Package ‘Evapotranspiration’

December 9, 2016

Version 1.10

Date 2016-12-08

Title Modelling Actual, Potential and Reference Crop Evapotranspiration

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Depends R (>= 2.10), 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.

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NeedsCompilation no

Repository CRAN

Date/Publication 2016-12-09 08:58:36

R topics documented:

`climatedata` *Raw Climate Data Required for Calculating Evapotranspiration*

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

```
climatedata
```

Format

A data frame containing 10240 obserations of 13 objects:

Station.Number - weather station number,
Year - year of record,
Month - month of record,
Day - day of record,
Hour - hour of record,
Julian - Julian day of record,
Temp.subdaily - subdaily temperature data in degree Celcius,
Tdew.subdaily - subdaily dew point temperature data in degree Celcius,
RH.subdaily - subdaily relative humidity data in degree Celcius,
n.daily - daily sunshine hour data in hours,
uz.subdaily - subdaily wind speed data in meter per second,

Tmin.daily - daily maximum temperature data in degree Celcius,
Tmax.daily - daily minimum temperature data in degree Celcius.

Source

Bureau of Meteorology, Kent Town, Adelaide, Australia

`constants` *Constants Required for Calculating Evapotranspriation*

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

```
constants
```

Format

A list containing 46 constant values including:

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

lambda latent heat of evaporisationin = 2.45 MJ.kg^-1 at 20 degree Celcius,
sigma Stefan-Boltzmann constant = 4.903*10^-9 MJ.K^-4.m^-2.day^-1,
Gsc solar constant = 0.0820 MJ.m^-2.min^-1
Roua mean density of air = 1.2 kg.m^-3 at 20 degree Celcius
Ca specific heat of air = 0.001013 MJ.kg^-1.K^-1
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^-2 (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^-2.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 fracion 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 W.m^-2.mbar^-1 for CRAE model for T >= 0 degree Celcius;
= 28.0*1.15 W.m^-2.mbar^-1 for CRAE model for T < 0 degree Celcius;
= 25.0 W.m^-2.mbar^-1 for CRWE model for T >= 0 degree Celcius;
= 28.75 W.m^-2.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, *gammaps* product of Psychrometric constant and atmospheric pressure as sea level:
= 0.66 mbar. degree Celcius^-1 for CRAE model for T >= 0 degree Celcius;
= 0.66/1.15 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 >= 0 degree Celcius;
= 21.88 when T < 0 degree Celcius.

betaMo constant in Morton's procedure:
= 237.3 degree Celcius when T >= 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^-1 when T >= 0 degree Celcius;
= 28.5*1.15W.day.kg^-1 when T < 0 degree Celcius.

Source

various references

See Also

defaultconstants

`data` *Processed Climate Data Required for Calculating Evapotranspiration*

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
```

Format

A list containing 17 non-empty climate 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,
uz - daily wind speed in meters per second,
n - daily sunshine hour in hours,
RHmax - daily maximum relative humidity in percentage,
RHmin - daily minimum relative humidity in percentage,
Tdew - daily dew point temperature data in degree Celcius.

Source

Bureau of Meteorology, Kent Town, Adelaide, Australia `defaultconstants` *Universal constants Required for Calculating Evapotranspriation*

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

```
constants
```

Format

A list containing 20 constant values including:
lambda latent heat of evaporisationin = 2.45 MJ.kg^-1 at 20 degree Celcius,
sigma Stefan-Boltzmann constant = 4.903*10^-9 MJ.K^-4.m^-2.day^-1,
Gsc solar constant = 0.0820 MJ.m^-2.min^-1
Roua mean density of air = 1.2 kg.m^-3 at 20 degree Celcius
Ca specific heat of air = 0.001013 MJ.kg^-1.K^-1
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^-2 (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^-2.K^-4.

Source

various references

See Also

`constants`

`ET` *ET Formulations*

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 *Tmax/Tmin* and *RHmax/RHmin* and either *uz* or *u2*, and either *Rs* of *n* or *Cd* are available, and short crop surface is specified in argument:
Penman-Monteith FAO56 (`ET.PenmanMonteith` with *crop* = *"short"*);

- If all variables of *Tmax/Tmin* and *RHmax/RHmin* and either *uz* or *u2*, and either *Rs* of *n* or *Cd* are available, and long crop surface is specified in argument:
Penman-Monteith ASCE-EWRI (`ET.PenmanMonteith` with *crop* = *"long"*);

- If all variables of *Tmax/Tmin* and *RHmax/RHmin* and either *uz* or *u2*, and either *Rs* of *n* or *Cd*

are available, and no surface is specified:
Penman (ET.Penman);

- If all variables of *Tmax/Tmin* and *RHmax/RHmin*, and either *Rs* of *n* or *Cd* are available:
Priestley-Taylor (ET.PriestleyTaylor);

- If all variables of *Tmax/Tmin* and either *Rs* of *n* or *Cd* are available:
Makkink (ET.Makkink);

- If all variables of *Tmax/Tmin* 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(data, constants)

# Call generic function ET() - leads to the use of Penman-Monteith model
results_crop <- ET(data, constants, crop = "short")
```

