

Package ‘snvecR’

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Title Calculate Earth’s Obliquity and Precession in the Past

Version 3.9.4

Description Easily calculate precession and obliquity from an orbital solution (defaults to ZB18a from Zeebe and Lourens (2019) <[doi:10.1126/science.aax0612](https://doi.org/10.1126/science.aax0612)>) and assumed or reconstructed values for tidal dissipation (Td) and dynamical ellipticity (Ed). This is a translation and adaptation of the 'C'-code in the supplementary material to Zeebe and Lourens (2022) <[doi:10.1029/2021PA004349](https://doi.org/10.1029/2021PA004349)>, with further details on the methodology described in Zeebe (2022) <[doi:10.3847/1538-3881/ac80f8](https://doi.org/10.3847/1538-3881/ac80f8)>. The name of the 'C'-routine is 'snvec', which refers to the key units of computation: spin vector *s* and orbit normal vector *n*.

License GPL (>= 3)

Encoding UTF-8

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Suggests astrochron, ggplot2, tidyr, testthat, roxygen2, knitr, withr, curl, rmarkdown

Imports deSolve, cli (>= 3.4.0), stats, dplyr, tibble, purrr, readr, tidyselect, rlang (>= 0.4.11), glue, tools, backports (>= 1.1.6)

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Depends R (>= 3.6.0)

VignetteBuilder knitr

URL <https://japhir.github.io/snvecR/>, <https://github.com/japhir/snvecR>

BugReports <https://github.com/japhir/snvecR/issues>

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full_ZB18a	<i>Full Astronomical Solution ZB18a for the past 100 Myr</i>
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Description

The HNBODY output of Zeebe & Lourens (2019) after some pre-processing using `prepare_solution()`. The wikipedia page on [Orbital elements](#) describes what the components relate to in order to uniquely specify an orbital plane. The function asks to download the files to the user's cache directory so that they can be accessed more quickly in the future.

Format

`get_solution("full-ZB18a")`:

A data frame with 250,001 rows and 20 columns:

t Time t (days).

time Time in thousands of years (kyr).

aa Semimajor axis a in astronomical units (au).

ee Eccentricity e (unitless).

inc Inclination I (degrees).

lph Longitude of perihelion ϖ (degrees).

lan Longitude of the ascending node Ω (degrees).

arp Argument of perihelion ω (degrees).

mna Mean anomaly M (degrees).

The following columns were computed from the above input with `prepare_solution()`:

lphu Unwrapped longitude of perihelion ϖ (degrees without jumps).

lanu Unwrapped longitude of the ascending node Ω (degrees without jumps).

hh Variable: $e \sin(\varpi)$.

kk Variable: $e \cos(\varpi)$.

pp Variable: $2 \sin(0.5I) \sin(\Omega)$.

qq Variable: $2 \sin(0.5I) \cos(\Omega)$.

cc Helper: $\cos(I)$.

dd Helper: $\cos(I)/2$.

nnx, nny, nnz The x , y , and z -components of the Earth's orbit unit normal vector \vec{n} , normal to Earth's instantaneous orbital plane.

Source

All astronomical solutions by Zeebe can be found on http://www.soest.hawaii.edu/oceanography/faculty/zeebe_files/Astro.html.

They can be loaded into R quickly, using `get_solution()`.

References

Zeebe, R. E., & Lourens, L. J. (2019). Solar System chaos and the Paleocene–Eocene boundary age constrained by geology and astronomy. *Science*, 365(6456), 926–929. doi:10.1126/science.aax0612.

Zeebe, R. E. and Lourens, L. J. (2022). A deep-time dating tool for paleo-applications utilizing obliquity and precession cycles: The role of dynamical ellipticity and tidal dissipation. *Paleoceanography and Paleoclimatology*. doi:10.1029/2021PA004349

See Also

`prepare_solution()`

get_solution	<i>Get an Astronomical Solution</i>
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Description

Download supported astronomical solutions from the web and store it in the user's cache directory. The next use of the function will load the data from the cache rather than downloading it again. This also provides a wrapper for `astrochron::getLaskar()` if one of their supported solutions is specified, but converts the output to a `tibble`. Note that we do not cache these solutions locally, however.

