

Package ‘CSLSevap’

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Type Package

Title Evapo(transpi)ration Calculations

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Description The package 'CSLSevap' bundles multiple ways of calculating evapo(transpi)ration for use in the Wisconsin Department of Natural Resources Central Sands Lakes Study. Methods include: 1) FAO Penman-Monteith reference evapotranspiration, 2) McJannet lake evaporation, and 3) Unmodified Hamond lake evaporation. For most uses, it is only necessary to interact with the 'evaporation' or 'CSLS_daily_met' functions. However, all functions are made accessible to the user since they may be useful in other contexts (e.g., for calculating saturation vapor pressure, dew point temperature).

Imports CSLSdata, dplyr, lubridate, magrittr, NISTunits, rlang, zoo

Suggests devtools, ggplot2, knitr, reshape2, rmarkdown, roxygen2, testthat

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Roxygen list(markdown = TRUE)

VignetteBuilder knitr

R topics documented:

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| aero_resist | <i>Aerodynamic resistance</i> |
|-------------|-------------------------------|

Description

Calculates the aerodynamic resistance (s/m) over a lake as defined by Calder and Neal (1984, pg. 93) and McJannet et al. (2008, Appendix B, Equation 10), and as presented in McMahon et al. (2013) Equation S11.23.

Usage

```
aero_resist(uz, wind_z, z0, A, lake_z, rho_a = 1.2, ca = 0.001013)
```

Arguments

| | |
|--------|---|
| uz | wind speed at wind_z height (m/s) |
| wind_z | height at which uz is measured (m) |
| z0 | aerodynamic roughness of land cover at measurement site (m) |
| A | surface area of the lake (km ²) |
| lake_z | elevation of lake above mean sea level (m) |
| rho_a | density of the air (kg/m ³), defaults to 1.20 kg/m ³ at 20 deg C |
| ca | specific heat of the air (MJ/kg/K), defaults to 0.001013 MJ/kg/K |

Value

ra aerodynamic resistance (s/m)

References

McMahon, T. A., Peel, M. C., Lowe, L., Srikanthan, R., and McVicar, T. R. (2013). Estimating actual, potential, reference crop and pan evaporation using standard meteorological data: a pragmatic synthesis, *Hydrol. Earth Syst. Sci.*, 17, 1331–1363. <https://doi.org/10.5194/hess-17-1331-2013>.

McJannet, D. L., Webster, I. T., Stenson, M. P., and Sherman, B.S. (2008). Estimating open water evaporation for the Murray-Darling Basin. A report to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yields Project, CSIRO, Australia, 50 pp. Retrieved from <http://www.clw.csiro.au/publications/waterforahealthycountry/mdbsy/technical/U-OpenWaterEvaporation.pdf>.

| | |
|--------------|--------------------------|
| cloud_factor | <i>Cloudiness factor</i> |
|--------------|--------------------------|

Description

Estimates the fraction of cloud cover based on McJannet et al. (2008b, Equations 14 and 15), as presented by McMahon et al. (2013), Equations S3.17 and S3.18.

Usage

cloud_factor(Rs, Rso)

Arguments

| | |
|-----|---|
| Rs | incoming solar radiation (MJ/m ² /day) |
| Rso | clear sky radiation (MJ/m ² /day). |

Value

Cf the fraction of cloud cover (-)

References

McMahon, T. A., Peel, M. C., Lowe, L., Srikanthan, R., and McVicar, T. R. (2013). Estimating actual, potential, reference crop and pan evaporation using standard meteorological data: a pragmatic synthesis, *Hydrol. Earth Syst. Sci.*, 17, 1331–1363. <https://doi.org/10.5194/hess-17-1331-2013>.

McJannet, D. L., Webster, I. T., Stenson, M. P., and Sherman, B.S. (2008). Estimating open water evaporation for the Murray-Darling Basin. A report to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yields Project, CSIRO, Australia, 50 pp. Retrieved from <http://www.clw.csiro.au/publications/waterforahealthycountry/mdbsy/technical/U-OpenWaterEvaporation.pdf>.

CSLS_daily_met

Given CSLS lake and method, calculate daily evaporation

Description

This function calculates daily evaporation for a CSLS lake given the desired method and lake name. While this function can use any of the methods available in [evaporation](#), it is currently hard-wired to load input data from the CSLS field campaign (as available in **CSLSdata**) and analysis is restricted to dates with available weather, lake surface temperature, and lake level data (via [CSLS_find_common_dates](#)) regardless of the requirements of the chosen method.

Usage

```
CSLS_daily_met(
  method = "McJannet",
  use_lst = TRUE,
  lakename,
  Lz = 90,
  wind_elev = 3,
  z0 = 0.02,
  no_condensation = FALSE
)
```

Arguments

| | |
|-----------------|--|
| method | denotes which evaporation method to use ("FAO", "McJannet", or "Hamon"). |
| use_lst | logical defaults to TRUE to use available lake surface temperature data. |
| lakename | name of lake currently evaluating |
| Lz | longitude of location's measurement timezone (degrees west of Greenwich). For example, Lz = 75, 90, 105 and 120° for measurement times based on the Eastern, Central, Rocky Mountain and Pacific time zones (United States). |
| wind_elev | height at which wind is measured (m), default: 3 |
| z0 | aerodynamic roughness of weather measurement site (m), default: 0.2 |
| no_condensation | defaults to FALSE. If TRUE, forces negative evapotranspiration values (i.e., condensation) to zero |

Value

weather, a data frame with daily weather information including:

| | |
|----------|---|
| date | day of each weather observation POSIXct |
| atmp_min | minimum air temperature for the day (deg C) |
| atmp_max | maximum air temperature for the day (deg C) |
| RH_min | minimum relative humidity for the day (percent) |
| RH_max | maximum relative humidity for the day (percent) |
| P | total precipitation for the day (mm) |
| E | total lake evaporation for the day (mm) |

Examples

```
# Note that "lakename" is not really used for "Hamon" method
# However, this function is currently hardwired to require it.
lake      <- "Pleasant"
daily_met <- CSLS_daily_met("McJannet", lakename = lake)
daily_met <- CSLS_daily_met("McJannet", use_lst = FALSE, lakename = lake)
daily_met <- CSLS_daily_met("Hamon", lakename = lake)
```

CSLS_find_common_dates

Given CSLS data, find common dates of record

Description

Finds date interval with records for lst, weather, and lake levels. Checks for the latest "start" date in each of these timeseries, then checks for the earliest "end" date in each timeseries, then restricts all input data to be within the overlapping interval. Lastly, interpolates the lake_levels dataset over NA values to ensure a continuous timeseries of lake area and lake depth for evaporation calculations.

Usage

```
CSLS_find_common_dates(weather, lake_levels, lst)
```

Arguments

| | |
|-------------|--|
| weather | a data frame with hourly weather data incl. air temperature (atmp), relative humidity (RH), incoming solar radiation (Rs), precipitation (P), and wind speed (wind). |
| lake_levels | a data frame with daily water level measurements as formatted in the lake_levels dataset, subset to lake level records for the lake of interest. |
| lst | a data frame with sub-monthly lake surface temperature measurements as formatted in the lst_HOBO dataset, subset for a single lake. |

Details

Note that this function may cause undesired behavior when using `CSLS_daily_met` with the Unmodified Hammon method or the McJannet method with `use_lst = FALSE`. Neither uses the `lst` dataset for calculations, yet other input data is restricted based on the availability of the `lst` dataset. Unmodified Hamon also does not use `lake_levels`, but is restricted by the availability of that dataset as well.

Value

a list with the following items:

| | |
|---------|--|
| weather | same as input weather data frame, but filtered to only include data during the overlap time period |
| lst | same as input lst data frame, but filtered to only include data during the overlap time period and summarized at a daily time step |

| | |
|-------------|---|
| lake_levels | same as input lake_levels data frame, but filtered to only include data during the overlap time period and with missing (NA) lake levels interpolated |
| wtmp0 | initial lake surface temperature (degC) from the day before the weather, lst, and lake_levels timeseries begin |

| | |
|------------------|---|
| CSLS_format_lake | <i>Given CSLS data, format "lake" input parameter</i> |
|------------------|---|

Description

Extracts location information for the lake from the site dictionary and reformats for input into lake evaporation functions.

