

Climate System II

Glacial Climate, Orbital Theory

7. November 2023 (3rd lecture)

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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



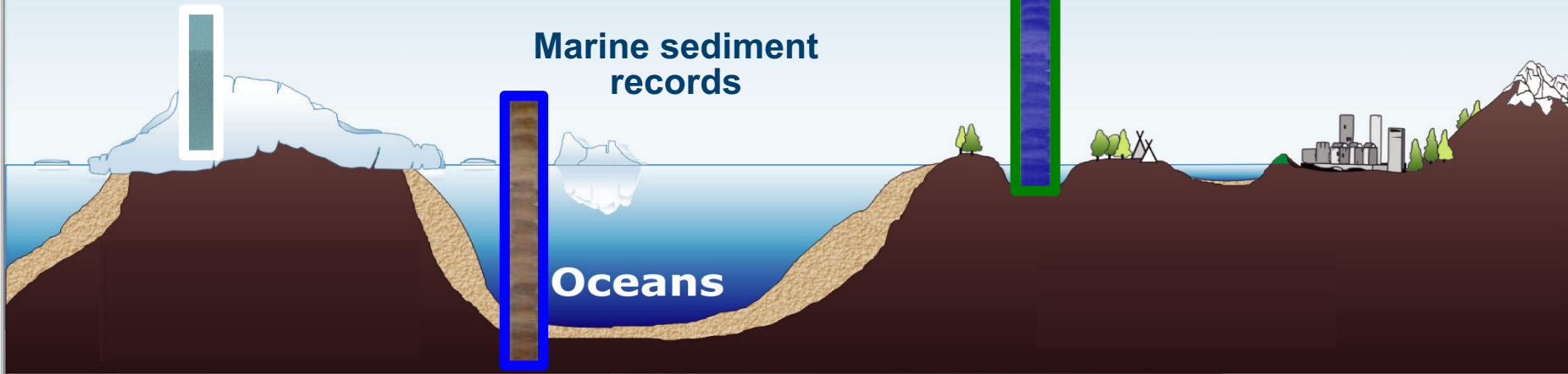
Lake/permafrost sediments

Climate records from
ice cores

Lake/permafrost
sediment records

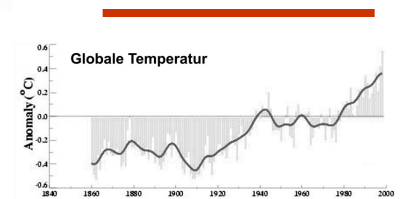
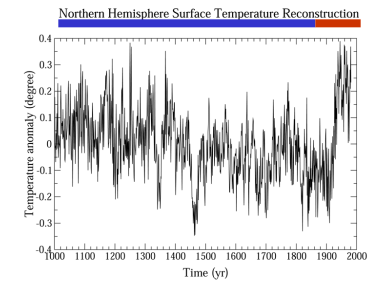
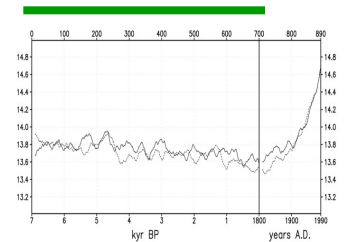
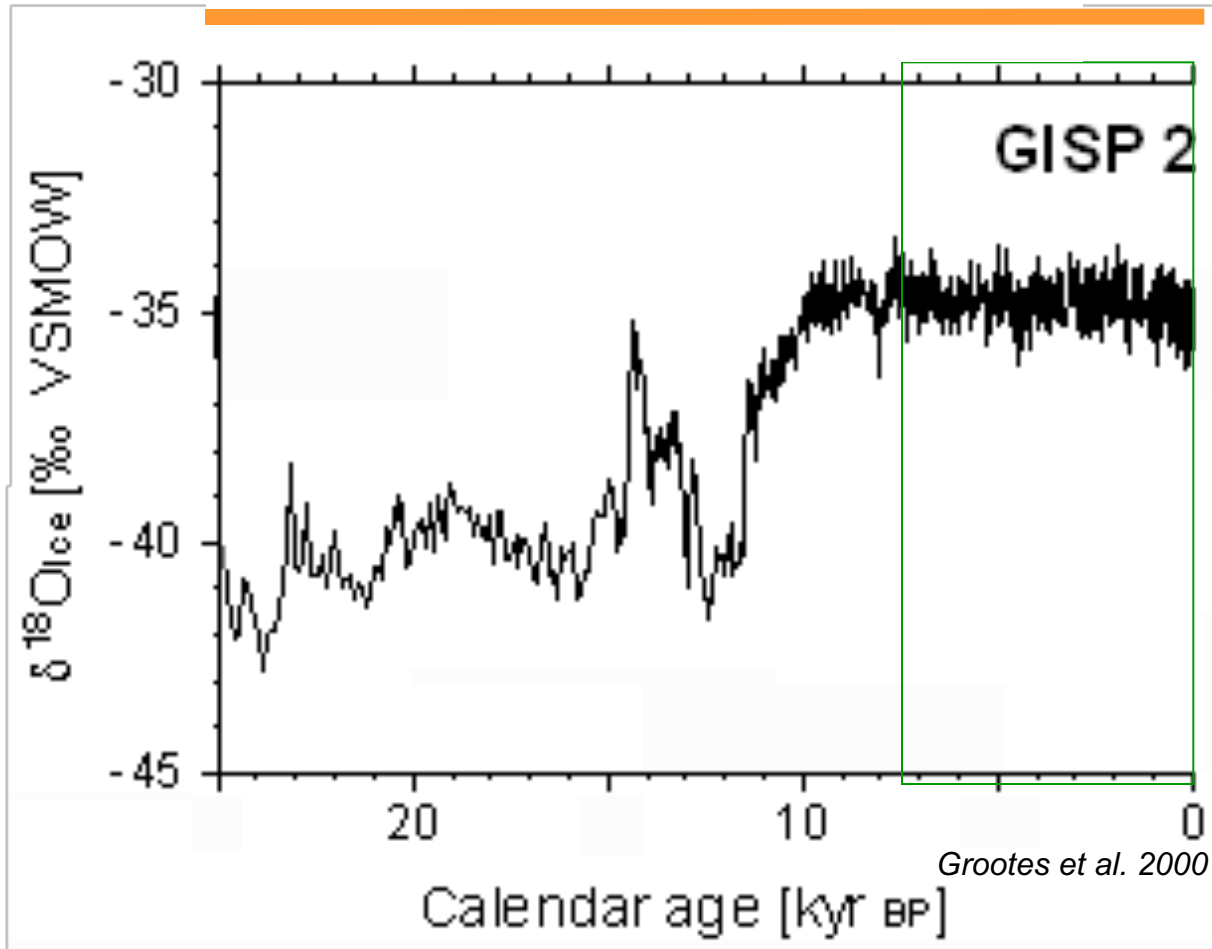
Marine sediment
records

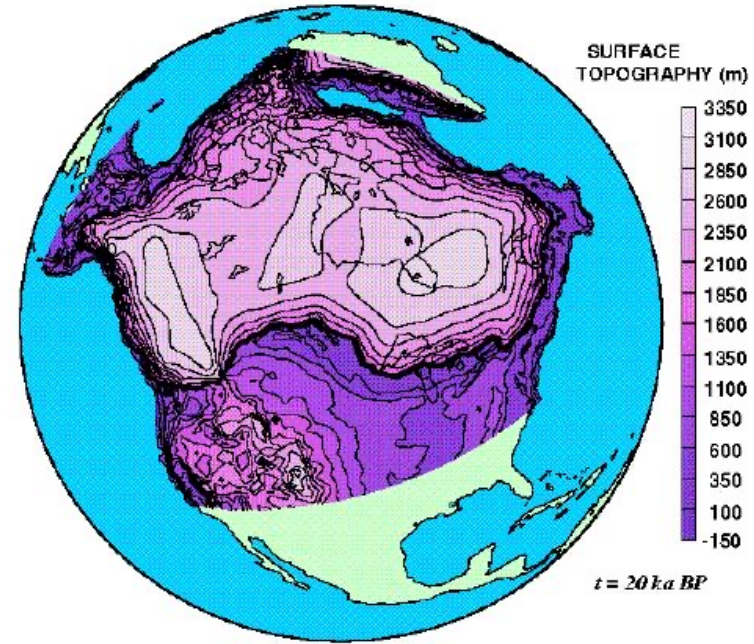
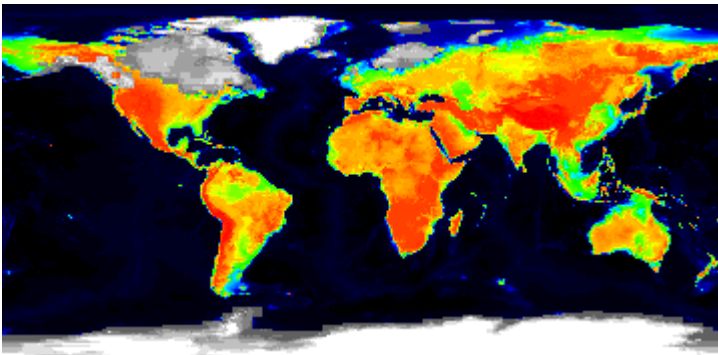
Oceans



