

# Package ‘Evapotranspiration’

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**Title** Modelling Actual, Potential and Reference Crop  
Evapotranspiration

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**Depends** R (>= 3.5.0), zoo

**Description** Uses data and constants to calculate potential evapotranspiration (PET) and actual evapotranspiration (AET) from 21 different formulations including Penman, Penman-Monteith FAO 56, Priestley-Taylor and Morton formulations.

**License** GPL (>= 2)

**NeedsCompilation** no

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climatedata	<i>Raw Climate Data Required for Calculating Evapotranspiration</i>
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## Description

This data set contains the raw climate data including the variables required for calculating evapotranspiration in function `ET` over the observation period between 1/3/2001 and 08/31/2004 at the Kent Town station in Adelaide, Australia.

## Usage

```
data(climatedata)
```

## Format

A data frame containing 10240 observations of 9 objects:

*Station.Number* - weather station number,  
*Year* - year of record,  
*Month* - month of record,  
*Day* - day of record,  
*Hour* - hour of record,  
*Tdew* - subdaily dew point temperature in degree Celcius,  
*RH* - subdaily relative humidity in percentage,  
*Rs* - subdaily solar radiation in Megajoule per square meter,  
*uz* - subdaily wind speed in meter per second.

**Source**

Bureau of Meteorology, Kent Town, Adelaide, Australia

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constants

*Constants Required for Calculating Evapotranspiration*

---

**Description**

This data set contains the universal constants, and examples of other variable constants required for calculating evapotranspiration in function `ET`, based on the climatic condition at Kent Town station in Adelaide, Australia.

**Usage**

`data(constants)`

**Format**

A list containing 36 constant values including:

- 20 universal constants, which should be kept unchanged for most conditions:

*lambda* latent heat of evaporation = 2.45 MJ.kg<sup>-1</sup> at 20 degree Celcius,

*sigma* Stefan-Boltzmann constant = 4.903\*10<sup>-9</sup> MJ.K<sup>-4</sup>.m<sup>-2</sup>.day<sup>-1</sup>,

*G<sub>sc</sub>* solar constant = 0.0820 MJ.m<sup>-2</sup>.min<sup>-1</sup>

*R<sub>oua</sub>* mean density of air = 1.2 kg.m<sup>-3</sup> at 20 degree Celcius

*C<sub>a</sub>* specific heat of air = 0.001013 MJ.kg<sup>-1</sup>.K<sup>-1</sup>

*G* soil heat flux negligible for daily time-step = 0 (Allen et al., 1998, page 68)

*alpha<sub>A</sub>* Albedo for Class-A pan = 0.14

*alpha<sub>PT</sub>* Priestley-Taylor coefficient:

= 1.26 for Priestley-Taylor formula (Priestley and Taylor, 1972, Sect. 6; Eichinger et al., 1996, p.163);

= 1.31 for Szilagyi-Jozsa formula (Szilagyi and Jozsa, 2008);

= 1.28 for Brutsaert-Strickler formula (Brutsaert and Strickler, 1979),

*ap* constant in Penpan formula = 2.4,

*b<sub>0</sub>* constant in Morton's procedure = 1 (Chiew and McMahon, 1991, Table A1),

*b<sub>1</sub>* constant in Morton's procedure = 14 W.m<sup>-2</sup> (Chiew and McMahon, 1991, Table A1),

\*Note: a re-calibrated value of 13.4 W.m<sup>-2</sup> was recommended to achieve a Priestley-Taylor coefficient of 1.26 (Wang et al., 2009), rather the original value (14 W.m<sup>-2</sup>) used by Morton that gave a Priestley-Taylor coefficient of 1.32;

*b<sub>2</sub>* constant in Morton's procedure = 1.2 (Chiew and McMahon, 1991, Table A1),

\*Note: a re-calibrated value of 1.13 was recommended to achieve a Priestley-Taylor coefficient of 1.26 (Wang et al., 2009), rather the original value (1.2) used by Morton that gave a

Priestley-Taylor coefficient of 1.32;

$e0$  constant for Blaney-Criddle formula = 0.81917 (Frevert et al., 1983, Table 1),  
 $e1$  constant for Blaney-Criddle formula = -0.0040922 (Frevert et al., 1983, Table 1),  
 $e2$  constant for Blaney-Criddle formula = 1.0705 (Frevert et al., 1983, Table 1),  
 $e3$  constant for Blaney-Criddle formula = 0.065649 (Frevert et al., 1983, Table 1),  
 $e4$  constant for Blaney-Criddle formula = -0.0059864 (Frevert et al., 1983, Table 1),  
 $e5$  constant for Blaney-Criddle formula = -0.0005967 (Frevert et al., 1983, Table 1),  
 $epsilonMo$  Land surface emissivity in Morton's procedure = 0.92,  
 $sigmaMo$  Stefan-Boltzmann constant in Morton's procedure =  $5.67e-08 \text{ W.m}^{-2}.\text{K}^{-4}$ .

- 16 variable constants, which are specific for the climatic condition at Kent Town station in Adelaide, Australia:

$lat$  latitude = -34.9211 degrees for Kent Town station,  
 $lat\_rad$  latitude in radians = -0.6095 radians for Kent Town station,  
 $as$  fraction of extraterrestrial radiation reaching earth on sunless days = 0.23 for Australia (Roderick, 1999, page 181),  
 $bs$  difference between fraction of extraterrestrial radiation reaching full-sun days and that on sunless days = 0.5 for Australia (Roderick, 1999, page 181),  
 $Elev$  ground elevation above mean sea level = 48m for Kent Town station,  
 $z$  height of wind instrument = 10m for Kent Town station,

$fz$  constant in Morton's procedure:

=  $28.0 \text{ W.m}^{-2}.\text{mbar}^{-1}$  for CRAE model for  $T \geq 0$  degree Celcius;

\*Note: a re-calibrated value of  $29.2 \text{ W.m}^{-2}.\text{mbar}^{-1}$  was recommended to achieve achieve a Priestley-Taylor coefficient of 1.26 (Wang et al., 2009), rather the original value ( $28.0 \text{ W.m}^{-2}.\text{mbar}^{-1}$ ) used by Morton that gave a Priestley-Taylor coefficient of 1.32;

=  $28.0 * 1.15 \text{ W.m}^{-2}.\text{mbar}^{-1}$  for CRAE model for  $T < 0$  degree Celcius;

=  $25.0 \text{ W.m}^{-2}.\text{mbar}^{-1}$  for CRWE model for  $T \geq 0$  degree Celcius;

=  $28.75 \text{ W.m}^{-2}.\text{mbar}^{-1}$  for CRWE model for  $T < 0$  degree Celcius (Morton, 1983a, page65).

$a_0$  constant for estimating sunshine hours from cloud cover data = 11.9 for Adelaide (Chiew and McMahon, 1991, Table A1),

$b_0$  constant for estimating sunshine hours from cloud cover data = -0.15 for Adelaide,

$c_0$  constant for estimating sunshine hours from cloud cover data = -0.25 for Adelaide,

$d_0$  constant for estimating sunshine hours from cloud cover data = -0.0107 for Adelaide,  $gammamaps$

product of Psychrometric constant and atmospheric pressure as sea level:

=  $0.66 \text{ mbar. degree Celcius}^{-1}$  for CRAE model for  $T \geq 0$  degree Celcius;

=  $0.66/1.15 \text{ mbar. degree Celcius}^{-1}$  for CRAE model for  $T < 0$  degree Celcius.

$PA$  annual precipitation = 285.8mm for Kent Town station,

$alphaMo$  constant in Morton's procedure:

= 17.27 when  $T \geq 0$  degree Celcius;

= 21.88 when  $T < 0$  degree Celcius.

*betaMo* constant in Morton's procedure:  
 = 237.3 degree Celcius when  $T \geq 0$  degree Celcius;  
 = 265.5 degree Celcius when  $T < 0$  degree Celcius.

*lambdaMo* latent heat of vaporisation in Morton's procedure:  
 = 28.5W.day.kg<sup>-1</sup> when  $T \geq 0$  degree Celcius;  
 = 28.5\*1.15W.day.kg<sup>-1</sup> when  $T < 0$  degree Celcius.

## References

McMahon, T., Peel, M., Lowe, L., Srikanthan, R. & McVicar, T. 2012. *Estimating actual, potential, reference crop and pan evaporation using standard meteorological data: a pragmatic synthesis*. Hydrology and Earth System Sciences Discussions, 9, 11829-11910.

Allen, R. G., Pereira, L. S., Raes, D. & Smith, M. 1998. *Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage*. paper 56. FAO, Rome, 300, 6541.

Szilagyi, J., & Jozsa, J. 2008. New findings about the complementary relationship-based evaporation estimation methods. *Journal of Hydrology*, 354(1-4), 171-186.

Brutsaert, W., & Stricker, H. 1979. An advection-aridity approach to estimate actual regional evapotranspiration. *Water Resources Research*, 15(2), 443-450.

Chiew, F. H. S., & McMahon, T. A. 1991. The applicability of Morton's and Penman's evapotranspiration estimates in rainfall-runoff modelling. *JAWRA Journal of the American Water Resources Association*, 27(4), 611-620.

Frevert, D.K., Hill, R.W.Braaten, B.C. 1983, Estimation of FAO evapotranspiration coefficients, *Journal of Irrigation and Drainage Engineering*, vol. 109, no. 2, pp. 265-270.

Roderick, M. L. 1999. Estimating the diffuse component from daily and monthly measurements of global radiation. *Agricultural and Forest Meteorology*, 95(3), 169-185.

Wang, Q. J., McConachy, F. L. N., Chiew, F. H. S., James, R., de Hoedt, G. C., & Wright, W. J. 2009. *Maps of Evapotranspiration*. Retrieved from Melbourne, Australia: <http://www.bom.gov.au/climate/averages/climatology/evapotranspiration/description.pdf>

Morton, F. I. 1983. Operational estimates of areal evapotranspiration and their significance to the science and practice of hydrology. *Journal of Hydrology*, 66(1-4), 1-76. doi:[http://dx.doi.org/10.1016/0022-1694\(83\)90177-4](http://dx.doi.org/10.1016/0022-1694(83)90177-4)

## See Also

[defaultconstants](#)

---

defaultconstants

*Universal constants Required for Calculating Evapotranspiration*

---

## Description

This data set contains the universal constants required for calculating evapotranspiration in function [ET](#), which should be kept unchanged for most conditions. Please note that additional constants may be ET models - check the manual for individual ET models for details.

**Usage**

data(defaultconstants)

**Format**

A list containing 20 constant values including:

*lambda* latent heat of evaporationin = 2.45 MJ.kg<sup>-1</sup> at 20 degree Celcius,

*sigma* Stefan-Boltzmann constant = 4.903\*10<sup>-9</sup> MJ.K<sup>-4</sup>.m<sup>-2</sup>.day<sup>-1</sup>,

*Gsc* solar constant = 0.0820 MJ.m<sup>-2</sup>.min<sup>-1</sup>

*Roua* mean density of air = 1.2 kg.m<sup>-3</sup> at 20 degree Celcius

*Ca* specific heat of air = 0.001013 MJ.kg<sup>-1</sup>.K<sup>-1</sup>

*G* soil heat flux negligible for daily time-step = 0 (Allen et al., 1998, page 68)

*alphaA* Albedo for Class-A pan = 0.14

*alphaPT* Priestley-Taylor coefficient:

= 1.26 for Priestley-Taylor formula (Priestley and Taylor, 1972, Sect. 6; Eichinger et al., 1996, p.163);

= 1.31 for Szilagyi-Jozsa formula (Szilagyi and Jozsa, 2008);

= 1.28 for Brutsaert-Strickler formula (Brutsaert and Strickler, 1979),

*ap* constant in Penpan formula = 2.4,

*b0* constant in Morton's procedure = 1 (Chiew and McMahon, 1991, Table A1),

*b1* constant in Morton's procedure = 14 W.m<sup>-2</sup> (Chiew and McMahon, 1991, Table A1),

*b2* constant in Morton's procedure = 1.2 (Chiew and McMahon, 1991, Table A1),

*e0* constant for Blaney-Criddle formula = 0.81917 (Frevert et al., 1983, Table 1),

*e1* constant for Blaney-Criddle formula = -0.0040922 (Frevert et al., 1983, Table 1),

*e2* constant for Blaney-Criddle formula = 1.0705 (Frevert et al., 1983, Table 1),

*e3* constant for Blaney-Criddle formula = 0.065649 (Frevert et al., 1983, Table 1),

*e4* constant for Blaney-Criddle formula = -0.0059864 (Frevert et al., 1983, Table 1),

*e5* constant for Blaney-Criddle formula = -0.0005967 (Frevert et al., 1983, Table 1),

*epsilonMo* Land surface emissivity in Morton's procedure = 0.92,

*sigmaMo* Stefan-Boltzmann constant in Morton's procedure = 5.67e-08 W.m<sup>-2</sup>.K<sup>-4</sup>.

**Source**

various references

**See Also**

[constants](#)

## Description

A generic function including 17 different specific methods that are all named following the format of *ET.methodname*. Once specific function is called the corresponding calculations are performed and a calculation summary is printed to screen.

## Usage

```
ET(data, constants, ...)
```

## Arguments

data	A list of climate data required for estimating evapotranspiration which differs for each evapotranspiration formulations, see specific formulations for details.
constants	A list named constants consists of constants required for the ET models which mdiffer for specific ET models - refer to the manual for individual models for details.
...	Arguments to be passed to methods which differs for each evapotranspiration formulations, see specific formulations for details.

## Details

Individual ET methods can be called by substituting the 'methodname' by the function name (e.g. [ET.Penman](#) to call the Penman model).

When the ET model selection is not specified by users, this function determines the default model to use based on the availability of climate data presented. Wherever data are available, the more comprehensive, physically-based models are always preferred over the empirical models, in the following hierarchy:

- If all variables of  $T_{max}/T_{min}$  and  $RH_{max}/RH_{min}$  and either  $u_z$  or  $u_2$ , and either  $R_s$  of  $n$  or  $C_d$  are available, and short crop surface is specified in argument:  
Penman-Monteith FAO56 ([ET.PenmanMonteith](#) with *crop* = "short");

- If all variables of  $T_{max}/T_{min}$  and  $RH_{max}/RH_{min}$  and either  $u_z$  or  $u_2$ , and either  $R_s$  of  $n$  or  $C_d$  are available, and long crop surface is specified in argument:  
Penman-Monteith ASCE-EWRI ([ET.PenmanMonteith](#) with *crop* = "long");

- If all variables of  $T_{max}/T_{min}$  and  $RH_{max}/RH_{min}$  and either  $u_z$  or  $u_2$ , and either  $R_s$  of  $n$  or  $C_d$  are available, and no surface is specified:  
Penman ([ET.Penman](#));

- If all variables of  $T_{max}/T_{min}$  and  $RH_{max}/RH_{min}$ , and either  $R_s$  of  $n$  or  $C_d$  are available:  
Priestley-Taylor ([ET.PriestleyTaylor](#));

- If all variables of  $T_{max}/T_{min}$  and either  $R_s$  of  $n$  or  $C_d$  are available:  
Makkink ([ET.Makkink](#));

- If all variables of  $T_{max}/T_{min}$  are available:  
Hargreaves-Samani ([ET.HargreavesSamani](#)).

### Author(s)

Danlu Guo

### Examples

```
# Use processed existing data set from kent Town, Adelaide
data("processeddata")
data("constants")

# Call generic function ET() - leads to the use of Penman model
results_default <- ET(processeddata, constants, save.csv="no")

# Call generic function ET() - leads to the use of Penman-Monteith model
results_crop <- ET(processeddata, constants, crop = "short", save.csv="no")
```

---

ET.Abtew

*Abtew Formulation*

---

### Description

Implementing the Abtew formulation for estimating actual evapotranspiration.

### Usage

```
## S3 method for class 'Abtew'
ET(data, constants, ts="daily", solar="sunshine hours",
message="yes", AdditionalStats="yes", save.csv="no", ...)
```

### Arguments

data	A list of data in class "Abtew" which contains the following items (climate variables) required by Abtew formulation: $T_{max}$ , $T_{min}$ (degree Celcius), $R_s$ (Megajoules per sqm) or $n$ (hour) or $Cd$ (okta)
constants	A list named constants consists of constants required for the calculation of Abtew formulation which must contain the following items: $Elev$ - ground elevation above mean sea level in m, $lambda$ - latent heat of vaporisation = 2.45 MJ.kg <sup>-1</sup> , $lat_{rad}$ - latitude in radians, $G_{sc}$ - solar constant = 0.0820 MJ.m <sup>-2</sup> .min <sup>-1</sup> , $sigma$ - Stefan-Boltzmann constant = 4.903*10 <sup>-9</sup> MJ.K <sup>-4</sup> .m <sup>-2</sup> .day <sup>-1</sup> .

The following constants are also required when argument solar has value of sunshine hours:

$as$  - fraction of extraterrestrial radiation reaching earth on sunless days,



	<i>bs</i> - difference between fraction of extraterrestrial radiation reaching full-sun days and that on sunless days.
ts	Must be either daily, monthly or annual, which indicates the desired time step that the output ET estimates should be on. Default is daily.
solar	Must be either data, sunshine hours, cloud or monthly precipitation: data indicates that solar radiation data is to be used directly for calculating evapotranspiration; sunshine hours indicates that solar radiation is to be calculated using the real data of sunshine hours; cloud sunshine hours is to be estimated from cloud data; monthly precipitation indicates that solar radiation is to be calculated directly from monthly precipitation. Default is sunshine hours.
message	Must be either yes or no, indicating whether message should be printed for calculation summary including the following elements: - ET model name and ET quantity estimated - Option for calculating solar radiation (i.e. the value of argument solar) - Time step of the output ET estimates (i.e. the value of argument ts) - Units of the output ET estimates - Time duration of the ET estimation - Number of ET estimates obtained in the entire time-series - Basic statistics of the estimated ET time-series including <i>mean</i> , <i>max</i> and <i>min</i> values.
AdditionalStats	"yes" or "no" indicating whether monthly averaged and annual averaged ET should be calculated.
save.csv	Must be either yes or no, indicating whether a .csv of ET estimates should be saved to working directory.
...	Dummy for generic function, no need to define.

