Package: ET0RadModels (via r-universe)

October 22, 2026

Type Package

Title Evapotranspiration Estimation Using Radiation-Based Models

Version 1.0.0

Description Provides functions to estimate daily reference evapotranspiration (ET0) using 10 radiation-based empirical models, with the Food and Agriculture Organization (FAO) Penman-Monteith method included as the standard reference for model comparison. Includes statistical evaluation metrics, such as Nash-Sutcliffe efficiency (NSE), root mean square error (RMSE), mean absolute error (MAE), and mean bias error (MBE), and visualization tools (scatter plots and Taylor diagrams). Based on Singh et al. (2026) <doi:10.1016/j.ejrh.2026.103925>.

License GPL (>= 3)

URL https://github.com/samirigfri/ET0RadModels

BugReports https://github.com/samirigfri/ET0RadModels/issues

Encoding UTF-8

LazyData true

RoxygenNote 7.3.3

Depends R (>= 3.5.0)

Imports graphics, grDevices, stats

Suggests testthat (>= 3.0.0), knitr, rmarkdown

Config/testthat/edition 3

VignetteBuilder knitr

Repository https://samirigfri.r-universe.dev

Date/Publication 2026-10-11 10:13:17 UTC

RemoteUrl https://github.com/samirigfri/et0radmodels

RemoteRef HEAD

RemoteSha 95bedca95b2b58d7a0506b188e04bd0f9ad2a087

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`ET0RadModels-package` *ET0RadModels: Reference Evapotranspiration Estimation Using Radiation-Based Models*

Description

The **ET0RadModels** package provides functions for estimating daily reference evapotranspiration (ET0) using 10 radiation-based empirical models, with the FAO Penman-Monteith method included as the standard reference for model comparison. The package also includes statistical evaluation metrics and visualization tools.

Radiation-Based Models (10)

Jensen-Haise (1963) Solar radiation and mean temperature.

McGuinness-Bordne (1972) Extraterrestrial radiation and mean temperature.

Irmak (2003) Solar radiation-based regression equation.

Makkink (1957) Solar radiation and slope of SVP curve.

Turc (1961) Solar radiation and mean temperature (humid conditions).

Caprio (1974) Linear function of solar radiation and temperature.

Abtew (1996) Simple solar radiation-based approach (coefficient 0.53).

Priestley-Taylor (1972) Net radiation with empirical coefficient alpha = 1.26.

Jones-Ritchie (1990) Simplified Priestley-Taylor with alpha = 1.1.

Hargreaves (1975) Radiation-based method using solar radiation.

Key Functions

`et0_rad_all` Compute ET0 using all 10 radiation-based models + FAO PM.

`et0_fao_pm` FAO Penman-Monteith reference method.

`evaluate_models` Compute all 9 statistical metrics.

`plot_taylor` Generate Taylor diagrams.

`plot_scatter` Generate scatter plots.

Data

The package includes a sample meteorological dataset (`jhansi_weather`) from a semi-arid region in central India for demonstrating package functionality.

Author(s)

Maintainer: Samir Barman <samir.igfri@gmail.com> (ORCID)

Authors:

- Ajay N. Satpute
- Amit Kumar Singh
- Avijit Ghosh
- Gaurendra Gupta

References

Satpute, A.N., Barman, S., Singh, A.K., Ghosh, A., & Gupta, G. (2026). A multi-scale evaluation of 30 empirical models for reference evapotranspiration estimation in a data-scarce semi-arid region: A case study of Jhansi, India. Journal of Hydrology: Regional Studies. doi:10.1016/j.ejrh.2026.103925

Allen, R.G., Pereira, L.S., Raes, D., & Smith, M. (1998). Crop evapotranspiration: Guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper No. 56.

See Also

Useful links:

- https://github.com/samirigfri/ET0RadModels
- Report bugs at https://github.com/samirigfri/ET0RadModels/issues

---

actual_vapor_pressure *Actual Vapor Pressure*

Description

Computes actual vapor pressure from relative humidity and temperature.

Usage

```
actual_vapor_pressure(Tmin, Tmax, RH_morning, RH_evening)
```

Arguments

Tmin	Minimum air temperature (degrees Celsius).
Tmax	Maximum air temperature (degrees Celsius).
RH_morning	Morning relative humidity (percent).
RH_evening	Evening relative humidity (percent).

Value

Actual vapor pressure (kPa).

