Package ‘TrenchR’

July 13, 2022

Title Tools for Microclimate and Biophysical Ecology

Description Tools for translating environmental change into organismal response. Microclimate models to vertically scale weather station data to organismal heights. The biophysical modeling tools include both general models for heat flows and specific models to predict body temperatures for a variety of ectothermic taxa. Additional functions model and temporally partition air and soil temperatures and solar radiation. Utility functions estimate the organismal and environmental parameters needed for biophysical ecology. 'TrenchR' focuses on relatively simple and modular functions so users can create transparent and flexible biophysical models. Many functions are derived from Gates (1980) <doi:10.1007/978-1-4612-6024-0> and Campbell and Norman (1988) <isbn:9780387949376>.

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URL https://trenchproject.github.io/,
https://github.com/trenchproject/TrenchR

BugReports https://github.com/trenchproject/TrenchR/issues

VignetteBuilder knitr

Depends R (>= 3.3.1)

Imports deSolve, msm, Rdpack (>= 0.7), stats, zoo

Suggests covr, knitr, rmarkdown, testthat

RdMacros Rdpack

Encoding UTF-8

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NeedsCompilation no

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R topics documented:

`actual_vapor_pressure` *Actual Vapor Pressure from Dewpoint Temperature*

Description

The function calculates actual vapor pressure from dewpoint temperature based on Stull (2000); Riddell et al. (2018).

Usage

```
actual_vapor_pressure(T_dewpoint)
```

Arguments

`T_dewpoint`	`numeric` dewpoint temperature (C).

Value

`numeric` actual vapor pressure (kPa).

Author(s)

Eric Riddell

References

Riddell EA, Odom JP, Damm JD, Sears MW (2018). "Plasticity reveals hidden resistance to extinction under climate change in the global hotspot of salamander diversity." *Science Advances*, **4**(4). doi: 10.1126/sciadv.aar5471.

Stull RB (2000). *Meteorology for Scientists and Engineers*. Brooks Cole. ISBN 978-0534372149.

See Also

Other biophysical models: `Grashof_number_Gates()`, `Grashof_number()`, `Nusselt_from_Grashof()`, `Nusselt_from_Reynolds()`, `Nusselt_number()`, `Prandtl_number()`, `Qconduction_animal()`, `Qconduction_substrate()`, `Qconvection()`, `Qemitted_thermal_radiation()`, `Qevaporation()`, `Qmetabolism_from_mass_temp()`, `Qmetabolism_from_mass()`, `Qnet_Gates()`, `Qradiation_absorbed()`, `Qthermal_radiation_absorbed()`, `Reynolds_number()`, `Tb_CampbellNorman()`, `Tb_Gates2()`, `Tb_Gates()`, `Tb_butterfly()`, `Tb_grasshopper()`, `Tb_limpetBH()`, `Tb_limpet()`, `Tb_lizard_Fei()`, `Tb_lizard()`, `Tb_mussel()`, `Tb_salamander_humid()`, `Tb_snail()`, `Tbed_mussel()`, `Tsoil()`, `boundary_layer_resistance()`, `external_resistance_to_water_vapor_transfer()`, `free_or_forced_convection`, `heat_transfer_coefficient_approximation()`, `heat_transfer_coefficient_simple()`, `heat_transfer_coeffici`, `saturation_vapor_pressure()`, `saturation_water_vapor_pressure()`

Examples

```
actual_vapor_pressure(T_dewpoint = 20)
```

---

airpressure_from_elev *Air Pressure from Elevation*

Description

The function estimates air pressure (kPa) as a function of elevation (Engineering ToolBox 2003).

Usage

```
airpressure_from_elev(elev)
```

Arguments

`elev`	`numeric` elevation (meters).

Value

`numeric` air pressure (kPa).

References

Engineering ToolBox (2003). *Atmospheric Pressure vs. Elevation above Sea Level*. https://www.engineeringtoolbox.com/air-altitude-pressure-d_462.html.

See Also

Other utility functions: `azimuth_angle()`, `day_of_year()`, `daylength()`, `dec_angle()`, `solar_noon()`, `temperature conversions`, `zenith_angle()`

Examples

```
airpressure_from_elev(elev = 1500)
```

air_temp_profile — *Air Temperature Profile using MICRO Routine*

Description

The function estimates air temperature (C) at a specified height (m). Estimates a single, unsegmented temperature profile using the MICRO routine from NicheMapR (Kearney and Porter 2017).

Usage

```
air_temp_profile(T_r, u_r, zr, z0, z, T_s)
```

Arguments

`T_r`	`numeric` air temperature (C) at reference height.
`u_r`	`numeric` windspeed (ms^-1) at reference height.
`zr`	`numeric` initial reference height (m).
`z0`	`numeric` surface roughness (m).
`z`	`numeric` height to scale (m).
`T_s`	`numeric` surface temperatures (C).

Value

`numeric` air temperature (C).

References

Kearney MR, Porter WP (2017). "NicheMapR - an R package for biophysical modelling: the microclimate model." *Ecography*, **40**, 664-674. doi: 10.1111/ecog.02360.

See Also

Other microclimate functions: `air_temp_profile_neutral()`, `air_temp_profile_segment()`, `degree_days()`, `direct_solar_radiation()`, `diurnal_radiation_variation()`, `diurnal_temp_variation_sineexp`
`diurnal_temp_variation_sinesqrt()`, `diurnal_temp_variation_sine()`, `monthly_solar_radiation()`, `partition_solar_radiation()`, `proportion_diffuse_solar_radiation()`, `solar_radiation()`, `surface_roughness()`, `wind_speed_profile_neutral()`, `wind_speed_profile_segment()`

Examples

```
air_temp_profile(T_r = 20,
                 u_r = 0.1,
                 zr  = 0.1,
                 z0  = 0.2,
                 z   = 0.15,
                 T_s = 25)
```

`air_temp_profile_neutral`

Air Temperature at a Specified Height Under Neutral Conditions

Description

The function calculates air temperature (C) at a specified height (m) within a boundary layer near the surface. The velocity profile is the neutral profile described by Sellers (1965). Function is included as equations (2) and (3) of Porter et al. (1973).

Usage

```
air_temp_profile_neutral(T_r, zr, z0, z, T_s)
```

Arguments

`T_r`	`numeric` air temperature (C) at reference height.
`zr`	`numeric` initial reference height (m).
`z0`	`numeric` surface roughness (m).
`z`	`numeric` height to scale to (m).
`T_s`	`numeric` surface temperatures (C).

Value

`numeric` air temperature (C).

References

Porter WP, Mitchell JW, Bekman A, DeWitt CB (1973). "Behavioral implications of mechanistic ecology: thermal and behavioral modeling of desert ectotherms and their microenvironments." *Oecologia*, **13**, 1-54.

Sellers WD (1965). *Physical climatology*. University of Chicago Press, Chicago, IL, USA.

See Also

Other microclimate functions: `air_temp_profile_segment()`, `air_temp_profile()`, `degree_days()`, `direct_solar_radiation()`, `diurnal_radiation_variation()`, `diurnal_temp_variation_sineexp()`, `diurnal_temp_variation_sinesqrt()`, `diurnal_temp_variation_sine()`, `monthly_solar_radiation()`, `partition_solar_radiation()`, `proportion_diffuse_solar_radiation()`, `solar_radiation()`, `surface_roughness()`, `wind_speed_profile_neutral()`, `wind_speed_profile_segment()`

Examples

```
air_temp_profile_neutral(T_r = 20,
                         zr  = 0.1,
                         z0  = 0.2,
                         z   = 0.15,
                         T_s = 25)
```

---

air_temp_profile_segment
Air Temperature at a Specified Height

Description

The function calculates air temperature (C) at a specified height (m). Estimates a three segment velocity and temperature profile based on user-specified, experimentally determined values for 3 roughness heights and reference heights. Multiple heights are appropriate in heterogenous areas with, for example, a meadow, bushes, and rocks. Implements the MICROSEGMT routine from NicheMapR as described in Kearney and Porter (2017).

Usage

```
air_temp_profile_segment(T_r, u_r, zr, z0, z, T_s)
```

Arguments

`T_r`	`numeric` a vector of air temperatures (C) at the 3 reference heights.
`u_r`	`numeric` a vector of wind speeds (ms^-1) at the 3 reference heights.
`zr`	`numeric` a vector of 3 reference heights (meters).
`z0`	`numeric` a vector of 3 experimentally determined roughness heights (meters).
`z`	`numeric` height for air temperature estimation (meters).
`T_s`	`numeric` surface temperatures (C).

Value

`numeric` air temperature (C).

References

Kearney MR, Porter WP (2017). "NicheMapR - an R package for biophysical modelling: the microclimate model." *Ecography*, **40**, 664-674. doi: 10.1111/ecog.02360.

See Also

Other microclimate functions: air_temp_profile_neutral(), air_temp_profile(), degree_days(), direct_solar_radiation(), diurnal_radiation_variation(), diurnal_temp_variation_sineexp(), diurnal_temp_variation_sinesqrt(), diurnal_temp_variation_sine(), monthly_solar_radiation(), partition_solar_radiation(), proportion_diffuse_solar_radiation(), solar_radiation(), surface_roughness(), wind_speed_profile_neutral(), wind_speed_profile_segment()

Examples

```
air_temp_profile_segment(T_r = c(25, 22, 20),
                         u_r = c(0.01, 0.025, 0.05),
                         zr  = c(0.05, 0.25, 0.5),
                         z0  = c(0.01, 0.15, 0.2),
                         z   = 0.3,
                         T_s = 27)
```

---

angle conversions — *Convert Angles Between Radians and Degrees*

Description

The function converts angles in radians to degrees or degrees to radians.

Usage

```
radians_to_degrees(rad)

degrees_to_radians(deg)
```

Arguments

rad	numeric angle (radians).
deg	numeric angle (degrees).

Value

numeric angle (degrees or radians).

Examples

```
radians_to_degrees(0.831)
degrees_to_radians(47.608)
```

`azimuth_angle` *Azimuth Angle*

Description

The function calculates the azimuth angle, the angle (degrees) from which the sunlight is coming measured from true north or south measured in the horizontal plane. The azimuth angle is measured with respect to due south, increasing in the counter clockwise direction so 90 degrees is east (Campbell and Norman 1998).

Usage

```
azimuth_angle(doy, lat, lon, hour, offset = NA)
```

Arguments

`doy`	`numeric` day of year (1-366). This can be obtained from standard date via `day_of_year`.
`lat`	`numeric` latitude (decimal degrees).
`lon`	`numeric` longitude (decimal degrees).
`hour`	`numeric` hour of the day.
`offset`	`numeric` number of hours to add to UTC (Coordinated Universal Time) to get local time (to improve accuracy but not always necessary). Optional. Defaults to NA.

Value

`numeric` azimuth angle (degrees).

References

Campbell GS, Norman JM (1998). *Introduction to environmental biophysics*, 2nd ed. edition. Springer, New York. ISBN 0387949372.

See Also

Other utility functions: `airpressure_from_elev()`, `day_of_year()`, `daylength()`, `dec_angle()`, `solar_noon()`, `temperature conversions`, `zenith_angle()`

Examples

```
azimuth_angle(doy    = 112,
              lat    = 47.61,
              lon    = -122.33,
              hour   = 12,
              offset = -8)
```

boundary_layer_resistance

Boundary Layer Resistance

Description

The function estimates boundary layer resistance under free convection based on the function in Riddell et al. (2018).

Usage

```
boundary_layer_resistance(T_a, e_s, e_a, elev, D, u = NA)
```

Arguments

T_a	numeric air temperature (K).
e_s	numeric saturation vapor pressure (kPa).
e_a	numeric actual vapor pressure (kPa).
elev	numeric elevation (m).
D	numeric characteristic dimension (e.g., body diameter) (m).
u	numeric wind speed (ms^-1), if not provided assume free convection; if provided, use forced convection if appropriate.

Value

numeric boundary layer resistance (scm^-1).

Author(s)

Eric Riddell

References

Riddell EA, Odom JP, Damm JD, Sears MW (2018). "Plasticity reveals hidden resistance to extinction under climate change in the global hotspot of salamander diversity." *Science Advances*, **4**(4). doi: 10.1126/sciadv.aar5471.

See Also

Other biophysical models: Grashof_number_Gates(), Grashof_number(), Nusselt_from_Grashof(), Nusselt_from_Reynolds(), Nusselt_number(), Prandtl_number(), Qconduction_animal(), Qconduction_substrate(), Qconvection(), Qemitted_thermal_radiation(), Qevaporation(), Qmetabolism_from_mass_temp(), Qmetabolism_from_mass(), Qnet_Gates(), Qradiation_absorbed(), Qthermal_radiation_absorbed(), Reynolds_number(), Tb_CampbellNorman(), Tb_Gates2(), Tb_Gates(), Tb_butterfly(), Tb_grasshopper(), Tb_limpetBH(), Tb_limpet(), Tb_lizard_Fei(), Tb_lizard(), Tb_mussel(), Tb_salamander_humid(), Tb_snail(), Tbed_mussel(), Tsoil(),

actual_vapor_pressure(), external_resistance_to_water_vapor_transfer(), free_or_forced_convection(), heat_transfer_coefficient_approximation(), heat_transfer_coefficient_simple(), heat_transfer_coeffici
saturation_vapor_pressure(), saturation_water_vapor_pressure()

Examples

```
boundary_layer_resistance(T_a  = 293,
                          e_s  = 2.5,
                          e_a  = 2.0,
                          elev = 500,
                          D    = 0.007,
                          u    = 2)
```

---

constants *General Use Constants*

Description

Basic functions for numerical constants for conversions.

Usage

```
specific_heat_h2o(units = "J_kg-1_K-1")

latent_heat_vaporization_h2o(units = "J_kg-1")

stefan_boltzmann_constant(units = "W_m-2_K-4")

von_karman_constant(units = "")
```

Arguments

units character indicating units

- specific_heat_h2o:
  - "J_kg-1_K-1": Jkg^-1K^-1
- latent_heat_vaporization_h2o:
  - "J_kg-1": Jkg^-1
- stefan_boltzmann_constant:
  - "W_m-2_K-4": Wm^-2K^-4
  - "mW_cm-2_K-4": $mWcm^-2K^-4$
- con_karman_constant:
  - "": dimensionless

Value

numeric values in units.

Examples

```
specific_heat_h2o()
latent_heat_vaporization_h2o()
stefan_boltzmann_constant()
```

---

daylength *Day Length*

Description

The function calculates daylength in hours as a function of latitude and day of year. Uses the CMB model (Campbell and Norman 1998).

Usage

```
daylength(lat, doy)
```

Arguments

lat	`numeric` latitude (decimal degrees).
doy	`numeric` day of year (1-366). This can be obtained from standard date via `day_of_year`.

Value

`numeric` day length (hours).

References

Campbell GS, Norman JM (1998). *Introduction to environmental biophysics*, 2nd ed. edition. Springer, New York. ISBN 0387949372.

See Also

Other utility functions: `airpressure_from_elev()`, `azimuth_angle()`, `day_of_year()`, `dec_angle()`, `solar_noon()`, `temperature conversions`, `zenith_angle()`

Examples

```
daylength(lat = 47.61,
          doy = 112)
```

day_of_year *Julian Day from Date*

Description

The function converts a date (day, month, year) to Julian Day (day of year).

Usage

```
day_of_year(day, format = "%Y-%m-%d")
```

Arguments

day	character numerical date in standard format (e.g. "2017-01-02", "01-02", "01/02/2017" etc).
format	character date format following as.POSIXlt conventions. Default value = "%Y-%m-%d".

Value

numeric Julian day number, 1-366 (e.g. 1 for January 1st).

See Also

Other utility functions: airpressure_from_elev(), azimuth_angle(), daylength(), dec_angle(), solar_noon(), temperature conversions, zenith_angle()

Examples

```
day_of_year(day    = "2017-04-22",
            format = "%Y-%m-%d")
day_of_year(day    = "2017-04-22")
day_of_year(day    = "04/22/2017",
            format = "%m/%d/%Y")
```

dec_angle *Solar Declination in Radians*

Description

The function calculates solar declination, which is the angular distance of the sun north or south of the earth's equator, based on the day of year (Campbell and Norman 1998).

Usage

```
dec_angle(doy)
```

Arguments

doy	numeric day of year (1-366). This can be obtained from standard date via day_of_year.

Value

numeric declination angle (radians).

References

Campbell GS, Norman JM (1998). *Introduction to environmental biophysics*, 2nd ed. edition. Springer, New York. ISBN 0387949372.

See Also

Other utility functions: airpressure_from_elev(), azimuth_angle(), day_of_year(), daylength(), solar_noon(), temperature conversions, zenith_angle()

Examples

```
dec_angle(doy = 112)
dec_angle(doy = 360)
```

---

degree_days *Degree Days*

Description

The function calculates degree days using the following approximations: single or double sine wave, single or double triangulation (University of California Integrated Pest Management Program 2016). Double approximation methods assume symmetry, such that a day's thermal minimum is equal to that of the previous day. Double sine wave approximation of degree days from Allen (1976).

Usage

```
degree_days(T_min, T_max, LDT = NA, UDT = NA, method = "single.sine")
```

Arguments

T_min	numeric Minimum temperature of the day (C).
T_max	numeric Maximum temperature of the day (C).
LDT	numeric lower developmental threshold (C).
UDT	numeric upper developmental threshold (C).
method	character type of method being used. Current choices: "single.sine", "double.sine", "single.triangulation", and "double.triangulation".

Value

`numeric` degree days (C).

References

Allen JC (1976). "A Modified Sine Wave Method for Calculating Degree Days." *Environmental Entomology*, **5**(3), 388-396. doi: 10.1093/ee/5.3.388.

University of California Integrated Pest Management Program (2016). *Degree Days: Methods*. `http://ipm.ucanr.edu/WEATHER/ddfigindex.html`.

See Also

Other microclimate functions: `air_temp_profile_neutral()`, `air_temp_profile_segment()`, `air_temp_profile()`, `direct_solar_radiation()`, `diurnal_radiation_variation()`, `diurnal_temp_variation_si` `diurnal_temp_variation_sinesqrt()`, `diurnal_temp_variation_sine()`, `monthly_solar_radiation()`, `partition_solar_radiation()`, `proportion_diffuse_solar_radiation()`, `solar_radiation()`, `surface_roughness()`, `wind_speed_profile_neutral()`, `wind_speed_profile_segment()`

Examples

```
degree_days(T_min  = 7,
            T_max  = 14,
            LDT    = 12,
            UDT    = 33,
            method = "single.sine")
degree_days(T_min  = 7,
            T_max  = 14,
            LDT    = 12,
            UDT    = 33,
            method = "single.triangulation")
```

`direct_solar_radiation` *Direct Solar Radiation*

Description

The function estimates direct solar radiation (W/m^2) based on latitude, day of year, elevation, and time. The function uses two methods (McCullough and Porter 1971; Campbell and Norman 1998) compiled in Tracy et al. (1983).

Usage

```
direct_solar_radiation(lat, doy, elev, t, t0, method = "Campbell 1977")
```

Arguments

lat	numeric latitude (degrees).
doy	numeric day of year (1-366).
elev	numeric elevation (m).
t	numeric local time (decimal hours).
t0	numeric time of local noon (decimal hours), can be estimated using solar_noon.
method	character method for estimating direct solar radiation, options: "Campbell 1977" (default), "Gates 1962".

Value

numeric direct solar radiation (W/m^2).

References

Campbell GS, Norman JM (1998). *Introduction to environmental biophysics*, 2nd ed. edition. Springer, New York. ISBN 0387949372.

McCullough EC, Porter WP (1971). "Computing Clear Day Solar Radiation Spectra for the Terrestrial Ecological Environment." *Ecology*, **52**(6), 1008-1015. doi: 10.2307/1933806.

Tracy CR, Hammond KA, Lechleitner RA, II WJS, Thompson DB, Whicker AD, Williamson SC (1983). "Estimating clear-day solar radiation: an evaluation of three models." *Journal of Thermal Biology*, **8**(3), 247-251. doi: 10.1016/03064565(83)900037, https://doi.org/10.1016/0306-4565(83)90003-7.

See Also

Other microclimate functions: air_temp_profile_neutral(), air_temp_profile_segment(), air_temp_profile(), degree_days(), diurnal_radiation_variation(), diurnal_temp_variation_sineexp(), diurnal_temp_variation_sinesqrt(), diurnal_temp_variation_sine(), monthly_solar_radiation(), partition_solar_radiation(), proportion_diffuse_solar_radiation(), solar_radiation(), surface_roughness(), wind_speed_profile_neutral(), wind_speed_profile_segment()

Examples

```
direct_solar_radiation(lat    = 47.61,
                       doy    = 112,
                       elev   = 1500,
                       t      = 9,
                       t0     = 12,
                       method = "Campbell 1977")
```

`diurnal_radiation_variation` *Hourly Solar Radiation*

Description

The function estimates hourly solar radiation (Wm^-2hr^-1) as a function of daily global solar radiation (Wm^-2d^-1). Based on Tham et al. (2010) and Tham et al. (2011).

Usage

```
diurnal_radiation_variation(doy, solrad, hour, lon, lat)
```

Arguments

`doy`	`numeric` the day of year.
`solrad`	`numeric` solar radiation (Wm^-2d^-1).
`hour`	`numeric` hour (0-24).
`lon`	`numeric` longitude (degrees).
`lat`	`numeric` latitude (degrees).

Value

`numeric` hourly solar radiation (Wm^-2).

References

Tham Y, Muneer T, Davison B (2010). "Estimation of hourly averaged solar irradiation: evaluation of models." *Building Services Engingeering Research Technology*, **31**(1). doi: 10.1177/0143624409350547.

Tham Y, Muneer T, Davison B (2011). "Prediction of hourly solar radiation on horizontal and inclined surfaces for Muscat/Oman." *The Journal of Engineering Research*, **8**(2), 19-31. doi: 10.24200/tjer.vol8iss2pp1931.

See Also

Other microclimate functions: `air_temp_profile_neutral()`, `air_temp_profile_segment()`, `air_temp_profile()`, `degree_days()`, `direct_solar_radiation()`, `diurnal_temp_variation_sineexp()`, `diurnal_temp_variation_sinesqrt()`, `diurnal_temp_variation_sine()`, `monthly_solar_radiation()`, `partition_solar_radiation()`, `proportion_diffuse_solar_radiation()`, `solar_radiation()`, `surface_roughness()`, `wind_speed_profile_neutral()`, `wind_speed_profile_segment()`

Examples

```
diurnal_radiation_variation(doy    = 112,
                            solrad = 8000,
                            hour   = 12,
                            lon    = -122.33,
                            lat    = 47.61)
```

---

diurnal_temp_variation_sine *Hourly Temperature Variation assuming a Sine Interpolation*

Description

The function estimates temperature for a specified hour using the sine interpolation in Campbell and Norman (1998).

Usage

```
diurnal_temp_variation_sine(T_max, T_min, t)
```

Arguments

`T_max, T_min`	`numeric` maximum and minimum daily temperatures (C).
`t`	`numeric` time for temperature estimate (hour).

Value

`numeric` temperature (C) at a specified hour.

References

Campbell GS, Norman JM (1998). *Introduction to environmental biophysics*, 2nd ed. edition. Springer, New York. ISBN 0387949372.

