Paleoclimate dynamics- identifying driving mechanisms of climate change

Glacial Climate, Orbital Theory

Climate System II course 2020 (3trd lecture)

Gerrit Lohmann

Paleoclimate dynamics

- to identify driving mechanisms for climate change
- external forcing and internal variability of the climate system
- to test models of the Earth system

- statistical analysis of instrumental and proxy data.

Proxy Data

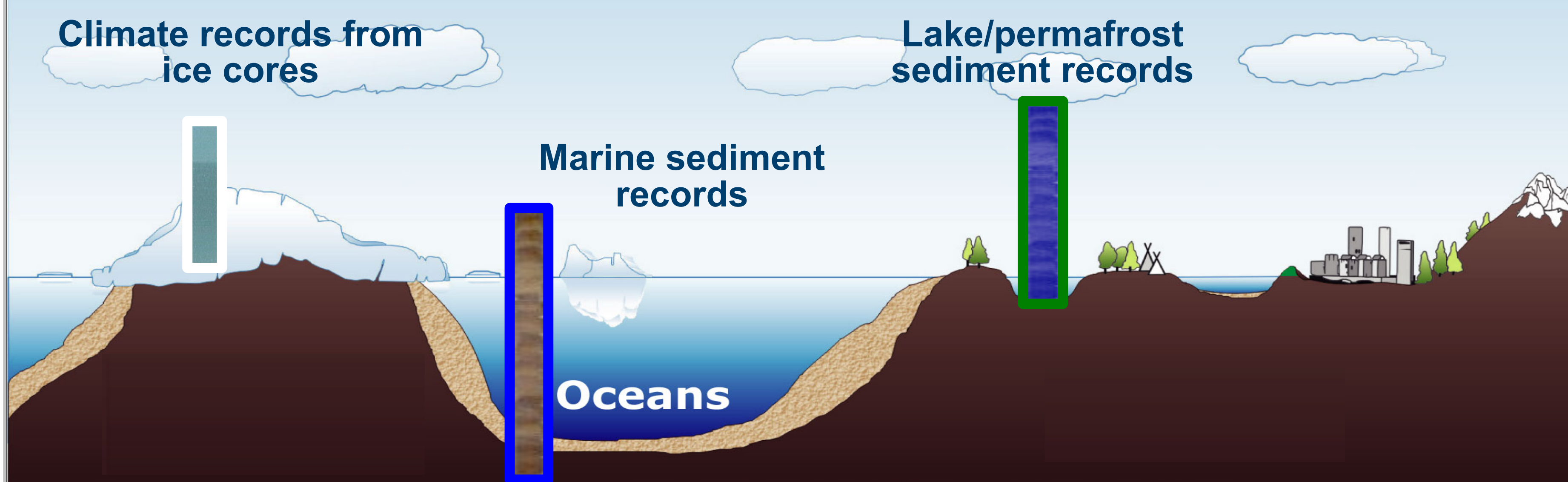
- Indirect data, often qualitative
- Long time series from archives
- Information beyond the instrumental record