### Details

The alternative calculation options can be selected through argument *solar*, please see Arguments for details.

### Value

The function generates a list containing the following components:

ET.Daily	Daily aggregated estimations of Abtew actual evapotranspiration.
ET.Monthly	Monthly aggregated estimations of Abtew actual evapotranspiration.
ET.Annual	Annually aggregated estimations of Abtew actual evapotranspiration.
ET.MonthlyAve	Monthly averaged estimations of daily Abtew actual evapotranspiration.
ET.AnnualAve	Annually averaged estimations of daily Abtew actual evapotranspiration.
ET_formulation	Name of the formulation used which equals to Abtew.
ET_type	Type of the estimation obtained which is Actual Evapotranspiration.

message1      A message to inform the users about how solar radiation has been calculated by using which data.

### Author(s)

Danlu Guo

### References

Abtew, W. 1996. *Evapotranspiration measurements and modeling for three wetland systems in south florida*. Wiley Online Library.

### See Also

[ET,processeddata,defaultconstants,constants](#)

### Examples

```
# Use processed existing data set and constants from kent Town, Adelaide
data("processeddata")
data("constants")

# Call ET.Abtew under the generic function ET
results <- ET.Abtew(processeddata, constants,ts="daily", solar="sunshine hours",
message="yes", AdditionalStats="yes", save.csv="no")
```

---

ET.BlaneyCriddle      *Blaney-Criddle Formulation*

---

### Description

Implementing the Blaney-Criddle formulation for estimating reference crop evapotranspiration.

### Usage

```
## S3 method for class 'BlaneyCriddle'
ET(data, constants, ts="daily", solar="sunshine hours", height = F,
message="yes", AdditionalStats="yes", save.csv="no", ...)
```

### Arguments

data      A list of data which contains the following items (climate variables) required by Blaney-Criddle formulation:  
*Tmax*, *Tmin* (degree Celcius), *RHmin* (per cent), *n* (hour) or *Cd* (okta), *u2* or *uz* (meter per second)

constants	A list named constants consists of constants required for the calculation of PenPan formulation which must contain the following items: <i>Elev</i> - ground elevation above mean sea level in m, <i>lambda</i> - latent heat of vaporisation = 2.45 MJ.kg <sup>-1</sup> , <i>lat_rad</i> - latitude in radians, <i>z</i> - height of wind instrument in m, <i>e0,e1,e2,e3,e4</i> - recommended values of 0.81917, -0.0040922, 1.0705, 0.065649, -0.0059684, -0.0005967 respectively (Table 1 in Frevert et al., 1983).
ts	Must be either daily, monthly or annual, which indicates the disired time step that the output ET estimates should be on. Default is daily.
solar	Must be either sunshine hours or cloud: sunshine hours indicates that solar radiation is to be calculated using the real data of sunshine hours; cloud sunshine hours is to be estimated from cloud data. Default is sunshine hours.
height	Must be T or F, indicating if adjustment for site elevation for arid and semi-arid regions is applied in Blaney-Criddle formulation (Allen and Brockway, 1983). Default is F for no adjustment.
message	Must be either yes or no, indicating whether message should be printed for calculation summary including the following elements: - ET model name and ET quantity estimated - Evaporative surface - Option for calculating solar radiation (i.e. the value of argument solar) - If height adjustment has been applied on results (i.e. the value of argument height) - Time step of the output ET estimates (i.e. the value of argument ts) - Units of the output ET estimates - Time duration of the ET estimation - Number of ET estimates obtained in the entire time-series - Basic statistics of the estimated ET time-series including <i>mean</i> , <i>max</i> and <i>min</i> values
AdditionalStats	"yes" or "no" indicating whether monthly averaged and annual averaged ET should be calculated.
save.csv	Must be either yes or no, indicating whether a .csv of ET estimates should be saved to working directory.
...	Dummy for generic function, no need to define.

### Details

The alternative calculation options can be selected through argument solar, please see Arguments for details.

Height adjustment for the estimations is available through argument height, please see Arguments for details.

**Value**

The function generates a list containing the following components:

ET.Daily	Daily aggregated estimations of Blaney-Criddle reference crop evapotranspiration.
ET.Monthly	Monthly aggregated estimations of Blaney-Criddle reference crop evapotranspiration.
ET.Annual	Annually aggregated estimations of Blaney-Criddle reference crop evapotranspiration.
ET.MonthlyAve	Monthly averaged estimations of daily Blaney-Criddle reference crop evapotranspiration.
ET.AnnualAve	Annually averaged estimations of daily Blaney-Criddle reference crop evapotranspiration.
ET_formulation	Name of the formulation used which equals to Blaney-Criddle.
ET_type	Type of the estimation obtained which is Reference Crop Evapotranspiration.
message1	A message to inform the users about how solar radiation has been calculated by using which data.
message3	A message to inform the users about if height adjustment has been applied to calculated Blaney-Criddle reference crop evapotranspiration.

**Author(s)**

Danlu Guo

**References**

- McMahon, T., Peel, M., Lowe, L., Srikanthan, R. & McVicar, T. 2012. *Estimating actual, potential, reference crop and pan evaporation using standard meteorological data: a pragmatic synthesis*. Hydrology and Earth System Sciences Discussions, 9, 11829-11910.
- Allen, R.G.Brockway, C.E. 1983, *Estimating consumptive use on a statewide basis*. Advances in Irrigation and Drainage@ sSurviving External Pressures, ASCE, pp. 79-89.
- Allen, R. & Pruitt, W. 1986. *Rational Use of The FAO Blaney-Criddle Formula*. Journal of Irrigation and Drainage Engineering, 112, 139-155.
- Frevert, D.K., Hill, R.W.Braaten, B.C. 1983, *Estimation of FAO evapotranspiration coefficients*, Journal of Irrigation and Drainage Engineering, vol. 109, no. 2, pp. 265-270.

**See Also**

[ET,processeddata,defaultconstants,constants](#)

**Examples**

```
# Use processed existing data set and constants from kent Town, Adelaide
data("processeddata")
data("constants")
```

```
# Call ET.BlaneyCriddle under the generic function ET
results <- ET.BlaneyCriddle(processeddata, constants, ts="daily", solar="sunshine hours",
height= FALSE, message="yes", AdditionalStats="yes", save.csv="no")
```

---

ET.BrutsaertStrickler *Brutsaert-Strickler Formulation*


---

## Description

Implementing the Brutsaert-Strickler formulation for actual areal evapotranspiration

## Usage

```
## S3 method for class 'BrutsaertStrickler'
ET(data, constants, ts="daily", solar="sunshine hours", alpha=0.23,
message="yes", AdditionalStats="yes", save.csv="no", ...)
```

## Arguments

data	A list of data which contains the following items (climate variables) required by Brutsaert-Strickler formulation: <i>Tmax</i> , <i>Tmin</i> (degree Celcius), <i>RHmax</i> , <i>RHmin</i> (per cent), <i>Rs</i> (Megajoules per sqm) or <i>n</i> (hour) or <i>Cd</i> (okta), <i>u2</i> or <i>uz</i> (meter per second)
constants	A list named constants consists of constants required for the calculation of Brutsaert-Strickler formulation which must contain the following items: <i>Elev</i> - ground elevation above mean sea level in m, <i>lambda</i> - latent heat of vaporisation = 2.45 MJ.kg <sup>-1</sup> , <i>lat_rad</i> - latitude in radians, <i>Gsc</i> - solar constant = 0.0820 MJ.m <sup>-2</sup> .min <sup>-1</sup> , <i>z</i> - height of wind instrument in m, <i>sigma</i> - Stefan-Boltzmann constant = 4.903*10 <sup>-9</sup> MJ.K <sup>-4</sup> .m <sup>-2</sup> .day <sup>-1</sup> .

The following constants are also required when argument solar has value of sunshine hours:

*as* - fraction of extraterrestrial radiation reaching earth on sunless days,  
*bs* - difference between fracion of extraterrestrial radiation reaching full-sun days and that on sunless days.

ts	Must be either daily, monthly or annual, which indicates the disired time step that the output ET estimates should be on. Default is daily.
solar	Must be either data, sunshine hours, cloud or monthly precipitation: data indicates that solar radiation data is to be used directly for calculating evapotranspiration; sunshine hours indicates that solar radiation is to be calculated using the real data of sunshine hours; cloud sunshine hours is to be estimated from cloud data;

	monthly precipitation indicates that solar radiation is to be calculated directly from monthly precipitation. Default is sunshine hours.
alpha	Any numeric value between 0 and 1 (dimensionless), albedo of the evaporative surface representing the portion of the incident radiation that is reflected back at the surface. Default is 0.23 for surface covered with short reference crop.
message	Must be either yes or no, indicating whether message should be printed for calculation summary including the following elements: <ul style="list-style-type: none"> <li>- ET model name and ET quantity estimated</li> <li>- Evaporative surface with values of albedo, surface resistance, crop height and roughness height</li> <li>- Option for calculating solar radiation (i.e. the value of argument solar)</li> <li>- Time step of the output ET estimates (i.e. the value of argument ts)</li> <li>- Units of the output ET estimates</li> <li>- Time duration of the ET estimation</li> <li>- Number of ET estimates obtained in the entire time-series</li> <li>- Basic statistics of the estimated ET time-series including <i>mean</i>, <i>max</i> and <i>min</i> values</li> </ul>
AdditionalStats	"yes" or "no" indicating whether monthly averaged and annual averaged ET should be calculated.
save.csv	Must be either yes or no, indicating whether a .csv of ET estimates should be saved to working directory.
...	Dummy for generic function, no need to define.

### Details

The alternative calculation options can be selected through argument `solar`, please see Arguments for details.

User-defined evaporative surface is allowed through argument `alpha`, please see Arguments for details.

### Value

The function also generates a list containing the following components:

ET.Daily	Daily aggregated estimations of Brutsaert-Strickler actual areal evapotranspiration.
ET.Monthly	Monthly aggregated estimations of Brutsaert-Strickler actual areal evapotranspiration.
ET.Annual	Annually aggregated estimations of Brutsaert-Strickler actual areal evapotranspiration.
ET.MonthlyAve	Monthly averaged estimations of daily Brutsaert-Strickler actual areal evapotranspiration.
ET.AnnualAve	Annually averaged estimations of daily Brutsaert-Strickler actual areal evapotranspiration.

ET\_formulation Name of the formulation used which equals to Brutsaert-Strickler.  
ET\_type Type of the estimation obtained which is Actual Areal Evapotranspiration.  
message1 A message to inform the users about how solar radiation has been calculated by using which data.

### Author(s)

Danlu Guo

### References

McMahon, T., Peel, M., Lowe, L., Srikanthan, R. & McVicar, T. 2012. *Estimating actual, potential, reference crop and pan evaporation using standard meteorological data: a pragmatic synthesis*. Hydrology and Earth System Sciences Discussions, 9, 11829-11910.

### See Also

[ET,processeddata,defaultconstants,constants](#)

### Examples

```
# Use processed existing data set and constants from kent Town, Adelaide
data("processeddata")
data("constants")

# Call ET.BrutsaertStrickler under the generic function ET
results <- ET.BrutsaertStrickler(processeddata, constants, ts="daily", solar="sunshine hours",
alpha=0.23, message="yes", AdditionalStats="yes", save.csv="no")
```

---

ET.ChapmanAustralian *Chapman Formulation*

---

### Description

Implementing the Chapman formulation for estimating potential evapotranspiration.

### Usage

```
## S3 method for class 'ChapmanAustralian'
ET(data, constants, ts="daily", PenPan= T,
solar="sunshine hours", alpha=0.23, message="yes", AdditionalStats="yes",
save.csv="no", ...)
```

**Arguments**

data	A list of data which contains the following items (climate variables) required by Chapman formulation: <i>Tmax</i> , <i>Tmin</i> (degree Celcius), <i>RHmax</i> , <i>RHmin</i> (per cent), <i>Rs</i> (Megajoules per sqm) or <i>n</i> (hour) or <i>Cd</i> (okta), <i>u2</i> or <i>uz</i> (meter per second)
constants	A list named constants consists of constants required for the calculation of Chapman formulation which must contain the following items: <i>Elev</i> - ground elevation above mean sea level in m, <i>lambda</i> - latent heat of vaporisation = 2.45 MJ.kg <sup>-1</sup> , <i>lat_rad</i> - latitude in radians, <i>Gsc</i> - solar constant = 0.0820 MJ.m <sup>-2</sup> .min <sup>-1</sup> , <i>z</i> - height of wind instrument in m, <i>sigma</i> - Stefan-Boltzmann constant = 4.903*10 <sup>-9</sup> MJ.K <sup>-4</sup> .m <sup>-2</sup> .day <sup>-1</sup> , <i>lat</i> - latitude in degrees, <i>alphaA</i> - albedo for Class-A pan, <i>ap</i> - a constant in PenPan = 2.4.  The following constants are also required when argument solar has value of sunshine hours: <i>as</i> - fraction of extraterrestrial radiation reaching earth on sunless days, <i>bs</i> - difference between fracion of extraterrestrial radiation reaching full-sun days and that on sunless days.
ts	Must be either daily, monthly or annual, which indicates the disired time step that the output ET estimates should be on. Default is daily.
PenPan	Must be T or F, indicating if the PenPan formulation is used for estimating Class-A pan evaporation required in Chapman formulation. If T PenPan will be used and if F the actual data of Class-A pan evaporation will be used. Default is T for using the PenPan formulation.
solar	Must be either data, sunshine hours, cloud or monthly precipitation: data indicates that solar radiation data is to be used directly for calculating evapotranspiration; sunshine hours indicates that solar radiation is to be calculated using the real data of sunshine hours; cloud sunshine hours is to be estimated from cloud data; monthly precipitation indicates that solar radiation is to be calculated directly from monthly precipitation. Default is sunshine hours.
alpha	Any numeric value between 0 and 1 (dimensionless), albedo of the evaporative surface incident radiation that is reflected back at the surface. Default is 0.23 for surface covered with short reference crop.
message	Must be either yes or no, indicating whether message should be printed for calculation summary including the following elements: - ET model name and ET quantity estimated, and the value of pan coefficient (only for when potential ET is estimated) - Evaporative surface with values of albedo - Option for calculating solar radiation (i.e. the value of argument solar)



- If the PenPan formulation is used for estimating Class-A pan evaporation required in Chapman formulation (i.e. the value of argument PenPan)
- Time step of the output ET estimates (i.e. the value of argument ts)
- Units of the output ET estimates
- Time duration of the ET estimation
- Number of ET estimates obtained in the entire time-series
- Basic statistics of the estimated ET time-series including *mean*, *max* and *min* values.

AdditionalStats	"yes" or "no" indicating whether monthly averaged and annual averaged ET should be calculated.
save.csv	Must be either yes or no, indicating whether a .csv of ET estimates should be saved to working directory.
...	Dummy for generic function, no need to define.

### Details

The alternative calculation options can be selected through arguments PenPan and solar, please see Arguments for details.

### Value

The function generates a list containing the following components:

ET.Daily	Daily aggregated estimations of Chapman potential evapotranspiration.
ET.Monthly	Monthly aggregated estimations of Chapman potential evapotranspiration.
ET.Annual	Annually aggregated estimations of Chapman equivalent Penmen-Monteith evapotranspiration.
ET.MonthlyAve	Monthly averaged estimations of daily Chapman potential evapotranspiration.
ET.AnnualAve	Annually averaged estimations of daily Chapman potential evapotranspiration.
ET_formulation	Name of the formulation used which equals to Chapman.
ET_type	Type of the estimation obtained which is Potential Evapotranspiration.
message1	A message to inform the users about how solar radiation has been calculated by using which data.
message5	A message to inform the users about if the Class-A pan evaporation is from actual data or from PenPan estimation.

### Author(s)

Danlu Guo

### References

McMahon, T., Peel, M., Lowe, L., Srikanthan, R. & McVicar, T. 2012. *Estimating actual, potential, reference crop and pan evaporation using standard meteorological data: a pragmatic synthesis*. Hydrology and Earth System Sciences Discussions, 9, 11829-11910.

Chapman, T. 2001, *Estimation of evaporation in rainfall-runoff models*, in F. Ghassemi, D. Post, M. Sivapalan R. Vertessy (eds), MODSIM2001: Integrating models for Natural Resources Management across Disciplines, Issues and Scales, MSSANZ, vol. 1, pp. 293-298.

### See Also

[ET,processeddata,defaultconstants,constants,ET.PenPan](#)

### Examples

```
# Use processed existing data set and constants from kent Town, Adelaide
data("processeddata")
data("constants")

# Call ET.ChapmanAustralian under the generic function ET
results <- ET.ChapmanAustralian(processeddata, constants, ts="daily", PenPan= TRUE,
solar="sunshine hours", alpha=0.23, message="yes", AdditionalStats="yes",
save.csv="no")
```

---

ET.GrangerGray

*Granger-Gray Formulation*

---

### Description

Implementing the Granger-Gray formulation for estimating actual areal evapotranspiration.

### Usage

```
## S3 method for class 'GrangerGray'
ET(data, constants, ts="daily",
solar="sunshine hours", windfunction_ver=1948, alpha=0.23,
message="yes", AdditionalStats="yes", save.csv="no", ...)
```

### Arguments

data	A list of data which contains the following items (climate variables) required by Granger-Gray formulation: <i>Tmax</i> , <i>Tmin</i> (degree Celcius), <i>RHmax</i> , <i>RHmin</i> (per cent), <i>Rs</i> (Megajoules per sqm) or <i>n</i> (hour) or <i>Cd</i> (okta), <i>u2</i> or <i>uz</i> (meter per second)
constants	A list named constants consists of constants required for the calculation of Granger-Gray formulation which must contain the following items: <i>Elev</i> - ground elevation above mean sea level in m, <i>lambda</i> - latent heat of vaporisation = 2.45 MJ.kg <sup>-1</sup> , <i>lat_rad</i> - latitude in radians, <i>Gsc</i> - solar constant = 0.0820 MJ.m <sup>-2</sup> .min <sup>-1</sup> , <i>z</i> - height of wind instrument in m, <i>sigma</i> - Stefan-Boltzmann constant = 4.903*10 <sup>-9</sup> MJ.K <sup>-4</sup> .m <sup>-2</sup> .day <sup>-1</sup> . <i>G</i> - soil heat flux in MJ.m <sup>-2</sup> .day <sup>-1</sup> , = 0 when using daily time step.