Climate Trends at different Timescales

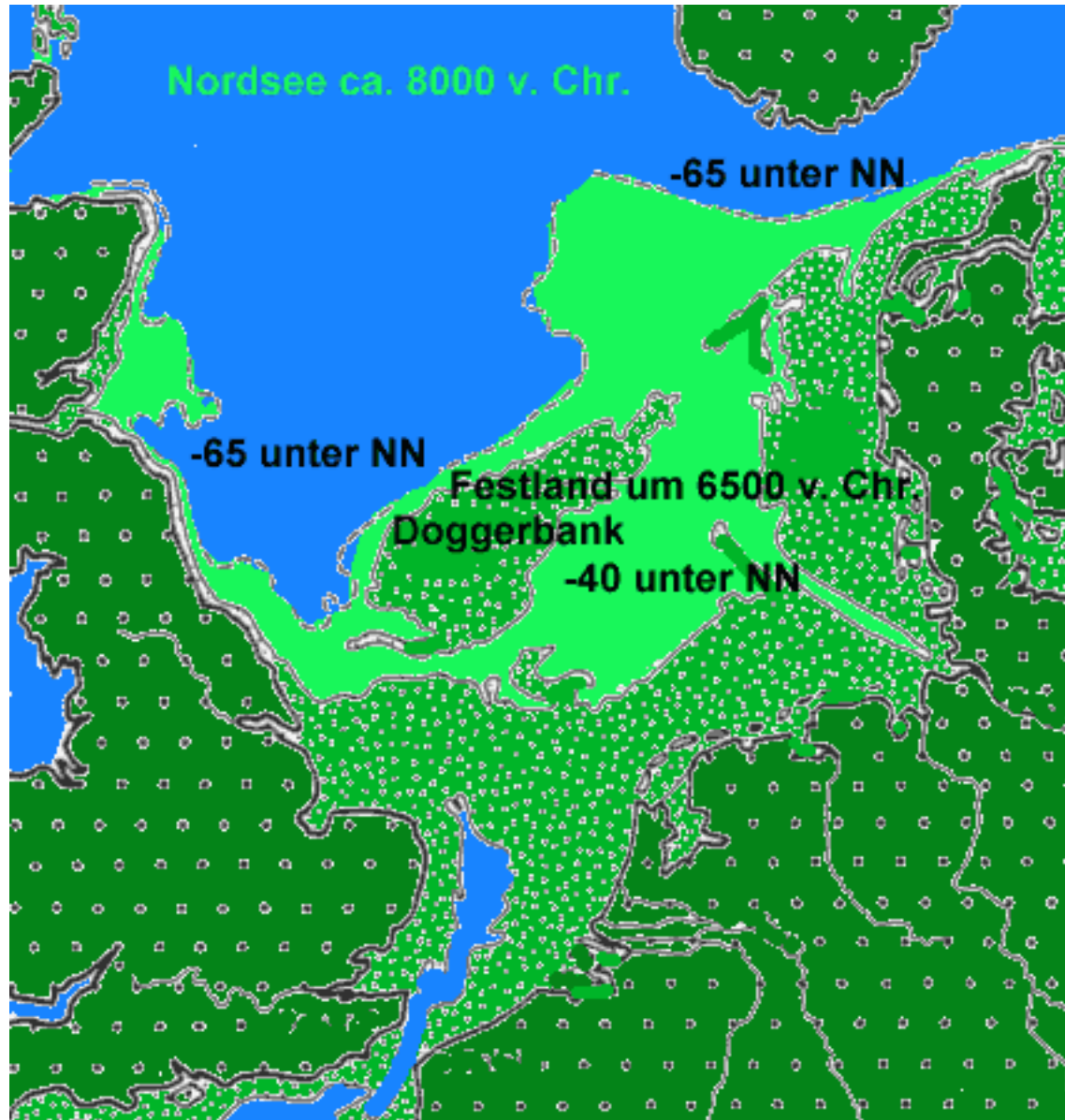
Deglaciation – Greenland ice core





Deglaciation

The Brexit is not new !

