Reconstruction, modeling and future implications of changes in past climate variability: II

Heidelberg Physics Graduate Days 2019

Kira Rehfeld

Institut für Umweltphysik, Ruprecht-Karls-Universität Heidelberg

October 7, 2019

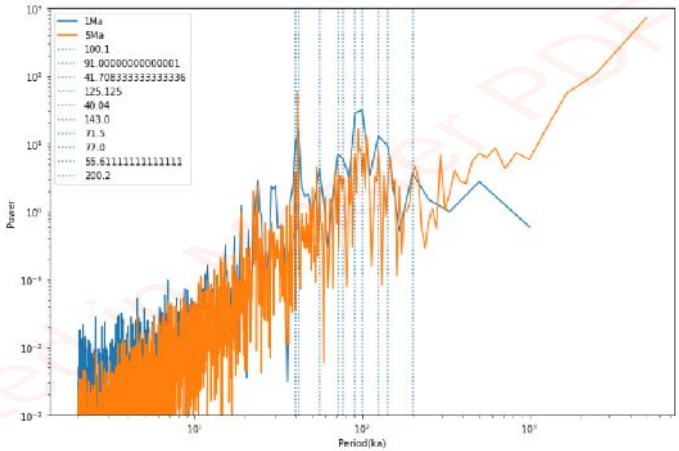
Recap: Palaeoclimate

Hands-on: Orbital timescales

1. Using power spectra, find the dominant periodicities in the Glacial/Interglacial cycles over the last
   - 5 million years,
   - 1 million years.
2. Compare them to orbital variations for the last 1 Million years, and discuss Milankovitch's theory of the ice ages.

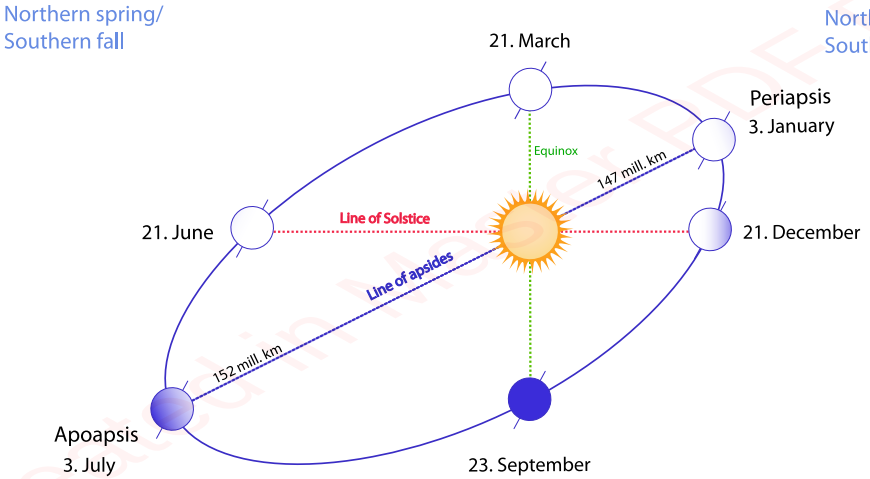
Reference solution:
`https://github.com/paleovar/graddays/returns/Monday/Rsolution`