Usage

```
CSLS_format_lake(elev_area_vol, lake_levels, lst = NULL, wtmp0, use_lst)
```

Arguments

| | |
|---------------|--|
| elev_area_vol | a data frame with the lake, stage_m, surf_area_m2, and volume_m3 as in the elev_area_voldataset, subset for a single lake. |
| lake_levels | a data frame with daily water level measurements as formatted in the lake_levels dataset, subset to lake level records for the lake of interest. |
| lst | a data frame with sub-monthly lake surface temperature measurements as formatted in the lst_HOBO dataset, subset for a single lake. |
| wtmp0 | initial water temperature for first day in timeseries (degC) |
| use_lst | logical defaults to TRUE to use available lake surface temperature data. |

Value

lake, a list with the following lake-specific parameters:

| | |
|---------|--|
| A | surface area of the lake (km ²) |
| depth_m | depth of the lake (m). Can be a static value or vector corresponding with date-times vector. |
| lst | optional data frame with date (datetime) and ltmp (lake temperature, degC). |
| wtmp0 | required initial water temperature for first day in datetimes (degC) |

| | |
|-----------------|--|
| CSLS_format_loc | <i>Given CSLS data, format "loc" input parameter</i> |
|-----------------|--|

Description

Extracts location information for the lake from the dictionary and reformats for input into lake evaporation functions.

Usage

```
CSLS_format_loc(dictionary, Lz = 90)
```

Arguments

| | |
|------------|---|
| dictionary | a data frame with the obs_type ("LK"), elev_m, lat_deg, and long_deg for the lake of interest. |
| Lz | the longitude of the local timezone (degrees west of Greenwich, ranges from 0 to 360 degrees). Defaults to 90 for Central Time Zone, USA. |

Value

*loc, a list with the following location-specific parameters:

| | |
|-----|---|
| z | elevation above mean sea level (m) |
| phi | latitude of location (radians). Positive for northern hemisphere, negative for southern hemisphere |
| Lm | longitude of location (degrees west of Greenwich) |
| Lz | longitude of location's measurement timezone (degrees west of Greenwich). For example, Lz = 75, 90, 105 and 120° for measurement times based on the Eastern, Central, Rocky Mountain and Pacific time zones (United States) and Lz = 0° for Greenwich, 330° for Cairo (Egypt), and 255° for Bangkok (Thailand). |

| | |
|---------------------|--|
| CSLS_format_weather | <i>Given CSLS data, format "weather" input parameter</i> |
|---------------------|--|

Description

Takes hourly weather data, summarizes as daily weather data, and re-formats for input to lake evaporation functions

Usage

```
CSLS_format_weather(weather, wind_elev = 3, z0 = 0.02)
```

Arguments

| | |
|-----------|--|
| weather | a data frame with hourly weather data incl. air temperature (atmp), relative humidity (RH), incoming solar radiation (Rs), precipitation (P), and wind speed (wind). |
| wind_elev | height at which wind is measured (m), default: 3 |
| z0 | aerodynamic roughness of weather measurement site (m), default: 0.02 |

Value

| | |
|---|---|
| weather a list with weather data that includes: | |
| dt | string indicating the timestep of input weather series. Expects "hourly", "daily", or "monthly". |
| datetimes | datetimes of weather records POSIXct . If monthly timestep, make sure date is the 15th of each month. |
| atmp | If hourly timestep, vector of air temperature (degrees C) corresponding with datetimes vector. If daily or monthly timestep, list with two vectors, "min" and "max", with mean daily min and max air temperature (degrees C) corresponding with datetimes vector |
| RH | If hourly timestep, vector of relative humidity (percent) corresponding with datetimes vector. If daily or monthly timestep, list with two vectors, "min" and "max", with mean daily min and max relative humidity (percent) corresponding with datetimes vector. |
| Rs | vector of incoming solar or shortwave radiation (MJ/m^2/hr if hourly timestep, MG/m^2/day if daily or monthly), corresponding with datetimes vector. |
| wind | vector with mean wind speed (m/s), corresponding with datetimes vector. |
| wind_elev | atomic number, height at which wind is measured (m) |
| z0 | aerodynamic roughness of weather measurement site (m) |

| | |
|----------------|-------------------------------|
| daylight_hours | <i>Maximum daylight hours</i> |
|----------------|-------------------------------|

Description

Calculates the maximum number of daylight hours using Equation 34 from Allen et al. (1998). Identical to Equation 2.3 in Harwell (2012).

Usage

daylight_hours(omega_s)

Arguments

| | |
|---------|-----------------------------|
| omega_s | sunset hour angle (radians) |
|---------|-----------------------------|

Value

| | |
|---|---------------------------------|
| D | maximum possible daylight hours |
|---|---------------------------------|

References

- Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). Crop evapotranspiration: Guidelines for computing crop water requirements. Rome: FAO. Retrieved from <http://www.fao.org/docrep/X0490E/x0490e00.htm>.
- Harwell, G.R., 2012, Estimation of evaporation from open water—A review of selected studies, summary of U.S. Army Corps of Engineers data collection and methods, and evaluation of two methods for estimation of evaporation from five reservoirs in Texas: U.S. Geological Survey Scientific Investigations Report 2012–5202, 96 p.

| | |
|-------------|--------------------------|
| declination | <i>Solar declination</i> |
|-------------|--------------------------|

Description

Calculates the solar declination (radians) using Equation 24 from Allen et al. (1998). Similar to Equation 2.1 in Harwell (2012), but with some rounding differences.

Usage

```
declination(J)
```

Arguments

| | |
|---|---|
| J | Julian day, i.e., the number of the day in the year between 1 (1 January) and 365 or 366 (31 December). |
|---|---|

Value

| | |
|-------|-----------------------------|
| delta | solar declination (radians) |
|-------|-----------------------------|

References

- Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). Crop evapotranspiration: Guidelines for computing crop water requirements. Rome: FAO. Retrieved from <http://www.fao.org/docrep/X0490E/x0490e00.htm>.
- Harwell, G.R., 2012, Estimation of evaporation from open water—A review of selected studies, summary of U.S. Army Corps of Engineers data collection and methods, and evaluation of two methods for estimation of evaporation from five reservoirs in Texas: U.S. Geological Survey Scientific Investigations Report 2012–5202, 96 p.

| | |
|-------------|----------------------------------|
| evaporation | <i>Evaporation (all methods)</i> |
|-------------|----------------------------------|

Description

Calculates evaporation (mm/day given daily or monthly inputs, or mm/hour given hourly inputs) using specified method. Options include:

1. **FAO**: FAO Penman-Montieth reference evapotranspiration (potential evaporation for a reference grass crop) based on Allen et al. (1998) for hourly, daily, or monthly timestep.
2. **McJannet**: Daily lake evaporation based on the method in McJannet et al. (2008) as presented in McMahon et al. (2013)
3. **Hamon**: Daily lake evaporation based on the unmodified Hamon method as presented in Harwell (2012)

Usage

```
evaporation(
  method = "FAO",
  loc,
  weather,
  lake = NULL,
  albedo = list(ref_crop = 0.23, water = 0.08),
  no_condensation = TRUE,
  rho_a = 1.2,
  ca = 0.001013
)
```

