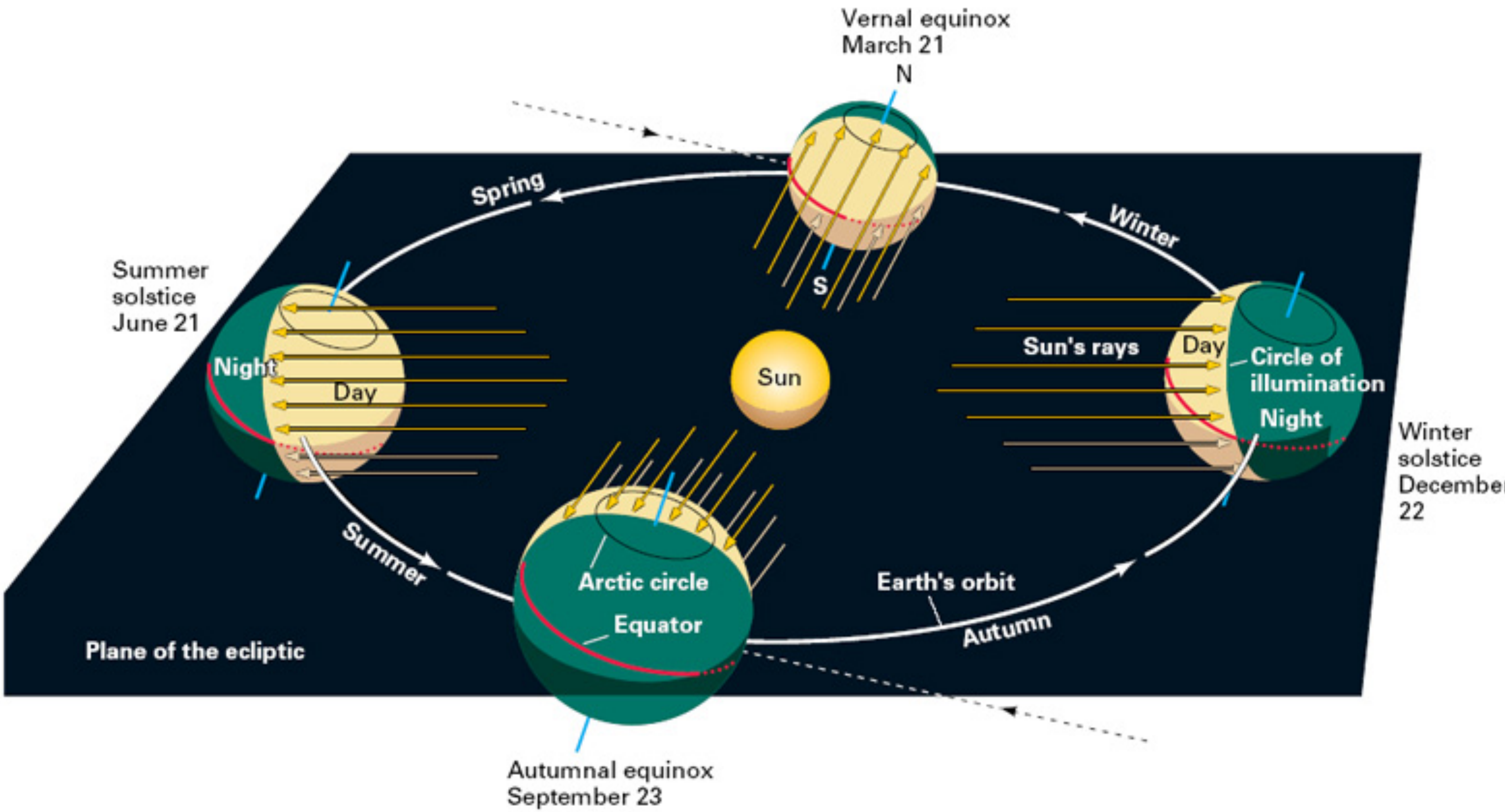
Climate System II course 2020 (4th lecture)

G. Lohmann & M. Werner

Orbital Theory, Ice Ages, Abrupt climate change

Gerrit Lohmann

The 4 seasons



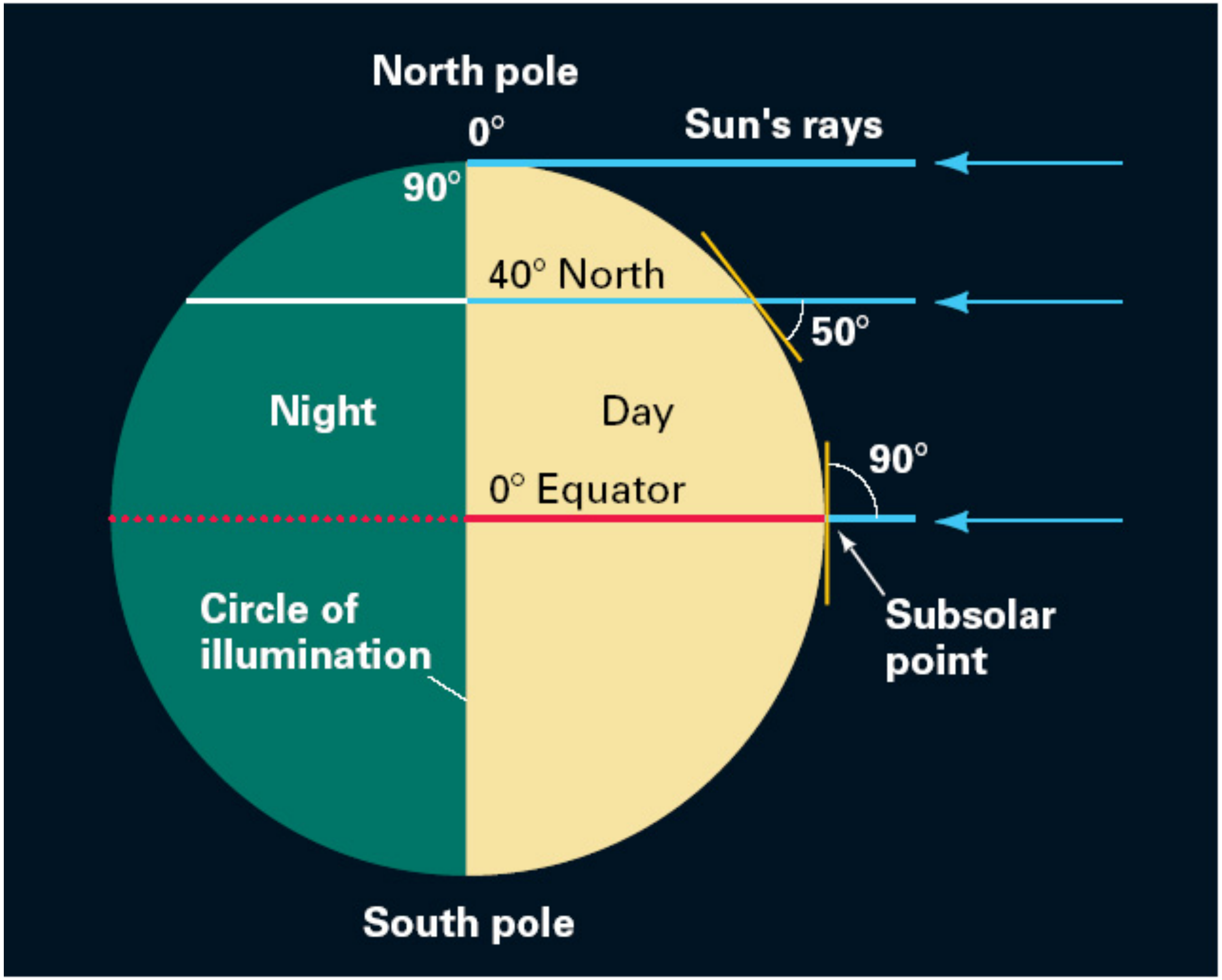
BQuelle: **Strahler: „Physical Geography“**,2002, Wiley-Verlag, ISBN=0-471-23800-7, Bild3.16,p.55

Equinox

at equinox, the circle of illumination passes through both poles

the subsolar point is the equator

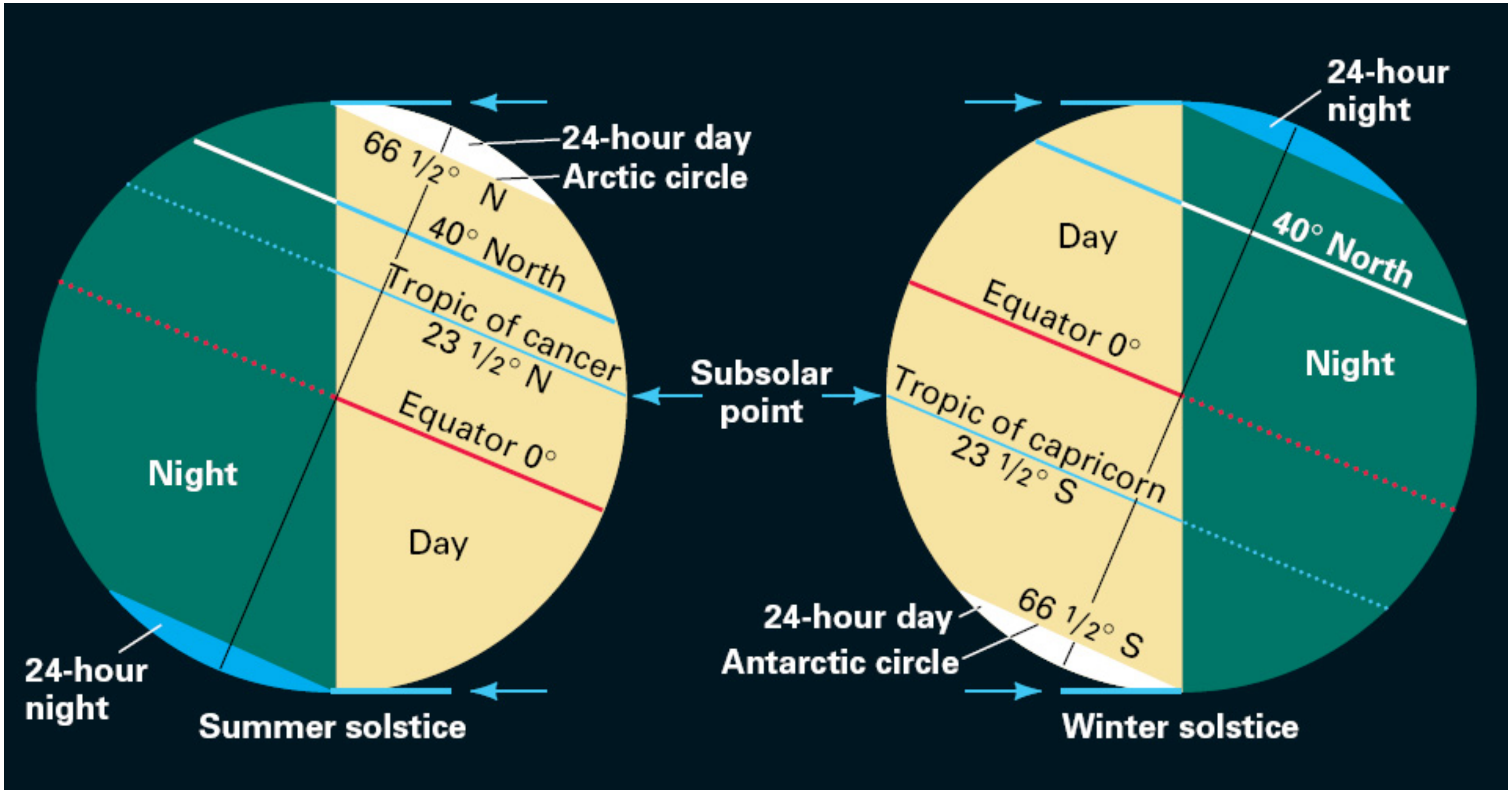
each location on Earth experiences 12 hours of sunlight and 12 hours of darkness