Results: tEam

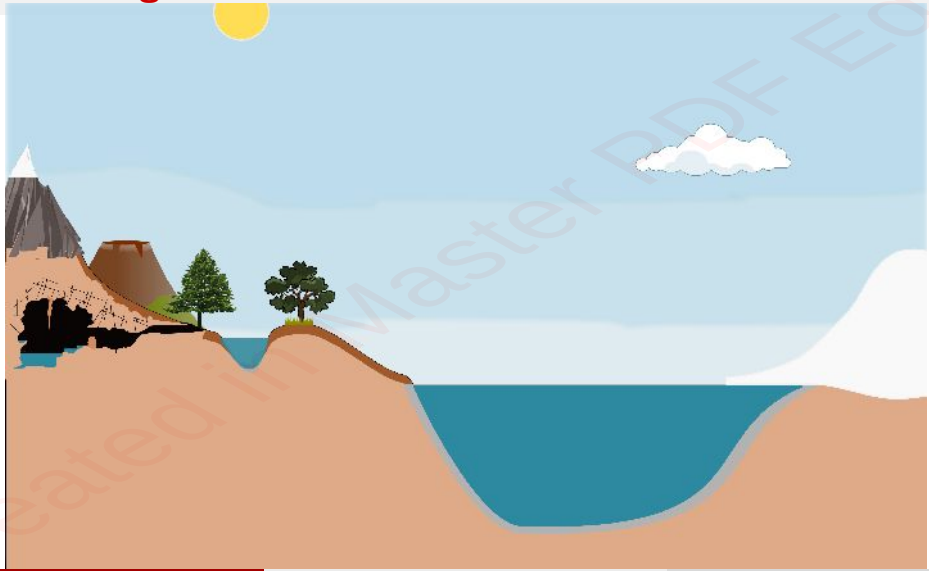


Orbital forcing

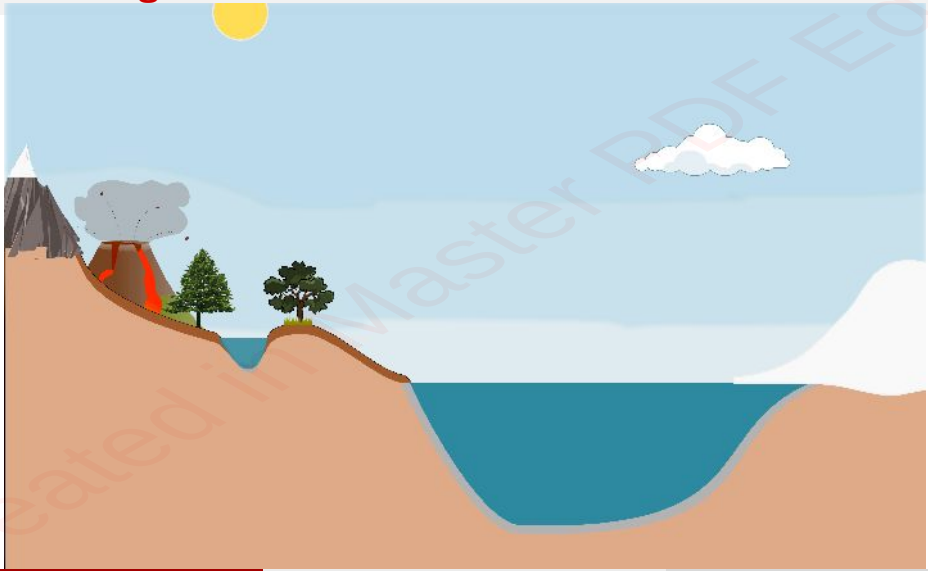
External forcing



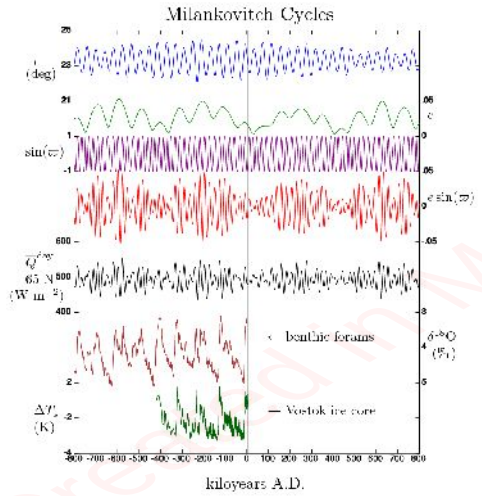
External forcing



External forcing



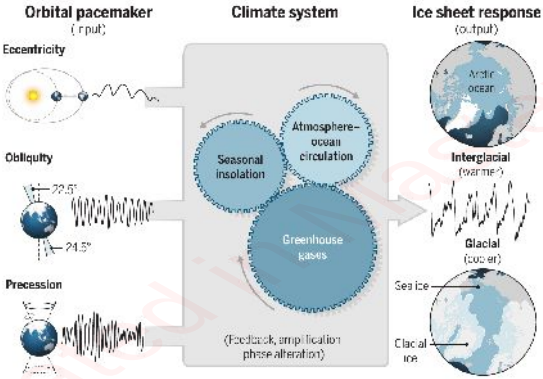
The 100 kyr problem



- Orbital insolation forcing peaks at ∼400, 100 (weak), 42 and ∼20 kyrs.
- Observed interglacial frequency 1/100k (Quaternary)
- This cannot be a linear relationship!

⇒ **Power spectral analysis of the benthic stack**

Pacemaker of the ice ages



Pacemaker: cyclic variations in Earth's orbital geometry

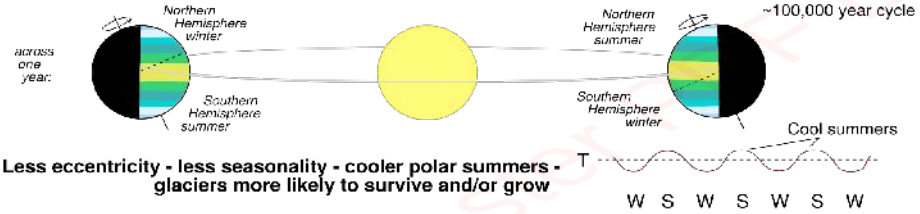
Heart: Climate system

Heartbeat: Glacial-/Interglacial cycles

Remaining challenge! Nonlinear amplification needed.