The following constants are also required when argument solar has value of sunshine hours:

*as* - fraction of extraterrestrial radiation reaching earth on sunless days,

*bs* - difference between fraction of extraterrestrial radiation reaching full-sun days and that on sunless days.

ts	Must be either daily, monthly or annual, which indicates the desired time step that the output ET estimates should be on. Default is daily.
solar	Must be either data, sunshine hours, cloud or monthly precipitation: data indicates that solar radiation data is to be used directly for calculating evapotranspiration; sunshine hours indicates that solar radiation is to be calculated using the real data of sunshine hours; cloud sunshine hours is to be estimated from cloud data; monthly precipitation indicates that solar radiation is to be calculated directly from monthly precipitation. Default is sunshine hours.
windfunction_ver	The version of Penman wind function that will be used within the Penman formulation. Must be either 1948 or 1956. 1948 is for applying the Penman's 1948 wind function (Penman, 1948); 1956 is for applying the Penman's 1956 wind function (Penman, 1956) Default is 1948.
alpha	Any numeric value between 0 and 1 (dimensionless), albedo of evaporative surface representing the portion of the incident radiation that is reflected back at the surface. Default is 0.23 for surface covered with short reference crop.
message	Must be either yes or no, indicating whether message should be printed for calculation summary including the following elements: - ET model name and ET quantity estimated - Evaporative surface with values of albedo - Option for calculating solar radiation (i.e. the value of argument solar) - The version of Penman wind function has been used (i.e. the value of argument windfunction_ver) - Time step of the output ET estimates (i.e. the value of argument ts) - Units of the output ET estimates - Time duration of the ET estimation - Number of ET estimates obtained in the entire time-series - Basic statistics of the estimated ET time-series including <i>mean</i> , <i>max</i> and <i>min</i> values.
AdditionalStats	"yes" or "no" indicating whether monthly averaged and annual averaged ET should be calculated.
save.csv	Must be either yes or no, indicating whether a .csv of ET estimates should be saved to working directory.
...	Dummy for generic function, no need to define.

### Details

The alternative calculation options can be selected through arguments solar and windfunction\_ver, please see Arguments for details.

User-defined evaporative surface is allowed through argument alpha, please see Arguments for details.

### Value

The function generates a list containing the following components:

ET.Daily	Daily aggregated estimations of Granger-Gray actual areal evapotranspiration.
ET.Monthly	Monthly aggregated estimations of Granger-Gray actual areal evapotranspiration.
ET.Annual	Annually aggregated estimations of Granger-Gray actual areal evapotranspiration.
ET.MonthlyAve	Monthly averaged estimations of daily Granger-Gray actual areal evapotranspiration.
ET.AnnualAve	Annually averaged estimations of daily Granger-Gray actual areal evapotranspiration.
ET_formulation	Name of the formulation used which equals to Granger-Gray.
ET_type	Type of the estimation obtained which is Actual Areal Evapotranspiration.
message1	A message to inform the users about how solar radiation has been calculated by using which data.
message2	A message to inform the users about which version of the Penman wind function has been used.

### Author(s)

Danlu Guo

### References

McMahon, T., Peel, M., Lowe, L., Srikanthan, R. & McVicar, T. 2012. *Estimating actual, potential, reference crop and pan evaporation using standard meteorological data: a pragmatic synthesis*. Hydrology and Earth System Sciences Discussions, 9, 11829-11910.

Penman, H. L. 1948. *Natural evaporation from open water, bare soil and grass*. Proceedings of the Royal Society of London. Series A. Mathematical and Physical Sciences, 193, 120-145.

Penman, H. L. 1956. *Evaporation: An introductory survey*. Netherlands Journal of Agricultural Science, 4, 9-29

### See Also

[ET,processeddata,defaultconstants,constants,ET.Penman](#)

**Examples**

```
# Use processed existing data set and constants from kent Town, Adelaide
data("processeddata")
data("constants")

# Call ET.GrangerGray under the generic function ET
results <- ET.GrangerGray(processeddata, constants, ts="daily",
solar="sunshine hours", windfunction_ver=1948, alpha=0.23,
message="yes", AdditionalStats="yes", save.csv="no")
```

---

ET.Hamon

*Hamon Formulation*


---

**Description**

Implementing the Hamon formulation for estimating potential evapotranspiration.

**Usage**

```
## S3 method for class 'Hamon'
ET(data, constants = NULL, ts="daily", message="yes", AdditionalStats="yes",
save.csv="no", ...)
```

**Arguments**

data	A list of data which contains the following items (climate variables) required by Hamon formulation: <i>Tmax, Tmin</i> (degree Celcius), <i>n</i> (hour)
constants	Dummy argument with a NULL value.
ts	Must be either <i>daily</i> , <i>monthly</i> or <i>annual</i> , which indicates the disired time step that the output ET estimates should be on. Default is <i>daily</i> .
message	Must be either <i>yes</i> or <i>no</i> , indicating whether message should be printed for calculation summary including the following elements: - ET model name and ET quantity estimated - Time step of the output ET estimates (i.e. the value of argument <i>ts</i> ) - Units of the output ET estimates - Time duration of the ET estimation - Number of ET estimates obtained in the entire time-series - Basic statistics of the estimated ET time-series including <i>mean</i> , <i>max</i> and <i>min</i> values.
AdditionalStats	"yes" or "no" indicating whether monthly averaged and annual averaged ET should be calculated.
save.csv	Must be either <i>yes</i> or <i>no</i> , indicating whether a .csv of ET estimates should be saved to working directory.
...	Dummy for generic function, no need to define.

**Details**

This formulation provides a single calculation method with no alternatives available.

**Value**

The function generates a list containing the following components:

ET.Daily	Daily aggregated estimations of Hamon potential evapotranspiration.
ET.Monthly	Monthly aggregated estimations of Hamon potential evapotranspiration.
ET.Annual	Annually aggregated estimations of Hamon potential evapotranspiration.
ET.MonthlyAve	Monthly averaged estimations of daily Hamon potential evapotranspiration.
ET.AnnualAve	Annually averaged estimations of daily Hamon potential evapotranspiration.
ET_formulation	Name of the formulation used which equals to Hamon.
ET_type	Type of the estimation obtained which is Potential Evapotranspiration.

**Author(s)**

Danlu Guo

**References**

- Hamon, W. R. 1961. *Estimating potential evapotranspiration*. Journal of the Hydraulics Division, 87, 107-120.
- Oudin, L., Hervieu, F., Michel, C., Perrin, C., Andreassian, V., Anctil, F., Loumagne, C. 2005, *Which potential evapotranspiration input for a lumped rainfall-runoff model?: Part 2-Towards a simple and efficient potential evapotranspiration model for rainfall-runoff modelling*. Journal of Hydrology, vol. 303, no. 1-4, pp. 290-306.

**See Also**

[ET,processeddata](#)

**Examples**

```
# Use processed existing data set and constants from kent Town, Adelaide
data("processeddata")
data("constants")

# Call ET.Hamon under the generic function ET
results <- ET.Hamon(processeddata, ts="daily", message="yes", AdditionalStats="yes", save.csv="no")
```

---

 ET.HargreavesSamani     *Hargreaves-Samani Formulation*


---

### Description

Implementing the Hargreaves-Samani formulation for estimating reference crop evapotranspiration.

### Usage

```
## S3 method for class 'HargreavesSamani'
ET(data, constants, ts="daily",
message="yes", AdditionalStats="yes", save.csv="no", ...)
```

### Arguments

data	A list of data which contains the following items (climate variables) required by Hargreaves-Samani formulation: <i>Tmax</i> , <i>Tmin</i> (degree Celcius)
constants	A list named constants consists of constants required for the calculation of Hargreaves-Samani formulation which must contain the following items: <i>Elev</i> - ground elevation above mean sea level in m, <i>lambda</i> - latent heat of vaporisation = 2.45 MJ.kg <sup>-1</sup> , <i>lat_rad</i> - latitude in radians, <i>Gsc</i> - solar constant = 0.0820 MJ.m <sup>-2</sup> .min <sup>-1</sup> .
ts	Must be either daily, monthly or annual, which indicates the disired time step that the output ET estimates should be on. Default is daily.
message	Must be either yes or no, indicating whether message should be printed for calculation summary including the following elements: - ET model name and ET quantity estimated - Evaporative surface with values of albedo - Time step of the output ET estimates (i.e. the value of argument ts) - Units of the output ET estimates - Time duration of the ET estimation - Number of ET estimates obtained in the entire time-series - Basic statistics of the estimated ET time-series including <i>mean</i> , <i>max</i> and <i>min</i> values.
AdditionalStats	"yes" or "no" indicating whether monthly averaged and annual averaged ET should be calculated.
save.csv	Must be either yes or no, indicating whether a .csv of ET estimates should be saved to working directory.
...	Dummy for generic function, no need to define.

### Details

This formulation provides a single calculation method with no alternatives available.

**Value**

The function generates a list containing the following components:

ET.Daily	Daily aggregated estimations of Hargreaves-Samani reference crop evapotranspiration.
ET.Monthly	Monthly aggregated estimations of Hargreaves-Samani reference crop evapotranspiration.
ET.Annual	Annually aggregated estimations of Hargreaves-Samani reference crop evapotranspiration.
ET.MonthlyAve	Monthly averaged estimations of daily Hargreaves-Samani reference crop evapotranspiration.
ET.AnnualAve	Annually averaged estimations of daily Hargreaves-Samani reference crop evapotranspiration.
ET_formulation	Name of the formulation used which equals to Hargreaves-Samani.
ET_type	Type of the estimation obtained which is Reference Crop Evapotranspiration.

**Author(s)**

Danlu Guo

**References**

McMahon, T., Peel, M., Lowe, L., Srikanthan, R. & McVicar, T. 2012. *Estimating actual, potential, reference crop and pan evaporation using standard meteorological data: a pragmatic synthesis*. Hydrology and Earth System Sciences Discussions, 9, 11829-11910.

Hargreaves, G.H.Samani, Z.A. 1985, *Reference crop evapotranspiration from ambient air temperature*. American Society of Agricultural Engineers.

**See Also**

[ET,processeddata,defaultconstants,constants](#)

**Examples**

```
# Use processed existing data set and constants from kent Town, Adelaide
data("processeddata")
data("constants")

# Call ET.HargreavesSamani under the generic function ET
results <- ET.HargreavesSamani(processeddata, constants, ts="daily", message="yes",
AdditionalStats="yes", save.csv="no")
```



---

ET.JensenHaise                      *Jensen-Haise Formulation*

---

### Description

Implementing the Jensen-Haise formulation for estimating potential evapotranspiration.

### Usage

```
## S3 method for class 'JensenHaise'
ET(data, constants, ts="daily", solar="sunshine hours",
message="yes", AdditionalStats="yes", save.csv="no", ...)
```

### Arguments

data	A list of data which contains the following items (climate variables) required by Jensen-Haise formulation: <i>Tmax</i> , <i>Tmin</i> , <i>Rs</i> or <i>n</i> or <i>Cd Tmax</i> , <i>Tmin</i> (degree Celcius), <i>Rs</i> (Megajoules per sqm) or <i>n</i> (hour) or <i>Cd</i> (okta)
constants	A list named constants consists of constants required for the calculation of Jensen-Haise formulation which must contain the following items: <i>Elev</i> - ground elevation above mean sea level in m, <i>lambda</i> - latent heat of vaporisation = 2.45 MJ.kg <sup>-1</sup> , <i>lat_rad</i> - latitude in radians, <i>Gsc</i> - solar constant = 0.0820 MJ.m <sup>-2</sup> .min <sup>-1</sup> .

The following constants are also required when argument solar has value of sunshine hours:

*as* - fraction of extraterrestrial radiation reaching earth on sunless days,  
*bs* - difference between fracion of extraterrestrial radiation reaching full-sun days and that on sunless days.

ts	Must be either daily, monthly or annual, which indicates the disired time step that the output ET estimates should be on. Default is daily.
solar	Must be either data, sunshine hours, cloud or monthly precipitation: data indicates that solar radiation data is to be used directly for calculating evapotranspiration; sunshine hours indicates that solar radiation is to be calculated using the real data of sunshine hours; cloud sunshine hours is to be estimated from cloud data; monthly precipitation indicates that solar radiation is to be calculated directly from monthly precipitation. Default is sunshine hours.
message	Must be either yes or no, indicating whether message should be printed for calculation summary including the following elements: - ET model name and ET quantity estimated - Option for calculating solar radiation (i.e. the value of argument solar)

	<ul style="list-style-type: none"> <li>- Time step of the output ET estimates (i.e. the value of argument ts)</li> <li>- Units of the output ET estimates</li> <li>- Time duration of the ET estimation</li> <li>- Number of ET estimates obtained in the entire time-series</li> <li>- Basic statistics of the estimated ET time-series including <i>mean</i>, <i>max</i> and <i>min</i> values.</li> </ul>
AdditionalStats	"yes" or "no" indicating whether monthly averaged and annual averaged ET should be calculated.
save.csv	Must be either yes or no, indicating whether a .csv of ET estimates should be saved to working directory.
...	Dummy for generic function, no need to define.

### Details

This formulation provides a single calculation method with no alternatives available.

### Value

The function also generates a list containing the following components:

ET.Daily	Daily aggregated estimations of Jensen-Haise potential evapotranspiration.
ET.Monthly	Monthly aggregated estimations of Jensen-Haise potential evapotranspiration.
ET.Annual	Annually aggregated estimations of Jensen-Haise potential evapotranspiration.
ET.MonthlyAve	Monthly averaged estimations of daily Jensen-Haise potential evapotranspiration.
ET.AnnualAve	Annually averaged estimations of daily Jensen-Haise potential evapotranspiration.
ET_formulation	Name of the formulation used which equals to Jensen-Haise.
ET_type	Type of the estimation obtained which is Potential Evapotranspiration.

### Author(s)

Danlu Guo

### References

- Jensen, M.E.Haise, H.R. 1963, *Estimating evapotranspiration from solar radiation*. Proceedings of the American Society of Civil Engineers, Journal of the Irrigation and Drainage Division, vol. 89, pp. 15-41.
- Prudhomme, C.Williamson, J. 2013, *Derivation of RCM-driven potential evapotranspiration for hydrological climate change impact analysis in Great Britain: a comparison of methods and associated uncertainty in future projections*. Hydrol. Earth Syst. Sci., vol. 17, no. 4, pp. 1365-1377.
- Xu, C.Y.Singh, V.P. 2000, *Evaluation and generalization of radiation-based methods for calculating evaporation.*, Hydrological Processes, vol. 14, no. 2, pp. 339-349.

**See Also**

[ET,processeddata,defaultconstants,constants](#)

**Examples**

```
# Use processed existing data set and constants from kent Town, Adelaide
data("processeddata")
data("constants")

# Call ET.JensenHaise under the generic function ET
results <- ET.JensenHaise(processeddata, constants, ts="daily", solar="sunshine hours",
message="yes",AdditionalStats="yes", save.csv="no")
```

---

ET.Linacre

*Linacre Formulation*


---

**Description**

Implementing the Linacre formulation for estimating actual evapotranspiration.

**Usage**

```
## S3 method for class 'Linacre'
ET(data, constants, ts="daily", message="yes", AdditionalStats="yes",
save.csv="no", ...)
```

**Arguments**

data	A list of data which contains the following items (climate variables) required by Linacre formulation: <i>Tmax, Tmin, Tdew</i> (degree Celcius)
constants	A list named constants consists of constants required for the calculation of Linacre formulation which must contain the following items: <i>Elev</i> - ground elevation above mean sea level in m, <i>lat</i> - latitude in degrees.
ts	Must be either <i>daily</i> , <i>monthly</i> or <i>annual</i> , which indicates the disired time step that the output ET estimates should be on. Default is <i>daily</i> .
message	Must be either <i>yes</i> or <i>no</i> , indicating whether message should be printed for calculation summary including the following elements: <ul style="list-style-type: none"> <li>- ET model name and ET quantity estimated</li> <li>- Time step of the output ET estimates (i.e. the value of argument <i>ts</i>)</li> <li>- Units of the output ET estimates</li> <li>- Time duration of the ET estimation</li> <li>- Number of ET estimates obtained in the entire time-series</li> <li>- Basic statistics of the estimated ET time-series including <i>mean</i>, <i>max</i> and <i>min</i> values.</li> </ul>

AdditionalStats	"yes" or "no" indicating whether monthly averaged and annual averaged ET should be calculated.
save.csv	Must be either yes or no, indicating whether a .csv of ET estimates should be saved to working directory.
...	Dummy for generic function, no need to define.

### Details

This formulation provides a single calculation method with no alternatives available.

### Value

The function generates a list containing the following components:

ET.Daily	Daily aggregated estimations of Linacre actual evapotranspiration.
ET.Monthly	Monthly aggregated estimations of Linacre actual evapotranspiration.
ET.Annual	Annually aggregated estimations of Linacre actual evapotranspiration.
ET.MonthlyAve	Monthly averaged estimations of daily Linacre actual evapotranspiration.
ET.AnnualAve	Annually averaged estimations of daily Linacre actual evapotranspiration.
ET_formulation	Name of the formulation used which equals to Linacre.
ET_type	Type of the estimation obtained which is Actual Evapotranspiration.

### Author(s)

Danlu Guo

### References

Linacre, E. T. 1977. *A simple formula for estimating evaporation rates in various climates, using temperature data alone*. Agricultural meteorology, 18, 409-424.