BQuelle: **Strahler: „Physical Geography“**,2002, Wiley-Verlag, ISBN=0-471-23800-7, Bild3.17,p.56 (bzw. Fig.1.18,p.41 in neuerer Auflage)

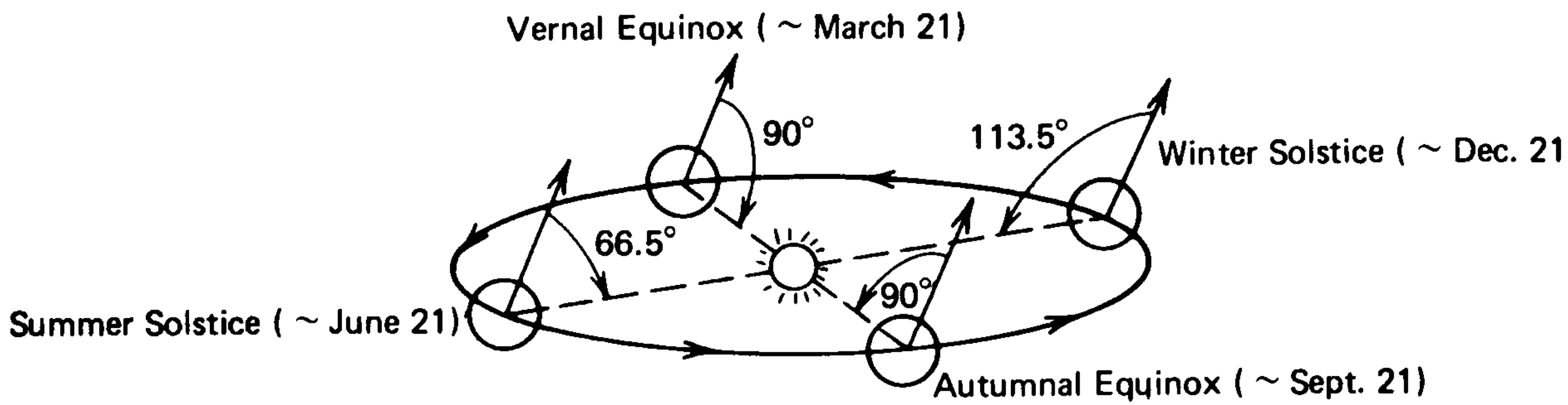
Solstice

Solstice ("sun stands still")
On June 22, the subsolar point is 23½° N (Tropic of Cancer)
On Dec. 22, the subsolar point is 23½° S (Tropic of Capricorn)



BQuelle: **Strahler: „Physical Geography"**,2002, Wiley-Verlag, ISBN=0-471-23800-7, Bild3.18,p.56 (bzw. Fig.1.19,p.41 in neuerer Auflage)

Seasons are a consequence of the inclination of the earth 's axis of rotation



Seasonal variation of the angle

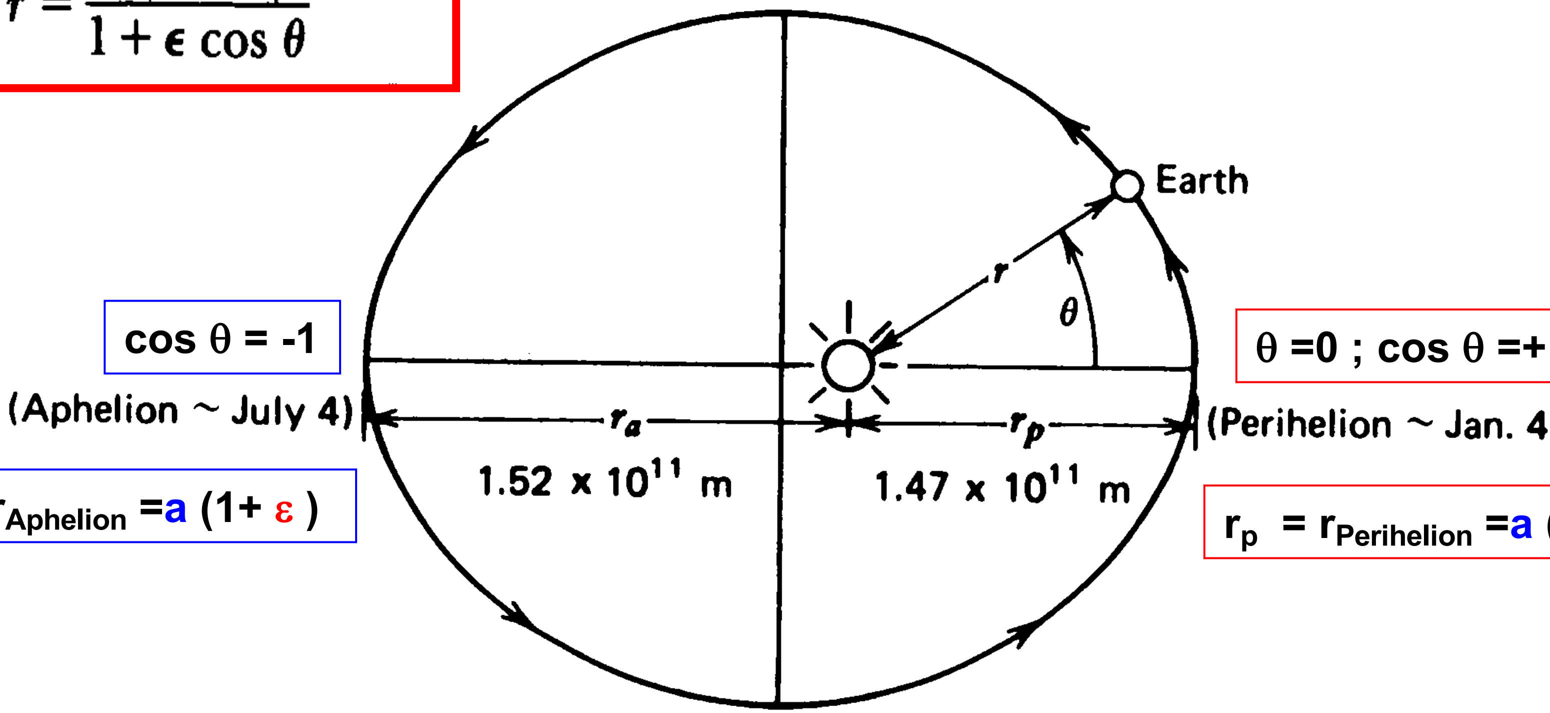
between **the earth 's polar axis** and the **earth-sun line**

The angle of inclination (between the **earth axis** of rotation and the **line perpendicular** to the **ecliptic** plane) **is 23.5° and remains constant throughout the year.**

Quelle:/ Wieder82, fig 2.2; p.21/

The earth's orbit (shown with an exaggerated eccentricity ε)

$$r = \frac{a(1-\epsilon^2)}{1+\epsilon\cos\theta}$$



$\cos\theta = -1$

$\theta = 0$; $\cos\theta = +1$

$r_a = r_{Aphelion} = a\,(1+\varepsilon)$

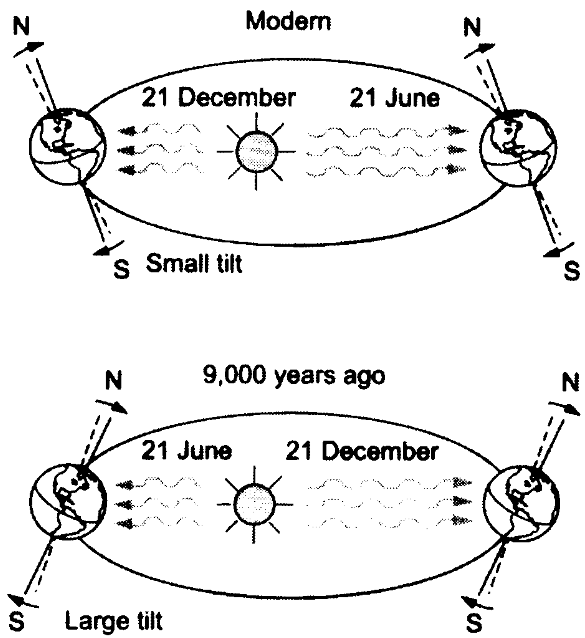
$r_p = r_{Perihelion} = a\,(1-\varepsilon)$

the mean orbital distance is **a = 149,7 [Gm]** = 149,7 Mio km
and the eccentricity is **ε = 0.0167**

also ca. :: $r = a \pm 2\%$

Quelle:/ Wieder82, Fig 2.1; p.20

Configuration of the earth's orbit 9000 years ago

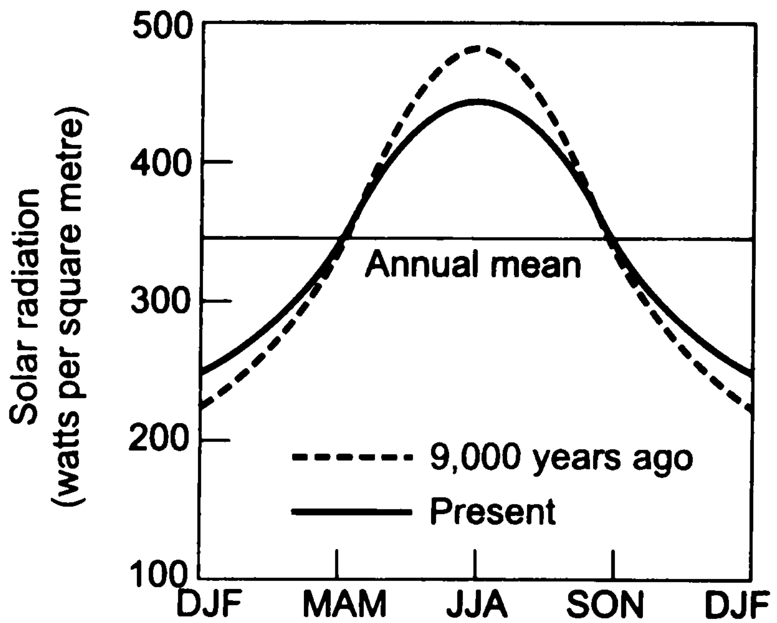


Today:
Perihelion in January

Tilt of the earth's axis:
23.5°

9000 years ago::
Perihelion in July

Tilt of the earth's axis:
24.0°



Changes in the average **solar radiation during the year** over the **northern hemisphere** (right). The incoming solar energy averaged over the northern hemisphere was ca. 7 % greater in July and correspondingly less in January.

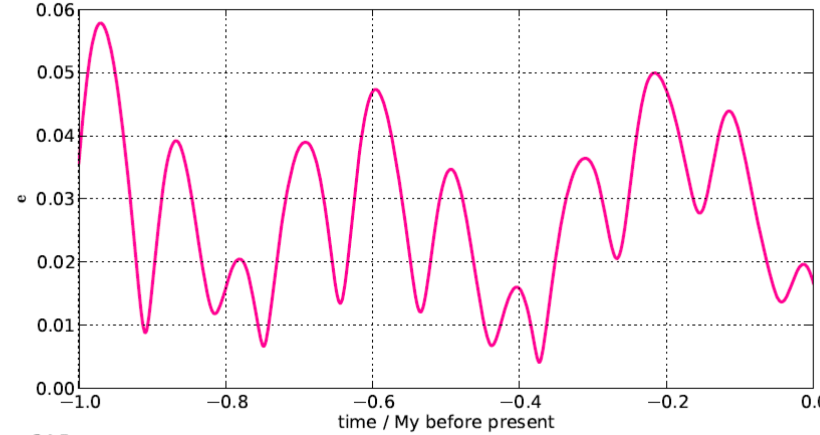
J.E. Kutzbach in „Climate System Modelling" (1992).