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",...)
```

Arguments

data	A list of data in class "Abtew" which contains the following items (climate variables) required by Abtew formulation: *Tmax*, *Tmin*, *Rs* or *n* or *Cd*

`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^-1,
lat_rad - latitude in radians,
Gsc - solar constant = 0.0820 MJ.m^-2.min^-1,
sigma - Stefan-Boltzmann constant = 4.903*10^-9 MJ.K^-4.m^-2.day^-1.

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`.

`...` 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 prints a calculation summary to the screen containing 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 *mean*, *max* and *min* values.

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

`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`,`data`,`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(data, constants,ts="daily", solar="sunshine hours")
```

`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 , ...)
```

Arguments

`data` A list of data which contains the following items (climate variables) required by Blaney-Criddle formulation:
Tmax, *Tmin*, *RHmin*, *n* or *Cd*, *u2* or *uz*

`constants` A list named `constants` consists of constants required for the calculation of PenPan 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^-1,
lat_rad - latitude in radians,
z - height of wind instrument in m,
e0,*e1*,*e2*,*e3*,*e4* - 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 \codesunshine 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.

`...` 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 prints a calculation summary to the screen containing 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 *mean*, *max* and *min* values.

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

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 ggregated 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,data,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(data, constants, ts="daily", solar="sunshine hours", height= FALSE)
```

`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, ...)
```

Arguments

`data` A list of data which contains the following items (climate variables) required by Brutsaert-Strickler formulation:
Tmax, *Tmin*, *RHmax*, *RHmin*, *Rs* or *n* or *Cd*, *u2* or *uz*

`constants` A list named `constants` consists of constants required for the calculation of Brutsaert-Strickler 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^-1,
lat_rad - latitude in radians,
Gsc - solar constant = 0.0820 MJ.m^-2.min^-1,
z - height of wind instrument in m,
sigma - Stefan-Boltzmann constant = 4.903*10^-9 MJ.K^-4.m^-2.day^-1.

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.

...	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 prints a calculation summary to the screen containing the following elements:
- ET model name and ET quantity estimated
- Evaporative surface with values of albedo, surface resistance, crop height and roughness height
- 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 *mean*, *max* and *min* values.

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

`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,data,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(data, constants, ts="daily", solar="sunshine hours", alpha=0.23)
```

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, ...)
```

Arguments

data	A list of data which contains the following items (climate variables) required by Chapman formulation: *Tmax*, *Tmin*, *RHmax*, *RHmin*, *Rs* or *n* or *Cd*, *u2* or *uz*
constants	A list named constants consists of constants required for the calculation of Chapman 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^-1, *lat_rad* - latitude in radians, *Gsc* - solar constant = 0.0820 MJ.m^-2.min^-1, *z* - height of wind instrument in m, *sigma* - Stefan-Boltzmann constant = 4.903*10^-9 MJ.K^-4.m^-2.day^-1, *lat* - latitude in degrees, *alphaA* - albedo for Class-A pan, *ap* - a constant in PenPan = 2.4.

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`.

`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.

`...` 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 prints a calculation summary to the screen containing 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.

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

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. SivapalanR. Vertessy (eds), MODSIM2001: Integrating models for Natural Resources Management across Disciplines, Issues and Scales, MSSANZ, vol. 1, pp. 293-298.

See Also

ET,data,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(data, constants, ts="daily", PenPan= TRUE,
solar="sunshine hours", alpha=0.23)
```

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, ...)
```

Arguments

`data` A list of data which contains the following items (climate variables) required by Granger-Gray formulation:
Tmax, *Tmin*, *RHmax*, *RHmin*, *Rs* or *n* or *Cd*, *u2* or *uz*

`constants` A list named `constants` consists of constants required for the calculation of Granger-Gray 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^-1,
lat_rad - latitude in radians,
Gsc - solar constant = 0.0820 MJ.m^-2.min^-1,
z - height of wind instrument in m,
sigma - Stefan-Boltzmann constant = 4.903*10^-9 MJ.K^-4.m^-2.day^-1.
G - soil heat flux in MJ.m^-2.day^-1, = 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 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`.

`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.
`...`	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 prints a calculation summary to the screen containing 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 *mean*, *max* and *min* values.

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

`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`,`data`,`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(data, constants, ts="daily",
solar="sunshine hours", windfunction_ver=1948, alpha=0.23)
```