### See Also

[ET,processeddata,defaultconstants,constants](#)

### Examples

```
# Use processed existing data set and constants from kent Town, Adelaide
data("processeddata")
data("constants")

# Call ET.Linacre under the generic function ET
results <- ET.Linacre(processeddata, constants, ts="daily",
message="yes", AdditionalStats="yes", save.csv="no")
```

**Description**

Implementing the Makkink formulation for estimating reference crop evapotranspiration.

**Usage**

```
## S3 method for class 'Makkink'
ET(data, constants, ts="daily", solar="sunshine hours",
message="yes", AdditionalStats="yes", save.csv="no", ...)
```

**Arguments**

data	A list of data which contains the following items (climate variables) required by Makkink formulation: <i>Tmax</i> , <i>Tmin</i> (degree Celcius), <i>Rs</i> (Megajoules per sqm) or <i>n</i> (hour) or <i>Cd</i> (okta)
constants	A list named constants consists of constants required for the calculation of Makkink formulation which must contain the following items: <i>Elev</i> - ground elevation above mean sea level in m, <i>lambda</i> - latent heat of vaporisation = 2.45 MJ.kg <sup>-1</sup> , <i>lat_rad</i> - latitude in radians, <i>Gsc</i> - solar constant = 0.0820 MJ.m <sup>-2</sup> .min <sup>-1</sup> .  The following constants are also required when argument solar has value of sunshine hours: <i>as</i> - fraction of extraterrestrial radiation reaching earth on sunless days, <i>bs</i> - difference between fracion of extraterrestrial radiation reaching full-sun days and that on sunless days.
ts	Must be either daily, monthly or annual, which indicates the disired time step that the output ET estimates should be on. Default is daily.
solar	Must be either data, sunshine hours, cloud or monthly precipitation: data indicates that solar radiation data is to be used directly for calculating evapotranspiration; sunshine hours indicates that solar radiation is to be calculated using the real data of sunshine hours; cloud sunshine hours is to be estimated from cloud data; monthly precipitation indicates that solar radiation is to be calculated directly from monthly precipitation. Default is sunshine hours.
message	Must be either yes or no, indicating whether message should be printed for calculation summary including the following elements: - ET model name and ET quantity estimated - Option for calculating solar radiation (i.e. the value of argument solar) - Time step of the output ET estimates (i.e. the value of argument ts)

	<ul style="list-style-type: none"> <li>- Units of the output ET estimates</li> <li>- Time duration of the ET estimation</li> <li>- Number of ET estimates obtained in the entire time-series</li> <li>- Basic statistics of the estimated ET time-series including <i>mean</i>, <i>max</i> and <i>min</i> values.</li> </ul>
AdditionalStats	"yes" or "no" indicating whether monthly averaged and annual averaged ET should be calculated.
save.csv	Must be either yes or no, indicating whether a .csv of ET estimates should be saved to working directory.
...	Dummy for generic function, no need to define.

### Details

The alternative calculation options can be selected through argument `solar`, please see Arguments for details.

### Value

The function generates a list containing the following components:

ET.Daily	Daily aggregated estimations of Makkink reference crop evapotranspiration.
ET.Monthly	Monthly aggregated estimations of Makkink reference crop evapotranspiration.
ET.Annual	Annually aggregated estimations of Makkink reference crop evapotranspiration.
ET.MonthlyAve	Monthly averaged estimations of daily Makkink reference crop evapotranspiration.
ET.AnnualAve	Annually averaged estimations of daily Makkink reference crop evapotranspiration.
ET_formulation	Name of the formulation used which equals to Makkink.
ET_type	Type of the estimation obtained which is Reference crop evapotranspiration.
message1	A message to inform the users about how solar radiation has been calculated by using which data.

### Author(s)

Danlu Guo

### References

- McMahon, T., Peel, M., Lowe, L., Srikanthan, R. & McVicar, T. 2012. *Estimating actual, potential, reference crop and pan evaporation using standard meteorological data: a pragmatic synthesis*. Hydrology and Earth System Sciences Discussions, 9, 11829-11910.
- De Bruin, H. 1981, *The determination of (reference crop) evapotranspiration from routine weather data*. Evaporation in relation to hydrology, pp. 25-37.

**See Also**

[ET,processeddata,defaultconstants,constants](#)

**Examples**

```
# Use processed existing data set and constants from kent Town, Adelaide
data("processeddata")
data("constants")

# Call ET.Makkink under the generic function ET
results <- ET.Makkink(processeddata, constants, ts="daily", solar="sunshine hours",
message="yes", AdditionalStats="yes", save.csv="no")
```

---

ET.MattShuttleworth     *Matt-Shuttleworth Formulation*

---

**Description**

Implementing the Matt-Shuttleworth formulation for reference crop evapotranspiration

**Usage**

```
## S3 method for class 'MattShuttleworth'
ET(data, constants, ts="daily", solar="sunshine hours",
alpha=0.23, r_s=70, CH=0.12, message="yes", AdditionalStats="yes", save.csv="no", ...)
```

**Arguments**

data	A list which contains the following items (climate variables) required by Matt-Shuttleworth formulation: <i>Tmax</i> , <i>Tmin</i> (degree Celcius), <i>RHmax</i> , <i>RHmin</i> (per cent), <i>Rs</i> (Megajoules per sqm) or <i>n</i> (hour) or <i>Cd</i> (okta), <i>u2</i> or <i>uz</i> (meter per second)
constants	A list named constants consists of constants required for the calculation of Matt-Shuttleworth formulation which must contain the following items: <i>Elev</i> - ground elevation above mean sea level in m, <i>lambda</i> - latent heat of vaporisation = 2.45 MJ.kg <sup>-1</sup> , <i>lat_rad</i> - latitude in radians, <i>Gsc</i> - solar constant = 0.0820 MJ.m <sup>-2</sup> .min <sup>-1</sup> , <i>z</i> - height of wind instrument in m, <i>sigma</i> - Stefan-Boltzmann constant = 4.903*10 <sup>-9</sup> MJ.K <sup>-4</sup> .m <sup>-2</sup> .day <sup>-1</sup> , <i>Roua</i> - mean air density = 1.20 kg.m <sup>-3</sup> , <i>Ca</i> - specific heat of air = 0.001013 MJ.kg <sup>-1</sup> .oC <sup>-1</sup> .

The following constants are also required when argument solar has value of sunshine hours:

	<p><i>as</i> - fraction of extraterrestrial radiation reaching earth on sunless days,  <i>bs</i> - difference between fraction of extraterrestrial radiation reaching full-sun days and that on sunless days.</p>
ts	Must be either <code>daily</code> , <code>monthly</code> or <code>annual</code> , which indicates the desired time step that the output ET estimates should be on. Default is <code>daily</code> .
solar	Must be either <code>data</code> , <code>sunshine hours</code> , <code>cloud</code> or <code>monthly precipitation</code> : <code>data</code> indicates that solar radiation data is to be used directly for calculating evapotranspiration; <code>sunshine hours</code> indicates that solar radiation is to be calculated using the real data of sunshine hours; <code>cloud</code> sunshine hours is to be estimated from cloud data; <code>monthly precipitation</code> indicates that solar radiation is to be calculated directly from monthly precipitation. Default is <code>sunshine hours</code> .
alpha	Any numeric value between 0 and 1 (dimensionless), albedo of evaporative surface representing the portion of the incident radiation that is reflected back at the surface. Default is 0.23 for surface covered with short reference crop, which is for the calculation of Matt-Shuttleworth reference crop evaporation.
r_s	Any value (seconds per metre), surface resistance depends on the type of reference crop. Default is 70 for short reference crop.
CH	Any value (metres), crop height depends on the reference crop. Default is 0.12 for short reference crop.
message	Must be either <code>yes</code> or <code>no</code> , indicating whether message should be printed for calculation summary including the following elements: <ul style="list-style-type: none"> <li>- ET model name and ET quantity estimated</li> <li>- Evaporative surface with values of albedo, surface resistance and crop height</li> <li>- Option for calculating solar radiation (i.e. the value of argument <code>solar</code>)</li> <li>- Time step of the output ET estimates (i.e. the value of argument <code>ts</code>)</li> <li>- Units of the output ET estimates</li> <li>- Time duration of the ET estimation</li> <li>- Number of ET estimates obtained in the entire time-series</li> <li>- Basic statistics of the estimated ET time-series including <i>mean</i>, <i>max</i> and <i>min</i> values.</li> </ul>
AdditionalStats	"yes" or "no" indicating whether monthly averaged and annual averaged ET should be calculated.
save.csv	Must be either <code>yes</code> or <code>no</code> , indicating whether a <code>.csv</code> of ET estimates should be saved to working directory.
...	Dummy for generic function, no need to define.

### Details

The alternative calculation options can be selected through argument `solar`, please see Arguments for details.



User-defined evaporative surface is allowed through arguments alpha, r\_s and CH, please see Arguments for details.

### Value

The function generates a list containing the following components:

ET.Daily	Daily aggregated estimations of Matt-Shuttleworth reference crop evapotranspiration.
ET.Monthly	Monthly aggregated estimations of Matt-Shuttleworth reference crop evapotranspiration.
ET.Annual	Annually aggregated estimations of Matt-Shuttleworth reference crop evapotranspiration.
ET.MonthlyAve	Monthly averaged estimations of daily Matt-Shuttleworth reference crop evapotranspiration.
ET.AnnualAve	Annually averaged estimations of daily Matt-Shuttleworth reference crop evapotranspiration.
ET_formulation	Name of the formulation used which equals to <i>Matt-Shuttleworth</i> .
ET_type	Type of the estimation obtained which is <i>Reference Crop Evapotranspiration</i> .
message1	A message to inform the users about how solar radiation has been calculated by using which data.

### Author(s)

Danlu Guo

### References

Shuttleworth, W. & Wallace, J. 2009. *Calculating the water requirements of irrigated crops in Australia using the Matt-Shuttleworth approach*. Transactions of the ASABE, 52, 1895-1906.

McMahon, T., Peel, M., Lowe, L., Srikanthan, R. & McVicar, T. 2012. *Estimating actual, potential, reference crop and pan evaporation using standard meteorological data: a pragmatic synthesis*. Hydrology and Earth System Sciences Discussions, 9, 11829-11910.

### See Also

[ET,processeddata,defaultconstants,constants](#)

### Examples

```
# Use processed existing data set and constants from kent Town, Adelaide
data("processeddata")
data("constants")

# Call ET.MattShuttleworth under the generic function ET
results <- ET.MattShuttleworth(processeddata, constants, ts="daily",
solar="sunshine hours", alpha=0.23, r_s=70, CH=0.12,
message="yes", AdditionalStats="yes", save.csv="no")
```

---

 ET.McGuinnessBordne    *McGuinness-Bordne Formulation*


---

### Description

Implementing the McGuinness-Bordne formulation for estimating potential evapotranspiration.

### Usage

```
## S3 method for class 'McGuinnessBordne'
ET(data, constants, ts="daily", message="yes",
    AdditionalStats="yes", save.csv="no", ...)
```

### Arguments

data	A list of data which contains the following items (climate variables) required by McGuinness-Bordne formulation: <i>Tmax</i> , <i>Tmin</i> (degree Celcius)
constants	A list named constants consists of constants required for the calculation of Jensen-Haise formulation which must contain the following items: <i>Elev</i> - ground elevation above mean sea level in m, <i>lambda</i> - latent heat of vaporisation = 2.45 MJ.kg <sup>-1</sup> , <i>lat_rad</i> - latitude in radians, <i>Gsc</i> - solar constant = 0.0820 MJ.m <sup>-2</sup> .min <sup>-1</sup> .
ts	Must be either <code>daily</code> , <code>monthly</code> or <code>annual</code> , which indicates the disired time step that the output ET estimates should be on. Default is <code>daily</code> .
message	Must be either <code>yes</code> or <code>no</code> , indicating whether message should be printed for calculation summary including the following elements: - ET model name and ET quantity estimated - Time step of the output ET estimates (i.e. the value of argument <code>ts</code> ) - Units of the output ET estimates - Time duration of the ET estimation - Number of ET estimates obtained in the entire time-series - Basic statistics of the estimated ET time-series including <i>mean</i> , <i>max</i> and <i>min</i> values.
AdditionalStats	"yes" or "no" indicating whether monthly averaged and annual averaged ET should be calculated.
save.csv	Must be either <code>yes</code> or <code>no</code> , indicating whether a .csv of ET estimates should be saved to working directory.
...	Dummy for generic function, no need to define.

### Details

This formulation provides a single calculation method with no alternatives available.

**Value**

The function generates a list containing the following components:

ET.Daily	Daily aggregated estimations of McGuinness-Bordne potential evapotranspiration.
ET.Monthly	Monthly aggregated estimations of McGuinness-Bordne potential evapotranspiration.
ET.Annual	Annually aggregated estimations of McGuinness-Bordne potential evapotranspiration.
ET.MonthlyAve	Monthly averaged estimations of daily McGuinness-Bordne potential evapotranspiration.
ET.AnnualAve	Annually averaged estimations of daily McGuinness-Bordne potential evapotranspiration.
ET_formulation	Name of the formulation used which equals to McGuinness-Bordne.
ET_type	Type of the estimation obtained which is Potential Evapotranspiration.

**Author(s)**

Danlu Guo

**References**

Oudin, L., Hervieu, F., Michel, C., Perrin, C., Andreassian, V., Anctil, F., Loumagne, C. 2005, *Which potential evapotranspiration input for a lumped rainfall-runoff model?: Part 2-Towards a simple and efficient potential evapotranspiration model for rainfall-runoff modelling*. Journal of Hydrology, vol. 303, no. 1-4, pp. 290-306.

Xu, C.Y., Singh, V.P. 2000, *Evaluation and generalization of radiation-based methods for calculating evaporation*., Hydrological Processes, vol. 14, no. 2, pp. 339-349.

**See Also**

[ET,processeddata,defaultconstants,constants](#)

**Examples**

```
# Use processed existing data set and constants from kent Town, Adelaide
data("processeddata")
data("constants")

# Call ET.McGuinnessBordne under the generic function ET
results <- ET.McGuinnessBordne(processeddata, constants, ts="daily",
message="yes", AdditionalStats="yes", save.csv="no")
```

ET.MortonCRAE

*Morton CRAE Formulation***Description**

Implementing the Morton CRAE formulation for estimating potential evapotranspiration, wet-environment areal evapotranspiration and actual areal evapotranspiration.

**Usage**

```
## S3 method for class 'MortonCRAE'
ET(data, constants, ts="monthly", est="potential ET",
solar="sunshine hours", Tdew= T, alpha = NULL, message="yes", AdditionalStats="yes",
save.csv="no", ...)
```

**Arguments**

data	A list of data which contains the following items (climate variables) required by Morton CRAE formulation: <i>Tmax</i> , <i>Tmin</i> , <i>Tdew</i> (degree Celcius) or <i>va</i> or <i>RHmax</i> and <i>RHmin</i> , <i>Rs</i> (Megajoules per sqm) or <i>n</i> (hour) or <i>Cd</i> (okta)
constants	A list named constants consists of constants required for the calculation of Morton CRAE formulation which must contain the following items: <i>Elev</i> - ground elevation above mean sea level in m, <i>lat_rad</i> - latitude in radians, <i>PA</i> - annual precipitation in mm, required when precipitation data is not available, <i>sigma</i> - Stefan-Boltzmann constant = $4.903 \times 10^{-9}$ MJ.K <sup>-4</sup> .m <sup>-2</sup> .day <sup>-1</sup> , <i>lat</i> - latitude in degrees, <i>epsilonMo</i> - surface emissivity = 0.92 (Morton, 1986), <i>fz</i> - A constant in Morton's procedure = $28.0 \text{ Wm}^{-2} \cdot \text{mbar}^{-1}$ for $T \geq 0$ degree Celcius, and = $28.0 \times 1.15 \text{ Wm}^{-2} \cdot \text{mbar}^{-1}$ for $T < 0$ degree Celcius for CRAE model (Morton, 1983), <i>b0</i> - a constants in Morton's procedure, = 1 for CRAE model (Morton, 1983), <i>b1</i> - a constant in Morton's procedure, = 14 for CRAE model (Morton, 1983), <i>b2</i> - a constant in Morton's procedure, = 1.2 for CRAE model (Morton, 1983), <i>gammaps</i> - Produce of Psychrometric constant and atmospheric pressure as sea level, = $0.66 \text{ mbar} \cdot \text{degree Celcius}^{-1}$ for $T \geq 0$ degree Celcius, = $0.66/1.15 \text{ mbar} \cdot \text{degree Celcius}^{-1}$ for $T < 0$ degree Celcius (Morton, 1983),  <i>alphaMo</i> - a constant in Morton's procedure, = 17.27 when $T \geq 0$ degree Celcius, = 21.88 when $T < 0$ degree Celcius (Morton, 1983), <i>betaMo</i> - a constant in Morton's procedure, = 237.3 degree Celcius when $T \geq 0$ degree Celcius, = 265.5 degree Celcius, when $T < 0$ degree Celcius (Morton, 1983), <i>sigmaMo</i> - Stefan-Boltzmann constant in Morton's procedure, = $5.67 \times 10^{-8} \text{ W} \cdot \text{m}^{-2} \cdot \text{K}^{-4}$ (Morton, 1983),

*lambdaMo* - Latent heat of vaporisation in Morton's procedure, =  $28.5 \text{W.day.kg}^{-1}$  when  $T \geq 0$  degree Celcius, =  $28.5 * 1.15 \text{W.day.kg}^{-1}$  when  $T < 0$  degree Celcius,

ts	Must be either monthly or annual, which indicates the disired time step that the output ET estimates should be on. Default is monthly.
solar	Must be either data, sunshine hours, cloud or monthly precipitation: data indicates that solar radiation data is to be used directly for calculating evapotranspiration; sunshine hours indicates that solar radiation is to be calculated using the real data of sunshine hours; cloud sunshine hours is to be estimated from cloud data; monthly precipitation indicates that solar radiation is to be calculated directly from monthly precipitation. Default is sunshine hours.
est	Must be either potential ET, wet areal ET or actual areal ET: potential ET proceeds to estimating potential evapotranspiration; wet areal ET proceeds to estimating wet-environmental areal evapotranspiration; actual areal ET proceeds to estimating actual areal evapotranspiraion. Default is potential ET.
Tdew	Must be T or F, indicating if real data of dew point temperature is used for calculating the radiation in Morton's formulations, if T the data will be used and if F the dew point temperature will be calculated from data of daily vapour pressure. Default is T for using actual dew point temperature data.
alpha	Only needed if argument solar has value of data. Any numeric value between 0 and 1 (dimensionless), albedo of evaporative surface representing the portion of the incident radiation that is reflected back at the surface. Default is NULL in line with the default use of sunshine hours to estimate solar radiation (i.e. argument solar is sunshine hours).
message	Must be either yes or no, indicating whether message should be printed for calculation summary including the following elements: - ET model name and ET quantity estimated (i.e. the value of argument est) - Option for calculating solar radiation (i.e. the value of argument solar) - If the actual dew point temperature data are used (i.e. the value of argument Tdew) - Time step of the output ET estimates (i.e. the value of argument ts) - Units of the output ET estimates - Time duration of the ET estimation - Number of ET estimates obtained in the entire time-series - Basic statistics of the estimated ET time-series including <i>mean</i> , <i>max</i> and <i>min</i> values.
AdditionalStats	"yes" or "no" indicating whether monthly averaged and annual averaged ET should be calculated.

save.csv	Must be either yes or no, indicating whether a .csv of ET estimates should be saved to working directory.
...	Dummy for generic function, no need to define.