Earth System: a polar perspective

Ice drilling camp, 2009

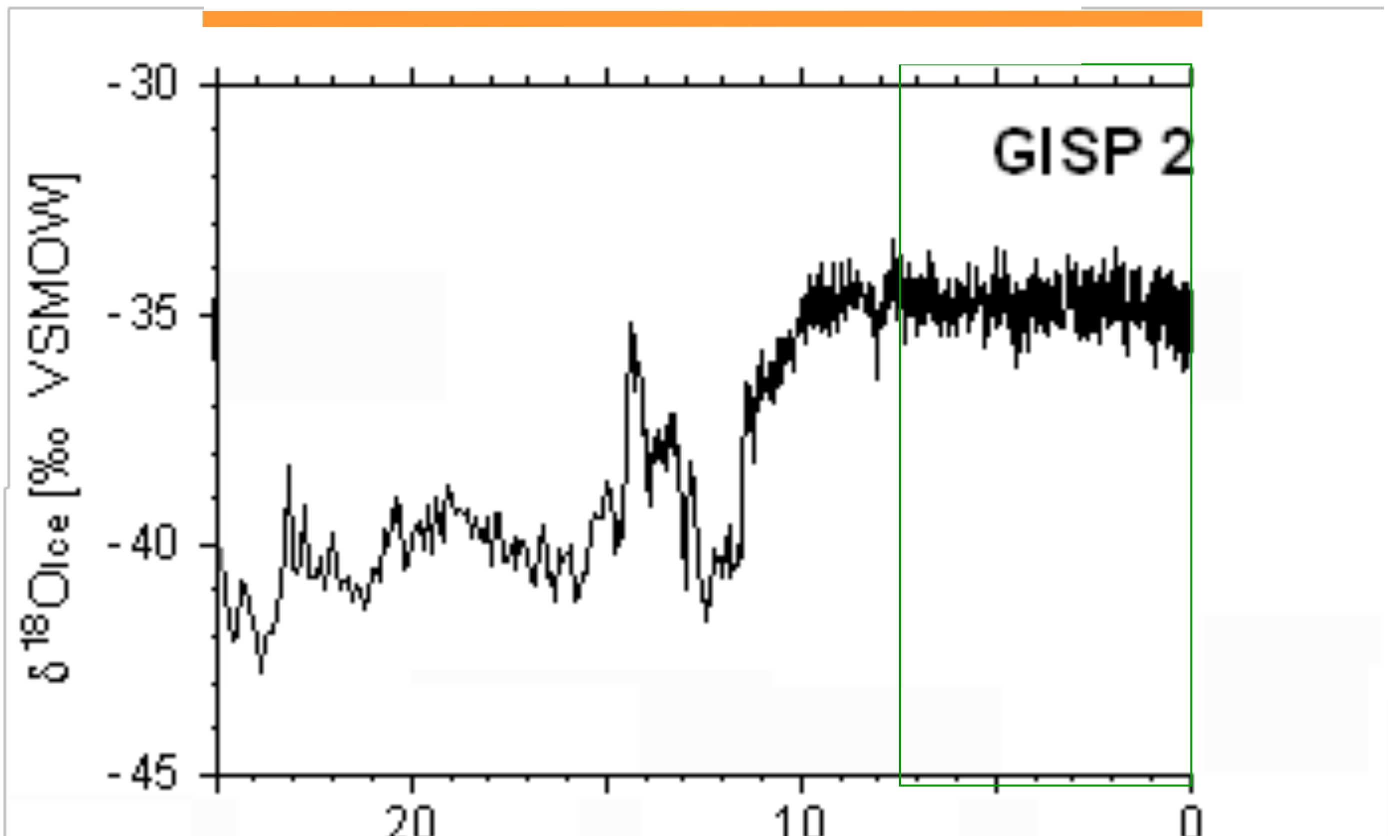
Polarstern, marine sediments

Lake/permafrost sediments

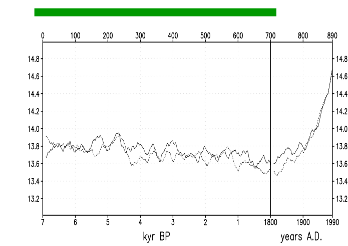


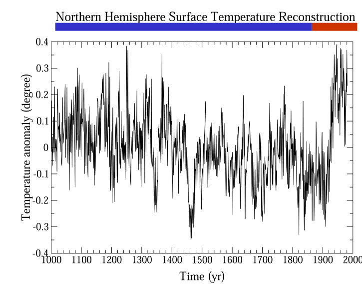
Climate Trends at different Timescales

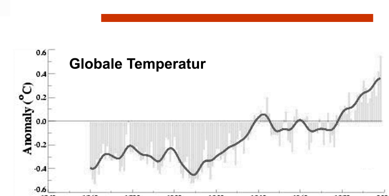
Deglaciation – Greenland ice core

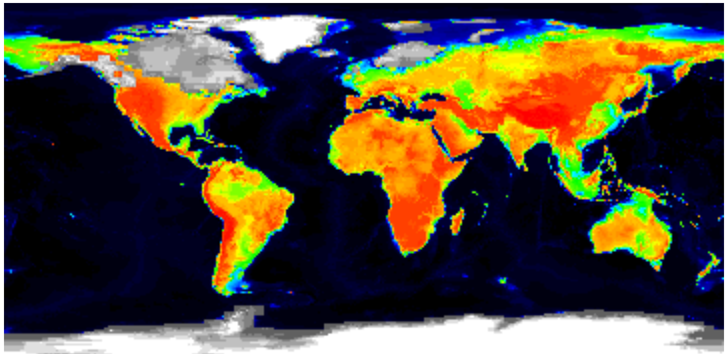


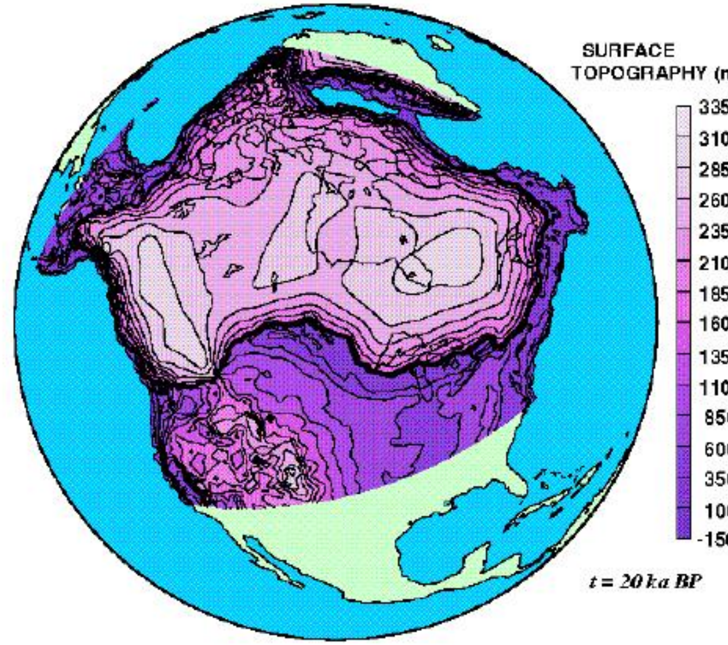
Grootes et al. 2000





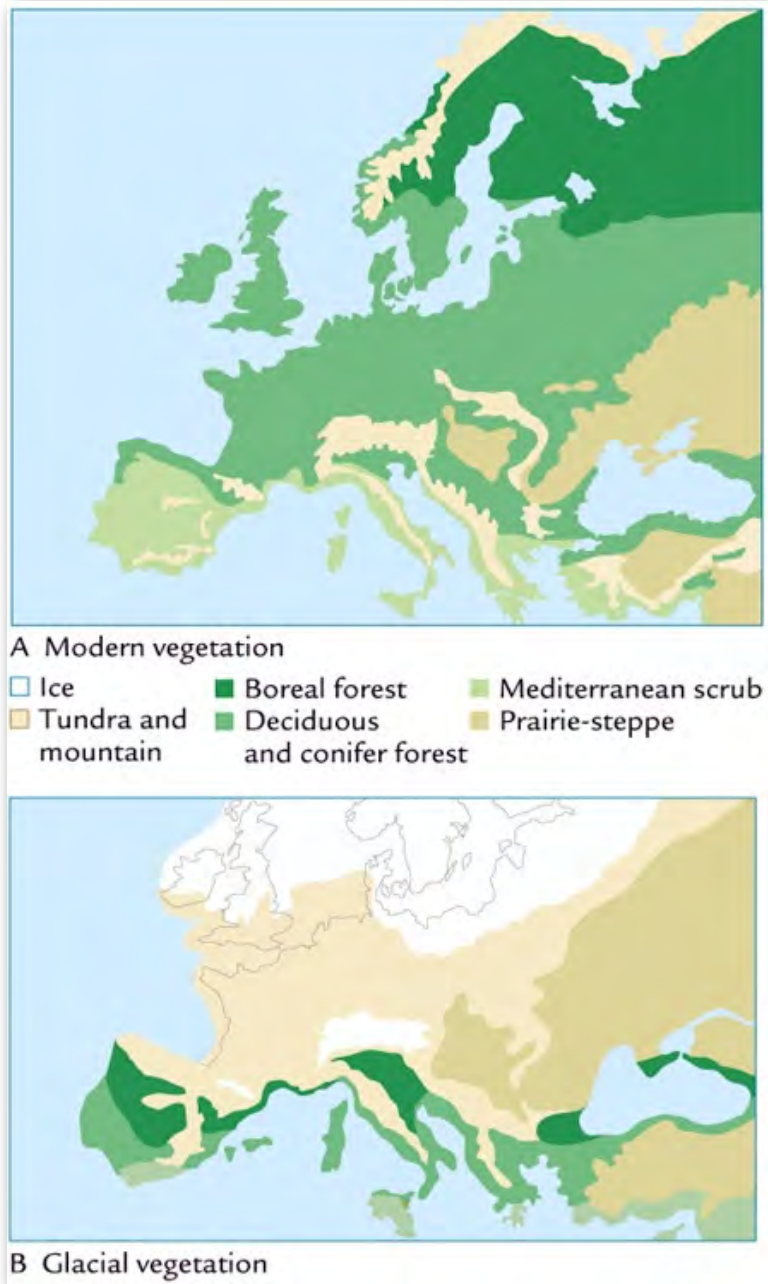






Deglaciation

LGM climate of North America and Europe

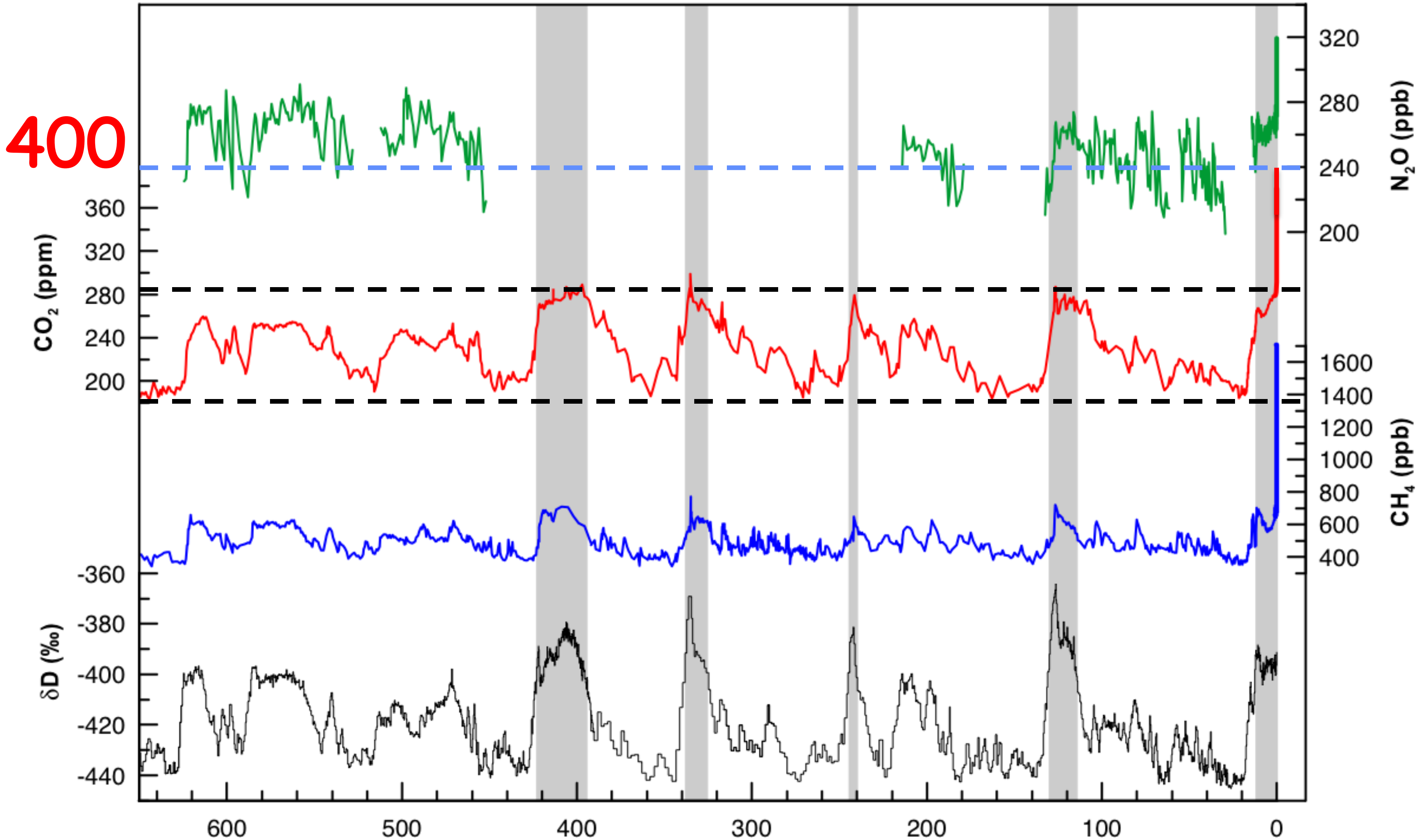


[from: Ruddiman, 2008]

Modern land cover

Glacial land cover

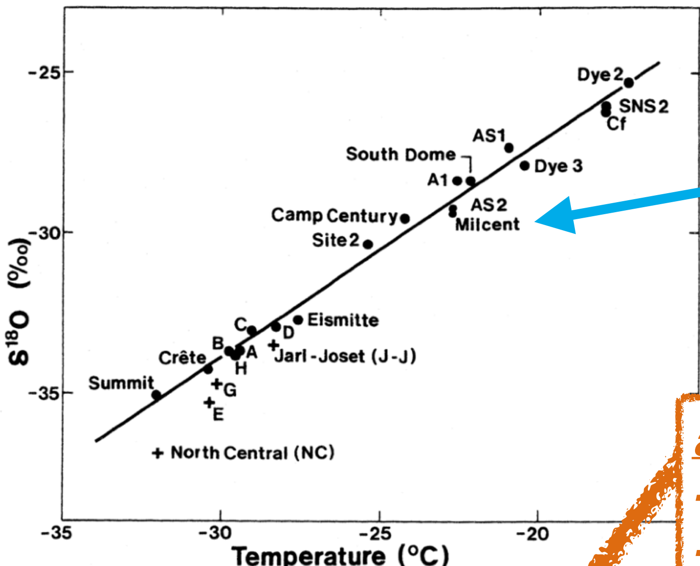
Atmospheric Gas Concentrations from Ice Cores



Time (Thousands of Years Before Present)

EPICA 2008

The use of of δ¹⁸O in precipitation as a temperature proxy



[Johnsen et al., Tellus, 1989]

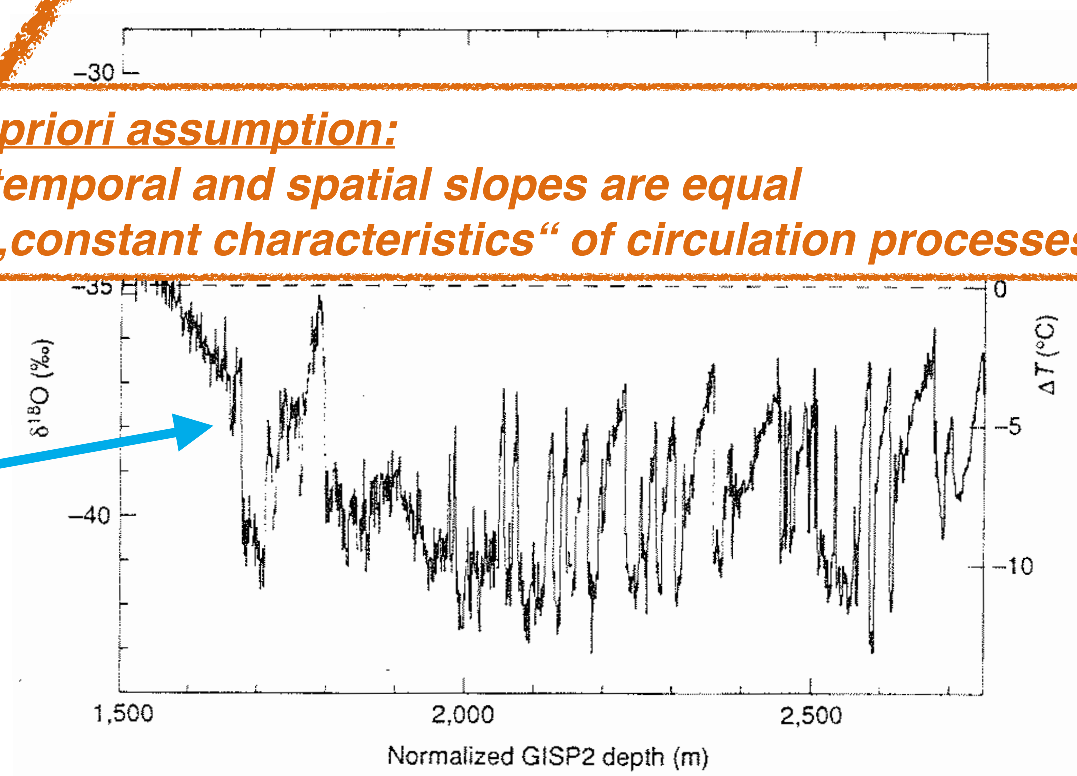
Modern spatial relation between δ¹⁸O and surface temperature (on Greenland):

$$\delta^{18}O = 0.67 \cdot T_{surf}$$

a priori assumption:

- temporal and spatial slopes are equal

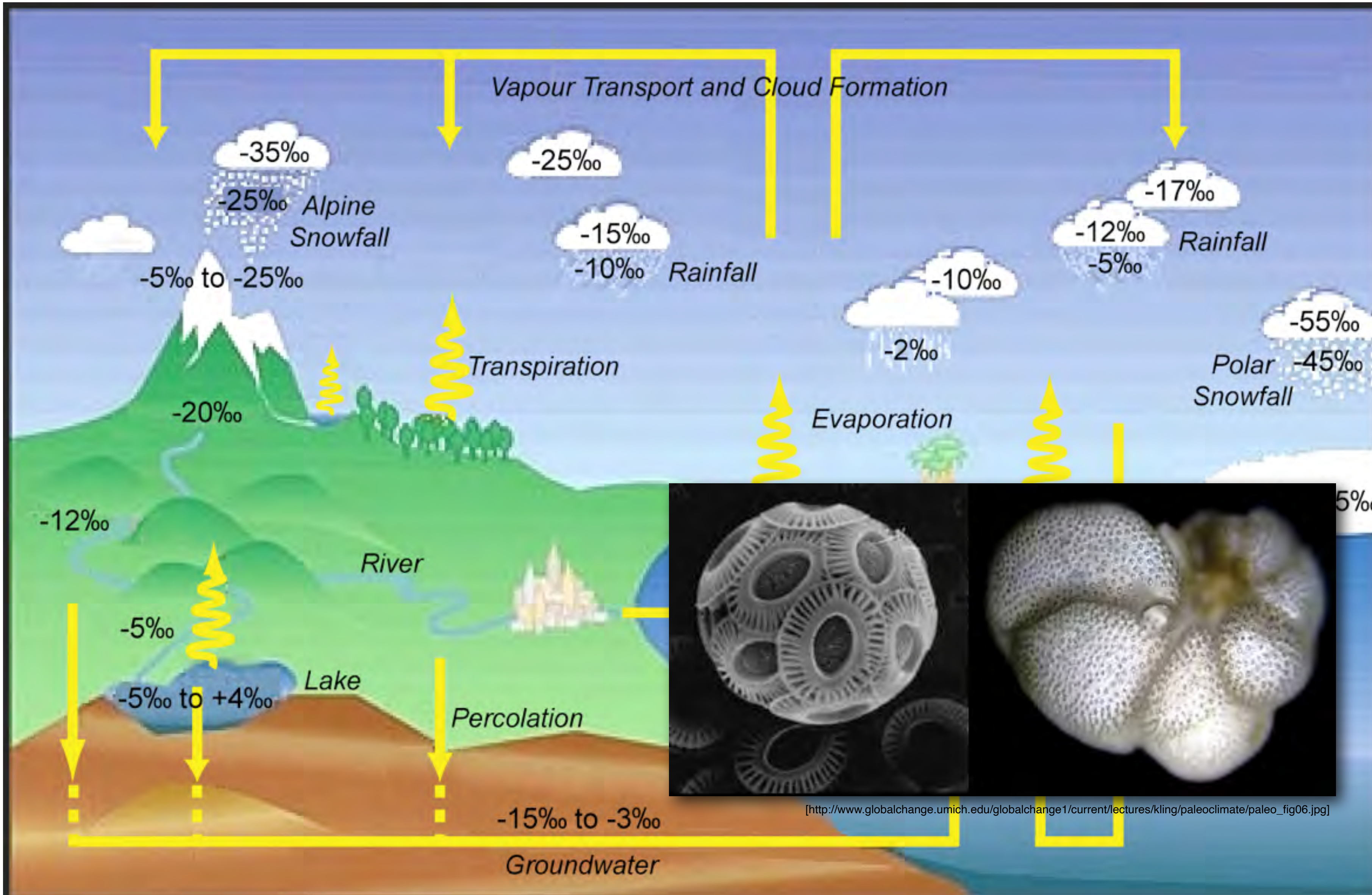
- „constant characteristics“ of circulation processes



[Grootes et al., Nature, 1993]

