

Package: ET0MassModels (via r-universe)

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Description Provides functions to estimate daily reference evapotranspiration (ET0) using 10 mass transfer-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/ET0MassModels/issues>

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ET0MassModels-package *ET0MassModels: Evapotranspiration Estimation Using Mass Transfer-Based Models*

Description

The **ET0MassModels** package provides functions for estimating daily reference evapotranspiration (ET0) using 10 mass transfer-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.

Mass Transfer-Based Models (10)

Dalton (1802) Linear wind function of vapor pressure deficit.
Trabert (1896) Square-root wind function of vapor pressure deficit.
Meyer (1926) Linear wind function of vapor pressure deficit.
Rohwer (1931) Wind function using vapor pressure deficit in mmHg.
Penman (1948) Mass transfer form using wind in miles/day and mmHg.
Albrecht (1950) Linear wind function of vapor pressure deficit.
WMO (1966) Linear wind function of vapor pressure deficit.
Brockamp-Wenner (1963) Power wind function of vapor pressure deficit.
Romanenko (1961) Temperature and relative humidity based approach.
Mahringer (1970) Square-root wind function of vapor pressure deficit.

Key Functions

`et0_mass_all` Compute ET0 using all 10 mass transfer-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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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/ET0MassModels>
- Report bugs at <https://github.com/samirigfri/ET0MassModels/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_albrecht *Albrecht ET0 Model*

Description

Estimates daily ET0 using the Albrecht (1950) mass transfer method.

Usage

```
et0_albrecht(Tmin, Tmax, RH_morning, RH_evening, u)
```

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).
u Wind speed (m/s).

Details

Vapor pressures are internally converted to hPa.

Value

Daily ET0 (mm/day).

References

Albrecht, F. (1950). Die Methoden zur Bestimmung der Verdunstung der natürlichen Erdoberfläche. Archiv für Meteorologie, Geophysik und Bioklimatologie, Serie B, 2, 1-38.

See Also

Other mass transfer models: [et0_brockamp_wenner\(\)](#), [et0_dalton\(\)](#), [et0_mahringer\(\)](#), [et0_meyer\(\)](#), [et0_penman\(\)](#), [et0_rohwer\(\)](#), [et0_romanenko\(\)](#), [et0_trabert\(\)](#), [et0_wmo\(\)](#)

Examples

```
et0_albrecht(15, 30, 90, 40, 1.5)
```

et0_brockamp_wenner	<i>Brockamp-Wenner ET0 Model</i>
---------------------	----------------------------------

Description

Estimates daily ET0 using the Brockamp and Wenner (1963) mass transfer method.

Usage

```
et0_brockamp_wenner(Tmin, Tmax, RH_morning, RH_evening, u)
```

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).
u	Wind speed (m/s).

Details

Vapor pressures are internally converted to hPa.

Value

Daily ET0 (mm/day).

References

Brockamp, B. & Wenner, H. (1963). Verdunstungsmessungen auf den Steiner See bei Munster. Deutsche Gewässerkundliche Mitteilungen, 7, 149-154.

See Also

Other mass transfer models: [et0_albrecht\(\)](#), [et0_dalton\(\)](#), [et0_mahringer\(\)](#), [et0_meyer\(\)](#), [et0_penman\(\)](#), [et0_rohwer\(\)](#), [et0_romanenko\(\)](#), [et0_trabert\(\)](#), [et0_wmo\(\)](#)

Examples

```
et0_brockamp_wenner(15, 30, 90, 40, 1.5)
```

et0_dalton

Dalton ET0 Model

Description

Estimates daily ET0 using the Dalton (1802) mass transfer method.

Usage

```
et0_dalton(Tmin, Tmax, RH_morning, RH_evening, u)
```

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).
u	Wind speed (m/s).

Details

Vapor pressures are internally converted to hPa as required by this model.

Value

Daily ET0 (mm/day).

References

Dalton, J. (1802). Experimental essays on the constitution of mixed gases. Memoirs of the Literary and Philosophical Society of Manchester, 5, 535-602.

See Also

Other mass transfer models: [et0_albrecht\(\)](#), [et0_brockamp_wenner\(\)](#), [et0_mahringer\(\)](#), [et0_meyer\(\)](#), [et0_penman\(\)](#), [et0_rohwer\(\)](#), [et0_romanenko\(\)](#), [et0_trabert\(\)](#), [et0_wmo\(\)](#)

Examples

```
et0_dalton(15, 30, 90, 40, 1.5)
```

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_mahringer*Mahringer ET0 Model*

Description

Estimates daily ET0 using the Mahringer (1970) mass transfer method.