See Also

Other microclimate functions: `air_temp_profile_neutral()`, `air_temp_profile_segment()`, `air_temp_profile()`, `degree_days()`, `direct_solar_radiation()`, `diurnal_radiation_variation()`, `diurnal_temp_variation_sineexp()`, `diurnal_temp_variation_sinesqrt()`, `monthly_solar_radiation()`, `partition_solar_radiation()`, `proportion_diffuse_solar_radiation()`, `solar_radiation()`, `surface_roughness()`, `wind_speed_profile_neutral()`, `wind_speed_profile_segment()`

Examples

```
diurnal_temp_variation_sine(T_max = 30,
                            T_min = 10,
                            t     = 11)
```

diurnal_temp_variation_sineexp

Hourly Temperature Variation assuming Sine and Exponential Components

Description

The function estimates temperature across hours using a diurnal temperature variation function incorporating sine and exponential components (Parton and Logan 1981).

Usage

```
diurnal_temp_variation_sineexp(
  T_max,
  T_min,
  t,
  t_r,
  t_s,
  alpha = 2.59,
  beta = 1.55,
  gamma = 2.2
)
```

Arguments

`T_max, T_min`	`numeric` maximum and minimum daily temperatures (C).
`t`	`numeric` time for temperature estimate (hour).
`t_r, t_s`	`numeric` times of sunrise and sunset (hour).
`alpha`	`numeric` time difference between `t_x` (time of maximum temperature) and noon (hour).
`beta`	`numeric` time difference between `t_x` and sunrise (hour).
`gamma`	`numeric` decay parameter for rate of `t` change from sunset to `t_n` (time of minimum temp).

Details

Default `alpha`, `beta`, and `gamma` values are the average of 5 North Carolina sites (Wann et al. 1985).

Other `alpha`, `beta`, and `gamma` parameterizations include values for Denver, Colorado from Parton and Logan (1981):

- 150 cm air temperature: `alpha` = 1.86, `beta` = 2.20, `gamma` = -0.17
- 10 cm air temperature: `alpha` = 1.52, `beta` = 2.00, `gamma` = -0.18
- soil surface temperature: `alpha` = 0.50, `beta` = 1.81, `gamma` = 0.49
- 10cm soil temperature: `alpha` = 0.45, `beta` = 2.28, `gamma` = 1.83

Value

`numeric` temperature (C) at a specified hour.

References

Parton WJ, Logan JA (1981). "A model for diurnal variation in soil and air temperature." *Agricultural Meteorology*, **23**, 205-216. doi: 10.1016/00021571(81)901059, https://www.sciencedirect.com/science/article/abs/pii/0002157181901059.

Wann M, Yen D, Gold HJ (1985). "Evaluation and calibration of three models for daily cycle of air temperature." *Agricultural and Forest Meteorology*, **34**, 121-128. https://agris.fao.org/agris-search/search.do?recordID=NL19850065824.

See Also

Other microclimate functions: `air_temp_profile_neutral()`, `air_temp_profile_segment()`, `air_temp_profile()`, `degree_days()`, `direct_solar_radiation()`, `diurnal_radiation_variation()`, `diurnal_temp_variation_sinesqrt()`, `diurnal_temp_variation_sine()`, `monthly_solar_radiation()`, `partition_solar_radiation()`, `proportion_diffuse_solar_radiation()`, `solar_radiation()`, `surface_roughness()`, `wind_speed_profile_neutral()`, `wind_speed_profile_segment()`

Examples

```
diurnal_temp_variation_sineexp(T_max = 30,
                               T_min = 10,
                               t     = 11,
                               t_r   = 6,
                               t_s   = 18,
                               alpha = 2.59,
                               beta  = 1.55,
                               gamma = 2.2)
```

---

diurnal_temp_variation_sinesqrt

Hourly Temperature Variation using Sine and Square Root Functions

---

Description

The function estimates temperature for a specified hour using sine and square root functions (Cesaraccio et al. 2001).

Usage

```
diurnal_temp_variation_sinesqrt(t, t_r, t_s, T_max, T_min, T_minp)
```

Arguments

`t`	`numeric` hour or hours for temperature estimate.
`t_r, t_s`	`numeric` sunrise and sunset hours (0-23).
`T_max, T_min`	`numeric` maximum and minimum temperatures of current day (C).
`T_minp`	`numeric` minimum temperature of following day (C).

Value

`numeric` temperature (C) at a specified hour.

References

Cesaraccio C, Spano D, Duce P, Snyder RL (2001). "An improved model for determining degree-day values from daily temperature data." *International Journal of Biometeorology*, **45**, 161-169. doi: 10.1007/s004840100104, https://www.researchgate.net/publication/11589157_An_improved_model_for_determining_degree-day_values_from_daily_temperature_data.

See Also

Other microclimate functions: `air_temp_profile_neutral()`, `air_temp_profile_segment()`, `air_temp_profile()`, `degree_days()`, `direct_solar_radiation()`, `diurnal_radiation_variation()`, `diurnal_temp_variation_sineexp()`, `diurnal_temp_variation_sine()`, `monthly_solar_radiation()`, `partition_solar_radiation()`, `proportion_diffuse_solar_radiation()`, `solar_radiation()`, `surface_roughness()`, `wind_speed_profile_neutral()`, `wind_speed_profile_segment()`

Examples

```
diurnal_temp_variation_sinesqrt(t      = 8,
                                t_r    = 6,
                                t_s    = 18,
                                T_max  = 30,
                                T_min  = 10,
                                T_minp = 12)
```

DRYAIR *Properties of Dry Air*

Description

The function calculates several properties of dry air and related characteristics shown as output variables below. The program is based on equations from List (1971) and code implementation from NicheMapR (Kearney and Porter 2017; Kearney and Porter 2020).

The user must supply values for the input variables `db`, `bp`, and `alt`. If `alt` is known (-1000 < alt < 20000) but not BP, then set `bp = 0`.

Usage

```
DRYAIR(db, bp = 0, alt = 0)
```

Arguments

`db`	`numeric` dry bulb temperature (C).
`bp`	`numeric` barometric pressure (Pa).
`alt`	`numeric` altitude (m).

Value

Named `list` with elements

- `patmos`: `numeric` standard atmospheric pressure (Pa)
- `density`: `numeric` density (kgm^-3)
- `visdyn`: `numeric` dynamic viscosity (kgm^-1s^-1)
- `viskin`: `numeric` kinematic viscosity (m^2s^-1)
- `difvpr`: `numeric` diffusivity of water vapor in air (m^2s^-1)
- `thcond`: `numeric` thermal conductivity (WK^-1m^-1)
- `htovpr`: `numeric` latent heat of vaporization of water (Jkg^-1)
- `tcoeff`: `numeric` temperature coefficient of volume expansion (K^-1)
- `ggroup`: `numeric` group of variables in Grashof number (m^-3K^-1)
- `bbemit`: `numeric` black body emittance (Wm^-2)
- `emtmax`: `numeric` wave length of maximum emittance (m)

References

Kearney MR, Porter WP (2017). "NicheMapR - an R package for biophysical modelling: the microclimate model." *Ecography*, **40**, 664-674. doi: 10.1111/ecog.02360.

Kearney MR, Porter WP (2020). "NicheMapR - an R package for biophysical modelling: the ectotherm and Dynamic Energy Budget models." *Ecography*, **43**(1), 85-96. doi: 10.1111/ecog.04680.

List RJ (1971). "Smithsonian Meteorological Tables." *Smithsonian Miscellaneous Collections*, **114**(1), 1-527. https://repository.si.edu/handle/10088/23746.

Examples

```
DRYAIR(db = 30,
       bp = 100*1000,
       alt = 0)
```

external_resistance_to_water_vapor_transfer
External Resistance to Water Vapor Transfer

Description

The function estimate external resistance to water vapor transfer using the Lewis rule relating heat and mass transport (Spotila et al. 1992)

Usage

```
external_resistance_to_water_vapor_transfer(H, rhocp = 12000)
```

Arguments

H	`numeric` heat transfer (convection) coefficient (Wm^-2C^-1).
rhocp	`numeric` aggregate parameter (Jm^-3C^-1) that is the product of the density of air (kgm^-3) and the specific heat of air at constant pressure (Jkg^-1C^-1). Default of 12000 (Jm^-3C^-1) commonly assumed.

Value

`numeric` external resistance to water vapor transfer (sm^-1).

References

Spotila JR, Feder ME, Burggren WW (1992). "Biophysics of Heat and Mass Transfer." *Environmental Physiology of the Amphibians*. https://press.uchicago.edu/ucp/books/book/chicago/E/bo3636401.html.

See Also

Other biophysical models: `Grashof_number_Gates()`, `Grashof_number()`, `Nusselt_from_Grashof()`, `Nusselt_from_Reynolds()`, `Nusselt_number()`, `Prandtl_number()`, `Qconduction_animal()`, `Qconduction_substrate()`, `Qconvection()`, `Qemitted_thermal_radiation()`, `Qevaporation()`, `Qmetabolism_from_mass_temp()`, `Qmetabolism_from_mass()`, `Qnet_Gates()`, `Qradiation_absorbed()`, `Qthermal_radiation_absorbed()`, `Reynolds_number()`, `Tb_CampbellNorman()`, `Tb_Gates2()`, `Tb_Gates()`, `Tb_butterfly()`, `Tb_grasshopper()`, `Tb_limpetBH()`, `Tb_limpet()`, `Tb_lizard_Fei()`, `Tb_lizard()`, `Tb_mussel()`, `Tb_salamander_humid()`, `Tb_snail()`, `Tbed_mussel()`, `Tsoil()`, `actual_vapor_pressure()`, `boundary_layer_resistance()`, `free_or_forced_convection()`, `heat_transfer_coefficient_approximation()`, `heat_transfer_coefficient_simple()`, `heat_transfer_coeffici`
`saturation_vapor_pressure()`, `saturation_water_vapor_pressure()`

Examples

```
external_resistance_to_water_vapor_transfer(H = 20)
```

`free_or_forced_convection` *Determine if Convection is Free or Forced*

Description

The function compares the Grashof and Reynolds numbers to determine whether convection is free or forced (Gates 1980).

Usage

```
free_or_forced_convection(Gr, Re)
```

Arguments

`Gr`	`numeric` Grashof Number (dimensionless).
`Re`	`numeric` Reynolds Number (dimensionless).

Value

`character` `"free"`, `"forced"`, or `"intermediate"`.

References

Gates DM (1980). *Biophysical Ecology*. Springer-Verlag, New York, NY, USA.

See Also

Other biophysical models: `Grashof_number_Gates()`, `Grashof_number()`, `Nusselt_from_Grashof()`, `Nusselt_from_Reynolds()`, `Nusselt_number()`, `Prandtl_number()`, `Qconduction_animal()`, `Qconduction_substrate()`, `Qconvection()`, `Qemitted_thermal_radiation()`, `Qevaporation()`, `Qmetabolism_from_mass_temp()`, `Qmetabolism_from_mass()`, `Qnet_Gates()`, `Qradiation_absorbed()`, `Qthermal_radiation_absorbed()`, `Reynolds_number()`, `Tb_CampbellNorman()`, `Tb_Gates2()`, `Tb_Gates()`, `Tb_butterfly()`, `Tb_grasshopper()`, `Tb_limpetBH()`, `Tb_limpet()`, `Tb_lizard_Fei()`, `Tb_lizard()`, `Tb_mussel()`, `Tb_salamander_humid()`, `Tb_snail()`, `Tbed_mussel()`, `Tsoil()`, `actual_vapor_pressure()`, `boundary_layer_resistance()`, `external_resistance_to_water_vapor_transfer()`, `heat_transfer_coefficient_approximation()`, `heat_transfer_coefficient_simple()`, `heat_transfer_coeffici` `saturation_vapor_pressure()`, `saturation_water_vapor_pressure()`

Examples

```
free_or_forced_convection(Gr = 100,
                          Re = 5)
```

`Grashof_number` *Grashof Number*

Description

The function estimates the Grashof Number, which describes the ability of a parcel of fluid warmer or colder than the surrounding fluid to rise against or fall with the attractive force of gravity. The Grashof Number is estimated as the ratio of a buoyant force times an inertial force to the square of a viscous force (Campbell and Norman 1998).

Usage

```
Grashof_number(T_a, T_g, D, nu)
```

Arguments

`T_a`	`numeric` Air temperature (C).
`T_g`	`numeric` ground (surface) temperature (C).
`D`	`numeric` characteristic dimension (e.g., body diameter) (meters).
`nu`	`numeric` the kinematic viscosity, ratio of dynamic viscosity to density of the fluid ($m^2 s^-1$); can calculate from `DRYAIR` or `WETAIR`.

Value

`numeric` Grashof number.

References

Campbell GS, Norman JM (1998). *Introduction to environmental biophysics*, 2nd ed. edition. Springer, New York. ISBN 0387949372.

See Also

Other biophysical models: `Grashof_number_Gates()`, `Nusselt_from_Grashof()`, `Nusselt_from_Reynolds()`, `Nusselt_number()`, `Prandtl_number()`, `Qconduction_animal()`, `Qconduction_substrate()`, `Qconvection()`, `Qemitted_thermal_radiation()`, `Qevaporation()`, `Qmetabolism_from_mass_temp()`, `Qmetabolism_from_mass()`, `Qnet_Gates()`, `Qradiation_absorbed()`, `Qthermal_radiation_absorbed()`, `Reynolds_number()`, `Tb_CampbellNorman()`, `Tb_Gates2()`, `Tb_Gates()`, `Tb_butterfly()`, `Tb_grasshopper()`, `Tb_limpetBH()`, `Tb_limpet()`, `Tb_lizard_Fei()`, `Tb_lizard()`, `Tb_mussel()`, `Tb_salamander_humid()`, `Tb_snail()`, `Tbed_mussel()`, `Tsoil()`, `actual_vapor_pressure()`, `boundary_layer_resistance()`, `external_resistance_to_water_vapor_transfer()`, `free_or_forced_convection()`, `heat_transfer_coefficient_approximation()`, `heat_transfer_coefficient_simple()`, `heat_transfer_coefficient()`, `saturation_vapor_pressure()`, `saturation_water_vapor_pressure()`

Examples

```
Grashof_number(T_a = 30,
               T_g = 35,
               D   = 0.001,
               nu = 1.2)
```

`Grashof_number_Gates` *Grashof Number as in Gates (1980)*

Description

The function estimates the Grashof Number, which describes the ability of a parcel of fluid warmer or colder than the surrounding fluid to rise against or fall with the attractive force of gravity (Gates 1980). The Grashof Number is estimated as the ratio of a buoyant force times an inertial force to the square of a viscous force.

Usage

```
Grashof_number_Gates(T_a, T_g, beta, D, nu)
```

Arguments

T_a	`numeric` Air temperature (C).
T_g	`numeric` Ground (surface) temperature (C).
beta	`numeric` coefficient of volumetric thermal expansion, `beta` = 3.67 x 10^-3C^-1 in air and 41.9 x 10^-4C^-1 in water.
D	`numeric` is characteristic dimension (e.g., body diameter) (m)
nu	`numeric` is the kinematic viscosity, the ratio of dynamic viscosity to density of the fluid (m^2s^-1); can calculate from `DRYAIR` or `WETAIR`.

Value

`numeric` Grashof number.

References

Gates DM (1980). *Biophysical Ecology*. Springer-Verlag, New York, NY, USA.

See Also

Other biophysical models: `Grashof_number()`, `Nusselt_from_Grashof()`, `Nusselt_from_Reynolds()`, `Nusselt_number()`, `Prandtl_number()`, `Qconduction_animal()`, `Qconduction_substrate()`, `Qconvection()`, `Qemitted_thermal_radiation()`, `Qevaporation()`, `Qmetabolism_from_mass_temp()`, `Qmetabolism_from_mass()`, `Qnet_Gates()`, `Qradiation_absorbed()`, `Qthermal_radiation_absorbed()`, `Reynolds_number()`, `Tb_CampbellNorman()`, `Tb_Gates2()`, `Tb_Gates()`, `Tb_butterfly()`, `Tb_grasshopper()`, Tb_limpetBH(), Tb_limpet(), Tb_lizard_Fei(), Tb_lizard(), Tb_mussel(), Tb_salamander_humid(), Tb_snail(), Tbed_mussel(), Tsoil(), actual_vapor_pressure(), boundary_layer_resistance(), external_resistance_to_water_vapor_transfer(), free_or_forced_convection(), heat_transfer_coefficient_approximation(), heat_transfer_coefficient_simple(), heat_transfer_coefficient(), saturation_vapor_pressure(), saturation_water_vapor_pressure()

Examples

```
Grashof_number_Gates(T_a   = 30,
                     T_g   = 35,
                     beta = 0.00367,
                     D    = 0.001,
                     nu   = 1.2)
```

---

heat_transfer_coefficient

Estimate the Heat Transfer Coefficient Empirically

Description

The function estimates the heat transfer coefficient for various taxa based on empirical measurements (Mitchell 1976).

Usage

```
heat_transfer_coefficient(V, D, K, nu, taxon = "cylinder")
```

Arguments

V	numeric air velocity $(m s^-1)$.
D	numeric characteristic dimension (e.g., diameter or snout-vent length) (meters).
K	numeric thermal conductivity of air $(W K^-1 m^-1)$, can calculate using DRYAIR or WETAIR.
nu	numeric kinematic viscosity of air $(m^2 s^-1)$, can calculate using DRYAIR or WETAIR.
taxon	character which class of organism, current choices: "sphere", "cylinder", "frog", "lizard_surface", "lizard_elevated", "flyinginsect", "spider". "cylinder" assumes 40 < Re < 4000. "lizard_surface" and "lizard_elevated" assume the lizard is prostrate on and elevated above the surface, respectively. The values are the average for lizards parallel and perpendicular to the air flow.

Value

numeric heat transfer coefficient, H_L $(W K^-1 m^-2)$.

References

Mitchell JW (1976). "Heat transfer from spheres and other animal forms." *Biophysical Journal*, **16**(6), 561-569. ISSN 0006-3495, doi: 10.1016/S00063495(76)857116, https://www.sciencedirect.com/science/article/pii/S0006349576857116.

See Also

Other biophysical models: `Grashof_number_Gates()`, `Grashof_number()`, `Nusselt_from_Grashof()`, `Nusselt_from_Reynolds()`, `Nusselt_number()`, `Prandtl_number()`, `Qconduction_animal()`, `Qconduction_substrate()`, `Qconvection()`, `Qemitted_thermal_radiation()`, `Qevaporation()`, `Qmetabolism_from_mass_temp()`, `Qmetabolism_from_mass()`, `Qnet_Gates()`, `Qradiation_absorbed()`, `Qthermal_radiation_absorbed()`, `Reynolds_number()`, `Tb_CampbellNorman()`, `Tb_Gates2()`, `Tb_Gates()`, `Tb_butterfly()`, `Tb_grasshopper()`, `Tb_limpetBH()`, `Tb_limpet()`, `Tb_lizard_Fei()`, `Tb_lizard()`, `Tb_mussel()`, `Tb_salamander_humid()`, `Tb_snail()`, `Tbed_mussel()`, `Tsoil()`, `actual_vapor_pressure()`, `boundary_layer_resistance()`, `external_resistance_to_water_vapor_transfer()`, `free_or_forced_convection()`, `heat_transfer_coefficient_approximation()`, `heat_transfer_coefficient_simp`
`saturation_vapor_pressure()`, `saturation_water_vapor_pressure()`

Examples

```
heat_transfer_coefficient(V     = 0.5,
                          D     = 0.05,
                          K     = 25.7 * 10^(-3),
                          nu    = 15.3 * 10^(-6),
                          taxon = "cylinder")
```

`heat_transfer_coefficient_approximation`
Estimate the Heat Transfer Coefficient Using a Spherical Approximation

---

Description

The function estimates the heat transfer coefficient for various taxa. Approximates forced convective heat transfer for animal shapes using the convective relationship for a sphere (Mitchell 1976).

Usage

```
heat_transfer_coefficient_approximation(V, D, K, nu, taxon = "sphere")
```

Arguments

V	`numeric` air velocity (ms^-1).
D	`numeric` characteristic dimension (e.g., diameter or snout-vent length) (meters).
K	`numeric` thermal conductivity of air (Wm^-2K^-1), can calculate using `DRYAIR` or `WETAIR`.

nu	numeric kinematic Viscosity of air ($m^2 s^-1$), can calculate using DRYAIR or WETAIR.
taxon	character of which class of organism, current choices: "sphere", "frog", "lizard", "flyinginsect", "spider".

Value

numeric heat transfer coefficient, H_L ($W m^-2 K^-1$).

References

Mitchell JW (1976). "Heat transfer from spheres and other animal forms." *Biophysical Journal*, **16**(6), 561-569. ISSN 0006-3495, doi: 10.1016/S00063495(76)857116, https://www.sciencedirect.com/science/article/pii/S0006349576857116.

See Also

Other biophysical models: Grashof_number_Gates(), Grashof_number(), Nusselt_from_Grashof(), Nusselt_from_Reynolds(), Nusselt_number(), Prandtl_number(), Qconduction_animal(), Qconduction_substrate(), Qconvection(), Qemitted_thermal_radiation(), Qevaporation(), Qmetabolism_from_mass_temp(), Qmetabolism_from_mass(), Qnet_Gates(), Qradiation_absorbed(), Qthermal_radiation_absorbed(), Reynolds_number(), Tb_CampbellNorman(), Tb_Gates2(), Tb_Gates(), Tb_butterfly(), Tb_grasshopper(), Tb_limpetBH(), Tb_limpet(), Tb_lizard_Fei(), Tb_lizard(), Tb_mussel(), Tb_salamander_humid(), Tb_snail(), Tbed_mussel(), Tsoil(), actual_vapor_pressure(), boundary_layer_resistance(), external_resistance_to_water_vapor_transfer(), free_or_forced_convection(), heat_transfer_coefficient_simple(), heat_transfer_coefficient(), saturation_vapor_pressure(), saturation_water_vapor_pressure()

Examples

```
heat_transfer_coefficient_approximation(V     = 3,
                                        D     = 0.05,
                                        K     = 25.7 * 10^(-3),
                                        nu    = 15.3 * 10^(-6),
                                        taxon = "sphere")
```

---

heat_transfer_coefficient_simple

Estimate the Heat Transfer Coefficient using Simple Relationships

---

Description

The function estimates the heat transfer coefficient (Mitchell 1976) using either the relationship in Spotila et al. (1992) or that in Gates (1980).

Usage

```
heat_transfer_coefficient_simple(V, D, type)
```

Arguments

V	numeric air velocity (ms^-1).
D	numeric characteristic dimension (e.g., diameter or snout-vent length) (m).
type	character choice between "Spotila" and "Gates" for equation to use.

Value

numeric heat transfer coefficient, H_L (Wm^-2K^-1).

References

Gates DM (1980). *Biophysical Ecology*. Springer-Verlag, New York, NY, USA.

Mitchell JW (1976). "Heat transfer from spheres and other animal forms." *Biophysical Journal*, **16**(6), 561-569. ISSN 0006-3495, doi: 10.1016/S00063495(76)857116, https://www.sciencedirect.com/science/article/pii/S0006349576857116.

Spotila JR, Feder ME, Burggren WW (1992). "Biophysics of Heat and Mass Transfer." *Environmental Physiology of the Amphibians*. https://press.uchicago.edu/ucp/books/book/chicago/E/bo3636401.html.

See Also

Other biophysical models: Grashof_number_Gates(), Grashof_number(), Nusselt_from_Grashof(), Nusselt_from_Reynolds(), Nusselt_number(), Prandtl_number(), Qconduction_animal(), Qconduction_substrate(), Qconvection(), Qemitted_thermal_radiation(), Qevaporation(), Qmetabolism_from_mass_temp(), Qmetabolism_from_mass(), Qnet_Gates(), Qradiation_absorbed(), Qthermal_radiation_absorbed(), Reynolds_number(), Tb_CampbellNorman(), Tb_Gates2(), Tb_Gates(), Tb_butterfly(), Tb_grasshopper(), Tb_limpetBH(), Tb_limpet(), Tb_lizard_Fei(), Tb_lizard(), Tb_mussel(), Tb_salamander_humid(), Tb_snail(), Tbed_mussel(), Tsoil(), actual_vapor_pressure(), boundary_layer_resistance(), external_resistance_to_water_vapor_transfer(), free_or_forced_convection(), heat_transfer_coefficient_approximation(), heat_transfer_coefficient(), saturation_vapor_pressure(), saturation_water_vapor_pressure()

Examples

```
heat_transfer_coefficient_simple(V    = 0.5,
                                 D    = 0.05,
                                 type = "Gates")
```

`mass_from_length` *Organism Mass from Length*

Description

The function estimates mass (g) from length (m) for a variety of taxa.