`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", ...)
```

Arguments

`data` A list of data which contains the following items (climate variables) required by Hamon formulation:
Tmax, *Tmin*

`constants` Dummy argument with a `NULL` value.

`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`.

`...` Dummy for generic function, no need to define.

Details

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

Value

The function prints a calculation summary to the screen containing 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 *mean*, *max* and *min* values.

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

`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,data

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(data, ts="daily")
```

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", ...)
```

Arguments

data	A list of data which contains the following items (climate variables) required by Hargreaves-Samani formulation: *Tmax*, *Tmin*
constants	A list named constants consists of constants required for the calculation of Hargreaves-Samani 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^-1, *lat_rad* - latitude in radians, *Gsc* - solar constant = 0.0820 MJ.m^-2.min^-1.
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.
...	Dummy for generic function, no need to define.

Details

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

Value

The function prints a calculation summary to the screen containing 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 *mean*, *max* and *min* values.

`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`,`data`,`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(data, constants, ts="daily")
```

`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", ...)
```

Arguments

`data`	A list of data which contains the following items (climate variables) required by Jensen-Haise formulation: *Tmax*, *Tmin*, *Rs* or *n* or *Cd*
`constants`	A list named `constants` consists of constants required for the calculation of Jensen-Haise 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^-1, *lat_rad* - latitude in radians, *Gsc* - solar constant = 0.0820 MJ.m^-2.min^-1. 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`.
`...`	Dummy for generic function, no need to define.

Details

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

Value

The function prints a calculation summary to the screen containing 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 *mean*, *max* and *min* values.

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

`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`,`data`,`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(data, constants, ts="daily", solar="sunshine hours")
```

ET.Linacre *Linacre Formulation*

Description

Implementing the Linacre formulation for estimating actual evapotranspiration.

Usage

```
## S3 method for class 'Linacre'
ET(data, constants, ts="daily", ...)
```

Arguments

`data`	A list of data which contains the following items (climate variables) required by Linacre formulation: *Tmax*, *Tmin*, *Tdew*
`constants`	A list named `constants` consists of constants required for the calculation of Linacre formulation which must contain the following items: *Elev* - ground elevation above mean sea level in m, *lat* - latitude in degrees.
`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`.
`...`	Dummy for generic function, no need to define.

Details

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

Value

The function prints a calculation summary to the screen containing 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 *mean*, *max* and *min* values.

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

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,data,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(data, constants, ts="daily")
```

ET.Makkink *Makkink Formulation*

Description

Implementing the Makkink formulation for estimating reference crop evapotranspiration.

Usage

```
## S3 method for class 'Makkink'
ET(data, constants, ts="daily", solar="sunshine hours", ...)
```

Arguments

`data` A list of data which contains the following items (climate variables) required by Makkink formulation:
Tmax, *Tmin*, *Rs* or *n* or *Cd*

`constants` A list named `constants` consists of constants required for the calculation of Makkink 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^-1,
lat_rad - latitude in radians,
Gsc - solar constant = 0.0820 MJ.m^-2.min^-1.

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`.

`...` 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 prints a calculation summary to the screen containing 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 *mean*, *max* and *min* values.

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

`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`,`data`,`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(data, constants, ts="daily", solar="sunshine hours")
```

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, ...)
```

Arguments

`data` A list which contains the following items (climate variables) required by Matt-Shuttleworth formulation: *Tmax*, *Tmin*, *RHmax*, *RHmin*, *Rs* or *n* or *Cd*, *u2* or *uz*

`constants` A list named `constants` consists of constants required for the calculation of Matt-Shuttleworth 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^-1,
lat_rad - latitude in radians,
Gsc - solar constant = 0.0820 MJ.m^-2.min^-1,
z - height of wind instrument in m,
sigma - Stefan-Boltzmann constant = 4.903*10^-9 MJ.K^-4.m^-2.day^-1,
Roua - mean air density = 1.20 kg.m^-3,
Ca - specific heat of air = 0.001013 MJ.kg^-1.oC^-1.

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 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.
`...`	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 prints a calculation summary to the screen containing the following elements:
- ET model name and ET quantity estimated
- Evaporative surface with values of albedo, surface resistance and crop height
- 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 *mean*, *max* and *min* values.

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

`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 *Matt-Shuttleworth*.

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

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,data,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(data, constants, ts="daily",
solar="sunshine hours", alpha=0.23, r_s=70, CH=0.12)
```