### Details

The type of evapotranspiration calculated can be selected through argument `est`, please see `Arguments` for details. The alternative calculation options can be selected through argument `solar` and `Tdew`, please see `Arguments` for details.

### Value

The function generates a list containing the following components:

ET.Daily	Daily aggregated estimations of Morton CRAE potential evapotranspiration, wet-environment areal evapotranspiration or actual areal evapotranspiration.
ET.Monthly	Monthly aggregated estimations of Morton CRAE potential evapotranspiration, wet-environment areal evapotranspiration or actual areal evapotranspiration.
ET.Annual	A zoo object containing annually aggregated estimations of Morton CRAE potential evapotranspiration, wet-environment areal evapotranspiration or actual areal evapotranspiration.
ET.MonthlyAve	A zoo object containing monthly averaged estimations of daily Morton CRAE potential evapotranspiration, wet-environment areal evapotranspiration or actual areal evapotranspiration.
ET.AnnualAve	A zoo object containing annually averaged estimations of daily Morton CRAE potential evapotranspiration, wet-environment areal evapotranspiration or actual areal evapotranspiration.
ET_formulation	Name of the formulation used which equals to MortonCRAE.
ET_type	Type of the estimation obtained which is either Potential Evapotranspiration, Wet-environment Areal Evapotranspiration and Actual Areal Evapotranspiration.
message1	A message to inform the users about how solar radiation has been calculated by using which data.
message6	A message to inform the users about if actual dew point temperature has been used in the calculations or alternative calculations has been performed without dew point temperature data.

### Author(s)

Danlu Guo

### References

- McMahon, T., Peel, M., Lowe, L., Srikanthan, R. & McVicar, T. 2012. *Estimating actual, potential, reference crop and pan evaporation using standard meteorological data: a pragmatic synthesis*. Hydrology and Earth System Sciences Discussions, 9, 11829-11910.
- Morton, F.I. 1983, *Operational estimates of areal evapotranspiration and their significance to the science and practice of hydrology*. Journal of Hydrology, vol. 66, no. 1-4, pp. 1-76.

**See Also**

[processeddata](#), [defaultconstants](#), [constants](#), [ET.MortonCRWE](#)

**Examples**

```
# Use processed existing data set and constants from
# kent Town, Adelaide
data("processeddata")
data("constants")

# Call ET.MortonCRAE under the generic function ET
results <- ET.MortonCRAE(processeddata, constants, ts="monthly",
est="potential ET", solar="sunshine hours", Tdew= TRUE,
alpha = NULL, message="yes", AdditionalStats="yes", save.csv="no")
```

---

ET.MortonCRWE

*Morton CRWE Formulation*


---

**Description**

Implementing the Morton CRWE formulation for estimating potential evapotranspiration or shallow lake evaporation.

**Usage**

```
## S3 method for class 'MortonCRWE'
ET(data, constants, ts="monthly", est="potential ET",
solar="sunshine hours", Tdew= T, alpha = NULL, message="yes", AdditionalStats="yes",
save.csv="no", ...)
```

**Arguments**

data	A list of data which contains the following items (climate variables) required by Morton CRWE formulation: <i>Tmax</i> , <i>Tmin</i> , <i>Tdew</i> (degree Celcius) or <i>va</i> or <i>RHmax</i> and <i>RHmin</i> , <i>Rs</i> (Megajoules per sqm) or <i>n</i> (hour) or <i>Cd</i> (okta)
constants	A list named constants consists of constants required for the calculation of Morton CRWE formulation which must contain the following items: <i>Elev</i> - ground elevation above mean sea level in m, <i>lat_rad</i> - latitude in radians, <i>PA</i> - annual precipitation in mm, required when precipitation data is not available, <i>sigma</i> - Stefan-Boltzmann constant = $4.903 \times 10^{-9} \text{ MJ.K}^{-4} \cdot \text{m}^{-2} \cdot \text{day}^{-1}$ , <i>lat</i> - latitude in degrees, <i>epsilonMo</i> - surface emissivity = 0.92 (Morton, 1986), <i>fz</i> - A constant in Morton's procedure = $25.0 \text{ Wm}^{-2} \cdot \text{mbar}^{-1}$ for $T \geq 0$ degree Celcius, and = $28.75 \text{ Wm}^{-2} \cdot \text{mbar}^{-1}$ for $T > 0$ degree Celcius for CRWE

model (Morton, 1986),

*b0* - A constants in Morton's procedure, = 1.12 for CRWE model, (Morton, 1986) *b1* - A constant in Morton's procedure, = 13 for CRWE model (Morton, 1986),

*b2* - A constant in Morton's procedure, = 1.12 for CRWE model (Morton, 1986),  
*gamma* - Produce of Psychrometric constant and atmospheric pressure as sea level, = 0.66 mbar. degree Celcius<sup>-1</sup> for T >= 0 degree Celcius, = 0.66/1.15 mbar. degree Celcius<sup>-1</sup> for T < 0 degree Celcius (Morton, 1983),

*alphaMo* - a constant in Morton's procedure, = 17.27 when T >= 0 degree Celcius, = 21.88 when T < 0 degree Celcius (Morton, 1983),

*betaMo* - a constant in Morton's procedure, = 237.3 degree Celcius when T >= 0 degree Celcius, = 265.5 degree Celcius, when T < 0 degree Celcius (Morton, 1983),

*sigmaMo* - Stefan-Boltzmann constant in Morton's procedure, = 5.67e-08 W.m<sup>-2</sup>.K<sup>-4</sup> (Morton, 1983),

*lambdaMo* - Latent heat of vaporisation in Morton's procedure, = 28.5W.day.kg<sup>-1</sup> when T >= 0 degree Celcius, = 28.5\*1.15W.day.kg<sup>-1</sup> when T < 0 degree Celcius,

ts	Must be either monthly or annual, which indicates the disired time step that the output ET estimates should be on. Default is monthly.
solar	Must be either data, sunshine hours, cloud or monthly precipitation: data indicates that solar radiation data is to be used directly for calculating evapotranspiration; sunshine hours indicates that solar radiation is to be calculated using the real data of sunshine hours; cloud sunshine hours is to be estimated from cloud data; monthly precipitation indicates that solar radiation is to be calculated directly from monthly precipitation. Default is sunshine hours.
est	Must be either potential ET or shallow lake ET: potential ET proceeds to estimating potential evapotranspiration; shallow lake ET proceeds to estimating shallow lake evaporation. Default is potential ET.
Tdew	Must be T or F, indicating if real data of dew point temperature is used for calculating the radiation in Morton's formulations, if T the data will be used and if F the dew point temperature will be calculated from data of daily vapour pressure. Default is T for using actual dew point temperature data.
alpha	Only needed if argument solar has value of data. Any numeric value between 0 and 1 (dimensionless), albedo of evaporative surface representing the portion of the incident radiation that is reflected back at the surface. Default is NULL in line with the default use of sunshine hours to estimate solar radiation (i.e. argument solar is sunshine hours).
message	Must be either yes or no, indicating whether message should be printed for calculation summary including the following elements:



- ET model name and ET quantity estimated (i.e. the value of argument `est`)
- Option for calculating solar radiation (i.e. the value of argument `solar`)
- If the actual dew point temperature data are used (i.e. the value of argument `Tdew`)
- Time step of the output ET estimates (i.e. the value of argument `ts`)
- Units of the output ET estimates
- Time duration of the ET estimation
- Number of ET estimates obtained in the entire time-series
- Basic statistics of the estimated ET time-series including *mean*, *max* and *min* values.

<code>AdditionalStats</code>	"yes" or "no" indicating whether monthly averaged and annual averaged ET should be calculated.
<code>save.csv</code>	Must be either yes or no, indicating whether a .csv of ET estimates should be saved to working directory.
<code>...</code>	Dummy for generic function, no need to define.

### Details

The type of evapotranspiration calculated can be selected through argument `est`, please see `Arguments` for details. The alternative calculation options can be selected through argument `solar` and `Tdew`, please see `Arguments` for details.

### Value

The function generates a list containing the following components:

<code>ET.Daily</code>	Daily aggregated estimations of MortonCRWE potential evapotranspiration or shallow lake evaporation.
<code>ET.Monthly</code>	Monthly aggregated estimations of MortonCRWE potential evapotranspiration or shallow lake evaporation.
<code>ET.Annual</code>	Annually aggregated estimations of MortonCRWE potential evapotranspiration or shallow lake evaporation.
<code>ET.MonthlyAve</code>	Monthly averaged estimations of daily MortonCRWE potential evapotranspiration or shallow lake evaporation.
<code>ET.AnnualAve</code>	Annually averaged estimations of daily MortonCRWE potential evapotranspiration or shallow lake evaporation.
<code>ET_formulation</code>	Name of the formulation used which equals to MortonCRWE.
<code>ET_type</code>	Type of the estimation obtained which is either Potential Evapotranspiration or Shallow Lake Evaporation.
<code>message1</code>	A message to inform the users about how solar radiation has been calculated by using which data.
<code>message6</code>	A message to inform the users about if actual dew point temperature has been used in the calculations or alternative calculations has been performed without dew point temperature data.

**Author(s)**

Danlu Guo

**References**

McMahon, T., Peel, M., Lowe, L., Srikanthan, R. & McVicar, T. 2012. *Estimating actual, potential, reference crop and pan evaporation using standard meteorological data: a pragmatic synthesis*. Hydrology and Earth System Sciences Discussions, 9, 11829-11910.

Morton, F.I. 1983, *Operational estimates of lake evaporation*. Journal of Hydrology, vol. 66, no. 1-4, pp. 77-100.

**See Also**

[processeddata,defaultconstants,constants,ET.MortonCRWE](#)

**Examples**

```
# Use processed existing data set and constants from
# kent Town, Adelaide
data("processeddata")
data("constants")

# Call ET.MortonCRWE under the generic function ET
results <- ET.MortonCRWE(processeddata, constants, ts="monthly",
est="potential ET", solar="sunshine hours", Tdew= TRUE,
alpha = NULL, message="yes", AdditionalStats="yes", save.csv="no")
```

---

ET.Penman

*Penman Formulation*

---

**Description**

Implementing the Penman formulation for estimating open-water evaporation or potential evapotranspiration

**Usage**

```
## S3 method for class 'Penman'
ET(data, constants, ts="daily", solar="sunshine hours",
wind="yes", windfunction_ver=1948, alpha=0.08, z0=0.001, message="yes",
AdditionalStats="yes", save.csv="no", ...)
```

**Arguments**

data	A list which contains the following items (climate variables) required by Penman formulation: <i>Tmax, Tmin, RHmax, RHmin, Rs</i> or <i>n</i> or <i>Cd, u2</i> or <i>uz</i>
constants	A list named constants consists of constants required for the calculation of Penman formulation which must contain the following items: <i>Elev</i> - ground elevation above mean sea level in m, <i>lambda</i> - latent heat of vaporisation = 2.45 MJ.kg <sup>-1</sup> , <i>lat_rad</i> - latitude in radians, <i>Gsc</i> - solar constant = 0.0820 MJ.m <sup>-2</sup> .min <sup>-1</sup> , <i>z</i> - height of wind instrument in m, <i>sigma</i> - Stefan-Boltzmann constant = 4.903*10 <sup>-9</sup> MJ.K <sup>-4</sup> .m <sup>-2</sup> .day <sup>-1</sup> .  The following constants are also required when argument solar has value of sunshine hours: <i>as</i> - only for when cloud data is used for calculating radiation i.e. solar = "cloud" - fraction of extraterrestrial radiation reaching earth on sunless days, <i>bs</i> - only for when cloud data is used for calculating radiation i.e. solar = "cloud" - difference between fraction of extraterrestrial radiation reaching full-sun days and that on sunless days.
ts	Must be either <i>daily</i> , <i>monthly</i> or <i>annual</i> , which indicates the desired time step that the output ET estimates should be on. Default is <i>daily</i> .
solar	Must be either <i>data</i> , <i>sunshine hours</i> , <i>cloud</i> or <i>monthly precipitation</i> : <i>data</i> indicates that solar radiation data is to be used directly for calculating evapotranspiration; <i>sunshine hours</i> indicates that solar radiation is to be calculated using the real data of sunshine hours; <i>cloud</i> sunshine hours is to be estimated from cloud data; <i>monthly precipitation</i> indicates that solar radiation is to be calculated directly from monthly precipitation. Default is <i>sunshine hours</i> .
wind	Must be either <i>yes</i> or <i>no</i> . <i>yes</i> indicates that the calculation will use real data of wind speed; <i>no</i> indicates that the alternative calculation without using wind data will be used in Penman formulation (Valiantzas 2006, Equation33). Default is <i>yes</i> .
windfunction_ver	The version of Penman wind function that will be used within the Penman formulation. Must be either 1948 or 1956. 1948 is for applying the Penman's 1948 wind function (Penman, 1948); 1956 is for applying the Penman's 1956 wind function (Penman, 1956) Default is 1948.
alpha	Any numeric value between 0 and 1 (dimensionless), albedo of evaporative surface representing the portion of the incident radiation that is reflected back at the surface. Default is 0.08 for open-water surface which is for the calculation of Penman

	open-water evaporation, all other values will trigger the calculation of Penman potential evapotranspiration.
<code>z0</code>	Any value (metres), roughness height of the evaporative surface. Default is 0.001 for open-water surface which is for the calculation of Penman open-water evaporation, all other values will trigger the calculation of Penman potential evapotranspiration.
<code>message</code>	Must be either <code>yes</code> or <code>no</code> , indicating whether message should be printed for calculation summary including the following elements: <ul style="list-style-type: none"> <li>- ET model name and ET quantity estimated</li> <li>- Evaporative surface with values of albedo and roughness height</li> <li>- Option for calculating solar radiation (i.e. the value of argument <code>solar</code>)</li> <li>- If actual wind data has been used for calculation (i.e. the value of argument <code>wind</code>) and which version of Penman wind function has been used (i.e. the value of argument <code>windfunction_ver</code>)</li> <li>- Time step of the output ET estimates (i.e. the value of argument <code>ts</code>)</li> <li>- Units of the output ET estimates</li> <li>- Time duration of the ET estimation</li> <li>- Number of ET estimates obtained in the entire time-series</li> <li>- Basic statistics of the estimated ET time-series including <i>mean</i>, <i>max</i> and <i>min</i> values</li> </ul>
<code>AdditionalStats</code>	"yes" or "no" indicating whether monthly averaged and annual averaged ET should be calculated.
<code>save.csv</code>	Must be either <code>yes</code> or <code>no</code> , indicating whether a .csv of ET estimates should be saved to working directory.
<code>...</code>	Dummy for generic function, no need to define.

### Details

The alternative calculation options can be selected through arguments `solar`, `wind` and `windfunction_ver`, please see `Arguments` for details.

User-defined evaporative surface is allowed through arguments `alpha` and `z0`, please see `Arguments` for details.

### Value

The function generates a list containing the following components:

<code>ET.Daily</code>	Daily aggregated estimations of Penman open-water evaporation or potential evapotranspiration.
<code>ET.Monthly</code>	Monthly aggregated estimations of Penman open-water evaporation or potential evapotranspiration.
<code>ET.Annual</code>	Annually aggregated estimations of Penman open-water evaporation or potential evapotranspiration.
<code>ET.MonthlyAve</code>	Monthly averaged estimations of daily Penman open-water evaporation or potential evapotranspiration.

ET.AnnualAve	Annually averaged estimations of daily Penman open-water evaporation or potential evapotranspiration.
ET_formulation	Name of the formulation used which equals to Penman.
ET_type	Type of the estimation obtained which is either Open-water Evaporation or Potential Evapotranspiration.
message1	A message to inform the users about how solar radiation has been calculated by using which data.
message2	A message to inform the users about if actual wind data has been used in the calculations or alternative calculations has been performed without wind data, and which version of the Penman wind function has been used.

### Author(s)

Danlu Guo

### References

- McMahon, T., Peel, M., Lowe, L., Srikanthan, R. & McVicar, T. 2012. *Estimating actual, potential, reference crop and pan evaporation using standard meteorological data: a pragmatic synthesis*. Hydrology and Earth System Sciences Discussions, 9, 11829-11910.
- Penman, H. L. 1948. *Natural evaporation from open water, bare soil and grass*. Proceedings of the Royal Society of London. Series A. Mathematical and Physical Sciences, 193, 120-145.
- Valiantzas, J. D. 2006. *Simplified versions for the Penman evaporation equation using routine weather data*. Journal of Hydrology, 331, 690-702.
- Penman, H. L. 1956. *Evaporation: An introductory survey*. Netherlands Journal of Agricultural Science, 4, 9-29.