References

Allen et al. (1998), FAO-56, Eq. 17.

Examples

```
actual_vapor_pressure(15, 30, 90, 40)
```

calc_d — *Willmott's Index of Agreement (d)*

Description

Computes Willmott's index of agreement. Values range from 0 to 1, with 1 indicating perfect agreement.

Usage

```
calc_d(observed, predicted)
```

Arguments

observed	Numeric vector of observed (reference) values.
predicted	Numeric vector of predicted (model) values.

Value

Index of agreement (numeric scalar between 0 and 1).

References

Willmott, C.J. (1981). On the validation of models. Physical Geography, 2(2), 184-194.

Examples

```
obs <- c(3.5, 4.2, 5.1, 2.8, 6.0)
pred <- c(3.3, 4.5, 4.9, 3.0, 5.8)
calc_d(obs, pred)
```

calc_mae — *Mean Absolute Error (MAE)*

Description

Mean Absolute Error (MAE)

Usage

```
calc_mae(observed, predicted)
```

Arguments

observed	Numeric vector of observed (reference) values.
predicted	Numeric vector of predicted (model) values.

Value

MAE value (numeric scalar).

Examples

```
calc_mae(c(3.5, 4.2, 5.1), c(3.3, 4.5, 4.9))
```

---

calc_mbe *Mean Bias Error (MBE)*

Description

Computes the mean bias error as mean percentage absolute error. Positive values indicate overall overestimation by the model.

Usage

```
calc_mbe(observed, predicted)
```

Arguments

observed	Numeric vector of observed (reference) values.
predicted	Numeric vector of predicted (model) values.

Value

MBE value (numeric scalar, as percentage).

Examples

```
calc_mbe(c(3.5, 4.2, 5.1), c(3.3, 4.5, 4.9))
```

---

calc_mse *Mean Squared Error (MSE)*

Description

Mean Squared Error (MSE)

Usage

```
calc_mse(observed, predicted)
```

Arguments

`observed`	Numeric vector of observed (reference) values.
`predicted`	Numeric vector of predicted (model) values.

Value

MSE value (numeric scalar).

Examples

```
calc_mse(c(3.5, 4.2, 5.1), c(3.3, 4.5, 4.9))
```

`calc_nrmse` *Normalized Root Mean Squared Error (NRMSE)*

Description

RMSE normalized by the mean of observed values.

Usage

```
calc_nrmse(observed, predicted)
```

Arguments

`observed`	Numeric vector of observed (reference) values.
`predicted`	Numeric vector of predicted (model) values.

Value

NRMSE value (numeric scalar).

Examples

```
calc_nrmse(c(3.5, 4.2, 5.1), c(3.3, 4.5, 4.9))
```

calc_nse — *Nash-Sutcliffe Efficiency (NSE)*

Description

Computes the Nash-Sutcliffe efficiency coefficient. A value of 1 indicates perfect agreement; values below 0 indicate the model is worse than the mean.

Usage

```
calc_nse(observed, predicted)
```

Arguments

observed	Numeric vector of observed (reference) values.
predicted	Numeric vector of predicted (model) values.

Value

NSE value (numeric scalar).

References

Nash, J.E. & Sutcliffe, J.V. (1970). River flow forecasting through conceptual models. Journal of Hydrology, 10(3), 282-290.

Examples

```
obs <- c(3.5, 4.2, 5.1, 2.8, 6.0)
pred <- c(3.3, 4.5, 4.9, 3.0, 5.8)
calc_nse(obs, pred)
```

calc_r — *Pearson Correlation Coefficient (r)*

Description

Pearson Correlation Coefficient (r)

Usage

```
calc_r(observed, predicted)
```

Arguments

observed	Numeric vector of observed (reference) values.
predicted	Numeric vector of predicted (model) values.

Value

Pearson correlation coefficient (numeric scalar).

Examples

```
calc_r(c(3.5, 4.2, 5.1), c(3.3, 4.5, 4.9))
```

---

calc_r2 *Coefficient of Determination (R-squared)*

Description

Computes R-squared as the square of the Pearson correlation coefficient.

Usage

```
calc_r2(observed, predicted)
```

Arguments

observed	Numeric vector of observed (reference) values.
predicted	Numeric vector of predicted (model) values.

Value

R-squared value (numeric scalar between 0 and 1).

