

Package ‘palinsol’

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Depends R (>= 2.10), stats, graphics

Suggests gsl

Description

R package to compute Incoming Solar Radiation (insolation) for palaeoclimate studies. Features three solutions: Berger (1978), Berger and Loutre (1991) and Laskar et al. (2004). Computes daily-mean, season-averaged and annual means and for all latitudes, and polar night dates.

License file LICENSE

LazyData true

KeepSource true

Encoding UTF-8

URL <https://github.com/mcrucifix/palinsol>

BugReports <https://github.com/mcrucifix/palinsol/issues>

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AnnualMean	<i>Annual Mean insolation</i>
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Description

Compute annual mean insolation for a given orbit and solar constant

Usage

```
AnnualMean(orbit, S0 = 1365, lats = seq(-90, 90, 1), degree = TRUE)
```

Arguments

orbit	Output from a solution, such as ber78, ber90 or la04
S0	Total solar irradiance
lats	list of latitudes at which annual mean is computed
degree	true if latitudes are provided in degrees

Value

an object of class "AnnualMean" with annual mean insolutions

astro	<i>Compute astronomical parameters in the past or in the future</i>
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Description

–

Usage

```
astro(t, solution = ber78, degree = FALSE)
```

Arguments

t	Time, years after 1950
solution	solution used. One of ber78, ber90 or la04
degree	returns angles in degrees if TRUE

Details

Both ber78 and ber90 compute astronomical elements based on a spectral decomposition (sum of sines and cosines) of obliquity and planetary precession parameters. ber78 uses the Berger (1978) algorithm and is accurate for +/- 1e6 years about the present. ber90 uses the Berger and Loutre (1991) algorithm and is accurate for +/- 3e6 years about the present (but with a tiny accuracy over the last 50 kyr, usually negligible for any palaeo application, see example below).

la04 interpolates tables provided by Laskar (2004), obtained by a symplectic numerical integration of the planetary system, in which the Moon is considered as a planet. This solution is valid for about 50 Myr around the present.

precession, coprecession and obliquity do as astro, but only return precession (e sin varpi), coprecession (e cos varpi) and obliquity, respectively.

Value

A vector of 3 (la04) or 4 (ber78 and ber90) astronomical elements

eps	obliquity,
ecc	eccentricity and
varpi	true solar longitude of the perihelion.

ber78 and ber90 also return epsp, the Hilbert transform of obliquity (sines changed in cosines in the spectral decomposition).

Angles are returned in radians unless degree=TRUE

Author(s)

Michel Crucifix, U. catholique de Louvain, Belgium.

References

- Berger, A. L. (1978). Long-term variations of daily insolation and Quaternary climatic changes, *J. Atmos. Sci.*, 35, 2362-2367, doi:10.1175/1520-0469(1978)035<2362:LTVODI>2.0.CO;2
- Berger and M.F. Loutre (1991), Insolation values for the climate of the last 10 million years, *Quaternary Science Reviews*, 10, 297 - 317, doi:10.1016/0277-3791(91)90033-Q
- J. Laskar et al. (2004), A long-term numerical solution for the insolation quantities of the Earth, *Astron. Astroph.*, 428, 261-285, doi:10.1051/0004-6361:20041335

Examples

```

## compare the obliquity over the last 2 Myr with the
## three solutions

times <- seq(-2e6,0,1e3)
Obl <- function(t) {c(time=t,ber78=ber78(t)['eps'],
                    ber90=ber90(t)['eps'], la04=la04(t)['eps'])}

Obls <- data.frame(t(sapply(times,Obl)))
## may take about 10 seconds to run
with(Obls, {
  plot(times/1e3, ber78.eps, type='l', xlab='time (kyr)',
        ylab='Obliquity (radians)')
  lines(times/1e3, ber90.eps, type='l', col='red')
  lines(times/1e3, la04.eps, type='l', col='green')
})

legend('topright', c('ber78','ber90','la04'), col=c('black','red','green'),
       lty=1)

## same but with a zoom over the last 300 000 years:

T <- which (times > -3e5)
with(Obls, {
  plot(times[T]/1e3, ber78.eps[T], type='l', xlab='time (kyr)',
        ylab='Obliquity (radians)')
  lines(times[T]/1e3, ber90.eps[T], type='l', col='red')
  lines(times[T]/1e3, la04.eps[T], type='l', col='green')
})

legend('topright', c('ber78','ber90','la04'), col=c('black','red','green'),
       lty=1)

