

Package ‘ET0TempModels’

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Title Evapotranspiration Estimation Using Temperature-Based Models

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Description Provides functions to estimate daily reference evapotranspiration (ET0) using 10 temperature-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](https://doi.org/10.1016/j.ejrh.2026.103925)>.

License GPL (>= 3)

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BugReports <https://github.com/samirigfri/ET0TempModels/issues>

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ET0TempModels-package *ET0TempModels: Evapotranspiration Estimation Using Temperature-Based Models*

Description

The **ET0TempModels** package provides functions for estimating daily reference evapotranspiration (ET0) using 10 temperature-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.

Temperature-Based Models (10)

Blaney-Criddle (1950) Requires only mean temperature.
Schendel (Bormann, 2011) Requires mean temperature and relative humidity.
Hargreaves-Samani (1985) Requires Tmin, Tmax, day of year, and latitude.
Linacre (1977) Requires temperature, humidity, elevation, and latitude.
Tabari-Talaei 1 (2011) Modified Hargreaves (coefficient 0.031).
Tabari-Talaei 2 (2011) Modified Hargreaves (coefficient 0.0028).
Droogers-Allen (2002) Modified Hargreaves with temperature range^{0.4}.
Berti et al. (2014) Modified Hargreaves with temperature range^{0.517}.
Dorji et al. (2016) Modified Hargreaves with temperature range^{0.296}.
Baier-Robertson (1965) Regression-based using Ra, Tmax, and temperature range.

Key Functions

`et0_temp_all` Compute ET0 using all 10 temperature-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)

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Authors:

- Ajay N. Satpute
- Amit Kumar Singh
- Avijit Ghosh
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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/ET0TempModels>
- Report bugs at <https://github.com/samirigfri/ET0TempModels/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	<i>Willmott's Index of Agreement (d)</i>
--------	--

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	<i>Mean Absolute Error (MAE)</i>
----------	----------------------------------

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	<i>Mean Bias Error (MBE)</i>
----------	------------------------------

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	<i>Mean Squared Error (MSE)</i>
----------	---------------------------------

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	<i>Normalized Root Mean Squared Error (NRMSE)</i>
------------	---

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	<i>Nash-Sutcliffe Efficiency (NSE)</i>
----------	--

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	<i>Pearson Correlation Coefficient (r)</i>
--------	--

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	<i>Daylight Hours</i>
----------------	-----------------------

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_baier_robertson` *Baier-Robertson ET0 Model*

Description

Estimates daily ET0 using the Baier and Robertson (1965) method, a regression-based equation using extraterrestrial radiation, maximum temperature and temperature range.

Usage

```
et0_baier_robertson(Tmin, Tmax, J, lat)
```

Arguments

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

Value

Daily ET0 (mm/day).

References

Baier, W. & Robertson, G.W. (1965). Estimation of latent evaporation from simple weather observations. Canadian Journal of Plant Science, 45(3), 276-284.

See Also

Other temperature models: [et0_berti\(\)](#), [et0_blaney_criddle\(\)](#), [et0_dorji\(\)](#), [et0_droogers_allen\(\)](#), [et0_hargreaves_samani\(\)](#), [et0_linacre\(\)](#), [et0_schendel\(\)](#), [et0_tabari_talee1\(\)](#), [et0_tabari_talee2\(\)](#)

Examples

```
et0_baier_robertson(15, 30, 172, 25.43)
```

et0_berti	<i>Berti et al. ET0 Model</i>
-----------	-------------------------------

Description

Estimates daily ET0 using the Berti et al. (2014) method, a modified Hargreaves formula using the temperature range raised to the power 0.517.

Usage

```
et0_berti(Tmin, Tmax, J, lat)
```

Arguments

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

Value

Daily ET0 (mm/day).

References

Berti, A., Tardivo, G., Chiaudani, A., Rech, F., & Borin, M. (2014). Assessing reference evapotranspiration by the Hargreaves method in north-eastern Italy. Agricultural Water Management, 140, 20-25.