Orbital parameters

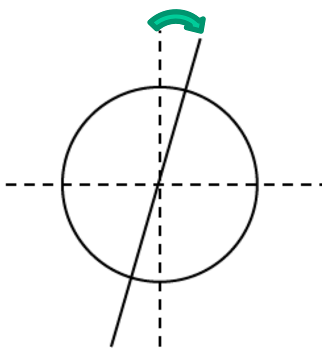
time

Excentricity

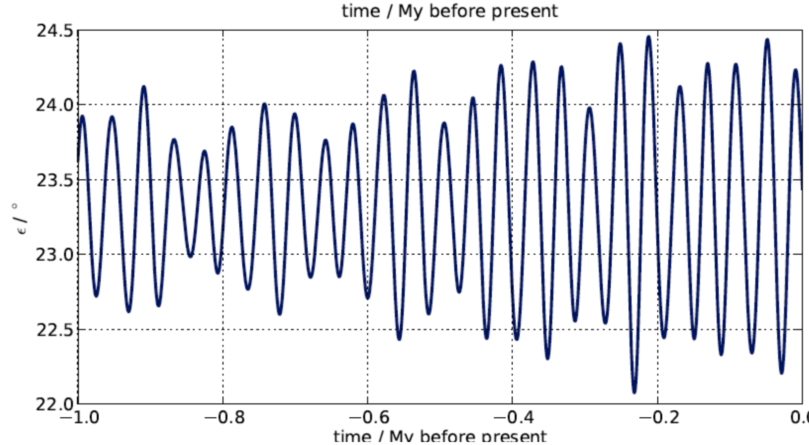
Periods:
100, 400 ky



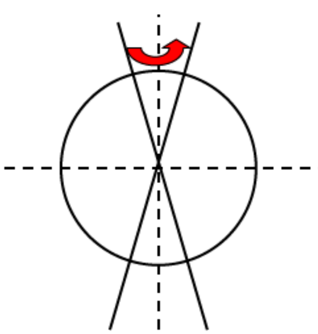
Obliquity



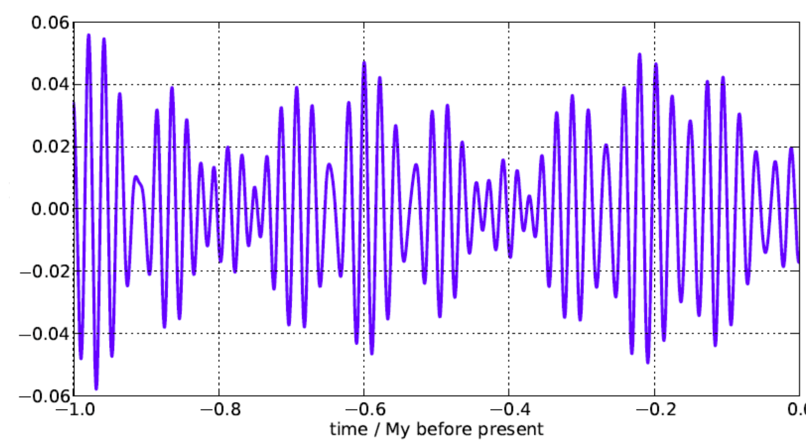
Periods:
39, 41, 54 ky
Modul. 1.2 My



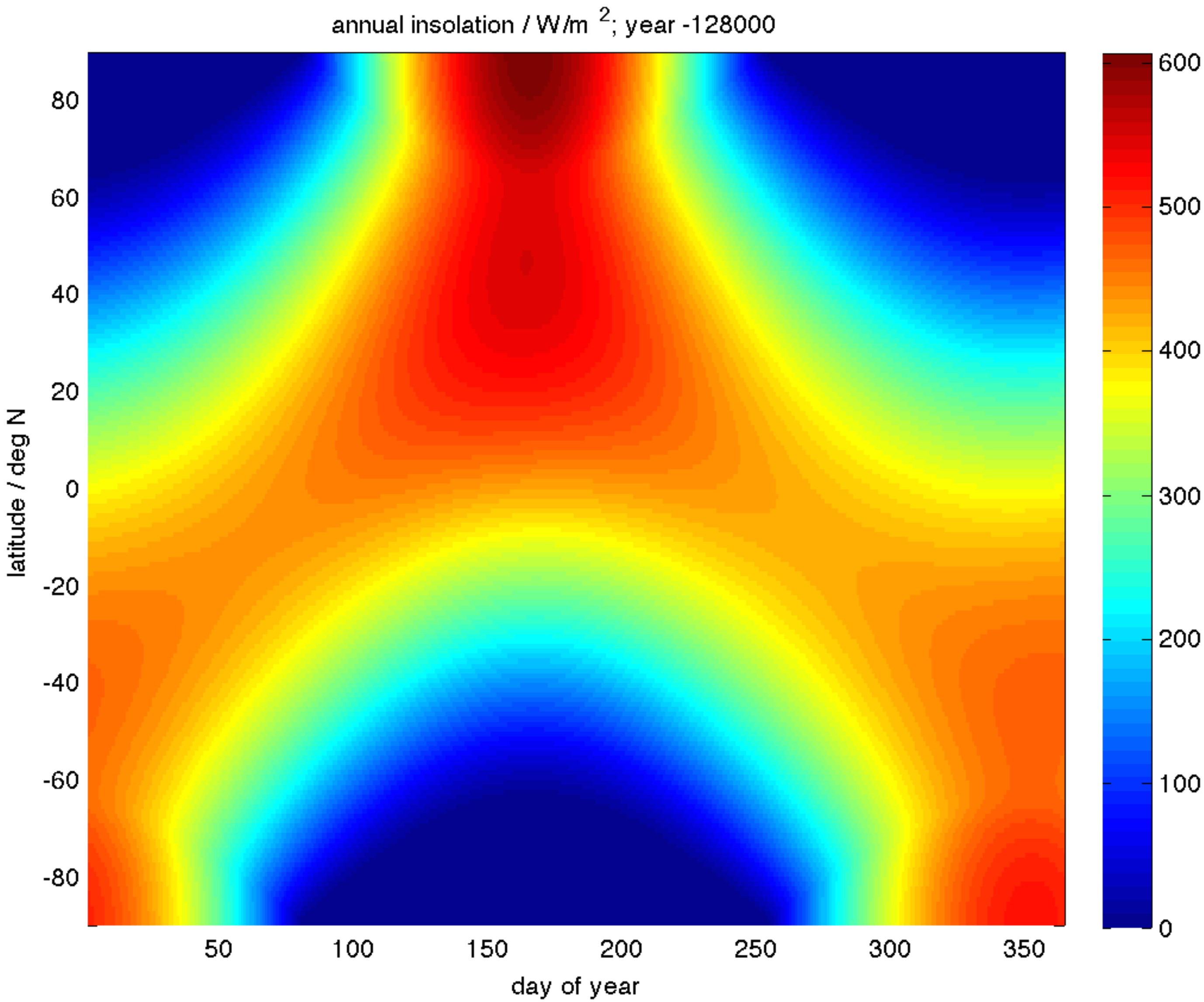
Precession



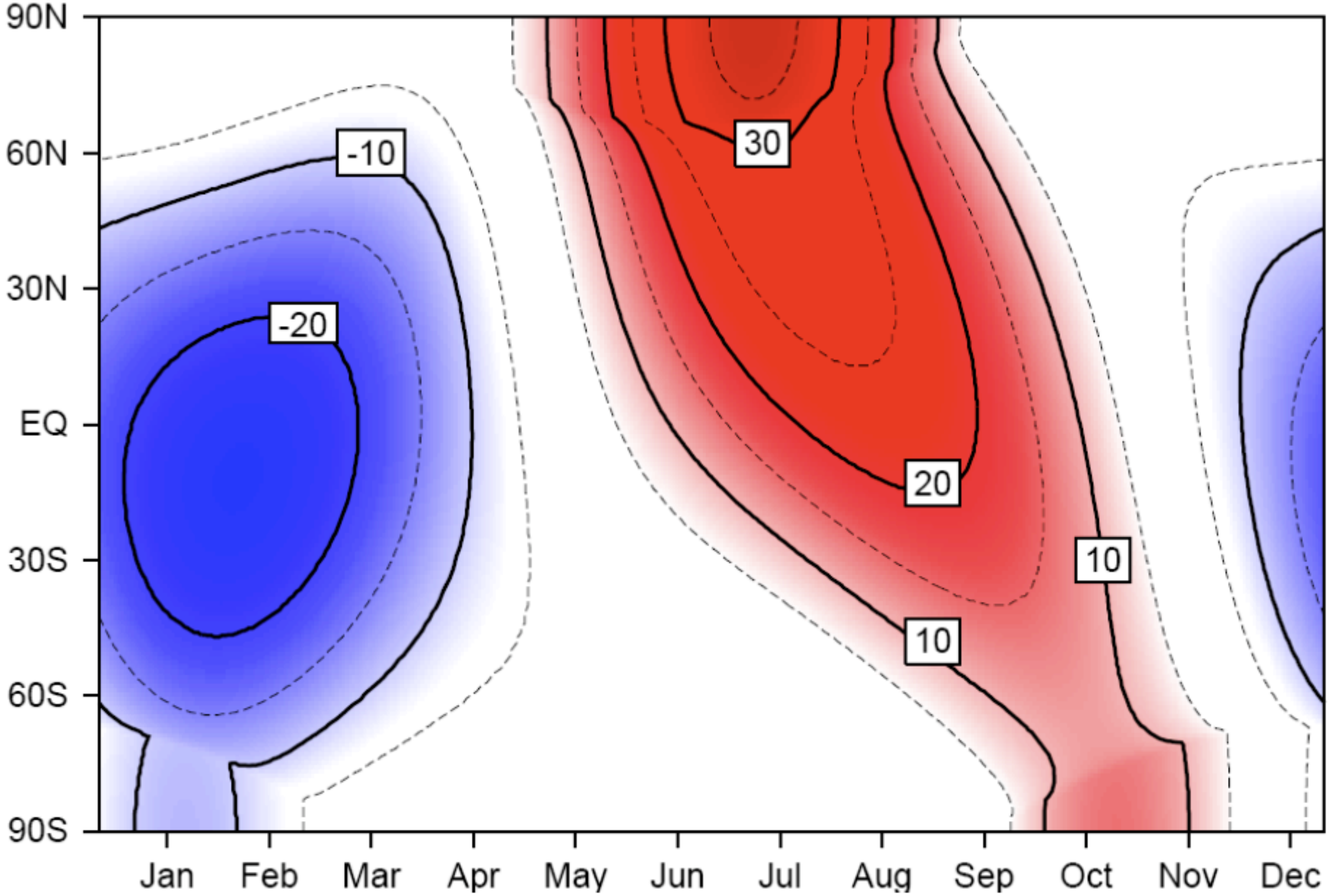
Periods:
19, 23 ky
Modul. Excentr



Insolation


annual insolation / W/m 2; year -128000
latitude / deg N
80
60
40
20
0
-20
-40
-60
-80
50
100
150
200
250
300
350
day of year
600
500
400
300
200
100
0

Insolation (6k minus present)