```

BER78

Tables supplied by BER78 and BER90

Description

Tables necessary for computation of astronomical solutions by Berger (1978) or Berger and Loutre (1990).

Usage

```

data(BER78)
data(BER90)

```

Format

text files reproducing the published tables with original units.

Note

Table 2 is reconstructed based on the electronic files supplied by the authors, based on the method provided by Berger and Loutre (1990) below.

Author(s)

Michel Crucifix, UCLouvain, Belgium.

Source

[dx.doi.org/10.5281/zenodo.7198111](https://doi.org/10.5281/zenodo.7198111) and [10.5281/zenodo.7198109](https://doi.org/10.5281/zenodo.7198109)

References

Berger, A. L. (1978). Long-term variations of daily insolation and Quaternary climatic changes, *J. Atmos. Sci.*, 35, 2362-2367, doi:10.1175/1520-0469(1978)035<2362:LTVODI>2.0.CO;2

A. Berger and M. F. Loutre (1990), Origine des fr'equences des `el`ements astronomiques intervenant dans l'insolation, *Bull. Classe des Sciences*, 1-3, 45-106

Berger and M.F. Loutre (1991), Insolation values for the climate of the last 10 million years, *Quaternary Science Reviews*, 10, 297 - 317, doi:10.1016/0277-3791(91)90033-Q

Examples

```
data(BER78)
data(BER90)
```

calins

Caloric insolation

Description

Computes caloric summer insolation for a given astronomical configuration and latitude.

Usage

```
calins(orbit, lat = 65 * pi/180, ...)
```

Arguments

orbit	Output from a solution, such as ber78, ber90 or la04
lat	latitude
...	Other arguments passed to Insol

Details

The caloric summer is a notion introduced by M. Milankovitch. It is defined as the halve of the tropical year during for which daily mean insolation are greater than all days of the other halves. The algorithm is an original algorithm by M. Crucifix, but consistent with earlier definitions and algorithms by A. Berger (see examples). Do not confuse this Berger (1978) reference with the Berger (1978), J. Atm. Sci. of the astronomical solution.

Value

Time-integrated insolation in kJ/m2 during the caloric summer.

Author(s)

Michel Crucifix, U. catholique de Louvain, Belgium.

References

Berger (1978) Long-term variations of caloric insolation resulting from the earth's orbital elements, Quaternary Research, 9, 139 - 167.

Examples

```
## reproduces Table 2 of Berger 1978
lat <- seq(90, 0, -10) * pi/180. ## angles in radians.
orbit_1 = ber78(0)
orbit_2 = orbit_1
orbit_2 ['eps'] = orbit_2['eps'] + 1*pi/180.

T <- sapply(lat, function(x) c(lat = x * 180/pi,
                             calins(orbit_2, lat=x, S0=1365) / (4.18 * 1e1)
                             - calins(orbit_1, lat=x, S0=1365) / (4.18 * 1e1) ))

data.frame(t(T))
# there are still some differences, of the order of 0.3 %, that are probably related to
# the slightly different methods.
# 41.8 is the factor from cal/cm2 to kJ/m2
```

 day2l

Converts calendar day into true solar longitude and vice-versa

Description

Converts calendar day into true solar longitude for a given astronomical configuration and vice-versa

Usage

```
day2l(orbit, day)
```

```
l2day(orbit, l)
```

```
date_of_perihelion(orbit)
```

Arguments

orbit	Output from a solution, such as ber78, ber90 or la04
day	calendar day, in a 360-d year
l	true solar longitude, in radians

Details

The 360-d calendar is a conventional calendar, for which day 80 is the day of NH spring equinox. The tropic year, which in reality is $365.24219876 * 86400$ seconds was the practical reference to define the Gregorian Calendar since this is the time needed to go through all the seasons. More discussion of calendars and conversions in Berger et al. (2010) appendix D.