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", ...)
```

Arguments

`data`	A list of data which contains the following items (climate variables) required by McGuinness-Bordne formulation: *Tmax*, *Tmin*
`constants`	A list named `constants` consists of constants required for the calculation of Jensen-Haise 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^-1, *lat_rad* - latitude in radians, *Gsc* - solar constant = 0.0820 MJ.m^-2.min^-1.
`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`.
`...`	Dummy for generic function, no need to define.

Details

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

Value

The function prints a calculation summary to the screen containing 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 *mean*, *max* and *min* values.

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

`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`,`data`,`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(data, constants, ts="daily")
```

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, ...)
```

Arguments

`data`	A list of data which contains the following items (climate variables) required by Morton CRAE formulation: *Tmax*, *Tmin*, *Tdew*, *Rs* or *n* or *Cd*

`constants` A list named `constants` consists of constants required for the calculation of Morton CRAE formulation which must contain the following items:
Elev - ground elevation above mean sea level in m,
lat_rad - latitude in radians,
PA - annual precipitation in mm, required when precipitation data is not available,
z - height of wind instrument in m,
sigma - Stefan-Boltzmann constant = 4.903*10^-9 MJ.K^-4.m^-2.day^-1,
lat - latitude in degrees,
epsilonMo - surface emissivity = 0.92 (Morton, 1986),
fz - A constant in Morton's procedure = 28.0 Wm^-2.mbar^-1 for T >= 0 degree Celcius, and = 28.0*1.15 Wm^-2.mbar^-1 for T >= 0 degree Celcius for CRAE model (Morton, 1983),
b0 - a constants in Morton's procedure, = 1 for CRAE model (Morton, 1983),
b1 - a constant in Morton's procedure, = 14 for CRAE model (Morton, 1983),
b2 - a constant in Morton's procedure, = 1.2 for CRAE model (Morton, 1983),
gammaps - Produce of Psychrometric constant and atmospheric pressure as sea level, = 0.66 mbar. degree Celcius^-1 for T >= 0 degree Celcius, = 0.66/1.15 mbar. degree Celcius^-1 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^-2.K^-4 (Morton, 1983),
lambdaMo - Latent heat of vaporisation in Morton's procedure, = 28.5W.day.kg^-1 when T >= 0 degree Celcius, = 28.5*1.15W.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.

...   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 prints a calculation summary to the screen containign 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.

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

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

data,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(data, constants, ts="monthly",
est="potential ET", solar="sunshine hours", Tdew= TRUE,
alpha = NULL)
```

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, ...)
```

Arguments

`data` A list of data which contains the following items (climate variables) required by Morton CRWE formulation:
Tmax, *Tmin*, *Tdew*, *Rs* or *n* or *Cd*

`constants` A list named `constants` consists of constants required for the calculation of Morton CRWE formulation which must contain the following items:
Elev - ground elevation above mean sea level in m,
lat_rad - latitude in radians,
PA - annual precipitation in mm, required when precipitation data is not available,
z - height of wind instrument in m,
sigma - Stefan-Boltzmann constant = 4.903*10^-9 MJ.K^-4.m^-2.day^-1,
lat - latitude in degrees,
epsilonMo - surface emissivity = 0.92 (Morton, 1986),
fz - A constant in Morton's procedure = 25.0 Wm^-2.mbar^-1 for T >= 0 degree Celcius, and = 28.75 Wm^-2.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),
gammaps - Produce of Psychrometric constant and atmospheric pressure as sea level, = 0.66 mbar. degree Celcius^-1 for T >= 0 degree Celcius, = 0.66/1.15 mbar. degree Celcius^-1 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^-2.K^-4 (Morton, 1983),
lambdaMo - Latent heat of vaporisation in Morton's procedure, = 28.5W.day.kg^-1 when T >= 0 degree Celcius, = 28.5*1.15W.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` 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`.
`...`	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 prints a calculation summary to the screen containign 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.

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

`ET.Daily`	Daily aggregated estimations of MortonCRWE potential evapotranspiration or shallow lake evaporation.
`ET.Monthly`	Monthly aggregated estimations of MortonCRWE potential evapotranspiration or shallow lake evaporation.

ET.Annual	Annually aggregated estimations of MortonCRWE potential evapotranspiration or shallow lake evaporation.
ET.MonthlyAve	Monthly averaged estimations of daily MortonCRWE potential evapotranspiration or shallow lake evaporation.
ET.AnnualAve	Annually averaged estimations of daily MortonCRWE potential evapotranspiration or shallow lake evaporation.
ET_formulation	Name of the formulation used which equals to MortonCRWE.
ET_type	Type of the estimation obtained which is either Potential Evapotranspiration or Shallow Lake Evaporation.
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 lake evaporation*. Journal of Hydrology, vol. 66, no. 1-4, pp. 77-100.

See Also

data,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(data, constants, ts="monthly",
est="potential ET", solar="sunshine hours", Tdew= TRUE,
alpha = NULL)
```