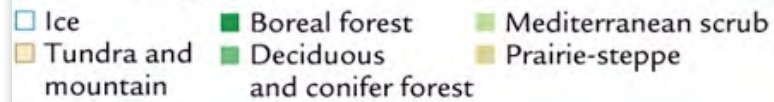


LGM climate of North America and Europe



Modern
land cover

A Modern vegetation

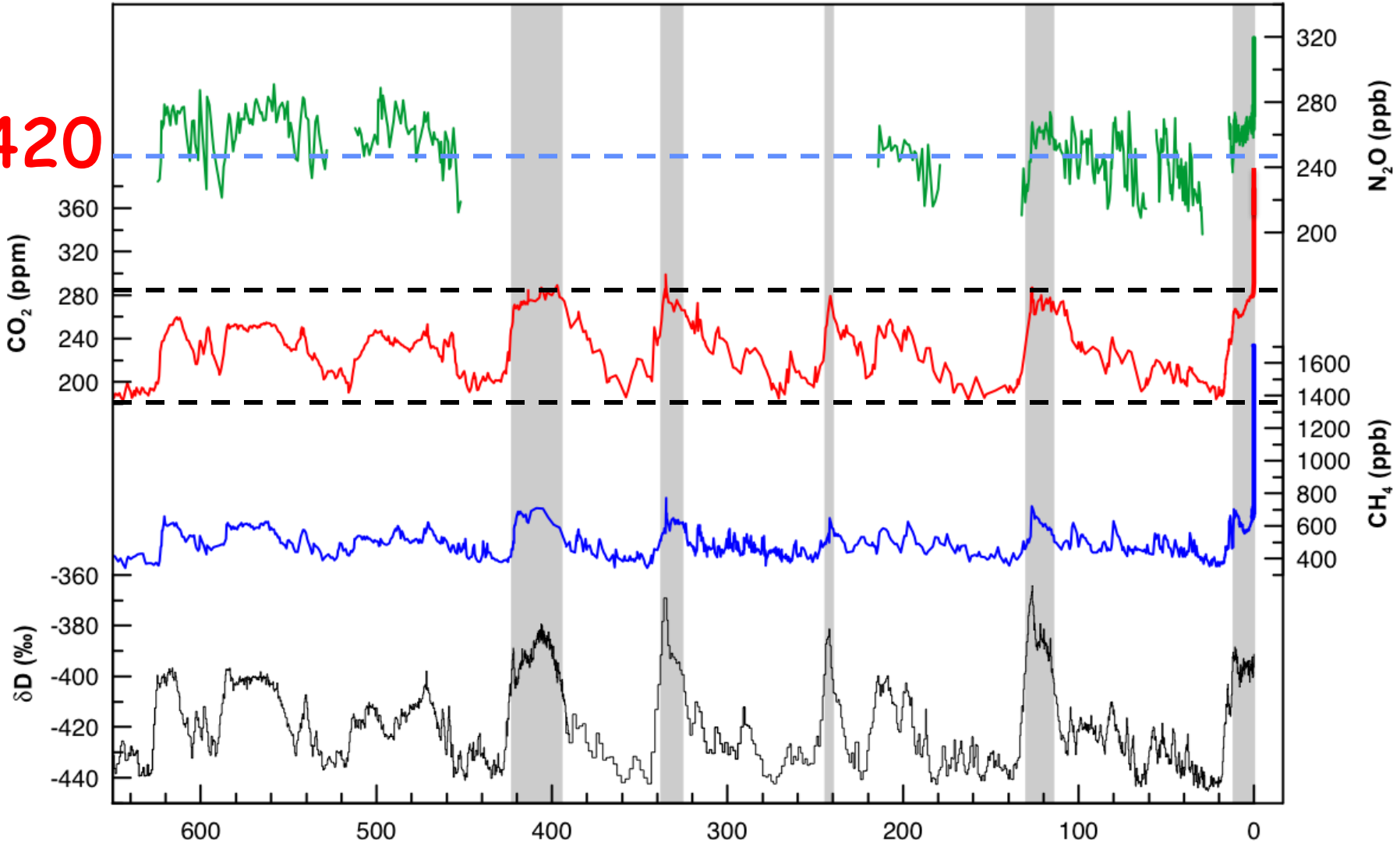


Glacial
land cover

B Glacial vegetation

Atmospheric Gas Concentrations from Ice Cores

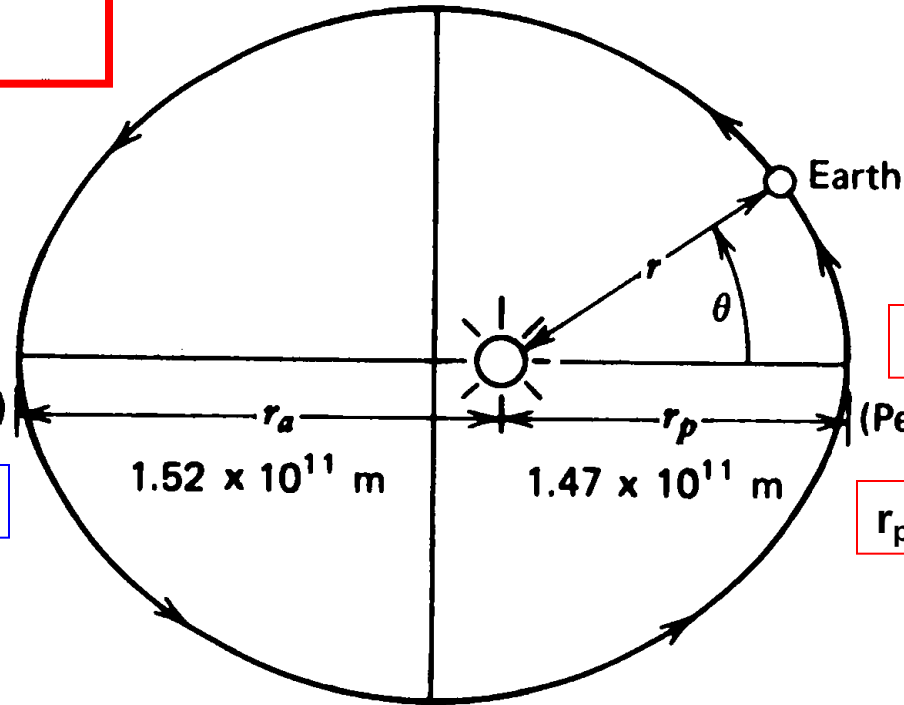
420



Time (Thousands of Years Before Present)

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

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



$$\cos \theta = -1$$

(Aphelion ~ July 4)

$$r_a = r_{\text{Aphelion}} = a(1 + \epsilon)$$

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

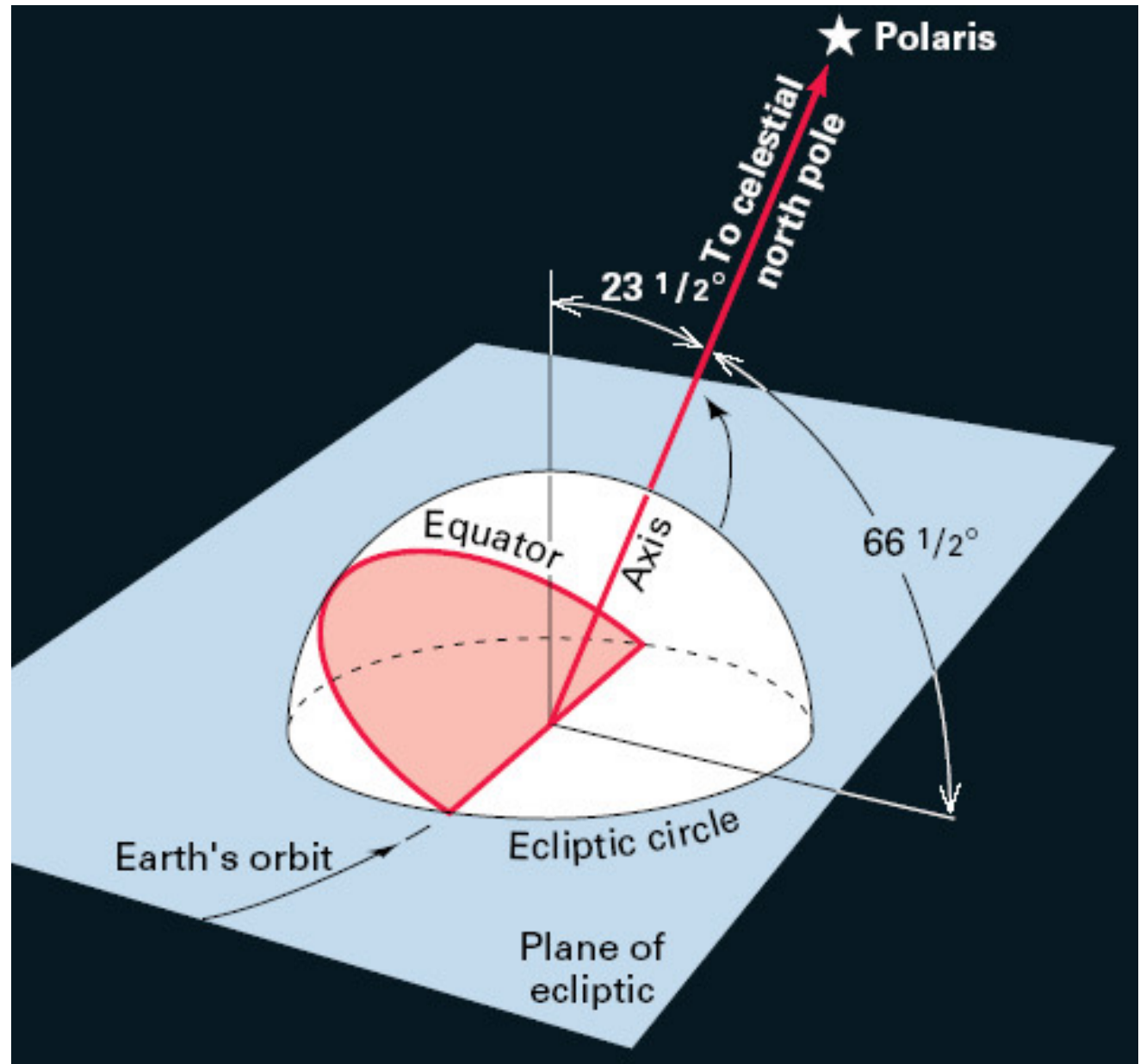
(Perihelion ~ Jan. 4)

$$r_p = r_{\text{Perihelion}} = a(1 - \epsilon)$$

the mean orbital distance is $a = 149,7 \text{ [Gm]} = 149,7 \text{ Mio km}$
 and the eccentricity is $\epsilon = 0.0167$

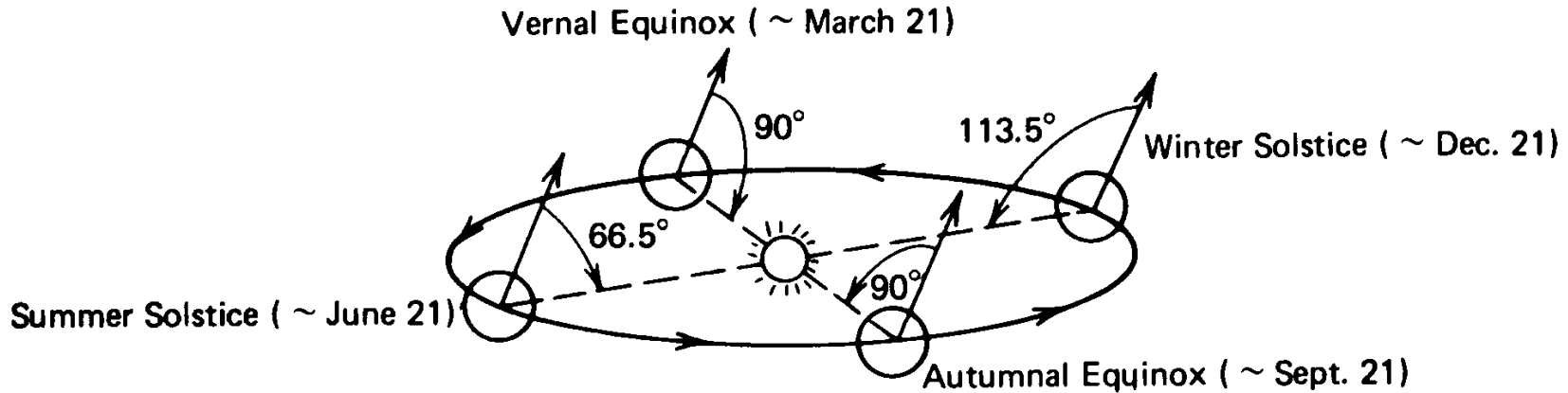
Radius: $r = a \pm 2\%$

The tilt of the Earth's axis with respect to its orbital plane (ecliptic)



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

Diagram 1.1



The seasonal variation of the angle between **the Earth 's polar axis** and the **Earth-Sun line**.