Examples

```
calc_r2(c(3.5, 4.2, 5.1), c(3.3, 4.5, 4.9))
```

---

calc_rmse *Root Mean Squared Error (RMSE)*

Description

Root Mean Squared Error (RMSE)

Usage

```
calc_rmse(observed, predicted)
```

Arguments

observed	Numeric vector of observed (reference) values.
predicted	Numeric vector of predicted (model) values.

Value

RMSE value (numeric scalar).

Examples

```
calc_rmse(c(3.5, 4.2, 5.1), c(3.3, 4.5, 4.9))
```

---

daylight_hours *Daylight Hours*

Description

Computes the maximum possible daylight hours for a given day and latitude.

Usage

```
daylight_hours(J, lat)
```

Arguments

J	Day of the year (1-366).
lat	Latitude (degrees, negative for Southern Hemisphere).

Value

Maximum daylight hours.

References

Allen et al. (1998), FAO-56, Eq. 34.

Examples

```
daylight_hours(172, 25.43)
```

dew_point_temperature *Dew Point Temperature*

Description

Estimates dew point temperature from actual vapor pressure.

Usage

```
dew_point_temperature(ea)
```

Arguments

ea	Actual vapor pressure (kPa).

Value

Dew point temperature (degrees Celsius).

Examples

```
ea <- actual_vapor_pressure(15, 30, 90, 40)
dew_point_temperature(ea)
```

et0_abtew *Abtew ET0 Model*

Description

Estimates daily ET0 using the Abtew (1996) method, a simple solar radiation-based approach developed for subtropical wetland conditions.

Usage

```
et0_abtew(Tmean, J, lat, n)
```

Arguments

Tmean	Mean air temperature (degrees Celsius).
J	Day of the year (1-366).
lat	Latitude (degrees).
n	Actual sunshine hours.

Value

Daily ET0 (mm/day).

References

Abtew, W. (1996). Evapotranspiration measurements and modelling for three wetland systems in south Florida. JAWRA, 32(3), 465-473.

See Also

Other radiation models: et0_caprio(), et0_hargreaves(), et0_irmak(), et0_jensen_haise(), et0_jones_ritchie(), et0_makkink(), et0_mcguinness_bordne(), et0_priestley_taylor(), et0_turc()

Examples

```
et0_abtew(25, 172, 25.43, 9)
```

---

et0_caprio *Caprio ET0 Model*

Description

Estimates daily ET0 using the Caprio (1974) method, a linear function of solar radiation and mean temperature.

Usage

```
et0_caprio(Tmean, J, lat, n)
```

Arguments

Tmean	Mean air temperature (degrees Celsius).
J	Day of the year (1-366).
lat	Latitude (degrees).
n	Actual sunshine hours.

Value

Daily ET0 (mm/day).

References

Caprio, J.M. (1974). The solar thermal unit concept in problems related to plant development and potential evapotranspiration. In: Phenology and Seasonality Modeling. Springer, Berlin, 353-364.

See Also

Other radiation models: et0_abtew(), et0_hargreaves(), et0_irmak(), et0_jensen_haise(), et0_jones_ritchie(), et0_makkink(), et0_mcguinness_bordne(), et0_priestley_taylor(), et0_turc()

Examples

```
et0_caprio(25, 172, 25.43, 9)
```

---

et0_fao_pm — *FAO Penman-Monteith Reference Evapotranspiration*

Description

Computes daily reference evapotranspiration (ET0) using the FAO Penman-Monteith equation (Allen et al., 1998). This is the standard reference method recommended by FAO.

Usage

```
et0_fao_pm(Tmin, Tmax, RH_morning, RH_evening, u2, n, J, lat, z = 0)
```

Arguments

`Tmin`	Minimum air temperature (degrees Celsius).
`Tmax`	Maximum air temperature (degrees Celsius).
`RH_morning`	Morning relative humidity (percent).
`RH_evening`	Evening relative humidity (percent).
`u2`	Wind speed at 2 m height (m/s).
`n`	Actual sunshine hours.
`J`	Day of the year (1-366).
`lat`	Latitude (degrees, negative for Southern Hemisphere).
`z`	Elevation above sea level (m).

Value

Daily ET0 (mm/day).

References

Allen, R.G., Pereira, L.S., Raes, D., & Smith, M. (1998). Crop evapotranspiration: Guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper No. 56.