Usage

```
get_solution(  
  astronomical_solution = "full-ZB18a",  
  quiet = FALSE,  
  force = FALSE  
)
```

Arguments

astronomical_solution	Character vector with the name of the desired solution. Defaults to "full-ZB18a".
quiet	Be quiet? <ul style="list-style-type: none">• If TRUE, hide info messages.• If FALSE (the default) print info messages and timing.
force	Force re-downloading the results, even if the solution is saved to the cache.

Value

A [tibble](#) with the astronomical solution (and some preprocessed new columns).

References

Zeebe, R. E., & Lourens, L. J. (2019). Solar System chaos and the Paleocene–Eocene boundary age constrained by geology and astronomy. *Science*, 365(6456), 926–929. doi:[10.1126/science.aax0612](https://doi.org/10.1126/science.aax0612).

Zeebe, R. E. and Lourens, L. J. (2022). A deep-time dating tool for paleo-applications utilizing obliquity and precession cycles: The role of dynamical ellipticity and tidal dissipation. *Paleoceanography and Paleoclimatology*. doi:[10.1029/2021PA004349](https://doi.org/10.1029/2021PA004349)

See Also

[full_ZB18a](#), [ZB17](#), [ZB18a](#), [ZB20](#)

Examples

```
get_solution("full-ZB18a")
get_solution("ZB20a")
get_solution("La11")
```

prepare_solution	<i>Prepare Astronomical Solution</i>
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Description

Calculates helper columns from an astronomical solution input.

Usage

```
prepare_solution(data, quiet = FALSE)
```

Arguments

data	<p>A data frame with the following columns:</p> <ul style="list-style-type: none"> • t Time t (days). • ee Eccentricity e (unitless). • lph Longitude of perihelion ϖ (degrees). • lan Longitude of the ascending node Ω (degrees). • inc Inclination I (degrees). <p>The easiest way to get this is with get_solution().</p>
quiet	<p>Be quiet?</p> <ul style="list-style-type: none"> • If TRUE, hide info messages. • If FALSE (the default) print info messages and timing.

Details

New columns include:

- lphu Unwrapped longitude of perihelion ϖ (degrees without jumps).
- lanu Unwrapped longitude of the ascending node Ω (degrees without jumps).
- hh Variable: $e \sin(\varpi)$.
- kk Variable: $e \cos(\varpi)$.
- pp Variable: $2 \sin(0.5I) \sin(\Omega)$.
- qq Variable: $2 \sin(0.5I) \cos(\Omega)$.
- cc Helper: $\cos(I)$.
- dd Helper: $\cos(I)/2$.
- nnx, nny, nnz The x , y , and z -components of the Earth's orbit unit normal vector \vec{n} , normal to Earth's instantaneous orbital plane.

Value

A [tibble](#) with the new columns added.

See Also

[get_solution\(\)](#)

snvec

Calculate Earth's Obliquity and Precession in the Past

Description

snvec() computes climatic precession and obliquity (or tilt) from an astronomical solution (AS) input and input values for dynamical ellipticity (E_d) and tidal dissipation (T_d). It solves a set of ordinary differential equations.

Usage

```
snvec(
  tend = -1000,
  ed = 1,
  td = 0,
  astronomical_solution = "full-ZB18a",
  os_ref_frame = "HCI",
  os_omt = NULL,
  os_inct = NULL,
  tres = -0.4,
  atol = 1e-05,
  rtol = 0,
  solver = "vode",
```

```

  quiet = FALSE,
  output = "nice"
)