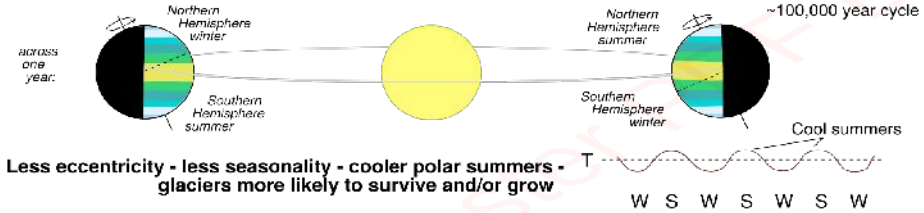
D. Hodell, 2016 **Science**, about Hays, Imbrie and Shackleton, 1976 **Science**

Eccentricity, seasonality and glaciation extent

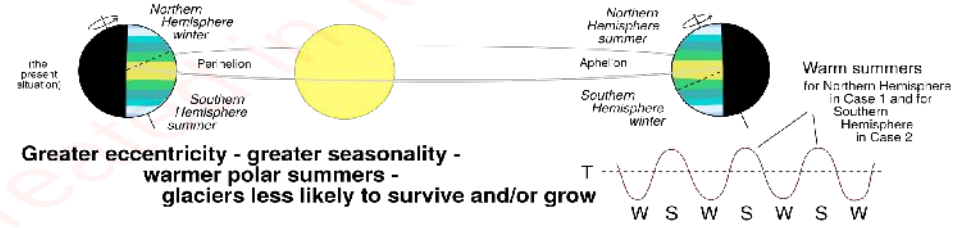


Less eccentricity - less seasonality - cooler polar summers - glaciers more likely to survive and/or grow

Eccentricity, seasonality and glaciation extent

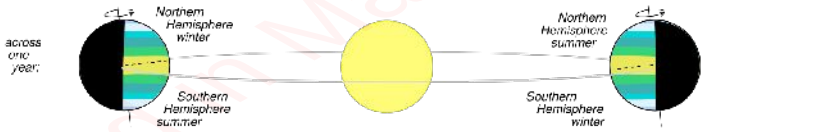


Less eccentricity - less seasonality - cooler polar summers - glaciers more likely to survive and/or grow



Greater eccentricity - greater seasonality - warmer polar summers - glaciers less likely to survive and/or grow

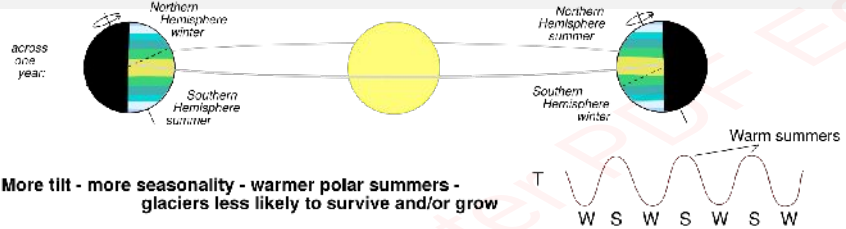
Obliquity, seasonality and glaciation extent



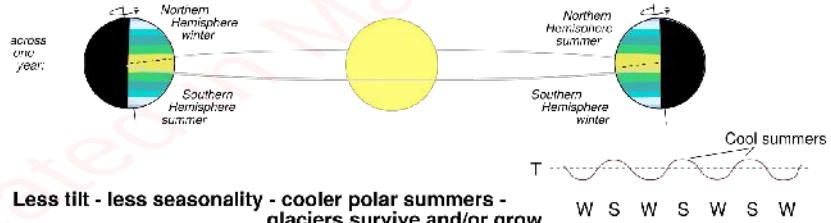
Less tilt - less seasonality - cooler polar summers - glaciers survive and/or grow