Monsoon: seasonal signal

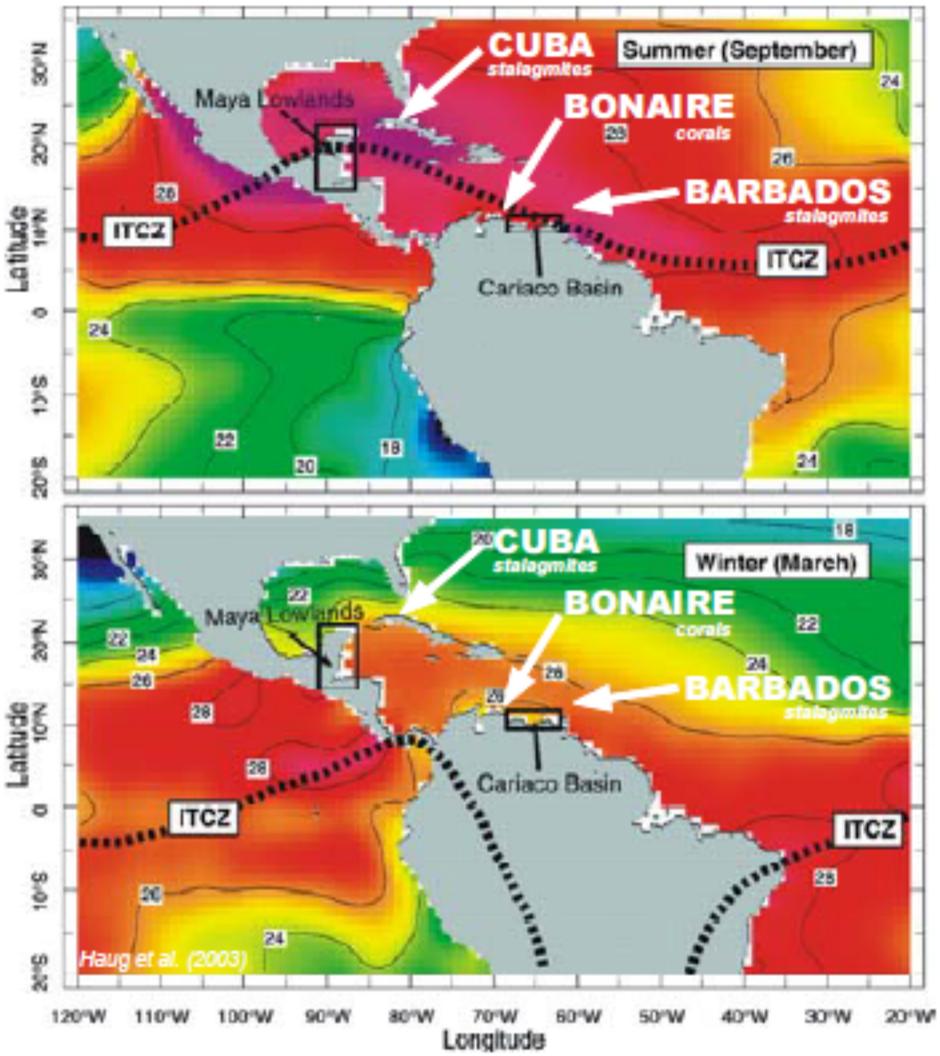


Figure 1. Seasonal variations in the mean position of the Intertropical Convergence Zone (ITCZ) over the Caribbean region, illustrated for typical summer (September) **(top)** and winter (March) **(bottom)** conditions. These variations control the pattern and timing of regional rainfall. Numbers and colours reflect sea surface temperatures in degrees Celsius. Locations of the study areas (Bonaire, Cuba, Barbados) and the Cariaco Basin and Maya Lowlands are indicated. Figure and legend modified from (Haug et al., 2003).

Monsson

seasonal reversing wind accompanied by corresponding changes in precipitation, but is now used to describe seasonal changes in atmospheric circulation and precipitation associated with the asymmetric heating of land and sea.

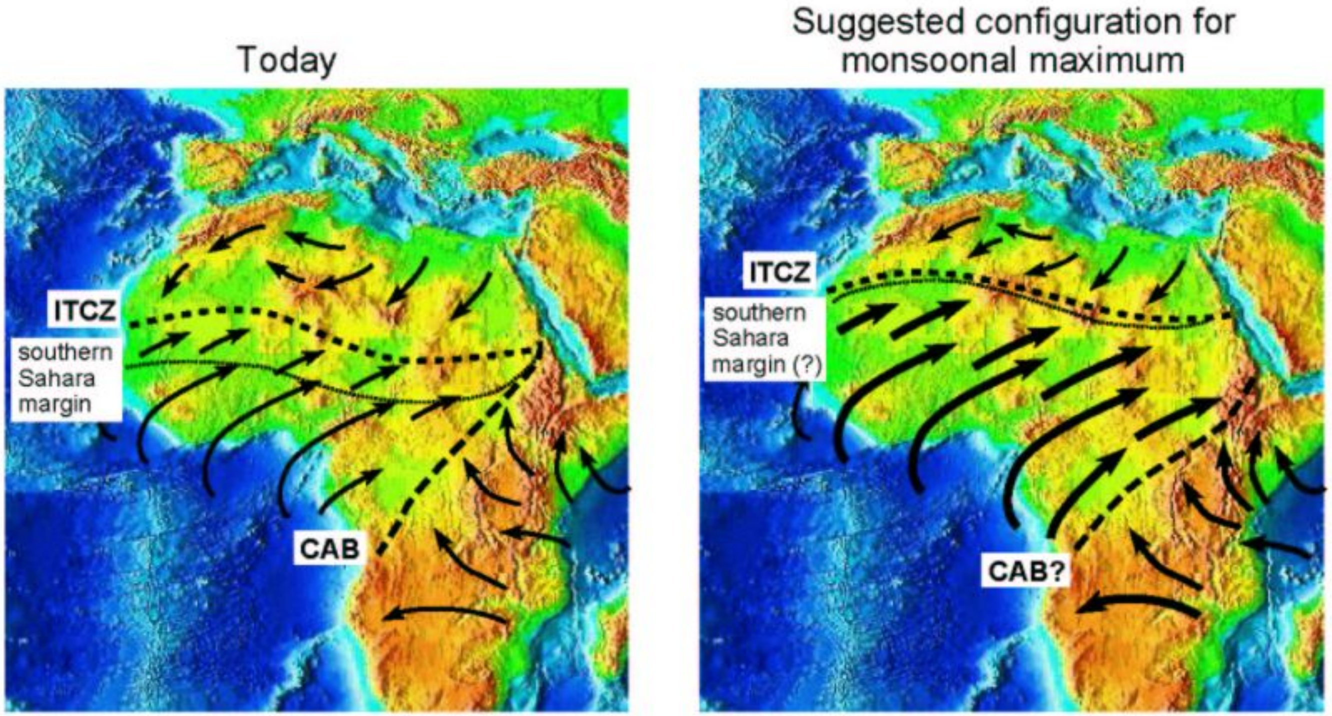
The English monsoon came from Portuguese monção, ultimately from Arabic mawsim (موسم "season") and/or Hindi "mausam", "perhaps partly via early modern Dutch monsun".

During warmer months sunlight heats the surfaces of both land and oceans, but land temperatures rise more quickly.
water heat capacity (4.2 J g−1 K−1)
dirt, sand, and rocks heat capacities (0.19 to 0.35 J g−1 K−1)

difference in pressure causes sea breezes to blow from the ocean to the land, bringing moist air inland

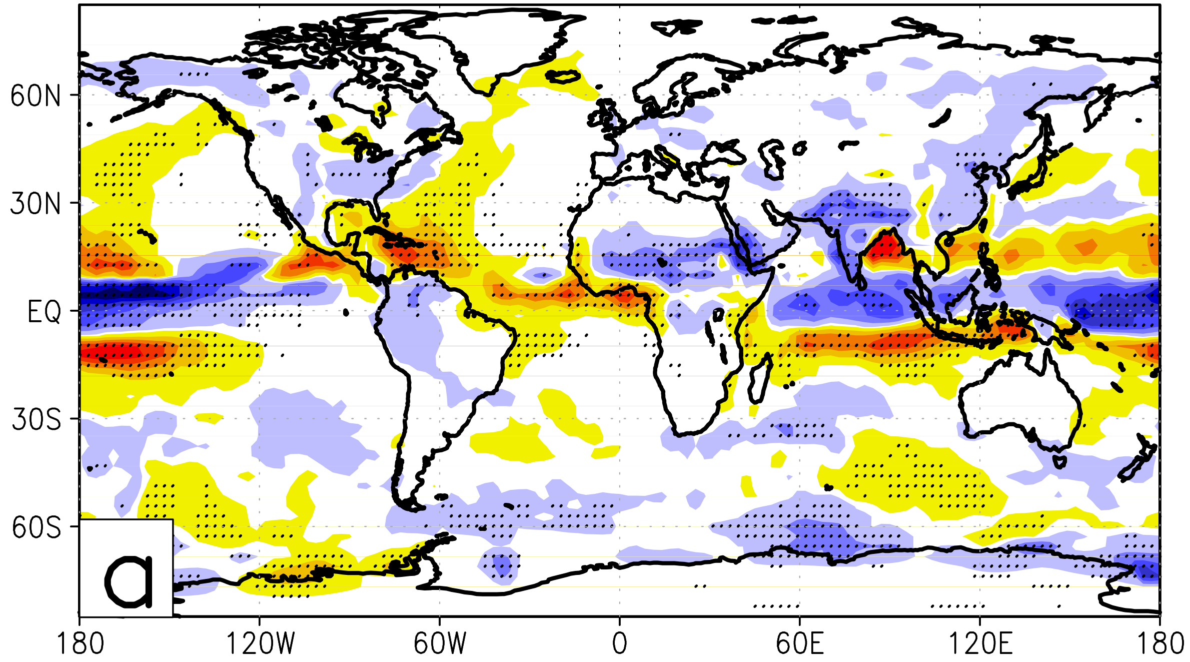
https://en.wikipedia.org/wiki/Monsoon

Precession: Effect on climate



Rough locations of the Intertropical Convergence Zone (ITCZ), the Congo Air Boundary (CAB), and the southen margin of the Sahara Desert for the present-day, and for the monsoonal maximum.

Holocene 6K- PI, precipitation JJA



Paintings

Mestikawi-Foggini-Höhle
Foggini-Höhle
Höhle Wadi Sura II

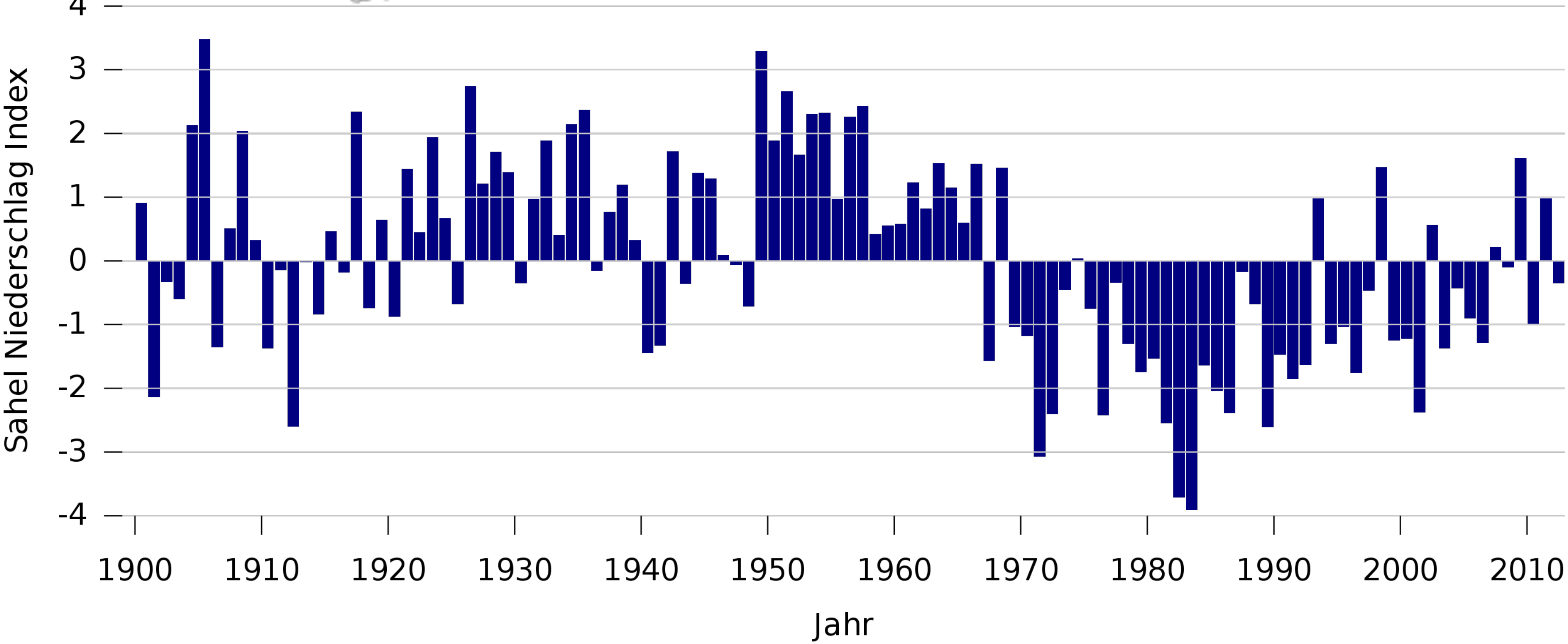
Older than 7000 years

2002 Archäologen Massimo & Jacopo Foggini, Ahmed Mestikawi

<u>Agadez</u> in <u>Niger</u>.