The day2l and l2day is based on algorithms given in Berger (1978), but which can be traced back to expansions of the mean and true anomaly by Brouwer and Clemente (1961), pp. 65 and 77 (see code for further details).

Value

day of year (360-d cal.) or true solar longitude (in radians).

Functions

- l2day(): Converts true solar longitude into calendar day
- date_of_perihelion(): Returns date of perihelion

Author(s)

Michel Crucifix, U. catholique de Louvain, Belgium.

References

Brouwer D. and G. M. Clemence, (1961), *Methods of celestial mechanics*, Academic Press, New York.

Berger, (1978) Long-term variations of daily insolation and Quaternary climatic changes, *J. Atmos. Sci.*, 35, 2362-2367 1978, doi:10.1175/1520-0469(1978)035<2362:LTVODI>2.0.CO;2

Berger, A. Loutre, M.F. and Yin Q. (2010), Total irradiation during any time interval of the year using elliptic integrals, *Quaternary Science Reviews*, 29, 1968 - 1982, doi:10.1016/j.quascirev.2010.05.007

Examples

```
## date of perihelion throughout today
orbit=c(eps=0.409214, ecc=0.01672393, varpi=4.92251)
date_of_perihelion(orbit)
## date of winter solstice)
l2day(orbit, 270*pi/180.)
```

 Insol

Computes incoming solar radiation (insolation)

Description

Computes incoming solar radiation (insolation) for a given astronomical configuration, true solar longitude and latitude

Usage

```
Insol(orbit, long = pi/2, lat = 65 * pi/180, S0 = 1365, H = NULL)
```

Arguments

orbit	Output from a solution, such as ber78, ber90 or la04
long	true solar longitude
lat	latitude
S0	Total solar irradiance
H	Sun hour angle, in radians

Details

True solar longitude is measured in radians:

pi/2	for June solstice
pi	for September equinox
3 * pi/2	for December solstice
0	for Spring equinox

It may be obtained for a given day in the year using the function day21.

Value

Daily-mean insolation (assuming fixed astronomical parameters during a true solar day) if 'H' is null. Otherwise, insolation at specified hour angle (H = 0 at noon, H = pi at midnight).

Author(s)

Michel Crucifix, U. catholique de Louvain, Belgium.

References

Berger, A. L. (1978). Long-term variations of daily insolation and Quaternary climatic changes, J. Atmos. Sci., 35, 2362-2367.

Examples

```
## make a little wrapper, with all default values

insolation <- function(times, astrosol=ber78,...)
  sapply(times, function(tt) Insol(orbit=astrosol(tt)))

tts <- seq(from = -400e3, to = 0, by = 1e3)
isl <- insolation(tts, ber78)
plot(tts, isl, typ='l')
```

Insol_1112

Time-integrated insolation

Description

Computes time-integrated incoming solar radiation (Insol) either between given true solar longitudes (Insol_1112) or days of year (Insol_d1d2) for a given orbit and latitude

Usage

```
Insol_1112(
  orbit,
  l1 = 0,
  l2 = 2 * pi,
  lat = 65 * pi/180,
  avg = FALSE,
  ell = TRUE,
  ...
)

Insol_d1d2(orbit, d1, d2, lat = 65 * pi/180, avg = FALSE, ...)
```

Arguments

orbit	Output from a solution, such as ber78, ber90 or la04
l1	lower true solar longitude bound of the time-integral
l2	upper true solar longitude bound of the time-integral
lat	latitude
avg	performs a time-average.
ell	uses elliptic integrals for the calculation (much faster)
...	other arguments to be passed to Insol
d1	lower calendar day (360-day year) of the time-integral
d2	upper calendar day (360-day year) of the time-integral

Details

All angles input measured in radians.