```

Arguments

tend	Final timestep in thousands of years (kyr). Defaults to -1000 kyr.
ed	Dynamical ellipticity E_d , normalized to modern. Defaults to 1.0 .
td	Tidal dissipation T_d , normalized to modern. Defaults to 0.0 .
astronomical_solution	Character vector with the name of the desired solution. Defaults to "full-ZB18a".
os_ref_frame	Character vector with the reference frame of the astronomical solution. Either "HCI" for heliocentric inertial reference frame or "J2000" for ecliptic J2000 reference frame. Defaults to "HCI" for HNBody output.
os_omt	Longitude of ascending node of the solar equator relative to ECLIPJ2000.
os_inct	Inclination of the solar equator relative to ECLIPJ2000.
tres	Output timestep resolution in thousands of years (kyr). Defaults to -0.4 . To determine the sign, think of from 0 to $tend$ by timestep $tres$.
atol	Numerical absolute tolerance passed to <code>deSolve::ode()</code> 's <code>atol</code> . Defaults to $1e-5$.
rtol	Numerical relative tolerance passed to <code>deSolve::ode()</code> 's <code>rtol</code> . Defaults to 0 .
solver	Character vector specifying the method passed to <code>deSolve::ode()</code> 's <code>method</code> . Defaults to "vode" for stiff problems with a variable timestep.
quiet	Be quiet? <ul style="list-style-type: none"> • If TRUE, hide info messages. • If FALSE (the default) print info messages and timing.
output	Character vector with name of desired output. One of: <ul style="list-style-type: none"> • "nice" (the default) A <code>tibble</code> with the columns <code>time</code>, <code>eei</code>, <code>ep1</code>, <code>phi</code>, <code>cp</code>. • "full" A <code>tibble</code> with all the computed and interpolated columns. • "ode" A matrix with the output of the ODE solver.

Details

This is a re-implementation of the C-code in the supplementary information of Zeebe & Lourens (2022). The terms are explained in detail in Zeebe (2022).

Value

`snvec()` returns different output depending on the `output` argument.

If `output = "nice"` (the default), returns a `tibble` with the following columns:

- `time` Time in thousands of years (kyr).
- `ep1` Calculated Obliquity ϵ (radians).
- `phi` Calculated Precession ϕ (radians) from ECLIPJ2000.

- cp Calculated Climatic precession (-) as $e \sin \bar{\omega}$.

where $\bar{\omega}$ is the longitude of perihelion relative to the moving equinox.

If output = "all" (for developers), additional columns are included, typically interpolated to output timescale.

- sx, sy, sz The x , y , and z -components of Earth's spin axis unit vector \vec{s} in the heliocentric inertial reference frame.

See the source code for descriptions of all the intermediate computational steps.

If output = "ode", it will return the raw output of the ODE solver, which is an object of class `deSolve` and `matrix`, with columns `time`, `sx`, `sy`, and `sz`. This can be useful for i.e. `deSolve::diagnostics()`.

Reference Frames of Astronomical Solutions

NASA provides their asteroid and planet positions in the ecliptic J2000 reference frame, while long-term astronomical solution integrations are often performed in the heliocentric inertial reference frame (HCI) or in the inertial reference frame. This is to align the reference frame with the spin vector of the Sun, making J2 corrections intuitive to implement.

Obliquity is typically given in the ecliptic reference frame, so `snvec` converts all outputs to J2000 if the `os_ref_frame` is equal to "HCI" and does no transformations if it is already in "J2000".

For this, it uses $\Omega_{\odot} = 75.5940$ and $i_{\odot} = 7.155$ as in Zeebe (2017). You can overwrite these defaults with `os_omt` and `os_inct` if desired.

ODE Solver

Note that the different ODE solver algorithm we use (Soetaert et al., 2010) means that the R routine returns an evenly-spaced time grid, whereas the C-routine has a variable time-step. This means we need to explicitly set the stepsize `tres`.

References

Zeebe, R.E. (2017). Numerical Solutions for the Orbital Motion of the Solar System over the Past 100 Myr: Limits and New Results. *The Astronomical Journal*, 154(5), doi:10.3847/15383881/aa8cce.

Zeebe, R. E., & Lourens, L. J. (2019). Solar System chaos and the Paleocene–Eocene boundary age constrained by geology and astronomy. *Science*, 365(6456), 926–929. doi:10.1126/science.aax0612.

Zeebe, R. E., & Lourens, L. J. (2022). A deep-time dating tool for paleo-applications utilizing obliquity and precession cycles: The role of dynamical ellipticity and tidal dissipation. *Paleoceanography and Paleoclimatology*, e2021PA004349. doi:10.1029/2021PA004349.