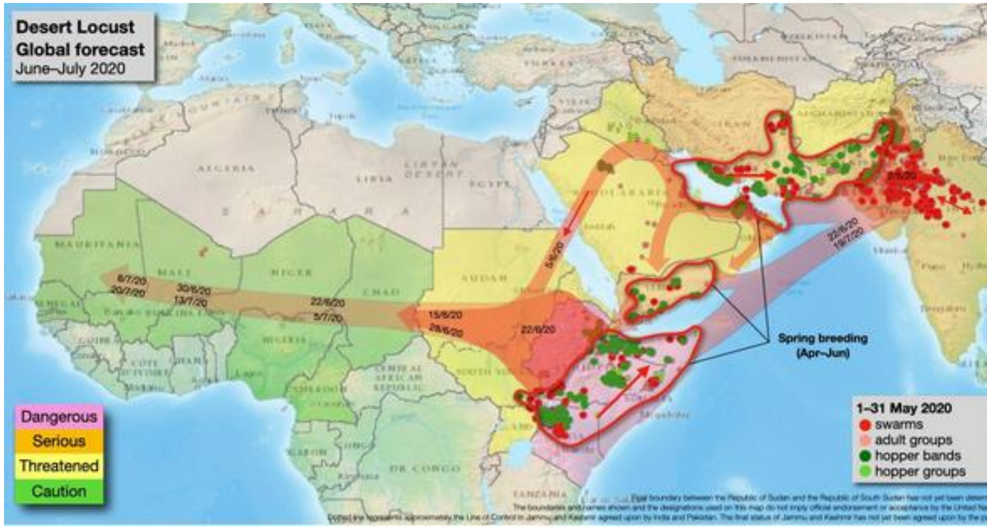
Sahel Zone

The famine in the Sahel in the 1970s and 1980s was the result of drought, affected about 50 million people and led to the death of an estimated one million people.



Sahel continued

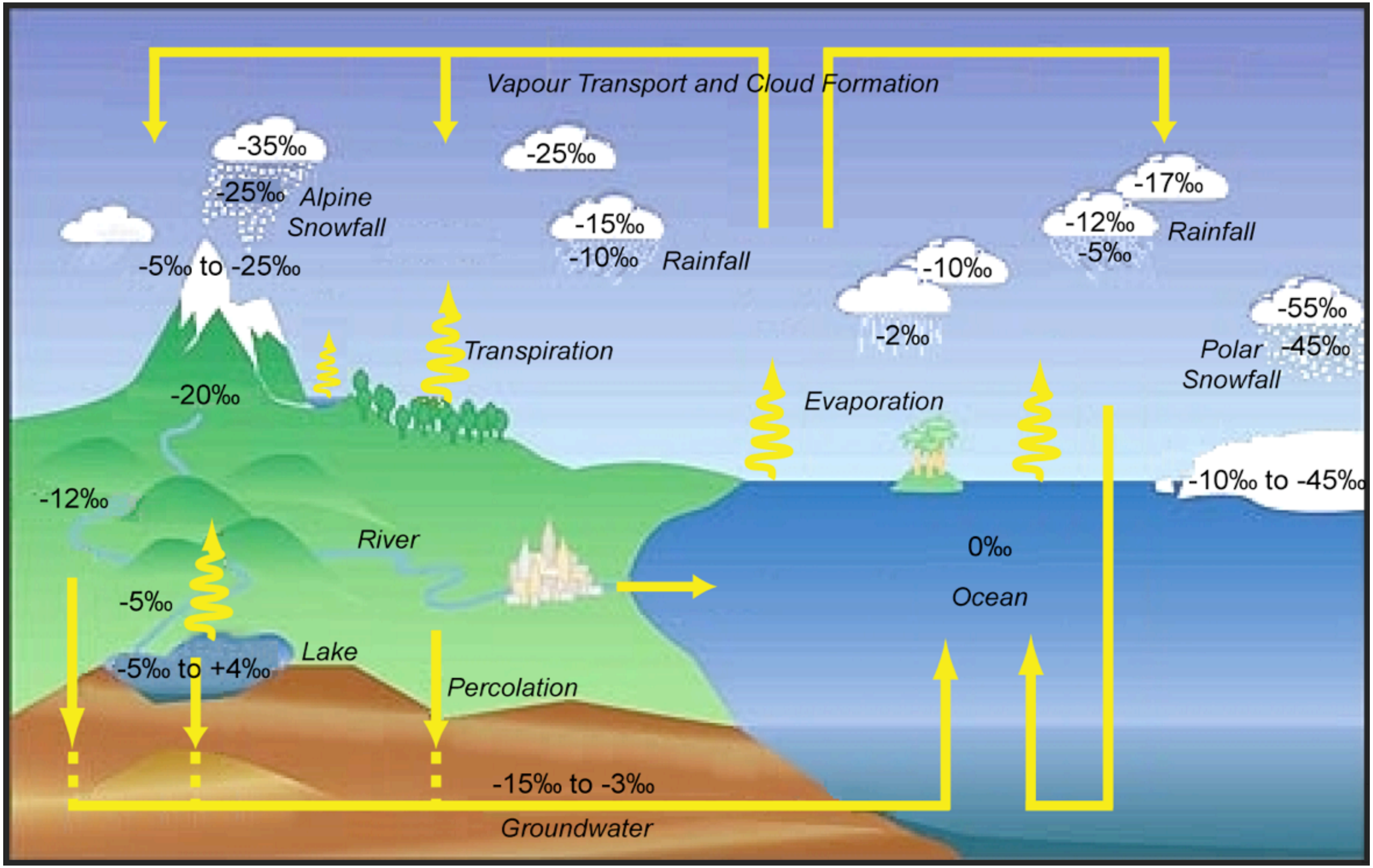
- **Human impacts include deforestation, overgrazing and overexploitation of agricultural land**
- **This exacerbated the problem of desertification**
- **Another reason for the famines in the Sahel zone is that more and more locusts are invading the zone in swarms and grazing the fields**



Sahel continued

- **Human impacts include deforestation, overgrazing and overexploitation of agricultural land**
- **This exacerbated the problem of desertification**

$\delta^{18}O$ Signal in the Hydrological Cycle

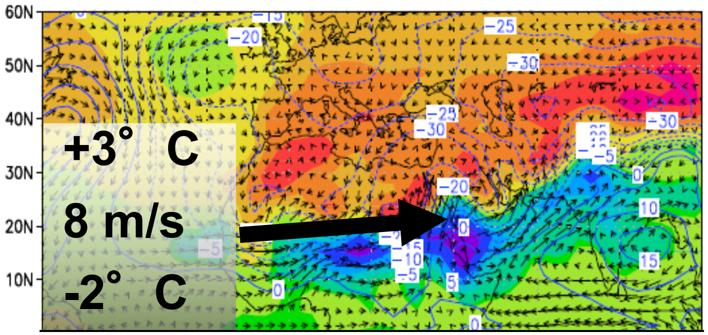


[plot adapted from the GNIP brochure, IAEA, 1996]

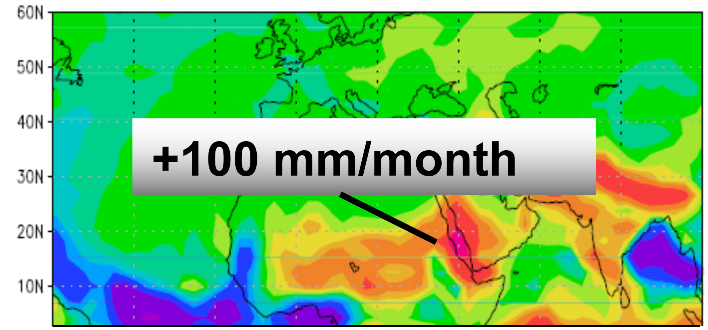
Scheme of typical isotope depletion in various parts of the hydrological cycle

Every phase change of a water mass is imprinted in its isotopic signature

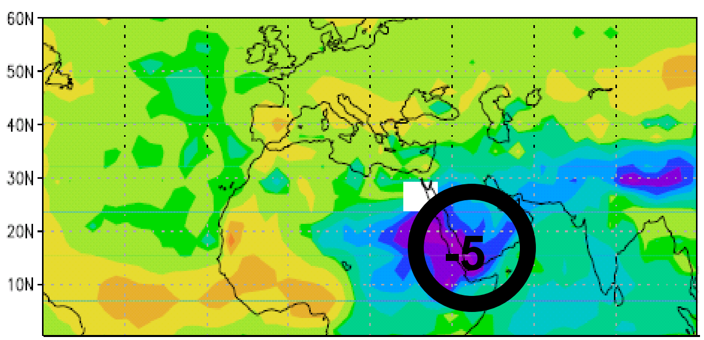
Eemian $\delta^{18}O$ & δD



Temperature & wind

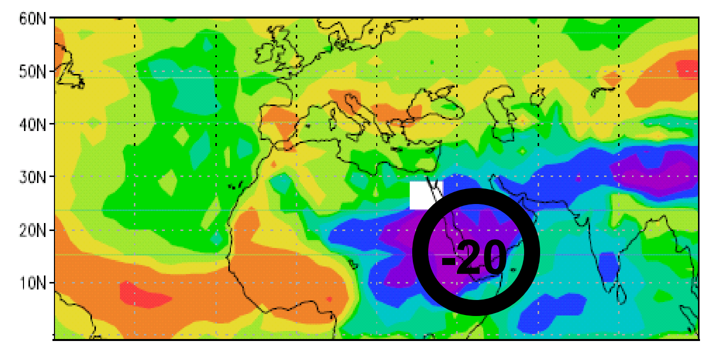


Precipitation



$\delta^{18}O$ (° /oo)

Using ECHAMiso



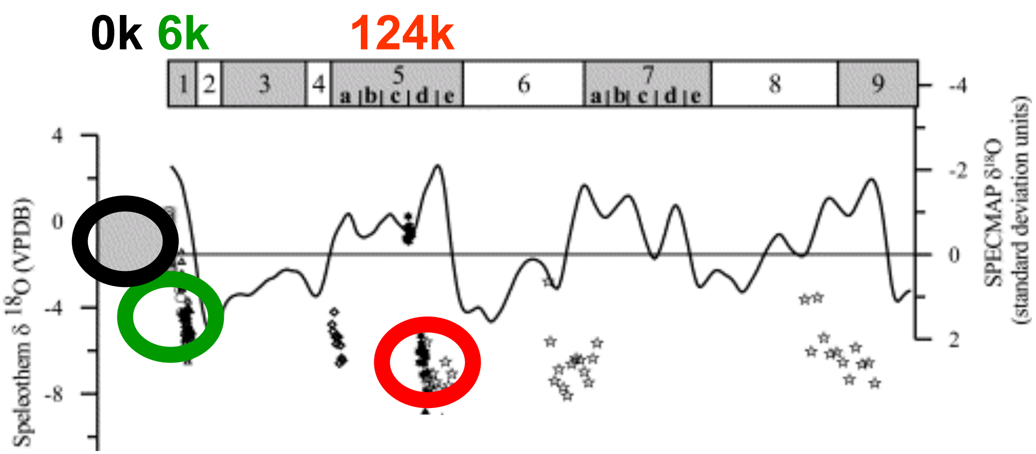
δD (° /oo)