### See Also

[ET,processeddata,defaultconstants,constants](#)

### Examples

```
# Use processed existing data set and constants from
# kent Town, Adelaide
data("processeddata")
data("constants")

# Call ET.Penman under the generic function ET
results <- ET.Penman(processeddata, constants, ts="daily",
solar="sunshine hours", wind="yes",
windfunction_ver = "1948", alpha = 0.08, z0 = 0.001,
message="yes", AdditionalStats="yes", save.csv="no")
```

---

 ET.PenmanMonteith      *Penman-Monteith Formulation*


---

### Description

Implementing the Penman-Monteith formulation (including the method for FAO-56 hypothetical short grass and the method for ASCE-EWRI Standardised crop) for estimating reference crop evapotranspiration

### Usage

```
## S3 method for class 'PenmanMonteith'
ET(data, constants, ts="daily", solar="sunshine hours",
wind="yes", crop="short", message="yes", AdditionalStats="yes", save.csv="no", ...)
```

### Arguments

data	A list which contains the following items (climate variables) required by Penman-Monteith formulation: <i>Tmax, Tmin, RHmax, RHmin, Rs</i> or <i>n</i> or <i>Cd, u2</i> or <i>uz</i>
constants	A list named constants consists of constants required for the calculation of Penman-Monteith formulation which must contain the following items: <i>Elev</i> - ground elevation above mean sea level in m, <i>lambda</i> - latent heat of vaporisation = 2.45 MJ.kg <sup>-1</sup> , <i>lat_rad</i> - latitude in radians, <i>Gsc</i> - solar constant = 0.0820 MJ.m <sup>-2</sup> .min <sup>-1</sup> , <i>z</i> - height of wind instrument in m, <i>sigma</i> - Stefan-Boltzmann constant = 4.903*10 <sup>-9</sup> MJ.K <sup>-4</sup> .m <sup>-2</sup> .day <sup>-1</sup> . <i>G</i> - soil heat flux in MJ.m <sup>-2</sup> .day <sup>-1</sup> , = 0 when using daily time step. The following constants are also required when argument solar has value of sunshine hours: <i>as</i> - only for when cloud data is used for calculating radiation i.e. solar = "cloud" - fraction of extraterrestrial radiation reaching earth on sunless days, <i>bs</i> - only for when cloud data is used for calculating radiation i.e. solar = "cloud" - difference between fraction of extraterrestrial radiation reaching full-sun days and that on sunless days.
ts	Must be either <i>daily</i> , <i>monthly</i> or <i>annual</i> , which indicates the disired time step that the output ET estimates should be on. Default is <i>daily</i> .
solar	Must be either <i>data</i> , <i>sunshine hours</i> , <i>cloud</i> or <i>monthly precipitation</i> : <i>data</i> indicates that solar radiation data is to be used directly for calculating evapotranspiration; <i>sunshine hours</i> indicates that solar radiation is to be calculated using the real data of sunshine hours; <i>cloud</i> sunshine hours is to be estimated from cloud data; <i>monthly precipitation</i> indicates that solar radiation is to be calculated directly from monthly precipitation. Default is <i>sunshine hours</i> .

wind	Must be either yes or no. yes indicates that the calculation will use real data of wind speed; no indicates that the alternative calculation without using wind data will be used in Penman formulation (Valiantzas 2006, Equation33). Default is yes.
crop	Must be either short or tall. short indicates that the method for FAO-56 hypothetical short grass will be applied (Allen et al., 1998, Equation 6); tall indicates that the method for ASCE-EWRI Standardised crop will be applied (ASCE, 2005, Equation 1, Table 1). Default is short.
message	Must be either yes or no, indicating whether message should be printed for calculation summary including the following elements: <ul style="list-style-type: none"> <li>- ET model name and ET quantity estimated</li> <li>- Evaporative surface with values of albedo, surface resistance, crop height and roughness height</li> <li>- Option for calculating solar radiation (i.e. the value of argument solar)</li> <li>- If actual wind data has been used for calculation (i.e. the value of argument wind)</li> <li>- Time step of the output ET estimates (i.e. the value of argument ts)</li> <li>- Units of the output ET estimates</li> <li>- Time duration of the ET estimation</li> <li>- Number of ET estimates obtained in the entire time-series</li> <li>- Basic statistics of the estimated ET time-series including <i>mean</i>, <i>max</i> and <i>min</i> values.</li> </ul>
AdditionalStats	"yes" or "no" indicating whether monthly averaged and annual averaged ET should be calculated.
save.csv	Must be either yes or no, indicating whether a .csv of ET estimates should be saved to working directory.
...	Dummy for generic function, no need to define.

### Details

The alternative calculation options can be selected through arguments solar and wind, please see Arguments for details.

User-defined evaporative surface is allowed through arguments crop, please see Arguments for details.

### Value

The function generates a list containing the following components:

ET.Daily	Daily aggregated estimations of Penman-Monteith reference crop evapotranspiration.
ET.Monthly	Monthly aggregated estimations of Penman-Monteith reference crop evapotranspiration.

ET.Annual	Annually aggregated estimations of Penman-Monteith reference crop evapotranspiration.
ET.MonthlyAve	Monthly averaged estimations of daily Penman-Monteith reference crop evapotranspiration.
ET.AnnualAve	Annually averaged estimations of daily Penman-Monteith reference crop evapotranspiration.
ET_formulation	Name of the formulation used which equals to either Penman-Monteith FA056 or Penman-Monteith ASCE-EWRI Standardised.
ET_type	A character string containing the type of the estimation obtained which is Reference Crop Evapotranspiration.
message1	A message to inform the users about how solar radiation has been calculated by using which data.
message2	A message to inform the users about if actual wind data has been used in the calculations or alternative calculations has been performed without wind data.

**Author(s)**

Danlu Guo

**References**

McMahon, T., Peel, M., Lowe, L., Srikanthan, R. & McVicar, T. 2012. *Estimating actual, potential, reference crop and pan evaporation using standard meteorological data: a pragmatic synthesis*. Hydrology and Earth System Sciences Discussions, 9, 11829-11910.

Allen, R. G., Pereira, L. S., Raes, D. & Smith, M. 1998. *Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage*. paper 56. FAO, Rome, 300, 6541.

Allen, R. G. 2005. *The ASCE standardized reference evapotranspiration equation*. Amer Society of Civil Engineers.

**See Also**

[ET,processeddata,defaultconstants,constants](#)

**Examples**

```
# Use processed existing data set and constants from kent Town, Adelaide
data("processeddata")
data("constants")

# Call ET.PenmanMonteith under the generic function ET
results <- ET.PenmanMonteith(processeddata, constants, ts="daily", solar="sunshine hours",
wind="yes", crop = "short", message="yes", AdditionalStats="yes", save.csv="no")
```



ET.PenPan

*PenPan Formulation***Description**

Implementing the PenPan formulation for Class-A pan evaporation.

**Usage**

```
## S3 method for class 'PenPan'
ET(data, constants, ts="daily", solar="sunshine hours",
  alpha=0.23, est="potential ET", pan_coeff=0.71, overest= F, message="yes",
  AdditionalStats="yes", save.csv="no", ...)
```

**Arguments**

- |           |  |
|-----------|--|
| data      | A list of data which contains the following items (climate variables) required by PenPan formulation:<br><i>Tmax</i> , <i>Tmin</i> (degree Celcius), <i>RHmax</i> , <i>RHmin</i> (per cent), <i>Rs</i> (Megajoules per sqm) or <i>n</i> (hour) or <i>Cd</i> (okta), <i>u2</i> or <i>uz</i> (meter per second)  |
| constants | A list named constants consists of constants required for the calculation of PenPan formulation which must contain the following items:<br><i>Elev</i> - ground elevation above mean sea level in m,<br><i>lambda</i> - latent heat of vaporisation = 2.45 MJ.kg <sup>-1</sup> ,<br><i>lat_rad</i> - latitude in radians,<br><i>Gsc</i> - solar constant = 0.0820 MJ.m <sup>-2</sup> .min <sup>-1</sup> ,<br><i>z</i> - height of wind instrument in m,<br><i>sigma</i> - Stefan-Boltzmann constant = 4.903*10 <sup>-9</sup> MJ.K <sup>-4</sup> .m <sup>-2</sup> .day <sup>-1</sup> ,<br><i>lat</i> - latitude in degrees,<br><i>alphaA</i> - albedo for Class-A pan,<br><i>ap</i> - a constant in PenPan = 2.4. |
|           | The following constants are also required when argument solar has value of sunshine hours:<br><i>as</i> - fraction of extraterrestrial radiation reaching earth on sunless days,<br><i>bs</i> - difference between fracion of extraterrestrial radiation reaching full-sun days and that on sunless days.  |
| ts        | Must be either <i>daily</i> , <i>monthly</i> or <i>annual</i> , which indicates the disired time step that the output ET estimates should be on. Default is <i>daily</i> .   |
| solar     | Must be either <i>data</i> , <i>sunshine hours</i> , <i>cloud</i> or <i>monthly precipitation</i> :<br><i>data</i> indicates that solar radiation data is to be used directly for calculating evapotranspiration;<br><i>sunshine hours</i> indicates that solar radiation is to be calculated using the real data of sunshine hours;<br><i>cloud sunshine hours</i> is to be estimated from cloud data;  |

	monthly precipitation indicates that solar radiation is to be calculated directly from monthly precipitation. Default is sunshine hours.
alpha	Any numeric value between 0 and 1 (dimensionless), albedo of surface surrounding the evaporation pan representing the portion of the incident radiation that is reflected back at the surface. Default is 0.23 for surface covered with short reference crop.
overest	Must be T or F, indicating if adjustment for the overestimation (i.e. divided by 1.078) of Class-A pan evaporation for Australian data is applied in PenPan formulation. Default is F for no adjustment.
est	Must be either pan or potential ET to specify if estimation for the Class-A pan evaporation or potential evapotranspiration is performed. Default is potential ET for estimating potential evapotranspiration.
pan_coeff	Only required if argument est has value of potential ET, which defines the pan coefficient used to adjust the estimated pan evaporation to the potential ET required.
message	Must be either yes or no, indicating whether message should be printed for calculation summary including the following elements: <ul style="list-style-type: none"> <li>- ET model name and ET quantity estimated (i.e. the value of argument est), and the value of pan coefficient (only for when potential ET is estimated)</li> <li>- Evaporative surface with values of albedo</li> <li>- Option for calculating solar radiation (i.e. the value of argument solar)</li> <li>- Time step of the output ET estimates (i.e. the value of argument ts)</li> <li>- Units of the output ET estimates</li> <li>- Time duration of the ET estimation</li> <li>- Number of ET estimates obtained in the entire time-series</li> <li>- Basic statistics of the estimated ET time-series including <i>mean</i>, <i>max</i> and <i>min</i> values.</li> </ul>
AdditionalStats	"yes" or "no" indicating whether monthly averaged and annual averaged ET should be calculated.
save.csv	Must be either yes or no, indicating whether a .csv of ET estimates should be saved to working directory.
...	Dummy for generic function, no need to define.

## Details

The alternative calculation options can be selected through argument `solar`, please see Arguments for details.

User-defined evaporative surface is allowed through argument `alpha`, please see Arguments for details.

Adjustment for overestimation on the estimations are available through argument `height`, please see Arguments for details.

**Value**

The function generates a list containing the following components:

ET.Daily	Daily aggregated estimations of PenPan Class-A pan evaporation/potential evapotranspiration.
ET.Monthly	Monthly aggregated estimations of PenPan Class-A pan evaporation/potential evapotranspiration.
ET.Annual	Annually aggregated estimations of PenPan Class-A pan evaporation/potential evapotranspiration.
ET.MonthlyAve	Monthly averaged estimations of daily PenPan Class-A pan evaporation/potential evapotranspiration.
ET.AnnualAve	Annually averaged estimations of daily PenPan Class-A pan evaporation/potential evapotranspiration.
ET_formulation	Name of the formulation used which equals to PenPan.
ET_type	Type of the estimation obtained which is Class-A Pan Evaporation or Potential Evapotranspiration depending on the value of est.
message1	A message to inform the users about how solar radiation has been calculated by using which data.

**Author(s)**

Danlu Guo

**References**

McMahon, T., Peel, M., Lowe, L., Srikanthan, R. & McVicar, T. 2012. *Estimating actual, potential, reference crop and pan evaporation using standard meteorological data: a pragmatic synthesis*. Hydrology and Earth System Sciences Discussions, 9, 11829-11910.

Rotstayn, L. D., Roderick, M. L. & Farquhar, G. D. 2006. *A simple pan-evaporation model for analysis of climate simulations: Evaluation over Australia*. Geophysical Research Letters, 33.

**See Also**

[ET,processeddata,defaultconstants,constants](#)

**Examples**

```
# Use processed existing data set and constants from
# kent Town, Adelaide
data("processeddata")
data("constants")

# Call ET.PenPan under the generic function ET
results <- ET.PenPan(processeddata, constants, ts="daily",
solar="sunshine hours", alpha=0.23,
est="potential ET", pan_coeff=0.71, overest= FALSE,
message="yes", AdditionalStats="yes", save.csv="no")
```

---

 ET.PriestleyTaylor      *Priestley-Taylor Formulation*


---

### Description

Implementing the Priestley-Taylor formulation for potential evaporation

### Usage

```
## S3 method for class 'PriestleyTaylor'
ET(data, constants, ts="daily", solar="sunshine hours", alpha=0.23,
message="yes", AdditionalStats="yes", save.csv="no", ...)
```

### Arguments

data	A list which contains the following items (climate variables) required by Priestley-Taylor formulation: <i>Tmax</i> , <i>Tmin</i> (degree Celcius), <i>RHmax</i> , <i>RHmin</i> (per cent), <i>Rs</i> (Megajoules per sqm) or <i>n</i> (hour) or <i>Cd</i> (okta)
constants	A list named constants consists of constants required for the calculation of Priestley-Taylor formulation which must contain the following items: <i>Elev</i> - ground elevation above mean sea level in m, <i>lambda</i> - latent heat of vaporisation = 2.45 MJ.kg <sup>-1</sup> , <i>lat_rad</i> - latitude in radians, <i>Gsc</i> - solar constant = 0.0820 MJ.m <sup>-2</sup> .min <sup>-1</sup> , <i>sigma</i> - Stefan-Boltzmann constant = 4.903*10 <sup>-9</sup> MJ.K <sup>-4</sup> .m <sup>-2</sup> .day <sup>-1</sup> , <i>alphaPT</i> - Priestley-Taylor coefficient = 1.26 for Priestley-Taylor model (Priestley and Taylor, 1972) <i>G</i> - soil heat flux in MJ.m <sup>-2</sup> .day <sup>-1</sup> , = 0 when using daily time step.  The following constants are also required when argument solar has value of sunshine hours: <i>as</i> - fraction of extraterrestrial radiation reaching earth on sunless days, <i>bs</i> - difference between fracion of extraterrestrial radiation reaching full-sun days and that on sunless days.
ts	Must be either <i>daily</i> , <i>monthly</i> or <i>annual</i> , which indicates the disired time step that the output ET estimates should be on. Default is <i>daily</i> .
solar	Must be either <i>data</i> , <i>sunshine hours</i> , <i>cloud</i> or <i>monthly precipitation</i> : <i>data</i> indicates that solar radiation data is to be used directly for calculating evapotranspiration; <i>sunshine hours</i> indicates that solar radiation is to be calculated using the real data of sunshine hours; <i>cloud</i> sunshine hours is to be estimated from cloud data; <i>monthly precipitation</i> indicates that solar radiation is to be calculated directly from monthly precipitation. Default is sunshine hours.

alpha	Any numeric value between 0 and 1 (dimensionless), albedo of evaporative surface representing the portion of the incident radiation that is reflected back at the surface. Default is 0.23 for surface covered with short reference crop, which is for the calculation of Priestly-Taylor reference crop evaporation.
message	Must be either yes or no, indicating whether message should be printed for calculation summary including the following elements: <ul style="list-style-type: none"> <li>- ET model name and ET quantity estimated</li> <li>- Evaporative surface with values of albedo</li> <li>- Option for calculating solar radiation (i.e. the value of argument solar)</li> <li>- Time step of the output ET estimates (i.e. the value of argument ts)</li> <li>- Units of the output ET estimates</li> <li>- Time duration of the ET estimation</li> <li>- Number of ET estimates obtained in the entire time-series</li> <li>- Basic statistics of the estimated ET time-series including <i>mean</i>, <i>max</i> and <i>min</i> values.</li> </ul>
AdditionalStats	"yes" or "no" indicating whether monthly averaged and annual averaged ET should be calculated.
save.csv	Must be either yes or no, indicating whether a .csv of ET estimates should be saved to working directory.
...	Dummy for generic function, no need to define.

### Details

The alternative calculation options can be selected through argument solar, please see Arguments for details.

User-defined evaporative surface is allowed through argument alpha, please see Arguments for details.

### Value

The function generates a list containing the following components, which is saved into a csv file named as *ET\_PriestleyTaylor.csv* in the working directory:

ET.Daily	Daily aggregated estimations of Priestley-Taylor potential evaporation.
ET.Monthly	Monthly aggregated estimations of Priestley-Taylor potential evaporation.
ET.Annual	Annually aggregated estimations of Priestley-Taylor potential evaporation.
ET.MonthlyAve	Monthly averaged estimations of daily Priestley-Taylor potential evaporation.
ET.AnnualAve	Annually averaged estimations of daily Priestley-Taylor potential evaporation.
ET_formulation	A character string containing the name of the formulation used which equals to Priestley-Taylor.
ET_type	Type of the estimation obtained which is Potential Evaporation.
message1	A message to inform the users about how solar radiation has been calculated by using which data.