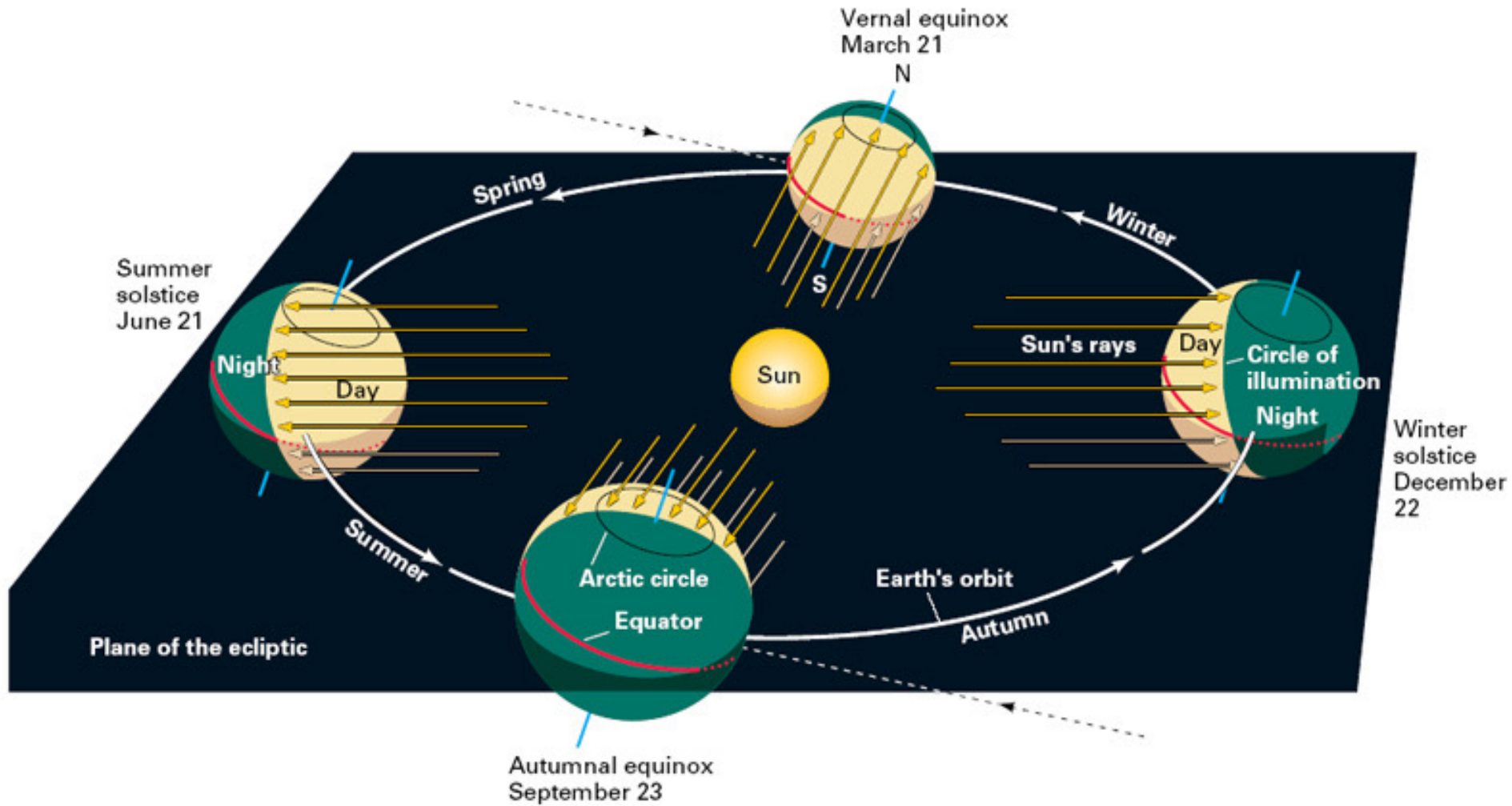
The **angle of inclination** (between the **earth axis** of rotation and the **line perpendicular** to the **ecliptic plane**)