Note that in contrast to Berger (2010) we consider the tropic year as the reference, rather than the sidereal year, which partly explains some of the small differences with the original publication

Value

Time-integrated insolation in kJ/m2 if avg=TRUE, else time-average in W/m2

Functions

- Insol_d1d2(): Mean and integrated insolation over an interval bounded by calendar days

Author(s)

Michel Crucifix, U. catholique de Louvain, Belgium.

References

Berger, A., Loutre, M.F. and Yin Q. (2010), Total irradiation during any time interval of the year using elliptic integrals, *Quaternary Science Reviews*, 29, 1968 - 1982, doi:10.1016/j.quascirev.2010.05.007

Examples

```
## reproduces Table 1a of Berger et al. 2010:
lat <- seq(85, -85, -10) * pi/180. ## angles in radians.
orbit=c(eps= 23.446 * pi/180., ecc= 0.016724, varpi= (102.04 - 180)* pi/180. )
T <- sapply(lat, function(x) c(lat = x * 180/pi,
  m1 = Insol_1112(orbit, 0, 70 * pi/180, lat=x, ell= TRUE, S0=1368) / 1e3,
  m2 = Insol_1112(orbit, 0, 70 * pi/180, lat=x, ell=FALSE, S0=1368) / 1e3) )
data.frame(t(T))
## reproduces Table 1b of Berger et al. 2010:
lat <- c(85, 55, 0, -55, -85) * pi/180. ## angles in radians.
T <- sapply(lat, function(x) c(lat = x * 180/pi,
  m1 = Insol_1112(orbit, 30 * pi/180. , 75 * pi/180,
```

```

        lat=x, ell= TRUE, S0=1368) / 1e3,
    m2 = Insol_l1l2(orbit, 30 * pi/180. , 75 * pi/180,
        lat=x, ell=FALSE, S0=1368) / 1e3) )
## reproduces Table 2a of Berger et al. 2010:
lat <- seq(85, -85, -10) * pi/180. ## angles in radians.

## 21 march in a 360-d year. By definition : day 80 = 21 march at 12u
d1 = 79.5
d2 = 79.5 + (10 + 30 + 30 ) * 360/365.2425 ## 30th May in a 360-d year

T <- sapply(lat, function(x) c(lat = x * 180/pi,
    m1 = Insol_d1d2(orbit, d1,d2, lat=x, ell= TRUE, S0=1368) / 1e3,
    m2 = Insol_d1d2(orbit, d1,d2, lat=x, ell= FALSE, S0=1368) / 1e3))

## I did not quite get the same results as on the table
## on this one; probably a matter of calendar
## note : the authors in fact used S0=1368 (pers. comm.)
## 1366 in the paper is a misprint

data.frame(t(T))

## annual mean insolation at 65N North, as a function of the longitude of the perihelion
## (expected to be invariant)

varpis <- seq(0,360,10)*pi/180.
sapply(varpis, function(varpi)
  { orbit=c(eps= 23.446 * pi/180., ecc= 0.016724, varpi= varpi )
    amean <- Insol_l1l2 (orbit, lat=65*pi/180., avg=TRUE)
    return(amean)
  })

```

 LA04

Astronomical elements supplied by Laskar et al. 2004

Description

Astronomical elements (longitude of perihelion, obliquity and eccentricity) supplied by Laskar et al. 2004 by step of 1ka, from -51Ma to present (la04past) and from present to + 21Ma.

Usage

```
data(LA04)
```

Format

text files

Author(s)

Michel Crucifix, U. catholique de Louvain, Belgium.