Arguments

| | |
|---------|--|
| method | denotes which evaporation method to use ("FAO", "McJannet", or "Hamon"). |
| loc | a list with location information that includes: <ul style="list-style-type: none"> • z: elevation above mean sea level (m) • phi: latitude of location (radians). Positive for northern hemisphere, negative for southern hemisphere. • Lm: longitude of location (degrees west of Greenwich). • Lz: longitude of location's measurement timezone (degrees west of Greenwich). For example, Lz = 75, 90, 105 and 120° for measurement times based on the Eastern, Central, Rocky Mountain and Pacific time zones (United States) and Lz = 0° for Greenwich, 330° for Cairo (Egypt), and 255° for Bangkok (Thailand). |
| weather | a list with weather data that includes: <ul style="list-style-type: none"> • dt: string indicating the timestep of input weather series. Expects "hourly", "daily", or "monthly". • datetimes: datetimes of weather records POSIXct. If monthly timestep, make sure date is the 15th of each month. • atmp: If hourly timestep, vector of air temperature (degrees C) corresponding with datetimes vector. If daily or monthly timestep, list with two vectors, "min" and "max", with mean daily min and max air temperature (degrees C) corresponding with datetimes vector |

| | |
|-----------------|---|
| | <ul style="list-style-type: none"> • RH: If hourly timestep, vector of relative humidity (percent) corresponding with datetimes vector. If daily or monthly timestep, list with two vectors, "min" and "max", with mean daily min and max relative humidity (percent) corresponding with datetimes vector. • Rs: vector of incoming solar or shortwave radiation ($\text{MJ}/\text{m}^2/\text{hr}$ if hourly timestep, $\text{MJ}/\text{m}^2/\text{day}$ if daily or monthly), corresponding with datetimes vector. • wind: vector with mean wind speed (m/s), corresponding with datetimes vector. • wind_elev: atomic number, height at which wind is measured (m) • z0: aerodynamic roughness of weather measurement site (m) |
| lake | <p>A list with lake data. Defaults to NULL, but for McJannet lake evaporation calculations, should include:</p> <ul style="list-style-type: none"> • A: surface area of the lake (km^2). • depth_m: depth of the lake (m). Can be a static value or vector corresponding with datetimes vector. • lst: optional data frame with date (datetime) and ltmp (lake temperature, degC). • wtmp0: required initial water temperature for first day in datetimes (degC). |
| albedo | <p>a list with albedos for different surfaces, defaults to:</p> <ul style="list-style-type: none"> • ref_crop: albedo of the hypothetical grass reference crop, 0.23 • water: albedo of water, 0.08. |
| no_condensation | defaults to TRUE to force negative evapotranspiration values (i.e., condensation) to zero |
| rho_a | density of the air (kg/m^3), defaults to $1.20 \text{ kg}/\text{m}^3$ at 20 deg C |
| ca | specific heat of the air ($\text{MJ}/\text{kg}/\text{K}$), defaults to $0.001013 \text{ MJ}/\text{kg}/\text{K}$ |

Details

When assessing which parameters are required for a given method, use the following guidelines:

| Input | FAO | McJannet | Hamond |
|---------|-------------------|--------------------|-------------------------------------|
| loc | all | all | only <i>phi</i> |
| weather | all but <i>z0</i> | all | only <i>datetimes</i> & <i>atmp</i> |
| lake | none, use NULL | all but <i>lst</i> | none, use NULL |

Value

| | |
|------|---|
| evap | Evapo(transpi)ration (mm/hour or mm/day) vector |
|------|---|

References

- Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). Crop evapotranspiration: Guidelines for computing crop water requirements. Rome: FAO. Retrieved from <http://www.fao.org/docrep/X0490E/x0490e00.htm>.
- McJannet, D. L., Webster, I. T., Stenson, M. P., and Sherman, B.S. (2008). Estimating open water evaporation for the Murray-Darling Basin. A report to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yields Project, CSIRO, Australia, 50 pp. Retrieved from <http://www.clw.csiro.au/publications/waterforahealthycountry/mdbsy/technical/U-OpenWaterEvaporation.pdf>.

McMahon, T. A., Peel, M. C., Lowe, L., Srikanthan, R., and McVicar, T. R. (2013). Estimating actual, potential, reference crop and pan evaporation using standard meteorological data: a pragmatic synthesis, *Hydrol. Earth Syst. Sci.*, 17, 1331–1363. <https://doi.org/10.5194/hess-17-1331-2013>.

Harwell, G.R., 2012, Estimation of evaporation from open water—A review of selected studies, summary of U.S. Army Corps of Engineers data collection and methods, and evaluation of two methods for estimation of evaporation from five reservoirs in Texas: U.S. Geological Survey Scientific Investigations Report 2012–5202, 96 p.

Examples

```
# Creating inputs
lakename <- "Pleasant"
dictionary <- CSLSData::dictionary[[lakename]]
loc <- CSLS_format_loc(dictionary, Lz)
```

| | |
|-----------|------------------|
| heat_flux | <i>Heat flux</i> |
|-----------|------------------|

Description

Calculates the heat flux for the land surface in question. When using the "FAO" evaporation method, calculates the soil heat flux beneath a dense cover of grass based on Equations 42-46 in Allen et al. (1998). When using the "McJannet" lake evaporation method, calculates the change in heat storage based on water temperature following McJannet et al. (2008) Equation 31 as presented in McMahon et al. S11.33 (2013).

Usage

```
heat_flux(
  method,
  loc,
  lake,
  weather,
  albedo,
  Rn = NULL,
  rho_w = 997.9,
  cw = 0.00419
)
```

Arguments

- | | |
|--------|--|
| method | denotes which evaporation method to use ("FAO", "McJannet", or "Hamon"). |
| loc | a list with location information that includes: <ul style="list-style-type: none"> • z: elevation above mean sea level (m) • phi: latitude of location (radians). Positive for northern hemisphere, negative for southern hemisphere. • Lm: longitude of location (degrees west of Greenwich). |

| | |
|--------------|---|
| | <ul style="list-style-type: none"> • Lz: longitude of location's measurement timezone (degrees west of Greenwich). For example, $Lz = 75, 90, 105$ and 120° for measurement times based on the Eastern, Central, Rocky Mountain and Pacific time zones (United States) and $Lz = 0^\circ$ for Greenwich, 330° for Cairo (Egypt), and 255° for Bangkok (Thailand). |
| lake | <p>A list with lake data. Defaults to NULL, but for McJannet lake evaporation calculations, should include:</p> <ul style="list-style-type: none"> • A: surface area of the lake (km^2). • depth_m: depth of the lake (m). Can be a static value or vector corresponding with datetimes vector. • lst: optional data frame with date (datetime) and ltmp (lake temperature, degC). • wtmp0: required initial water temperature for first day in datetimes (degC). |
| weather | <p>a list with weather data that includes:</p> <ul style="list-style-type: none"> • dt: string indicating the timestep of input weather series. Expects "hourly", "daily", or "monthly". • datetimes: datetimes of weather records POSIXct. If monthly timestep, make sure date is the 15th of each month. • atmp: If hourly timestep, vector of air temperature (degrees C) corresponding with datetimes vector. If daily or monthly timestep, list with two vectors, "min" and "max", with mean daily min and max air temperature (degrees C) corresponding with datetimes vector • RH: If hourly timestep, vector of relative humidity (percent) corresponding with datetimes vector. If daily or monthly timestep, list with two vectors, "min" and "max", with mean daily min and max relative humidity (percent) corresponding with datetimes vector. • Rs: vector of incoming solar or shortwave radiation ($\text{MJ}/\text{m}^2/\text{hr}$ if hourly timestep, $\text{MG}/\text{m}^2/\text{day}$ if daily or monthly), corresponding with datetimes vector. • wind: vector with mean wind speed (m/s), corresponding with datetimes vector. • wind_elev: atomic number, height at which wind is measured (m) • z0: aerodynamic roughness of weather measurement site (m) |
| albedo | <p>a list with albedos for different surfaces, defaults to:</p> <ul style="list-style-type: none"> • ref_crop: albedo of the hypothetical grass reference crop, 0.23 • water: albedo of water, 0.08. |
| Rn | Net solar or shortwave radiation ($\text{MJ}/\text{m}^2/\text{timestep}$) |
| rho_w | density of water (kg/m^3), defaults to $997.9 \text{ kg}/\text{m}^3$ at 20 deg C |
| cw | specific heat of water ($\text{MJ}/\text{kg}/\text{K}$), defaults to 0.00419 |
| Value | |
| G | heat flux ($\text{MJ}/\text{m}^2/\text{hr}$) |

References

Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). Crop evapotranspiration: Guidelines for computing crop water requirements. Rome: FAO. Retrieved from <http://www.fao.org/docrep/X0490E/x0490e00.htm>.