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 sidereal day..**

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

The 4 seasons

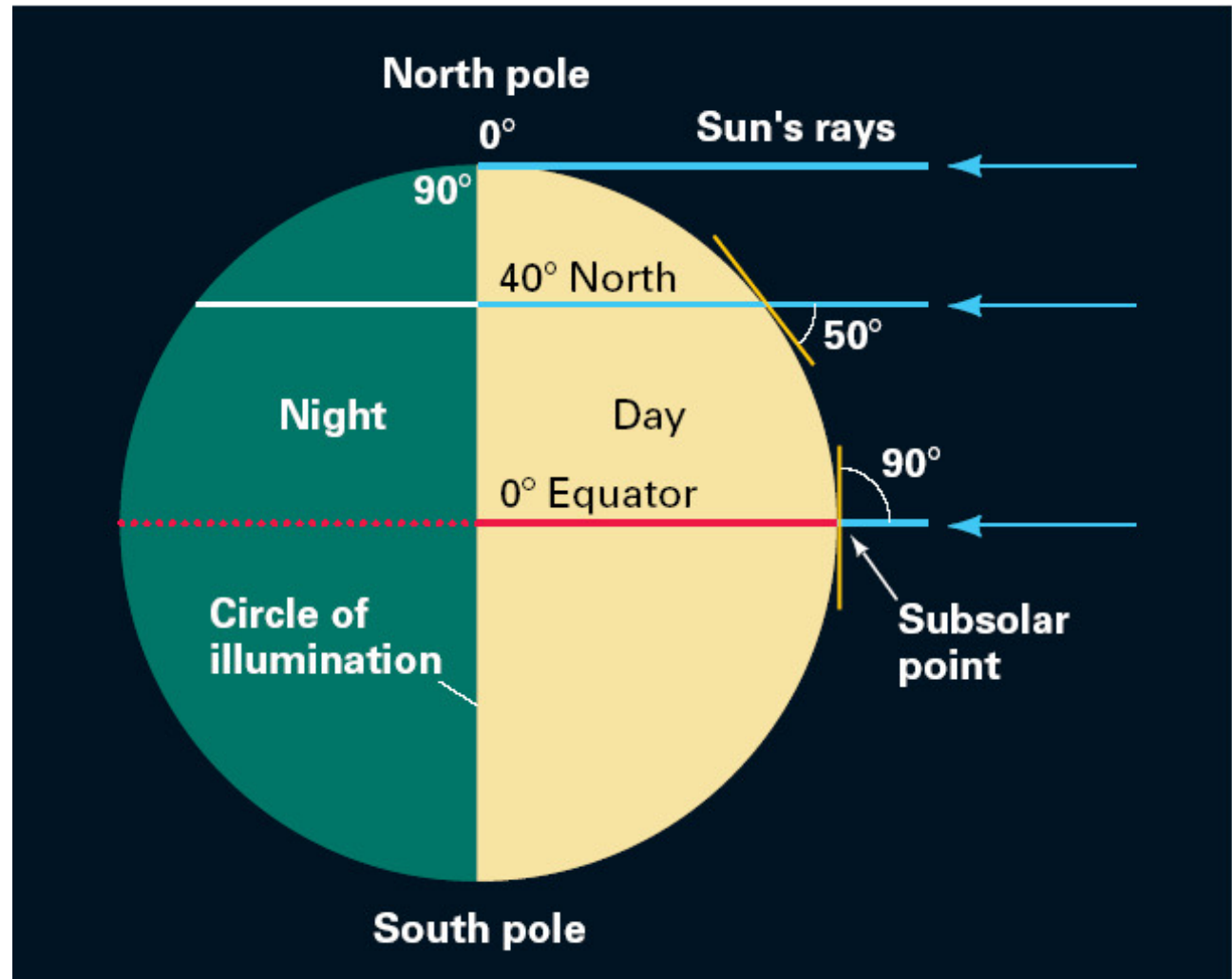


Equinox

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

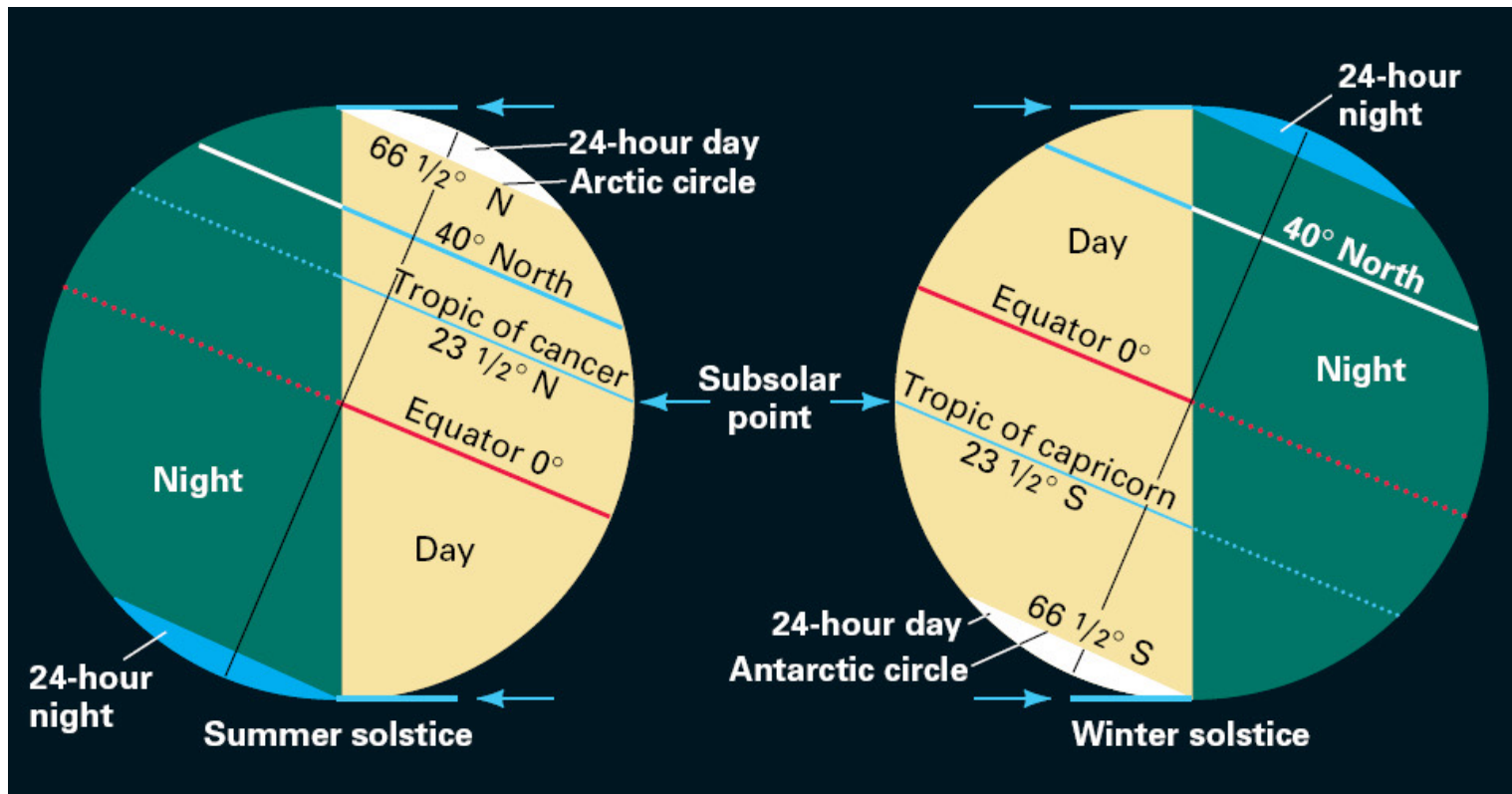


Solstice

Solstice (“sun stands still”)

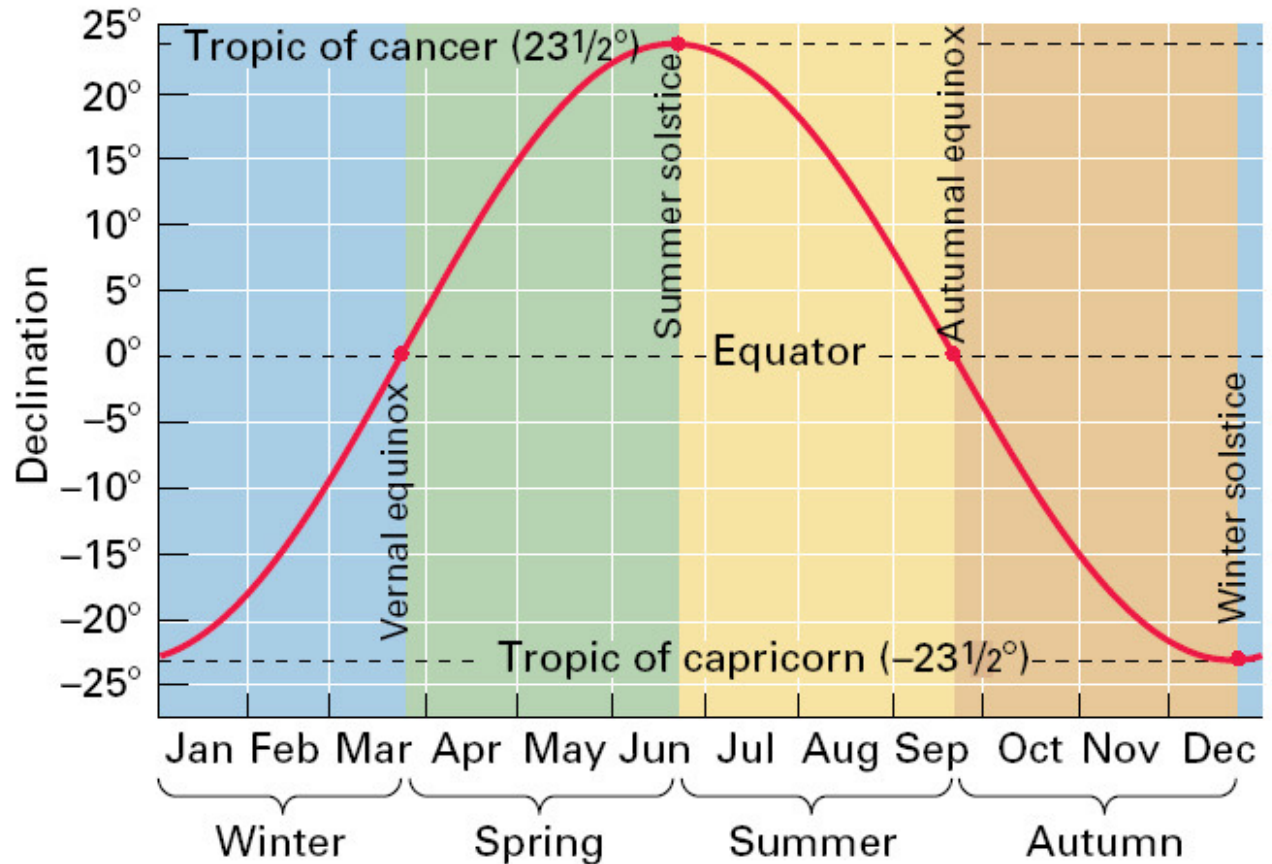
On June 22, the **subsolar point** is $23\frac{1}{2}^{\circ}$ N (Tropic of Cancer)

On Dec. 22, the **subsolar point** is $23\frac{1}{2}^{\circ}$ S (Tropic of Capricorn)



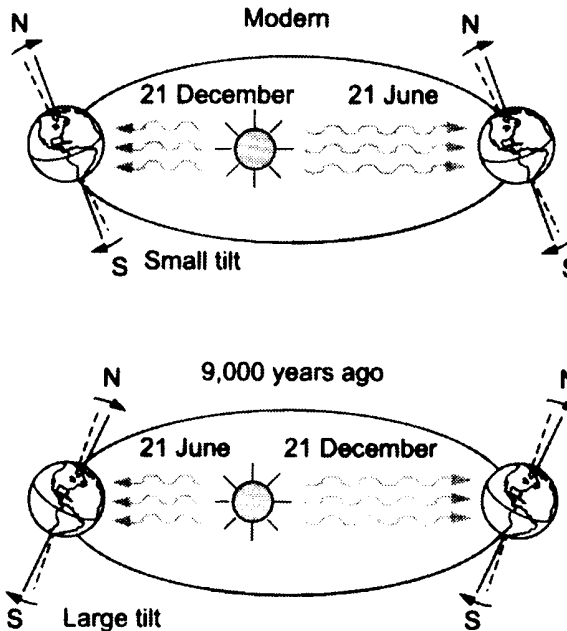
Declination over the year

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

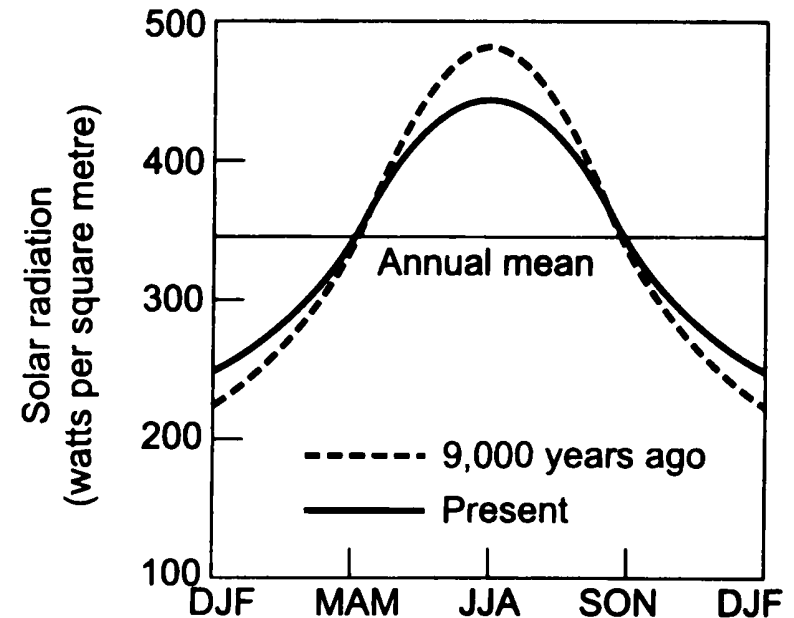


Configuration of the earth's orbit **9000 years ago**

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

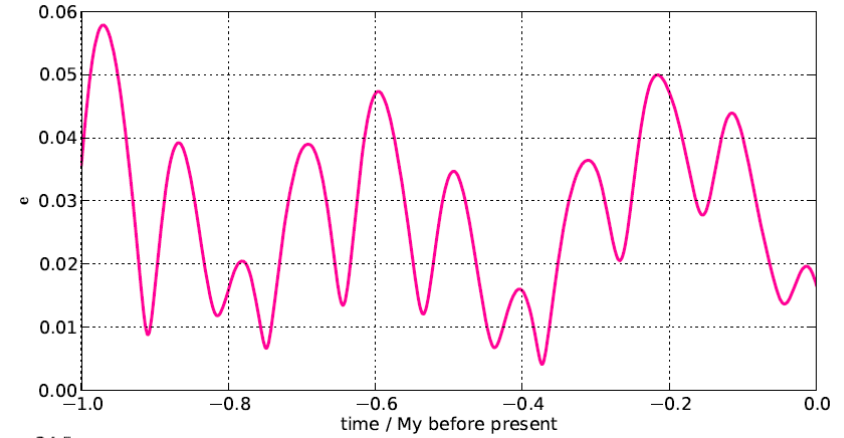
Changes in the average **solar radiation during the year** over the **northern hemisphere** (right). The incoming solar energy averaged over the northern hemisphere was ca. **7% greater in July** and less in January.