**Author(s)**

Danlu Guo

**References**

McMahon, T., Peel, M., Lowe, L., Srikanthan, R. & McVicar, T. 2012. *Estimating actual, potential, reference crop and pan evaporation using standard meteorological data: a pragmatic synthesis*. Hydrology and Earth System Sciences Discussions, 9, 11829-11910.

Priestley, C. & Taylor, R. 1972, *On the assessment of surface heat flux and evaporation using large-scale parameters*. Monthly Weather Review, vol. 100, no. 2, pp. 81-92.

**See Also**

[ET,processeddata,defaultconstants,constants](#)

**Examples**

```
# Use processed existing data set and constants from kent Town, Adelaide
data("processeddata")
data("constants")

# Call ET.PriestleyTaylor under the generic function ET
results <- ET.PriestleyTaylor(processeddata, constants, ts="daily",
solar="sunshine hours", alpha=0.23, message="yes", AdditionalStats="yes", save.csv="no")
```

---

ET.Romanenko

*Romanenko Formulation*


---

**Description**

Implementing the Romanenko formulation for estimating potential evapotranspiration.

**Usage**

```
## S3 method for class 'Romanenko'
ET(data, constants = NULL, ts="daily",
message="yes", AdditionalStats="yes", save.csv="no", ...)
```

**Arguments**

data	A list of data which contains the following items (climate variables) required by Romanenko formulation: <i>Tmax</i> , <i>Tmin</i> (degree Celcius), <i>RHmax</i> , <i>RHmin</i> (per cent)
constants	Dummy argument with a NULL value.
ts	Must be either <i>daily</i> , <i>monthly</i> or <i>annual</i> , which indicates the disired time step that the output ET estimates should be on. Default is <i>daily</i> .

message	Must be either yes or no, indicating whether message should be printed for calculation summary including the following elements: - ET model name and ET quantity estimated - Time step of the output ET estimates (i.e. the value of argument ts) - Units of the output ET estimates - Time duration of the ET estimation - Number of ET estimates obtained in the entire time-series - Basic statistics of the estimated ET time-series including <i>mean</i> , <i>max</i> and <i>min</i> values.
AdditionalStats	"yes" or "no" indicating whether monthly averaged and annual averaged ET should be calculated.
save.csv	Must be either yes or no, indicating whether a .csv of ET estimates should be saved to working directory.
...	Dummy for generic function, no need to define.

### Details

This formulation provides a single calculation method with no alternatives available.

### Value

The function generates a list containing the following components:

ET.Daily	Daily aggregated estimations of Romanenko potential evapotranspiration.
ET.Monthly	Monthly aggregated estimations of Romanenko potential evapotranspiration.
ET.Annual	Annually aggregated estimations of Romanenko potential evapotranspiration.
ET.MonthlyAve	Monthly averaged estimations of daily Romanenko potential evapotranspiration.
ET.AnnualAve	Annually averaged estimations of daily Romanenko potential evapotranspiration.
ET_formulation	Name of the formulation used which equals to Romanenko.
ET_type	Type of the estimation obtained which is Potential Evapotranspiration.

### Author(s)

Danlu Guo

### References

Oudin, L., Hervieu, F., Michel, C., Perrin, C., Andreassian, V., Anctil, F., Loumagne, C. 2005, *Which potential evapotranspiration input for a lumped rainfall-runoff model?: Part 2-Towards a simple and efficient potential evapotranspiration model for rainfall-runoff modelling*. Journal of Hydrology, vol. 303, no. 1-4, pp. 290-306.

### See Also

[ET,processeddata](#)

## Examples

```
# Use processed existing data set and constants from kent Town, Adelaide
data("processeddata")
data("constants")

# Call ET.Romanenko under the generic function ET
results <- ET.Romanenko(processeddata, ts="daily", message="yes",
AdditionalStats="yes", save.csv="no")
```

---

ET.Szilagyijozsa      *Szilagyijozsa Formulation*

---

## Description

Implementing the Szilagyijozsa formulation for estimating actual evapotranspiration

## Usage

```
## S3 method for class 'Szilagyijozsa'
ET(data, constants, ts="daily", solar="sunshine hours", wind="yes",
windfunction_ver=1948, alpha=0.23, z0=0.2, message="yes", AdditionalStats="yes",
save.csv="no", ...)
```

## Arguments

data	A list of data which contains the following items (climate variables) required by Szilagyijozsa formulation: <i>Tmax</i> , <i>Tmin</i> (degree Celcius), <i>RHmax</i> , <i>RHmin</i> (per cent), <i>Rs</i> (Megajoules per sqm) or <i>n</i> (hour) or <i>Cd</i> (okta), <i>u2</i> or <i>uz</i> (meter per second)
constants	A list named constants consists of constants required for the calculation of Szilagyijozsa formulation which must contain the following items: <i>Elev</i> - ground elevation above mean sea level in m, <i>lambda</i> - latent heat of vaporisation = 2.45 MJ.kg <sup>-1</sup> , <i>lat_rad</i> - latitude in radians, <i>Gsc</i> - solar constant = 0.0820 MJ.m <sup>-2</sup> .min <sup>-1</sup> , <i>z</i> - height of wind instrument in m, <i>sigma</i> - Stefan-Boltzmann constant = 4.903*10 <sup>-9</sup> MJ.K <sup>-4</sup> .m <sup>-2</sup> .day <sup>-1</sup> .  The following constants are also required when argument solar has value of sunshine hours: <i>as</i> - fraction of extraterrestrial radiation reaching earth on sunless days, <i>bs</i> - difference between fracion of extraterrestrial radiation reaching full-sun days and that on sunless days.
ts	Must be either daily, monthly or annual, which indicates the disired time step that the output ET estimates should be on. Default is daily.



solar	<p>Must be either data, sunshine hours, cloud or monthly precipitation: data indicates that solar radiation data is to be used directly for calculating evapotranspiration;</p> <p>sunshine hours indicates that solar radiation is to be calculated using the real data of sunshine hours;</p> <p>cloud sunshine hours is to be estimated from cloud data;</p> <p>monthly precipitation indicates that solar radiation is to be calculated directly from monthly precipitation.</p> <p>Default is sunshine hours.</p>
wind	<p>Must be either yes or no.</p> <p>yes indicates that the calculation will use real data of wind speed;</p> <p>no indicates that the alternative calculation without using wind data will be used in Penman formulation (Valiantzas 2006, Equation33), which is required in the Szilagyijozsa model.</p> <p>Default is yes.</p>
windfunction_ver	<p>The version of Penman wind function that will be used within the Penman formulation. Must be either 1948 or 1956.</p> <p>1948 is for applying the Penman's 1948 wind function (Penman, 1948);</p> <p>1956 is for applying the Penman's 1956 wind function (Penman, 1956) Default is 1948.</p>
alpha	<p>Any numeric value between 0 and 1 (dimensionless), albedo of evaporative surface representing the portion of the incident radiation that is reflected back at the surface.</p> <p>Default is 0.23 for short reference crop.</p>
z0	<p>Any value (metres), roughness height of the evaporative surface.</p> <p>Default is 0.23 for short reference crop.</p>
message	<p>Must be either yes or no, indicating whether message should be printed for calculation summary including the following elements:</p> <ul style="list-style-type: none"> <li>- ET model name and ET quantity estimated</li> <li>- Evaporative surface with values of albedo, as well as the roughness height</li> <li>- Option for calculating solar radiation (i.e. the value of argument solar)</li> <li>- If actual wind data has been used for calculation (i.e. the value of argument wind) and which version of Penman wind function has been used (i.e. the value of argument windfunction_ver)</li> <li>- Time step of the output ET estimates (i.e. the value of argument ts)</li> <li>- Units of the output ET estimates</li> <li>- Time duration of the ET estimation</li> <li>- Number of ET estimates obtained in the entire time-series</li> <li>- Basic statistics of the estimated ET time-series including <i>mean</i>, <i>max</i> and <i>min</i> values.</li> </ul>
AdditionalStats	<p>"yes" or "no" indicating whether monthly averaged and annual averaged ET should be calculated.</p>
save.csv	<p>Must be either yes or no, indicating whether a .csv of ET estimates should be saved to working directory.</p>
...	<p>Dummy for generic function, no need to define.</p>

### Details

The alternative calculation options can be selected through arguments `solar`, `wind` and `windfunction_ver`, please see Arguments for details.

User-defined evaporative surface is allowed through arguments `alpha` and `z0`, please see Arguments for details.

### Value

The function generates a list containing the following components:

<code>ET.Daily</code>	Daily aggregated estimations of Szilagyi-Jozsa actual evapotranspiration.
<code>ET.Monthly</code>	Monthly aggregated estimations of Szilagyi-Jozsa actual evapotranspiration.
<code>ET.Annual</code>	Annually aggregated estimations of Szilagyi-Jozsa actual evapotranspiration.
<code>ET.MonthlyAve</code>	Monthly averaged estimations of daily Szilagyi-Jozsa actual evapotranspiration.
<code>ET.AnnualAve</code>	Annually averaged estimations of daily Szilagyi-Jozsa actual evapotranspiration.
<code>ET_formulation</code>	Name of the formulation used which equals to Szilagyi-Jozsa.
<code>ET_type</code>	A character string containing the type of the estimation obtained which is Actual Evapotranspiration.
<code>message1</code>	A message to inform the users about how solar radiation has been calculated by using which data.
<code>message2</code>	A message to inform the users about if actual wind data has been used in the calculations or alternative calculations has been performed without wind data, and which version of the Penman wind function has been used.

### Author(s)

Danlu Guo

### References

- Szilagyi, J. 2007. *On the inherent asymmetric nature of the complementary relationship of evaporation*. Geophysical Research Letters, 34, L02405.
- McMahon, T., Peel, M., Lowe, L., Srikanthan, R. & McVicar, T. 2012. *Estimating actual, potential, reference crop and pan evaporation using standard meteorological data: a pragmatic synthesis*. Hydrology and Earth System Sciences Discussions, 9, 11829-11910.
- Penman, H. L. 1948. *Natural evaporation from open water, bare soil and grass*. Proceedings of the Royal Society of London. Series A. Mathematical and Physical Sciences, 193, 120-145.
- Valiantzas, J. D. 2006. *Simplified versions for the Penman evaporation equation using routine weather data*. Journal of Hydrology, 331, 690-702.
- Penman, H. L. 1956. *Evaporation: An introductory survey*. Netherlands Journal of Agricultural Science, 4, 9-29.

**See Also**

[ET,processeddata,defaultconstants,constants,ET.Penman](#)

**Examples**

```
# Use processed existing data set and constants from kent Town, Adelaide
data("processeddata")
data("constants")

# Call ET.SzilagyiJozsa under the generic function ET
results <- ET.SzilagyiJozsa(processeddata, constants, ts="daily",
solar="sunshine hours", wind="yes", windfunction_ver=1948, alpha=0.23, z0=0.2,
message="yes", AdditionalStats="yes", save.csv="no")
```

---

ET.Turc

*Turc Formulation*


---

**Description**

Implementing the Turc formulation for estimating reference crop evapotranspiration.

**Usage**

```
## S3 method for class 'Turc'
ET(data, constants, ts="daily", solar="sunshine hours", humid= F,
message="yes", AdditionalStats="yes", save.csv="no", ...)
```

**Arguments**

data	A list of data which contains the following items (climate variables) required by Turc formulation: <i>Tmax</i> , <i>Tmin</i> (degree Celcius), <i>Rs</i> (Megajoules per sqm) or <i>n</i> (hour) or <i>Cd</i> (okta)
constants	A list named constants consists of constants required for the calculation of Turc formulation which must contain the following items: <i>Elev</i> - ground elevation above mean sea level in m, <i>lambda</i> - latent heat of vaporisation = 2.45 MJ.kg <sup>-1</sup> , <i>lat_rad</i> - latitude in radians, <i>Gsc</i> - solar constant = 0.0820 MJ.m <sup>-2</sup> .min <sup>-1</sup> , <i>sigma</i> - Stefan-Boltzmann constant = 4.903*10 <sup>-9</sup> MJ.K <sup>-4</sup> .m <sup>-2</sup> .day <sup>-1</sup> .

The following constants are also required when argument solar has value of sunshine hours:

*as* - fraction of extraterrestrial radiation reaching earth on sunless days,  
*bs* - difference between fracion of extraterrestrial radiation reaching full-sun days and that on sunless days.

ts	Must be either daily, monthly or annual, which indicates the disired time step that the output ET estimates should be on. Default is daily.
solar	Must be either data, sunshine hours, cloud or monthly precipitation: data indicates that solar radiation data is to be used directly for calculating evapotranspiration; sunshine hours indicates that solar radiation is to be calculated using the real data of sunshine hours; cloud sunshine hours is to be estimated from cloud data; monthly precipitation indicates that solar radiation is to be calculated directly from monthly precipitation. Default is sunshine hours.
humid	Must be T or F, indicating if adjustment for non-humid conditions is applied in Turc formulation (Alexandris et al., 2008, Equation 5b). Default is F for no adjustment.
message	Must be either yes or no, indicating whether message should be printed for calculation summary including the following elements: - ET model name and ET quantity estimated - Evaporative surface - Option for calculating solar radiation (i.e. the value of argument solar) - if adjustment for non-humid conditions has been applied (i.e. the value of argument humid) - Time step of the output ET estimates (i.e. the value of argument ts) - Units of the output ET estimates - Time duration of the ET estimation - Number of ET estimates obtained in the entire time-series - Basic statistics of the estimated ET time-series including <i>mean</i> , <i>max</i> and <i>min</i> values.
AdditionalStats	"yes" or "no" indicating whether monthly averaged and annual averaged ET should be calculated.
save.csv	Must be either yes or no, indicating whether a .csv of ET estimates should be saved to working directory.
...	Dummy for generic function, no need to define.

### Details

The alternative calculation options can be selected through argument `solar`, please see Arguments for details.

Humidity adjustment for the estimations is available through argument `humid`, please see Arguments for details.

### Value

The function generates a list containing the following components:

ET.Daily      Daily aggregated estimations of Turc reference crop evapotranspiration.

ET.Monthly	Monthly aggregated estimations of Turc reference crop evapotranspiration.
ET.Annual	Annually aggregated estimations of Turc reference crop evapotranspiration.
ET.MonthlyAve	Monthly averaged estimations of daily Turc reference crop evapotranspiration.
ET.AnnualAve	Annually averaged estimations of daily Turc reference crop evapotranspiration.
ET_formulation	Name of the formulation used which equals to Turc.
ET_type	Type of the estimation obtained which is Reference Crop Evapotranspiration.
message1	A message to inform the users about how solar radiation has been calculated by using which data.
message4	A message to inform the users about if adjustment for non-humid conditions has been applied to calculated Turc reference crop evapotranspiration.

### Author(s)

Danlu Guo

### References

McMahon, T., Peel, M., Lowe, L., Srikanthan, R. & McVicar, T. 2012. *Estimating actual, potential, reference crop and pan evaporation using standard meteorological data: a pragmatic synthesis*. Hydrology and Earth System Sciences Discussions, 9, 11829-11910.

Turc, L. 1961, *Estimation of irrigation water requirements, potential evapotranspiration: a simple climatic formula evolved up to date*. Ann. Agron, vol. 12, no. 1, pp. 13-49.

Alexandris, S., Stricevic, R., Petkovic, S. 2008, *Comparative analysis of reference evapotranspiration from the surface of rainfed grass in central Serbia, calculated by six empirical methods against the Penman-Monteith formula*. European Water, vol. 21, no. 22, pp. 17-28.

### See Also

[ET,processeddata,defaultconstants,constants](#)

### Examples

```
# Use processed existing data set and constants from kent Town, Adelaide
data("processeddata")
data("constants")

# Call ET.Turc under the generic function ET
results <- ET.Turc(processeddata, constants, ts="daily", solar="sunshine hours", humid= FALSE,
message="yes", AdditionalStats="yes", save.csv="no")
```

---

 ETComparison

---

*Compare esimated evapotranspiration among multiple sets of result*


---

### Description

Produce comparison plots for results and statistics from different estimations produced by using different formulations and/or different input data. The number of different sets of results can be between 2 and 7. Plotting type can be selected among daily aggregation, monthly aggregation, annual aggregation, monthly average and annual average. For each type three comparison plots will be produced including time series, non-exceedance probability and box plot.

### Usage

```
ETComparison(results1, results2, results3 = NULL, results4 = NULL, results5 = NULL,
results6 = NULL, results7 = NULL, labs, Sdate = NULL, Edate = NULL,
type = "Monthly", ylim = rep(NA,2))
```

### Arguments

results1	A list named <code>results</code> which has been derived from function <code>ET</code> which can be from any model such as Penman, Penman-Monteith or Priestley-Taylor.
results2	A list named <code>results</code> which has been derived from function <code>ET</code> which can be from any model such as Penman, Penman-Monteith or Priestley-Taylor.
results3	A list named <code>results</code> which has been derived from function <code>ET</code> which can be from any model such as Penman, Penman-Monteith or Priestley-Taylor. The default is <code>NULL</code> if the user requires the comparison between only two sets of results.
results4	A list named <code>results</code> which has been derived from function <code>ET</code> which can be from any model such as Penman, Penman-Monteith or Priestley-Taylor. The default is <code>NULL</code> if the user requires the comparison among only three sets of results.
results5	A list named <code>results</code> which has been derived from function <code>ET</code> which can be from any model such as Penman, Penman-Monteith or Priestley-Taylor. The default is <code>NULL</code> if the user requires the comparison among only four sets of results.
results6	A list named <code>results</code> which has been derived from function <code>ET</code> which can be from any model such as Penman, Penman-Monteith or Priestley-Taylor. The default is <code>NULL</code> if the user requires the comparison among only five sets of results.
results7	A list named <code>results</code> which has been derived from function <code>ET</code> which can be from any model such as Penman, Penman-Monteith or Priestley-Taylor. The default is <code>NULL</code> if the user requires the comparison among only six sets of results.

labs	A character vector with the length equal to the number of sets of results to compare, defining the labels for the comparison plots
Sdate	Only used when argument type is Daily, Monthly or Annual to define the start date for the plotting windows, which can be defined by user in the format <i>YYYY-MM-DD</i> ; if missing the default is the first day of data is used.
Edate	Only used when argument type is Daily, Monthly or Annual to define the end date for the plotting windows, which can be defined by user in the format <i>YYYY-MM-DD</i> ; if missing the default is the last day of data is used.
ylim	A numeric vector of length 2 defining the lower and upper limit of the y-axis for plotting, if missing the default is from 0 to 1.5 times of maximum value from the first set of result that is used to compare with others.
type	A character string indicating the type of plot produced, can be one of the following: Daily - comparison plots of estimated daily evapotranspiration; Monthly - comparison plots of monthly aggregated evapotranspiration; Annual - comparison plots of annually aggregated evapotranspiration; MonthlyAve - comparison plots of monthly averaged daily evapotranspiration; AnnualAve - comparison plots of annually averaged daily evapotranspiration.