Usage

```
et0_mahringer(Tmin, Tmax, RH_morning, RH_evening, u)
```

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).
u	Wind speed (m/s).

Details

Vapor pressures are internally converted to hPa.

Value

Daily ET0 (mm/day).

References

Mahringer, W. (1970). Verdunstungsstudien am Neusiedler See. Archiv fur Meteorologie, Geophysik und Bioklimatologie, Serie B, 18, 1-20.

See Also

Other mass transfer models: [et0_albrecht\(\)](#), [et0_brockamp_wenner\(\)](#), [et0_dalton\(\)](#), [et0_meyer\(\)](#), [et0_penman\(\)](#), [et0_rohwer\(\)](#), [et0_romanenko\(\)](#), [et0_trabert\(\)](#), [et0_wmo\(\)](#)

Examples

```
et0_mahringer(15, 30, 90, 40, 1.5)
```

et0_mass_all	<i>Compute ET0 Using All 10 Mass Transfer-Based Models and FAO Penman-Monteith</i>
--------------	--

Description

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

Usage

```
et0_mass_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).
RH_evening	Evening relative humidity (percent).
u2	Wind speed at 2 m height (m/s). Used by FAO Penman-Monteith and by the wind-dependent mass transfer models.
n	Actual sunshine hours. Used by FAO Penman-Monteith only.
J	Day of the year (1-366). Used by FAO Penman-Monteith only.
lat	Latitude (degrees, negative for Southern Hemisphere). Used by FAO Penman-Monteith only.
z	Elevation above sea level (m). Default is 0. Used by FAO Penman-Monteith only.

Details

The 10 mass transfer-based models included are:

- Dalton (1802)
- Trabert (1896)
- Meyer (1926)
- Rohwer (1931)
- Penman (1948)
- Albrecht (1950)
- WMO (1966)
- Brockamp-Wenner (1963)
- Romanenko (1961)
- Mahringer (1970)

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 mass transfer-based model. The number of rows equals the length of the input vectors.

Examples

```
result <- et0_mass_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_meyer	<i>Meyer ET0 Model</i>
-----------	------------------------

Description

Estimates daily ET0 using the Meyer (1926) mass transfer method.

Usage

```
et0_meyer(Tmin, Tmax, RH_morning, RH_evening, u)
```

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).
u	Wind speed (m/s).

Details

Vapor pressures are internally converted to hPa.

Value

Daily ET0 (mm/day).

References

Meyer, A. (1926). Uber einige Zusammenhange zwischen Klima und Boden in Europa. Chemie der Erde, 2, 209-347.

See Also

Other mass transfer models: [et0_albrecht\(\)](#), [et0_brockamp_wenner\(\)](#), [et0_dalton\(\)](#), [et0_mahringer\(\)](#), [et0_penman\(\)](#), [et0_rohwer\(\)](#), [et0_romanenko\(\)](#), [et0_trabert\(\)](#), [et0_wmo\(\)](#)

Examples

```
et0_meyer(15, 30, 90, 40, 1.5)
```

et0_penman

Penman Mass Transfer ET0 Model

Description

Estimates daily ET0 using the Penman (1948) mass transfer method.

Usage

```
et0_penman(Tmin, Tmax, RH_morning, RH_evening, u)
```

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).
u	Wind speed (m/s).

Details

Wind speed is internally converted to miles/day and vapor pressures to mmHg as required by the original Penman formulation.

Value

Daily ET0 (mm/day).

References

Penman, H.L. (1948). Natural evaporation from open water, bare soil and grass. Proceedings of the Royal Society A, 193, 120-145.

See Also

Other mass transfer models: [et0_albrecht\(\)](#), [et0_brockamp_wenner\(\)](#), [et0_dalton\(\)](#), [et0_mahringer\(\)](#), [et0_meyer\(\)](#), [et0_rohwer\(\)](#), [et0_romanenko\(\)](#), [et0_trabert\(\)](#), [et0_wmo\(\)](#)

Examples

```
et0_penman(15, 30, 90, 40, 1.5)
```

et0_rohwer

Rohwer ET0 Model

Description

Estimates daily ET0 using the Rohwer (1931) mass transfer method.

Usage

```
et0_rohwer(Tmin, Tmax, RH_morning, RH_evening, u)
```

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).
u	Wind speed (m/s).

Details

Vapor pressures are internally converted to mmHg as required by this model.

Value

Daily ET0 (mm/day).

References

Rohwer, C. (1931). Evaporation from free water surfaces. USDA Technical Bulletin No. 271.