Orbital parameters

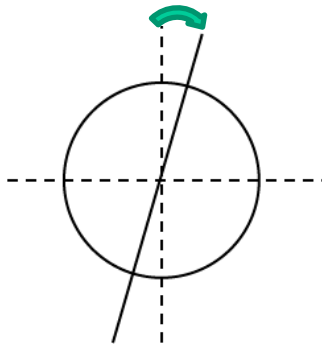
time →

Excentricity

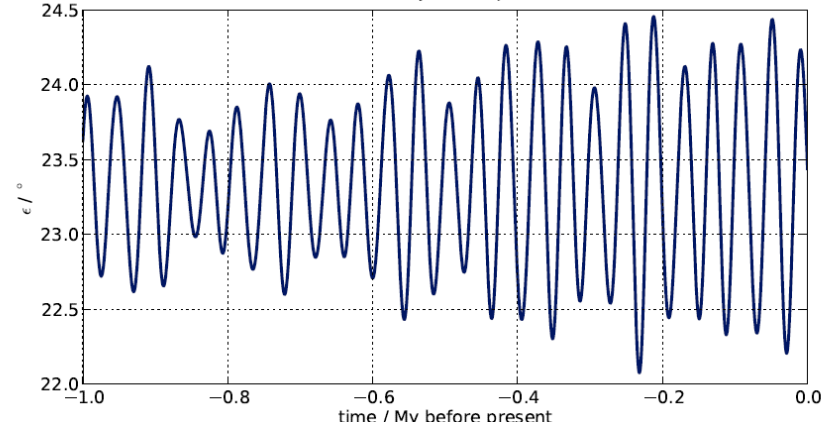
Periods:
100, 400 ky



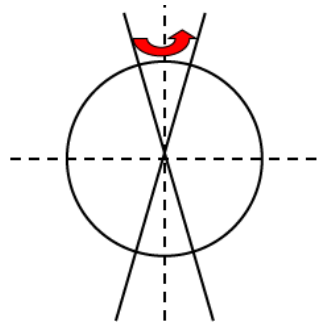
Obliquity



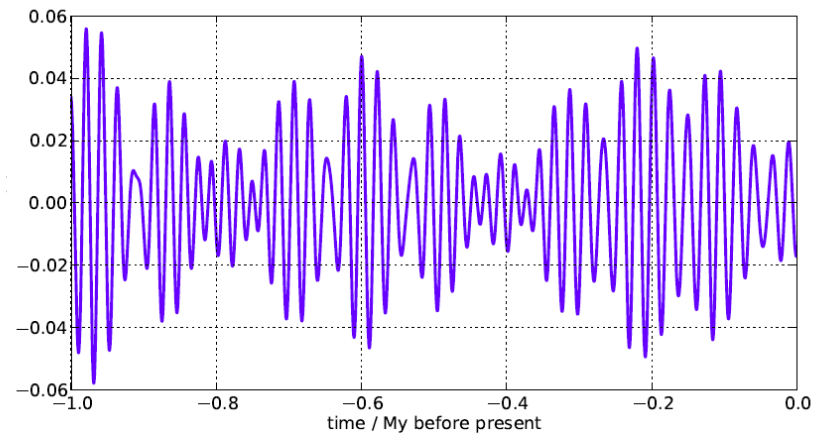
Periods:
39, 41, 54 ky
Modul. 1.2 My



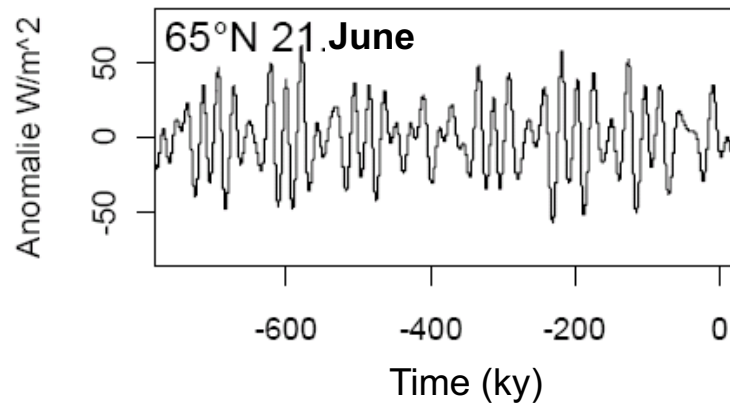
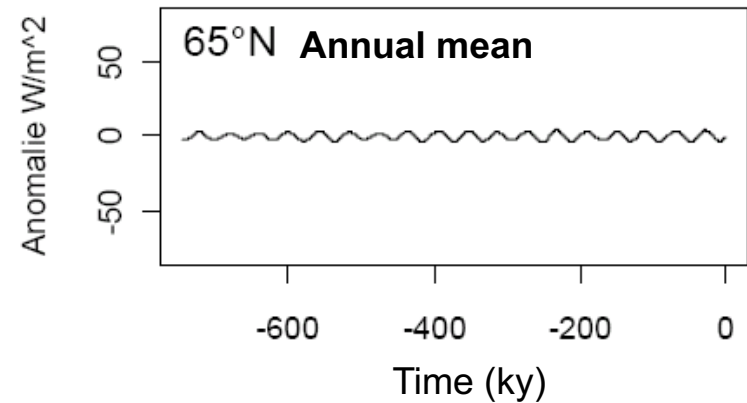
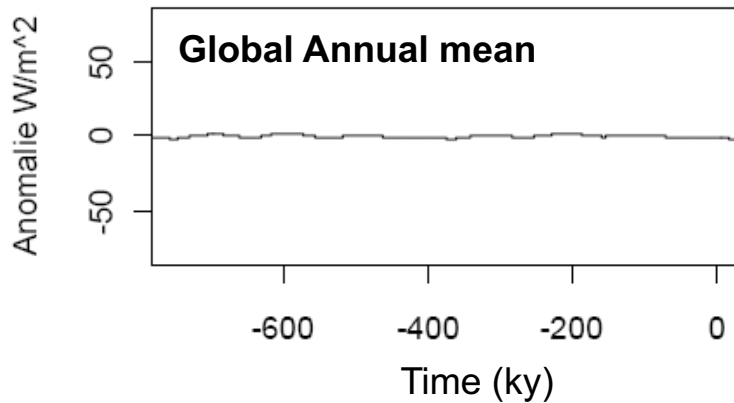
Precession