See Also

Other temperature models: [et0_baier_robertson\(\)](#), [et0_blaney_criddle\(\)](#), [et0_dorji\(\)](#), [et0_droogers_allen\(\)](#), [et0_hargreaves_samani\(\)](#), [et0_linacre\(\)](#), [et0_schendel\(\)](#), [et0_tabari_talee1\(\)](#), [et0_tabari_talee2\(\)](#)

Examples

```
et0_berti(15, 30, 172, 25.43)
```

et0_blaney_criddle	<i>Blaney-Criddle ET0 Model</i>
--------------------	---------------------------------

Description

Estimates daily ET0 using the Blaney-Criddle (1950) method, which relies only on mean air temperature.

Usage

```
et0_blaney_criddle(Tmean)
```

Arguments

Tmean	Mean air temperature (degrees Celsius).
-------	---

Value

Daily ET0 (mm/day).

References

Blaney, H.F. & Criddle, W.D. (1950). Determining water requirements in irrigated areas from climatological and irrigation data. USDA Soil Conservation Service, SCS-TP 96.

See Also

Other temperature models: [et0_baier_robertson\(\)](#), [et0_berti\(\)](#), [et0_dorji\(\)](#), [et0_droogers_allen\(\)](#), [et0_hargreaves_samani\(\)](#), [et0_linacre\(\)](#), [et0_schendel\(\)](#), [et0_tabari_talee1\(\)](#), [et0_tabari_talee2\(\)](#)

Examples

```
et0_blaney_criddle(25)
```

et0_dorji	<i>Dorji et al. ET0 Model</i>
-----------	-------------------------------

Description

Estimates daily ET0 using the Dorji et al. (2016) method, a modified Hargreaves formula using the temperature range raised to the power 0.296.

Usage

```
et0_dorji(Tmin, Tmax, J, lat)
```

Arguments

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

Value

Daily ET0 (mm/day).

References

Dorji, U., Olesen, J.E., & Seidenkrantz, M.S. (2016). Water balance in the complex mountainous terrain of Bhutan and linkages to land use. Journal of Hydrology: Regional Studies, 7, 55-68.

See Also

Other temperature models: [et0_baier_robertson\(\)](#), [et0_berti\(\)](#), [et0_blaney_criddle\(\)](#), [et0_droogers_allen\(\)](#), [et0_hargreaves_samani\(\)](#), [et0_linacre\(\)](#), [et0_schendel\(\)](#), [et0_tabari_talee1\(\)](#), [et0_tabari_talee2\(\)](#)

Examples

```
et0_dorji(15, 30, 172, 25.43)
```

et0_droogers_allen	<i>Droogers-Allen ET0 Model</i>
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Description

Estimates daily ET0 using the Droogers and Allen (2002) method, a modified Hargreaves formula using the temperature range raised to the power 0.4.

Usage

```
et0_droogers_allen(Tmin, Tmax, J, lat)
```

Arguments

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

Value

Daily ET0 (mm/day).

References

Droogers, P. & Allen, R.G. (2002). Estimating reference evapotranspiration under inaccurate data conditions. *Irrigation and Drainage Systems*, 16(1), 33-45.

See Also

Other temperature models: [et0_baier_robertson\(\)](#), [et0_berti\(\)](#), [et0_blaney_criddle\(\)](#), [et0_dorji\(\)](#), [et0_hargreaves_samani\(\)](#), [et0_linacre\(\)](#), [et0_schendel\(\)](#), [et0_tabari_talee1\(\)](#), [et0_tabari_talee2\(\)](#)

Examples

```
et0_droogers_allen(15, 30, 172, 25.43)
```

et0_fao_pm	<i>FAO Penman-Monteith Reference Evapotranspiration</i>
------------	---

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_samani *Hargreaves-Samani ET0 Model*

Description

Estimates daily ET0 using the Hargreaves-Samani (1985) method based on temperature range and extraterrestrial radiation.