McMahon, T. A., Peel, M. C., Lowe, L., Srikanthan, R., and McVicar, T. R. (2013). Estimating actual, potential, reference crop and pan evaporation using standard meteorological data: a pragmatic synthesis, *Hydrol. Earth Syst. Sci.*, 17, 1331–1363. <https://doi.org/10.5194/hess-17-1331-2013>.

McJannet, D. L., Webster, I. T., Stenson, M. P., and Sherman, B.S. (2008). Estimating open water evaporation for the Murray-Darling Basin. A report to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yields Project, CSIRO, Australia, 50 pp. Retrieved from <http://www.clw.csiro.au/publications/waterforahealthycountry/mdbsy/technical/U-OpenWaterEvaporation.pdf>.

hour_angle

Solar time angle

Description

Calculates the beginning, midpoint, and end solar time angle (radians) for a given location and day of the year using Equations 29-33 from Allen et al. (1998). Used for calculations at an hourly or shorter timestep.

Usage

hour_angle(tm_{id}, tL, L_m, L_z)

Arguments

| | |
|------------------|--|
| tm _{id} | date and time of the midpoint of the time period POSIXct . |
| tL | length of the time period, from lubridate function "interval_len". |
| L _m | longitude of the measurement site (degrees west of Greenwich). |
| L _z | longitude of the center of the time zone used for measurements (degrees west of Greenwich). For example, L _z = 75, 90, 105 and 120° for the Eastern, Central, Rocky Mountain and Pacific time zones (United States) and L _z = 0° for Greenwich, 330° for Cairo (Egypt), and 255° for Bangkok (Thailand). |

Value

| | |
|--------------------|---|
| omega ₁ | solar time angle at the beginning of the period (radians) |
| omega ₂ | solar time angle at the end of the period (radians) |

References

Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). Crop evapotranspiration: Guidelines for computing crop water requirements. Rome: FAO. Retrieved from <http://www.fao.org/docrep/X0490E/x0490e00.htm>.

| | |
|-------------------|--------------------------|
| hour_angle_sunset | <i>Sunset hour angle</i> |
|-------------------|--------------------------|

Description

Calculates the sunset hour angle (radians) for a given location and day of the year using Equation 25 from Allen et al. (1998). Identical to Equation 2.2 in Harwell (2012).

Usage

```
hour_angle_sunset(phi, delta)
```

Arguments

| | |
|-------|---|
| phi | latitude of the location (radians). Positive for northern hemisphere, negative for southern hemisphere. |
| delta | the solar declination based on the Julian day (radians) |

Value

| | |
|---------|-----------------------------|
| omega_s | sunset hour angle (radians) |
|---------|-----------------------------|

References

Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). Crop evapotranspiration: Guidelines for computing crop water requirements. Rome: FAO. Retrieved from <http://www.fao.org/docrep/X0490E/x0490e00.htm>.

Harwell, G.R., 2012, Estimation of evaporation from open water—A review of selected studies, summary of U.S. Army Corps of Engineers data collection and methods, and evaluation of two methods for estimation of evaporation from five reservoirs in Texas: U.S. Geological Survey Scientific Investigations Report 2012–5202, 96 p.

| | |
|--------------|--|
| inverse_dist | <i>Inverse relative distance Earth-Sun</i> |
|--------------|--|

Description

Calculates the inverse relative distance Earth-Sun using Equation 23 from Allen et al. (1998).

Usage

```
inverse_dist(J)
```

Arguments

| | |
|---|---|
| J | Julian day, i.e., the number of the day in the year between 1 (1 January) and 365 or 366 (31 December). |
|---|---|

Value

| | |
|----|--|
| dr | inverse relative distance Earth-Sun (unitless) |
|----|--|

References

Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). Crop evapotranspiration: Guidelines for computing crop water requirements. Rome: FAO. Retrieved from <http://www.fao.org/docrep/X0490E/x0490e00.htm>.

| | |
|-------------------|------------------------------------|
| latent_heat_vapor | <i>Latent heat of vaporization</i> |
|-------------------|------------------------------------|

Description

Calculates the latent heat of vaporization as a function of air temperature.

Usage

```
latent_heat_vapor(atmp)
```

Arguments

| | |
|------|-----------------------------|
| atmp | air temperature (degrees C) |
|------|-----------------------------|

Value

| | |
|--------|---|
| lambda | the latent heat of vaporization (MJ/kg) |
|--------|---|

References

<https://cran.r-project.org/web/packages/bigleaf/bigleaf.pdf>

| | |
|------------------------|-------------------------------|
| psychrometric_constant | <i>Psychrometric constant</i> |
|------------------------|-------------------------------|

Description

Calculates the psychrometric constant for a given elevation based on Equation 7 and 8 in Allen et al. (1998).

Usage

```
psychrometric_constant(
  z,
  atmp = NULL,
  lambda = 2.45,
  cp = 0.001013,
  epsilon = 0.622
)
```


Arguments

| | |
|---------|--|
| z | elevation above sea level (m) |
| atmp | air temperature (degrees C). Optional value used to calculate the latent heat of vaporization. Defaults to NULL to use constant value of lambda. |
| lambda | latent heat of vaporization (MJ/kg). Default is 2.45. |
| cp | specific heat at constant pressure (MJ/kg/degC). Default is 1.1013e-3. |
| epsilon | ratio molecular weight of water vapour/dry air (-). Default is 0.622 |

Value

| | |
|-------|--|
| gamma | the psychrometric constant for the given elevation (kPa/degrees C) |
|-------|--|

References

Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). Crop evapotranspiration: Guidelines for computing crop water requirements. Rome: FAO. Retrieved from <http://www.fao.org/docrep/X0490E/x0490e00.htm>.

| | |
|-----|--|
| R_a | <i>Radiation, extraterrestrial solar</i> |
|-----|--|

Description

Calculates the extraterrestrial radiation for a given location and timestep. For daily periods, uses Equation 21 from Allen et al. (1998). For hourly or shorter periods, uses Equation 28 from Allen et al. (1998).

Usage

```
R_a(dt, datetimes, phi, Lm, Lz, Gsc = 0.082)
```

Arguments

| | |
|-----------|--|
| dt | a string indicating the timestep of calculation. If not "hourly", assumes a daily or larger timestep |
| datetimes | timeseries of datetimes to use in calculations POSIXct |
| phi | latitude of the location (radians). Positive for northern hemisphere, negative for southern hemisphere. |
| Lm | longitude of the measurement site (degrees west of Greenwich). |
| Lz | longitude of the center of the time zone used for measurements (degrees west of Greenwich). For example, Lz = 75, 90, 105 and 120° for the Eastern, Central, Rocky Mountain and Pacific time zones (United States) and Lz = 0° for Greenwich, 330° for Cairo (Egypt), and 255° for Bangkok (Thailand). |
| Gsc | solar constant (MJ/m ² /min). Defaults to 0.0820 MJ/m ² /min. |

Value

| | |
|----|--|
| Ra | extraterrestrial radiation (MJ/m ² /day) or (MJ/m ² /hour), depending on length of input time period |
|----|--|

References

Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). Crop evapotranspiration: Guidelines for computing crop water requirements. Rome: FAO. Retrieved from <http://www.fao.org/docrep/X0490E/x0490e00.htm>.

| | |
|------|-------------------------------------|
| R_il | <i>Radiation, incoming longwave</i> |
|------|-------------------------------------|

Description

Calculates the incoming longwave radiation using cloud cover fraction and mean daily air temperature based on McMahon et al. (2013) Equation S11.27.