Examples

```
et0_fao_pm(Tmin = 15, Tmax = 30, RH_morning = 90, RH_evening = 40,
           u2 = 1.5, n = 8, J = 172, lat = 25.43, z = 216)
```

et0_hargreaves — *Hargreaves (1975) Radiation-Based ET0 Model*

Description

Estimates daily ET0 using the Hargreaves (1975) radiation-based method, distinct from the Hargreaves-Samani (1985) temperature-range method.

Usage

```
et0_hargreaves(Tmean, J, lat, n)
```

Arguments

Tmean	Mean air temperature (degrees Celsius).
J	Day of the year (1-366).
lat	Latitude (degrees).
n	Actual sunshine hours.

Value

Daily ET0 (mm/day).

References

Hargreaves, G.H. (1975). Moisture availability and crop production. Transactions of the ASAE, 18(5), 980-984.

See Also

Other radiation models: et0_abtew(), et0_caprio(), et0_irmak(), et0_jensen_haise(), et0_jones_ritchie(), et0_makkink(), et0_mcguinness_bordne(), et0_priestley_taylor(), et0_turc()

Examples

```
et0_hargreaves(25, 172, 25.43, 9)
```

`et0_irmak` *Irmak ET0 Model*

Description

Estimates daily ET0 using the Irmak et al. (2003) solar radiation-based regression equation.

Usage

```
et0_irmak(Tmean, J, lat, n)
```

Arguments

`Tmean`	Mean air temperature (degrees Celsius).
`J`	Day of the year (1-366).
`lat`	Latitude (degrees).
`n`	Actual sunshine hours.

Value

Daily ET0 (mm/day).

References

Irmak, S., Irmak, A., Allen, R.G., & Jones, J.W. (2003). Solar and net radiation-based equations to estimate reference evapotranspiration in humid climates. Journal of Irrigation and Drainage Engineering, 129(5), 336-347.

See Also

Other radiation models: `et0_abtew()`, `et0_caprio()`, `et0_hargreaves()`, `et0_jensen_haise()`, `et0_jones_ritchie()`, `et0_makkink()`, `et0_mcguinness_bordne()`, `et0_priestley_taylor()`, `et0_turc()`

Examples

```
et0_irmak(25, 172, 25.43, 9)
```

et0_jensen_haise *Jensen-Haise ET0 Model*

Description

Estimates daily ET0 using the Jensen and Haise (1963) method based on solar radiation and mean air temperature.

Usage

```
et0_jensen_haise(Tmean, J, lat, n)
```

Arguments

Tmean	Mean air temperature (degrees Celsius).
J	Day of the year (1-366).
lat	Latitude (degrees).
n	Actual sunshine hours.

Value

Daily ET0 (mm/day).

References

Jensen, M.E. & Haise, H.R. (1963). Estimating evapotranspiration from solar radiation. Journal of Irrigation and Drainage Division, ASCE, 89(4), 15-41.

See Also

Other radiation models: et0_abtew(), et0_caprio(), et0_hargreaves(), et0_irmak(), et0_jones_ritchie(), et0_makkink(), et0_mcguinness_bordne(), et0_priestley_taylor(), et0_turc()

Examples

```
et0_jensen_haise(25, 172, 25.43, 9)
```

et0_jones_ritchie *Jones-Ritchie ET0 Model*

Description

Estimates daily ET0 using the Jones and Ritchie (1990) radiation-based approach, a simplified Priestley-Taylor variant with alpha = 1.1.

Usage

```
et0_jones_ritchie(Tmin, Tmax, J, lat, n)
```

Arguments

Tmin	Minimum air temperature (degrees Celsius).
Tmax	Maximum air temperature (degrees Celsius).
J	Day of the year (1-366).
lat	Latitude (degrees).
n	Actual sunshine hours.

Value

Daily ET0 (mm/day).

References

Jones, C.A. & Ritchie, J.T. (1990). Chapter 4: crop growth models. In: Jones, J.W. & Kiniry, J.R. (Eds.), CERES-Maize: A Simulation Model of Maize Growth and Development. Texas A&M University Press, 49-75.

See Also

Other radiation models: et0_abtew(), et0_caprio(), et0_hargreaves(), et0_irmak(), et0_jensen_haise(), et0_makkink(), et0_mcguinness_bordne(), et0_priestley_taylor(), et0_turc()

Examples

```
et0_jones_ritchie(15, 35, 172, 25.43, 9)
```

et0_makkink — *Makkink ET0 Model*

Description

Estimates daily ET0 using the Makkink (1957) method based on solar radiation and the slope of the saturation vapor pressure curve.