Source

<http://www.imcce.fr/Equipes/ASD/insola/earth/earth.html>

References

J. Laskar et al., A long-term numerical solution for the insolation quantities of the Earth, *Astron. Astroph.*, 428, 261-285 200

Examples

```
data(LA04)
```

Milankovitch

Milankovitch graph for a given astronomical configuration

Description

Computes the distribution in latitude and longitude of incoming solar radiation, known as a Milankovitch graph, with possibility of plotting with a dedicated plot function

Usage

```
Milankovitch(
  orbit,
  S0 = 1365,
  lat = seq(-pi/2, pi/2, l = 73),
  long = seq(0, 2 * pi, l = 145),
  deg = TRUE
)
```

Arguments

orbit	Output from a solution, such as ber78, ber90 or la04
S0	Total solar irradiance
lat	latitudes, passed as an array
long	true solar longitudes, passed as an array
deg	If true : the axes of the Milankovitch object are expressed in degrees. Inputs are always in radians

Value

A object of Milankovitch class, which may be plotted using the regular plot function

Note

The polar night option may not be bullet-proof for exotic obliquities

Author(s)

Michel Crucifix, U. catholique de Louvain, Belgium.

References

Berger, A. L. (1978). Long-term variations of daily insolation and Quaternary climatic changes, J. Atmos. Sci., 35, 2362-2367.

Examples

```
orbit <- c(eps=0.409214, ecc=0.01672393, varpi=4.92251)
M <- Milankovitch(orbit)
plot(M, plot=contour)
plot(M, plot=contour, month=FALSE)
```

plot.Milankovitch *plot Milankovitch graph*

Description

plot Milankovitch object

Usage

```
## S3 method for class 'Milankovitch'
plot(
  x,
  months = TRUE,
  polar_night = TRUE,
  plot_function = contour,
  col = "black",
  ...
)
```

Arguments

x	Milankovitch object
months	if true : x-axis of the plot indicates months conventionnally defined with the true solar longitude; x-axis is simply the true solar longitude otherwise
polar_night	if true : the polar night zone will be hashed
plot_function	function used to plot the matrix. Typically contour or image but may also be image.plot if using the fields package.
col	main color for positive contours (negative contours are in red)
...	Other arguments passed to plotting function

Author(s)

Michel Crucifix, U. catholique de Louvain, Belgium.

polar_night

Begin and end of the polar night

Description

Provides the true solar longitude (in degrees) of the beginning and end of the polar night for a given latitude and orbit

Usage

```
polar_night(lat, orbit)
```

Arguments

lat latitude

orbit Output from a solution, such as ber78, ber90 or la04

Value

Either a message about the absence of polar night (for specified reasons), or the true solar longitude, in degrees, of the beginning and end of the polar night.

Author(s)

Michel Crucifix, U. catholique de Louvain, Belgium.

References

any standard text book of spherical astronomy

Examples

```
current_orbit <- la04(0)

# polar night at the equator ?
polar_night (0, current_orbit)

# polar night at 80 N ?
polar_night (80*pi/180, current_orbit)

# polar nights expressed as day of year
l2day(current_orbit, polar_night (80*pi/180, current_orbit))
```

thrins *Integrated insolation for all days exceeding a threshold*

Description

Integrated insolation over the part during which daily-mean insolation exceeds a threshold, expressed in W/m²

Usage

```
thrins(lat = 65 * pi/180, orbit, threshold = 400, ...)
```

Arguments

lat	latitude
orbit	Output from a solution, such as ber78, ber90 or la04
threshold	threshold insolation ,in W/m ²
...	other arguments to be passed to Insol

Details

Algorithm is by M. Crucifix, but the idea of thresholded insolation is due to Huybers and Tziperman (2008), reference below.

Value

Time-integrated insolation in kJ/m² . The quantity is calculated by brute-force integration with a 1-degree time-step in true solar longitude and this can be quite slow if long series are to be calculated.

Author(s)

Michel Crucifix, U. catholique de Louvain, Belgium.

References

P. Huybers and E. Tziperman (2008), Integrated summer insolation forcing and 40,000-year glacial cycles: The perspective from an ice-sheet/energy-balance model, *Paleoceanography*, 23.

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