Usage

```
mass_from_length(l, taxon)
```

Arguments

`l`	`numeric` vector of length (m). Can be 1 or more values. Snout-vent length is used for amphibians and reptiles, except turtles where length is carapace length.
`taxon`	`character` taxon of organism, current choices: `"insect"`, `"lizard"`, `"salamander"`, `"frog"`, `"snake"`, `"turtle"`.

Details

All models follow ($m = a * l^b$) with mass in grams and length in meters.

- Lizards: Meiri (2010):

  $a = 16368.17$
  $b = 3.022$
- Salamanders: Pough (1980):

  $a = 13654.4$
  $b = 2.94$
- Frogs: Pough (1980):

  $a = 181197.1$
  $b = 3.24$
- Snakes: Pough (1980):

  $a = 723.6756$
  $b = 3.02$
- Turtles: Pough (1980):

  $a = 93554.48$
  $b = 2.69$
- Insects: Sample et al. (1993):

  $a = 806.0827$
  $b = 2.494$

Value

`numeric` mass (g).

References

Meiri S (2010). "Length - weight allometries in lizards." *Journal of Zoology*, **281**(3), 218-226. doi: 10.1111/j.14697998.2010.00696.x.

Pough FH (1980). "The Advantages of Ectothermy for Tetrapods." *The American Naturalist*, **115**(1), 92–112. ISSN 00030147, 15375323.

Sample BE, Cooper RJ, Greer RD, Whitmore RC (1993). "Estimation of Insect Biomass by Length and Width." *The American Midland Naturalist*, **129**(2), 234–240. ISSN 00030031, 19384238, doi: 10.2307/2426503.

See Also

Other allometric functions: `proportion_silhouette_area_shapes()`, `proportion_silhouette_area()`, `surface_area_from_length()`, `surface_area_from_mass()`, `surface_area_from_volume()`, `volume_from_length()`

Examples

```
mass_from_length(l     = 0.04,
                 taxon = "insect")
mass_from_length(l     = 0.04,
                 taxon = "lizard")
mass_from_length(l     = 0.04,
                 taxon = "salamander")
mass_from_length(l     = 0.04,
                 taxon = "frog")
mass_from_length(l     = 0.04,
                 taxon = "snake")
mass_from_length(l     = 0.04,
                 taxon = "turtle")
```

`monthly_solar_radiation` *Average Monthly Solar Radiation*

Description

The function estimates average monthly solar radiation (Wm^-2d^-1) using basic topographic and climatic information as input. Cloudiness is stochastically modeled, so output will vary between functional calls. Based on Nikolov and Zeller (1992).

Usage

```
monthly_solar_radiation(lat, lon, doy, elev, T_a, Hr, P)
```

Arguments

lat	numeric latitude (degrees).
lon	numeric longitude (degrees).
doy	numeric day of year (1-366).
elev	numeric elevation (meters).
T_a	numeric mean monthly air temperature (C).
Hr	numeric mean month relative humidity (percentage).
P	numeric total monthly precipitation (mm).

Value

numeric average monthly solar radiation (Wm^-2).

References

Nikolov NT, Zeller K (1992). "A solar radiation algorithm for ecosystem dynamic models." *Ecological Modelling*, **61**(3-4), 149-168. doi: 10.24200/tjer.vol8iss2pp1931, https://www.researchgate.net/publication/253240330_Prediction_of_Hourly_Solar_Radiation_on_Horizontal_and_Inclined_Surfaces_for_MuscatOman.

See Also

Other microclimate functions: air_temp_profile_neutral(), air_temp_profile_segment(), air_temp_profile(), degree_days(), direct_solar_radiation(), diurnal_radiation_variation(), diurnal_temp_variation_sineexp(), diurnal_temp_variation_sinesqrt(), diurnal_temp_variation_sine(), partition_solar_radiation(), proportion_diffuse_solar_radiation(), solar_radiation(), surface_roughness(), wind_speed_profile_neutral(), wind_speed_profile_segment()

Examples

```
monthly_solar_radiation(lat  = 47.61,
                        lon  = -122.33,
                        doy  = 112,
                        elev = 1500,
                        T_a  = 15,
                        Hr   = 50,
                        P   = 50)
```

Nusselt_from_Grashof *Nusselt Number from the Grashof Number*

Description

The function estimates the Nusselt number from the Grashof Number (Gates 1980).

Usage

```
Nusselt_from_Grashof(Gr)
```

Arguments

Gr	numeric Grashof Number (dimensionless).

Value

numeric Nusselt number (dimensionless).

References

Gates DM (1980). *Biophysical Ecology*. Springer-Verlag, New York, NY, USA.

See Also

Other biophysical models: Grashof_number_Gates(), Grashof_number(), Nusselt_from_Reynolds(), Nusselt_number(), Prandtl_number(), Qconduction_animal(), Qconduction_substrate(), Qconvection(), Qemitted_thermal_radiation(), Qevaporation(), Qmetabolism_from_mass_temp(), Qmetabolism_from_mass(), Qnet_Gates(), Qradiation_absorbed(), Qthermal_radiation_absorbed(), Reynolds_number(), Tb_CampbellNorman(), Tb_Gates2(), Tb_Gates(), Tb_butterfly(), Tb_grasshopper(), Tb_limpetBH(), Tb_limpet(), Tb_lizard_Fei(), Tb_lizard(), Tb_mussel(), Tb_salamander_humid(), Tb_snail(), Tbed_mussel(), Tsoil(), actual_vapor_pressure(), boundary_layer_resistance(), external_resistance_to_water_vapor_transfer(), free_or_forced_convection(), heat_transfer_coefficient_approximation(), heat_transfer_coefficient_simple(), heat_transfer_coefficient(), saturation_vapor_pressure(), saturation_water_vapor_pressure()

Examples

```
Nusselt_from_Grashof(Gr = 5)
```

Nusselt_from_Reynolds *Nusselt Number from the Reynolds Number*

Description

The function estimates the Nusselt number from the Reynolds number for various taxa using Mitchell (1976) (Table 1: Convective Heat Transfer Relations for Animal Shapes).

Usage

```
Nusselt_from_Reynolds(Re, taxon = "cylinder")
```

Arguments

`Re`	`numeric` Reynolds Number (dimensionless).
`taxon`	`character` which class of organism. Current choices: `"sphere"`, `"cylinder"`, `"frog"`, `"lizard_traverse_to_air_flow"`, `"lizard_parallel_to_air_flow"`, `"lizard_surface"`, `"lizard_elevated"`, `"flyinginsect"`, `"spider"`.

Value

`numeric` Nusselt number (dimensionless).

References

Mitchell JW (1976). "Heat transfer from spheres and other animal forms." *Biophysical Journal*, **16**(6), 561-569. ISSN 0006-3495, doi: 10.1016/S00063495(76)857116, `https://www.sciencedirect.com/science/article/pii/S0006349576857116`.

See Also

Other biophysical models: `Grashof_number_Gates()`, `Grashof_number()`, `Nusselt_from_Grashof()`, `Nusselt_number()`, `Prandtl_number()`, `Qconduction_animal()`, `Qconduction_substrate()`, `Qconvection()`, `Qemitted_thermal_radiation()`, `Qevaporation()`, `Qmetabolism_from_mass_temp()`, `Qmetabolism_from_mass()`, `Qnet_Gates()`, `Qradiation_absorbed()`, `Qthermal_radiation_absorbed()`, `Reynolds_number()`, `Tb_CampbellNorman()`, `Tb_Gates2()`, `Tb_Gates()`, `Tb_butterfly()`, `Tb_grasshopper()`, `Tb_limpetBH()`, `Tb_limpet()`, `Tb_lizard_Fei()`, `Tb_lizard()`, `Tb_mussel()`, `Tb_salamander_humid()`, `Tb_snail()`, `Tbed_mussel()`, `Tsoil()`, `actual_vapor_pressure()`, `boundary_layer_resistance()`, `external_resistance_to_water_vapor_transfer()`, `free_or_forced_convection()`, `heat_transfer_coefficient_`
`heat_transfer_coefficient_simple()`, `heat_transfer_coefficient()`, `saturation_vapor_pressure()`, `saturation_water_vapor_pressure()`

Examples

```
Nusselt_from_Reynolds(Re    = 5,
                      taxon = "cylinder")
```

Nusselt_number *Nusselt Number*

Description

The function estimates the Nusselt Number, which describes dimensionless conductance (Gates 1980).

Usage

```
Nusselt_number(H_L, D, K)
```

Arguments

H_L	numeric convective heat transfer coefficient (Wm^-2K^-1).
D	numeric characteristic dimension (e.g., body diameter) (m).
K	numeric thermal conductivity (WK^-1m^-1).

Value

numeric Nusselt number.

References

Gates DM (1980). *Biophysical Ecology*. Springer-Verlag, New York, NY, USA.

See Also

Other biophysical models: Grashof_number_Gates(), Grashof_number(), Nusselt_from_Grashof(), Nusselt_from_Reynolds(), Prandtl_number(), Qconduction_animal(), Qconduction_substrate(), Qconvection(), Qemitted_thermal_radiation(), Qevaporation(), Qmetabolism_from_mass_temp(), Qmetabolism_from_mass(), Qnet_Gates(), Qradiation_absorbed(), Qthermal_radiation_absorbed(), Reynolds_number(), Tb_CampbellNorman(), Tb_Gates2(), Tb_Gates(), Tb_butterfly(), Tb_grasshopper(), Tb_limpetBH(), Tb_limpet(), Tb_lizard_Fei(), Tb_lizard(), Tb_mussel(), Tb_salamander_humid(), Tb_snail(), Tbed_mussel(), Tsoil(), actual_vapor_pressure(), boundary_layer_resistance(), external_resistance_to_water_vapor_transfer(), free_or_forced_convection(), heat_transfer_coefficient_ heat_transfer_coefficient_simple(), heat_transfer_coefficient(), saturation_vapor_pressure(), saturation_water_vapor_pressure()

Examples

```
Nusselt_number(H_L = 20,
               D   = 0.01,
               K   = 0.5)
```

partition_solar_radiation *Diffuse Fraction for Partitioning Solar Radiation*

Description

The function partitions solar radiation (Wm^-2) into direct and diffuse components by estimating the diffuse fraction (k_d). The function uses the models presented in Wong and Chow (2001).

Usage

```
partition_solar_radiation(method, kt, lat = NA, sol.elev = NA)
```

Arguments

method	character method to use for estimating the diffuse fraction, currently available: "Liu_Jordan", "Orgill_Hollands", "Erbs", "Olyphant", "Spencer", "Reindl-1", "Reindl-2", "Lam_Li".
kt	numeric the clearness index (dimensionless), which is the ratio of the global solar radiation measured at the surface to the total solar radiation at the top of the atmosphere. (0-1)
lat	numeric latitude (degrees). Needed only if method is "Spencer".
sol.elev	numeric the solar elevation angles (degrees). Needed only if method is "Reindl-2".

Value

numeric diffuse fraction.

References

Wong LT, Chow WK (2001). "Solar radiation model." *Applied Energy*, **69**(3), 191-224. ISSN 0306-2619, doi: 10.1016/S03062619(01)000125, https://www.sciencedirect.com/science/article/pii/S0306261901000125.

See Also

Other microclimate functions: air_temp_profile_neutral(), air_temp_profile_segment(), air_temp_profile(), degree_days(), direct_solar_radiation(), diurnal_radiation_variation(), diurnal_temp_variation_sineexp(), diurnal_temp_variation_sinesqrt(), diurnal_temp_variation_sine(), monthly_solar_radiation(), proportion_diffuse_solar_radiation(), solar_radiation(), surface_roughness(), wind_speed_profile_neutral(), wind_speed_profile_segment()

Examples

```
partition_solar_radiation(method   = "Erbs",
                          kt       = 0.5,
                          lat      = 40,
                          sol.elev = 60)
```

`Prandtl_number` *Prandtl Number*

Description

The function estimates the Prandtl Number, which describes the ratio of kinematic viscosity to thermal diffusivity (Gates 1980).

Usage

```
Prandtl_number(c_p, mu, K)
```

Arguments

c_p	`numeric` specific heat at constant pressure ($Jmol^-1K^-1$).
mu	`numeric` dynamic viscosity ($mols^-1m^-1$).
K	`numeric` thermal conductivity (WK^-1m^-1).

Value

`numeric` Prandtl number.

References

Gates DM (1980). *Biophysical Ecology*. Springer-Verlag, New York, NY, USA.

See Also

Other biophysical models: Grashof_number_Gates(), Grashof_number(), Nusselt_from_Grashof(), Nusselt_from_Reynolds(), Nusselt_number(), Qconduction_animal(), Qconduction_substrate(), Qconvection(), Qemitted_thermal_radiation(), Qevaporation(), Qmetabolism_from_mass_temp(), Qmetabolism_from_mass(), Qnet_Gates(), Qradiation_absorbed(), Qthermal_radiation_absorbed(), Reynolds_number(), Tb_CampbellNorman(), Tb_Gates2(), Tb_Gates(), Tb_butterfly(), Tb_grasshopper(), Tb_limpetBH(), Tb_limpet(), Tb_lizard_Fei(), Tb_lizard(), Tb_mussel(), Tb_salamander_humid(), Tb_snail(), Tbed_mussel(), Tsoil(), actual_vapor_pressure(), boundary_layer_resistance(), external_resistance_to_water_vapor_transfer(), free_or_forced_convection(), heat_transfer_coefficient_ heat_transfer_coefficient_simple(), heat_transfer_coefficient(), saturation_vapor_pressure(), saturation_water_vapor_pressure()

Examples

```
Prandtl_number(c_p = 29.3,
               mu  = 0.00001,
               K   = 0.5)
```

---

proportion_diffuse_solar_radiation
Ratio of Diffuse to Direct Solar Radiation

Description

The function estimates the ratio of diffuse to direct solar radiation based on the approximation of the SOLRAD model (McCullough and Porter 1971) described in Tracy et al. (1983).

Usage

```
proportion_diffuse_solar_radiation(psi, p_a, A)
```

Arguments

psi	`numeric` Zenith angle of the sun (degrees).
p_a	`numeric` Atmospheric pressure (kPa).
A	`numeric` albedo of the substrate (fraction of 1).

Value

`numeric` diffuse fraction.

References

McCullough EC, Porter WP (1971). "Computing Clear Day Solar Radiation Spectra for the Terrestrial Ecological Environment." *Ecology*, **52**(6), 1008-1015. doi: 10.2307/1933806.

Tracy CR, Hammond KA, Lechleitner RA, II WJS, Thompson DB, Whicker AD, Williamson SC (1983). "Estimating clear-day solar radiation: an evaluation of three models." *Journal of Thermal Biology*, **8**(3), 247-251. doi: 10.1016/03064565(83)900037, `https://doi.org/10.1016/0306-4565(83)90003-7`.

See Also

Other microclimate functions: `air_temp_profile_neutral()`, `air_temp_profile_segment()`, `air_temp_profile()`, `degree_days()`, `direct_solar_radiation()`, `diurnal_radiation_variation()`, `diurnal_temp_variation_sineexp()`, `diurnal_temp_variation_sinesqrt()`, `diurnal_temp_variation_sine()`, `monthly_solar_radiation()`, `partition_solar_radiation()`, `solar_radiation()`, `surface_roughness()`, `wind_speed_profile_neutral()`, `wind_speed_profile_segment()`

Examples

```
proportion_diffuse_solar_radiation(psi = 60,
                                   p_a = 86.1,
                                   A   = 0.25)
```

`proportion_silhouette_area` *Organism Silhouette Area*

Description

The function estimates the projected (silhouette) area as a portion of the surface area of the organism as a function of zenith angle. The function is useful for estimating absorbed solar radiation.

Usage

```
proportion_silhouette_area(z, taxon, raz = 0, posture = "prostrate")
```

Arguments

`z`	`numeric` zenith angle in degrees between `0` and `360`.
`taxon`	`character` organism name. Current choices are `"lizard"`, `"frog"`, and `"grasshopper"`.
`raz`	`numeric` relative solar azimuth angle (in degrees). Required if `taxon` = `"lizard"`. This is the horizontal angle of the sun relative to the head and frontal plane of the lizard and options currently include `0` (in front), `90` (to side), and `180` (behind) degrees.
`posture`	`character` value describing posture. Required if `taxon` = `"lizard"`. Options include `"prostrate"` (default) and `"elevated"`.

Details

Relationships come from

- Lizards: Muth (1977)
- Frogs: Tracy (1976)
- Grasshoppers: Anderson et al. (1979)

Value

`numeric` silhouette area as a proportion.

References

Anderson RV, Tracy CR, Abramsky Z (1979). "Habitat Selection in Two Species of Short-Horned Grasshoppers. The Role of Thermal and Hydric Stresses." *Oecologia*, **38**(3), 359–374. doi: 10.1007/BF00345194.

Muth A (1977). "Thermoregulatory Postures and Orientation to the Sun: A Mechanistic Evaluation for the Zebra-Tailed Lizard, Callisaurus draconoides." *Copeia*, **4**, 710 - 720.

Tracy CR (1976). "A Model of the Dynamic Exchanges of Water and Energy between a Terrestrial Amphibian and Its Environment." *Ecological Monographs*, **46**(3), 293-326. doi: 10.2307/1942256.

See Also

Other allometric functions: `mass_from_length()`, `proportion_silhouette_area_shapes()`, `surface_area_from_length()`, `surface_area_from_mass()`, `surface_area_from_volume()`, `volume_from_length()`

Examples

```
proportion_silhouette_area(z     = 60,
                           taxon = "frog")
proportion_silhouette_area(z     = 60,
                           taxon = "grasshopper")
proportion_silhouette_area(z       = 60,
                           taxon   = "lizard",
                           posture = "prostrate",
                           raz     = 90)
proportion_silhouette_area(z       = 60,
                           taxon   = "lizard",
                           posture = "elevated",
                           raz     = 180)
```

`proportion_silhouette_area_shapes`

Organism Silhouette Area using Shape Approximations

Description

The function estimates the projected (silhouette) area as a portion of the surface area of the organism. The function estimates the projected area as a function of the dimensions and the angle between the solar beam and the longitudinal axis of the solid, using Figure 11.6 in Campbell and Norman (1998). The function is useful for estimating absorbed solar radiation.

Usage

```
proportion_silhouette_area_shapes(shape, theta, h, d)
```

Arguments

shape	`character` Shape to use to approximate an organism. Shapes are assumed to be prolate or have the longest axis parallel with the ground. Current choices are `"spheroid"`, `"cylinder flat ends"`, and `"cylinder hemisphere ends"`.
theta	`numeric` angle between the solar beam and the longitudinal axis (degrees).
h	`numeric` height (long axis in m). Cross section length for spheroid.
d	`numeric` diameter (short axis in m). Cross section length for spheroid.

Value

`numeric` silhouette area as a proportion.

References

Campbell GS, Norman JM (1998). *Introduction to environmental biophysics*, 2nd ed. edition. Springer, New York. ISBN 0387949372.

See Also

Other allometric functions: `mass_from_length()`, `proportion_silhouette_area()`, `surface_area_from_length()`, `surface_area_from_mass()`, `surface_area_from_volume()`, `volume_from_length()`

Examples

```
proportion_silhouette_area_shapes(shape = "spheroid",
                                   theta = 60,
                                   h     = 0.01,
                                   d     = 0.001)
proportion_silhouette_area_shapes(shape = "cylinder flat ends",
                                   theta = 60,
                                   h     = 0.01,
                                   d     = 0.001)
proportion_silhouette_area_shapes(shape = "cylinder hemisphere ends",
                                   theta = 60,
                                   h     = 0.01,
                                   d     = 0.001)
```

`Qconduction_animal` *Conductance Assuming Animal Thermal Conductivity is Rate Limiting*

Description

The function calculates conductance (W) of an ectothermic animal to its substrate. Method assumes the major resistance to conduction is within surface layers of the animal and that the interior of the animal is equal in temperature to its surface (thermally well mixed) (Spotila et al. 1992).

Usage

```
Qconduction_animal(T_g, T_b, d, K = 0.5, A, proportion)
```

Arguments

T_g	numeric ground surface temperature (Kelvin).
T_b	numeric body temperature (Kelvin).
d	numeric mean thickness of the animal skin (surface) in (meters). The function assumes a well mixed interior.
K	numeric thermal conductivity (WK^-1m^-1). K = 0.5 for naked skin and K = 0.15 for insect cuticle (Galushko et al. 2005). The conductivity of the ground is generally greater than that of animal tissues, so animal thermal conductivity is generally the rate limiting step.
A	numeric surface area (m^2).
proportion	numeric proportion of body in contact with the surface (0-1).

Value

numeric conductance (W).

References

Galushko D, Ermakov N, Karpovski M, Palevski A, Ishay JS, Bergman DJ (2005). "Electrical, thermoelectric and thermophysical properties of hornet cuticle." *Semiconductor Science and Technology*, **20**(3), 286–289. doi: 10.1088/02681242/20/3/005.

Spotila JR, Feder ME, Burggren WW (1992). "Biophysics of Heat and Mass Transfer." *Environmental Physiology of the Amphibians*. https://press.uchicago.edu/ucp/books/book/chicago/E/bo3636401.html.

See Also

Other biophysical models: Grashof_number_Gates(), Grashof_number(), Nusselt_from_Grashof(), Nusselt_from_Reynolds(), Nusselt_number(), Prandtl_number(), Qconduction_substrate(), Qconvection(), Qemitted_thermal_radiation(), Qevaporation(), Qmetabolism_from_mass_temp(), Qmetabolism_from_mass(), Qnet_Gates(), Qradiation_absorbed(), Qthermal_radiation_absorbed(), Reynolds_number(), Tb_CampbellNorman(), Tb_Gates2(), Tb_Gates(), Tb_butterfly(), Tb_grasshopper(), Tb_limpetBH(), Tb_limpet(), Tb_lizard_Fei(), Tb_lizard(), Tb_mussel(), Tb_salamander_humid(), Tb_snail(), Tbed_mussel(), Tsoil(), actual_vapor_pressure(), boundary_layer_resistance(), external_resistance_to_water_vapor_transfer(), free_or_forced_convection(), heat_transfer_coefficient_approximation(), heat_transfer_coefficient_simple(), heat_transfer_coefficient(), saturation_vapor_pressure(), saturation_water_vapor_pressure()

Examples

```
Qconduction_animal(T_g        = 293,
                   T_b        = 303,
                   d          = 10^-6,
```

```
K          = 0.5,
A          = 10^-3,
proportion = 0.2)
```

Qconduction_substrate *Conductance Assuming Substrate Thermal Conductivity is Rate Limiting*

Description

The function calculates conductance (W) of an ectothermic animal to its substrate. The method assumes the major resistance to conduction is the substrate and that the interior of the animal is equal in temperature to its surface (thermally well mixed) (Spotila et al. 1992).

Usage

```
Qconduction_substrate(T_g, T_b, D, K_g = 0.5, A, proportion)
```

Arguments

T_g	numeric surface temperature (K).
T_b	numeric body temperature (K).
D	numeric characteristic dimension of the animal (m).
K_g	numeric thermal conductivity of substrate (WK^-1m^-1).
A	numeric surface area (m^2).
proportion	numeric proportion in contact to the surface.