Usage

```
R_il(Cf, atmp, SBc = 4.903e-09)
```

Arguments

| | |
|------|--|
| Cf | fraction of cloud cover (-) |
| atmp | air temperature (degrees C). When dt is "daily" or larger, argument should be a list with elements "min" and "max" for daily min and max temperatures. When dt is "hourly", argument should be a vector with hourly recorded temperatures. |
| SBc | Stefan-Boltzman constant (MJ/m ² /day). Defaults to 4.903e-9 MJ/m ² /day. |

Value

| | |
|----|---------------------------------|
| Cf | the fraction of cloud cover (-) |
|----|---------------------------------|

References

McMahon, T. A., Peel, M. C., Lowe, L., Srikanthan, R., and McVicar, T. R.: Estimating actual, potential, reference crop and pan evaporation using standard meteorological data: a pragmatic synthesis, Hydrol. Earth Syst. Sci., 17, 1331–1363, <https://doi.org/10.5194/hess-17-1331-2013>, 2013.

| | |
|-----|-----------------------|
| R_n | <i>Radiation, net</i> |
|-----|-----------------------|

Description

Calculates the net solar or shortwave radiation using the "FAO" Penman Monteith approach for reference evapotranspiration (Allen et al., 1998, Equation 38), the "McJannet" approach for lake temperature (McMahon et al., 2013, Equation S11.25), or the McJannet approach for "wet_bulb" temperature (McMahon et al., 2013, Equation S11.31).

Usage

```
R_n(type = "FAO", loc, lake, weather, albedo)
```

Arguments

| | |
|---------|---|
| type | type of net radiation function to use. Defaults to "FAO" for FAO Penman-Monteith reference evapotranspiration. Other options include "McJannet" for net radiation at lake temperature and "wet_bulb" for net radiation at wet-bulb temperature. |
| loc | <p>a list with location information that includes:</p> <ul style="list-style-type: none"> • z: elevation above mean sea level (m) • phi: latitude of location (radians). Positive for northern hemisphere, negative for southern hemisphere. • Lm: longitude of location (degrees west of Greenwich). • Lz: longitude of location's measurement timezone (degrees west of Greenwich). For example, Lz = 75, 90, 105 and 120° for measurement times based on the Eastern, Central, Rocky Mountain and Pacific time zones (United States) and Lz = 0° for Greenwich, 330° for Cairo (Egypt), and 255° for Bangkok (Thailand). |
| lake | <p>A list with lake data. Defaults to NULL, but for McJannet lake evaporation calculations, should include:</p> <ul style="list-style-type: none"> • A: surface area of the lake (km²). • depth_m: depth of the lake (m). Can be a static value or vector corresponding with datetimes vector. • lst: optional data frame with date (datetime) and ltmp (lake temperature, degC). • wtmp0: required initial water temperature for first day in datetimes (degC). |
| weather | <p>a list with weather data that includes:</p> <ul style="list-style-type: none"> • dt: string indicating the timestep of input weather series. Expects "hourly", "daily", or "monthly". • datetimes: datetimes of weather records POSIXct. If monthly timestep, make sure date is the 15th of each month. • atmp: If hourly timestep, vector of air temperature (degrees C) corresponding with datetimes vector. If daily or monthly timestep, list with two vectors, "min" and "max", with mean daily min and max air temperature (degrees C) corresponding with datetimes vector • RH: If hourly timestep, vector of relative humidity (percent) corresponding with datetimes vector. If daily or monthly timestep, list with two vectors, "min" and "max", with mean daily min and max relative humidity (percent) corresponding with datetimes vector. • Rs: vector of incoming solar or shortwave radiation (MJ/m²/hr if hourly timestep, MG/m²/day if daily or monthly), corresponding with datetimes vector. • wind: vector with mean wind speed (m/s), corresponding with datetimes vector. • wind_elev: atomic number, height at which wind is measured (m) • z0: aerodynamic roughness of weather measurement site (m) |
| albedo | <p>a list with albedos for different surfaces, defaults to:</p> <ul style="list-style-type: none"> • ref_crop: albedo of the hypothetical grass reference crop, 0.23 • water: albedo of water, 0.08. |

Value

Rn net radiation (MJ/m²/timestep)

References

Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). Crop evapotranspiration: Guidelines for computing crop water requirements. Rome: FAO. Retrieved from <http://www.fao.org/docrep/X0490E/x0490e00.htm>.

McMahon, T. A., Peel, M. C., Lowe, L., Srikanthan, R., and McVicar, T. R. (2013). Estimating actual, potential, reference crop and pan evaporation using standard meteorological data: a pragmatic synthesis, Hydrol. Earth Syst. Sci., 17, 1331–1363. <https://doi.org/10.5194/hess-17-1331-2013>.

| | |
|------|--------------------------------|
| R_nI | <i>Radiation, net longwave</i> |
|------|--------------------------------|

Description

Calculates the net outgoing longwave radiation for a given location based on incoming solar radiation, incoming clear-sky radiation, and air temperature records. Based on Equation 39 and p.74-75 in Allen et al. (1998).

Usage

R_nI(dt, Rs, Rso, ea, atmp, SBc = 4.903e-09)

Arguments

| | |
|------|---|
| dt | string indicating the timestep of input weather series. Expects "hourly", "daily", or "monthly". |
| Rs | incoming solar radiation (MJ/m ² /timestep), vector or atomic number |
| Rso | clear-sky solar radiation (MJ/m ² /timestep), vector or atomic number. |
| ea | actual vapour pressure (kPa), vector or atomic number. |
| atmp | air temperature (degrees C). When dt is "daily" or larger, argument should be a list with elements "min" and "max" for daily min and max temperatures. When dt is "hourly", argument should be a vector or atomic number with hourly recorded temperatures. |
| SBc | Stefan-Boltzman constant (MJ/m ² /day). Defaults to 4.903e-9 MJ/m ² /day. |

Value

RnI Net outgoing longwave radiation (MJ/m²/hour or MJ/m²/day, depending on dt)

References

Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). Crop evapotranspiration: Guidelines for computing crop water requirements. Rome: FAO. Retrieved from <http://www.fao.org/docrep/X0490E/x0490e00.htm>.

| | |
|------|---------------------------------------|
| R_ns | <i>Radiation, net solar/shortwave</i> |
|------|---------------------------------------|

Description

Calculates the net solar or shortwave radiation for a given location based on incoming solar radiation timeseries. Based on Equation 38 in Allen et al. (1998).

Usage

```
R_ns(Rs, albedo = 0.23)
```

Arguments

| | |
|--------|--|
| Rs | incoming solar radiation (MJ/m ² /timestep) |
| albedo | albedo or canopy reflection coefficient (-). Defaults to 0.23 for the hypothetical grass reference crop. |

Value

| | |
|-----|--|
| Rns | Net solar or shortwave radiation (MJ/m ² /timestep) |
|-----|--|

References

Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). Crop evapotranspiration: Guidelines for computing crop water requirements. Rome: FAO. Retrieved from <http://www.fao.org/docrep/X0490E/x0490e00.htm>.

| | |
|------|-------------------------------------|
| R_ol | <i>Radiation, outgoing longwave</i> |
|------|-------------------------------------|

Description

Calculates the outgoing longwave radiation for a lake as a function of lake temperature ("McJannet"; McMahon et al., 2013, Equation S11.27) or as a function of wet bulb temperature ("wet_bulb"; McMahon et al., 2013, Equation S11.32).

Usage

```
R_ol(type = "McJannet", tmp1, tmp2 = NULL, SBc = 4.903e-09)
```

Arguments

| | |
|------|---|
| type | type of outgoing longwave radiation function to use. Defaults to "McJannet" for outgoing longwave radiation at lake temperature. Set to "wet_bulb" for outgoing longwave radiation at wet-bulb temperature. |
| tmp1 | daily lake water temperature (if "McJannet") or wet bulb temperature (if "wet_bulb") (degrees C). |

| | |
|------|--|
| tmp2 | defaults to NULL. If "wet_bulb", set to air temperature (degrees C). When dt is "daily" or larger, argument should be a list with elements "min" and "max" for daily min and max temperatures. When dt is "hourly", argument should be a vector with hourly recorded temperatures. |
| SBC | Stefan-Boltzman constant (MJ/m ² /day). Defaults to 4.903e-9 MJ/m ² /day. |

Value

| | |
|-----|--|
| Ro1 | outgoing longwave radiation (MJ/m ² /day) |
|-----|--|

References

McMahon, T. A., Peel, M. C., Lowe, L., Srikanthan, R., and McVicar, T. R.: Estimating actual, potential, reference crop and pan evaporation using standard meteorological data: a pragmatic synthesis, *Hydrol. Earth Syst. Sci.*, 17, 1331–1363, <https://doi.org/10.5194/hess-17-1331-2013>, 2013.

| | |
|------|-----------------------------------|
| R_so | <i>Radiation, clear-sky solar</i> |
|------|-----------------------------------|

Description

Calculates the clear-sky solar radiation based on Equation 37 in Allen et al. (1998).