Enhanced zonal wind & more precipitation

Isotopic Depletion: Consistent with stalagmite data

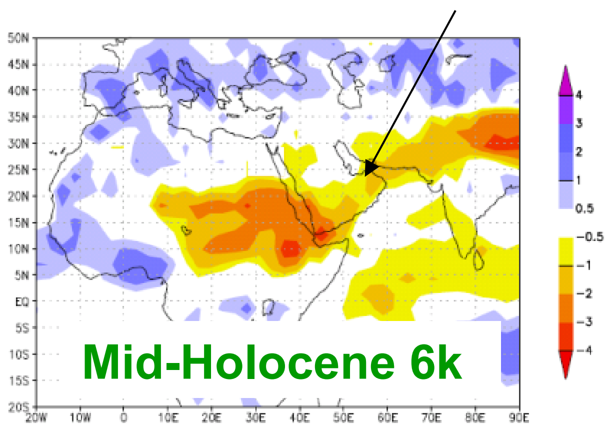
Herold and Lohmann 2009

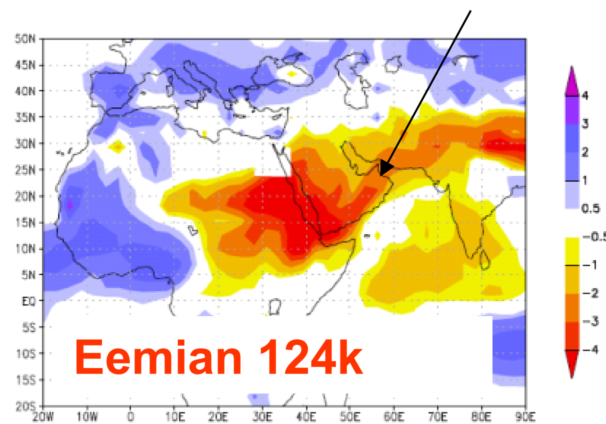
Comparison with O isotope records: Hoti Cave