Value

numeric conductance (W).

References

Spotila JR, Feder ME, Burggren WW (1992). "Biophysics of Heat and Mass Transfer." *Environmental Physiology of the Amphibians*. https://press.uchicago.edu/ucp/books/book/chicago/E/bo3636401.html.

See Also

Other biophysical models: Grashof_number_Gates(), Grashof_number(), Nusselt_from_Grashof(), Nusselt_from_Reynolds(), Nusselt_number(), Prandtl_number(), Qconduction_animal(), Qconvection(), Qemitted_thermal_radiation(), Qevaporation(), Qmetabolism_from_mass_temp(), Qmetabolism_from_mass(), Qnet_Gates(), Qradiation_absorbed(), Qthermal_radiation_absorbed(), Reynolds_number(), Tb_CampbellNorman(), Tb_Gates2(), Tb_Gates(), Tb_butterfly(), Tb_grasshopper(), Tb_limpetBH(), Tb_limpet(), Tb_lizard_Fei(), Tb_lizard(), Tb_mussel(), Tb_salamander_humid(), Tb_snail(), Tbed_mussel(), Tsoil(), actual_vapor_pressure(), boundary_layer_resistance(),

external_resistance_to_water_vapor_transfer(), free_or_forced_convection(), heat_transfer_coefficient_
heat_transfer_coefficient_simple(), heat_transfer_coefficient(), saturation_vapor_pressure(),
saturation_water_vapor_pressure()

Examples

```
Qconduction_substrate(T_g        = 293,
                      T_b        = 303,
                      D          = 0.01,
                      K_g        = 0.3,
                      A          = 10^-2,
                      proportion = 0.2)
```

Qconvection *Organismal Convection*

Description

The function calculates convection from an organism to its environment as in Mitchell (1976). It includes an enhancement factor associated with outdoor environments.

Usage

```
Qconvection(T_a, T_b, A, proportion, H_L = 10.45, ef = 1.23)
```

Arguments

T_a	numeric air temperature (K).
T_b	numeric initial body temperature (K).
A	numeric surface area (m^2).
proportion	numeric proportion of surface area exposed to air.
H_L	numeric convective heat transfer coefficient (WK^-1m^-2).
ef	numeric is the enhancement factor, used to adjust H to field conditions. Approximated as mean value of 1.23 by default, but see Mitchell (1976) for further information.

Value

numeric convection (W).

References

Mitchell JW (1976). "Heat transfer from spheres and other animal forms." *Biophysical Journal*, **16**(6), 561-569. ISSN 0006-3495, doi: 10.1016/S00063495(76)857116, https://www.sciencedirect.com/science/article/pii/S0006349576857116.

See Also

Other biophysical models: Grashof_number_Gates(), Grashof_number(), Nusselt_from_Grashof(), Nusselt_from_Reynolds(), Nusselt_number(), Prandtl_number(), Qconduction_animal(), Qconduction_substrate(), Qemitted_thermal_radiation(), Qevaporation(), Qmetabolism_from_mass_temp(), Qmetabolism_from_mass(), Qnet_Gates(), Qradiation_absorbed(), Qthermal_radiation_absorbed(), Reynolds_number(), Tb_CampbellNorman(), Tb_Gates2(), Tb_Gates(), Tb_butterfly(), Tb_grasshopper(), Tb_limpetBH(), Tb_limpet(), Tb_lizard_Fei(), Tb_lizard(), Tb_mussel(), Tb_salamander_humid(), Tb_snail(), Tbed_mussel(), Tsoil(), actual_vapor_pressure(), boundary_layer_resistance(), external_resistance_to_water_vapor_transfer(), free_or_forced_convection(), heat_transfer_coefficient_approximation(), heat_transfer_coefficient_simple(), heat_transfer_coefficient(), saturation_vapor_pressure(), saturation_water_vapor_pressure()

Examples

```
Qconvection(T_a        = 293,
            T_b        = 303,
            H_L        = 10.45,
            A          = 0.0025,
            proportion = 0.85)
```

Qemitted_thermal_radiation

Emitted Thermal Radiation

Description

The function estimates thermal radiation (W) emitted by the surface of an animal (Gates 1980; Spotila et al. 1992).

Usage

```
Qemitted_thermal_radiation(
  epsilon = 0.96,
  A,
  psa_dir,
  psa_ref,
  T_b,
  T_g,
  T_a,
  enclosed = FALSE
)
```

Arguments

epsilon	`numeric` longwave infrared emissivity of skin (proportion), 0.95 to 1 for most animals (Gates 1980).
A	`numeric` surface area ((m^2).
psa_dir	`numeric` proportion surface area exposed to sky (or enclosure) (0-1)
psa_ref	`numeric` proportion surface area exposed to ground (0-1).
T_b	`numeric` body surface temperature (K).
T_g	`numeric` ground surface temperature (K).
T_a	`numeric` ambient air temperature (K), only required if the animal is in an enclosed environment.
enclosed	`logical` whether the animal is an enclosed environment or not.

Value

`numeric` emitted thermal radiation, `Qemit` (W).

References

Gates DM (1980). *Biophysical Ecology*. Springer-Verlag, New York, NY, USA.

Spotila JR, Feder ME, Burggren WW (1992). "Biophysics of Heat and Mass Transfer." *Environmental Physiology of the Amphibians*. https://press.uchicago.edu/ucp/books/book/chicago/E/bo3636401.html.

See Also

Other biophysical models: `Grashof_number_Gates()`, `Grashof_number()`, `Nusselt_from_Grashof()`, `Nusselt_from_Reynolds()`, `Nusselt_number()`, `Prandtl_number()`, `Qconduction_animal()`, `Qconduction_substrate()`, `Qconvection()`, `Qevaporation()`, `Qmetabolism_from_mass_temp()`, `Qmetabolism_from_mass()`, `Qnet_Gates()`, `Qradiation_absorbed()`, `Qthermal_radiation_absorbed()`, `Reynolds_number()`, `Tb_CampbellNorman()`, `Tb_Gates2()`, `Tb_Gates()`, `Tb_butterfly()`, `Tb_grasshopper()`, `Tb_limpetBH()`, `Tb_limpet()`, `Tb_lizard_Fei()`, `Tb_lizard()`, `Tb_mussel()`, `Tb_salamander_humid()`, `Tb_snail()`, `Tbed_mussel()`, `Tsoil()`, `actual_vapor_pressure()`, `boundary_layer_resistance()`, `external_resistance_to_water_vapor_transfer()`, `free_or_forced_convection()`, `heat_transfer_coefficient_`
`heat_transfer_coefficient_simple()`, `heat_transfer_coefficient()`, `saturation_vapor_pressure()`, `saturation_water_vapor_pressure()`

Examples

```
Qemitted_thermal_radiation(epsilon  = 0.96,
                           A        = 1,
                           psa_dir  = 0.4,
                           psa_ref  = 0.6,
                           T_b      = 303,
                           T_g      = 293,
                           T_a      = 298,
                           enclosed = FALSE)
```

`Qevaporation` *Heat Loss Associated with Evaporative Water Loss*

Description

The function estimates heat loss associated with evaporative water loss for an amphibian (Spotila et al. 1992) or lizard. The lizard estimation is based on empirical measurements in Porter et al. (1973)).

Usage

```
Qevaporation(A, T_b, taxon, rho_s = NA, rho_a = NA, h = NA, H = NA, r_i = NA)
```

Arguments

A	`numeric` surface area (m^2).
T_b	`numeric` body temperature (K).
taxon	`character` organism type. Current choices: `"lizard"`, `"amphibian_wetskin"` (fully wet skin), `"amphibian"` (not fully wet skin).
rho_s	`numeric` saturation water vapor density at skin surface (kgm^-3) (needed if amphibian).
rho_a	`numeric` saturation water vapor density in ambient air (kgm^-3) (needed if amphibian).
h	`numeric` relative humidity (0-1) (needed if amphibian).
H	`numeric` convective heat transfer coefficient (Wm^-2K^-1) (needed if amphibian).
r_i	`numeric` internal (cutaneous) resistance to vapor transport (sm^-1) (needed if amphibian).

Value

`numeric` evaporative heat loss (W).

References

Porter WP, Mitchell JW, Bekman A, DeWitt CB (1973). “Behavioral implications of mechanistic ecology: thermal and behavioral modeling of desert ectotherms and their microenvironments.” *Oecologia*, **13**, 1-54.

Spotila JR, Feder ME, Burggren WW (1992). “Biophysics of Heat and Mass Transfer.” *Environmental Physiology of the Amphibians*. https://press.uchicago.edu/ucp/books/book/chicago/E/bo3636401.html.

See Also

Other biophysical models: Grashof_number_Gates(), Grashof_number(), Nusselt_from_Grashof(), Nusselt_from_Reynolds(), Nusselt_number(), Prandtl_number(), Qconduction_animal(), Qconduction_substrate(), Qconvection(), Qemitted_thermal_radiation(), Qmetabolism_from_mass_temp(), Qmetabolism_from_mass(), Qnet_Gates(), Qradiation_absorbed(), Qthermal_radiation_absorbed(), Reynolds_number(), Tb_CampbellNorman(), Tb_Gates2(), Tb_Gates(), Tb_butterfly(), Tb_grasshopper(), Tb_limpetBH(), Tb_limpet(), Tb_lizard_Fei(), Tb_lizard(), Tb_mussel(), Tb_salamander_humid(), Tb_snail(), Tbed_mussel(), Tsoil(), actual_vapor_pressure(), boundary_layer_resistance(), external_resistance_to_water_vapor_transfer(), free_or_forced_convection(), heat_transfer_coefficient_ heat_transfer_coefficient_simple(), heat_transfer_coefficient(), saturation_vapor_pressure(), saturation_water_vapor_pressure()

Examples

```
Qevaporation(A      = 0.1,
             T_b    = 293,
             taxon = "amphibian",
             rho_s = 0.003,
             rho_a = 0.002,
             h     = 0.5,
             H     = 20,
             r_i   = 50)
Qevaporation(A     = 0.1,
             T_b   = 293,
             taxon = "lizard")
```

Qmetabolism_from_mass *Metabolism as a Function of Mass*

Description

The function estimates the field metabolic rate (W) of various taxa as a function of mass (g). The function does not account for temperature and is based on empirical relationships from Nagy (2005).

Usage

```
Qmetabolism_from_mass(m, taxon = "reptile")
```

Arguments

m	numeric mass (grams).
taxon	character taxon for calculation. Options: "reptile", "bird", "mammal".

Value

numeric metabolism (W).

References

Nagy KA (2005). "Field metabolic rate and body size." *Journal of Experimental Biology*, **208**, 1621-1625. doi: 10.1242/jeb.01553, https://journals.biologists.com/jeb/article/208/9/1621/9364/Field-metabolic-rate-and-body-size.

See Also

Other biophysical models: Grashof_number_Gates(), Grashof_number(), Nusselt_from_Grashof(), Nusselt_from_Reynolds(), Nusselt_number(), Prandtl_number(), Qconduction_animal(), Qconduction_substrate(), Qconvection(), Qemitted_thermal_radiation(), Qevaporation(), Qmetabolism_from_mass_temp(), Qnet_Gates(), Qradiation_absorbed(), Qthermal_radiation_absorbed(), Reynolds_number(), Tb_CampbellNorman(), Tb_Gates2(), Tb_Gates(), Tb_butterfly(), Tb_grasshopper(), Tb_limpetBH(), Tb_limpet(), Tb_lizard_Fei(), Tb_lizard(), Tb_mussel(), Tb_salamander_humid(), Tb_snail(), Tbed_mussel(), Tsoil(), actual_vapor_pressure(), boundary_layer_resistance(), external_resistance_to_water_vapor_transfer(), free_or_forced_convection(), heat_transfer_coefficient_ heat_transfer_coefficient_simple(), heat_transfer_coefficient(), saturation_vapor_pressure(), saturation_water_vapor_pressure()

Examples

```
Qmetabolism_from_mass(m     = 12,
                      taxon = "reptile")
```

Qmetabolism_from_mass_temp

Metabolism as a Function of Mass and Body Temperature

Description

The function estimates basal (or resting) metabolic rate (W) as a function of mass (g) and temperature (K). The function is based on empirical data and the metabolic theory of ecology (assumes a 3/4 scaling exponent) (Gillooly et al. 2001).

Usage

```
Qmetabolism_from_mass_temp(m, T_b, taxon)
```

Arguments

m	numeric mass (grams).
T_b	numeric body temperature (K).
taxon	character organism type. Options: "bird", "mammal", "reptile", "amphibian", "invertebrate".

Value

numeric basal metabolism (W).

References

Gillooly JF, Brown JH, West GB, Savage VM, Charnov EL (2001). "Effects of size and temperature on metabolic rate." *Science*, **293**, 2248-2251. doi: 10.1126/science.1061967.

See Also

Other biophysical models: `Grashof_number_Gates()`, `Grashof_number()`, `Nusselt_from_Grashof()`, `Nusselt_from_Reynolds()`, `Nusselt_number()`, `Prandtl_number()`, `Qconduction_animal()`, `Qconduction_substrate()`, `Qconvection()`, `Qemitted_thermal_radiation()`, `Qevaporation()`, `Qmetabolism_from_mass()`, `Qnet_Gates()`, `Qradiation_absorbed()`, `Qthermal_radiation_absorbed()`, `Reynolds_number()`, `Tb_CampbellNorman()`, `Tb_Gates2()`, `Tb_Gates()`, `Tb_butterfly()`, `Tb_grasshopper()`, `Tb_limpetBH()`, `Tb_limpet()`, `Tb_lizard_Fei()`, `Tb_lizard()`, `Tb_mussel()`, `Tb_salamander_humid()`, `Tb_snail()`, `Tbed_mussel()`, `Tsoil()`, `actual_vapor_pressure()`, `boundary_layer_resistance()`, `external_resistance_to_water_vapor_transfer()`, `free_or_forced_convection()`, `heat_transfer_coefficient_`
`heat_transfer_coefficient_simple()`, `heat_transfer_coefficient()`, `saturation_vapor_pressure()`, `saturation_water_vapor_pressure()`

Examples

```
Qmetabolism_from_mass_temp(m     = 100,
                           T_b   = 303,
                           taxon = "reptile")
```

`Qnet_Gates` *Net Energy Exchange Between an Animal and the Environment*

Description

The function estimates the net energy exchange (W) between an animal and the environment. The function follows Gates (1980) and others.

Usage

```
Qnet_Gates(Qabs, Qemit, Qconv, Qcond, Qmet, Qevap)
```

Arguments

`Qabs`	`numeric` solar radiation absorbed (W).
`Qemit`	`numeric` thermal radiation emitted (W).
`Qconv`	`numeric` energy exchange due to convection; Energy exchange from an animal to its surrounding environment (air or water) (W).
`Qcond`	`numeric` energy exchange due to conduction; Energy exchange from animal to a surface if they are in contact (W).
`Qmet`	`numeric` energy emitted due to metabolism (W).
`Qevap`	`numeric` energy emitted due to evaporative water loss (W).

Value

`numeric` net energy exchange (W).

References

Gates DM (1980). *Biophysical Ecology*. Springer-Verlag, New York, NY, USA.

See Also

Other biophysical models: `Grashof_number_Gates()`, `Grashof_number()`, `Nusselt_from_Grashof()`, `Nusselt_from_Reynolds()`, `Nusselt_number()`, `Prandtl_number()`, `Qconduction_animal()`, `Qconduction_substrate()`, `Qconvection()`, `Qemitted_thermal_radiation()`, `Qevaporation()`, `Qmetabolism_from_mass_temp()`, `Qmetabolism_from_mass()`, `Qradiation_absorbed()`, `Qthermal_radiation_absorb` `Reynolds_number()`, `Tb_CampbellNorman()`, `Tb_Gates2()`, `Tb_Gates()`, `Tb_butterfly()`, `Tb_grasshopper()`, `Tb_limpetBH()`, `Tb_limpet()`, `Tb_lizard_Fei()`, `Tb_lizard()`, `Tb_mussel()`, `Tb_salamander_humid()`, `Tb_snail()`, `Tbed_mussel()`, `Tsoil()`, `actual_vapor_pressure()`, `boundary_layer_resistance()`, `external_resistance_to_water_vapor_transfer()`, `free_or_forced_convection()`, `heat_transfer_coefficient_` `heat_transfer_coefficient_simple()`, `heat_transfer_coefficient()`, `saturation_vapor_pressure()`, `saturation_water_vapor_pressure()`

Examples

```
Qnet_Gates(Qabs  = 500,
           Qemit = 10,
           Qconv = 100,
           Qcond = 100,
           Qmet  = 10,
           Qevap = 5)
```

`Qradiation_absorbed` *Absorbed Solar and Thermal Radiation*

Description

The function estimates solar and thermal radiation (W) absorbed by the surface of an animal following (Gates 1980) and (Spotila et al. 1992).

Usage

```
Qradiation_absorbed(
  a = 0.9,
  A,
  psa_dir,
  psa_ref,
  S_dir,
  S_dif,
  S_ref = NA,
```

```
  a_s = NA
)
```

Arguments

a	numeric solar absorptivity of animal surface (proportion), default value is for reptiles (0-1).
A	numeric surface area ((m^2)).
psa_dir	numeric proportion surface area exposed to solar radiation (0-1).
psa_ref	numeric proportion surface area exposed to reflected solar radiation (0-1).
S_dir	numeric direct solar radiation (Wm^-2).
S_dif	numeric diffuse solar radiation (Wm^-2).
S_ref	numeric reflected solar radiation (Wm^-2), either provided or estimated if surface albedo is provided instead
a_s	numeric is surface albedo (proportion), optional (not used) if reflected radiation is provided. Values available in (Gates 1980) Table 8.2.

Value

numeric solar radiation absorbed (W)

References

Gates DM (1980). *Biophysical Ecology*. Springer-Verlag, New York, NY, USA.

Spotila JR, Feder ME, Burggren WW (1992). "Biophysics of Heat and Mass Transfer." *Environmental Physiology of the Amphibians*. https://press.uchicago.edu/ucp/books/book/chicago/E/bo3636401.html.

See Also

Other biophysical models: Grashof_number_Gates(), Grashof_number(), Nusselt_from_Grashof(), Nusselt_from_Reynolds(), Nusselt_number(), Prandtl_number(), Qconduction_animal(), Qconduction_substrate(), Qconvection(), Qemitted_thermal_radiation(), Qevaporation(), Qmetabolism_from_mass_temp(), Qmetabolism_from_mass(), Qnet_Gates(), Qthermal_radiation_absorbed(), Reynolds_number(), Tb_CampbellNorman(), Tb_Gates2(), Tb_Gates(), Tb_butterfly(), Tb_grasshopper(), Tb_limpetBH(), Tb_limpet(), Tb_lizard_Fei(), Tb_lizard(), Tb_mussel(), Tb_salamander_humid(), Tb_snail(), Tbed_mussel(), Tsoil(), actual_vapor_pressure(), boundary_layer_resistance(), external_resistance_to_water_vapor_transfer(), free_or_forced_convection(), heat_transfer_coefficient_approximation(), heat_transfer_coefficient_simple(), heat_transfer_coefficient(), saturation_vapor_pressure(), saturation_water_vapor_pressure()

Examples

```
Qradiation_absorbed(a       = 0.9,
                    A       = 1,
                    psa_dir = 0.4,
                    psa_ref = 0.4,
```

```
                          S_dir   = 1000,
                          S_dif   = 200,
                          a_s     = 0.5)
```

`Qthermal_radiation_absorbed`

Absorbed Thermal Radiation

Description

The function estimates longwave (thermal) radiation (W) absorbed from the sky and the ground (Campbell and Norman 1998; Riddell et al. 2018).

Usage

```
Qthermal_radiation_absorbed(
  T_a,
  T_g,
  epsilon_ground = 0.97,
  a_longwave = 0.965
)
```

Arguments

`T_a`	`numeric` air temperature (C).
`T_g`	`numeric` ground temperature (C).
`epsilon_ground`	`numeric` emissivity (proportion) for more soil types (Campbell and Norman 1998).
`a_longwave`	`numeric` absorptance (proportion) of organism to longwave radiation (Bartlett and Gates 1967; Buckley 2008).

Value

`numeric` thermal radiation absorbed (W).

Author(s)

Eric Riddell

References

Bartlett PN, Gates DM (1967). "The energy budget of a lizard on a tree trunk." *Ecology*, **48**, 316-322.

Buckley LB (2008). "Linking traits to energetics and population dynamics to predict lizard ranges in changing environments." *American Naturalist*, **171**(1), E1 - E19. doi: 10.1086/523949, `https:`

//pubmed.ncbi.nlm.nih.gov/18171140/.

Campbell GS, Norman JM (1998). *Introduction to environmental biophysics*, 2nd ed. edition. Springer, New York. ISBN 0387949372.

Riddell EA, Odom JP, Damm JD, Sears MW (2018). "Plasticity reveals hidden resistance to extinction under climate change in the global hotspot of salamander diversity." *Science Advances*, **4**(4). doi: 10.1126/sciadv.aar5471.

See Also

Other biophysical models: `Grashof_number_Gates()`, `Grashof_number()`, `Nusselt_from_Grashof()`, `Nusselt_from_Reynolds()`, `Nusselt_number()`, `Prandtl_number()`, `Qconduction_animal()`, `Qconduction_substrate()`, `Qconvection()`, `Qemitted_thermal_radiation()`, `Qevaporation()`, `Qmetabolism_from_mass_temp()`, `Qmetabolism_from_mass()`, `Qnet_Gates()`, `Qradiation_absorbed()`, `Reynolds_number()`, `Tb_CampbellNorman()`, `Tb_Gates2()`, `Tb_Gates()`, `Tb_butterfly()`, `Tb_grasshopper()`, `Tb_limpetBH()`, `Tb_limpet()`, `Tb_lizard_Fei()`, `Tb_lizard()`, `Tb_mussel()`, `Tb_salamander_humid()`, `Tb_snail()`, `Tbed_mussel()`, `Tsoil()`, `actual_vapor_pressure()`, `boundary_layer_resistance()`, `external_resistance_to_water_vapor_transfer()`, `free_or_forced_convection()`, `heat_transfer_coefficient_` `heat_transfer_coefficient_simple()`, `heat_transfer_coefficient()`, `saturation_vapor_pressure()`, `saturation_water_vapor_pressure()`

Examples

```
Qthermal_radiation_absorbed(T_a            = 20,
                            T_g            = 25,
                            epsilon_ground = 0.97,
                            a_longwave     = 0.965)
```

`Reynolds_number` *Reynolds Number*

Description

The function estimates the Reynolds Number, which describes the dynamic properties of the fluid surrounding the animal as the ratio of internal viscous forces (Gates 1980).

Usage

```
Reynolds_number(u, D, nu)
```

Arguments

u	`numeric` wind speed (ms^-1).
D	`numeric` characteristic dimension (e.g., body diameter) (m)
nu	`numeric` the kinematic viscosity, ratio of dynamic viscosity to density of the fluid (m^2s^-1); can calculate from `DRYAIR` or `WETAIR`.

Value

`numeric` Reynolds number.

References

Gates DM (1980). *Biophysical Ecology*. Springer-Verlag, New York, NY, USA.