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,
...)
```

Arguments

`data` A list which contains the following items (climate variables) required by Penman formulation:
Tmax, *Tmin*, *RHmax*, *RHmin*, *Rs* or *n* or *Cd*, *u2* or *uz*

`constants` A list named `constants` consists of constants required for the calculation of Penman 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^-1,
lat_rad - latitude in radians,
Gsc - solar constant = 0.0820 MJ.m^-2.min^-1,
z - height of wind instrument in m,
sigma - Stefan-Boltzmann constant = 4.903*10^-9 MJ.K^-4.m^-2.day^-1.

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`.

`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`.
`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 evapotranspriation.
`z0`	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 evapotranspriation.
`...`	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 prints a calculation summary to the screen containing the following elements:
- ET model name and ET quantity estimated
- Evaporative surface with values of albedo and roughness height
- Option for calculating solar radiation (i.e. the value of argument `solar`)
- 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`)
- 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.

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

`ET.Daily`	Daily aggregated estimations of Penman open-water evaporation or potential evapotranspiration.

`ET.Monthly`	Monthly aggregated estimations of Penman open-water evaporation or potential evapotranspiration.
`ET.Annual`	Annually aggregated estimations of Penman open-water evaporation or potential evapotranspiration.
`ET.MonthlyAve`	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`,`data`,`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(data, constants, ts="daily",
solar="sunshine hours", wind="yes",
windfunction_ver = "1948", alpha = 0.08, z0 = 0.001)
```

ET.PenmanMonteith *Penman-Monteith Formulation*

Description

Implementing the Penman-Monteith formulation. To estimate crop evapotranspiration, the formulation can take possible of either FAO-56 model for hypothetical short grass, the ASCE-EWRI Standardised model for tall grass. The model can also estimate ET from several other vegetation types based on Equation 6.70 in Dingman (2015).

Usage

```
## S3 method for class 'PenmanMonteith'
ET(data, constants, ts="daily", solar="sunshine hours", wind="yes",
vegetation="reference crop", ...)
```

Arguments

`data` A list which contains the following items (climate variables) required by Penman-Monteith formulation:
Tmax, *Tmin*, *RHmax*, *RHmin*, *Rs* or *n* or *Cd*, *u2* or *uz*

`constants` A list named `constants` consists of constants required for the calculation of Penman-Monteith 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^-1,
lat_rad - latitude in radians,
Gsc - solar constant = 0.0820 MJ.m^-2.min^-1,
z - height of wind instrument in m,
sigma - Stefan-Boltzmann constant = 4.903*10^-9 MJ.K^-4.m^-2.day^-1.
G - soil heat flux in MJ.m^-2.day^-1, = 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 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`.

`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`.

`vegetation` Must be either:
`reference crop`,
`long grass`,
`deciduous broad-leaf forest`,
`evergreen needle-leaf forest`,
`open shrubland` or
`grassland`.

`reference crop` indicates that the method for FAO-56 hypothetical short grass will be applied (Allen et al., 1998, Equation 6);
`long grass` indicates that the method for ASCE-EWRI Standardised crop will be applied (ASCE, 2005, Equation 1, Table 1).
All other options lead to the use of Equation 6.70 in Dingman (2015) to estimate ET for specific vegetation cover, with wind measured at instrument height adjusted to 2m following Federer er al. (1996) . Constants for each vegetation type are defined according to values suggested in `http://ldas.gsfc.nasa.gov/nldas/web/web.veg.table.html`.

Default is `reference crop`.

`...` 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 `vegetation`, please see `Arguments` for details.