$\delta^{18}O$ (°/oo) of Speleothem

$\delta^{18}O$ (°/oo) of Precipitation

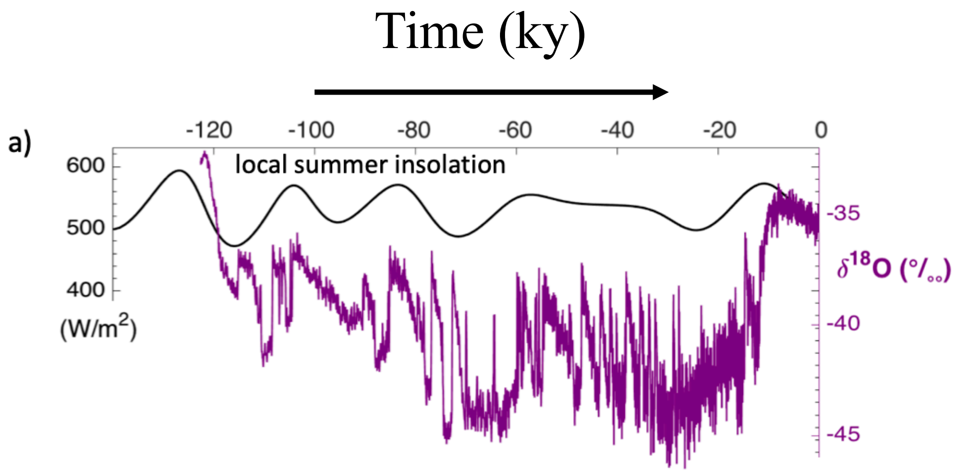




Fleitmann et al., 2003

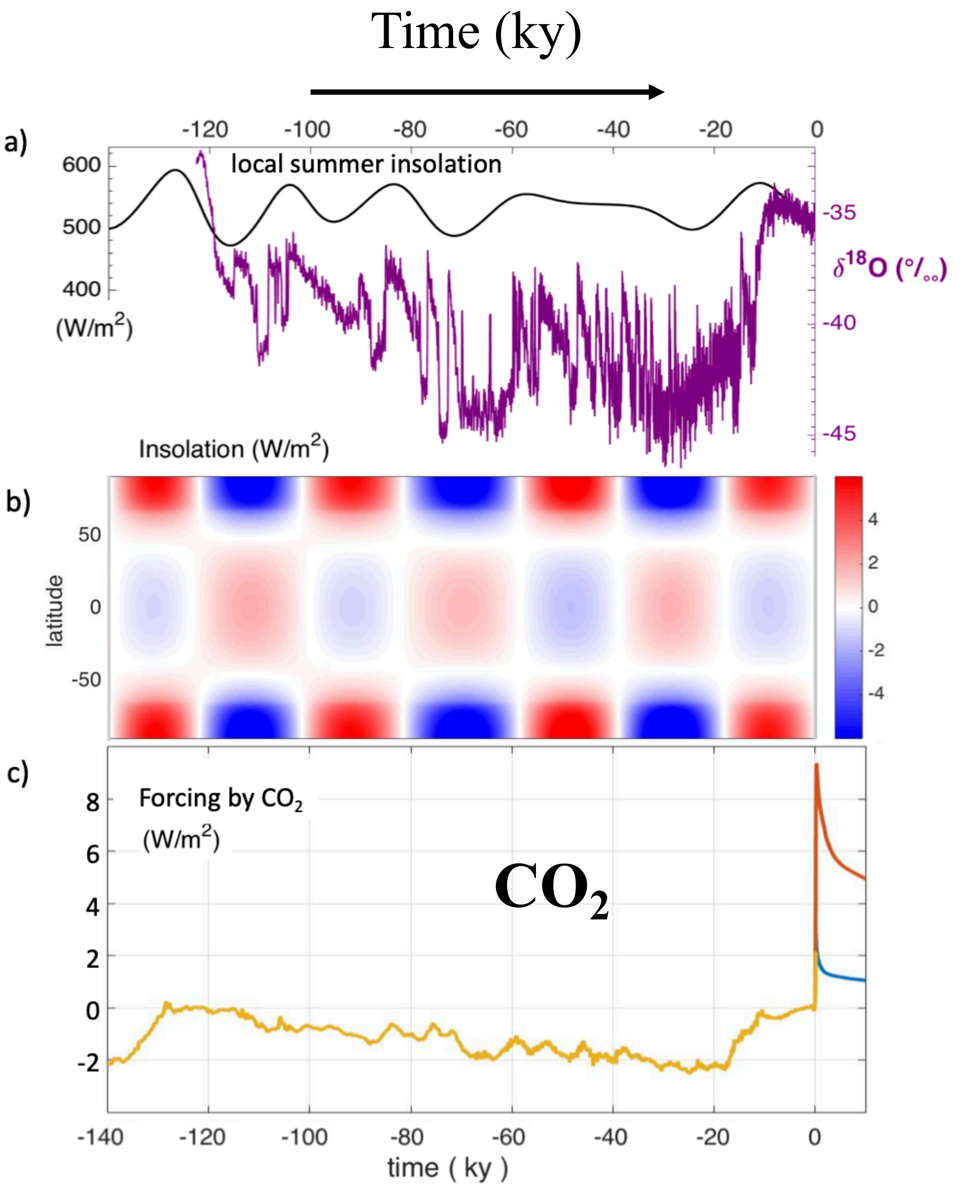
Lohmann, Herold, Fleitmann, in prep

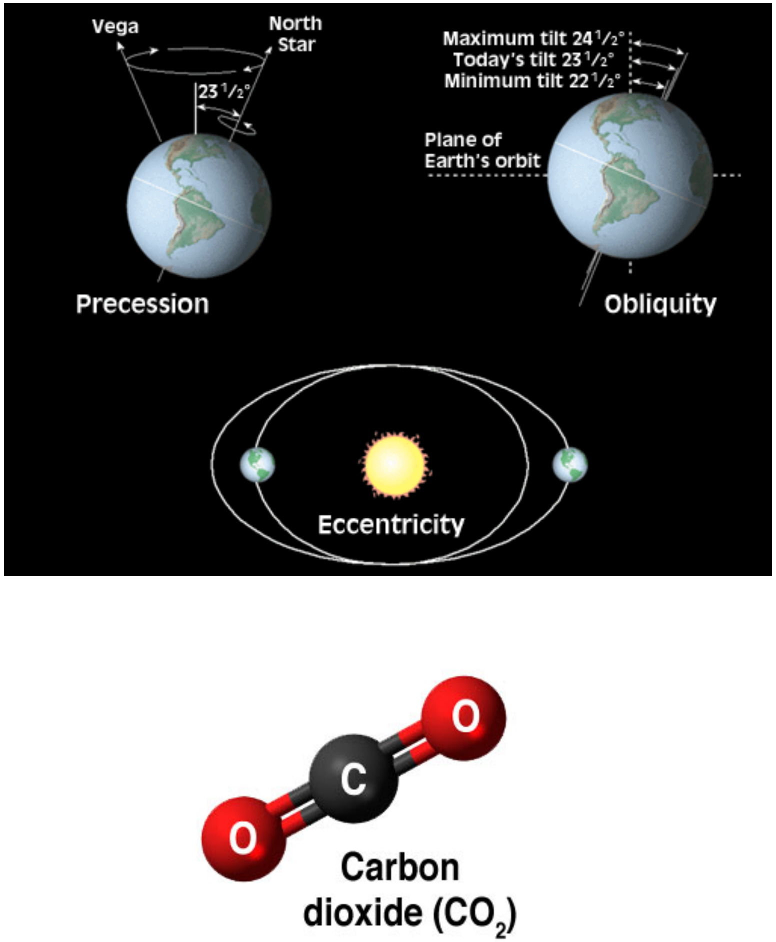
The last 120,000 years



Modulation of local insolation

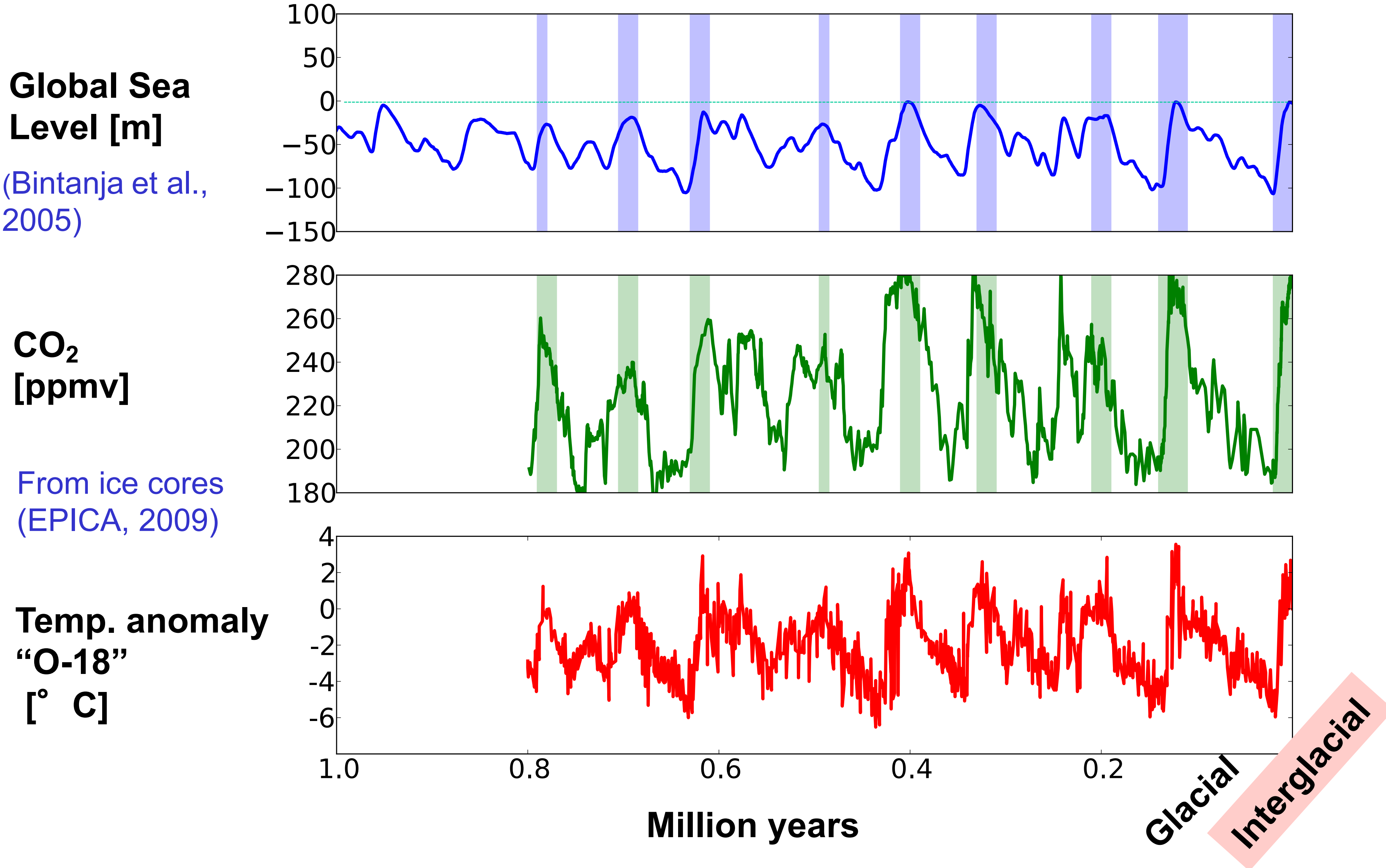
NGRIP, 2004; Berger, 1988



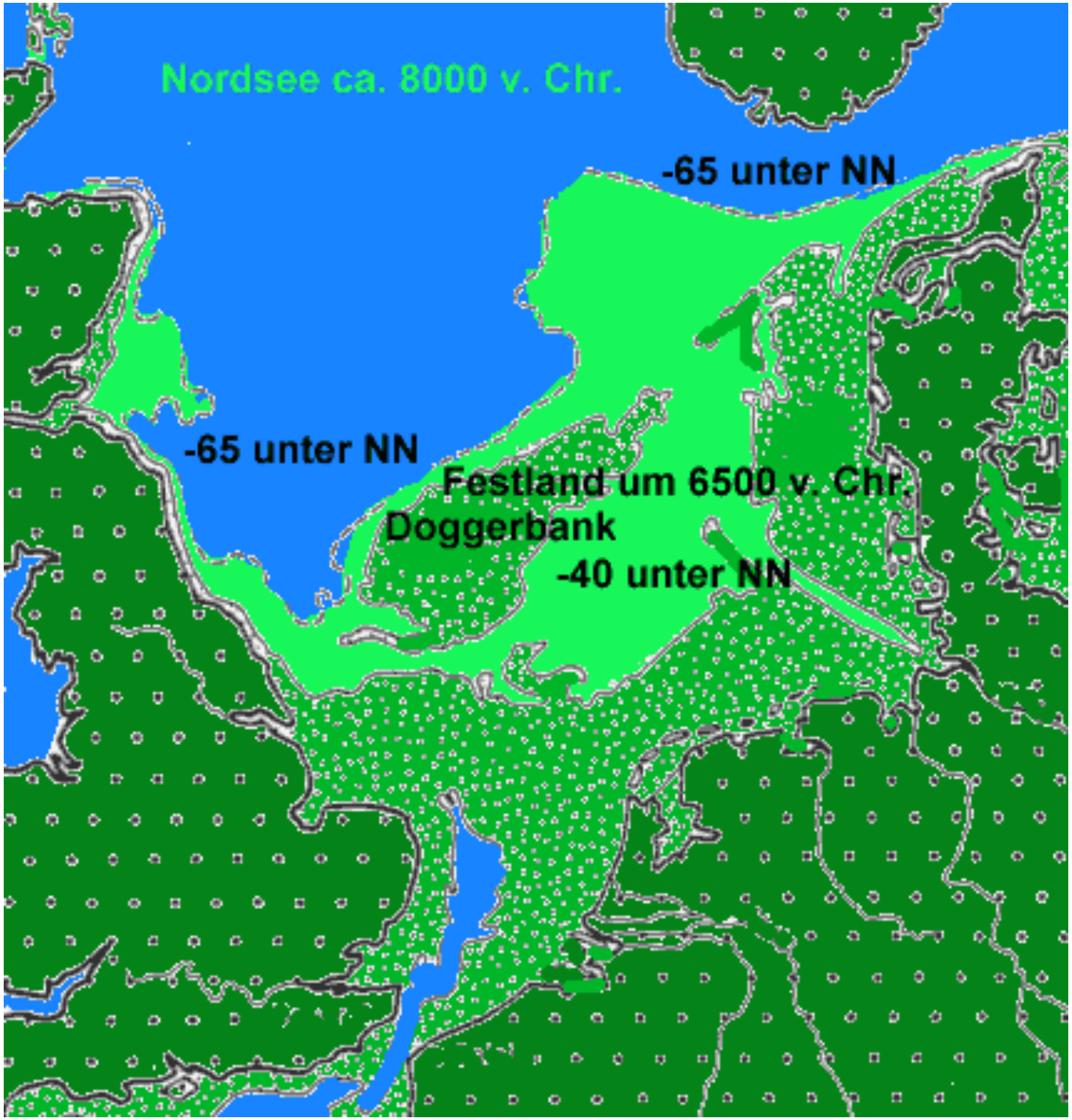


Lohmann et al. (2020) based on NGRIP, 2004; Berger, 1988; Köhler et al., 2017; Archer and Brovkin, 2008

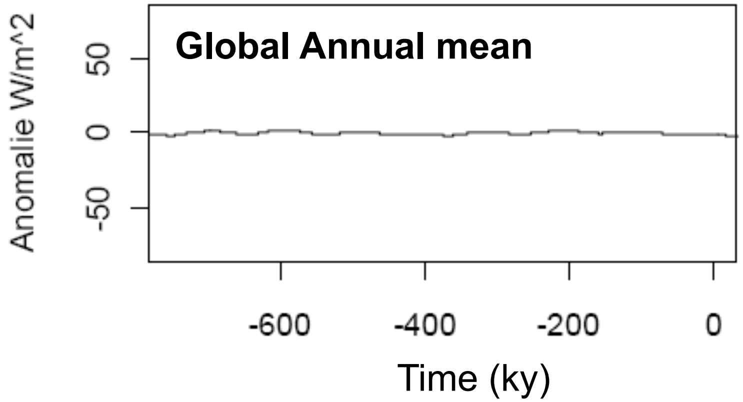
Glacial-Interglacial variability

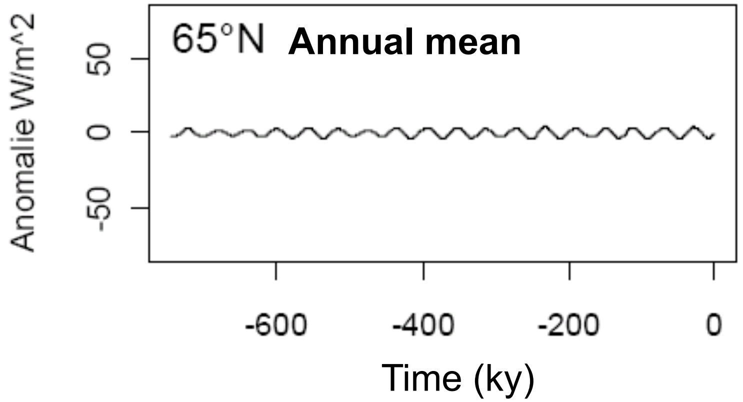


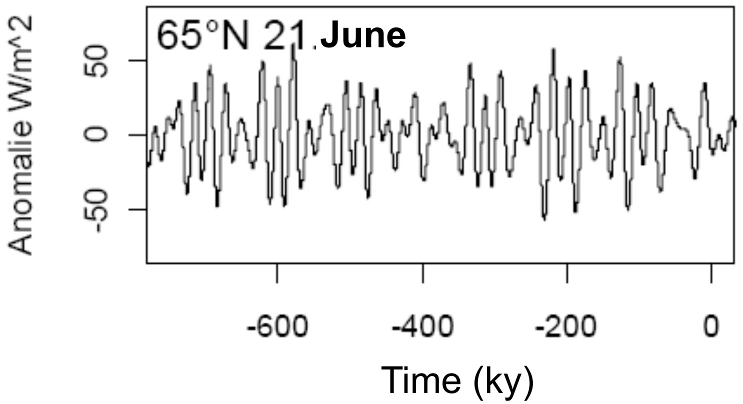
The Brexit is not new !



Insolation: Resulting Effect



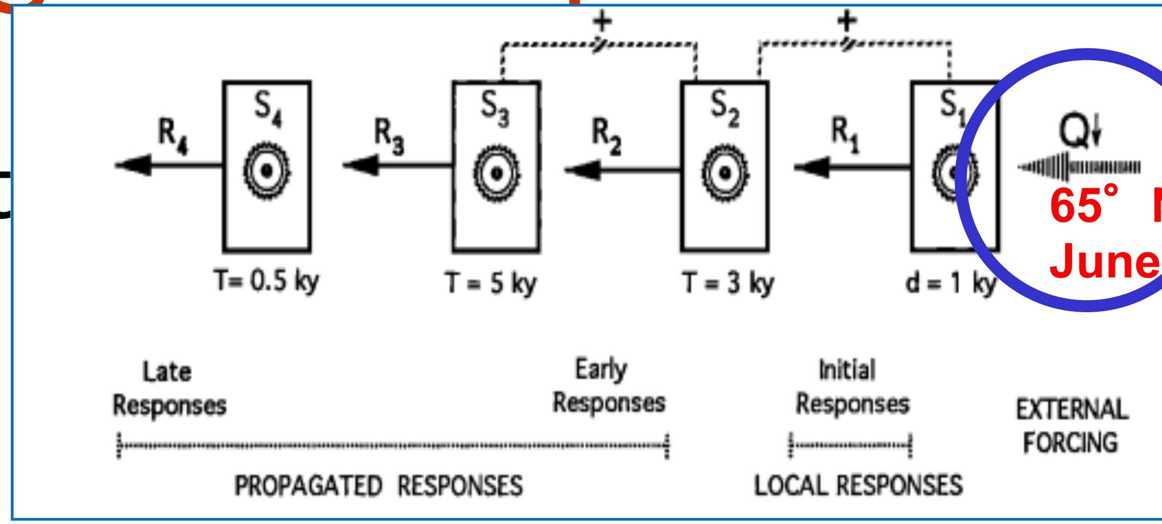




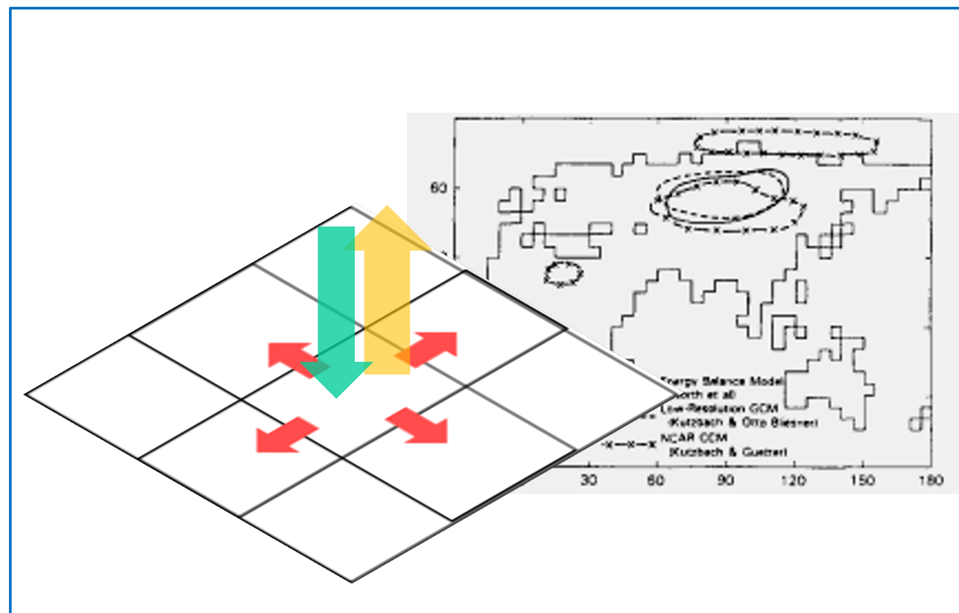
Non-linearities are important

Ice Ages: Concepts

- Global Concept (Imbrie 92)