See Also

Other biophysical models: `Grashof_number_Gates()`, `Grashof_number()`, `Nusselt_from_Grashof()`, `Nusselt_from_Reynolds()`, `Nusselt_number()`, `Prandtl_number()`, `Qconduction_animal()`, `Qconduction_substrate()`, `Qconvection()`, `Qemitted_thermal_radiation()`, `Qevaporation()`, `Qmetabolism_from_mass_temp()`, `Qmetabolism_from_mass()`, `Qnet_Gates()`, `Qradiation_absorbed()`, `Qthermal_radiation_absorbed()`, `Tb_CampbellNorman()`, `Tb_Gates2()`, `Tb_Gates()`, `Tb_butterfly()`, `Tb_grasshopper()`, `Tb_limpetBH()`, `Tb_limpet()`, `Tb_lizard_Fei()`, `Tb_lizard()`, `Tb_mussel()`, `Tb_salamander_humid()`, `Tb_snail()`, `Tbed_mussel()`, `Tsoil()`, `actual_vapor_pressure()`, `boundary_layer_resistance()`, `external_resistance_to_water_vapor_transfer()`, `free_or_forced_convection`
`heat_transfer_coefficient_approximation()`, `heat_transfer_coefficient_simple()`, `heat_transfer_coeffici`
`saturation_vapor_pressure()`, `saturation_water_vapor_pressure()`

Examples

```
Reynolds_number(u  = 1,
                D  = 0.001,
                nu = 1.2)
```

`saturation_vapor_pressure` *Saturation Vapor Pressure*

Description

The function calculates saturation vapor pressure (kPa) based on the Clausius-Clapeyron equation (Stull 2000; Riddell et al. 2018).

Usage

```
saturation_vapor_pressure(T_a)
```

Arguments

`T_a`	`numeric` air temperature (K).

Value

`numeric` saturation vapor pressure, `e_s` (kPa).

Author(s)

Eric Riddell

References

Riddell EA, Odom JP, Damm JD, Sears MW (2018). "Plasticity reveals hidden resistance to extinction under climate change in the global hotspot of salamander diversity." *Science Advances*, **4**(4). doi: 10.1126/sciadv.aar5471.

Stull RB (2000). *Meteorology for Scientists and Engineers*. Brooks Cole. ISBN 978-0534372149.

See Also

Other biophysical models: `Grashof_number_Gates()`, `Grashof_number()`, `Nusselt_from_Grashof()`, `Nusselt_from_Reynolds()`, `Nusselt_number()`, `Prandtl_number()`, `Qconduction_animal()`, `Qconduction_substrate()`, `Qconvection()`, `Qemitted_thermal_radiation()`, `Qevaporation()`, `Qmetabolism_from_mass_temp()`, `Qmetabolism_from_mass()`, `Qnet_Gates()`, `Qradiation_absorbed()`, `Qthermal_radiation_absorbed()`, `Reynolds_number()`, `Tb_CampbellNorman()`, `Tb_Gates2()`, `Tb_Gates()`, `Tb_butterfly()`, `Tb_grasshopper()`, `Tb_limpetBH()`, `Tb_limpet()`, `Tb_lizard_Fei()`, `Tb_lizard()`, `Tb_mussel()`, `Tb_salamander_humid()`, `Tb_snail()`, `Tbed_mussel()`, `Tsoil()`, `actual_vapor_pressure()`, `boundary_layer_resistance()`, `external_resistance_to_water_vapor_transfer()`, `free_or_forced_convection()`, `heat_transfer_coefficient_approximation()`, `heat_transfer_coefficient_simp`
`heat_transfer_coefficient()`, `saturation_water_vapor_pressure()`

Examples

```
saturation_vapor_pressure(T_a = 293)
```

`saturation_water_vapor_pressure`
Saturation Water Vapor Pressure

Description

The function approximates saturation water vapor pressure as a function of ambient temperature for temperatures from 0 to 40 C using Rosenberg (1974) in Spotila et al. (1992). See also NicheMapR `WETAIR` and `DRYAIR` (Kearney and Porter 2020).

Usage

```
saturation_water_vapor_pressure(T_a)
```

Arguments

`T_a`	`numeric` air temperature (C).

Value

numeric Saturation water vapor pressure, e_s (Pa).

References

Kearney MR, Porter WP (2020). “NicheMapR - an R package for biophysical modelling: the ectotherm and Dynamic Energy Budget models.” *Ecography*, **43**(1), 85-96. doi: 10.1111/ecog.04680.

Rosenberg NJ (1974). *Microclimate: the biological environment*. Wiley, New York.

Spotila JR, Feder ME, Burggren WW (1992). “Biophysics of Heat and Mass Transfer.” *Environmental Physiology of the Amphibians*. https://press.uchicago.edu/ucp/books/book/chicago/E/bo3636401.html.

See Also

Other biophysical models: Grashof_number_Gates(), Grashof_number(), Nusselt_from_Grashof(), Nusselt_from_Reynolds(), Nusselt_number(), Prandtl_number(), Qconduction_animal(), Qconduction_substrate(), Qconvection(), Qemitted_thermal_radiation(), Qevaporation(), Qmetabolism_from_mass_temp(), Qmetabolism_from_mass(), Qnet_Gates(), Qradiation_absorbed(), Qthermal_radiation_absorbed(), Reynolds_number(), Tb_CampbellNorman(), Tb_Gates2(), Tb_Gates(), Tb_butterfly(), Tb_grasshopper(), Tb_limpetBH(), Tb_limpet(), Tb_lizard_Fei(), Tb_lizard(), Tb_mussel(), Tb_salamander_humid(), Tb_snail(), Tbed_mussel(), Tsoil(), actual_vapor_pressure(), boundary_layer_resistance(), external_resistance_to_water_vapor_transfer(), free_or_forced_convection(), heat_transfer_coefficient_approximation(), heat_transfer_coefficient_simp heat_transfer_coefficient(), saturation_vapor_pressure()

Examples

```
saturation_water_vapor_pressure(T_a = 20)
```

`soil_conductivity` *Soil Thermal Conductivity*

Description

The function estimates soil thermal conductivity $(Wm^{-}1K^{-}1)$ using the methods of deVries (1963).

Usage

```
soil_conductivity(x, lambda, g_a)
```

Arguments

`x`	`numeric` vector of volume fractions of soil constituents (e.g., clay, quartz, minerals other than quartz, organic matter, water, air). The volume fractions should sum to 1. Note that `x` and `lambda` values in the example correspond to these soil constituents.
`lambda`	`numeric` vector of the thermal conductivities (Wm^-1K^-1) of the soil constituents.
`g_a`	`numeric` shape factor on soil particles. The soil particles are assumed to be ellipsoids with axes `g_a`, `g_b`, and `g_c`, where `g_a + g_b + g_c = 1` and `g_a = g_b`. deVries (1952) suggests `g_a = g_b = 0.125`.

Value

`numeric` soil thermal conductivity (Wm^-1K^-1).

Author(s)

Joseph Grigg

References

deVries DA (1952). "Thermal Conductivity of Soil." *Nature*, **178**, 1074. doi: 10.1038/1781074a0.

deVries DA (1963). "Thermal Properties of Soils." In *Physics of Plant Environment*. North Holland Publishing Company. doi: 10.1002/qj.49709038628.

See Also

Other soil temperature functions: `soil_specific_heat()`, `soil_temperature_equation()`, `soil_temperature_functio` `soil_temperature_integrand()`, `soil_temperature()`

Examples

```
soil_conductivity(x      = c(0.10, 0.40, 0.11, 0.01, 0.2, 0.18),
                  lambda = c(0.10, 0.40, 0.11, 0.01, 0.2, 0.18),
                  g_a     = 0.125)
```

`soil_specific_heat` *Soil Specific Heat*

Description

The function estimates soil specific heat (Jkg^-1K^-1) using the methods of deVries (1963). The function incorporates the volume fraction of organic material, minerals, and water in soil.

Usage

```
soil_specific_heat(x_o, x_m, x_w, rho_so)
```

Arguments

x_o	numeric volume fraction of organic material (0-1).
x_m	numeric volume fraction of minerals (0-1).
x_w	numeric volume fraction of water (0-1).
rho_so	numeric particle density of soil in (kgm^-3) (bulk density).

Value

numeric soil specific heat (Jkg^-1K^-1).

Author(s)

Joseph Grigg

References

deVries DA (1963). "Thermal Properties of Soils." In *Physics of Plant Environment*. North Holland Publishing Company. doi: 10.1002/qj.49709038628.

See Also

Other soil temperature functions: soil_conductivity(), soil_temperature_equation(), soil_temperature_function(), soil_temperature_integrand(), soil_temperature()

Examples

```
soil_specific_heat(x_o    = 0.01,
                   x_m    = 0.6,
                   x_w    = 0.2,
                   rho_so = 1620)
```

---

soil_temperature *Calculate Soil Temperature using ODEs*

Description

This function is called to calculate soil temperature (C) as in Beckman et al. (1973). This function calls soil_temperature_function, which uses ODEs to calculate a soil profile using equations from deVries (1963)

Usage

```
soil_temperature(
  z_r.intervals = 12,
  z_r,
  z,
  T_a,
  u,
  Tsoil0,
  z0,
  SSA,
  TimeIn,
  H,
  water_content = 0.2,
  air_pressure,
  rho_so = 1620,
  shade = FALSE
)
```

Arguments

`z_r.intervals`	`numeric` the number of intervals in the soil profile to calculate, defaults to 12.
`z_r`	`numeric` reference height (m).
`z`	`numeric` interval of the soil profile to return (1 to `z_r.intervals`).
`T_a`	`numeric` vector of air temperature (degrees C), Note: missing values will be linearly interpolated.
`u`	`numeric` vector of wind speeds (ms^-1).
`Tsoil0`	`numeric` initial soil temperature (degrees C).
`z0`	`numeric` surface roughness (m).
`SSA`	`numeric` solar absorptivity of soil surface as a fraction.
`TimeIn`	`numeric` vector of time periods for the model.
`H`	`numeric` vector of solar radiation (Wm^-2).
`water_content`	`numeric` percent water content (percent).
`air_pressure`	`numeric` air pressure (kPa).
`rho_so`	`numeric` particle density of soil.
`shade`	`logical` whether or not soil temperature should be calculated in the shade.

Value

`numeric` soil temperature (C).

Author(s)

Joseph Grigg

References

Beckman WA, Mitchell JW, Porter WP (1973). "Thermal Model for Prediction of a Desert Iguana's Daily and Seasonal Behavior." *Journal of Heat Transfer*, **95**(2), 257-262. doi: 10.1115/1.3450037.

deVries DA (1963). "Thermal Properties of Soils." In *Physics of Plant Environment*. North Holland Publishing Company. doi: 10.1002/qj.49709038628.

See Also

Other soil temperature functions: `soil_conductivity()`, `soil_specific_heat()`, `soil_temperature_equation()`, `soil_temperature_function()`, `soil_temperature_integrand()`

Examples

```
set.seed(123)
temp_vector       <- runif(48, min = -10, max = 10)
wind_speed_vector <- runif(48, min = 0, max = 0.4)
time_vector       <- rep(1:24, 2)
solrad_vector     <- rep(c(rep(0, 6),
                           seq(10, 700, length.out = 6),
                           seq(700, 10, length.out = 6),
                           rep(0, 6)),
                         2)

soil_temperature(z_r.intervals = 12,
                 z_r           = 1.5,
                 z             = 2,
                 T_a           = temp_vector,
                 u             = wind_speed_vector,
                 Tsoil0        = 20,
                 z0            = 0.02,
                 SSA           = 0.7,
                 TimeIn        = time_vector,
                 H             = solrad_vector,
                 water_content = 0.2,
                 air_pressure  = 85,
                 rho_so        = 1620,
                 shade         = FALSE)
```

---

soil_temperature_equation

Core Function Called to Solve Equation for Soil Temperature

Description

The function called by `soil_temperature_function` to solve equation for soil temperature from Beckman et al. (1973).

Usage

```
soil_temperature_equation(L, rho_a, c_a, V_inst, z_r, z0, T_inst, T_s)
```

Arguments

L	numeric Monin-Obukhov length, a measure of the instability of heat flow (see Beckman et al. (1973)).
rho_a	numeric density of air (kgm^-3).
c_a	numeric specific heat of air (Jkg^-1K^-1).
V_inst	numeric instantaneous wind speed (ms^-1).
z_r	numeric reference height (m).
z0	numeric surface roughness (m).
T_inst	numeric instantaneous air temperature (K).
T_s	numeric initial soil surface temperature (C).

Value

numeric soil temperature (C).

Author(s)

Joseph Grigg

References

Beckman WA, Mitchell JW, Porter WP (1973). "Thermal Model for Prediction of a Desert Iguana's Daily and Seasonal Behavior." *Journal of Heat Transfer*, **95**(2), 257-262. doi: 10.1115/1.3450037.

See Also

Other soil temperature functions: soil_conductivity(), soil_specific_heat(), soil_temperature_function(), soil_temperature_integrand(), soil_temperature()

Examples

```
soil_temperature_equation(L      = -10,
                          rho_a  = 1.177,
                          c_a    = 1006,
                          V_inst = 0.3,
                          z_r    = 1.5,
                          z0     = 0.02,
                          T_inst = 265,
                          T_s    = 20)
```

`soil_temperature_function` *Core Function for Calculating Soil Temperature*

Description

This function is called to calculate soil temperature as in Beckman et al. (1973). Parameters are passed as a list to facilitating solving the equations. This function is not intended to be called directly. The energy balance equations are from Porter et al. (1973) and Kingsolver (1979)

Usage

```
soil_temperature_function(j, T_so, params)
```

Arguments

`j`	`numeric` the number of the iteration of running the model.
`T_so`	`numeric` the initial soil temperature profile in C.
`params`	`list` containing the following param, which are described or calculated in `soil_temperature`: `SSA`, `epsilon_so`, `k_so`, `c_so`, `dz`, `z_r`, `z0`, `H`, `T_a`, `u`, `rho_a`, `rho_so`, `c_a`, `TimeIn`, `dt`, `shade`.

Value

Soil temperature profile as a `list`.

Author(s)

Joseph Grigg

References

Beckman WA, Mitchell JW, Porter WP (1973). "Thermal Model for Prediction of a Desert Iguana's Daily and Seasonal Behavior." *Journal of Heat Transfer*, **95**(2), 257-262. doi: 10.1115/1.3450037.

Kingsolver JG (1979). "Thermal and hydric aspects of environmental hetergeneity in the pitcher plant mosquito." *Ecological Monographs*, **49**, 357-376.

Porter WP, Mitchell JW, Bekman A, DeWitt CB (1973). "Behavioral implications of mechanistic ecology: thermal and behavioral modeling of desert ectotherms and their microenvironments." *Oecologia*, **13**, 1-54.

See Also

Other soil temperature functions: `soil_conductivity()`, `soil_specific_heat()`, `soil_temperature_equation()`, `soil_temperature_integrand()`, `soil_temperature()`

Examples

```
  set.seed(123)
  temp_vector       <- runif(96, min = -10, max = 10)
  wind_speed_vector <- runif(96, min = 0, max = 0.4)
  time_vector       <- rep(1:24, 4)
  solrad_vector     <- rep(c(rep(0, 6),
                           seq(10, 700, length.out = 6),
                           seq(700, 10, length.out = 6),
                           rep(0, 6)),
                         4)
  params            <- list(SSA        = 0.7,
                          epsilon_so = 0.98,
                          k_so       = 0.293,
                          c_so       = 800,
                          dz         = 0.05,
                          z_r        = 1.5,
                          z0         = 0.02,
                          H          = solrad_vector,
                          T_a        = temp_vector,
                          u          = wind_speed_vector,
                          rho_a      = 1.177,
                          rho_so     = 1620,
                          c_a        = 1006,
                          TimeIn     = time_vector,
                          dt         = 60 * 60,
                          shade      = FALSE)

soil_temperature_function(j      = 1,
                          T_so   = rep(20,13),
                          params = params)
```

`soil_temperature_integrand`

Solve Equation for Soil Temperature

Description

This function is called by `soil_temperature_equation` to solve the equation for soil temperature from Beckman et al. (1973). The function represents the integrand in the equation. It is not intended to be called directly.

Usage

```
soil_temperature_integrand(x, L, z0)
```

Arguments

x	numeric vector of volume fractions of soil constituents (e.g., clay, quartz, minerals other than quartz, organic matter, water, air). The volume fractions should sum to 1. Note that x and lambda values in the example correspond to these soil constituents.
L	numeric Monin-Obukhov length, a measure of the instability of heat flow (Beckman et al. 1973).
z0	numeric surface roughness (m).

Value

numeric integrand for soil temperature function.

Author(s)

Joseph Grigg

References

Beckman WA, Mitchell JW, Porter WP (1973). "Thermal Model for Prediction of a Desert Iguana's Daily and Seasonal Behavior." *Journal of Heat Transfer*, **95**(2), 257-262. doi: 10.1115/1.3450037.

See Also

Other soil temperature functions: soil_conductivity(), soil_specific_heat(), soil_temperature_equation(), soil_temperature_function(), soil_temperature()

Examples

```
soil_temperature_integrand(x  = c(0.10, 0.40, 0.11, 0.01, 0.2, 0.18),
                           L  = -10,
                           z0 = 0.2)
```

---

solar_noon *Time of Solar Noon*

Description

The function calculates the time of solar noon in hours as a function of the day of year and longitude (Campbell and Norman 1998).

Usage

```
solar_noon(lon, doy, offset = NA)
```

Arguments

lon	numeric longitude (decimal degrees).
doy	numeric day of year (1-366). This can be obtained from a standard date via day_of_year.
offset	numeric number of hours to add to UTC (Coordinated Universal Time) to get local time (improves accuracy but not always necessary). Defaults to NA.

Value

numeric time of solar noon (hours).

References

Campbell GS, Norman JM (1998). *Introduction to environmental biophysics*, 2nd ed. edition. Springer, New York. ISBN 0387949372.

See Also

Other utility functions: airpressure_from_elev(), azimuth_angle(), day_of_year(), daylength(), dec_angle(), temperature conversions, zenith_angle()

Examples

```
solar_noon(lon = -122.335,
           doy = 112)
```

---

solar_radiation — *Estimate the Three Components of Solar Radiation (Direct, Diffuse and Reflected)*

Description

The function estimate direct, diffuse, and reflected components of solar radiation (Wm^-2) as a function of day of year using the model in Campbell and Norman (1998).

Usage

```
solar_radiation(doy, psi, tau, elev, rho = 0.7)
```

Arguments

doy	numeric the day of year; day_of_year.
psi	numeric zenith angle (radians).
tau	numeric atmospheric transmissivity (proportion), which is ratio of global solar radiation at ground level to extra-terrestrial solar radiation.
elev	numeric elevation (meters).
rho	numeric albedo as a proportion (0-1).

Value

numeric radiation components - direct, diffused and reflected (Wm^-2).

References

Campbell GS, Norman JM (1998). *Introduction to environmental biophysics*, 2nd ed. edition. Springer, New York. ISBN 0387949372.

See Also

Other microclimate functions: air_temp_profile_neutral(), air_temp_profile_segment(), air_temp_profile(), degree_days(), direct_solar_radiation(), diurnal_radiation_variation(), diurnal_temp_variation_sineexp(), diurnal_temp_variation_sinesqrt(), diurnal_temp_variation_sine(), monthly_solar_radiation(), partition_solar_radiation(), proportion_diffuse_solar_radiation(), surface_roughness(), wind_speed_profile_neutral(), wind_speed_profile_segment()

Examples

```
solar_radiation(doy  = 112,
                psi  = 1,
                tau  = 0.6,
                elev = 1500,
                rho  = 0.7)
```

---

surface_area_from_length
Organism Surface Area from Length

Description

This function estimates surface area (m^2) from length (m) by approximating the animal's body as a rotational ellipsoid with half the body length as the semi-major axis.

Usage

```
surface_area_from_length(l)
```

Arguments

l	numeric length (m).

Details

Following Samietz et al. (2005) and Lactin and Johnson (1998).

Value

numeric surface area (m^2).

References

Lactin DJ, Johnson DL (1998). "Convective heat loss and change in body temperature of grasshopper and locust nymphs: Relative importance of wind speed, insect size and insect orientation." *Journal of Thermal Biology*, **23**(1), 5-13. ISSN 0306-4565, doi: 10.1016/S03064565(97)000375, `https://www.sciencedirect.com/science/article/pii/S0306456597000375`.

Samietz J, Salser MA, Dingle H (2005). "Altitudinal variation in behavioural thermoregulation: local adaptation vs. plasticity in California grasshoppers." *Journal of Evolutionary Biology*, **18**(4), 1087-1096. doi: 10.1111/j.14209101.2005.00893.x.

See Also

Other allometric functions: `mass_from_length()`, `proportion_silhouette_area_shapes()`, `proportion_silhouette_a`
`surface_area_from_mass()`, `surface_area_from_volume()`, `volume_from_length()`

Examples

```
surface_area_from_length(l = 0.04)
```

`surface_area_from_mass`

Organism Surface Area from Mass

Description

The function estimates surface area (m^2) from mass (g) for one of a variety of taxa.

Usage

```
surface_area_from_mass(m, taxon)
```

Arguments

`m`	`numeric` vector of mass (g).
`taxon`	`character` taxonomic classification of organism, current choices: `"lizard"`, `"salamander"`, `"frog"`, `"insect"`.

Details

All models follow ($SA = aM^b$) with mass in grams and surface area in $meters^2$.

- Lizards (Norris 1965; Porter and James 1979; Roughgarden 1981; O'Connor 1999; Fei et al. 2012):

  $a = 0.000314\pi$
  $b = 2/3$

- Salamanders (Whitford and Hutchison 1967; Riddell et al. 2017):

  $a = 0.000842$
  $b = 0.694$

- Frogs (McClanahan and Baldwin 1969):

  $a = 0.00099$
  $b = 0.56$

- Insects (Lactin and Johnson 1997):

  $a = 0.0013$
  $b = 0.8$

Value

numeric surface area (m^2).

References

Fei T, Skidmore AK, Venus V, Wang T, Schlerf M, Toxopeus B, van Overjijk S, Bian M, Liu Y (2012). "A body temperature model for lizards as estimated from the thermal environment." *Journal of Thermal Biology*, **37**(1), 56-64. ISSN 0306-4565, doi: 10.1016/j.jtherbio.2011.10.013, https://www.sciencedirect.com/science/article/pii/S0306456511001513.

Lactin DJ, Johnson DL (1997). "Response of body temperature to solar radiation in restrained nymphal migratory grasshoppers (Orthoptera: Acrididae): influences of orientation and body size." *Physiological Entomology*, **22**(2), 131-139. doi: 10.1111/j.13653032.1997.tb01150.x.

McClanahan L, Baldwin R (1969). "Rate of water uptake through the integument of the desert toad, Bufo punctatus." *Comparative Biochemistry and Physiology*, **28**(1), 381-389. ISSN 0010-406X, doi: 10.1016/0010406X(69)913516, https://doi.org/10.1016/0010-406X(69)91351-6.

Norris KS (1965). "Color adaptation in desert reptiles and its thermal relationships." In *Symposium on Lizard Ecology*, 162- 229. U. Missouri Press.

O'Connor M (1999). "Physiological and ecological implications of a simple model of heating and cooling in reptiles." *Journal of Thermal Biology*, **24**, 113-136.

Porter WP, James FC (1979). "Behavioral Implications of Mechanistic Ecology II: The African Rainbow Lizard, Agama agama." *Copeia*, **1979**(4), 594–619. ISSN 00458511, 19385110, doi: 10.2307/1443867.

Riddell EA, Apanovitch EK, Odom JP, Sears MW (2017). "Physical calculations of resistance to water loss improve predictions of species range models." *Ecological Monographs*, **87**(1), 21-33. doi: 10.1002/ecm.1240.

Roughgarden J (1981). "Resource partitioning of space and its relationship to body temperature in Anolis lizard populations." *Oecologia*, **50**, 256 – 264. https://link.springer.com/article/

10.1007/BF00348048.