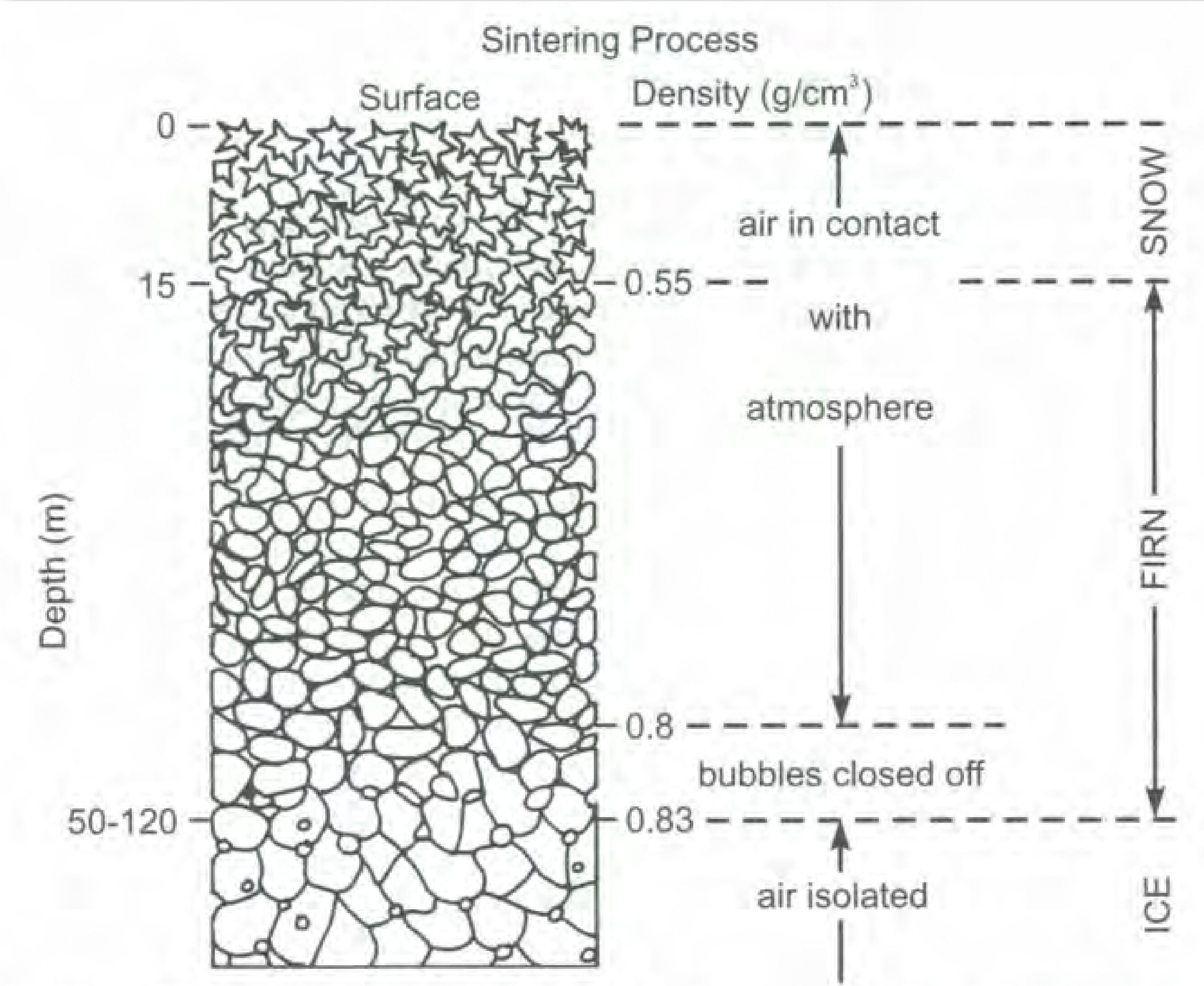
Converting temporal changes of δ¹⁸O into past temperature changes

The δ¹⁸O signal in marine sediment cores



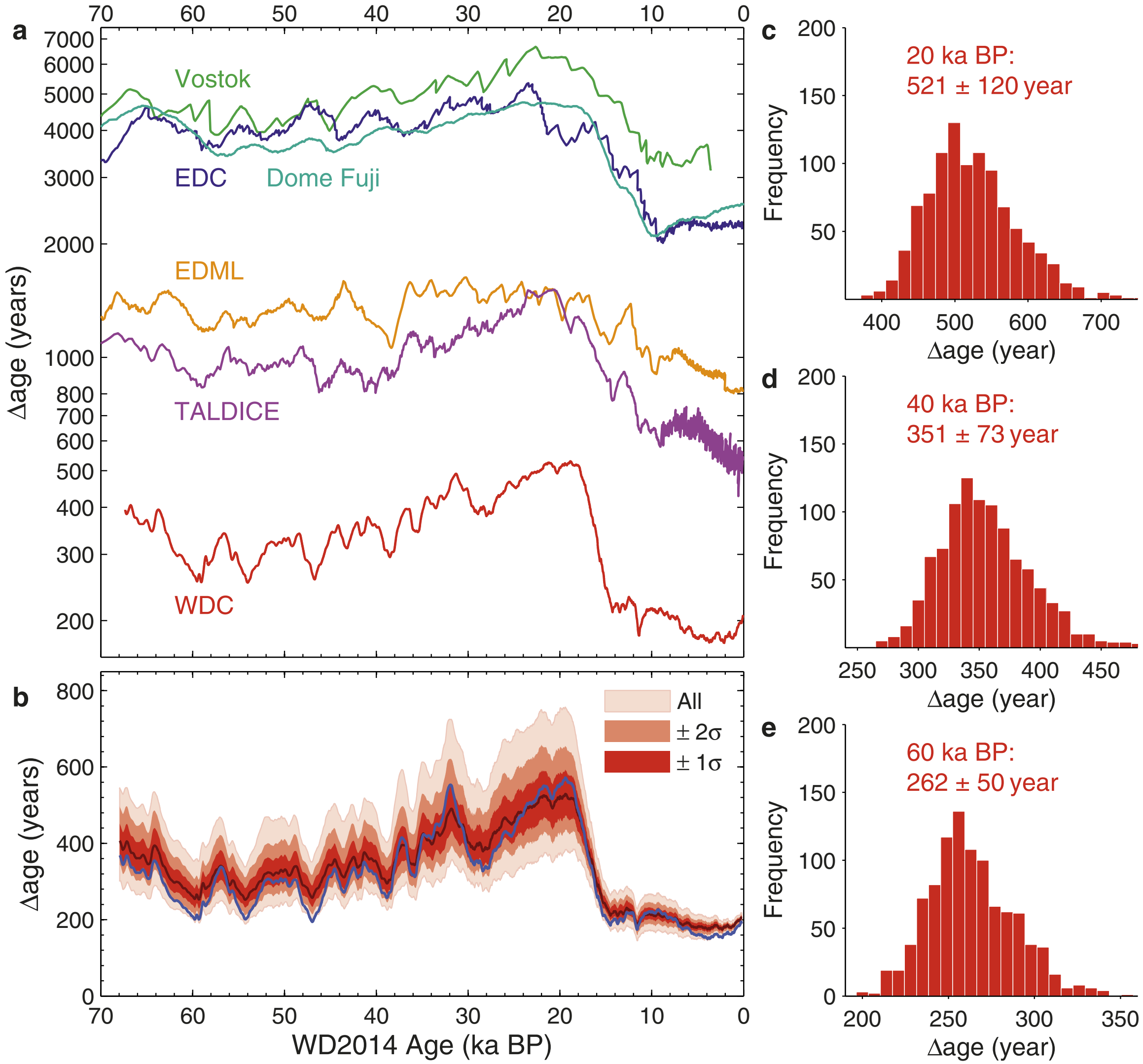
[plot adapted from the GNIP brochure, IAEA, 1996]

Transformation of snow to ice



Bradley, Abb. 5.30

Example: difference between ice age and gas age



Extended Data Figure 1 | Difference between gas age and ice age (Δage) at WAIS Divide. **a**, Comparison of WDC Δage with other Antarctic cores. Ice core abbreviations: EDC, EPICA Dome Concordia; EDML, EPICA Dronning Maud Land; TALDICE, Talos Dome; WDC, WAIS Divide. Δage values are taken from refs 23, 63–65. The vertical axis is on a logarithmic scale. **b**, Δage uncertainty bounds obtained from an ensemble of 1,000 alternative Δage scenarios; details are given elsewhere[23]. A Δage scenario obtained with an alternative densification model (ref. 39 instead of ref. 38) is shown in blue. **c–e**, Histograms of the 1,000 Δage scenarios at 20 kyr BP (**c**), 40 kyr BP (**d**) and 60 kyr BP (**e**); stated values give the distribution mean ± the 2σ standard deviation.

WAIS Divide Project Members, Nature, 2015

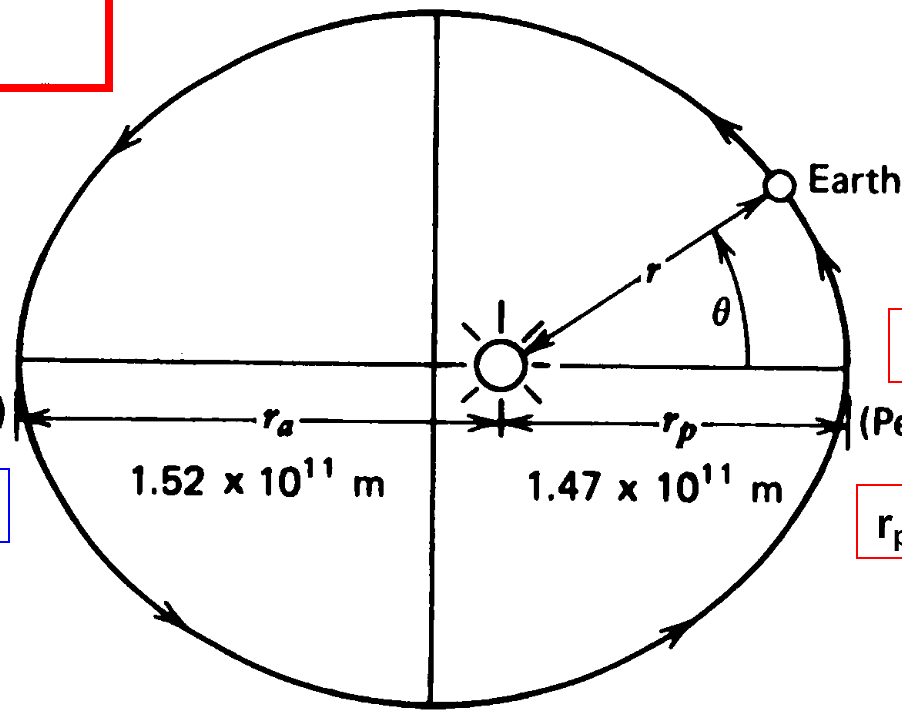
The earth's orbit (shown with an exaggerated eccentricity ε)

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

cos θ = -1

(Aphelion ~ July 4)

r_a = $r_{Aphelion}$ = a (1+ ε)



θ =0 ; cos θ =+ 1

(Perihelion ~ Jan. 4)

r_p = $r_{Perihelion}$ = a (1- ε)

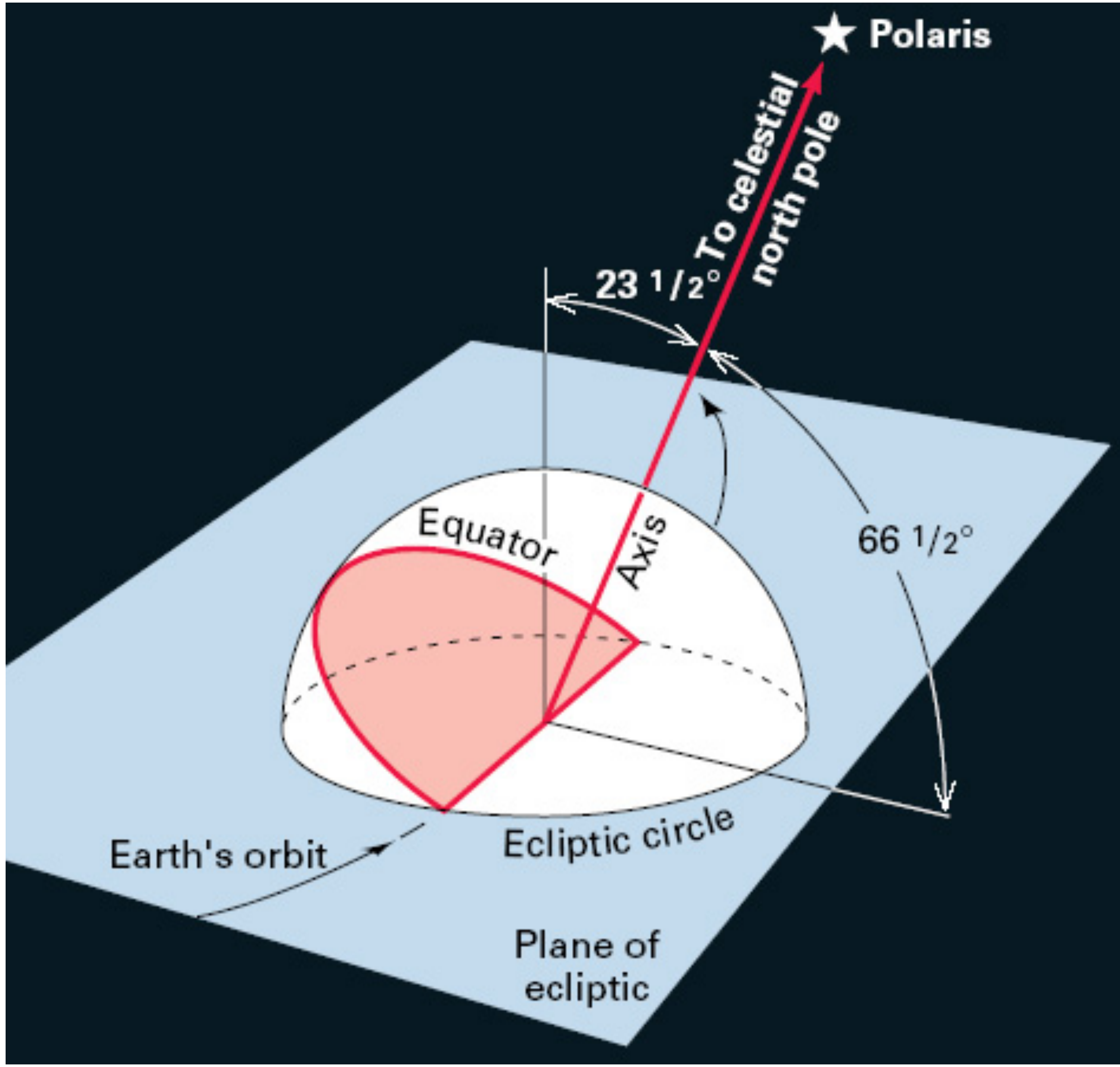
the mean orbital distance is **a = 149,7 [Gm]** = 149,7 Mio km
and the eccentricity is **ε = 0.0167**

also ca. :: r = a +/- 2%

Quelle:/ Wieder82, fig 2.1; p.20/

The tilt of
the Earth‘s axis

with respect to
its orbital plane
(ecliptic)



BQuelle: **Strahler: „Physical Geography“**,2002, Wiley-Verlag, ISBN=0-471-23800-7, Bild3.15,p.55

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

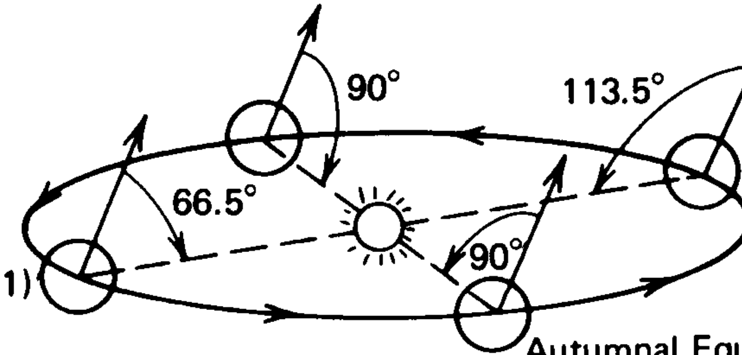


Fig 2.2: The **seasonal variation of the angle** between **the earth 's polar axis** and the **earth-sun line**.