Zeebe, R. E. (2022). Reduced Variations in Earth's and Mars' Orbital Inclination and Earth's Obliquity from 58 to 48 Myr ago due to Solar System Chaos. *The Astronomical Journal*, 164(3), doi:10.3847/15383881/ac80f8.

Wikipedia page on Orbital Elements: https://en.wikipedia.org/wiki/Orbital_elements

Karline Soetaert, Thomas Petzoldt, R. Woodrow Setzer (2010). Solving Differential Equations in R: Package `deSolve`. *Journal of Statistical Software*, 33(9), 1–25. doi:10.18637/jss.v033.i09.

See Also

- `deSolve::ode()` from Soetaert et al., (2010) for the ODE solver that we use.
- `get_solution()` Get astronomical solutions.

Examples

```
# default call
snvec(tend = -1e3, ed = 1, td = 0, tres = -0.4)
```

ZB17

Astronomical Solutions ZB17 for the past 100 Myr

Description

Astronomical Solutions ZB17 for the past 100 Myr

Format

`get_solution("ZB17x")`:

A data frame with 62,501 rows and 3 columns:

time Time in thousands of years (kyr).

ecc Eccentricity e (unitless).

inc Inclination I (degrees).

Source

All astronomical solutions by Zeebe can be found on http://www.soest.hawaii.edu/oceanography/faculty/zeebe_files/Astro.html.

They can be loaded into R quickly, using `get_solution()`.

References

Zeebe, R. E. (2017). Numerical Solutions for the orbital motion of the Solar System over the Past 100 Myr: Limits and new results. *The Astronomical Journal*. doi:10.3847/15383881/aa8cce

ZB18a_100

Astronomical Solution ZB18a for the Past 100 Myr

Description

Astronomical Solution ZB18a for the Past 100 Myr

Format

```
get_solution("ZB18a-100"):
```

A data frame with 62,501 rows and 3 columns:

time Time in thousands of years (kyr).

ecc Eccentricity e (unitless).

inc Inclination I (degrees).

Source

All astronomical solutions by Zeebe can be found on http://www.soest.hawaii.edu/oceanography/faculty/zeebe_files/Astro.html.

They can be loaded into R quickly, using `get_solution()`.

References

Zeebe, R. E., & Lourens, L. J. (2019). Solar System chaos and the Paleocene–Eocene boundary age constrained by geology and astronomy. *Science*, 365(6456), 926–929. doi:10.1126/science.aax0612.

ZB18a_300

Astronomical Solution ZB18a for the Past 300 Myr

Description

Astronomical Solution ZB18a for the Past 300 Myr

Format

```
get_solution("ZB18a-300"):
```

A data frame with 187,501 rows and 3 columns:

time Time in thousands of years (kyr).

ecc Eccentricity e (unitless).

inc Inclination I (degrees).

Source

All astronomical solutions by Zeebe can be found on http://www.soest.hawaii.edu/oceanography/faculty/zeebe_files/Astro.html.

They can be loaded into R quickly, using `get_solution()`.

References

Zeebe, R. E., & Lourens, L. J. (2019). Solar System chaos and the Paleocene–Eocene boundary age constrained by geology and astronomy. *Science*, 365(6456), 926–929. doi:10.1126/science.aax0612.

Zeebe, R. E. and Lourens, L. J. (2022). Geologically constrained astronomical solutions for the Cenozoic era. *Earth and Planetary Science Letters*. doi:10.1016/j.epsl.2022.117595

ZB20

Astronomical Solutions ZB20 for the past 300 Myr

Description

Astronomical Solutions ZB20 for the past 300 Myr

Format

`get_solution("ZB20x")`:

A data frame with 187,501 rows and 3 columns:

time Time in thousands of years (kyr).

ee Eccentricity e (unitless).

inc Inclination I (degrees).

Source

All astronomical solutions by Zeebe can be found on http://www.soest.hawaii.edu/oceanography/faculty/zeebe_files/Astro.html.

They can be loaded into R quickly, using `get_solution()`.

References

Zeebe, R. E. and Lourens, L. J. (2022). Geologically constrained astronomical solutions for the Cenozoic era. *Earth and Planetary Science Letters*. doi:10.1016/j.epsl.2022.117595

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