Whitford WG, Hutchison VH (1967). "Body Size and Metabolic Rate in Salamanders." *Physiological Zoology*, **40**(2), 127-133. doi: 10.1086/physzool.40.2.30152447.

See Also

Other allometric functions: mass_from_length(), proportion_silhouette_area_shapes(), proportion_silhouette_a
surface_area_from_length(), surface_area_from_volume(), volume_from_length()

Examples

```
surface_area_from_mass(m     = 1:50,
                       taxon = "lizard")
surface_area_from_mass(m     = 1:50,
                       taxon = "salamander")
surface_area_from_mass(m     = 1:50,
                       taxon = "frog")
surface_area_from_mass(m     = seq(0.1, 5, 0.1),
                       taxon = "insect")
```

---

surface_area_from_volume   *Organism Surface Area from Volume*

Description

The function estimates surface area (m^2) from volume (m^3) for a variety of taxa following Mitchell (1976).

Usage

```
surface_area_from_volume(V, taxon)
```

Arguments

V	numeric vector of volume (m^3). Can be one or more values.
taxon	character taxon of organism, current choices: "lizard", "frog", "sphere".

Details

All models follow ($SA = Ka * V^{2/3}$) with surface area and volume in meters.

- Lizards: Norris (1965):

  $Ka = 11.0$

- Frogs: Tracy (1972):

  $Ka = 11.0$
- Sphere: Mitchell (1976):

  $Ka = 4.83$

Value

`numeric` surface area (m^2).

References

Mitchell JW (1976). "Heat transfer from spheres and other animal forms." *Biophysical Journal*, **16**(6), 561-569. ISSN 0006-3495, doi: 10.1016/S00063495(76)857116, https://www.sciencedirect.com/science/article/pii/S0006349576857116.

Norris KS (1965). "Color adaptation in desert reptiles and its thermal relationships." In *Symposium on Lizard Ecology*, 162- 229. U. Missouri Press.

Tracy CR (1972). "Newton's Law: Its Application for Expressing Heat Losses from Homeotherms." *BioScience*, **22**(11), 656-659. ISSN 0006-3568, doi: 10.2307/1296267.

See Also

Other allometric functions: `mass_from_length()`, `proportion_silhouette_area_shapes()`, `proportion_silhouette_a`
`surface_area_from_length()`, `surface_area_from_mass()`, `volume_from_length()`

Examples

```
surface_area_from_volume(V     = 0.001,
                         taxon = "lizard")
surface_area_from_volume(V     = 0.001,
                         taxon = "frog")
surface_area_from_volume(V     = 0.001,
                         taxon = "sphere")
```

`surface_roughness` *Surface Roughness from Empirical Measurements*

Description

The function estimates surface roughness (m) from empirical wind speed (ms^-1) data collected at a vector of heights (m) (Kingsolver and Buckley 2015; Campbell and Norman 1998; Porter and James 1979).

Usage

```
surface_roughness(u_r, zr)
```

Arguments

u_r	`numeric` wind velocity (ms^-1) at a vector of reference heights.
zr	`numeric` vector of reference heights (m).

Value

`numeric` surface roughness (m).

References

Campbell GS, Norman JM (1998). *Introduction to environmental biophysics*, 2nd ed. edition. Springer, New York. ISBN 0387949372.

Kingsolver JG, Buckley LB (2015). "Climate variability slows evolutionary responses of Colias butterflies to recent climate change." *Proceedings of the Royal Society B*, **282**(1802). doi: 10.1098/rspb.2014.2470.

Porter WP, James FC (1979). "Behavioral Implications of Mechanistic Ecology II: The African Rainbow Lizard, Agama agama." *Copeia*, **1979**(4), 594–619. ISSN 00458511, 19385110, doi: 10.2307/1443867.

See Also

Other microclimate functions: `air_temp_profile_neutral()`, `air_temp_profile_segment()`, `air_temp_profile()`, `degree_days()`, `direct_solar_radiation()`, `diurnal_radiation_variation()`, `diurnal_temp_variation_sineexp()`, `diurnal_temp_variation_sinesqrt()`, `diurnal_temp_variation_sine()`, `monthly_solar_radiation()`, `partition_solar_radiation()`, `proportion_diffuse_solar_radiation()`, `solar_radiation()`, `wind_speed_profile_neutral()`, `wind_speed_profile_segment()`

Examples

```
surface_roughness(u_r = c(0.01, 0.025, 0.05, 0.1, 0.2),
                  zr  = c(0.05, 0.25, 0.5, 0.75, 1))
```

Tbed_mussel *Operative Environmental Temperature of a Mussel Bed*

Description

The function estimates body temperature of a mussel (C). The function implements a steady-state model, which assumes unchanging environmental conditions. Based on Helmuth (1999).

Usage

```
Tbed_mussel(l, T_a, S, k_d, u, evap = FALSE, cl = NA)
```

Arguments

l	numeric mussel length (anterior/posterior axis) (m).
T_a	numeric air temperature at 4 m above ground (C).
S	numeric direct solar flux density (Wm^-2).
k_d	numeric diffuse fraction, proportion of solar radiation that is diffuse.
u	numeric wind speed at 4 m above ground (ms^-1).
evap	logical Are mussels gaping to evaporatively cool? If TRUE, assumes constant mass loss rate of 5 percent of initial body mass per hour.
cl	numeric fraction of the sky covered by cloud, optional.

Details

Conduction is considered negligible due to a small area of contact.

Thermal radiative flux is calculated following Helmuth (1998), Helmuth (1999), and Idso and Jackson (1969).

Value

numeric predicted body (operative environmental) temperature (C).

References

Helmuth B (1999). "Thermal biology of rocky intertidal mussels: quantifying body temperatures using climatological data." *Ecology*, **80**(1), 15-34. doi: 10.1890/00129658(1999)080[0015:TBORIM]2.0.CO;2, https://doi.org/10.1890/0012-9658(1999)080[0015:TBORIM]2.0.CO;2.

Helmuth BST (1998). "Intertidal Mussel Microclimates: Predicting the Body Temperature of a Sessile Invertebrate." *Ecological Monographs*, **68**(1), 51–74. ISSN 00129615, doi: 10.2307/2657143.

Idso SB, Jackson RD (1969). "Thermal radiation from the atmosphere." *Journal of Geophysical Research (1896-1977)*, **74**(23), 5397-5403. doi: 10.1029/JC074i023p05397.

See Also

Other biophysical models: Grashof_number_Gates(), Grashof_number(), Nusselt_from_Grashof(), Nusselt_from_Reynolds(), Nusselt_number(), Prandtl_number(), Qconduction_animal(), Qconduction_substrate(), Qconvection(), Qemitted_thermal_radiation(), Qevaporation(), Qmetabolism_from_mass_temp(), Qmetabolism_from_mass(), Qnet_Gates(), Qradiation_absorbed(), Qthermal_radiation_absorbed(), Reynolds_number(), Tb_CampbellNorman(), Tb_Gates2(), Tb_Gates(), Tb_butterfly(), Tb_grasshopper(), Tb_limpetBH(), Tb_limpet(), Tb_lizard_Fei(), Tb_lizard(), Tb_mussel(), Tb_salamander_humid(), Tb_snail(), Tsoil(), actual_vapor_pressure(), boundary_layer_resistance(), external_resistance_to_water_vapor_transfer(), free_or_forced_convection

heat_transfer_coefficient_approximation(), heat_transfer_coefficient_simple(), heat_transfer_coeffici
saturation_vapor_pressure(), saturation_water_vapor_pressure()

Examples

```
Tbed_mussel(l    = 0.1,
            T_a  = 25,
            S    = 500,
            k_d  = 0.2,
            u    = 1,
            evap = FALSE)
```

Tb_butterfly *Operative Environmental Temperature of a Butterfly*

Description

The function estimates body temperatures (C, operative environmental temperatures) of a butterfly based on Kingsolver (1983) and Buckley and Kingsolver (2012). The function is designed for butterflies that bask with closed wings such as Colias.

Usage

```
Tb_butterfly(
  T_a,
  T_g,
  T_sh,
  u,
  H_sdir,
  H_sdif,
  z,
  D,
  delta,
  alpha,
  r_g = 0.3,
  shade = FALSE
)
```

Arguments

T_a	numeric air temperature (C).
T_g	numeric surface temperature (C) in the sunlight.
T_sh	numeric surface temperature (C) in the shade.
u	numeric wind speed (ms^-1).
H_sdir	numeric direct solar radiation flux (Wm^-2).

`H_sdif`	`numeric` diffuse solar radiation flux (Wm^-2).
`z`	`numeric` solar zenith angle (degrees).
`D`	`numeric` thoracic diameter (cm).
`delta`	`numeric` thoracic fur thickness (mm).
`alpha`	`numeric` wing solar absorptivity (proportion). The range for Colias butterflies is 0.4 to 0.7.
`r_g`	`numeric` substrate solar reflectivity (proportion). See Kingsolver (1983).
`shade`	`logical` whether body temperature should be calculated in sun (`FALSE`) or shade (`TRUE`).

Details

Thermal radiative flux is calculated following Gates (1980) based on Swinbank (1960). Kingsolver (1983) estimates using the Brunt equation with black body sky temperature from Swinbank (1963).

Value

`numeric` predicted body (operative environmental) temperature (C).

References

Buckley LB, Kingsolver JG (2012). "The demographic impacts of shifts in climate means and extremes on alpine butterflies." *Functional Ecology*, **26**(4), 969-977. doi: 10.1111/j.13652435.2012.01969.x.

Gates DM (1980). *Biophysical Ecology*. Springer-Verlag, New York, NY, USA.

Kingsolver JG (1983). "Thermoregulation and Flight in Colias Butterflies: Elevational Patterns and Mechanistic Limitations." *Ecology*, **64**(3), 534-545. doi: 10.2307/1939973.

Swinbank WC (1960). "Wind profile in thermally stratified flow." *Nature*, **186**, 463-464.

Swinbank WC (1963). "Long-wave radiation from clear skies." *Quarterly Journal of the Royal Meteorological Society*, **89**, 339-348.

See Also

Other biophysical models: `Grashof_number_Gates()`, `Grashof_number()`, `Nusselt_from_Grashof()`, `Nusselt_from_Reynolds()`, `Nusselt_number()`, `Prandtl_number()`, `Qconduction_animal()`, `Qconduction_substrate()`, `Qconvection()`, `Qemitted_thermal_radiation()`, `Qevaporation()`, `Qmetabolism_from_mass_temp()`, `Qmetabolism_from_mass()`, `Qnet_Gates()`, `Qradiation_absorbed()`, `Qthermal_radiation_absorbed()`, `Reynolds_number()`, `Tb_CampbellNorman()`, `Tb_Gates2()`, `Tb_Gates()`, `Tb_grasshopper()`, `Tb_limpetBH()`, `Tb_limpet()`, `Tb_lizard_Fei()`, `Tb_lizard()`, `Tb_mussel()`, `Tb_salamander_humid()`, `Tb_snail()`, `Tbed_mussel()`, `Tsoil()`, `actual_vapor_pressure()`, `boundary_layer_resistance()`, `external_resistance_to_water_vapor_transfer()`, `free_or_forced_convection`
`heat_transfer_coefficient_approximation()`, `heat_transfer_coefficient_simple()`, `heat_transfer_coeffici`
`saturation_vapor_pressure()`, `saturation_water_vapor_pressure()`

Examples

```
Tb_butterfly(T_a    = 25,
             T_g    = 25,
             T_sh   = 20,
             u      = 0.4,
             H_sdir = 300,
             H_sdif = 100,
             z      = 30,
             D      = 0.36,
             delta  = 1.46,
             alpha  = 0.6,
             r_g    = 0.3)
```

Tb_CampbellNorman *Operative Environmental Temperature of an Ectotherm based on Campbell and Norman (1988)*

Description

The function estimates body temperatures (K, operative environmental temperature) of an ectotherm using an approximation based on Campbell and Norman (1998) and Mitchell (1976).

Usage

```
Tb_CampbellNorman(
  T_a,
  T_g,
  S,
  alpha_S = 0.7,
  alpha_L = 0.96,
  epsilon = 0.96,
  c_p = 29.3,
  D,
  V
)
```

Arguments

T_a	`numeric` air temperature (K).
T_g	`numeric` ground temperature (K).
S	`numeric` flux density of solar radiation ($Wm^{-}2$), combining direct, diffuse, and reflected radiation accounting for view factors.
alpha_S	`numeric` organismal solar absorptivity (proportion).
alpha_L	`numeric` organismal thermal absorptivity (proportion); 0.965 for lizards (Bartlett and Gates 1967).

epsilon	numeric longwave infrared emissivity of skin (proportion), 0.95 to 1 for most animals (Gates 1980).
c_p	numeric specific heat of air ($Jmol^-1K^-1$).
D	numeric characteristic dimension of the animal (m).
V	numeric wind speed (ms^-1).

Details

Boundary conductance uses a factor of 1.4 to account for increased convection (Mitchell 1976). The function assumes forced conduction.

Value

numeric operative environmental temperature, T_e (K).

References

Bartlett PN, Gates DM (1967). "The energy budget of a lizard on a tree trunk." *Ecology*, **48**, 316-322.

Campbell GS, Norman JM (1998). *Introduction to environmental biophysics*, 2nd ed. edition. Springer, New York. ISBN 0387949372.

Gates DM (1980). *Biophysical Ecology*. Springer-Verlag, New York, NY, USA.

Mitchell JW (1976). "Heat transfer from spheres and other animal forms." *Biophysical Journal*, **16**(6), 561-569. ISSN 0006-3495, doi: 10.1016/S00063495(76)857116, https://www.sciencedirect.com/science/article/pii/S0006349576857116.

See Also

Other biophysical models: Grashof_number_Gates(), Grashof_number(), Nusselt_from_Grashof(), Nusselt_from_Reynolds(), Nusselt_number(), Prandtl_number(), Qconduction_animal(), Qconduction_substrate(), Qconvection(), Qemitted_thermal_radiation(), Qevaporation(), Qmetabolism_from_mass_temp(), Qmetabolism_from_mass(), Qnet_Gates(), Qradiation_absorbed(), Qthermal_radiation_absorbed(), Reynolds_number(), Tb_Gates2(), Tb_Gates(), Tb_butterfly(), Tb_grasshopper(), Tb_limpetBH(), Tb_limpet(), Tb_lizard_Fei(), Tb_lizard(), Tb_mussel(), Tb_salamander_humid(), Tb_snail(), Tbed_mussel(), Tsoil(), actual_vapor_pressure(), boundary_layer_resistance(), external_resistance_to_water_vapor_transfer(), free_or_forced_convection heat_transfer_coefficient_approximation(), heat_transfer_coefficient_simple(), heat_transfer_coeffici saturation_vapor_pressure(), saturation_water_vapor_pressure()

Examples

```
Tb_CampbellNorman (T_a     = 303,
                   T_g     = 303,
                   S       = 823,
                   alpha_S = 0.7,
                   alpha_L = 0.96,
```

```
                    epsilon = 0.96,
                    c_p     = 29.3,
                    D       = 0.17,
                    V       = 1)
```

Tb_Gates *Operative Environmental Temperature of an Ectotherm Based on Gates (1980)*

Description

The function predicts body temperatures (K, operative environmental temperature) of an ectotherm using the approximation in Gates (1980). The functions omits evaporative and metabolic heat loss (Mitchell 1976; Kingsolver 1983).

Usage

```
Tb_Gates(
  A,
  D,
  psa_dir,
  psa_ref,
  psa_air,
  psa_g,
  T_g,
  T_a,
  Qabs,
  epsilon,
  H_L,
  ef = 1.3,
  K
)
```

Arguments

A	`numeric` surface area (m^2).
D	`numeric` characteristic dimension for conduction (meters).
psa_dir	`numeric` proportion surface area exposed to direct radiation from the sky (or enclosure) (0-1).
psa_ref	`numeric` proportion surface area exposed to reflected radiation from the ground (0-1).
psa_air	`numeric` proportion surface area exposed to air (0-1).
psa_g	`numeric` proportion surface area in contact with substrate (0-1).
T_g	`numeric` ground surface temperature (K).

`T_a` numeric ambient air temperature (K).

`Qabs` numeric Solar radiation absorbed (W).

`epsilon` numeric longwave infrared emissivity of skin (proportion), 0.95 to 1 for most animals (Gates 1980).

`H_L` numeric Convective heat transfer coefficient (Wm^-2K^-1).

`ef` numeric enhancement factor used to adjust H_L to field conditions using h_L approximation from Mitchell (1976). Approximated as 1.23 by default, but see Mitchell (1976) for relationship.

`K` numeric Thermal conductivity (WK^-1m^-1), K = 0.5 WK^-1m^-1 for naked skin, K = 0.15 $WK^-1m^-1$for insect cuticle Galushko et al. (2005); conductivity of the ground is generally greater than that of animal tissues, so animal thermal conductivity is generally the rate limiting step.

Value

`numeric` operative environmental temperature, `T_e` (K).

References

Galushko D, Ermakov N, Karpovski M, Palevski A, Ishay JS, Bergman DJ (2005). "Electrical, thermoelectric and thermophysical properties of hornet cuticle." *Semiconductor Science and Technology*, **20**(3), 286–289. doi: 10.1088/02681242/20/3/005.

Gates DM (1980). *Biophysical Ecology*. Springer-Verlag, New York, NY, USA.

Kingsolver JG (1983). "Thermoregulation and Flight in Colias Butterflies: Elevational Patterns and Mechanistic Limitations." *Ecology*, **64**(3), 534-545. doi: 10.2307/1939973.

Mitchell JW (1976). "Heat transfer from spheres and other animal forms." *Biophysical Journal*, **16**(6), 561-569. ISSN 0006-3495, doi: 10.1016/S00063495(76)857116, `https://www.sciencedirect.com/science/article/pii/S0006349576857116`.

See Also

Other biophysical models: `Grashof_number_Gates()`, `Grashof_number()`, `Nusselt_from_Grashof()`, `Nusselt_from_Reynolds()`, `Nusselt_number()`, `Prandtl_number()`, `Qconduction_animal()`, `Qconduction_substrate()`, `Qconvection()`, `Qemitted_thermal_radiation()`, `Qevaporation()`, `Qmetabolism_from_mass_temp()`, `Qmetabolism_from_mass()`, `Qnet_Gates()`, `Qradiation_absorbed()`, `Qthermal_radiation_absorbed()`, `Reynolds_number()`, `Tb_CampbellNorman()`, `Tb_Gates2()`, `Tb_butterfly()`, `Tb_grasshopper()`, `Tb_limpetBH()`, `Tb_limpet()`, `Tb_lizard_Fei()`, `Tb_lizard()`, `Tb_mussel()`, `Tb_salamander_humid()`, `Tb_snail()`, `Tbed_mussel()`, `Tsoil()`, `actual_vapor_pressure()`, `boundary_layer_resistance()`, `external_resistance_to_water_vapor_transfer()`, `free_or_forced_convection` `heat_transfer_coefficient_approximation()`, `heat_transfer_coefficient_simple()`, `heat_transfer_coeffici` `saturation_vapor_pressure()`, `saturation_water_vapor_pressure()`

Examples

```
Tb_Gates (A       = 1,
          D       = 0.001,
          psa_dir = 0.6,
          psa_ref = 0.4,
          psa_air = 0.6,
          psa_g   = 0.2,
          T_g     = 303,
          T_a     = 310,
          Qabs    = 2,
          epsilon = 0.95,
          H_L     = 10,
          ef      = 1.23,
          K       = 0.5)
```

Tb_Gates2 — *Operative Environmental Temperature of an Ectotherm Based on a Variant of Gates (1980)*

Description

The function predicts body temperatures (K, operative environmental temperature) of an ectotherm using the approximation in Gates (1980). The function omits evaporative and metabolic heat loss.

Usage

```
Tb_Gates2(A, D, T_g, T_a, Qabs, V, epsilon)
```

Arguments

A	`numeric` surface area (m^2).
D	`numeric` characteristic dimension for conduction (meters).
T_g	`numeric` ground surface temperature (K).
T_a	`numeric` ambient air temperature (K).
Qabs	`numeric` Solar radiation absorbed (W).
V	`numeric` Wind speed (ms^-1).
epsilon	`numeric` longwave infrared emissivity of skin (proportion), 0.95 to 1 for most animals (Gates 1980).

Value

`numeric` operative environmental temperature (K).

References

Gates DM (1980). *Biophysical Ecology*. Springer-Verlag, New York, NY, USA.

See Also

Other biophysical models: Grashof_number_Gates(), Grashof_number(), Nusselt_from_Grashof(), Nusselt_from_Reynolds(), Nusselt_number(), Prandtl_number(), Qconduction_animal(), Qconduction_substrate(), Qconvection(), Qemitted_thermal_radiation(), Qevaporation(), Qmetabolism_from_mass_temp(), Qmetabolism_from_mass(), Qnet_Gates(), Qradiation_absorbed(), Qthermal_radiation_absorbed(), Reynolds_number(), Tb_CampbellNorman(), Tb_Gates(), Tb_butterfly(), Tb_grasshopper(), Tb_limpetBH(), Tb_limpet(), Tb_lizard_Fei(), Tb_lizard(), Tb_mussel(), Tb_salamander_humid(), Tb_snail(), Tbed_mussel(), Tsoil(), actual_vapor_pressure(), boundary_layer_resistance(), external_resistance_to_water_vapor_transfer(), free_or_forced_convection heat_transfer_coefficient_approximation(), heat_transfer_coefficient_simple(), heat_transfer_coeffici saturation_vapor_pressure(), saturation_water_vapor_pressure()

Examples

```
Tb_Gates2(A       = 1,
          D       = 0.001,
          T_g     = 300,
          T_a     = 310,
          Qabs    = 2,
          V       = 0.1,
          epsilon = 1)
```

Tb_grasshopper *Operative Environmental Temperature of a Grasshopper*

Description

The function estimates body temperatures (C, operative environmental temperatures) of a grasshopper based on Lactin and Johnson (1998). Part of the model is based on Swinbank (1963), following Gates (1962) in Kingsolver (1983).

Usage

```
Tb_grasshopper(
  T_a,
  T_g,
  u,
  H,
  K_t,
  psi,
  l,
  Acondfact = 0.25,
  z = 0.001,
  abs = 0.7,
  r_g = 0.3
)
```

Arguments

`T_a`	`numeric` air temperature (C).
`T_g`	`numeric` surface temperature (C). Kingsolver (1983) assumes `T_g - T_a = 8.4`.
`u`	`numeric` wind speed (ms^-1).
`H`	`numeric` total (direct + diffuse) solar radiation flux (Wm^-2).
`K_t`	`numeric` clearness index (dimensionless), which is the ratio of the global solar radiation measured at the surface to the total solar radiation at the top of the atmosphere.
`psi`	`numeric` solar zenith angle (degrees).
`l`	`numeric` grasshopper length (m).
`Acondfact`	`numeric` the proportion of the grasshopper surface area that is in contact with the ground.
`z`	`numeric` distance from the ground to the grasshopper (m).
`abs`	`numeric` absorptivity of the grasshopper to solar radiation (proportion). See Anderson et al. (1979).
`r_g`	`numeric` substrate solar reflectivity (proportion). See Kingsolver (1983).

Details

Total radiative flux is calculated as thermal radiative heat flux plus convective heat flux, following Kingsolver (1983), with the Erbs et al. (1982) model from Wong and Chow (2001).

Energy balance is based on Kingsolver (1983).

Radiation is calculated without area dependence (Anderson et al. 1979).

The body of a grasshopper female is approximated by a rotational ellipsoid with half the body length as the semi-major axis (Samietz et al. 2005).

The diffuse fraction is corrected following Olyphant (1984).