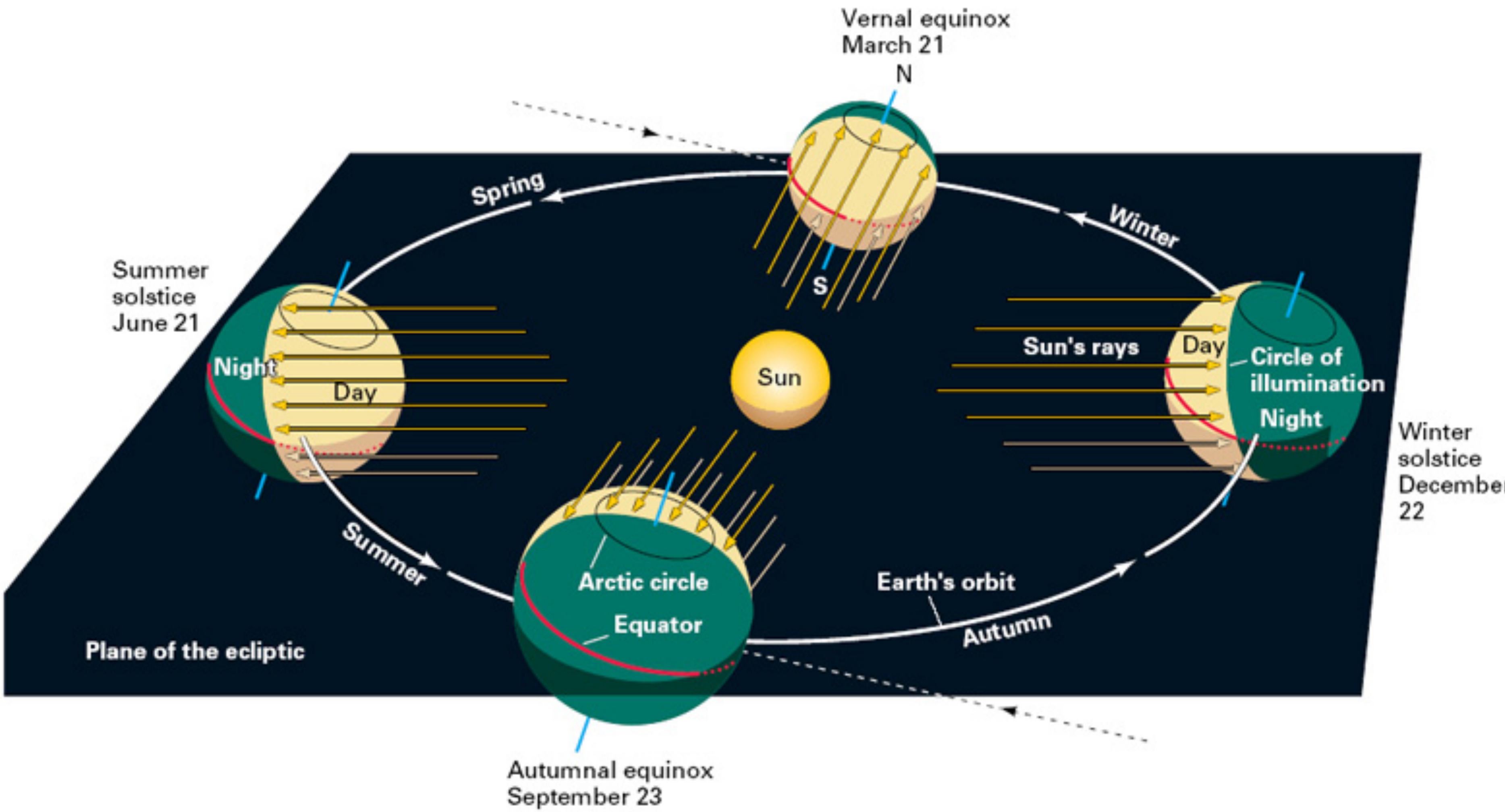
The angle of inclination (between the **earth axis** of rotation and the **line perpendicular** to the **ecliptic** plane) **is 23.5° and remains constant throughout the year.**

The rate of rotation is also constant and equal to one rotation every 23.93 hr = a sideral day..

Summer solstice (June 21) :	earth axis of rotation is tilted	90 - 23,5 = 66.5 °	toward the sun
Winter solstice (December 21) :		90 + 23.5 = 113.5°	away from the sun
Autumnal equinox (September 23) :		90 °	
Vernal equinox (March 21) :		90°	

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

The 4 seasons



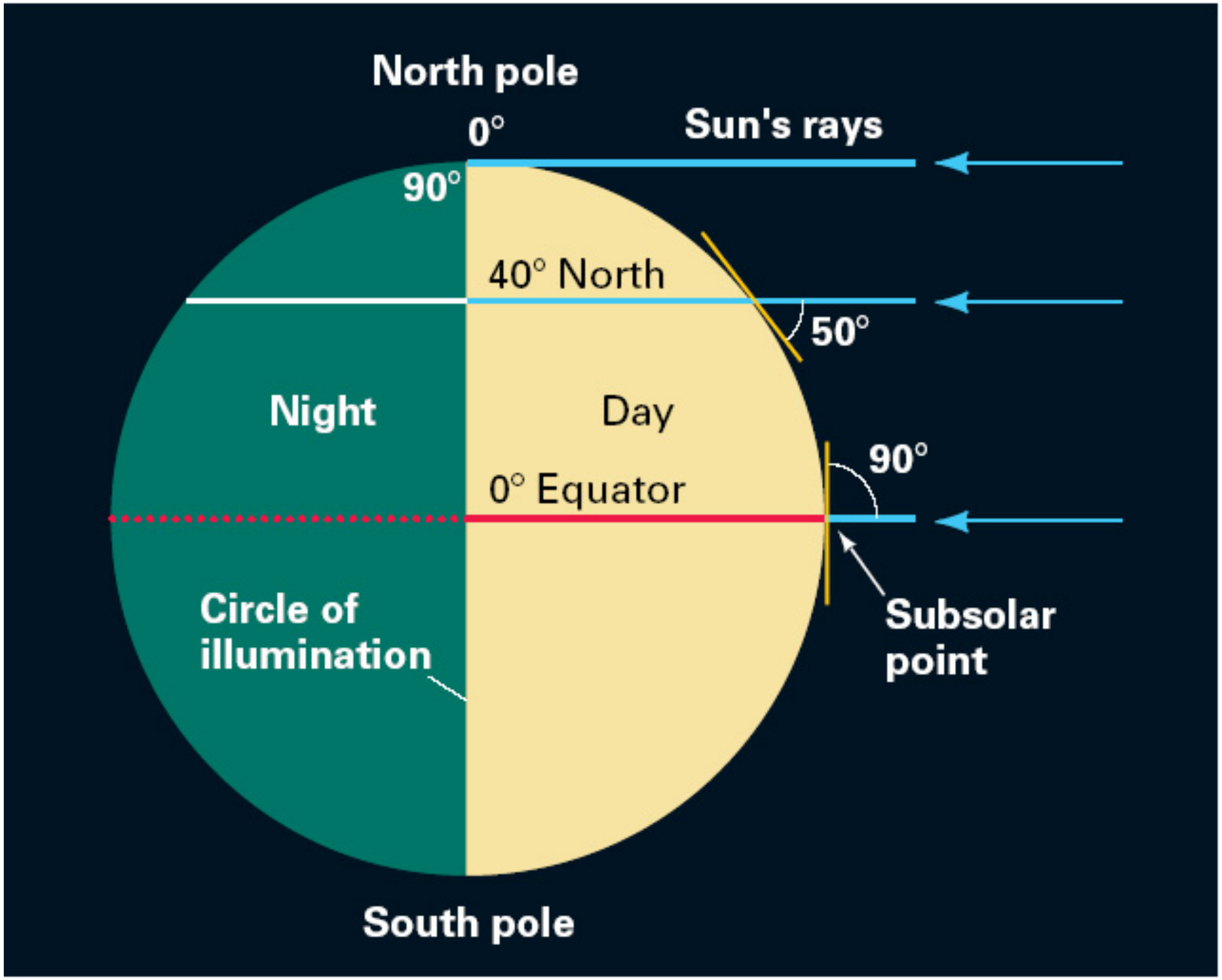
BQuelle: **Strahler: „Physical Geography“**,2002, Wiley-Verlag, ISBN=0-471-23800-7, Bild3.16,p.55 bzw. G4e_01_17, (ein Buch mit wunderschönen Bildern)

Equinox

at equinox, the circle of illumination passes through both poles

the subsolar point is the equator

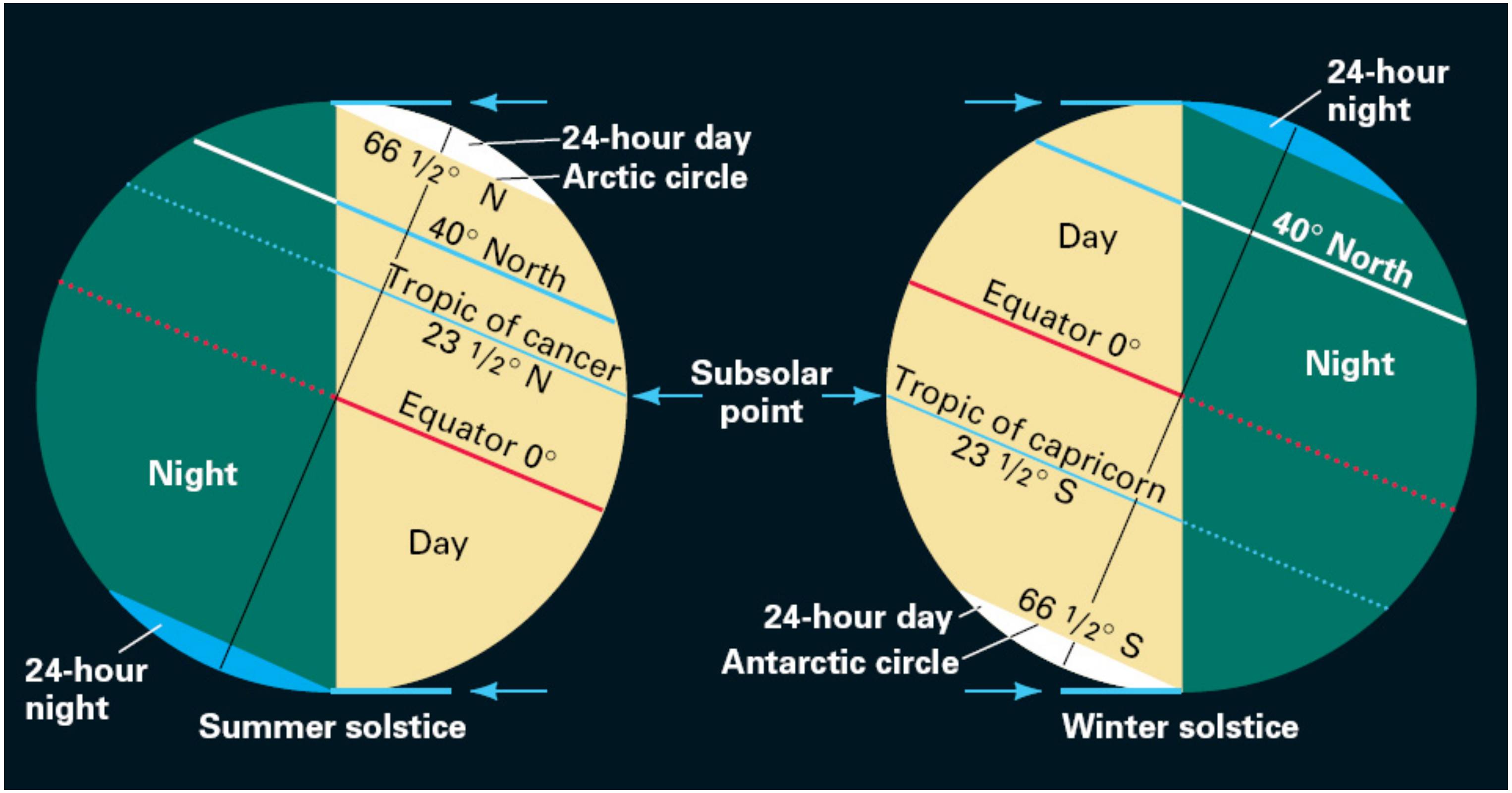
each location on Earth experiences 12 hours of sunlight and 12 hours of darkness



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)

Declination over the year

the latitude of the subsolar point marks the sun's declination which changes throughout the year