Periods:
19, 23 ky
Modul. Excentr

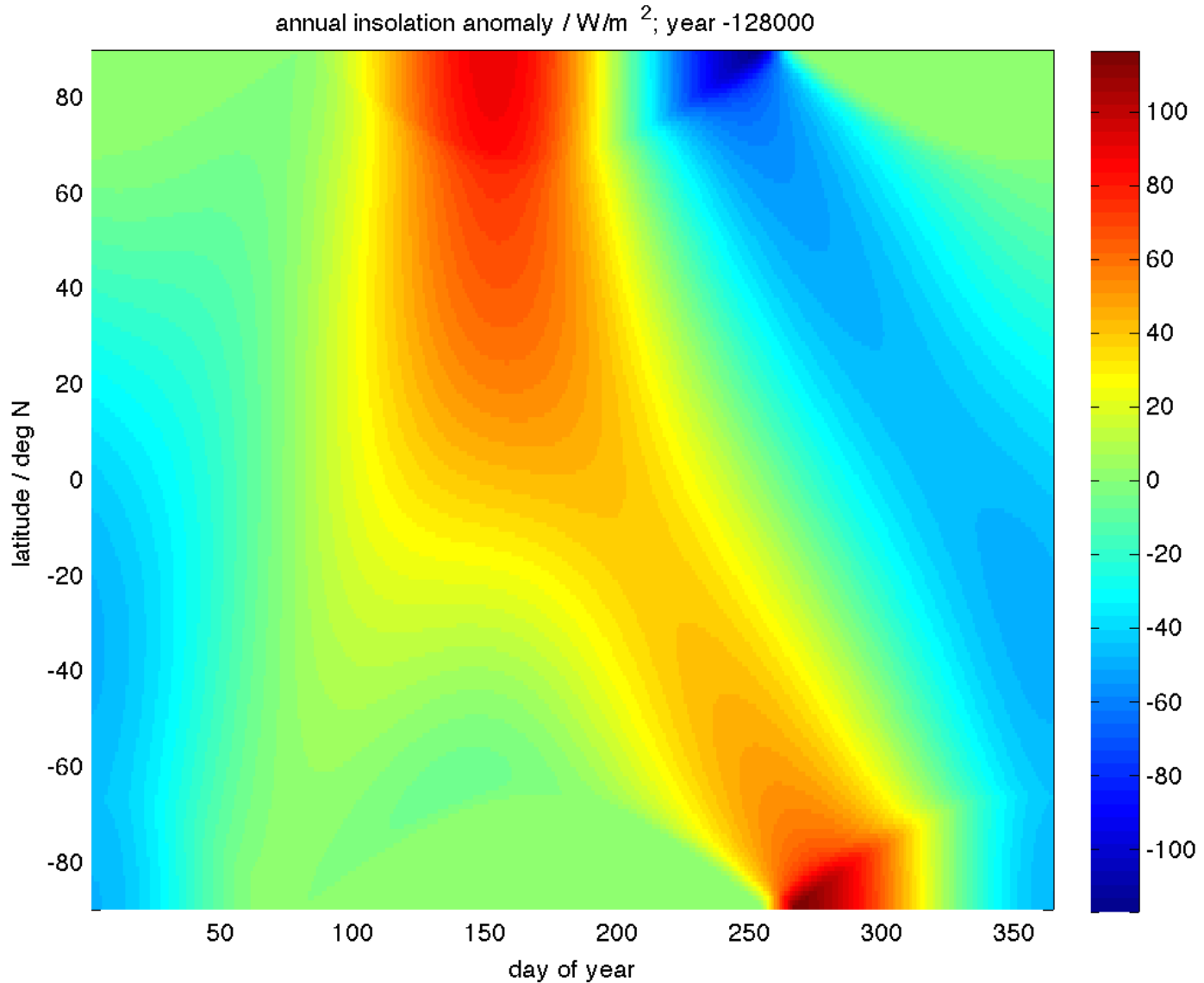


Resulting Effect

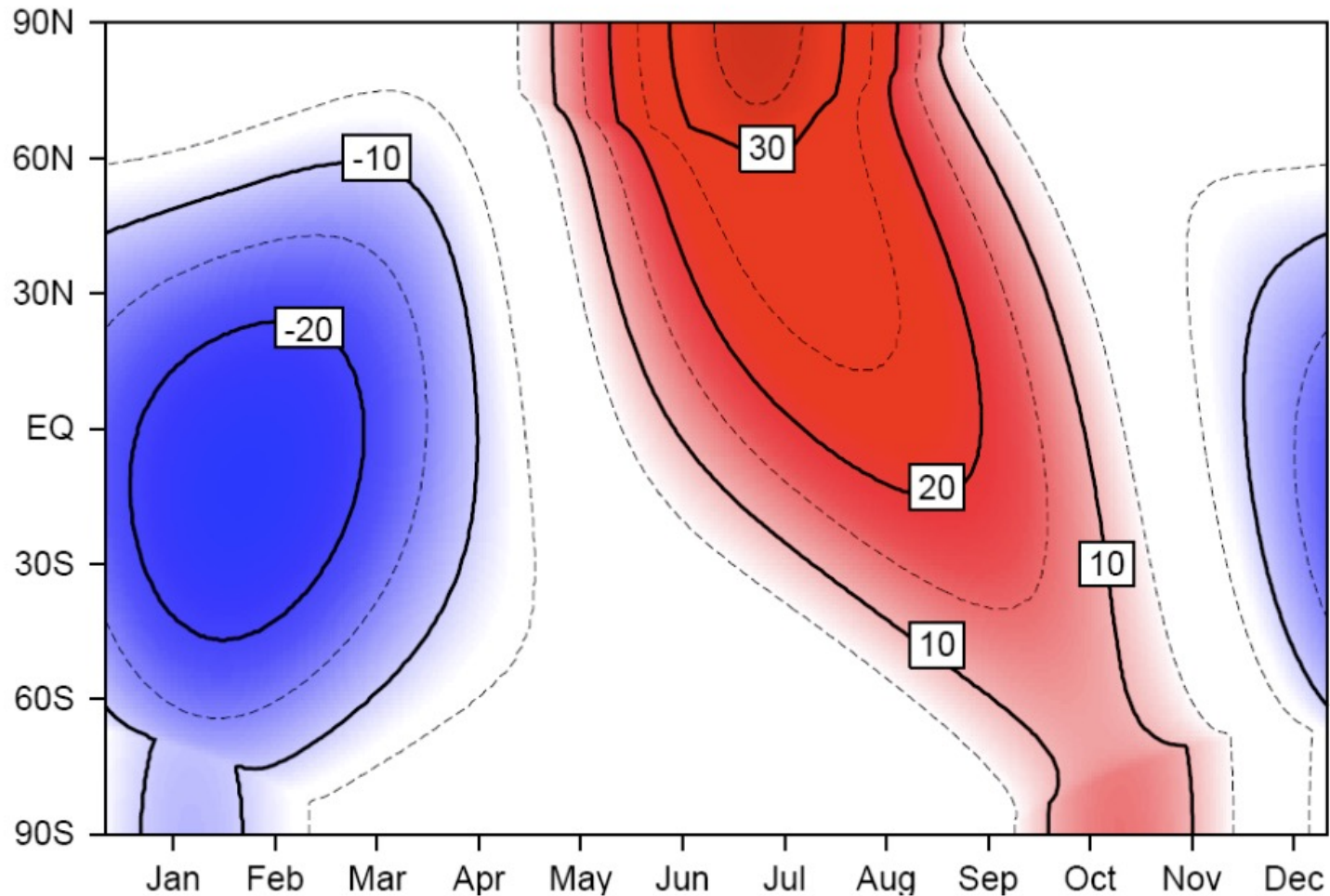


Non-linearities are important

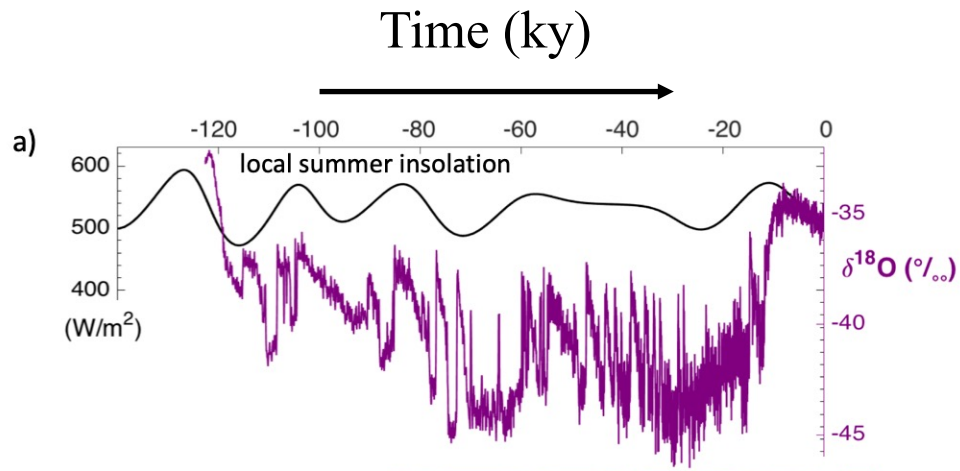
Insolation anomaly



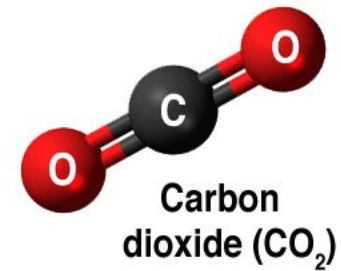
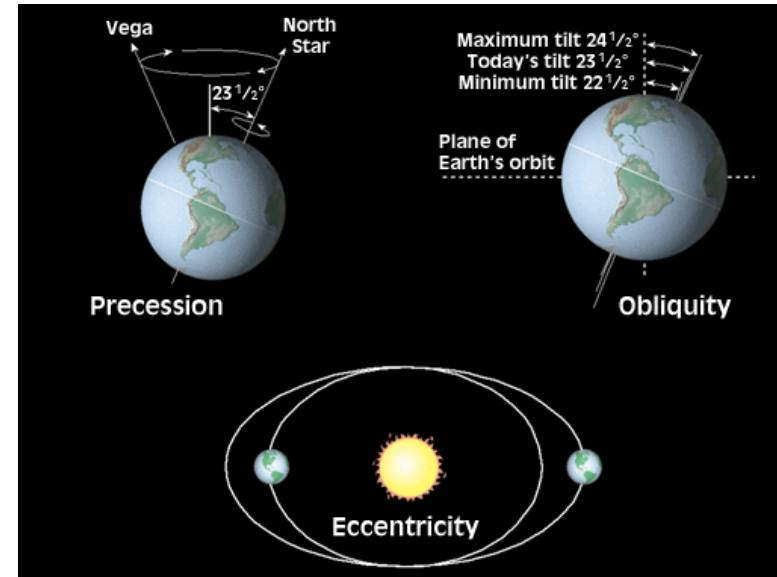
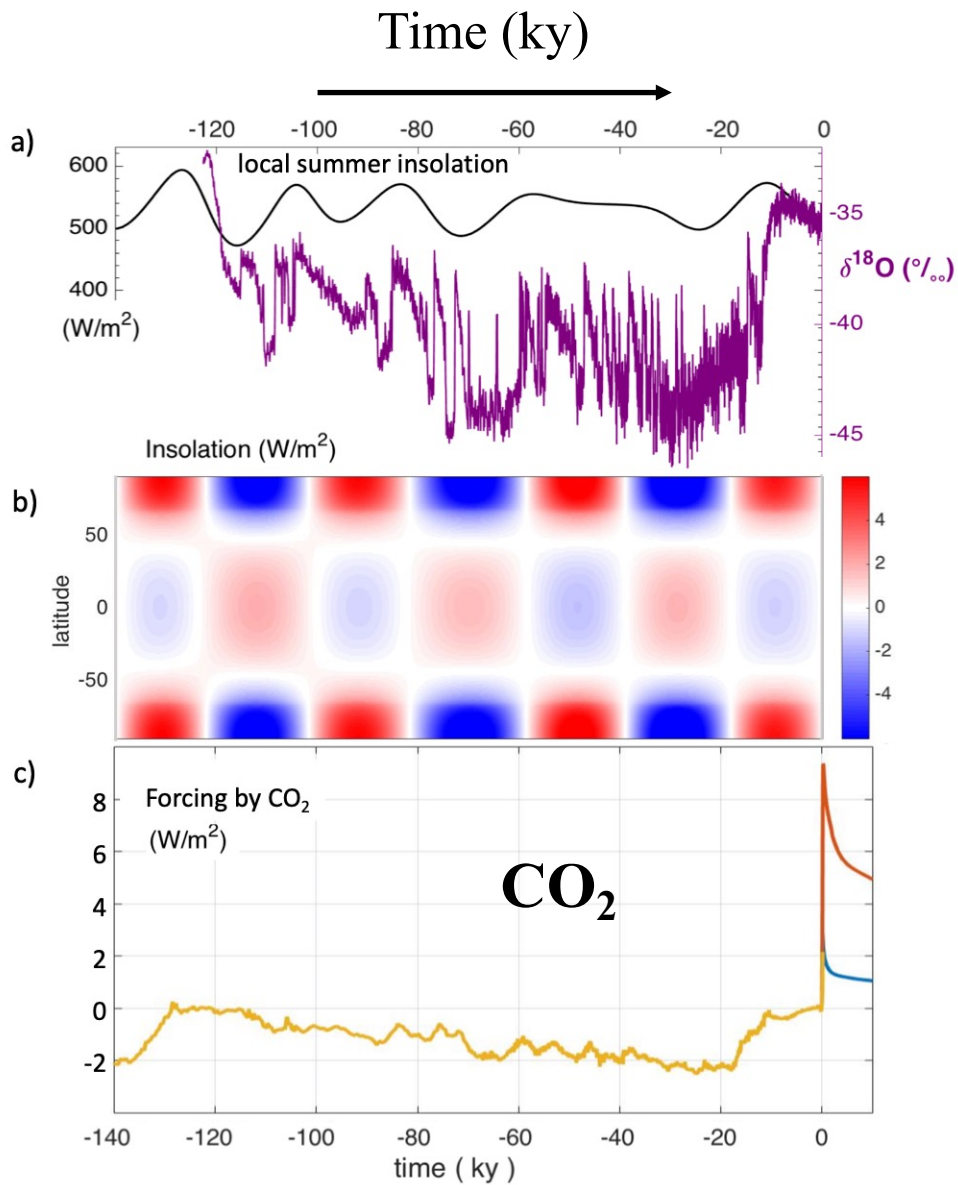
Insolation (6k minus present)