Usage

```
et0_hargreaves_samani(Tmin, Tmax, J, lat)
```

Arguments

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

Value

Daily ET0 (mm/day).

References

Hargreaves, G.H. & Samani, Z.A. (1985). Reference crop evapotranspiration from temperature. Applied Engineering in Agriculture, 1(2), 96-99.

See Also

Other temperature models: [et0_baier_robertson\(\)](#), [et0_berti\(\)](#), [et0_blaney_criddle\(\)](#), [et0_dorji\(\)](#), [et0_droogers_allen\(\)](#), [et0_linacre\(\)](#), [et0_schendel\(\)](#), [et0_tabari_talee1\(\)](#), [et0_tabari_talee2\(\)](#)

Examples

```
et0_hargreaves_samani(15, 30, 172, 25.43)
```

et0_linacre	<i>Linacre ET0 Model</i>
-------------	--------------------------

Description

Estimates daily ET0 using the Linacre (1977) method, which accounts for altitude, latitude and dew point depression.

Usage

```
et0_linacre(Tmean, Tmin, Tmax, RH_morning, RH_evening, z, lat)
```

Arguments

Tmean	Mean air temperature (degrees Celsius).
Tmin	Minimum air temperature (degrees Celsius).
Tmax	Maximum air temperature (degrees Celsius).
RH_morning	Morning relative humidity (percent).
RH_evening	Evening relative humidity (percent).
z	Elevation above sea level (m).
lat	Latitude (degrees).

Value

Daily ET0 (mm/day).

References

Linacre, E.T. (1977). A simple formula for estimating evaporation rates in various climates, using temperature data alone. Agricultural Meteorology, 18(6), 409-424.

See Also

Other temperature models: [et0_baier_robertson\(\)](#), [et0_berti\(\)](#), [et0_blaney_criddle\(\)](#), [et0_dorji\(\)](#), [et0_droogers_allen\(\)](#), [et0_hargreaves_samani\(\)](#), [et0_schendel\(\)](#), [et0_tabari_talee1\(\)](#), [et0_tabari_talee2\(\)](#)

Examples

```
et0_linacre(25, 15, 35, 90, 40, 216, 25.43)
```

et0_schendel	<i>Schendel ET0 Model</i>
--------------	---------------------------

Description

Estimates daily ET0 using the Schendel method (Bormann, 2011), which uses mean temperature and relative humidity.

Usage

```
et0_schendel(Tmean, RH)
```

Arguments

Tmean	Mean air temperature (degrees Celsius).
RH	Mean relative humidity (percent).

Value

Daily ET0 (mm/day).

References

Bormann, H. (2011). Sensitivity analysis of 18 different potential evapotranspiration models to observed climatic change at German climate stations. *Climatic Change*, 104(3), 729-753.

See Also

Other temperature models: [et0_baier_robertson\(\)](#), [et0_berti\(\)](#), [et0_blaney_criddle\(\)](#), [et0_dorji\(\)](#), [et0_droogers_allen\(\)](#), [et0_hargreaves_samani\(\)](#), [et0_linacre\(\)](#), [et0_tabari_talee1\(\)](#), [et0_tabari_talee2\(\)](#)

Examples

```
et0_schendel(25, 60)
```

et0_tabari_talee1	<i>Tabari-Talae Model 1 ET0</i>
-------------------	---------------------------------

Description

Estimates daily ET0 using the first Tabari and Talae (2011) modified Hargreaves equation with coefficient 0.031.

Usage

```
et0_tabari_talee1(Tmin, Tmax, J, lat)
```

Arguments

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

Value

Daily ET0 (mm/day).

References

Tabari, H. & Talae, P.H. (2011). Local calibration of the Hargreaves and Priestley-Taylor equations for estimating reference evapotranspiration in arid and cold climates of Iran based on the Penman-Monteith model. *Journal of Hydrologic Engineering*, 16(10), 837-845.