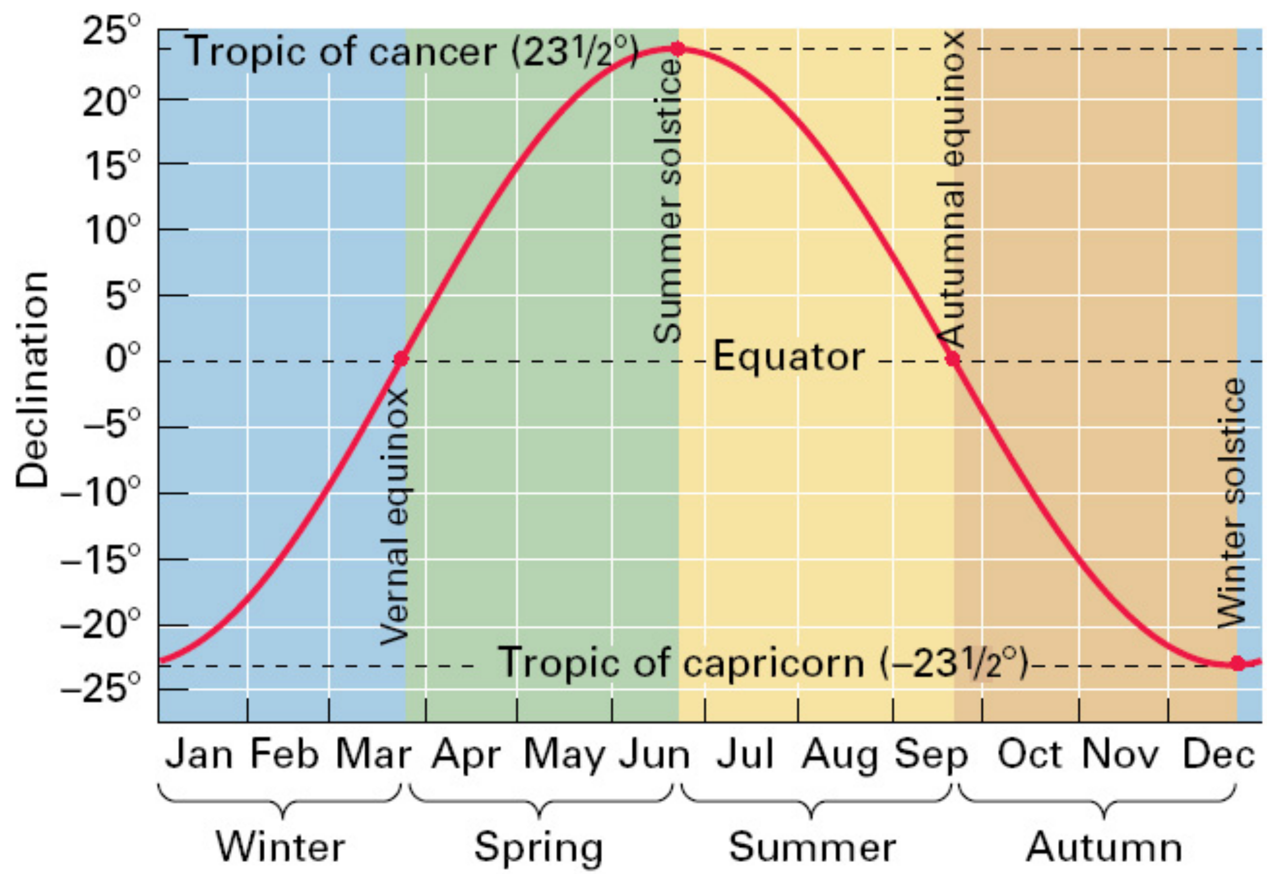


Figure 1.20, p. 42

BQuelle: **Strahler: „Physical Geography“**,2002, Wiley-Verlag, ISBN=0-471-23800-7, Bild3.16,p.55 [bzw. Fig.1.20,p42] (ein Buch mit wunderschönen Bildern)

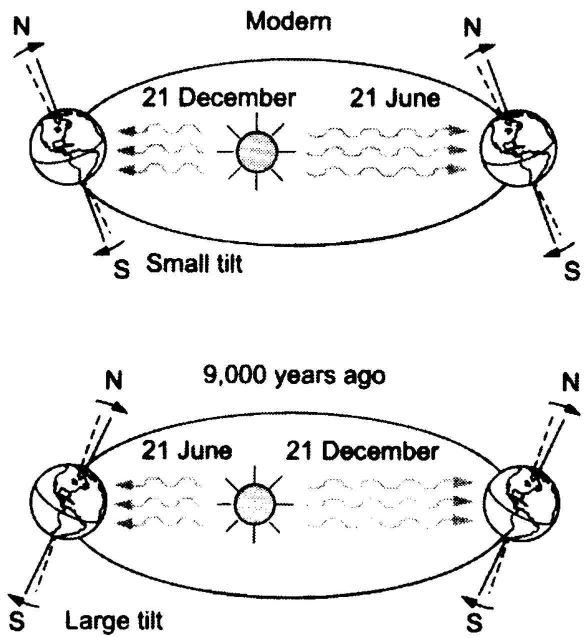
Configuration of the earth's orbit 9000 years ago

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°



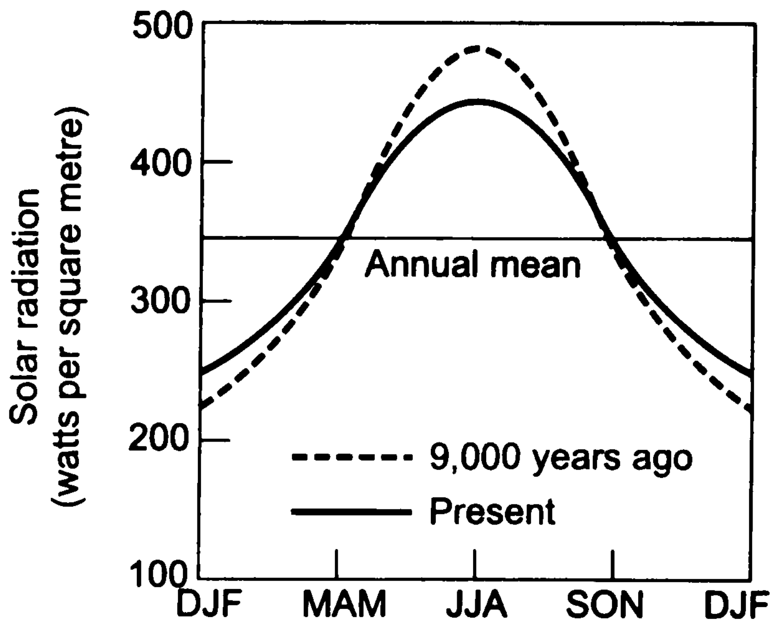


Fig. 5.19: Changes in the **Earth's elliptical orbit** from the present configuration to **9,000 years ago**.(left)

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.

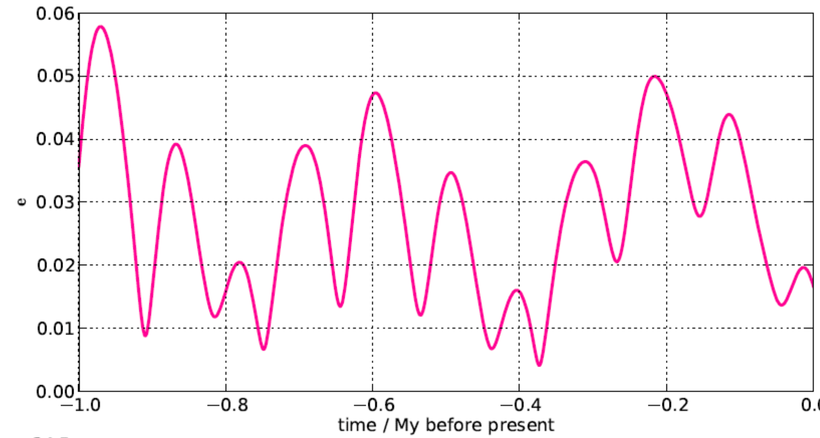
Urquelle:J.E. Kutzbach in „Climate System Modelling" (1992). Quelle:/ Houghton, J.: „ Global Warming" (1997), fig 5.19; p.82/