See Also

Other mass transfer models: [et0_albrecht\(\)](#), [et0_brockamp_wenner\(\)](#), [et0_dalton\(\)](#), [et0_mahringer\(\)](#), [et0_meyer\(\)](#), [et0_penman\(\)](#), [et0_romanenko\(\)](#), [et0_trabert\(\)](#), [et0_wmo\(\)](#)

Examples

```
et0_rohwer(15, 30, 90, 40, 1.5)
```

et0_romanenko	<i>Romanenko ET0 Model</i>
---------------	----------------------------

Description

Estimates daily ET0 using the Romanenko (1961) mass transfer method.

Usage

```
et0_romanenko(Tmean, Tmin, Tmax, RH_morning, RH_evening)
```

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).

Value

Daily ET0 (mm/day).

References

Romanenko, V.A. (1961). Computation of the autumn soil moisture using a universal relationship for a large area. Proceedings of the Ukrainian Hydrometeorological Research Institute, 3, 12-25.

See Also

Other mass transfer models: [et0_albrecht\(\)](#), [et0_brockamp_wenner\(\)](#), [et0_dalton\(\)](#), [et0_mahringer\(\)](#), [et0_meyer\(\)](#), [et0_penman\(\)](#), [et0_rohwer\(\)](#), [et0_trabert\(\)](#), [et0_wmo\(\)](#)

Examples

```
et0_romanenko(25, 15, 35, 90, 40)
```

et0_trabert	<i>Trabert ET0 Model</i>
-------------	--------------------------

Description

Estimates daily ET0 using the Trabert (1896) mass transfer method.

Usage

```
et0_trabert(Tmin, Tmax, RH_morning, RH_evening, u)
```

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).
u	Wind speed (m/s).

Details

Vapor pressures are internally converted to hPa.

Value

Daily ET0 (mm/day).

References

Trabert, W. (1896). Neue Beobachtungen uber Verdampfungsgeschwindigkeiten. Meteorologische Zeitschrift, 13, 261-263.

See Also

Other mass transfer models: [et0_albrecht\(\)](#), [et0_brockamp_wenner\(\)](#), [et0_dalton\(\)](#), [et0_mahringer\(\)](#), [et0_meyer\(\)](#), [et0_penman\(\)](#), [et0_rohwer\(\)](#), [et0_romanenko\(\)](#), [et0_wmo\(\)](#)

Examples

```
et0_trabert(15, 30, 90, 40, 1.5)
```

et0_wmo

WMO ET0 Model

Description

Estimates daily ET0 using the World Meteorological Organization (WMO, 1966) mass transfer method.

Usage

```
et0_wmo(Tmin, Tmax, RH_morning, RH_evening, u)
```

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).
u	Wind speed (m/s).

Details

Vapor pressures are internally converted to hPa.

Value

Daily ET0 (mm/day).

References

World Meteorological Organization (1966). Measurement and estimation of evaporation and evapotranspiration. Technical Note No. 83.

See Also

Other mass transfer models: [et0_albrecht\(\)](#), [et0_brockamp_wenner\(\)](#), [et0_dalton\(\)](#), [et0_mahringer\(\)](#), [et0_meyer\(\)](#), [et0_penman\(\)](#), [et0_rohwer\(\)](#), [et0_romanenko\(\)](#), [et0_trabert\(\)](#)

Examples

```
et0_wmo(15, 30, 90, 40, 1.5)
```

`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

<code>observed</code>	Numeric vector of observed (reference) ET0 values.
<code>predicted</code>	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	<i>Sample Meteorological Data from Jhansi, India</i>
----------------	--

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)
```

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)
```

mass_transfer_models	<i>Mass Transfer-Based ET0 Models</i>
----------------------	---------------------------------------

Description

Functions implementing 10 mass transfer-based empirical models for reference evapotranspiration (ET0) estimation. These models are based on the vapor pressure deficit and wind speed.

metrics	<i>Statistical Evaluation Metrics for ET0 Models</i>
---------	--

Description

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

net_radiation	<i>Net Radiation</i>
---------------	----------------------

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	<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

<code>observed</code>	Numeric vector of observed (reference) ET0 values.
<code>predicted</code>	A named list or data.frame of predicted ET0 values.
<code>model_names</code>	Character vector of model names to plot. If NULL, all models are plotted.
<code>main</code>	Title for the plot.
<code>colors</code>	Character vector of colors. If NULL, colors are generated automatically.
<code>normalize</code>	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	<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.

psychrometric_constant	<i>Psychrometric Constant</i>
------------------------	-------------------------------

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 *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	<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)
```

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