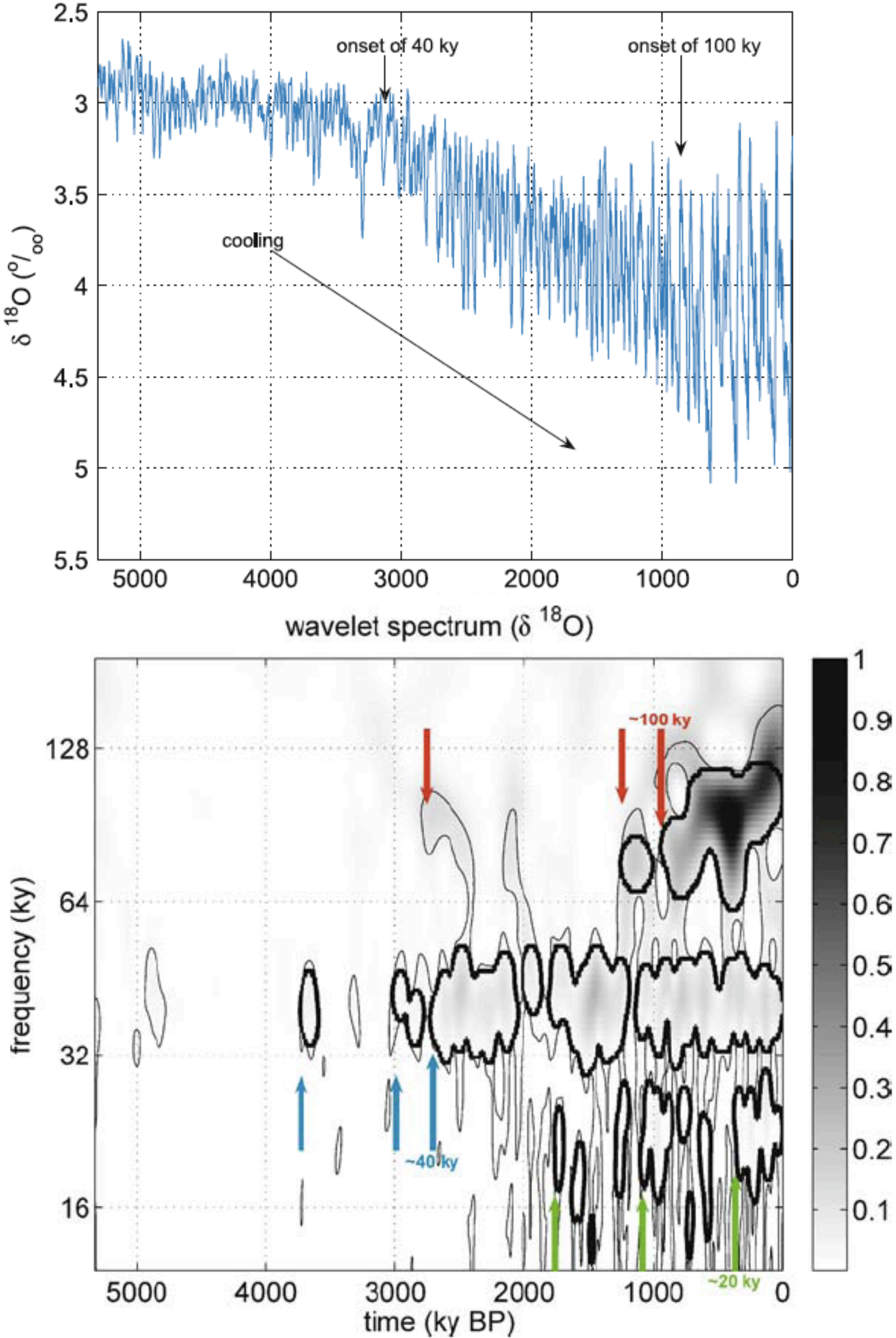
- Local Model (Short et al., 91) 2D linear EBM



- Complex Models

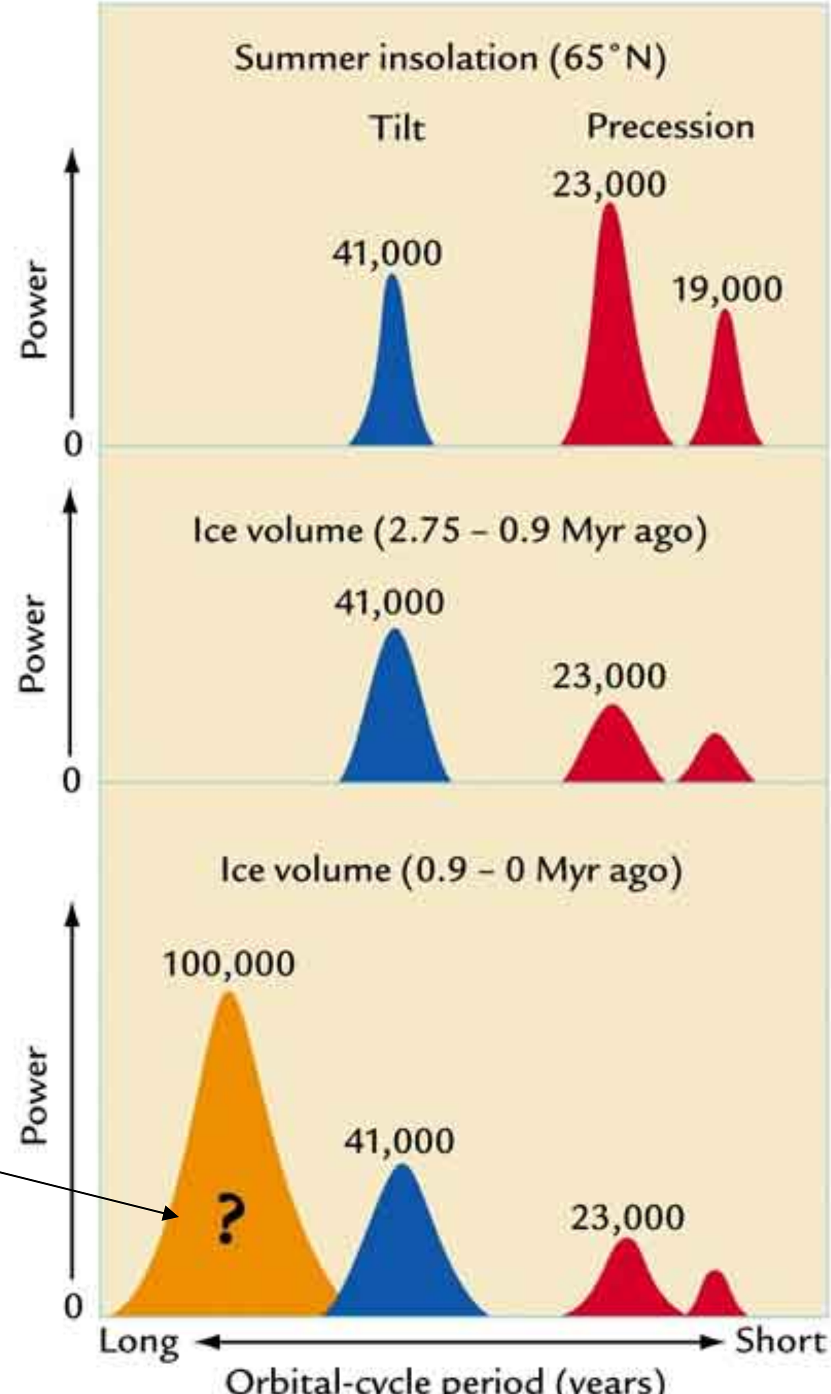
Computer

Ice ages



onset of 40 ky
onset of 100 ky
cooling
δ 18O (°/oo)
wavelet spectrum (δ 18O)
~100 ky
~40 ky
~20 ky
frequency (ky)
time (ky BP)

A holy grail



Summer insolation (65°N)
Tilt
Precession
23,000
41,000
19,000
Power
0
Ice volume (2.75 – 0.9 Myr ago)
41,000
23,000
Power
0
Ice volume (0.9 – 0 Myr ago)
100,000
41,000
?
23,000
Power
0
Long
Short
Orbital-cycle period (years)

Theory of ice ages

External:

Increased eccentricity of the earth's orbit

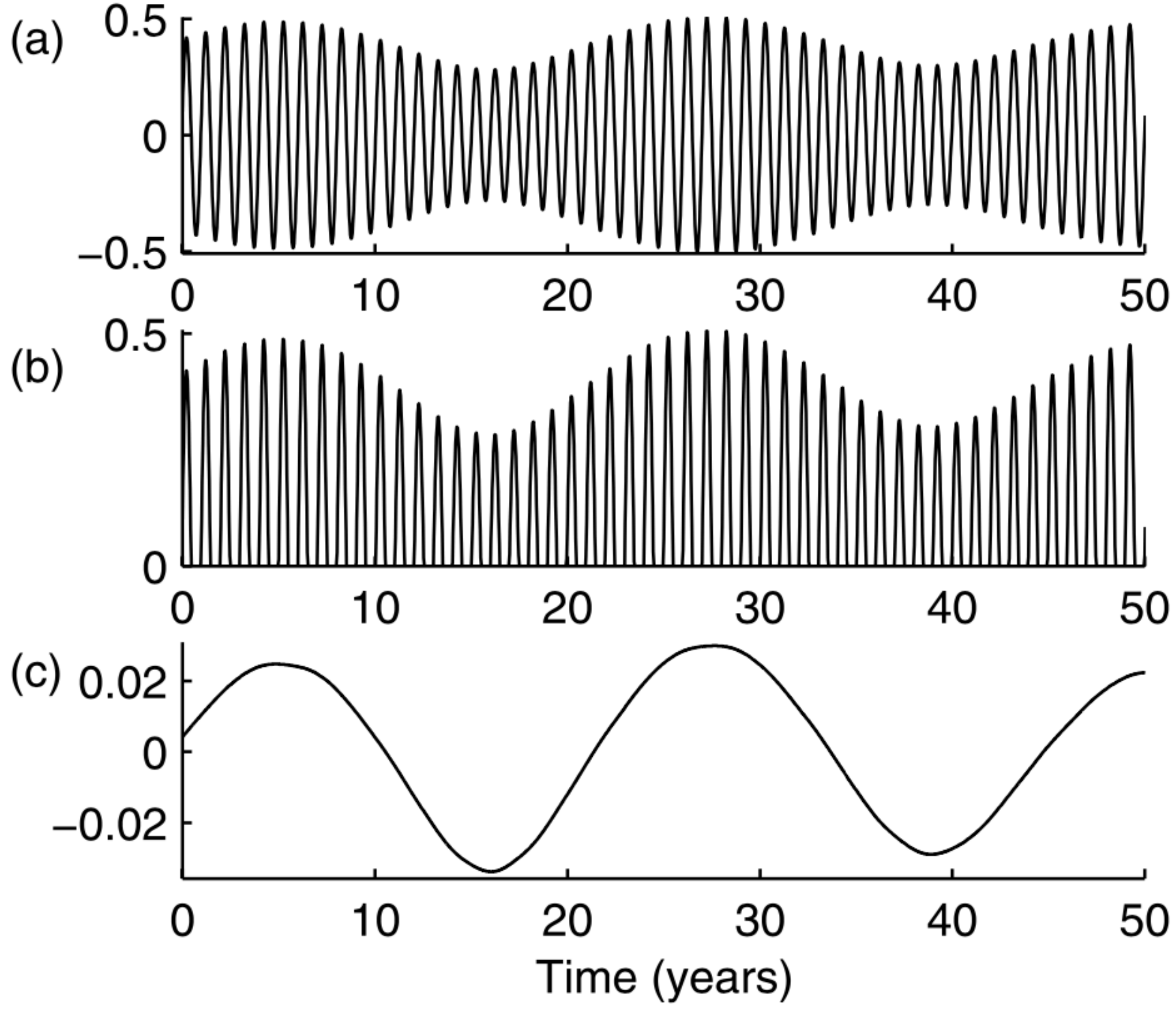
Changes in the intensity of solar radiation

The earth passing through cold regions of space

Internal: ice sheet, CO_2, stochastic

Amplifiers: thresholds, rectification

Theory of ice ages: Rectification



Exercise

- R markdown

http://paleodyn.uni-bremen.de/gl/tmp/Orbital.html

Show that rectification of the precessional signal can lead to variability of the enveloping curve.

Use R program or analytical solution.