Orbital parameters

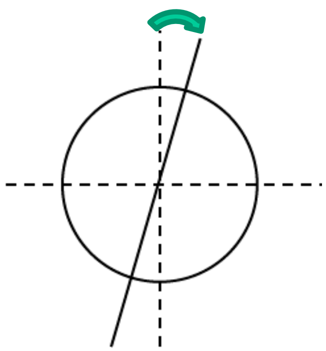
time

Excentricity

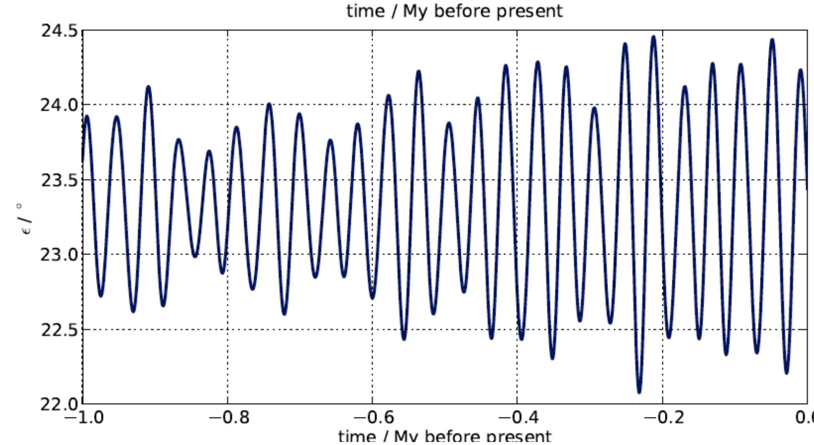
Periods:
100, 400 ky



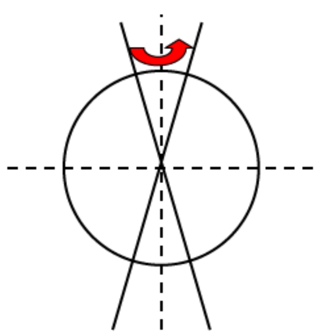
Obliquity



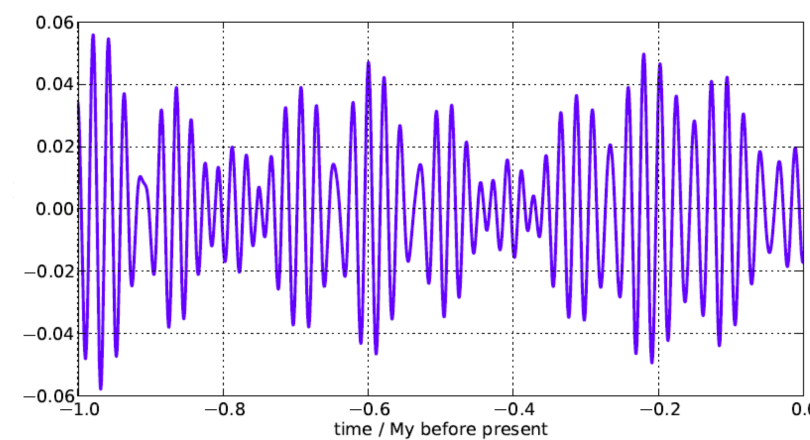
Periods:
39, 41, 54 ky
Modul. 1.2 My



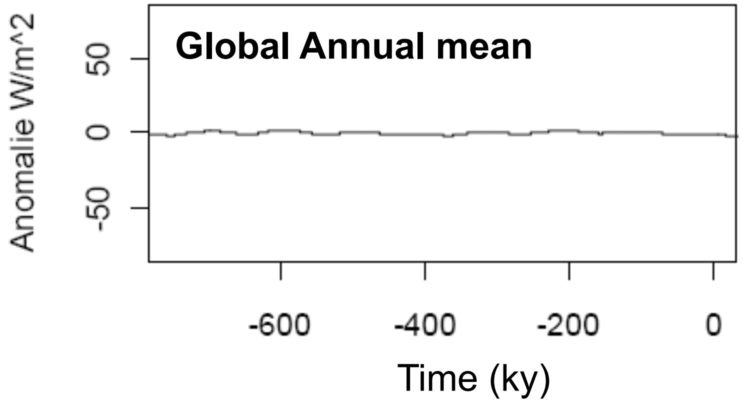
Precession

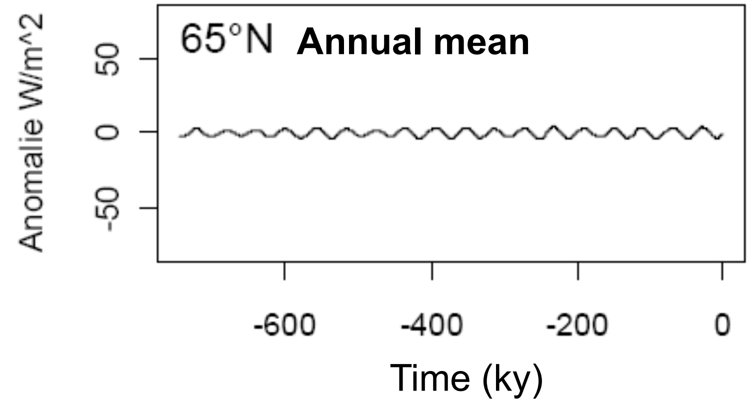


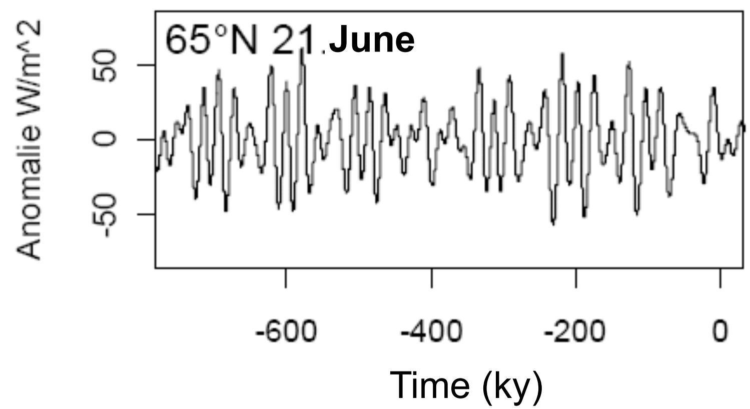
Periods:
19, 23 ky
Modul. Excentr



Resulting Effect

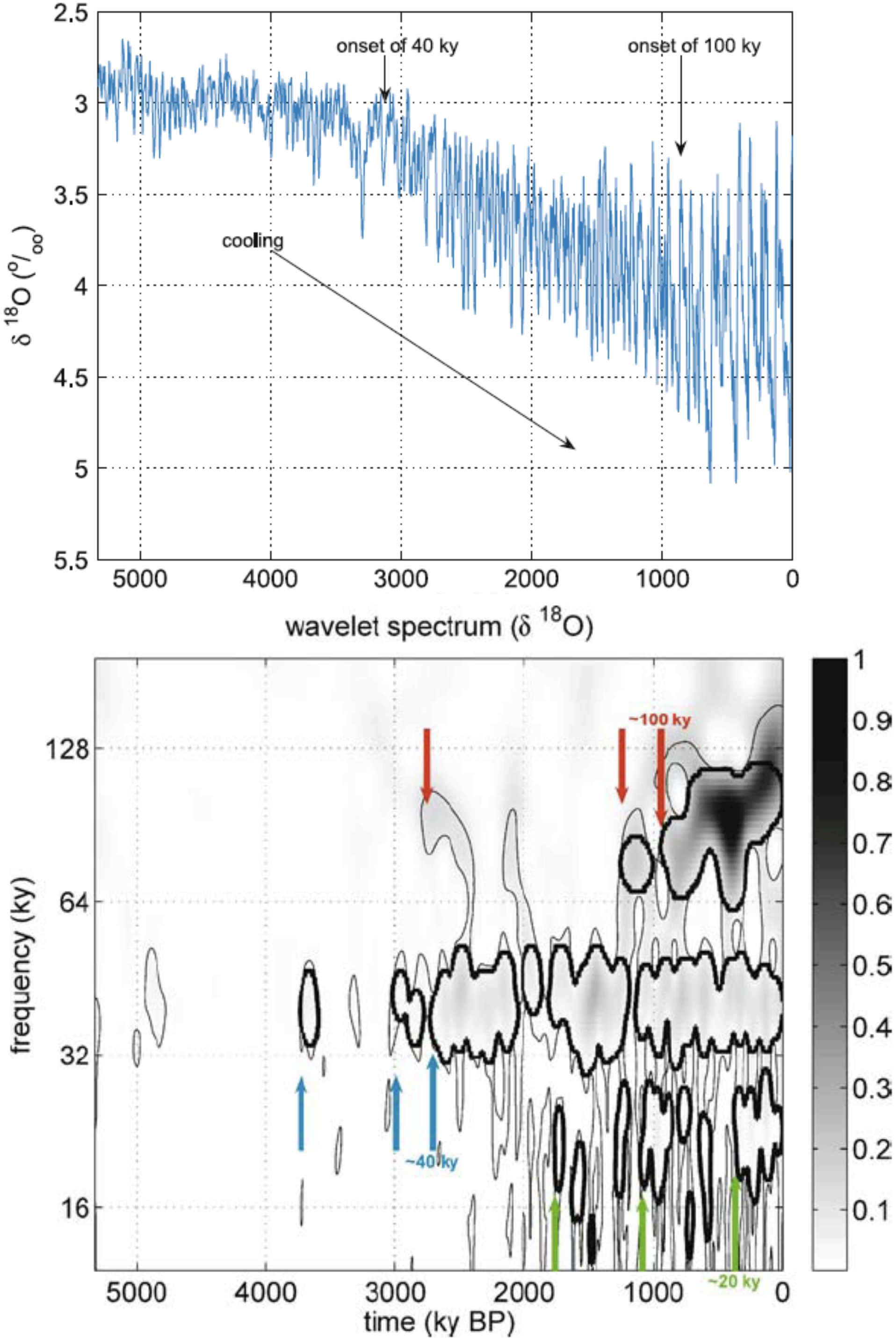






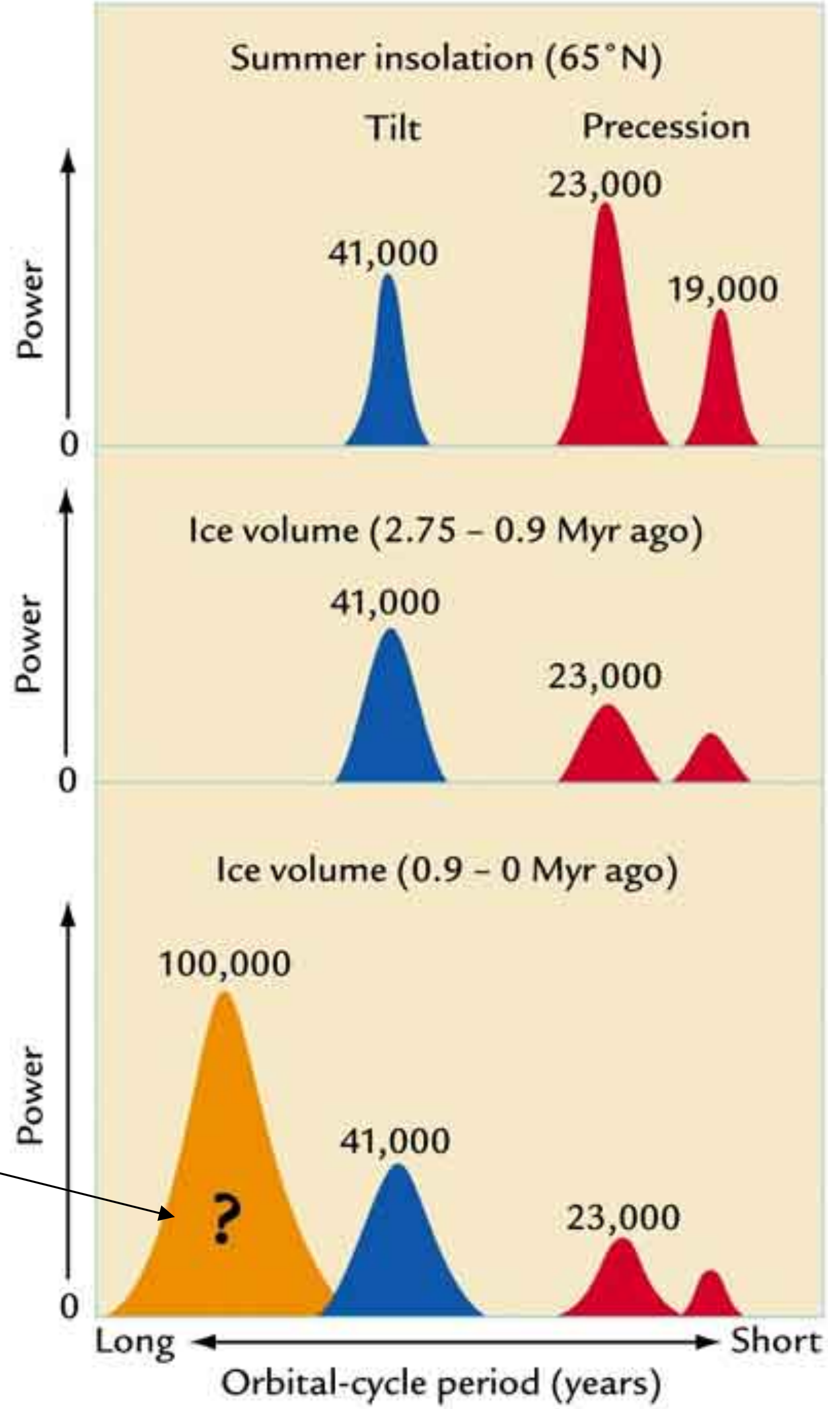
Non-linearities are important

Ice ages



onset of 40 ky
onset of 100 ky
cooling
δ 18O (o/oo)
2.5
3
3.5
4
4.5
5
5.5
5000
4000
3000
2000
1000
0
wavelet spectrum (δ 18O)
~100 ky
~40 ky
~20 ky
frequency (ky)
128
64
32
16
time (ky BP)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1

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

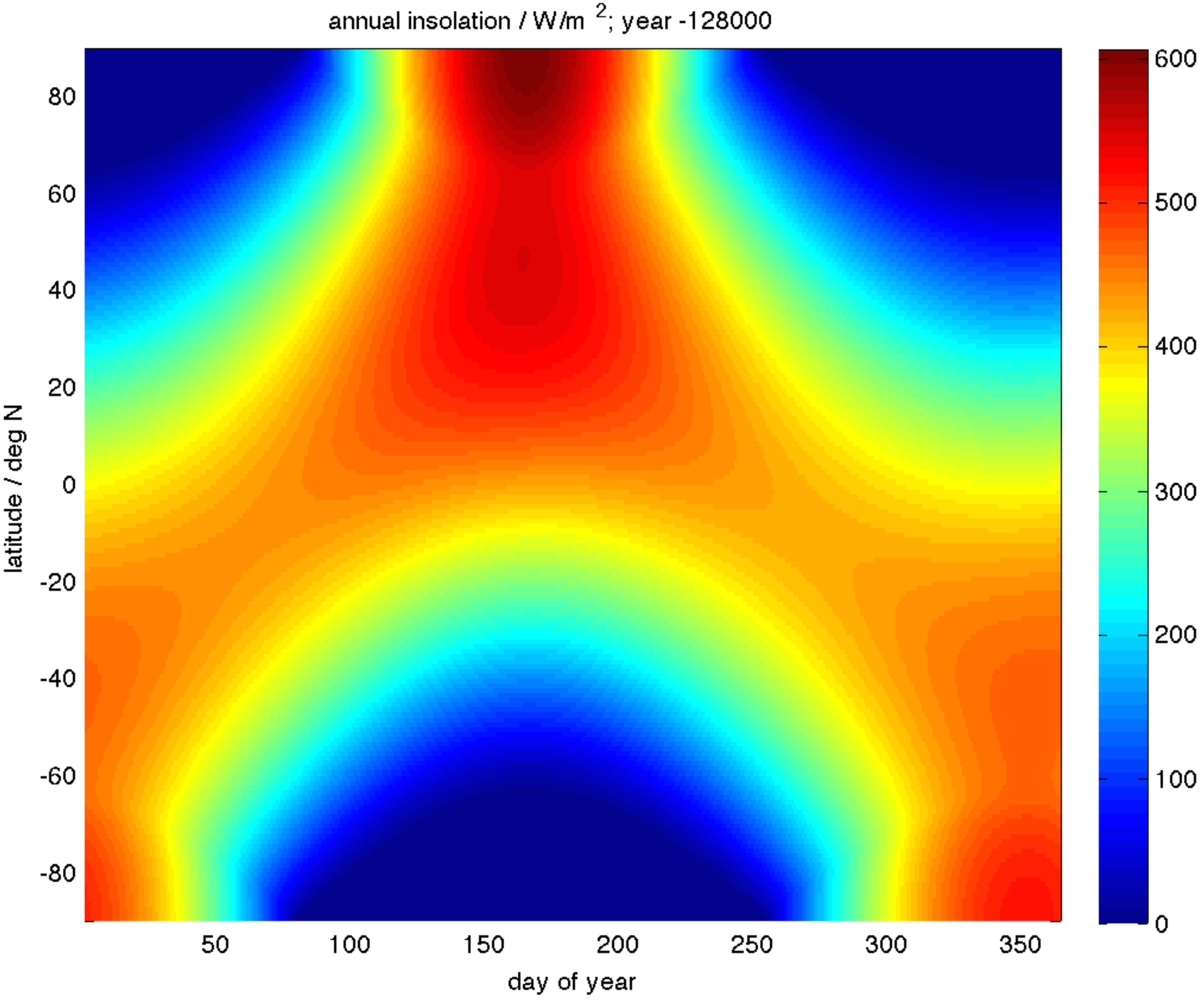
Changes in the intensity of solar radiation