### Value

Three plots are generated for each type of comparison plot selected, including:

- 1) time series plot of the estimated/aggregated/averaged values from each set of result;
- 2) non-exceedance plot of the distribution of estimated/aggregated/averaged values from each set of result;
- 3) box plot of the distribution of estimated/aggregated/averaged values from each set of result.

### Author(s)

Danlu Guo

### See Also

[ETPlot](#)

### Examples

```
# Use processed existing data set and constants from kent Town, Adelaide
data("processeddata")
data("constants")

# Call ET.Penman under the generic function ET
results_Penman <- ET.Penman(processeddata, constants, ts="daily", solar="sunshine hours",
wind="yes", windfunction_ver = "1948", alpha = 0.08, z0 = 0.001, save.csv="no")

# Call ET.PenmanMonteith under the generic function ET
results_PenmanMonteith <- ET.PenmanMonteith(processeddata, constants, ts="daily",
solar="sunshine hours", wind="yes", crop = "short", save.csv="no")
```

```
# Plot the estimated Penman open-water evaporation against average temperature
ETComparison(results_Penman, results_PenmanMonteith, type = "Monthly", ylim=c(0,400),
labs=c("Penman", "PenmanMonteith"))
```

---

ETForcings

*Plot esimated evapotranspiration with climate variables*


---

### Description

Produce plot of daily, monthly and annual averaged estimated evapotranspiration with selected climate variables of the same time step.

### Usage

```
ETForcings(data, results, forcing)
```

### Arguments

data	A list of data named data which must contain a component with the name of a climate variable that the estimated evapotranspiration should be plotted against, see forcing.
results	A list named results which has been derived from function ET.
forcing	A character string as the name of a climate variable that the estimated evapotranspiration should be plotted against, can be any of: <i>Tmax</i> - maximum temperature, <i>Tmin</i> - minimum temperature, <i>u2</i> - average wind speed at 2m, <i>uz</i> - average wind speed, <i>Rs</i> - solar radiation, <i>n</i> - daily sunshine hours, <i>Precip</i> - precipitation, <i>Epan</i> - Class-A pan evaporation, <i>RHmax</i> - maximum relative humidity, <i>RHmin</i> - minimum relative humidity, <i>Tdew</i> - average dew point temepature.

### Value

Three plots are generated for the response of calculated evapotranspiration to each climate variable, including:

- 1) daily evapotranspiration estimate vs. daily average temperature;
- 2) monthly mean daily evaporationion estimate vs. monthly average temperature;
- 3) annual mean daily evaporationion estimate vs. annual average temperature.



**Author(s)**

Danlu Guo

**See Also**[ETPlot](#)**Examples**

```
# Use processed existing data set and constants from kent Town, Adelaide
data("processeddata")
data("constants")

# Call ET.Penman under the generic function ET
results <- ET.Penman(processeddata, constants, ts="daily", solar="sunshine hours",
wind="yes", windfunction_ver = "1948", alpha = 0.08, z0 = 0.001, save.csv="no")

# Plot the estimated Penman open-water evaporation against average temperature
ETForcings(processeddata, results, forcing = "Tmax")
```

---

ETPlot	<i>Plot the daily, monthly and annual aggregations of esimated evapotranspiration</i>
--------	---

---

**Description**

Produce plot of aggregated estimations of evapotranspiration in daily, monthly and annual steps, or averaged daily estimations in monthly or annual steps.

**Usage**

```
ETPlot(results, type = "Aggregation", OBS, OBSplot, Sdate = time(results$ET.Daily)[1],
Edate = time(results$ET.Daily)[length(results$ET.Daily)])
```

**Arguments**

results	A list named results which has been derived from function ET. . ().
type	A character string of either Aggregation or Average to indicate the type of plot required. The default is Aggregation. For aggregation plot the user can define the start and end date of plotting or by default using the calculation period for plotting. For average plot the plotting period equals to the calculation period.
OBS	A list named OBS which has been derived from function ReadOBSEvaporation.
OBSplot	Must be eith TRUE or FALSE. TRUE indicates that the observed evaporation will be plotted together with the estimations and FALSE indicates that the observations will not be shown on the plots.

Sdate	Only used when type = Aggregation to define the start date for the plotting windows, the default is the first day for the estimate evapotranspiration, but can be defined by user in the format <i>YYYY-MM-DD</i> .
Edate	Only used when type = Aggregation to define the end date for the plotting windows, the default is the last day for the estimate evapotranspiration, but can be defined by user in the format <i>YYYY-MM-DD</i> .

### Value

If argument type is Aggregation, three plots are displayed in the following order (the next one appears after pressing enter):

- 1) Daily evapotranspiration estimates;
- 2) Monthly evapotranspiration estimates aggregated from daily estimates;
- 3) Annual evapotranspiration estimates aggregated from daily estimates.

If argument type is Average, two plots are displayed in the following order

- 1) Monthly averaged daily estimations of evapotranspiration;
- 2) Annually averaged daily estimations of evapotranspiration.

### Author(s)

Danlu Guo

### See Also

[ETComparison](#)

### Examples

```
# Use processed existing data set and constants from kent Town, Adelaide
data("processeddata")
data("constants")

# Call ET.Penman under the generic function ET
results <- ET.Penman(processeddata, constants, ts="daily", solar="sunshine hours",
wind="yes", windfunction_ver = "1948", alpha = 0.08, z0 = 0.001, save.csv="no")

# Read evaporation data
data("E_OBS")
OBS <- ReadOBSEvaporation(E_OBS, processeddata)

# Plot the aggregation of estimated Penman open-water evaporation with observed evaporation
ETPlot(results, type = "Aggregation", OBS, OBSplot = TRUE, Sdate = "2001-05-01",
Edate = "2004-05-01")
```

---

E_OBS	<i>Observed Class-A Pan Evaporation</i>
-------	---

---

**Description**

This data set contains the Class-A pan evaporation observed over the period between 1/3/2001 and 31/8/2004 at the Kent Town station in Adelaide, Australia.

**Usage**

data(E\_OBS)

**Format**

A list containing 48 observations of 5 variables

**Source**

Bureau of Meteorology, Kent Town, Adelaide, Australia

---

processeddata	<i>Processed Climate Data Required for Calculating Evapotranspiration</i>
---------------	---

---

**Description**

This data set contains the processed climate data including the variables required for calculating evapotranspiration in function [ET](#) over the observation period between 1/3/2001 and 31/8/2004 at the Kent Town station in Adelaide, Australia.

**Usage**

data(processeddata)

**Format**

A list containing 11 non-empty variables:

*Date.daily* - date in daily time step,  
*Date.monthly* - date in monthly time step,  
*J* - julian days,  
*i* - month,  
*ndays* - days in month,  
*Tmax* - daily maximum temperature in degree Celcius,  
*Tmin* - daily minimum temperature in degree Celcius,  
*RHmax* - daily maximum relative humidity in percentage,  
*RHmin* - daily minimum relative humidity in percentage,  
*uz* - daily wind speed in meters per second,  
*Rs* - daily solar radiation in Megajoule per square meter.

**Source**

Bureau of Meteorology, Kent Town, Adelaide, Australia

---

ReadInputs

*ReadInputs raw date and climate data*

---

**Description**

Load raw date and climate data, perform pre-processing, check for missing and error entries and then compile data list of daily time step.

**Usage**

```
ReadInputs(varnames, climatedata, constants, stopmissing, timestep = "daily",
           interp_missing_days = FALSE,
           interp_missing_entries = FALSE,
           interp_abnormal = FALSE,
           missing_method = NULL,
           abnormal_method = NULL,
           message = "yes")
```

**Arguments**

**varnames** A character vector with length equals to the number of climate variables to be processed. Can include any element from: *Tmax*, *Tmin*, *Temp*, *Tdew*, *RHmax*, *RHmin*, *RH*, *Rs*, *n*, *Cd*, *Precip*, *uz*, *u2*, *Epan*, *va*, *vs*.

Each variable is detailed as below:

*Tmax* - daily maximum temperature in degree Celcius,

*Tmin* - daily minimum temperature in degree Celcius,

*Temp* - subdaily temperature in degree Celcius

*Tdew* - dew point temperature in degree Celcius, either daily or subdaily accepted,

*RHmax* - daily maximum relative humidity in percentage,

*RHmin* - daily minimum relative humidity in percentage,

*RH* - subdaily relative humidity in percentage,

*Rs* - incoming solar radiation in Megajoules per square metres per day, either daily or subdaily accepted,

*n* - daily sunshine hour in hours,

*Cd* - daily cloud cover in oktas,

*Precip* - precipitation in millimetres, either daily or subdaily accepted,

*u2* - wind speed measured at 2 metres from the ground surface in metres per second, either daily or subdaily accepted,

*uz* - wind speed in metres per second, either daily or subdaily accepted,

*Epan* - daily Class-A pan evaporation in millimetres,

*va* - average vapour pressure in KPa, either daily or subdaily accepted,

*vs* - saturated vapour pressure in KPa, either daily or subdaily accepted.

climatedata	<p>A data frame named "climatedata" containing the raw data of date and climate variables. The data frame must have objects named as <i>Year</i>, <i>Month</i> and <i>Day</i> to indicate the date. The climate variables to include should be consistent with <i>varnames</i>. In order to determine which variables are needed for ET estimation, please see <a href="#">ET</a> for the specific data requirements for different formulations.</p>
timestep	<p>Should be either daily or subdaily to specify the time step of raw climate data used.</p>
constants	<p>A list named "constants" consists of constants required for data pre-processing which may contain the following items: <i>a_0</i>, <i>b_0</i>, <i>c_0</i>, <i>d_0</i>. These four constants which are constants required to calculate daily sunshine hours from daily cloud cover (see Equation S3.10 in McMahon et al., 2012) - if the user requires such calculation these constants must be included in "constants". The suggested values for various Australian locations are presented in Chiew and McMahon (1991), in which the four constants are named as a0, b0, c0, d0.</p>
stopmissing	<p>A numeric vector of length 3: - the first value represents the maximum percentage of missing data that the user can tolerate; - the second value represents the maximum percentage of the duration of missing data to the total data duration that the user can tolerate; - the third value represents the maximum percentage of missing days (within the date data, as a fraction of the total number of days) that the user can tolerate. All values should be numbers between 1 and 99. The percentages of the number and duration of missing data in the date data and each input variable are compared to the corresponding threshold; if any of the threshold is exceeded the program will be terminated due to unsatisfactory data quality.</p>
interp_missing_days	<p>T or F, indicating if missing days (within the date data) should be interpolated, with a default of F which assigns NA to data at the missing days.</p>
interp_missing_entries	<p>T or F, indicating if missing data entries within individual climate variables should be interpolated, with a default of F which assigns NA to the missing entries.</p>
interp_abnormal	<p>T or F, if abnormal values within individual climate variables should be interpolated, with a default of F which leaves the abnormal values unchanged. Abnormal values are defined differently according to the input variable, as following:  - <i>Tmax</i> &gt; 100 or &lt; -50 degree Celcius</p>

- $T_{min} > T_{max}$  or  $< -50$  degree Celcius
- $Temp > 100$  or  $< -50$  degree Celcius
- $T_{dew} > 100$  or  $< -50$  degree Celcius
- $RH_{max} > 100$  or  $< 0$  per cent
- $RH_{min} > RH_{max}$  or  $< 0$  per cent
- $RH > 100$  per cent
- $R_s < 0$  MJ.m<sup>2</sup>
- $n < 0$  hour
- $Cd < 0$  Okta
- $Precip < 0$  mm
- $uz < 0$  m/s
- $u2 < 0$  m/s
- $Epan < 0$  mm
- $vs < 0$  KPa
- $va < 0$  KPa

`missing_method` A character string for the name of the interpolated methods chosen for filling in missing days and missing data entries. Can be either:

`monthly average` - replacement with same-month average (adapted from Narapusetty et al., 2009);  
`seasonal average` - replacement with same-season average (adapted from Narapusetty et al., 2009);  
`DoY average` - replacement with same day-of-the-year average (Narapusetty et al., 2009);  
`neighbouring average` - interpolation between the two bounding values, which is only suitable for time increments in which values are available at adjacent increments (McMahon et al., 2013). When there is more than one consecutive missing entry, this interpolation fails, with a warning given.

`abnormal_method`

A character string for the name of the interpolated methods chosen for replacing data entries with abnormal values. Can be either:

`monthly average` - replacement with same-month average (adapted from Narapusetty et al., 2009);  
`seasonal average` - replacement with same-season average (adapted from Narapusetty et al., 2009);  
`DoY average` - replacement with same day-of-the-year average (Narapusetty et al., 2009);  
`neighbouring average` - interpolation between the two bounding values, which is only suitable for time increments in which non-abnormal values are available at adjacent increments (McMahon et al., 2013). When there is more than one consecutive abnormal entry, this interpolation fails, with a warning given.

`message` "yes" or "no" indicating whether checking messages should be printed on screen.

**Value**

This function returns a list with all components of class zoo which have been processed from the raw data, including:

Date.daily	A zoo object containing the date in daily step in the format of yyyy-mm-dd.
Date.monthly	A zoo object containing the date in daily step in the format of mmm-yyyy.
J	A zoo object containing the Julian Day for every day during the period that the data spans.
i	A zoo object containing the month number for every day during the period that the data spans.
ndays	A zoo object containing the number of days for every month during the period that the data spans.
Tmax	A zoo object containing the daily maximum temperatures in degree Celcius.
Tmin	A zoo object containing the daily minimum temperatures in degree Celcius.
u2	A zoo object containing the daily wind speed at 2m from the ground in m/s.
uz	A zoo object containing the daily wind speed measured at the height of wind instrument in m/s.
Rs	A zoo object containing the daily solar radiation in MJ/m <sup>2</sup> /day.
n	A zoo object containing the daily sunshine hours.
Cd	A zoo object containing the daily cloud cover in oktas.
Precip	A zoo object containing the daily precipitation in mm.
Epan	A zoo object containing the daily Class-A pan evaporation in mm.
RHmax	A zoo object containing the daily maximum relative humidity in percentage.
RHmin	A zoo object containing the daily minimum relative humidity in percentage.
Tdew	A zoo object containing the average daily dew temperatures in degree Celcius.

Note that the components might have value of NULL when the corresponding input variable cannot be found in the raw data (i.e. "climatedata").

**Author(s)**

Danlu Guo

**References**

- McMahon, T., Peel, M., Lowe, L., Srikanthan, R. & McVicar, T. 2012. *Estimating actual, potential, reference crop and pan evaporation using standard meteorological data: a pragmatic synthesis*. Hydrology and Earth System Sciences Discussions, 9, 11829-11910.
- Chiew, F. H. & McMahon, T. A. 1991. *The applicability of Morton's and Penman's evapotranspiration estimates in rainfall-runoff modeling I*. JAWRA Journal of the American Water Resources Association, 27, 611-620.
- Narapusetty, B., DelSole, T., Tippet, M.K. 2009, *Optimal Estimation of the Climatological Mean*. Journal of Climate, vol. 22, no. 18, pp. 4845-4859.

**See Also**

[ET,climatedata,data](#)

**Examples**

```
# ReadInputs climate data
data("climatedata")
data("constants")
data <- ReadInputs(varnames = c("Temp","Tdew","n","RH","uz"),
                  climatedata,
                  constants,
                  stopmissing=c(10,10,3),
                  timestep = "subdaily",
                  interp_missing_days = FALSE,
                  interp_missing_entries = FALSE,
                  interp_abnormal = FALSE,
                  missing_method = NULL,
                  abnormal_method = NULL)
```

---

ReadOBSEvaporations     *Read Raw Data of Observed Evaporation from file*

---

**Description**

Load raw date and evaporation data and then compile data list of daily time step.

**Usage**

```
ReadOBSEvaporation(E_OBS, data)
```

**Arguments**

E_OBS	A list of evaporation data named E_OBS which must contain the following columns: Year, Month, Day as the date and, EVAP.Obs as the observed evaporation in mm. The observations can be of daily and monthly time steps and must match with the corresponding dates recorded.
data	A list of data named data which contains data of climate variables over the same period as the evaporation data

**Value**

This function returns a list with all components of class zoo which have been processed from the raw data, including:

Date.OBS	A zoo object containing the date data with time step consistent with the raw evaporation data in E_OBS.
----------	--



E\_obs.Daily     A zoo object containing the daily evaporation data.  
E\_obs.Monthly   A zoo object containing the monthly aggregated observed evaporation in mm.  
E\_obs.Annual    A zoo object containing the annually aggregated observed evaporation in mm.  
E\_obs.MonthlyAve  
                  A zoo object containing the monthly averaged daily evaporation from observation in mm/day.  
E\_obs.AnnualAve  
                  A zoo object containing the annually average daily evaporation from observation in mm/day.

Note that the components might have value of NULL when the corresponding raw data cannot be found in E\_OBS.

**Author(s)**

Danlu Guo

**Examples**

```
# Get the time period from "data"  
# Use processed existing data set from kent Town, Adelaide  
data("processeddata")  
data("constants")  
  
# Reading observations of evaporation within specified time period  
data("E_OBS")  
OBS <- ReadOBSEvaporation(E_OBS, processeddata)
```

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