Obliquity, seasonality and glaciation extent

~41,000 year cycle

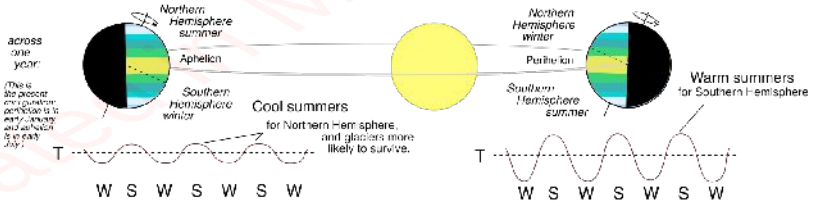


More tilt - more seasonality - warmer polar summers - glaciers less likely to survive and/or grow

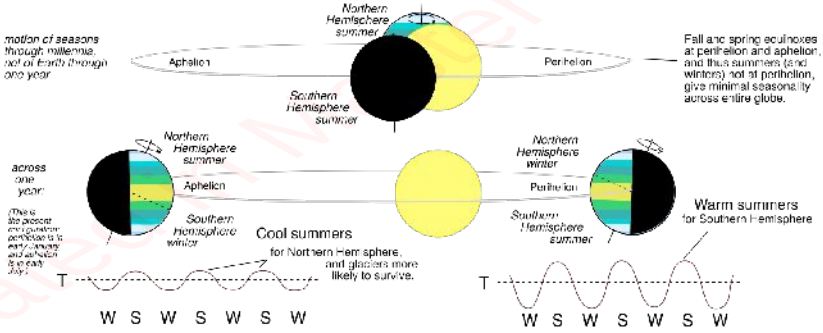


Less tilt - less seasonality - cooler polar summers - glaciers survive and/or grow

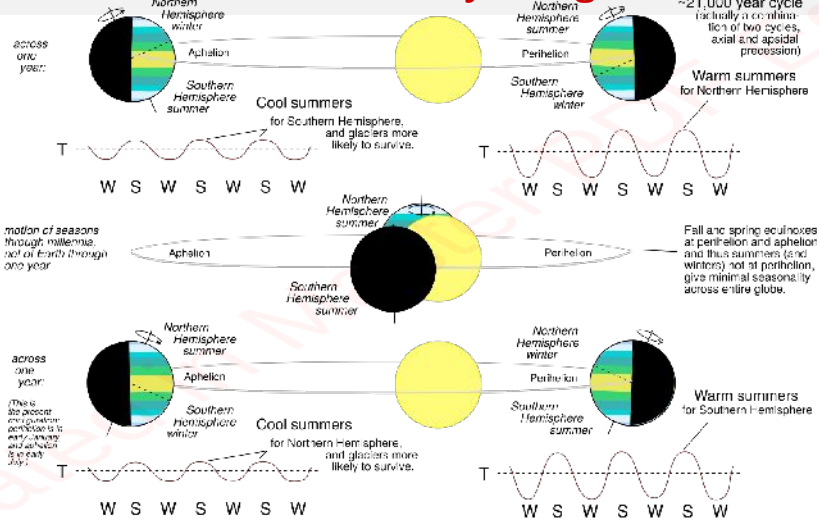
Precession of the seasons, seasonality and glaciation



Precession of the seasons, seasonality and glaciation



Precession of the seasons, seasonality and glaciation



Important to take away

- Dominant orbital forcing at
  - 19 and 23kyrs (Precession),
  - 41 kyrs (Obliquity)
  - 100 kyrs (Eccentricity)
- In the last 1 million years: 100-kyr world
- The Earth system is nonlinearly responding to orbital insolation changes Hays et al., 1976
- Unresolved: Mid-Pleistocene transition (frequency change) Hodell, 2016
- . . . how to compute power spectra
- . . . to be aware of resolution and unit changes

Berger et al., 1991; Lisiecki et al., 2005

Hands on II: Antarctic ice core data

Explore the relationship between atmospheric CO2 and reconstructed temperature.

Datasets in github repository

git clone `https://github.com/paleovar/graddays.git`

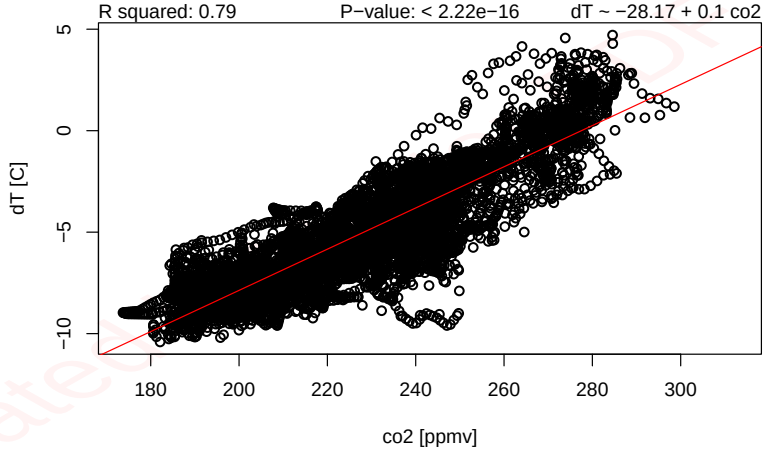
Climate response

EPICA δD and temperature reconstruction for the last 800 000 years Jouzel et al., 2007
`/graddays/Datasets/Monday/LR04stack.csv`