The earth passing through cold regions of space

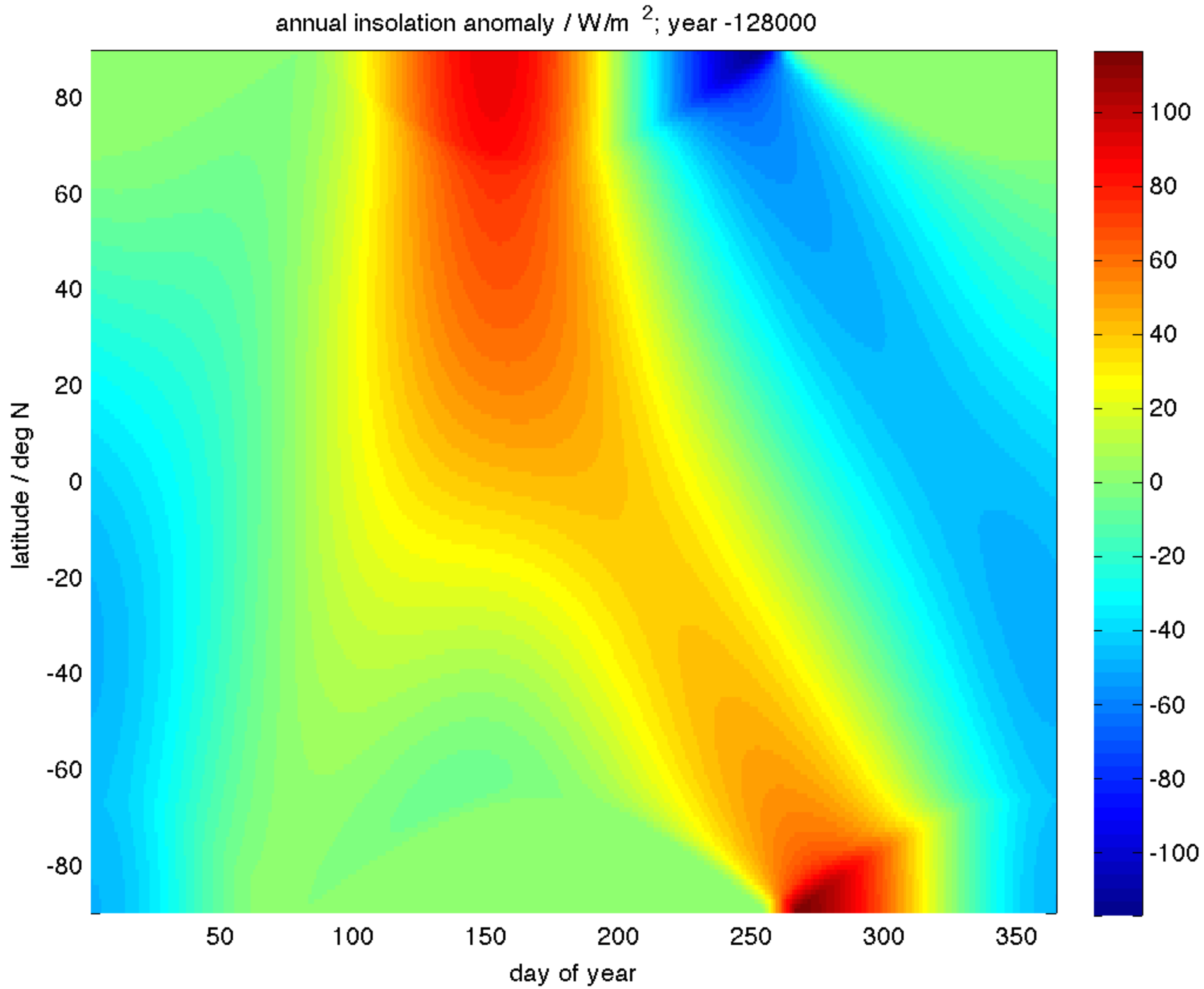
Internal: ice sheet, CO_2, stochastic

Amplifiers: thresholds, rectification

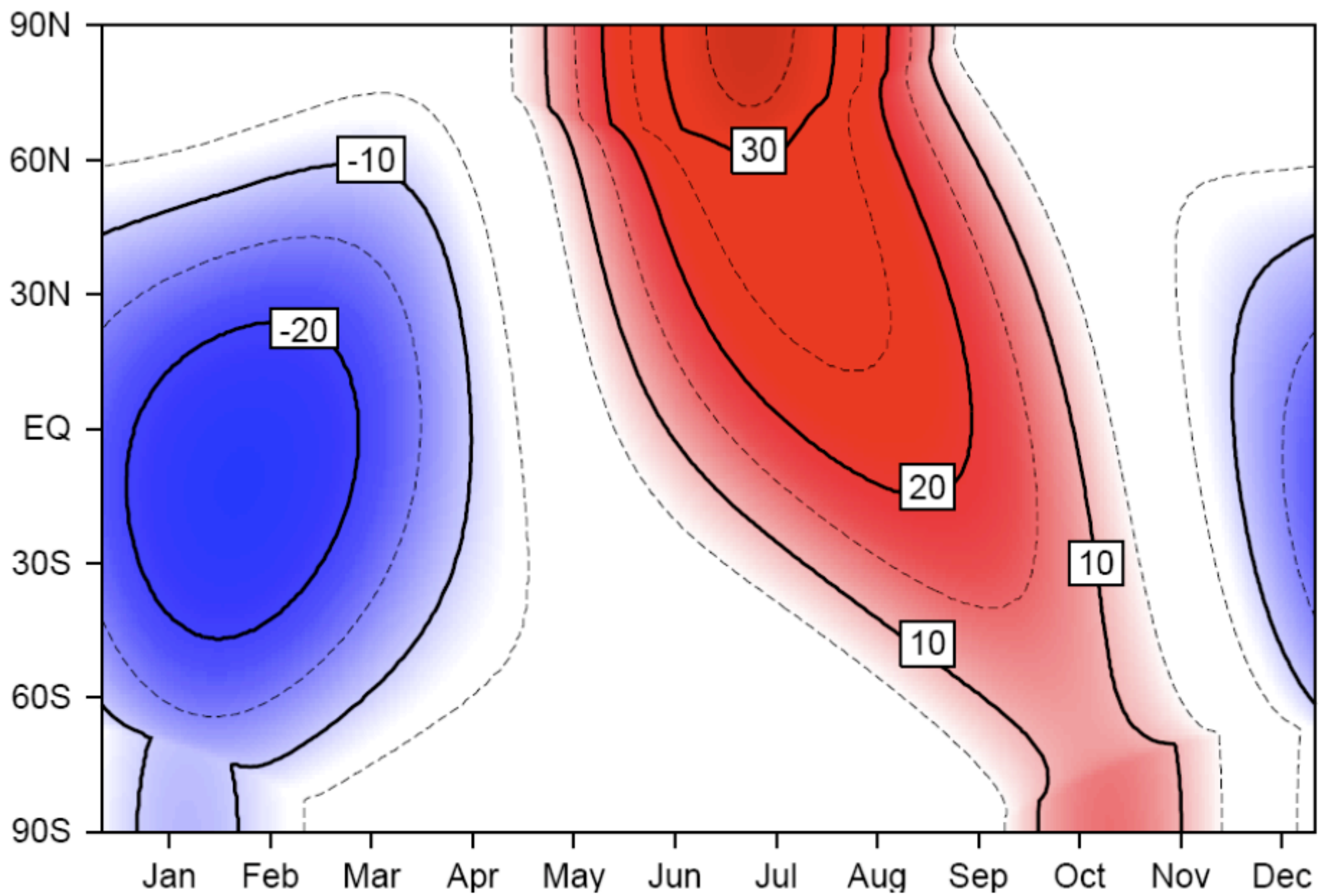
Insolation


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 anomaly

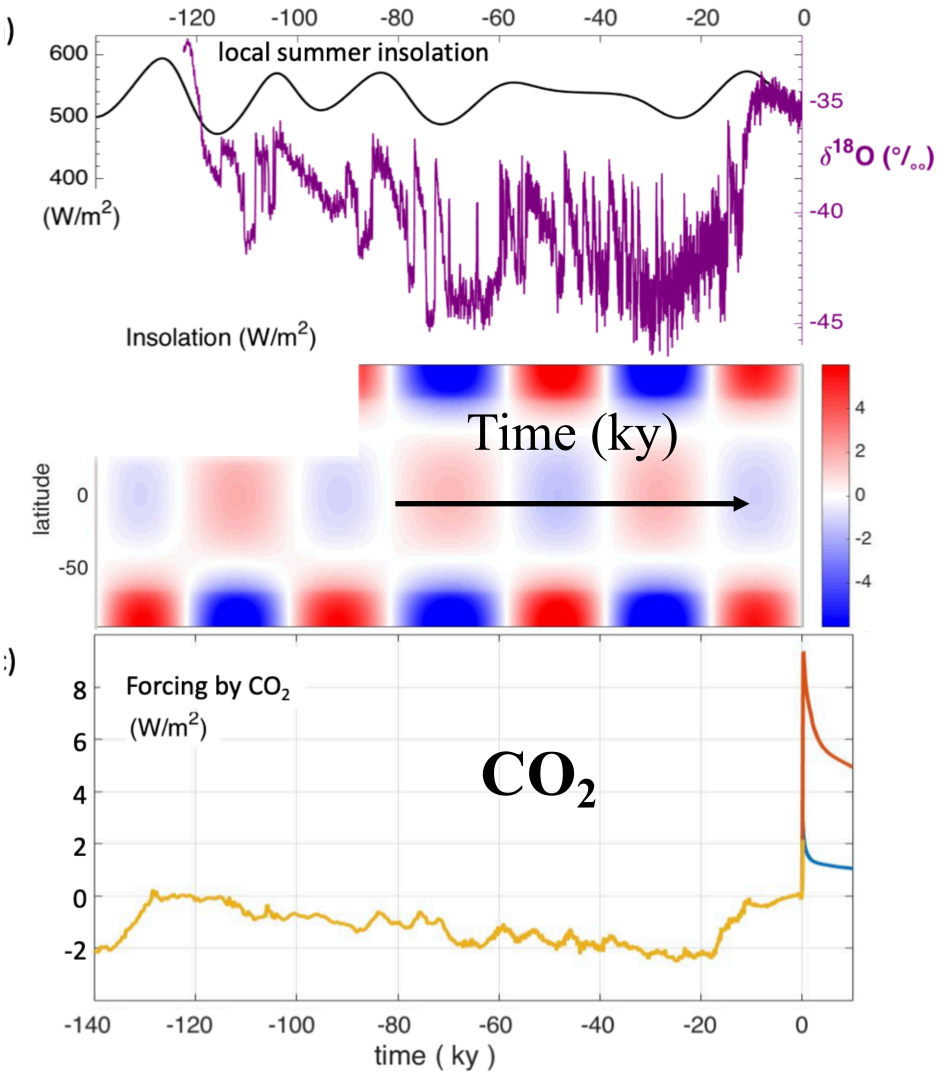


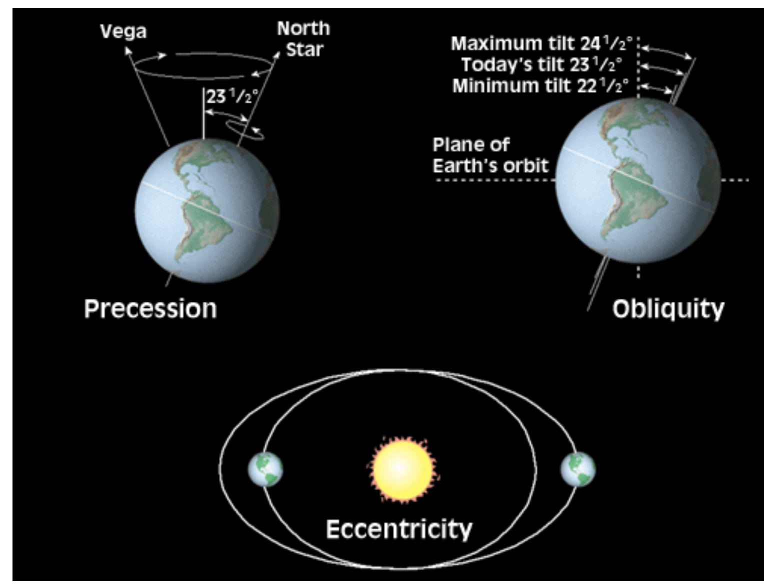
Insolation (6k minus present)