Value

`numeric` predicted body (operative environmental) temperature (C).

References

Anderson RV, Tracy CR, Abramsky Z (1979). "Habitat Selection in Two Species of Short-Horned Grasshoppers. The Role of Thermal and Hydric Stresses." *Oecologia*, **38**(3), 359–374. doi: 10.1007/BF00345194.

Erbs D, Klein S, Duffie J (1982). "Estimation of the diffuse radiation fraction for hourly, daily and monthly-average global radiation." *Solar Energy*, **28**, 293-302.

Gates DM (1962). "Leaf temperature and energy exchange." *Archiv fur Meteorologie, Geophysik* *und Bioklimatologie, Serie B volume*, **12**, 321-336.

Kingsolver JG (1983). “Thermoregulation and Flight in Colias Butterflies: Elevational Patterns and Mechanistic Limitations.” *Ecology*, **64**(3), 534-545. doi: 10.2307/1939973.

Lactin DJ, Johnson DL (1998). “Convective heat loss and change in body temperature of grasshopper and locust nymphs: Relative importance of wind speed, insect size and insect orientation.” *Journal of Thermal Biology*, **23**(1), 5-13. ISSN 0306-4565, doi: 10.1016/S03064565(97)000375, `https://www.sciencedirect.com/science/article/pii/S0306456597000375`.

Olyphant G (1984). “Insolation Topoclimates and Potential Ablation in Alpine Snow Accumulation Basins: Front Range, Colorado.” *Water Resources Research*, **20**(4), 491-498.

Samietz J, Salser MA, Dingle H (2005). “Altitudinal variation in behavioural thermoregulation: local adaptation vs. plasticity in California grasshoppers.” *Journal of Evolutionary Biology*, **18**(4), 1087-1096. doi: 10.1111/j.14209101.2005.00893.x.

Swinbank WC (1963). “Long-wave radiation from clear skies.” *Quarterly Journal of the Royal Meteorological Society*, **89**, 339-348.

Wong LT, Chow WK (2001). “Solar radiation model.” *Applied Energy*, **69**(3), 191-224. ISSN 0306-2619, doi: 10.1016/S03062619(01)000125, `https://www.sciencedirect.com/science/article/pii/S0306261901000125`.

See Also

Other biophysical models: `Grashof_number_Gates()`, `Grashof_number()`, `Nusselt_from_Grashof()`, `Nusselt_from_Reynolds()`, `Nusselt_number()`, `Prandtl_number()`, `Qconduction_animal()`, `Qconduction_substrate()`, `Qconvection()`, `Qemitted_thermal_radiation()`, `Qevaporation()`, `Qmetabolism_from_mass_temp()`, `Qmetabolism_from_mass()`, `Qnet_Gates()`, `Qradiation_absorbed()`, `Qthermal_radiation_absorbed()`, `Reynolds_number()`, `Tb_CampbellNorman()`, `Tb_Gates2()`, `Tb_Gates()`, `Tb_butterfly()`, `Tb_limpetBH()`, `Tb_limpet()`, `Tb_lizard_Fei()`, `Tb_lizard()`, `Tb_mussel()`, `Tb_salamander_humid()`, `Tb_snail()`, `Tbed_mussel()`, `Tsoil()`, `actual_vapor_pressure()`, `boundary_layer_resistance()`, `external_resistance_to_water_vapor_transfer()`, `free_or_forced_convection` `heat_transfer_coefficient_approximation()`, `heat_transfer_coefficient_simple()`, `heat_transfer_coeffici` `saturation_vapor_pressure()`, `saturation_water_vapor_pressure()`

Examples

```
Tb_grasshopper(T_a       = 25,
               T_g       = 25,
               u         = 0.4,
               H         = 400,
               K_t       = 0.7,
               psi       = 30,
               l         = 0.02,
               Acondfact = 0.25,
               z         = 0.001,
               abs       = 0.7,
               r_g       = 0.3)
```

Tb_limpet *Operative Environmental Temperature of a Limpet*

Description

The function estimates body temperatures (C, operative environmental temperatures) of a limpet based on Denny and Harley (2006).

Usage

```
Tb_limpet(T_a, T_r, l, h, I, u, psi, c, position = "anterior")
```

Arguments

T_a	numeric air temperature (C).
T_r	numeric rock surface temperature (C) in the sunlight.
l	numeric limpet length (anterior/posterior axis, m).
h	numeric limpet height (dorsal/ventral axis, m).
I	numeric solar irradiance (Wm^-2).
u	numeric wind speed (ms^-1).
psi	numeric solar zenith angle (degrees). Can be calculated from zenith_angle function.
c	numeric fraction of the sky covered by cloud (proportion).
position	character direction of the limpet that is facing upwind. Options are "anterior", "posterior", and "broadside".

Details

The original equation uses a finite-difference approach where they divide the rock into series of chunks, and calculate the temperature at each node to derive the conductive heat. For simplification, here it takes the rock temperature as a parameter, and conductive heat is calculated as a product of the area, thermal conductivity of rock and the temperature difference between the rock and the body.

Limpets are simulated as cones following and using solar emissivity values from Campbell and Norman (1998).

The area of the limpet's shell (m^2) is projected according to the direction at which sunlight strikes the organism (Pennell and Deignan 1989).

Air conductivity values (Wm^-1K^-1) are calculated following Denny and Harley (2006).

Value

numeric predicted body (operative environmental) temperature (C).

References

Campbell GS, Norman JM (1998). *Introduction to environmental biophysics*, 2nd ed. edition. Springer, New York. ISBN 0387949372.

Denny MW, Harley CDG (2006). "Hot limpets: predicting body temperature in a conductance-mediated thermal system." *Journal of Experimental Biology*, **209**(13), 2409-2419. ISSN 0022-0949, doi: 10.1242/jeb.02356.

Pennell S, Deignan J (1989). "Computing the Projected Area of a Cone." *SIAM Review*, **31**, 299-302. `https://epubs.siam.org/doi/10.1137/1031052`.

See Also

Other biophysical models: `Grashof_number_Gates()`, `Grashof_number()`, `Nusselt_from_Grashof()`, `Nusselt_from_Reynolds()`, `Nusselt_number()`, `Prandtl_number()`, `Qconduction_animal()`, `Qconduction_substrate()`, `Qconvection()`, `Qemitted_thermal_radiation()`, `Qevaporation()`, `Qmetabolism_from_mass_temp()`, `Qmetabolism_from_mass()`, `Qnet_Gates()`, `Qradiation_absorbed()`, `Qthermal_radiation_absorbed()`, `Reynolds_number()`, `Tb_CampbellNorman()`, `Tb_Gates2()`, `Tb_Gates()`, `Tb_butterfly()`, `Tb_grasshopper()`, `Tb_limpetBH()`, `Tb_lizard_Fei()`, `Tb_lizard()`, `Tb_mussel()`, `Tb_salamander_humid()`, `Tb_snail()`, `Tbed_mussel()`, `Tsoil()`, `actual_vapor_pressure()`, `boundary_layer_resistance()`, `external_resistance_to_water_vapor_transfer()`, `free_or_forced_convection`
`heat_transfer_coefficient_approximation()`, `heat_transfer_coefficient_simple()`, `heat_transfer_coeffici`
`saturation_vapor_pressure()`, `saturation_water_vapor_pressure()`

Examples

```
Tb_limpet(T_a      = 25,
          T_r      = 30,
          l        = 0.0176,
          h        = 0.0122,
          I        = 1300,
          u        = 1,
          psi      = 30,
          c        = 1,
          position = "anterior")
```

`Tb_limpetBH` *Operative Environmental Temperature of a Limpet Based on a Model by Helmuth*

Description

The function predicts body temperatures (C, operative environmental temperatures) of a limpet. The function was provided by Brian Helmuth – although radiation and convection are altered from his original model – and based on Denny and Harley (2006).

Usage

```
Tb_limpetBH(T_a, T_r, l, h, I, u, s_aspect, s_slope, c)
```

Arguments

`T_a`	`numeric` air temperature (C).
`T_r`	`numeric` rock surface temperature (C) in the sunlight.
`l`	`numeric` limpet length (anterior/posterior axis) (m).
`h`	`numeric` limpet height (dorsal/ventral axis) (m).
`I`	`numeric` solar irradiance (Wm^-2).
`u`	`numeric` wind speed (ms^-1).
`s_aspect`	`numeric` solar aspect angle (degree), the angle between the limpet's length dimension and the vector to the Sun. Generally between 70 and 110 degrees.
`s_slope`	`numeric` solar elevation angle (degree), the altitude of the sun, which is the angle between the horizon and the sun.
`c`	`numeric` fraction of the sky covered by clouds.

Details

The original equation uses a finite-difference approach where they divide the rock into series of chunks, and calculate the temperature at each node to derive the conductive heat. For simplification, here it takes the rock temperature as a parameter, and conductive heat is calculated by the product of the area, thermal conductivity of rock and the difference in temperatures of the rock and the body.

Limpets are simulated as cones following and using solar emissivity values from Campbell and Norman (1998).

The area of the limpet's shell (m^2) is projected in the direction at which sunlight strikes the organism Pennell and Deignan (1989).

Air conductivity values (Wm^-1K^-1) are calculated following Denny and Harley (2006).

Value

`numeric` predicted body (operative environmental) temperature (C).

Author(s)

Brian Helmuth et al.

References

Campbell GS, Norman JM (1998). *Introduction to environmental biophysics*, 2nd ed. edition. Springer, New York. ISBN 0387949372.

Denny MW, Harley CDG (2006). "Hot limpets: predicting body temperature in a conductance-mediated thermal system." *Journal of Experimental Biology*, **209**(13), 2409-2419. ISSN 0022-0949, doi: 10.1242/jeb.02356.

Pennell S, Deignan J (1989). "Computing the Projected Area of a Cone." *SIAM Review*, **31**, 299-302. https://epubs.siam.org/doi/10.1137/1031052.

See Also

Other biophysical models: Grashof_number_Gates(), Grashof_number(), Nusselt_from_Grashof(), Nusselt_from_Reynolds(), Nusselt_number(), Prandtl_number(), Qconduction_animal(), Qconduction_substrate(), Qconvection(), Qemitted_thermal_radiation(), Qevaporation(), Qmetabolism_from_mass_temp(), Qmetabolism_from_mass(), Qnet_Gates(), Qradiation_absorbed(), Qthermal_radiation_absorbed(), Reynolds_number(), Tb_CampbellNorman(), Tb_Gates2(), Tb_Gates(), Tb_butterfly(), Tb_grasshopper(), Tb_limpet(), Tb_lizard_Fei(), Tb_lizard(), Tb_mussel(), Tb_salamander_humid(), Tb_snail(), Tbed_mussel(), Tsoil(), actual_vapor_pressure(), boundary_layer_resistance(), external_resistance_to_water_vapor_transfer(), free_or_forced_convection heat_transfer_coefficient_approximation(), heat_transfer_coefficient_simple(), heat_transfer_coeffici saturation_vapor_pressure(), saturation_water_vapor_pressure()

Examples

```
Tb_limpetBH(T_a = 25,
            T_r = 30,
            l = 0.0176,
            h = 0.0122,
            I = 1300,
            u = 1,
            s_aspect = 90,
            s_slope = 60,
            c = 1)
```

Tb_lizard *Operative Environmental Temperature of a Lizard*

Description

The function estimates body temperature (C, operative environmental temperature) of a lizard based on Campbell and Norman (1998). The function was designed for Sceloporus lizards and described in Buckley (2008).

Usage

```
Tb_lizard(
  T_a,
  T_g,
  u,
```

```
  svl,
  m,
  psi,
  rho_S,
  elev,
  doy,
  sun = TRUE,
  surface = TRUE,
  alpha_S = 0.9,
  alpha_L = 0.965,
  epsilon_s = 0.965,
  F_d = 0.8,
  F_r = 0.5,
  F_a = 0.5,
  F_g = 0.5
)
```

Arguments

T_a	numeric air temperature (C).
T_g	numeric surface temperature (C).
u	numeric wind speed (ms^-1).
svl	numeric lizard snout vent length (mm).
m	numeric lizard mass (g); note that it can be estimated as in mass_from_length: $3.55 * 10^-5 * length^3$
psi	numeric solar zenith angle (degrees).
rho_S	numeric surface albedo (proportion). ~ 0.25 for grass, ~ 0.1 for dark soil, > 0.75 for fresh snow (Campbell and Norman 1998).
elev	numeric elevation (m).
doy	numeric day of year (1-366).
sun	logical indicates whether lizard is in sun (TRUE) or shade (FALSE).
surface	logical indicates whether lizard is on ground surface (TRUE) or above the surface (FALSE, e.g. in a tree).
alpha_S	numeric lizard solar absorptivity (proportion), alpha_S = 0.9 (Gates 1980) (Table 11.4).
alpha_L	numeric lizard thermal absorptivity (proportion), alpha_L = 0.965 (Bartlett and Gates 1967).
epsilon_s	numeric surface emissivity of lizards (proportion), epsilon_s = 0.965 (Bartlett and Gates 1967).
F_d	numeric the view factor between the surface of the lizard and diffuse solar radiation (proportion). i.e., the portion of the lizard surface that is exposed to diffuse solar radiation (Bartlett and Gates 1967).
F_r	numeric the view factor between the surface of the lizard and reflected solar radiation (proportion).

F_a numeric the view factor between the surface of the lizard and atmospheric radiation (proportion).

F_g numeric the view factor between the surface of the lizard and ground thermal radiation (proportion).

Details

The proportion of radiation that is direct is determined following Sears et al. (2011).

Boundary conductance uses a factor of 1.4 to account for increased convection (Mitchell 1976).

Value

T_e numeric predicted body (operative environmental) temperature (C).

References

Bartlett PN, Gates DM (1967). "The energy budget of a lizard on a tree trunk." *Ecology*, **48**, 316-322.

Buckley LB (2008). "Linking traits to energetics and population dynamics to predict lizard ranges in changing environments." *American Naturalist*, **171**(1), E1 - E19. doi: 10.1086/523949, https://pubmed.ncbi.nlm.nih.gov/18171140/.

Campbell GS, Norman JM (1998). *Introduction to environmental biophysics*, 2nd ed. edition. Springer, New York. ISBN 0387949372.

Gates DM (1980). *Biophysical Ecology*. Springer-Verlag, New York, NY, USA.

Mitchell JW (1976). "Heat transfer from spheres and other animal forms." *Biophysical Journal*, **16**(6), 561-569. ISSN 0006-3495, doi: 10.1016/S00063495(76)857116, https://www.sciencedirect.com/science/article/pii/S0006349576857116.

Sears MW, Raskin E, Angilletta Jr. MJ (2011). "The World Is not Flat: Defining Relevant Thermal Landscapes in the Context of Climate Change." *Integrative and Comparative Biology*, **51**(5), 666-675. ISSN 1540-7063, doi: 10.1093/icb/icr111, https://academic.oup.com/icb/article-pdf/51/5/666/1757893/icr111.pdf.

See Also

Other biophysical models: Grashof_number_Gates(), Grashof_number(), Nusselt_from_Grashof(), Nusselt_from_Reynolds(), Nusselt_number(), Prandtl_number(), Qconduction_animal(), Qconduction_substrate(), Qconvection(), Qemitted_thermal_radiation(), Qevaporation(), Qmetabolism_from_mass_temp(), Qmetabolism_from_mass(), Qnet_Gates(), Qradiation_absorbed(), Qthermal_radiation_absorbed(), Reynolds_number(), Tb_CampbellNorman(), Tb_Gates2(), Tb_Gates(), Tb_butterfly(), Tb_grasshopper(), Tb_limpetBH(), Tb_limpet(), Tb_lizard_Fei(), Tb_mussel(), Tb_salamander_humid(), Tb_snail(), Tbed_mussel(), Tsoil(), actual_vapor_pressure(), boundary_layer_resistance(), external_resistance_to_water_vapor_transfer(), free_or_forced_convection heat_transfer_coefficient_approximation(), heat_transfer_coefficient_simple(), heat_transfer_coeffici saturation_vapor_pressure(), saturation_water_vapor_pressure()

Examples

```
Tb_lizard(T_a       = 25,
          T_g       = 30,
          u         = 0.1,
          svl       = 60,
          m         = 10,
          psi       = 34,
          rho_S     = 0.24,
          elev      = 500,
          doy       = 200,
          sun       = TRUE,
          surface   = TRUE,
          alpha_S   = 0.9,
          alpha_L   = 0.965,
          epsilon_s = 0.965,
          F_d       = 0.8,
          F_r       = 0.5,
          F_a       = 0.5,
          F_g       = 0.5)
```

`Tb_lizard_Fei` *Operative Temperature of a Lizard Using Fei et al. (2012)*

Description

The function predicts body temperature (K, operative environmental temperature) of a lizard based on Fei et al. (2012).

Usage

```
Tb_lizard_Fei(T_a, T_g, H, lw, shade, m, Acondfact, Agradfact)
```

Arguments

`T_a`	`numeric` air temperature at lizard height (K).
`T_g`	`numeric` surface temperature (K).
`H`	`numeric` total (direct + diffuse) solar radiation flux ($Wm{-}^2$).
`lw`	`numeric` downward flux of near-infrared radiation ($Wm{-}^2$).
`shade`	`numeric` proportion of shade.
`m`	`numeric` lizard mass (g).
`Acondfact`	`numeric` proportion of the lizard projected area that is in contact with the ground. `Acondfact = 0.1` for standing and `Acondfact = 0.4` for lying on ground.
`Agradfact`	`numeric` proportion of the lizard projected area exposed to radiation from the ground. `Agradfact = 0.3` for standing and `Agradfact = 0.0` for lying on ground.

Details

Thermal radiative flux is calculated following Fei et al. (2012) based on Bartlett and Gates (1967) and Porter et al. (1973).

Value

`numeric` predicted body (operative environmental) temperature (K).

Author(s)

Ofir Levy

References

Bartlett PN, Gates DM (1967). "The energy budget of a lizard on a tree trunk." *Ecology*, **48**, 316-322.

Fei T, Skidmore AK, Venus V, Wang T, Schlerf M, Toxopeus B, van Overjijk S, Bian M, Liu Y (2012). "A body temperature model for lizards as estimated from the thermal environment." *Journal of Thermal Biology*, **37**(1), 56-64. ISSN 0306-4565, doi: 10.1016/j.jtherbio.2011.10.013, `https://www.sciencedirect.com/science/article/pii/S0306456511001513`.

Porter WP, Mitchell JW, Bekman A, DeWitt CB (1973). "Behavioral implications of mechanistic ecology: thermal and behavioral modeling of desert ectotherms and their microenvironments." *Oecologia*, **13**, 1-54.

See Also

Other biophysical models: `Grashof_number_Gates()`, `Grashof_number()`, `Nusselt_from_Grashof()`, `Nusselt_from_Reynolds()`, `Nusselt_number()`, `Prandtl_number()`, `Qconduction_animal()`, `Qconduction_substrate()`, `Qconvection()`, `Qemitted_thermal_radiation()`, `Qevaporation()`, `Qmetabolism_from_mass_temp()`, `Qmetabolism_from_mass()`, `Qnet_Gates()`, `Qradiation_absorbed()`, `Qthermal_radiation_absorbed()`, `Reynolds_number()`, `Tb_CampbellNorman()`, `Tb_Gates2()`, `Tb_Gates()`, `Tb_butterfly()`, `Tb_grasshopper()`, `Tb_limpetBH()`, `Tb_limpet()`, `Tb_lizard()`, `Tb_mussel()`, `Tb_salamander_humid()`, `Tb_snail()`, `Tbed_mussel()`, `Tsoil()`, `actual_vapor_pressure()`, `boundary_layer_resistance()`, `external_resistance_to_water_vapor_transfer()`, `free_or_forced_convection`
`heat_transfer_coefficient_approximation()`, `heat_transfer_coefficient_simple()`, `heat_transfer_coeffici`
`saturation_vapor_pressure()`, `saturation_water_vapor_pressure()`

Examples

```
Tb_lizard_Fei(T_a       = 293,
              T_g       = 300,
              H         = 1300,
              lw        = 60,
              shade     = 0.5,
              m         = 10.5,
              Acondfact = 0.1,
              Agradfact = 0.3)
```

Tb_mussel *Operative Environmental Temperature of a Mussel*

Description

The function estimates body temperature (C, operative environmental temperature) of a mussel. The function implements a steady-state model, which assumes unchanging environmental conditions.

Usage

```
Tb_mussel(l, h, T_a, T_g, S, k_d, u, psi, cl, evap = FALSE, group = "solitary")
```

Arguments

l	`numeric` mussel length (anterior/posterior axis, m).
h	`numeric` mussel height (dorsal/ventral axis, m). It is reasonable to assume `h = 0.5 * l`.
T_a	`numeric` air temperature (C).
T_g	`numeric` ground temperature (C).
S	`numeric` direct solar flux density (Wm^-2).
k_d	`numeric` diffuse fraction, proportion of solar radiation that is diffuse.
u	`numeric` wind speed (ms^-1).
psi	`numeric` solar zenith angle (degrees): can be calculated from `zenith_angle`.
cl	`numeric` fraction of the sky covered by cloud.
evap	`logical` Whether mussel is gaping to evaporatively cool. If `TRUE`, the function assumes a constant mass loss rate of 5 percent of the initial body mass per hour.
group	`character`; options are `"aggregated"`: mussels living in beds; `"solitary"`: solitary individual, anterior or posterior end facing upwind; and `"solitary_valve"`: solitary individual, valve facing upwind.

Details

Thermal radiative flux is calculated following Helmuth (1998), Helmuth (1999), and Idso and Jackson (1969).

Value

`numeric` predicted body (operative environmental) temperature (C).

References

Helmuth B (1999). "Thermal biology of rocky intertidal mussels: quantifying body temperatures using climatological data." *Ecology*, **80**(1), 15-34. doi: 10.1890/00129658(1999)080[0015:TBORIM]2.0.CO;2, `https://doi.org/10.1890/0012-9658(1999)080[0015:TBORIM]2.0.CO;2`.

Helmuth BST (1998). "Intertidal Mussel Microclimates: Predicting the Body Temperature of a Sessile Invertebrate." *Ecological Monographs*, **68**(1), 51–74. ISSN 00129615, doi: 10.2307/2657143.

Idso SB, Jackson RD (1969). "Thermal radiation from the atmosphere." *Journal of Geophysical Research (1896-1977)*, **74**(23), 5397-5403. doi: 10.1029/JC074i023p05397.

See Also

Other biophysical models: `Grashof_number_Gates()`, `Grashof_number()`, `Nusselt_from_Grashof()`, `Nusselt_from_Reynolds()`, `Nusselt_number()`, `Prandtl_number()`, `Qconduction_animal()`, `Qconduction_substrate()`, `Qconvection()`, `Qemitted_thermal_radiation()`, `Qevaporation()`, `Qmetabolism_from_mass_temp()`, `Qmetabolism_from_mass()`, `Qnet_Gates()`, `Qradiation_absorbed()`, `Qthermal_radiation_absorbed()`, `Reynolds_number()`, `Tb_CampbellNorman()`, `Tb_Gates2()`, `Tb_Gates()`, `Tb_butterfly()`, `Tb_grasshopper()`, `Tb_limpetBH()`, `Tb_limpet()`, `Tb_lizard_Fei()`, `Tb_lizard()`, `Tb_salamander_humid()`, `Tb_snail()`, `Tbed_mussel()`, `Tsoil()`, `actual_vapor_pressure()`, `boundary_layer_resistance()`, `external_resistance_to_water_vapor_transfer()`, `free_or_forced_convection`, `heat_transfer_coefficient_approximation()`, `heat_transfer_coefficient_simple()`, `heat_transfer_coeffici`, `saturation_vapor_pressure()`, `saturation_water_vapor_pressure()`

Examples

```
Tb_mussel(l     = 0.1,
          h     = 0.05,
          T_a   = 25,
          T_g   = 30,
          S     = 500,
          k_d   = 0.2,
          u     = 2,
          psi   = 30,
          evap  = FALSE,
          cl    = 0.5,
          group = "solitary")
```

`Tb_salamander_humid` *Humid Operative Environmental Temperature of a Salamander*

Description

The function estimates the humid body temperature (C, operative environmental temperature) using an adaptation of Campbell and Norman (1998) described in Riddell et al. (2018).