Usage

```
et0_makkink(Tmean, J, lat, n, z = 0)
```

Arguments

Tmean	Mean air temperature (degrees Celsius).
J	Day of the year (1-366).
lat	Latitude (degrees).
n	Actual sunshine hours.
z	Elevation above sea level (m). Default is 0.

Value

Daily ET0 (mm/day).

References

Makkink, G.F. (1957). Testing the Penman formula by means of lysimeters. Journal of the Institution of Water Engineers, 11(3), 277-288.

See Also

Other radiation models: et0_abtew(), et0_caprio(), et0_hargreaves(), et0_irmak(), et0_jensen_haise(), et0_jones_ritchie(), et0_mcguinness_bordne(), et0_priestley_taylor(), et0_turc()

Examples

```
et0_makkink(25, 172, 25.43, 9, 216)
```

et0_mcguinness_bordne *McGuinness-Bordne ET0 Model*

Description

Estimates daily ET0 using the McGuinness and Bordne (1972) method based on extraterrestrial radiation and mean air temperature.

Usage

```
et0_mcguinness_bordne(Tmean, J, lat, n)
```

Arguments

Tmean	Mean air temperature (degrees Celsius).
J	Day of the year (1-366).
lat	Latitude (degrees).
n	Actual sunshine hours.

Value

Daily ET0 (mm/day).

References

McGuinness, J.L. & Bordne, E.F. (1972). A comparison of lysimeter-derived potential evapotranspiration with computed values. USDA Technical Bulletin No. 1452.

See Also

Other radiation models: et0_abtew(), et0_caprio(), et0_hargreaves(), et0_irmak(), et0_jensen_haise(), et0_jones_ritchie(), et0_makkink(), et0_priestley_taylor(), et0_turc()

Examples

```
et0_mcguinness_bordne(25, 172, 25.43, 9)
```

et0_priestley_taylor *Priestley-Taylor ET0 Model*

Description

Estimates daily ET0 using the Priestley and Taylor (1972) method, an equilibrium evaporation approach using net radiation with an empirical coefficient (alpha = 1.26).

Usage

```
et0_priestley_taylor(Tmin, Tmax, RH_morning, RH_evening, n, J, lat, z = 0)
```

Arguments

Tmin	Minimum air temperature (degrees Celsius).
Tmax	Maximum air temperature (degrees Celsius).
RH_morning	Morning relative humidity (percent).
RH_evening	Evening relative humidity (percent).
n	Actual sunshine hours.
J	Day of the year (1-366).
lat	Latitude (degrees).
z	Elevation above sea level (m). Default is 0.

Value

Daily ET0 (mm/day).

References

Priestley, C.H.B. & Taylor, R.J. (1972). On the assessment of surface heat flux and evaporation using large-scale parameters. Monthly Weather Review, 100(2), 81-92.

See Also

Other radiation models: et0_abtew(), et0_caprio(), et0_hargreaves(), et0_irmak(), et0_jensen_haise(), et0_jones_ritchie(), et0_makkink(), et0_mcguinness_bordne(), et0_turc()

Examples

```
et0_priestley_taylor(15, 35, 90, 40, 9, 172, 25.43, 216)
```

`et0_rad_all` *Compute ET0 Using All 10 Radiation-Based Models and FAO Penman-Monteith*

Description

A convenience wrapper that computes daily reference evapotranspiration using all 10 radiation-based empirical models plus the FAO Penman-Monteith standard method as the reference/base for comparison.

Usage

```
et0_rad_all(Tmin, Tmax, RH_morning, RH_evening, u2, n, J, lat, z = 0)
```

Arguments

`Tmin`	Minimum air temperature (degrees Celsius).
`Tmax`	Maximum air temperature (degrees Celsius).
`RH_morning`	Morning relative humidity (percent). Used by Priestley-Taylor and FAO Penman-Monteith.
`RH_evening`	Evening relative humidity (percent). Used by Priestley-Taylor and FAO Penman-Monteith.
`u2`	Wind speed at 2 m height (m/s). Used by FAO Penman-Monteith only.
`n`	Actual sunshine hours.
`J`	Day of the year (1-366).
`lat`	Latitude (degrees, negative for Southern Hemisphere).
`z`	Elevation above sea level (m). Default is 0.