Value

The function prints a calculation summary to the screen containing the following elements:
- ET model name and ET quantity estimated
- Evaporative surface with values of albedo, surface resistance, crop height and roughness height
- Option for calculating solar radiation (i.e. the value of argument `solar`)
- If actual wind data has been used for calculation (i.e. the value of argument `wind`)
- 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.

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

- `ET.Daily` Daily aggregated estimations of Penman-Monteith evapotranspiration.
- `ET.Monthly` Monthly aggregated estimations of Penman-Monteith evapotranspiration.
- `ET.Annual` Annually aggregated estimations of Penman-Monteith evapotranspiration.
- `ET.MonthlyAve` Monthly averaged estimations of daily Penman-Monteith evapotranspiration.
- `ET.AnnualAve` Annually averaged estimations of daily Penman-Monteith evapotranspiration.
- `ET_formulation` Name of the formulation used which equals to either `Penman-Monteith FAO56` or `Penman-Monteith ASCE-EWRI Standardised`.
- `ET_type` A character string containing the type of the estimation obtained depending on the vegetation type.
- `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.

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Federer, C. A., et al. (1996). *Intercomparison of Methods for Calculating Potential Evaporation in Regional and Global Water Balance Models*, Water Resources Research 32(7): 2315-2321.

See Also

`ET`,`data`,`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(data, constants, ts="daily", solar="sunshine hours",
wind="yes")

# Call ET.PenmanMonteith to estimate ET from different vegetation covers

# referecen crop (FAO-56)
results <- ET.PenmanMonteith(data, constants, ts="daily", solar="sunshine hours",
wind="yes",vegetation="reference crop")

# long grass (ASCE-EWRI)
results <- ET.PenmanMonteith(data, constants, ts="daily", solar="sunshine hours",
wind="yes",vegetation="long grass")

# other types etc. (Equation 6.70 in Dingman (2015))
results <- ET.PenmanMonteith(data, constants, ts="daily", solar="sunshine hours",
wind="yes",vegetation="deciduous broad-leaf forest")
```

`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,
...)
```

Arguments

`data` A list of data which contains the following items (climate variables) required by PenPan formulation:
Tmax, *Tmin*, *RHmax*, *RHmin*, *Rs* or *n* or *Cd*, *u2* or *uz*

`constants` A list named `constants` consists of constants required for the calculation of PenPan 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^-1,
lat_rad - latitude in radians,

Gsc - solar constant = 0.0820 MJ.m^-2.min^-1,
z - height of wind instrument in m,
sigma - Stefan-Boltzmann constant = 4.903*10^-9 MJ.K^-4.m^-2.day^-1,
lat - latitude in degrees,
alphaA - albedo for Class-A pan,
ap - a constant in PenPan = 2.4.

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 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 evapotranspriation is performed.
Default is `potential ET` for estimating potential evapotranspriation.

`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.

`...` 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 prints a calculation summary to the screen containing the following elements:
- 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)
- Evaporative surface with values of albedo
- 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 *mean*, *max* and *min* values.

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

`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 Evapotranspiratic` 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,data,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(data, constants, ts="daily",
solar="sunshine hours", alpha=0.23,
est="potential ET", pan_coeff=0.71, overest= FALSE)
```

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, ...)
```

Arguments

`data` A list which contains the following items (climate variables) required by Priestley-Taylor formulation:
Tmax, *Tmin*, *RHmax*, *RHmin*, *Rs* or *n* or *Cd*

`constants` A list named `constants` consists of constants required for the calculation of Priestley-Taylor 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^-1,
lat_rad - latitude in radians,
Gsc - solar constant = 0.0820 MJ.m^-2.min^-1,
sigma - Stefan-Boltzmann constant = 4.903*10^-9 MJ.K^-4.m^-2.day^-1,
alphaPT - Priestley-Taylor coefficient = 1.26 for Priestley-Taylor model (Priestley and Taylor, 1972)
G - soil heat flux in MJ.m^-2.day^-1, = 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 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 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.
...	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 prints a calculation summary to the screen containing 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`)
- 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.

The function also 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,data,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(data, constants, ts="daily", solar="sunshine hours", alpha=0.23)
```

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", ...)
```

Arguments

`data`	A list of data which contains the following items (climate variables) required by Romanenko formulation: *Tmax*, *Tmin*, *RHmax*, *RHmin*
`constants`	Dummy argument with a `NULL` value.
`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`.
`...`	Dummy for generic function, no need to define.

Details

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

Value

The function prints a calculation summary to the screen containing 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 *mean*, *max* and *min* values.