See Also

Other temperature models: [et0_baier_robertson\(\)](#), [et0_berti\(\)](#), [et0_blaney_criddle\(\)](#), [et0_dorji\(\)](#), [et0_droogers_allen\(\)](#), [et0_hargreaves_samani\(\)](#), [et0_linacre\(\)](#), [et0_schendel\(\)](#), [et0_tabari_talee2\(\)](#)

Examples

```
et0_tabari_talee1(15, 30, 172, 25.43)
```

et0_tabari_talee2	<i>Tabari-Talaee Model 2 ET0</i>
-------------------	----------------------------------

Description

Estimates daily ET0 using the second Tabari and Talaee (2011) modified Hargreaves equation with coefficient 0.0028.

Usage

```
et0_tabari_talee2(Tmin, Tmax, J, lat)
```

Arguments

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

Value

Daily ET0 (mm/day).

References

Tabari, H. & Talaee, P.H. (2011). Local calibration of the Hargreaves and Priestley-Taylor equations for estimating reference evapotranspiration in arid and cold climates of Iran based on the Penman-Monteith model. *Journal of Hydrologic Engineering*, 16(10), 837-845.

See Also

Other temperature models: [et0_baier_robertson\(\)](#), [et0_berti\(\)](#), [et0_blaney_criddle\(\)](#), [et0_dorji\(\)](#), [et0_droogers_allen\(\)](#), [et0_hargreaves_samani\(\)](#), [et0_linacre\(\)](#), [et0_schendel\(\)](#), [et0_tabari_talee1\(\)](#)

Examples

```
et0_tabari_talee2(15, 30, 172, 25.43)
```

et0_temp_all	<i>Compute ET0 Using All 10 Temperature-Based Models and FAO Penman-Monteith</i>
--------------	--

Description

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

Usage

```
et0_temp_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 Schendel, Linacre, and FAO Penman-Monteith.
RH_evening	Evening relative humidity (percent). Used by Schendel, Linacre, and FAO Penman-Monteith.
u2	Wind speed at 2 m height (m/s). Used by FAO Penman-Monteith only.
n	Actual sunshine hours. Used by FAO Penman-Monteith only.
J	Day of the year (1-366).
lat	Latitude (degrees, negative for Southern Hemisphere).
z	Elevation above sea level (m). Used by Linacre and FAO Penman-Monteith. Default is 0.

Details

The 10 temperature-based models included are:

- Blaney-Criddle (1950)
- Schendel (Bormann, 2011)
- Hargreaves-Samani (1985)
- Linacre (1977)
- Tabari-Talaei 1 (2011)
- Tabari-Talaei 2 (2011)
- Droogers-Allen (2002)
- Berti et al. (2014)
- Dorji et al. (2016)
- Baier-Robertson (1965)

The **FAO Penman-Monteith** column serves as the standard reference against which the temperature-based models can be evaluated using [evaluate_models](#).

Value

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

Examples

```
# Single day example
result <- et0_temp_all(Tmin = 15, Tmax = 30, RH_morning = 90,
                      RH_evening = 40, u2 = 1.5, n = 8,
                      J = 172, lat = 25.43, z = 216)

print(result)
```

 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	<i>Latent Heat of Vaporization</i>
-------------	------------------------------------

Description

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

Usage

```
latent_heat(Tmean)
```


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)
```

plots	<i>Visualization Functions for ET0 Model Comparison</i>
-------	---

Description

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

plot_annual_bar	<i>Annual ET0 Bar Chart</i>
-----------------	-----------------------------

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)
```

`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)
```

`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	<i>Slope of Saturation Vapor Pressure Curve</i>
----------------------	---

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	<i>Solar Radiation (Angstrom)</i>
-----------------	-----------------------------------

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)
```

temperature_models	<i>Temperature-Based ETO Models</i>
--------------------	-------------------------------------

Description

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

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