Details

The 10 radiation-based models included are:

- Jensen-Haise (1963)
- McGuinness-Bordne (1972)
- Irmak (2003)
- Makkink (1957)
- Turc (1961)
- Caprio (1974)
- Abtew (1996)
- Priestley-Taylor (1972)
- Jones-Ritchie (1990)
- Hargreaves (1975)

The **FAO Penman-Monteith** column serves as the standard reference against which models can be evaluated using `evaluate_models`.

Value

A `data.frame` with 11 columns: `FAO_PM` (reference) plus one column per radiation-based model. The number of rows equals the length of the input vectors.

Examples

```
result <- et0_rad_all(Tmin = 15, Tmax = 35, RH_morning = 90,
                      RH_evening = 40, u2 = 1.5, n = 9,
                      J = 172, lat = 25.43, z = 216)
print(result)
```

---

et0_turc *Turc ET0 Model*

Description

Estimates daily ET0 using the Turc (1961) method based on solar radiation and mean air temperature. Assumes humid conditions (RH >= 50

Usage

```
et0_turc(Tmean, J, lat, n)
```

Arguments

`Tmean`	Mean air temperature (degrees Celsius).
`J`	Day of the year (1-366).
`lat`	Latitude (degrees).
`n`	Actual sunshine hours.

Value

Daily ET0 (mm/day).

References

Turc, L. (1961). Estimation of irrigation water requirements, potential evapotranspiration: a simple climatic formula evolved up to date. Annals of Agronomy, 12, 13-49.

See Also

Other radiation models: `et0_abtew()`, `et0_caprio()`, `et0_hargreaves()`, `et0_irmak()`, `et0_jensen_haise()`, `et0_jones_ritchie()`, `et0_makkink()`, `et0_mcguinness_bordne()`, `et0_priestley_taylor()`

Examples

```
et0_turc(25, 172, 25.43, 9)
```

evaluate_models — *Evaluate Multiple ET0 Models Against a Reference*

Description

Computes all 9 statistical evaluation metrics for one or more ET0 models compared against a reference method (typically FAO Penman-Monteith).

Usage

```
evaluate_models(observed, predicted)
```

Arguments

observed	Numeric vector of observed (reference) ET0 values.
predicted	A named list or data.frame of predicted ET0 values. Each element/column represents a different model.

Value

A `data.frame` with one row per model and columns for each metric: NSE, d, MSE, RMSE, NRMSE, MAE, MBE, r, R2.

Examples

```
obs <- c(3.5, 4.2, 5.1, 2.8, 6.0)
preds <- data.frame(
  Model_A = c(3.3, 4.5, 4.9, 3.0, 5.8),
  Model_B = c(4.0, 4.0, 5.5, 2.5, 6.5)
)
evaluate_models(obs, preds)
```

extraterrestrial_radiation — *Extraterrestrial Radiation*

Description

Computes the extraterrestrial radiation (Ra) for a given day and latitude following Allen et al. (1998).

Usage

```
extraterrestrial_radiation(J, lat)
```

Arguments

`J`	Day of the year (1-366).
`lat`	Latitude (degrees, negative for Southern Hemisphere).

Value

Extraterrestrial radiation (MJ/m2/day).

References

Allen et al. (1998), FAO-56, Eq. 21.

Examples

```
extraterrestrial_radiation(172, 25.43)
```

`jhansi_weather` *Sample Meteorological Data from Jhansi, India*

Description

A dataset containing daily meteorological observations from the Central Research Farm of ICAR-Indian Grassland and Fodder Research Institute (IGFRI), Jhansi, Uttar Pradesh, India (25 deg 26' N, 78 deg 30' E, 216 m above sea level). The data covers one year (2010) and is representative of semi-arid climate conditions.

Usage

```
jhansi_weather
```

Format

A data frame with 365 rows and 8 columns:

Date Date of observation (Date class).

J Day of the year (1-365).

Tmax Maximum air temperature (degrees Celsius).

Tmin Minimum air temperature (degrees Celsius).

RH_morning Morning relative humidity (percent).

RH_evening Evening relative humidity (percent).

SSH Bright sunshine hours.

WS Wind speed at 2 m height (m/s).

Details

The study area has a semi-arid climate with extreme summers (average 32.7 degrees C) and mild winters (average 25.1 degrees C). The average annual precipitation is 840 mm, with 90 percent contributed by southwest monsoons between July and September. This dataset is suitable for demonstrating the package functions and comparing ET0 model performance in data-scarce semi-arid conditions.

The latitude for this station is 25.43 degrees N and the elevation is 216 m above sea level.

