_l = -0.14 \) are the recommended values by FAO (1977).

2.8.3 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 \((R_{nl})\):

\[ R_n = R_{ns} - R_{nl} \]  

(32)

Figure 3. various components of the solar radiation
3 CONCLUSIONS

Apart from the site location, the FAO Penman-Monteith equation requires latitude and elevation, the minimum and maximum daily air temperature, maximum relative humidity, solar radiation and wind speed data for even just monthly calculations. The availability of this data will serve to determine different parameters of the Penman Monteith equation (Fig.4)
Figure 4. Calculation Diagram of the ET0 Penman Monteith
APPENDIX 1
ALTERNATIVE EQUATIONS FOR \(\text{ET}_0\) WHEN WEATHER DATA ARE MISSING

\textit{A1.1 Priestley - Taylor method}

Is a simplified version of the combination Penman (1948) equation, used when surface areas are generally wet, which is a condition required for potential Evapotranspiration, ET. The aerodynamic component is neglected and the energy component is multiplied by a coefficient, \(\alpha = 1.26\), corresponding to areas under wet or humid conditions. A value of \(\alpha = 1.7-1.75\) seems more appropriate for arid regions (ASCE, 1990).

\[
\text{ET}_0 = \alpha \frac{\Delta}{\Delta + \gamma \cdot \lambda \rho} R_n
\]  \hspace{1cm} (33)

\(R_n\): net radiation at the \([\text{MJ m}^{-2} \text{day}^{-1}]\), \(\Delta\): slope of the vapor pressure curve \([\text{kPa} \text{C}^{-1}]\), \(\lambda\): latent heat of vaporization, 2.45 \([\text{MJ kg}^{-1}]\), \(\gamma\): psychrometric constant \([\text{kPa} \text{C}^{-1}]\) and \(\rho\): water density \([\text{kg m}^{-3}]\)

\textit{A1.2 Hargreaves}

When solar radiation data, relative humidity data and/or wind speed data are missing, they should be estimated using the procedures presented in this section. Unfortunately, there is no dependable way to estimate air temperature when it is missing. Therefore it is suggested that maximum and minimum daily air temperature data should be available to calculate \(\text{ET}_0\).

As an alternative, \(\text{ET}_0\) can be estimated using the Hargreaves \(\text{ET}_0\) equation [Hargreaves et al. 1982]:

\[
\text{ET}_{rc} = 0.0023 \cdot R_0 \cdot \sqrt{\frac{\Delta'}{T}} \cdot (T + 17.8) \]  \hspace{1cm} (34)

\(\text{ET}_{rc}\): Evapotranspiration for a reference crop \([\text{mm day}^{-1}]\); \(R_0\): equivalent evaporation height at the extraterrestrial radiation for the situation and the day of interest (Maidment, 1993) = 0.408 \(R_a\) \([\text{MJ m}^{-2} \text{day}^{-1}]\); \(\Delta'\): \(T_{\max} - T_{\min}\) the difference between the minimum and the maximum daily temperature \([\text{C}^\circ]\); and \(T\): mean daily temperature \([\text{C}^\circ]\).

The Evapotranspiration can be also calculated with monthly air temperature.

This equation has the tendency to underestimate the \(\text{ET}_0\) in conditions of intense wind and overestimate it in conditions of high relative humidity [Allen et al. 1998].

- The FAO Blaney Criddle method is not recommended in view of its strongly empirical configuration.
APPENDIX 2

AVAILABLE DATA BASE ON AGROCLIMATIC WEBSITES

Situations might occur where data for some weather variables are missing, therefore they can be obtained for free from internet sites that publish meteorological data taken from satellite. As an example we can mention The web site of ORNL DAAC (Oak Ridge National Laboratory Distributed Active Archive Center), which is a NASA-sponsored source for biogeochemical and ecological data and models useful in environmental research: http://www.daac.ornl.gov/

Available data on the ORNL DAAC web site are:

- Precipitation, mean temperature, diurnal temperature range, wet-day frequency, vapour pressure, cloud cover (OKTA), and ground-frost frequency.
- Of 10-year mean monthly over global land areas
- Gridded at 0.5 degree latitude/longitude resolution
- For the period between 1901-1990
- In ASCII format

The download procedure is presented below.
ORNL DAAC Data Holdings

Introduction

The ORNL DAAC is a source for biogeochemical and ecological data useful for studying environmental processes. These data have been collected on the ground, from aircraft, or by satellite or have been generated by computer models. The extent of data ranges from site-specific to global, and durations range from days to years.