Usage

R_so(Ra, z)

Arguments

| | |
|----|---|
| Ra | extraterrestrial solar radiation (MJ/m ² /day) |
| z | station elevation above sea level (m). |

Value

| | |
|-----|--|
| Rso | clear-sky solar radiation (MJ/m ² /day) |
|-----|--|

References

Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). Crop evapotranspiration: Guidelines for computing crop water requirements. Rome: FAO. Retrieved from <http://www.fao.org/docrep/X0490E/x0490e00.htm>.

| | |
|-------------------|---------------------------------|
| sat_vapor_density | <i>Saturation vapor density</i> |
|-------------------|---------------------------------|

Description

Calculates the saturation vapor density from the ideal gas law based on Equation 2.6 in Harwell (2012).

Usage

```
sat_vapor_density(atmp)
```

Arguments

| | |
|------|--|
| atmp | air temperature (degrees C). When dt is "daily" or larger, argument should be a list with elements "min" and "max" for daily min and max temperatures. When dt is "hourly", argument should be a vector with hourly recorded temperatures. |
|------|--|

Value

| | |
|-----|---|
| svd | saturated vapor density (g/m ³) |
|-----|---|

References

Harwell, G.R., 2012, Estimation of evaporation from open water—A review of selected studies, summary of U.S. Army Corps of Engineers data collection and methods, and evaluation of two methods for estimation of evaporation from five reservoirs in Texas: U.S. Geological Survey Scientific Investigations Report 2012–5202, 96 p.

| | |
|------------|----------------------|
| time_const | <i>Time constant</i> |
|------------|----------------------|

Description

Calculates the time constant (day) based on McJannet et al. (2008) Equation 5 and de Bruin (1982) Equation 4, as presented in McMahon et al. (2013) S11.29.

Usage

```
time_const(loc, lake, weather, rho_w = 997.9, cw = 0.00419, SBc = 4.903e-09)
```

Arguments

| | |
|-----|--|
| loc | a list with location information that includes: <ul style="list-style-type: none"> • z: elevation above mean sea level (m) • phi: latitude of location (radians). Positive for northern hemisphere, negative for southern hemisphere. • Lm: longitude of location (degrees west of Greenwich). |
|-----|--|

| | |
|---------|---|
| | <ul style="list-style-type: none"> • Lz: longitude of location's measurement timezone (degrees west of Greenwich). For example, $Lz = 75, 90, 105$ and 120° for measurement times based on the Eastern, Central, Rocky Mountain and Pacific time zones (United States) and $Lz = 0^\circ$ for Greenwich, 330° for Cairo (Egypt), and 255° for Bangkok (Thailand). |
| lake | <p>A list with lake data. Defaults to NULL, but for McJannet lake evaporation calculations, should include:</p> <ul style="list-style-type: none"> • A: surface area of the lake (km^2). • depth_m: depth of the lake (m). Can be a static value or vector corresponding with datetimes vector. • lst: optional data frame with date (datetime) and ltmp (lake temperature, degC). • wtmp0: required initial water temperature for first day in datetimes (degC). |
| weather | <p>a list with weather data that includes:</p> <ul style="list-style-type: none"> • dt: string indicating the timestep of input weather series. Expects "hourly", "daily", or "monthly". • datetimes: datetimes of weather records POSIXct. If monthly timestep, make sure date is the 15th of each month. • atmp: If hourly timestep, vector of air temperature (degrees C) corresponding with datetimes vector. If daily or monthly timestep, list with two vectors, "min" and "max", with mean daily min and max air temperature (degrees C) corresponding with datetimes vector • RH: If hourly timestep, vector of relative humidity (percent) corresponding with datetimes vector. If daily or monthly timestep, list with two vectors, "min" and "max", with mean daily min and max relative humidity (percent) corresponding with datetimes vector. • Rs: vector of incoming solar or shortwave radiation ($\text{MJ}/\text{m}^2/\text{hr}$ if hourly timestep, $\text{MG}/\text{m}^2/\text{day}$ if daily or monthly), corresponding with datetimes vector. • wind: vector with mean wind speed (m/s), corresponding with datetimes vector. • wind_elev: atomic number, height at which wind is measured (m) • z0: aerodynamic roughness of weather measurement site (m) |
| rho_w | density of water (kg/m^3), defaults to $997.9 \text{ kg}/\text{m}^3$ at 20 deg C |
| cw | specific heat of water ($\text{MJ}/\text{kg}/\text{K}$), defaults to 0.00419 |
| SBC | Stefan-Boltzman constant ($\text{MJ}/\text{m}^2/\text{day}$). Defaults to $4.903\text{e-}9 \text{ MJ}/\text{m}^2/\text{day}$. |

Value

| | |
|-------|---------------------|
| Ctime | time constant (day) |
|-------|---------------------|

References

McMahon, T. A., Peel, M. C., Lowe, L., Srikanthan, R., and McVicar, T. R.: Estimating actual, potential, reference crop and pan evaporation using standard meteorological data: a pragmatic synthesis, *Hydrol. Earth Syst. Sci.*, 17, 1331–1363, <https://doi.org/10.5194/hess-17-1331-2013>, 2013.

| | |
|---------|-------------------------------|
| tmp_dew | <i>Temperature, dew point</i> |
|---------|-------------------------------|

Description

Calculates the dew point temperature as a function of actual vapour pressure, based on McJannet et al. (2008) Equation 26 as presented in McMahon et al. (2013) Equation S2.3

Usage

```
tmp_dew(atmp, RH)
```

Arguments

| | |
|------|--|
| atmp | air temperature (degrees C). When dt is "daily" or larger, argument should be a list with elements "min" and "max" for daily min and max temperatures. When dt is "hourly", argument should be a vector with hourly recorded temperatures. |
| RH | relative humidity (percent). When dt is "daily" or larger, argument should be a list with elements "min" and "max" for daily min and max relative humidities. When dt is "hourly", argument should be a vector with hourly recorded relative humidities. |

Value

| | |
|--------|---------------------------------------|
| dewtmp | the dew point temperature (degrees C) |
|--------|---------------------------------------|

References

McMahon, T. A., Peel, M. C., Lowe, L., Srikanthan, R., and McVicar, T. R. (2013). Estimating actual, potential, reference crop and pan evaporation using standard meteorological data: a pragmatic synthesis, *Hydrol. Earth Syst. Sci.*, 17, 1331–1363. <https://doi.org/10.5194/hess-17-1331-2013>.

McJannet, D. L., Webster, I. T., Stenson, M. P., and Sherman, B.S. (2008). Estimating open water evaporation for the Murray-Darling Basin. A report to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yields Project, CSIRO, Australia, 50 pp. Retrieved from <http://www.clw.csiro.au/publications/waterforahealthycountry/mdbsy/technical/U-OpenWaterEvaporation.pdf>.

| | |
|-----------|---------------------------------|
| tmp_equil | <i>Temperature, equilibrium</i> |
|-----------|---------------------------------|

Description

Calculates the equilibrium temperature based on de Bruin (1982) Equation 3, as presented in McMahon et al. (2013) S11.30.