Usage

```
Tb_salamander_humid(r_i, r_b, D, T_a, elev, e_a, e_s, Qabs, epsilon = 0.96)
```

Arguments

`r_i`	`numeric` internal (skin) resistance $(scm^{-}1)$.
`r_b`	`numeric` boundary layer resistance $(scm^{-}1)$.
`D`	`numeric` body diameter (m); can estimate as diameter = 0.0016*log(mass) + 0.0061 for mass(g).
`T_a`	`numeric` ambient temperature (C).
`elev`	`numeric` elevation (m).
`e_a`	`numeric` actual vapor pressure (kPa).
`e_s`	`numeric` saturation vapor pressure (kPa).
`Qabs`	`numeric` Solar and thermal radiation absorbed (W).
`epsilon`	`numeric` emissivity of salamander skin (proportion).

Value

`numeric` humid operative temperature (C).

Author(s)

Eric Riddell

References

Campbell GS, Norman JM (1998). *Introduction to environmental biophysics*, 2nd ed. edition. Springer, New York. ISBN 0387949372.

Riddell EA, Odom JP, Damm JD, Sears MW (2018). “Plasticity reveals hidden resistance to extinction under climate change in the global hotspot of salamander diversity.” *Science Advances*, **4**(4). doi: 10.1126/sciadv.aar5471.

See Also

Other biophysical models: `Grashof_number_Gates()`, `Grashof_number()`, `Nusselt_from_Grashof()`, `Nusselt_from_Reynolds()`, `Nusselt_number()`, `Prandtl_number()`, `Qconduction_animal()`, `Qconduction_substrate()`, `Qconvection()`, `Qemitted_thermal_radiation()`, `Qevaporation()`, `Qmetabolism_from_mass_temp()`, `Qmetabolism_from_mass()`, `Qnet_Gates()`, `Qradiation_absorbed()`, `Qthermal_radiation_absorbed()`, `Reynolds_number()`, `Tb_CampbellNorman()`, `Tb_Gates2()`, `Tb_Gates()`, `Tb_butterfly()`, `Tb_grasshopper()`, `Tb_limpetBH()`, `Tb_limpet()`, `Tb_lizard_Fei()`, `Tb_lizard()`, `Tb_mussel()`, `Tb_snail()`, `Tbed_mussel()`, `Tsoil()`, `actual_vapor_pressure()`, `boundary_layer_resistance()`, `external_resistance_to_water_vapor_transfer()`, `free_or_forced_convection`
`heat_transfer_coefficient_approximation()`, `heat_transfer_coefficient_simple()`, `heat_transfer_coeffici`
`saturation_vapor_pressure()`, `saturation_water_vapor_pressure()`

Examples

```
Tb_salamander_humid(r_i     = 4,
                    r_b     = 1,
                    D       = 0.01,
                    T_a     = 20,
                    elev    = 500,
                    e_a     = 2.0,
                    e_s     = 2.5,
                    Qabs    = 400,
                    epsilon = 0.96)
```

`Tb_snail` *Operative Environmental Temperature of a Marine Snail*

Description

The function estimates body temperature (C, operative environmental temperature) of a marine snail. The function implements a steady-state model, which assumes unchanging environmental conditions and is based on (Iacarella and Helmuth 2012). Body temperature and desiccation constrain the activity of Littoraria irrorata within the Spartina alterniflora canopy. The function was provided by Brian Helmuth and is a simplified version of the published model.

Usage

```
Tb_snail(temp, l, solar, WS, CC, WL, WSH)
```

Arguments

`temp`	`numeric` air temperature (C).
`l`	`numeric` snail length (m).
`solar`	`numeric` direct solar flux density (Wm^-2).
`WS`	`numeric` wind speed (ms^-1).
`CC`	`numeric` fraction of the sky covered by cloud (0-1).
`WL`	`numeric` water loss rate (kgs^-1), 5 percent loss of body mass over one hour is a reasonable maximum level (Helmuth 1999).
`WSH`	`numeric` wind sensor height (m).

Details

Thermal radiative flux is calculated following Helmuth (1998), Helmuth (1999), and Idso and Jackson (1969).

Value

`numeric` predicted body (operative environmental) temperature (C).

Author(s)

Brian Helmuth et al.

References

Helmuth B (1999). "Thermal biology of rocky intertidal mussels: quantifying body temperatures using climatological data." *Ecology*, **80**(1), 15-34. doi: 10.1890/00129658(1999)080[0015:TBORIM]2.0.CO;2, https://doi.org/10.1890/0012-9658(1999)080[0015:TBORIM]2.0.CO;2.

Helmuth BST (1998). "Intertidal Mussel Microclimates: Predicting the Body Temperature of a Sessile Invertebrate." *Ecological Monographs*, **68**(1), 51–74. ISSN 00129615, doi: 10.2307/2657143.

Iacarella J, Helmuth B (2012). "Body temperature and desiccation constrain the activity of Littoraria irrorata within the Spartina alterniflora canopy." *Journal of Thermal Biology*, **37**(1). doi: 10.1016/j.jtherbio.2011.10.003, https://www.researchgate.net/publication/238501940_Body_temperature_and_desiccation_constrain_the_activity_of_Littoraria_irrorata_within_the_Spartina_alterniflora_canopy.

Idso SB, Jackson RD (1969). "Thermal radiation from the atmosphere." *Journal of Geophysical Research (1896-1977)*, **74**(23), 5397-5403. doi: 10.1029/JC074i023p05397.

See Also

Other biophysical models: `Grashof_number_Gates()`, `Grashof_number()`, `Nusselt_from_Grashof()`, `Nusselt_from_Reynolds()`, `Nusselt_number()`, `Prandtl_number()`, `Qconduction_animal()`, `Qconduction_substrate()`, `Qconvection()`, `Qemitted_thermal_radiation()`, `Qevaporation()`, `Qmetabolism_from_mass_temp()`, `Qmetabolism_from_mass()`, `Qnet_Gates()`, `Qradiation_absorbed()`, `Qthermal_radiation_absorbed()`, `Reynolds_number()`, `Tb_CampbellNorman()`, `Tb_Gates2()`, `Tb_Gates()`, `Tb_butterfly()`, `Tb_grasshopper()`, `Tb_limpetBH()`, `Tb_limpet()`, `Tb_lizard_Fei()`, `Tb_lizard()`, `Tb_mussel()`, `Tb_salamander_humid()`, `Tbed_mussel()`, `Tsoil()`, `actual_vapor_pressure()`, `boundary_layer_resistance()`, `external_resistance_to_water_vapor_transfer()`, `free_or_forced_convection`
`heat_transfer_coefficient_approximation()`, `heat_transfer_coefficient_simple()`, `heat_transfer_coeffici`
`saturation_vapor_pressure()`, `saturation_water_vapor_pressure()`

Examples

```
Tb_snail(temp  = 25,
         l     = 0.012,
         solar = 800,
         WS    = 1,
         CC    = 0.5,
         WL    = 0,
         WSH   = 10)
```

`temperature conversions`

Convert Among Temperature Scales

Description

The function converts temperatures among Celsius, Fahrenheit, and Kelvin (J. Blischak et al. 2016).

Usage

```
fahrenheit_to_kelvin(temperature)

kelvin_to_celsius(temperature)

celsius_to_kelvin(temperature)

fahrenheit_to_celsius(temperature)
```

Arguments

`temperature`	`numeric` temperature (Celsius, Fahrenheit, or Kelvin).

Value

`numeric` temperature (Celsius, Fahrenheit, or Kelvin).

References

J. Blischak, D. Chen, H. Dashnow, Haine D (2016). *Software Carpentry: Programming with R*. doi: 10.5281/zenodo.57541, Version 2016.06, June 2016.

See Also

Other utility functions: `airpressure_from_elev()`, `azimuth_angle()`, `day_of_year()`, `daylength()`, `dec_angle()`, `solar_noon()`, `zenith_angle()`

Examples

```
kelvin_to_celsius(temperature = 270)
fahrenheit_to_kelvin(temperature = 85)
fahrenheit_to_celsius(temperature = 85)
celsius_to_kelvin(temperature = -10)
```

TPC *Gaussian-Quadratic Function Thermal Performance Curve*

Description

The function constructs a thermal performance curve by combining as a Gaussian function to describe the rise in performance up to the optimal temperature and a quadratic decline to zero performance at critical thermal maxima and higher temperatures (Deutsch et al. 2008).

Usage

```
TPC(T_b, T_opt, CT_min, CT_max)
```

Arguments

T_b	numeric vector of temperature range (C).
T_opt	numeric thermal optima (C), the temperature at which peak performance occurs.
CT_min, CT_max	numeric critical thermal minimum and maximum (C), the lower and upper temperature limits for performance.

Value

performance

References

Deutsch CA, Tewksbury JJ, Huey RB, Sheldon KS, Ghalambor CK, Haak DC, Martin PR (2008). “Impacts of climate warming on terrestrial ectotherms across latitude.” *Proceedings of the National Academy of Science of the United States of America*, **105**, 6668-6672. doi: 10.1073/pnas.0709472105.

Examples

```
TPC(T_b    = 0:60,
    T_opt  = 30,
    CT_min = 10,
    CT_max = 40)
```

`TPC_beta` *Beta Function Thermal Performance Curve*

Description

The function constructs a thermal performance curve based on a beta function (Asbury and Angilletta 2010).

Usage

```
TPC_beta(T_b, shift = -1, breadth = 0.1, aran = 0, tolerance = 43, skew = 0.7)
```

Arguments

`T_b`	`numeric` temperature (C).
`shift`	`numeric` mode of the thermal performance curve.
`breadth`	`numeric` breadth of the thermal performance curve.
`aran`	`numeric` scale performance value. If `0`, no scaling; if `1`, include a thermodynamic effect on mean performance.
`tolerance`	`numeric` maximal breath (C) of the thermal performance curve.
`skew`	`numeric` skewness of the thermal performance curve (0-1).

Value

`numeric` performance.

References

Asbury DA, Angilletta MJ (2010). "Thermodynamic effects on the evolution of performance curves." *American Naturalist*, **176**(2), E40-E49. doi: 10.1086/653659.

Examples

```
TPC_beta(T_b       = 0:60,
         shift     = -1,
         breadth   = 0.1,
         aran      = 0,
         tolerance = 43,
         skew      = 0.7)
```

`TrenchR` *Tools for Microclimate and Biophysical Ecology*

Description

Tools for translating environmental change into organismal response. Microclimate models to vertically scale weather station data to organismal heights. The biophysical modeling tools include both general models for heat flows and specific models to predict body temperatures for a variety of ectothermic taxa. Additional functions model and temporally partition air and soil temperatures and solar radiation. Utility functions estimate the organismal and environmental parameters needed for biophysical ecology. 'TrenchR' focuses on relatively simple and modular functions so users can create transparent and flexible biophysical models. Many functions are derived from Gates (1980) and Campbell and Norman (1988).

`Tsoil` *Approximate Soil Temperature*

Description

The function estimates soil temperature (C) at a given depth and hour by approximating diurnal variation as sinusoidal. The function is adapted from Campbell and Norman (1998) and described in Riddell et al. (2018).

Usage

```
Tsoil(T_g_max, T_g_min, hour, depth)
```

Arguments

`T_g_max`	`numeric` daily maximum soil surface temperature (C).
`T_g_min`	`numeric` daily minimum soil surface temperature (C).
`hour`	`numeric` hour of the day.
`depth`	`numeric` depth (cm).

Value

`numeric` soil temperature (C).

Author(s)

Eric Riddell

References

Campbell GS, Norman JM (1998). *Introduction to environmental biophysics*, 2nd ed. edition. Springer, New York. ISBN 0387949372.

Riddell EA, Odom JP, Damm JD, Sears MW (2018). "Plasticity reveals hidden resistance to extinction under climate change in the global hotspot of salamander diversity." *Science Advances*, **4**(4). doi: 10.1126/sciadv.aar5471.

See Also

Other biophysical models: `Grashof_number_Gates()`, `Grashof_number()`, `Nusselt_from_Grashof()`, `Nusselt_from_Reynolds()`, `Nusselt_number()`, `Prandtl_number()`, `Qconduction_animal()`, `Qconduction_substrate()`, `Qconvection()`, `Qemitted_thermal_radiation()`, `Qevaporation()`, `Qmetabolism_from_mass_temp()`, `Qmetabolism_from_mass()`, `Qnet_Gates()`, `Qradiation_absorbed()`, `Qthermal_radiation_absorbed()`, `Reynolds_number()`, `Tb_CampbellNorman()`, `Tb_Gates2()`, `Tb_Gates()`, `Tb_butterfly()`, `Tb_grasshopper()`, `Tb_limpetBH()`, `Tb_limpet()`, `Tb_lizard_Fei()`, `Tb_lizard()`, `Tb_mussel()`, `Tb_salamander_humid()`, `Tb_snail()`, `Tbed_mussel()`, `actual_vapor_pressure()`, `boundary_layer_resistance()`, `external_resistance_to_water_vapor_transfer()`, `free_or_forced_convection`
`heat_transfer_coefficient_approximation()`, `heat_transfer_coefficient_simple()`, `heat_transfer_coeffici`
`saturation_vapor_pressure()`, `saturation_water_vapor_pressure()`

Examples

```
Tsoil(T_g_max = 30,
      T_g_min = 15,
      hour    = 12,
      depth   = 5)
```

`VAPPRS` *Saturation Vapor Pressure*

Description

The function calculates saturation vapor pressure for a given air temperature. The program is based on equations from List (1971) and code implementation from NicheMapR (Kearney and Porter 2017; Kearney and Porter 2020).

Usage

```
VAPPRS(db)
```

Arguments

db	`numeric` Dry bulb temperature (C)

Value

esat `numeric` Saturation vapor pressure (Pa)

References

Kearney MR, Porter WP (2017). "NicheMapR - an R package for biophysical modelling: the microclimate model." *Ecography*, **40**, 664-674. doi: 10.1111/ecog.02360.

Kearney MR, Porter WP (2020). "NicheMapR - an R package for biophysical modelling: the ectotherm and Dynamic Energy Budget models." *Ecography*, **43**(1), 85-96. doi: 10.1111/ecog.04680.

List RJ (1971). "Smithsonian Meteorological Tables." *Smithsonian Miscellaneous Collections*, **114**(1), 1-527. `https://repository.si.edu/handle/10088/23746`.

Examples

```
VAPPRS(db = 30)
```

`volume_from_length` *Organism Volume from Length*

Description

The function estimates volume (m^3) from length (m) for a variety of taxa following Mitchell (1976).

Usage

```
volume_from_length(l, taxon)
```

Arguments

`l`	`numeric` length (m). Use snout-vent length for lizards and frogs.
`taxon`	`character` taxon of organism, current choices: `"lizard"`, `"frog"`, `"sphere"`.

Details

Relationships come from

- Lizards: Norris (1965)
- Frogs: Tracy (1972)
- Sphere: Mitchell (1976)

Value

`numeric` volume (m^3).

References

Mitchell JW (1976). "Heat transfer from spheres and other animal forms." *Biophysical Journal*, **16**(6), 561-569. ISSN 0006-3495, doi: 10.1016/S00063495(76)857116, `https://www.sciencedirect.com/science/article/pii/S0006349576857116`.

Norris KS (1965). "Color adaptation in desert reptiles and its thermal relationships." In *Symposium on Lizard Ecology*, 162- 229. U. Missouri Press.

Tracy CR (1972). "Newton's Law: Its Application for Expressing Heat Losses from Homeotherms." *BioScience*, **22**(11), 656-659. ISSN 0006-3568, doi: 10.2307/1296267.

See Also

Other allometric functions: `mass_from_length()`, `proportion_silhouette_area_shapes()`, `proportion_silhouette_a` `surface_area_from_length()`, `surface_area_from_mass()`, `surface_area_from_volume()`

Examples

```
volume_from_length(l     = 0.05,
                   taxon = "lizard")
volume_from_length(l     = 0.05,
                   taxon = "frog")
volume_from_length(l     = 0.05,
                   taxon = "sphere")
```

`WETAIR` *Properties of Wet Air*

Description

The function calculates several properties of humid air described as output variables below. The program is based on equations from List (1971) and code implementation from NicheMapR (Kearney and Porter 2017; Kearney and Porter 2020).
WETAIR must be used in conjunction with `VAPPRS`. Input variables are shown below. See Details.

Usage

```
WETAIR(db, wb = db, rh = 0, dp = 999, bp = 101325)
```

Arguments

`db`	`numeric` dry bulb temperature (C).
`wb`	`numeric` wet bulb temperature (C).
`rh`	`numeric` relative humidity (%).
`dp`	`numeric` dew point temperature (C).
`bp`	`numeric` barometric pressure (Pa).

Details

The user must supply known values for DB and BP (BP at one standard atmosphere is 101,325 pascals). Values for the remaining variables are determined by whether the user has either (1) psychrometric data (WB or RH), or (2) hygrometric data (DP):

- Psychrometric data: If WB is known but not RH, then set RH = -1 and DP = 999. If RH is known but not WB then set WB = 0 and DP = 999
- Hygrometric data: If DP is known, set WB = 0 and RH = 0

Value

Named `list` with elements

- `e`: `numeric` saturation vapor pressure (Pa)
- `vd`: `numeric` vapor density (kgm^-3)
- `rw`: `numeric` mixing ratio ($kgkg^-1$)
- `tvir`: `numeric` virtual temperature (K)
- `tvinc`: `numeric` virtual temperature increment (K)
- `denair`: `numeric` density of the air (kgm^-3)
- `cp`: `numeric` specific heat of air at constant pressure (Jkg^-1K^-1)
- `wtrpot`: `numeric` water potential (Pa)
- `rh`: `numeric` relative humidity (%)

References

Kearney MR, Porter WP (2017). "NicheMapR - an R package for biophysical modelling: the microclimate model." *Ecography*, **40**, 664-674. doi: 10.1111/ecog.02360.

Kearney MR, Porter WP (2020). "NicheMapR - an R package for biophysical modelling: the ectotherm and Dynamic Energy Budget models." *Ecography*, **43**(1), 85-96. doi: 10.1111/ecog.04680.

List RJ (1971). "Smithsonian Meteorological Tables." *Smithsonian Miscellaneous Collections*, **114**(1), 1-527. https://repository.si.edu/handle/10088/23746.

Examples

```
WETAIR(db = 30,
       wb = 28,
       rh = 60,
       bp = 100 * 1000)
```

wind_speed_profile_neutral

Wind Speed at a Specific Height Under Neutral Conditions

Description

The function calculates wind speed (ms^-1) at a specified height (m) within a boundary layer near the surface. The profile assumes neutral conditions. The velocity profile is the neutral profile described by Sellers (1965). Function is equations (2) and (3) of Porter et al. (1973).

Usage

```
wind_speed_profile_neutral(u_r, zr, z0, z)
```

Arguments

`u_r`	`numeric` wind velocity (ms^-1) at reference height.
`zr`	`numeric` initial reference height (m).
`z0`	`numeric` surface roughness (m).
`z`	`numeric` height to scale (m).

Value

`numeric` windspeed (ms^-1).

References

Porter WP, Mitchell JW, Bekman A, DeWitt CB (1973). "Behavioral implications of mechanistic ecology: thermal and behavioral modeling of desert ectotherms and their microenvironments." *Oecologia*, **13**, 1-54.

Sellers WD (1965). *Physical climatology*. University of Chicago Press, Chicago, IL, USA.

See Also

Other microclimate functions: `air_temp_profile_neutral()`, `air_temp_profile_segment()`, `air_temp_profile()`, `degree_days()`, `direct_solar_radiation()`, `diurnal_radiation_variation()`, `diurnal_temp_variation_sineexp()`, `diurnal_temp_variation_sinesqrt()`, `diurnal_temp_variation_sine()`, `monthly_solar_radiation()`, `partition_solar_radiation()`, `proportion_diffuse_solar_radiation()`, `solar_radiation()`, `surface_roughness()`, `wind_speed_profile_segment()`

Examples

```
wind_speed_profile_neutral(u_r = 0.1,
                           zr  = 0.1,
                           z0  = 0.2,
                           z   = 0.15)
```

`wind_speed_profile_segment` *Wind Speed at a Specified Height*

Description

The function calculates wind speed (ms^-1) at a specified height (m). The function estimates a three segment velocity and temperature profile based on user-specified, experimentally determined values for 3 roughness heights and reference heights. Multiple heights are appropriate in heterogenous areas with, for example, a meadow, bushes, and rocks. Implements the MICROSEGMT routine from NicheMapR as described in Kearney and Porter (2017).

Usage

```
wind_speed_profile_segment(u_r, zr, z0, z)
```

Arguments

`u_r`	`numeric` a vector of wind speeds (ms^-1) at the 3 reference heights.
`zr`	`numeric` a vector of 3 reference heights (m).
`z0`	`numeric` a vector of 3 experimentally determined roughness heights (m).
`z`	`numeric` height to scale (m).

Value

`numeric` wind speed (ms^-1).

References

Kearney MR, Porter WP (2017). "NicheMapR - an R package for biophysical modelling: the microclimate model." *Ecography*, **40**, 664-674. doi: 10.1111/ecog.02360.

See Also

Other microclimate functions: `air_temp_profile_neutral()`, `air_temp_profile_segment()`, `air_temp_profile()`, `degree_days()`, `direct_solar_radiation()`, `diurnal_radiation_variation()`, `diurnal_temp_variation_sineexp()`, `diurnal_temp_variation_sinesqrt()`, `diurnal_temp_variation_sine()`, `monthly_solar_radiation()`, `partition_solar_radiation()`, `proportion_diffuse_solar_radiation()`, `solar_radiation()`, `surface_roughness()`, `wind_speed_profile_neutral()`

Examples

```
wind_speed_profile_segment(u_r = c(0.01, 0.025, 0.05),
                           zr  = c(0.05, 0.25, 0.5),
                           z0  = c(0.01, 0.15, 0.2),
                           z   = 0.3)
```

zenith_angle *Zenith Angle*

Description

The function calculates the zenith angle, the location of the sun as an angle (in degrees) measured from vertical (Campbell and Norman 1998).

Usage

```
zenith_angle(doy, lat, lon, hour, offset = NA)
```

Arguments

`doy`	`numeric` day of year (1-366). This can be obtained from standard date via `day_of_year`.
`lat`	`numeric` latitude (decimal degrees).
`lon`	`numeric` longitude (decimal degrees).
`hour`	`numeric` hour of the day.
`offset`	`numeric` the number of hours to add to UTC (Coordinated Universal Time) to get local time (improves accuracy but not always necessary). Optional. Defaults to NA.

Value

`numeric` zenith angle (degrees)

References

Campbell GS, Norman JM (1998). *Introduction to environmental biophysics*, 2nd ed. edition. Springer, New York. ISBN 0387949372.

See Also

Other utility functions: `airpressure_from_elev()`, `azimuth_angle()`, `day_of_year()`, `daylength()`, `dec_angle()`, `solar_noon()`, `temperature conversions`

Examples

```
zenith_angle(doy  = 112,
             lat  = 47.61,
             lon  = -122.33,
             hour = 12)
```

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