Package 'CSLSevap'

April 2, 2021

Type Package

Title Evapo(transpi)ration Calculations

Version 2.1.0

Author Carolyn Voter <cvoter@wisc.edu>

Maintainer Carolyn Voter <cvoter@wisc.edu>

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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Encoding UTF-8

LazyData true

RoxygenNote 7.1.1

Roxygen list(markdown = TRUE)

VignetteBuilder knitr

R topics documented:

`aero_resist` *Aerodynamic resistance*

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` *Cloudiness factor*

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 availaible 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,
  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.
`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

```
daily_met <- CSLS_daily_met("McJannet")
daily_met <- CSLS_daily_met("McJannet", use_lst = FALSE)
daily_met <- CSLS_daily_met("Hamon")
```

`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 avilability 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 temperatuer (degC) from the day before the weather, lst, and lake_levels timeseries begin

CSLS_format_lake *Given CSLS data, format "lake" input parameter*

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 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)

CSLS_format_loc *Given CSLS data, format "loc" input parameter*

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 *Given CSLS data, format "weather" input parameter*

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)

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daylight_hours *Maximum daylight hours*

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` *Solar declination*

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` *Evaporation (all methods)*

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:

- **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:

- **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)

`lake` A list with lake data. Defaults to NULL, but for McJannet lake evaporation calculations, should include:

- **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` 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.

`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 kg/m^3 at 20 deg C

`ca` specific heat of the air (MJ/kg/K), defaults to 0.001013 MJ/kg/K

Details

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

Input	**FAO**	**McJannet**	**Hamond**
loc	all	all	only *phi*
weather	all but *z0*	all	only *datetimes* & *atmp*
lake	none, use NULL	all but *lst*	none, use NULL

Value

`evap` a vector with evapo(transpi)ration (mm/hour or mm/day) for each timestep in `weather$datetimes`

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.

heat_flux   *Heat flux*

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:

- **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` A list with lake data. Defaults to NULL, but for McJannet lake evaporation calculations, should include:

- **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` 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)

`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.

`Rn` Net solar or shortwave radiation (MJ/m^2/timestep)

`rho_w` density of water (kg/m^3), defaults to 997.9 kg/m^3 at 20 deg C

`cw` specific heat of water (MJ/kg/K), defaults to 0.00419

Value

`G` heat flux (MJ/m^2/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(tmid, tL, Lm, Lz)
```

Arguments

tmid	date and time of the midpoint of the time period POSIXct.
tL	length of the time period, from lubridate function "interval_len".
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).

Value

omega1	solar time angle at the beginning of the period (radians)
omega2	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.

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hour_angle_sunset *Sunset hour angle*

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` *Inverse relative distance Earth-Sun*

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` *Latent heat of vaporization*

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

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psychrometric_constant   *Psychrometric constant*

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 — *Radiation, extraterrestrial solar*

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 — *Radiation, incoming longwave*

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` *Radiation, net*

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` a list with location information that includes:

- **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` A list with lake data. Defaults to NULL, but for McJannet lake evaporation calculations, should include:

- **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` 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)

`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

`Rn` net 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.

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_nl   *Radiation, net longwave*

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_nl(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

`Rnl`	Net outgoing longwave radiation (MJ/m^2/hour or MJ/m^2/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   *Radiation, net solar/shortwave*

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` *Radiation, outgoing longwave*

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

`Rol`	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 *Radiation, clear-sky solar*

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 *Saturation vapor density*

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` *Time constant*

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:

- **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` A list with lake data. Defaults to NULL, but for McJannet lake evaporation calculations, should include:

- **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` 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)

`rho_w` density of water (kg/m^3), defaults to 997.9 kg/m^3 at 20 deg C

`cw` specific heat of water (MJ/kg/K), defaults to 0.00419

`SBc` Stefan-Boltzman constant (MJ/m^2/day). Defaults to 4.903e-9 MJ/m^2/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` *Temperature, dew point*

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 *Temperature, equilibrium*

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` a list with location information that includes:

- **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` A list with lake data. Defaults to NULL, but for McJannet lake evaporation calculations, should include:

- **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` 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)

`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.

`SBc` Stefan-Boltzman constant (MJ/m^2/day). Defaults to 4.903e-9 MJ/m^2/day.

Value

`eqtmp` equilibrium temperature (degrees C)

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` *Temperature, lake water*

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 appoach.

Usage

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

Arguments

`loc` a list with location information that includes:

- **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` A list with lake data. Defaults to NULL, but for McJannet lake evaporation calculations, should include:

- **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` 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)

`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` *Temperature, wet bulb*

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 *Wind speed at 2m height*

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 *Wind speed at 10m height*

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 *Wind function for lakes*

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 *Vapour pressure, mean actual*

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.

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vp_deficit *Vapour pressure deficit*

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 maxiumum 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 *Vapour pressure, saturation*

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 *Slope of saturation vapour pressure curve*

Description

Calculates the slope of the saturation vapour ressure 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` *Vapour pressure, mean saturated*

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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