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

`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,data

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(data, ts="daily")
```

ET.SzilagyiJozsa *Szilagyi-Jozsa Formulation*

Description

Implementing the Szilagyi-Jozsa 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, ...)
```

Arguments

data	A list of data which contains the following items (climate variables) required by Szilagyi-Jozsa formulation: *Tmax*, *Tmin*, *RHmax*, *RHmin*, *Rs* or *n* or *Cd*, *u2* or *uz*
constants	A list named `constants` consists of constants required for the calculation of Szilagyi-Jozsa 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^-1, *lat_rad* - latitude in radians, *Gsc* - solar constant = 0.0820 MJ.m^-2.min^-1, *z* - height of wind instrument in m, *sigma* - Stefan-Boltzmann constant = 4.903*10^-9 MJ.K^-4.m^-2.day^-1. 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.

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), which is required in the Szilagyi-Jozsa model.
Default is yes.

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 short reference crop.

z0
: Any value (metres), roughness height of the evaporative surface.
Default is 0.23 for short reference crop.

...
: 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 prints a calculation summary to the screen containing the following elements:
- ET model name and ET quantity estimated
- Evaporative surface with values of albedo, as well as the roughness height
- Option for calculating solar radiation (i.e. the value of argument solar)
- 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)
- 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.

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

`ET.Daily`	Daily aggregated estimations of Szilagyi-Jozsa actual evapotranspiration.
`ET.Monthly`	Monthly aggregated estimations of Szilagyi-Jozsa actual evapotranspiration.
`ET.Annual`	Annually aggregated estimations of Szilagyi-Jozsa actual evapotranspiration.
`ET.MonthlyAve`	Monthly averaged estimations of daily Szilagyi-Jozsa actual evapotranspiration.
`ET.AnnualAve`	Annually averaged estimations of daily Szilagyi-Jozsa actual evapotranspiration.
`ET_formulation`	Name of the formulation used which equals to `Szilagyi-Jozsa`.
`ET_type`	A character string containing the 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.
`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

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`,`data`,`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(data, constants, ts="daily",
solar="sunshine hours", wind="yes", windfunction_ver=1948, alpha=0.23, z0=0.2)
```

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, ...)
```

Arguments

`data` A list of data which contains the following items (climate variables) required by Turc formulation:
Tmax, *Tmin*, *Rs* or *n* or *Cd*

`constants` A list named `constants` consists of constants required for the calculation of Turc 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^-1,
lat_rad - latitude in radians,
Gsc - solar constant = 0.0820 MJ.m^-2.min^-1,
sigma - Stefan-Boltzmann constant = 4.903*10^-9 MJ.K^-4.m^-2.day^-1.

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.
`...`	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 prints a calculation summary to the screen containing 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 *mean*, *max* and *min* values.

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

`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,data,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(data, constants, ts="daily", solar="sunshine hours", humid= FALSE)
```

ETComparison — *Compare esimtated 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 `results` which has been derived from function `ET` which can be from any model such as `Penman`, `Penman-Monteith` or `Priestley-Taylor`.

`results2` A list named `results` which has been derived from function `ET` which can be from any model such as `Penman`, `Penman-Monteith` or `Priestley-Taylor`.

`results3` A list named `results` which has been derived from function `ET` which can be from any model such as `Penman`, `Penman-Monteith` or `Priestley-Taylor`. The default is NULL if the user requires the comparison between only two sets of results.

`results4` A list named `results` which has been derived from function `ET` which can be from any model such as `Penman`, `Penman-Monteith` or `Priestley-Taylor`. The default is NULL if the user requires the comparison among only three sets of results.

`results5` A list named `results` which has been derived from function `ET` which can be from any model such as `Penman`, `Penman-Monteith` or `Priestley-Taylor`. The default is NULL if the user requires the comparison among only four sets of results.

`results6` A list named `results` which has been derived from function `ET` which can be from any model such as `Penman`, `Penman-Monteith` or `Priestley-Taylor`. The default is NULL if the user requires the comparison among only five sets of results.

`results7` A list named `results` which has been derived from function `ET` which can be from any model such as `Penman`, `Penman-Monteith` or `Priestley-Taylor`. The default is NULL 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 *YYYY-MM-DD*; 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 *YYYY-MM-DD*; 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(data, constants, ts="daily", solar="sunshine hours",
wind="yes", windfunction_ver = "1948", alpha = 0.08, z0 = 0.001)

# Call ET.PenmanMonteith under the generic function ET
results_PenmanMonteith <- ET.PenmanMonteith(data, constants, ts="daily", solar="sunshine hours",
wind="yes", crop = "short")

# 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 esimtated 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:
Tmax - maximum temperature,
Tmin - minimum temperature,
u2 - average wind speed at 2m,
uz - average wind speed,
Rs - solar radiation,
n - daily sunshine hours,
Precip - precipitation,
Epan - Class-A pan evaporation,
RHmax - maximum relative humidity,
RHmin - minimum relative humidity,
Tdew - average dew point temeprature.

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(data, constants, ts="daily", solar="sunshine hours",
wind="yes", windfunction_ver = "1948", alpha = 0.08, z0 = 0.001)

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

`ETPlot` *Plot the daily, monthly and annual aggregations of esimtated evapotranspiration*

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 *YYYY-MM-DD*.
`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 *YYYY-MM-DD*.

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 estiamtions of evapotranspriation.

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(data, constants, ts="daily", solar="sunshine hours",
wind="yes", windfunction_ver = "1948", alpha = 0.08, z0 = 0.001)


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

# 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 *Observed Class-A Pan Evaporation*

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