For a brief printable description of our projects and archived data holdings, see the Data Set Overview. For a hardcopy of a comprehensive list of archived data holdings, see the Complete Data Set List. Click on the project links on these pages to obtain data.

Data Citation Policy

Please read our Data Citation Policy before using ORNL DAAC data or referencing our Web site. If you cite our data in any publications, please send us a reprint of your publication. Please contact us for instructions about mailing reprints.

Regional and Global Data

CLIMATE COLLECTIONS

The ORNL DAAC compiles, archives, and distributes data on temperature, precipitation, humidity, radiation, wind velocity, and cloud cover. These data are monthly and are either station or grid-looked.

HYDROCLIMATOLOGY COLLECTIONS

The ORNL DAAC compiles, archives, and distributes data on streamflow and climatology. The data are from a range of time scales (daily and monthly) and are from networked stations or streamflow discharge stations.

NP

NEF Primary Productivity (NEP)

The NEF primary productivity data from existing field measurements are being compiled for approximately 100 study sites covering several major world ecosystem types. These data are used by global change models to develop and validate models of vegetation-atmosphere interactions within the global carbon cycle and to help scientists conduct farming of vegetation worldwide.

RIVDIS

RIVER DISCHARGE (RIVDIS)

Global River Discharge Database (RIVDIS v1.1)

RIVDIS

RUSSIAN LAND COVER

The Russian Land Cover database consists of land and land cover satellite-based map products of Russia and of the Former Soviet Union. The DS products include provide scientists and resource managers with the information needed in the management, characterization, and measurement of Russian forest resources as well as the
After doing the registration, one becomes able to download all the required climatic data.
The products you have selected for possible ordering are listed to the left. If you have registered or logged in, clicking on the product name will display the file components of that product in that space. Clicking on a file component will display that file in your browser. It takes about One Minute Per Megabyte at Best to download and display so you may want to utilize the "Add to Cart" button after you register/login to have us package your products for you. Once you have displayed a file, you can use your browser's "Save As..." feature to save the displayed product file to a file on your computer. Be sure you have sufficient disk space available before saving any displayed file.

The following components will be displayed when you click on a product name:

- **Product Ref Doc**: If there is one available, the Product Reference Document provides information about the data in the file.
- **Component Files**: These are files that describe various aspects of the data (e.g., supplemental information and data, software, graphs, and notes).
- **Image Viewers or Special Interfaces**: This list takes you to specialized image viewers and ordering systems.
- **Product Files**: These are the actual textual data files or model files.
- **Details**: In the details you will see the Time Period and Latitude/Longitude for each file. You may choose files that fall within your time or geographic needs.

If you are not sure you can download or have any other questions or problems, contact User Services for help.

**Revision Date: 06/14/2006**

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Data Set Files: (184.3 MB, 90 files)
All Data Taken At Latitude: 90.00 N, Longitude: 180.00 E

You may order only the files you are interested in by checking the "Add to Cart" box and then the "Add" button below. You may also click on the file link to view the file and save it to your computer if you wish. You will need to display and save any companion files listed above. You may also order the complete data set by returning to the previous page and checking the "Add to Cart".
APPENDIX 3
MEASUREMENT OF METEOROLOGICAL FACTORS DETERMINING ET$_0$

A3.1 Air temperature

Agrometeorology is concerned with the air temperature near the level of the crop canopy. It is measured with thermometers, thermistors or thermocouples mounted in the shelter. Thermographs plot the instantaneous temperature over a day or week. Electronic weather stations often sample air temperature each minute and report hourly averages in addition to 24-hour maximum and minimum values.

Figure 5. Dry and wet bulb thermometers inside the screen

Figure 6. Thermograph
A3.2 Humidity

The water content of the air can be expressed in several ways. In agrometeorology, vapour pressure, dewpoint temperature and relative humidity are common expressions to indicate air humidity. Relative humidity is measured directly with hygrometers. Vapour pressure can be measured indirectly with psychrometers which measure the temperature difference between two thermometers, the so-called dry and wet bulb thermometers. The dewpoint temperature is measured with dewpoint meters.
A3.3 Solar radiation

As the radiation penetrates the atmosphere, some of the radiation is scattered, reflected or absorbed by the atmospheric gases, clouds and dust. The amount of radiation reaching a horizontal plane is known as the solar radiation, Rs. It can be measured with pyranometers, radiometers or solarimeters.

The instruments contain a sensor installed on a horizontal surface that measures the intensity of the total solar radiation, i.e., both direct and diffuse radiation from cloudy conditions.

Fig. 10. Pyranometer

A3.4 Wind speed

Wind is characterized by its direction and velocity. It is measured with anemometers.

Figure 11. Anemometer