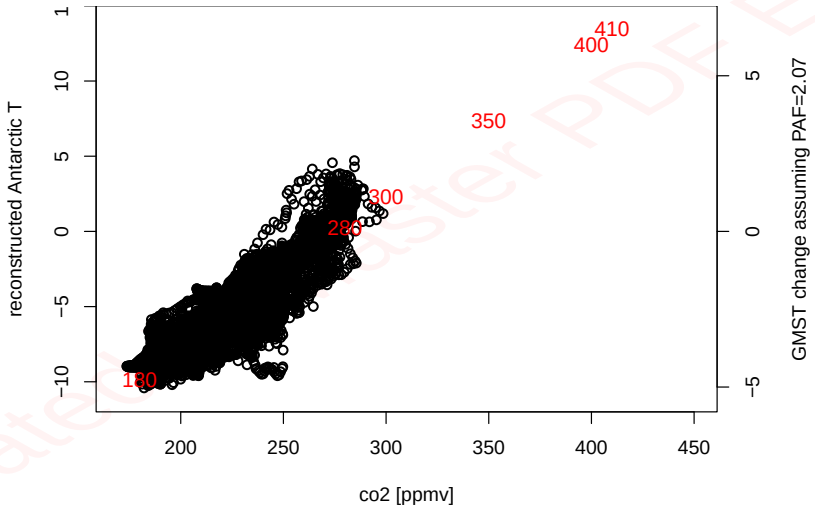
Climate forcing

CO_2 data Bereiter et al., 2015; EPICA-Community-Members, 2004
`/graddays/Datasets/Monday/antarctica2015co2_composite.csv`
Orbital Berger et al., 1991
`/graddays/Datasets/Monday/orbit/orbit91`

Temperature to CO_2 relationship: Antarctic ice cores



Temperature to CO_2 relationship: Antarctic ice cores



Reference solution:

`https://github.com/paleovar/graddays/returns/Monday/Rsolution`

Note that a polar amplification factor of ~ 2 was assumed Masson-Delmotte et al., 2006

References I

Bereiter, B. et al. (2015). "Revision of the EPICA Dome C CO2 record from 800 to 600-kyr before present". In: *Geophysical Research Letters* 42.2. DOI: 10.1002/2014GL061957.

Berger, A. and M. Loutre (1991). "Insolation values for the climate of the last 10 million years". In: *Quaternary Science Reviews* 10.4. DOI: 10.1016/0277-3791(91)90033-Q.

EPICA-Community-Members (2004). "Eight glacial cycles from an Antarctic ice core". In: *Nature* 429.6992. DOI: 10.1038/nature02599.

Hays, J. D., J. Imbrie, and N. J. Shackleton (1976). "Variations in the Earth's Orbit: Pacemaker of the Ice Ages". In: *Science* 194.4270. DOI: 10.1126/science.194.4270.1121.

Hodell, D. A. (2016). "The smoking gun of the ice ages". In: *Science* 354.6317. DOI: 10.1126/science.aal4111.

Jouzel, J. et al. (2007). "Orbital and millennial Antarctic climate variability over the past 800,000 years.". In: *Science (New York, N.Y.)* 317.5839. DOI: 10.1126/science.1141038.

Lisiecki, L. E. L. and M. E. Raymo (2005). "A Pliocene-Pleistocene stack of 57 globally distributed benthic δ 18 O records". In: *Paleoceanography* 20.1. DOI: 10.1029/2004PA001071.

References II

Masson-Delmotte, V. et al. (2006). "Past and future polar amplification of climate change: climate model intercomparisons and ice-core constraints". In: *Climate Dynamics* 26.5. DOI: 10.1007/s00382-005-0081-9.

Additional resources

https://a-little-book-of-r-for-time-series.readthedocs.io/en/latest/
https://www.ncdc.noaa.gov/data-access/paleoclimatology-data
Modified orbital illustrations after railsback.org
Used graphics: see references, openclipart.org, own work and wikimedia commons