Source

ICAR-Indian Grassland and Fodder Research Institute (IGFRI), Jhansi, India.

Examples

```
data(jhansi_weather)
head(jhansi_weather)

# Compute FAO-PM ET0 for the first day
with(jhansi_weather[1, ],
  et0_fao_pm(Tmin, Tmax, RH_morning, RH_evening, WS, SSH, J,
             lat = 25.43, z = 216))
```

---

latent_heat *Latent Heat of Vaporization*

Description

Computes the latent heat of vaporization as a function of air temperature following Allen et al. (1998).

Usage

```
latent_heat(Tmean)
```

Arguments

`Tmean`	Mean air temperature (degrees Celsius).

Value

Latent heat of vaporization (MJ/kg).

References

Allen, R.G., Pereira, L.S., Raes, D., & Smith, M. (1998). FAO Irrigation and Drainage Paper No. 56.

Examples

```
latent_heat(25)
```

---

metrics — *Statistical Evaluation Metrics for ET0 Models*

Description

Functions to compute statistical performance metrics for comparing ET0 model estimates against a reference (e.g., FAO Penman-Monteith).

---

net_radiation — *Net Radiation*

Description

Computes net radiation (Rn) following the FAO-56 approach.

Usage

```
net_radiation(J, lat, n, Tmin, Tmax, ea, albedo = 0.23, a_s = 0.25, b_s = 0.5)
```

Arguments

J	Day of the year (1-366).
lat	Latitude (degrees).
n	Actual sunshine hours.
Tmin	Minimum air temperature (degrees Celsius).
Tmax	Maximum air temperature (degrees Celsius).
ea	Actual vapor pressure (kPa).
albedo	Surface albedo (default 0.23 for reference crop).
a_s	Angstrom coefficient a (default 0.25).
b_s	Angstrom coefficient b (default 0.50).

Value

Net radiation (MJ/m2/day).

References

Allen et al. (1998), FAO-56.

Examples

```
ea <- actual_vapor_pressure(15, 30, 90, 40)
net_radiation(172, 25.43, 8, 15, 30, ea)
```

plot_annual_bar *Annual ET0 Bar Chart*

Description

Creates a bar chart comparing total annual ET0 estimated by each model against the FAO-PM reference.

Usage

```
plot_annual_bar(annual_et0, main = "Annual ET0 by Model", colors = NULL)
```

Arguments

annual_et0	A named numeric vector of total annual ET0 values for each model. Must include FAO_PM.
main	Title for the plot.
colors	Character vector of bar colors. If NULL, generated automatically.

Value

Invisible NULL.

Examples

```
annual <- c(FAO_PM = 1571, Blaney_Criddle = 1933, Schendel = 2593,
            Hargreaves_Samani = 1393)
plot_annual_bar(annual)
```

plot_monthly_comparison *Monthly Comparison Plot*

Description

Creates a line plot comparing the average monthly ET0 from multiple models against the FAO-PM reference.

Usage

```
plot_monthly_comparison(
  monthly_data,
  model_names = NULL,
  main = "Monthly ET0 Comparison",
  colors = NULL
)
```

Arguments

monthly_data	A data.frame with columns: Month (1-12) and one column per model containing mean monthly ET0 values. Must include a FAO_PM column.
model_names	Character vector of model names to plot (in addition to FAO_PM). If NULL, all models are plotted.
main	Title for the plot.
colors	Named character vector of colors per model. If NULL, colors are generated automatically.

Value

Invisible NULL.

Examples

```
monthly <- data.frame(
  Month = 1:12,
  FAO_PM = c(2.0, 2.5, 3.5, 5.0, 6.5, 7.0, 6.0, 5.5, 4.5, 3.5, 2.5, 2.0),
  Model_A = c(2.2, 2.8, 3.8, 5.3, 6.8, 7.3, 6.3, 5.8, 4.8, 3.8, 2.8, 2.2)
)
plot_monthly_comparison(monthly)
```

---

plot_scatter *Scatter Plot of Predicted vs Observed ET0*

Description

Creates a scatter plot comparing predicted ET0 values from one or more models against observed (reference) values, with 1:1 line and regression lines.