```
climatedata
```

Format

A list containing 48 obserations of 5 variables

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(climatedata, constants, stopmissing, timestep,
                         interp_missing_days = FALSE,
                         interp_missing_entries = FALSE,
                         interp_abnormal = FALSE,
                         missing_method = NULL,
                         abnormal_method = NULL)
```

Arguments

`climatedata` A data frame named "climatedata" containing the raw data of date and climate variables.
The data frame contain objects named as "Year", "Month" and "Day" to indicate the date.
The climate variables will be of the following names while it is not compulsory to have all of them:

Tmax.daily - daily maximum temperature in degree Celcius,
Tmin.daily - daily minimum temperature in degree Celcius,
Temp.subdaily - subdaily temperature in degree Celcius,
Tdew.subdaily - subdaily dew point temperature in degree Celcius,
RHmax.daily - daily maximum relative humidity in percentage,
RHmin.daily - daily minimum relative humidity in percentage,
RH.subdaily - subdaily relative humidity in degree Celcius,
Rs.daily - daily incoming solar radiation in Megajoules per square metres per day,
n.daily - daily sunshine hour in hours,
Cd.daily - daily cloud cover in oktas,
Precip.daily - daily precipitation in millimitres,
u2.subdaily - subdaily wind speed measured at 2 metres from the ground surface in metres per second,
uz.subdaily - subdaily wind speed in metres per second,
Epan.daily - daily Class-A pan evaporation in millimitres,
Vp.daily - daily vapour pressure in hectopascal,
Vp.subdaily - subdaily vapour pressure in hectopascal.

In order to determine which variables to include in "climatedata", please see `ET` for the specific data requirements for different formulations.

`constants` A list named "constants" consists of constants required for data pre-processing which may contain the following items:
a_0, *b_0*, *c_0*, *d_0*.
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.

`stopmissing` 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 duaration that the user can toleratre;
- 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.

`interp_missing_days`
`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.

`interp_missing_entries`
`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.

`interp_abnormal`
`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:

- *Tmax.daily* > 100 degree Celcius
- *Tmin.daily* > Tmax.daily
- *Temp.subdaily* > 100 degree Celcius
- *Tdew.daily/Tdew.subdaily* > 100 degree Celcius
- *RHmax.daily* > 100 per cent
- *RHmin.daily* > RHmax.daily
- *RH.subdaily* > 100 per cent
- *Rs.daily/Rs.subdaily* < 0 MJ.m^2
- *n.daily* < 0 hour
- *Cd.daily* < 0 Okta
- *Precip.daily* < 0 mm
- *uz.daily/uz.subdaily* < 0 m/s
- *u2.daily/u2.subdaily* < 0 m/s

- *Epan.daily* < 0 mm
- *Vp.daily/Vp.subdaily* < 0 hPa

`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.

`timestep` Should be either `daily` or `subdaily` to specify the time step of raw climate data used.

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^2/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 modeling1*. JAWRA Journal of the American Water Resources Association, 27, 611-620.

Narapusetty, B., DelSole, T.Tippett, 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")

# Demo - Processing the first year of data
data <- ReadInputs(climatedata[1:2448,],
constants,
stopmissing=c(10,10,3),
timestep="subdaily",
interp_missing_days = TRUE,
interp_missing_entries = TRUE,
```

```
interp_abnormal = TRUE,
missing_method = "DoY average",
abnormal_method = "DoY average")
```

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 aggregaated 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 obsevations of evaporation within specified time period
data("E_OBS")
OBS <- ReadOBSEvaporation(E_OBS, data)
```

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