Usage

```
tmp_equil(loc, lake, weather, albedo, SBc = 4.903e-09)
```

Arguments

| | |
|--------------|---|
| loc | <p>a list with location information that includes:</p> <ul style="list-style-type: none"> • z: elevation above mean sea level (m) • phi: latitude of location (radians). Positive for northern hemisphere, negative for southern hemisphere. • Lm: longitude of location (degrees west of Greenwich). • Lz: longitude of location's measurement timezone (degrees west of Greenwich). For example, $Lz = 75, 90, 105$ and 120° for measurement times based on the Eastern, Central, Rocky Mountain and Pacific time zones (United States) and $Lz = 0^\circ$ for Greenwich, 330° for Cairo (Egypt), and 255° for Bangkok (Thailand). |
| lake | <p>A list with lake data. Defaults to NULL, but for McJannet lake evaporation calculations, should include:</p> <ul style="list-style-type: none"> • A: surface area of the lake (km^2). • depth_m: depth of the lake (m). Can be a static value or vector corresponding with datetimes vector. • lst: optional data frame with date (datetime) and ltmp (lake temperature, degC). • wtmp0: required initial water temperature for first day in datetimes (degC). |
| weather | <p>a list with weather data that includes:</p> <ul style="list-style-type: none"> • dt: string indicating the timestep of input weather series. Expects "hourly", "daily", or "monthly". • datetimes: datetimes of weather records POSIXct. If monthly timestep, make sure date is the 15th of each month. • atmp: If hourly timestep, vector of air temperature (degrees C) corresponding with datetimes vector. If daily or monthly timestep, list with two vectors, "min" and "max", with mean daily min and max air temperature (degrees C) corresponding with datetimes vector • RH: If hourly timestep, vector of relative humidity (percent) corresponding with datetimes vector. If daily or monthly timestep, list with two vectors, "min" and "max", with mean daily min and max relative humidity (percent) corresponding with datetimes vector. • Rs: vector of incoming solar or shortwave radiation ($\text{MJ}/\text{m}^2/\text{hr}$ if hourly timestep, $\text{MG}/\text{m}^2/\text{day}$ if daily or monthly), corresponding with datetimes vector. • wind: vector with mean wind speed (m/s), corresponding with datetimes vector. • wind_elev: atomic number, height at which wind is measured (m) • z0: aerodynamic roughness of weather measurement site (m) |
| albedo | <p>a list with albedos for different surfaces, defaults to:</p> <ul style="list-style-type: none"> • ref_crop: albedo of the hypothetical grass reference crop, 0.23 • water: albedo of water, 0.08. |
| SBC | <p>Stefan-Boltzman constant ($\text{MJ}/\text{m}^2/\text{day}$). Defaults to $4.903\text{e-}9 \text{ MJ}/\text{m}^2/\text{day}$.</p> |
| Value | |
| eqtmp | <p>equilibrium temperature (degrees C)</p> |

References

McMahon, T. A., Peel, M. C., Lowe, L., Srikanthan, R., and McVicar, T. R.: Estimating actual, potential, reference crop and pan evaporation using standard meteorological data: a pragmatic synthesis, *Hydrol. Earth Syst. Sci.*, 17, 1331–1363, <https://doi.org/10.5194/hess-17-1331-2013>, 2013.

| | |
|-----------|--------------------------------|
| tmp_water | <i>Temperature, lake water</i> |
|-----------|--------------------------------|

Description

Calculates the water temperature based on the water temperature of the previous day following McJannet et al. (2008) Equation 23 and de Bruin (1982) Equation 10 as presented in McMahon et al. S11.28 (2013). If measured lake surface temperatures are provided (in lake\$lst), will force water temperature to those values on all days with measurements and estimate any missing values using the McJannet and de Bruin approach.

Usage

```
tmp_water(loc, lake, weather, albedo)
```

Arguments

- | | |
|---------|---|
| loc | <p>a list with location information that includes:</p> <ul style="list-style-type: none"> • z: elevation above mean sea level (m) • phi: latitude of location (radians). Positive for northern hemisphere, negative for southern hemisphere. • Lm: longitude of location (degrees west of Greenwich). • Lz: longitude of location's measurement timezone (degrees west of Greenwich). For example, Lz = 75, 90, 105 and 120° for measurement times based on the Eastern, Central, Rocky Mountain and Pacific time zones (United States) and Lz = 0° for Greenwich, 330° for Cairo (Egypt), and 255° for Bangkok (Thailand). |
| lake | <p>A list with lake data. Defaults to NULL, but for McJannet lake evaporation calculations, should include:</p> <ul style="list-style-type: none"> • A: surface area of the lake (km²). • depth_m: depth of the lake (m). Can be a static value or vector corresponding with datetimes vector. • lst: optional data frame with date (datetime) and ltmp (lake temperature, degC). • wtmp0: required initial water temperature for first day in datetimes (degC). |
| weather | <p>a list with weather data that includes:</p> <ul style="list-style-type: none"> • dt: string indicating the timestep of input weather series. Expects "hourly", "daily", or "monthly". • datetimes: datetimes of weather records POSIXct. If monthly timestep, make sure date is the 15th of each month. • atmp: If hourly timestep, vector of air temperature (degrees C) corresponding with datetimes vector. If daily or monthly timestep, list with two vectors, "min" and "max", with mean daily min and max air temperature (degrees C) corresponding with datetimes vector |

- **RH**: If hourly timestep, vector of relative humidity (percent) corresponding with datetimes vector. If daily or monthly timestep, list with two vectors, "min" and "max", with mean daily min and max relative humidity (percent) corresponding with datetimes vector.
 - **Rs**: vector of incoming solar or shortwave radiation ($\text{MJ}/\text{m}^2/\text{hr}$ if hourly timestep, $\text{MG}/\text{m}^2/\text{day}$ if daily or monthly), corresponding with datetimes vector.
 - **wind**: vector with mean wind speed (m/s), corresponding with datetimes vector.
 - **wind_elev**: atomic number, height at which wind is measured (m)
 - **z0**: aerodynamic roughness of weather measurement site (m)
- albedo
- a list with albedos for different surfaces, defaults to:
- **ref_crop**: albedo of the hypothetical grass reference crop, 0.23
 - **water**: albedo of water, 0.08.

Value

wtmp water temperature (degrees C)

References

McMahon, T. A., Peel, M. C., Lowe, L., Srikanthan, R., and McVicar, T. R. (2013). Estimating actual, potential, reference crop and pan evaporation using standard meteorological data: a pragmatic synthesis, *Hydrol. Earth Syst. Sci.*, 17, 1331–1363. <https://doi.org/10.5194/hess-17-1331-2013>.

McJannet, D. L., Webster, I. T., Stenson, M. P., and Sherman, B.S. (2008). Estimating open water evaporation for the Murray-Darling Basin. A report to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yields Project, CSIRO, Australia, 50 pp. Retrieved from <http://www.clw.csiro.au/publications/waterforahealthycountry/mdbsy/technical/U-OpenWaterEvaporation.pdf>.

| | |
|--------------|------------------------------|
| tmp_wet_bulb | <i>Temperature, wet bulb</i> |
|--------------|------------------------------|

Description

Calculates the wet bulb temperature as a function of actual vapour pressure, dew point temperature, and air temperature based on McJannet et al. (2008) Equation 25 as presented in McMahon et al. (2013) Equation S2.2

Usage

tmp_wet_bulb(atmp, RH)

Arguments

| | |
|------|--|
| atmp | air temperature (degrees C). When dt is "daily" or larger, argument should be a list with elements "min" and "max" for daily min and max temperatures. When dt is "hourly", argument should be a vector with hourly recorded temperatures. |
| RH | relative humidity (percent). When dt is "daily" or larger, argument should be a list with elements "min" and "max" for daily min and max relative humidities. When dt is "hourly", argument should be a vector with hourly recorded relative humidities. |

Value

wbtmp the wet bulb temperature (degrees C)

References

McMahon, T. A., Peel, M. C., Lowe, L., Srikanthan, R., and McVicar, T. R. (2013). Estimating actual, potential, reference crop and pan evaporation using standard meteorological data: a pragmatic synthesis, *Hydrol. Earth Syst. Sci.*, 17, 1331–1363. <https://doi.org/10.5194/hess-17-1331-2013>.

McJannet, D. L., Webster, I. T., Stenson, M. P., and Sherman, B.S. (2008). Estimating open water evaporation for the Murray-Darling Basin. A report to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yields Project, CSIRO, Australia, 50 pp. Retrieved from <http://www.clw.csiro.au/publications/waterforahealthycountry/mdbsy/technical/U-OpenWaterEvaporation.pdf>.

| | |
|--------|--------------------------------|
| u2_fcn | <i>Wind speed at 2m height</i> |
|--------|--------------------------------|

Description

Calculates the wind speed at 2 m height given a wind speed at z m height based on Equation 47 in Allen et al. (1998).