Usage

```
plot_scatter(
  observed,
  predicted,
  model_names = NULL,
  main = "Predicted vs Observed ET0",
  colors = NULL,
  ...
)
```

Arguments

`observed`	Numeric vector of observed (reference) ET0 values.
`predicted`	A named list or data.frame of predicted ET0 values.
`model_names`	Character vector of model names to plot. If `NULL`, all models in `predicted` are plotted.
`main`	Title for the plot.
`colors`	Character vector of colors. If `NULL`, colors are generated automatically.
`...`	Additional arguments passed to `plot`.

Value

Invisible `NULL`. Called for its side effect of producing a plot.

Examples

```
obs <- c(3.5, 4.2, 5.1, 2.8, 6.0, 3.1, 4.8)
preds <- data.frame(
  Model_A = c(3.3, 4.5, 4.9, 3.0, 5.8, 3.4, 4.6),
  Model_B = c(4.0, 4.0, 5.5, 2.5, 6.5, 3.8, 5.0)
)
plot_scatter(obs, preds)
```

`plot_taylor` *Taylor Diagram*

Description

Creates a Taylor diagram showing the correlation coefficient, standard deviation, and centered RMSE of multiple models relative to the observed reference.

Usage

```
plot_taylor(
  observed,
  predicted,
  model_names = NULL,
  main = "Taylor Diagram",
  colors = NULL,
  normalize = FALSE
)
```

Arguments

observed	Numeric vector of observed (reference) ET0 values.
predicted	A named list or data.frame of predicted ET0 values.
model_names	Character vector of model names to plot. If NULL, all models are plotted.
main	Title for the plot.
colors	Character vector of colors. If NULL, colors are generated automatically.
normalize	Logical; if TRUE, standard deviations are normalized by the observed standard deviation (default FALSE).

Value

Invisible NULL. Called for its side effect of producing a plot.

Examples

```
set.seed(42)
obs <- rnorm(100, mean = 5, sd = 2)
preds <- list(
  Model_A = obs + rnorm(100, 0, 0.5),
  Model_B = obs * 1.1 + rnorm(100, 0, 1)
)
plot_taylor(obs, preds)
```

---

plots *Visualization Functions for ET0 Model Comparison*

Description

Functions for graphical evaluation of ET0 model performance including scatter plots, Taylor diagrams, monthly comparison plots, and annual bar charts.

---

psychrometric_constant *Psychrometric Constant*

Description

Computes the psychrometric constant as a function of atmospheric pressure.

Usage

```
psychrometric_constant(P = NULL, z = 0)
```

Arguments

P	Atmospheric pressure (kPa). If NULL, computed from elevation.
z	Elevation above sea level (m). Used only if P is NULL.

Value

Psychrometric constant (kPa/degrees C).

References

Allen et al. (1998), FAO-56, Eq. 8.

Examples

```
psychrometric_constant(z = 216)
```

---

radiation_models *Radiation-Based ET0 Models*

Description

Functions implementing 10 radiation-based empirical models for reference evapotranspiration (ET0) estimation.

---

saturation_vapor_pressure *Saturation Vapor Pressure*

Description

Computes the saturation vapor pressure at a given temperature using the Tetens formula (Allen et al., 1998).

Usage

```
saturation_vapor_pressure(Temp)
```

Arguments

Temp	Air temperature (degrees Celsius).

Value

Saturation vapor pressure (kPa).

References

Allen et al. (1998), FAO-56, Eq. 11.

Examples

```
saturation_vapor_pressure(25)
```

`slope_vapor_pressure` *Slope of Saturation Vapor Pressure Curve*

Description

Computes the slope of the saturation vapor pressure-temperature curve.

Usage

```
slope_vapor_pressure(Tmean)
```

Arguments

`Tmean`	Mean air temperature (degrees Celsius).

Value

Slope of saturation vapor pressure curve (kPa/degrees C).

References

Allen et al. (1998), FAO-56, Eq. 13.

Examples

```
slope_vapor_pressure(25)
```

solar_radiation *Solar Radiation (Angstrom)*

Description

Estimates incoming solar radiation (Rs) using the Angstrom formula with sunshine hours.

Usage

```
solar_radiation(J, lat, n, a_s = 0.25, b_s = 0.5)
```

Arguments

J	Day of the year (1-366).
lat	Latitude (degrees).
n	Actual sunshine hours.
a_s	Angstrom coefficient a (default 0.25).
b_s	Angstrom coefficient b (default 0.50).

Value

Solar radiation (MJ/m2/day).

References

Allen et al. (1998), FAO-56, Eq. 35.

Examples

```
solar_radiation(172, 25.43, 8)
```

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