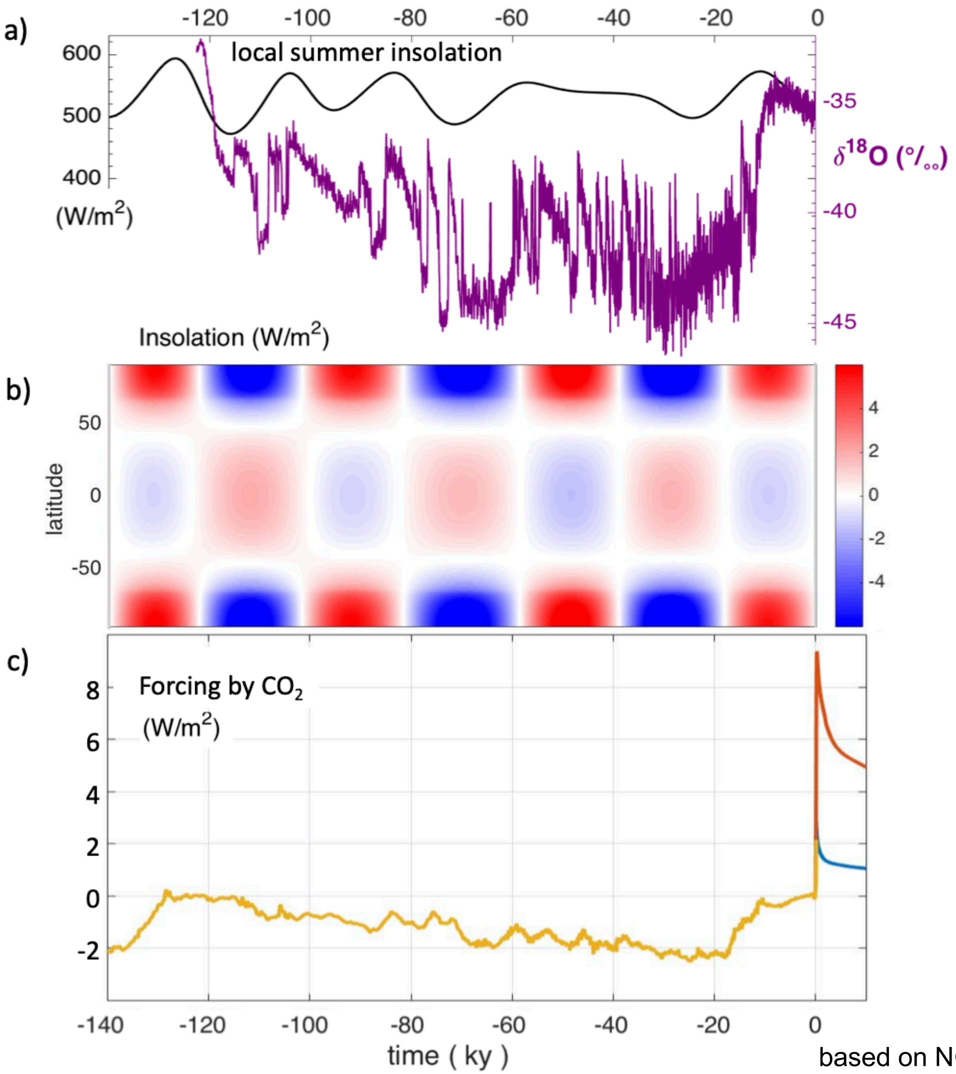


Climate dynamics

Forcing by insolation

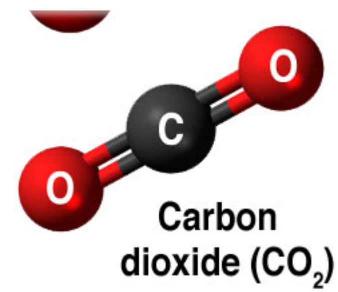






Climate dynamics

Forcing by insolation



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

Monsoon: seasonal signal

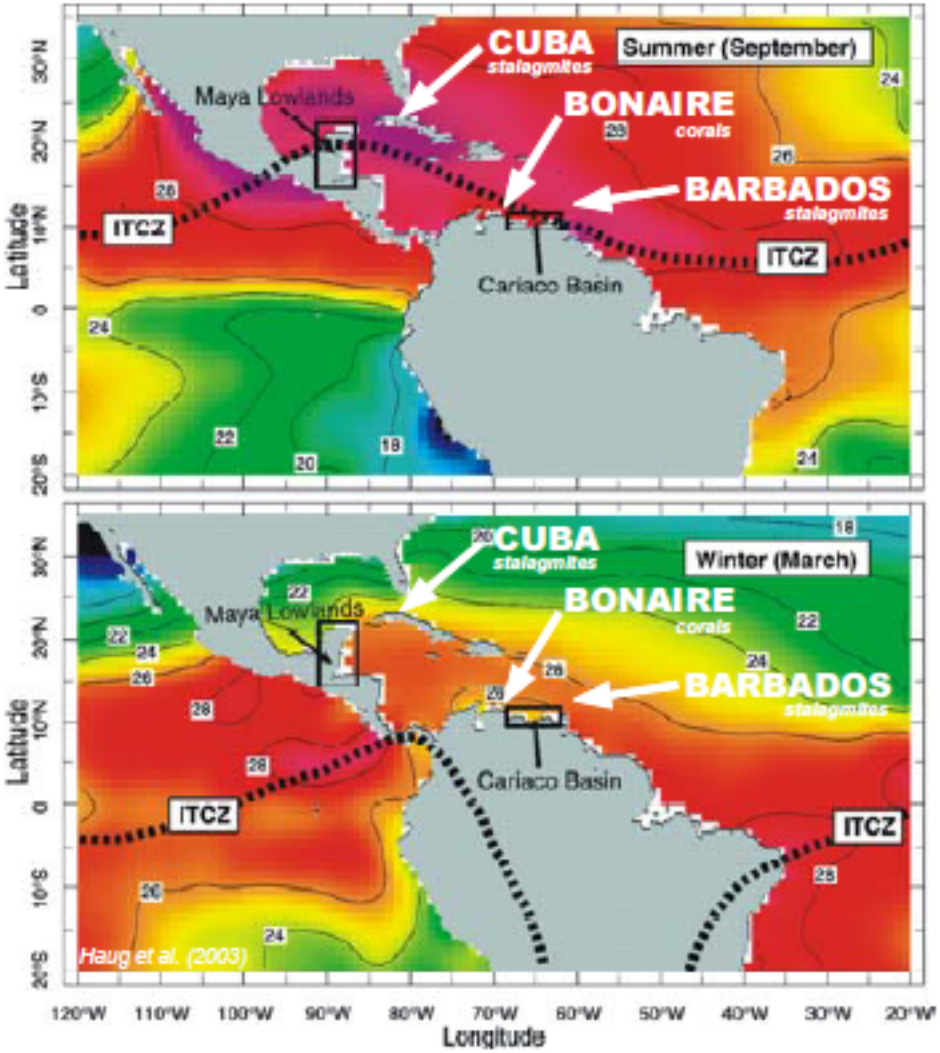


Figure 1. Seasonal variations in the mean position of the Intertropical Convergence Zone (ITCZ) over the Caribbean region, illustrated for typical summer (September) **(top)** and winter (March) **(bottom)** conditions. These variations control the pattern and timing of regional rainfall. Numbers and 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

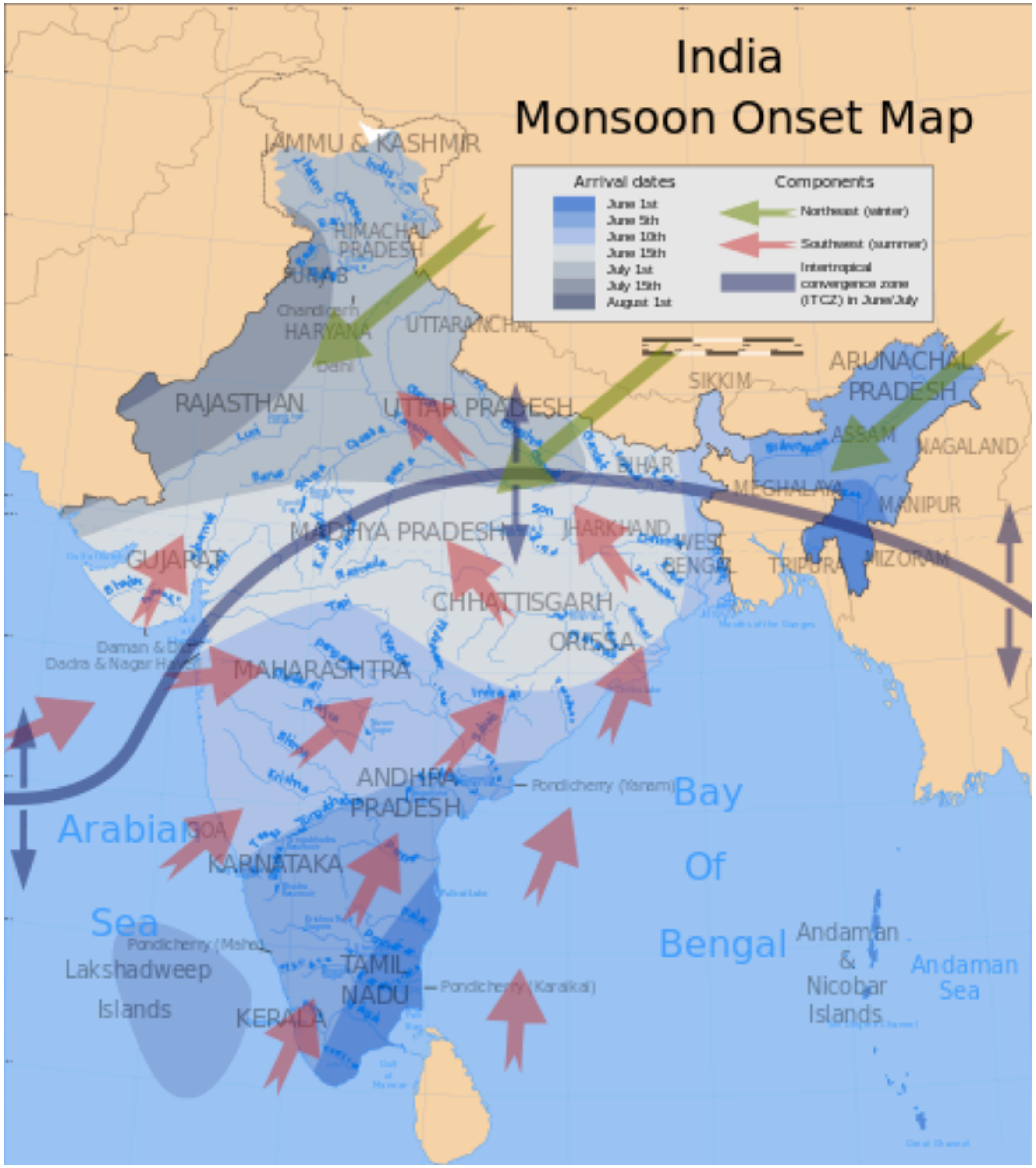
seasonal reversing wind accompanied by corresponding changes in precipitation, but is now used to describe seasonal changes in atmospheric circulation and precipitation associated with the asymmetric heating of land and sea.

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

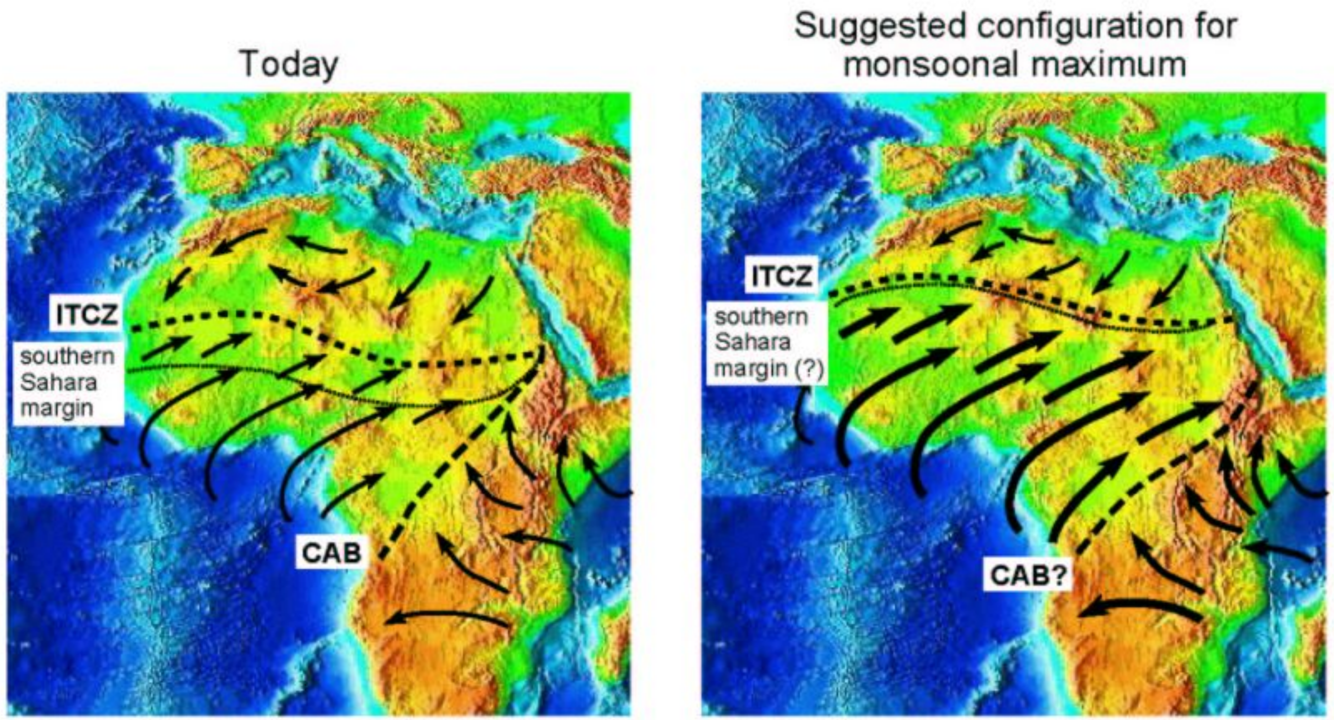
During warmer months sunlight heats the surfaces of both land and oceans, but land temperatures rise more quickly.
water heat capacity (4.2 J g^{-1} K^{-1})
dirt, sand, and rocks heat capacities (0.19 to 0.35 J g^{-1} K^{-1})

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

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


India
Monsoon Onset Map
Arrival dates
June 1st
June 5th
June 10th
June 15th
July 1st
July 15th
August 1st
Components
Northeast (winter)
Southwest (summer)
Intertropical convergence zone (ITCZ) in June/July
JAMMU & KASHMIR
HIMACHAL PRADESH
PUNJAB
HARYANA
UTTARANCHAL
RAJASTHAN
UTTAR PRADESH
SIKKIM
ARUNACHAL PRADESH
ASSAM
NAGALAND
BIHAR
MEGHALAYA
MANIPUR
MADHYA PRADESH
JHARKHAND
WEST BENGAL
TRIPURA
MIZORAM
GUJARAT
CHHATTISGARH
ORISSA
MAHARASHTRA
ANDHRA PRADESH
Pondicherry (Yanam)
GOA
KARNATAKA
TAMIL NADU
Pondicherry (Karaikal)
KERALA
Arabian Sea
Lakshadweep Islands
Bay Of Bengal
Andaman & Nicobar Islands
Andaman Sea

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.

Exercise 1

The obliquity is the angle between an object's rotational axis and its orbital axis. Earth's obliquity oscillates between 22.1 and 24.5 degrees on a 41,000-year cycle; the earth's mean obliquity is currently 23.4 degrees and decreasing. The Earth radius is 6,371 km. How many meters per year is the movement of the Tropic of Cancer due to obliquity changes?