Usage

u2_fcn(uz, z = 10)

Arguments

uz wind speed at z m above ground surface (m/s)

z height of measurement above ground surface (m). Default is 10m, a common height for wind speed measurements in meteorology.

Value

u2 wind speed at 2 m above ground surface (m/s)

References

Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). Crop evapotranspiration: Guidelines for computing crop water requirements. Rome: FAO. Retrieved from <http://www.fao.org/docrep/X0490E/x0490e00.htm>.

| | |
|-----------|---------------------------------|
| uz_to_u10 | <i>Wind speed at 10m height</i> |
|-----------|---------------------------------|

Description

Calculates the wind speed at 10 m height given a wind speed at z m height based on Equation S4.4 in McMahon et al. (2013).

Usage

```
uz_to_u10(uz, z = 2, z0 = 0.02)
```

Arguments

| | |
|----|--|
| uz | wind speed at z m above ground surface (m/s) |
| z | height of measurement above ground surface (m). Default is 2m, a common height for wind speed measurements in agronomy |
| z0 | roughness length for the measurement surface (m). Defaults to 0.02 for a short grass. |

Value

| | |
|-----|---|
| u10 | wind speed at 10 m above ground surface (m/s) |
|-----|---|

References

McMahon, T. A., Peel, M. C., Lowe, L., Srikanthan, R., and McVicar, T. R. (2013). Estimating actual, potential, reference crop and pan evaporation using standard meteorological data: a pragmatic synthesis, *Hydrol. Earth Syst. Sci.*, 17, 1331–1363. <https://doi.org/10.5194/hess-17-1331-2013>.

| | |
|-------|--------------------------------|
| u_fcn | <i>Wind function for lakes</i> |
|-------|--------------------------------|

Description

Calculates the wind function given the wind speed at 10m and the surface area of the lake, based on McJannet et al. (2008) Appendix B, Equation 10, as presented in Equation S11.24 in McMahon et al. (2013).

Usage

```
u_fcn(u10, A)
```

Arguments

| | |
|-----|---|
| u10 | wind speed at 10 m above ground surface (m/s) |
| A | area of the water body (km ²) |

Value

ufcn wind function from McJannet et al., 2008

References

McMahon, T. A., Peel, M. C., Lowe, L., Srikanthan, R., and McVicar, T. R. (2013). Estimating actual, potential, reference crop and pan evaporation using standard meteorological data: a pragmatic synthesis, *Hydrol. Earth Syst. Sci.*, 17, 1331–1363. <https://doi.org/10.5194/hess-17-1331-2013>.

McJannet, D. L., Webster, I. T., Stenson, M. P., and Sherman, B.S. (2008). Estimating open water evaporation for the Murray-Darling Basin. A report to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yields Project, CSIRO, Australia, 50 pp. Retrieved from <http://www.clw.csiro.au/publications/waterforahealthycountry/mdbsy/technical/U-OpenWaterEvaporation.pdf>.

| | |
|-------------|-------------------------------------|
| vp_act_mean | <i>Vapour pressure, mean actual</i> |
|-------------|-------------------------------------|

Description

Calculates the mean actual vapour pressure for an hourly, daily, or larger time period based on Equations 17 and 54 of Allen et al. (1998).

Usage

vp_act_mean(atmp, RH)

Arguments

| | |
|------|--|
| atmp | air temperature (degrees C). When dt is "daily" or larger, argument should be a list with elements "min" and "max" for daily min and max temperatures. When dt is "hourly", argument should be a vector with hourly recorded temperatures. |
| RH | relative humidity (percent). When dt is "daily" or larger, argument should be a list with elements "min" and "max" for daily min and max relative humidities. When dt is "hourly", argument should be a vector with hourly recorded relative humidities. |

Value

| | |
|----|---|
| ea | mean actual vapour pressure (kPa) during time period of interest (hourly or daily timestep) |
|----|---|

References

Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). Crop evapotranspiration: Guidelines for computing crop water requirements. Rome: FAO. Retrieved from <http://www.fao.org/docrep/X0490E/x0490e00.htm>.

| | |
|------------|--------------------------------|
| vp_deficit | <i>Vapour pressure deficit</i> |
|------------|--------------------------------|

Description

Calculates the vapour pressure deficit for a given time period (daily timestep or larger) using the mean daily minimum temperature, mean daily maximum temperature, mean daily minimum relative humidity, and mean daily maximum humidity during that time period. See p.39 and p.74 in Allen et al. (1998).

Usage

```
vp_deficit(atmp, RH)
```

Arguments

| | |
|------|--|
| atmp | air temperature (degrees C). When dt is "daily" or larger, argument should be a list with elements "min" and "max" for daily min and max temperatures. When dt is "hourly", argument should be a vector with hourly recorded temperatures. |
| RH | relative humidity (percent). When dt is "daily" or larger, argument should be a list with elements "min" and "max" for daily min and max relative humidities. When dt is "hourly", argument should be a vector with hourly recorded relative humidities. |

Value

| | |
|-----|---|
| vpd | vapour pressure deficit (kPa) for the given time period |
|-----|---|

References

Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). Crop evapotranspiration: Guidelines for computing crop water requirements. Rome: FAO. Retrieved from <http://www.fao.org/docrep/X0490E/x0490e00.htm>.

| | |
|--------|------------------------------------|
| vp_sat | <i>Vapour pressure, saturation</i> |
|--------|------------------------------------|

Description

Calculates the saturation vapour pressure at a given temperature based on equation 11 of Allen et al. (1998). Identical to Equation 2.4 in Harwell (2012).

Usage

```
vp_sat(tmp)
```

Arguments

| | |
|-----|---|
| tmp | temperature of air or water (degrees C), vector or atomic number. |
|-----|---|

Value

eo saturation vapour pressure at the temperature (kPa)

References

Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). Crop evapotranspiration: Guidelines for computing crop water requirements. Rome: FAO. Retrieved from <http://www.fao.org/docrep/X0490E/x0490e00.htm>.

Harwell, G.R., 2012, Estimation of evaporation from open water—A review of selected studies, summary of U.S. Army Corps of Engineers data collection and methods, and evaluation of two methods for estimation of evaporation from five reservoirs in Texas: U.S. Geological Survey Scientific Investigations Report 2012–5202, 96 p.

| | |
|--------------------|--|
| vp_sat_curve_slope | <i>Slope of saturation vapour pressure curve</i> |
|--------------------|--|

Description

Calculates the slope of the saturation vapour pressure curve (i.e., the slope of the relationship between saturation vapour pressure and temperature) based on Equation 13 in Allen et al. (1998).

Usage

vp_sat_curve_slope(atmp)

Arguments

| | |
|------|--|
| atmp | air temperature (degrees C). When dt is "daily" or larger, argument should be a list with elements "min" and "max" for daily min and max temperatures. When dt is "hourly", argument should be a vector with hourly recorded temperatures. |
|------|--|

Value

| | |
|-------|--|
| Delta | slope of the saturation vapour pressure curve at the given air temperature |
|-------|--|

References

Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). Crop evapotranspiration: Guidelines for computing crop water requirements. Rome: FAO. Retrieved from <http://www.fao.org/docrep/X0490E/x0490e00.htm>.

| | |
|-------------|--|
| vp_sat_mean | <i>Vapour pressure, mean saturated</i> |
|-------------|--|

Description

Calculates the mean saturation vapour pressure for an hourly, daily, or larger time period based on Equations 11 and 12 of Allen et al. (1998).

Usage

```
vp_sat_mean(atmp)
```

Arguments

| | |
|------|--|
| atmp | air temperature (degrees C). When dt is "daily" or larger, argument should be a list with elements "min" and "max" for daily min and max temperatures. When dt is "hourly", argument should be a vector with hourly recorded temperatures. |
|------|--|

Value

| | |
|----|--|
| es | mean saturation vapour pressure (kPa) during time period of interest |
|----|--|

References

Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). Crop evapotranspiration: Guidelines for computing crop water requirements. Rome: FAO. Retrieved from <http://www.fao.org/docrep/X0490E/x0490e00.htm>.

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