The last 120,000 years



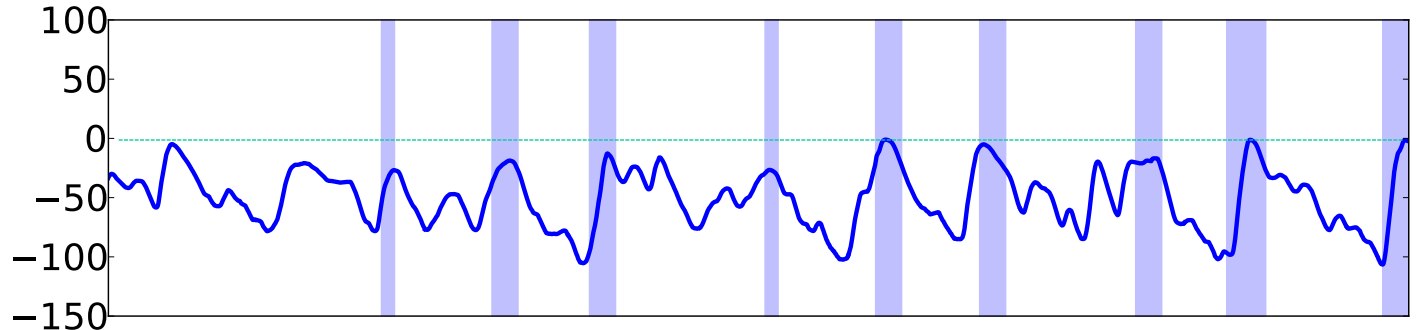
Modulation of local
insolation



Glacial-Interglacial variability

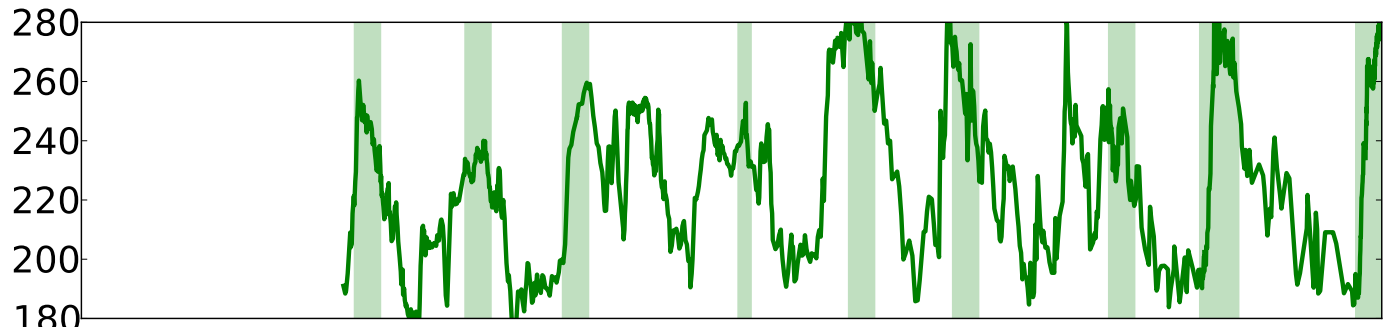
Global Sea Level [m]

(Bintanja et al., 2005)

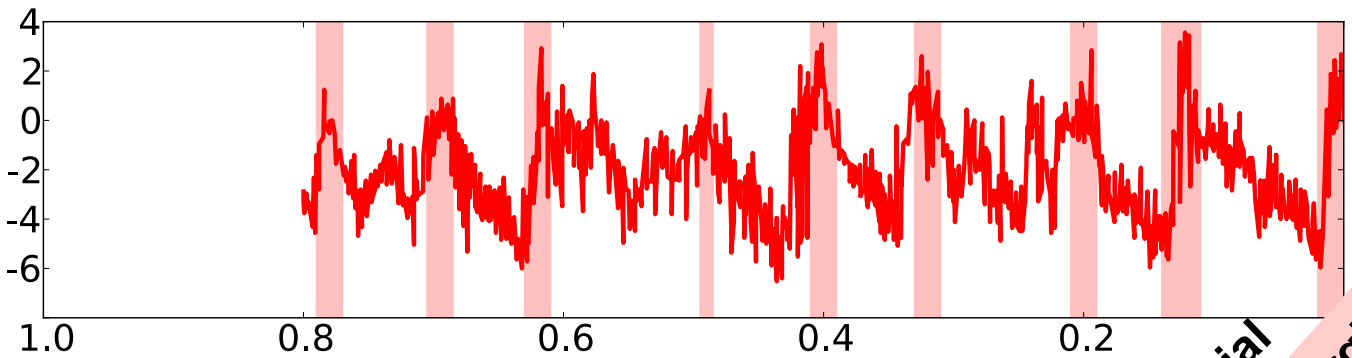


CO₂ [ppmv]

From ice cores (EPICA, 2009)



Temp. anomaly "O-18" [° C]



Million years

Glacial
Interglacial

Monsoon: seasonal signal

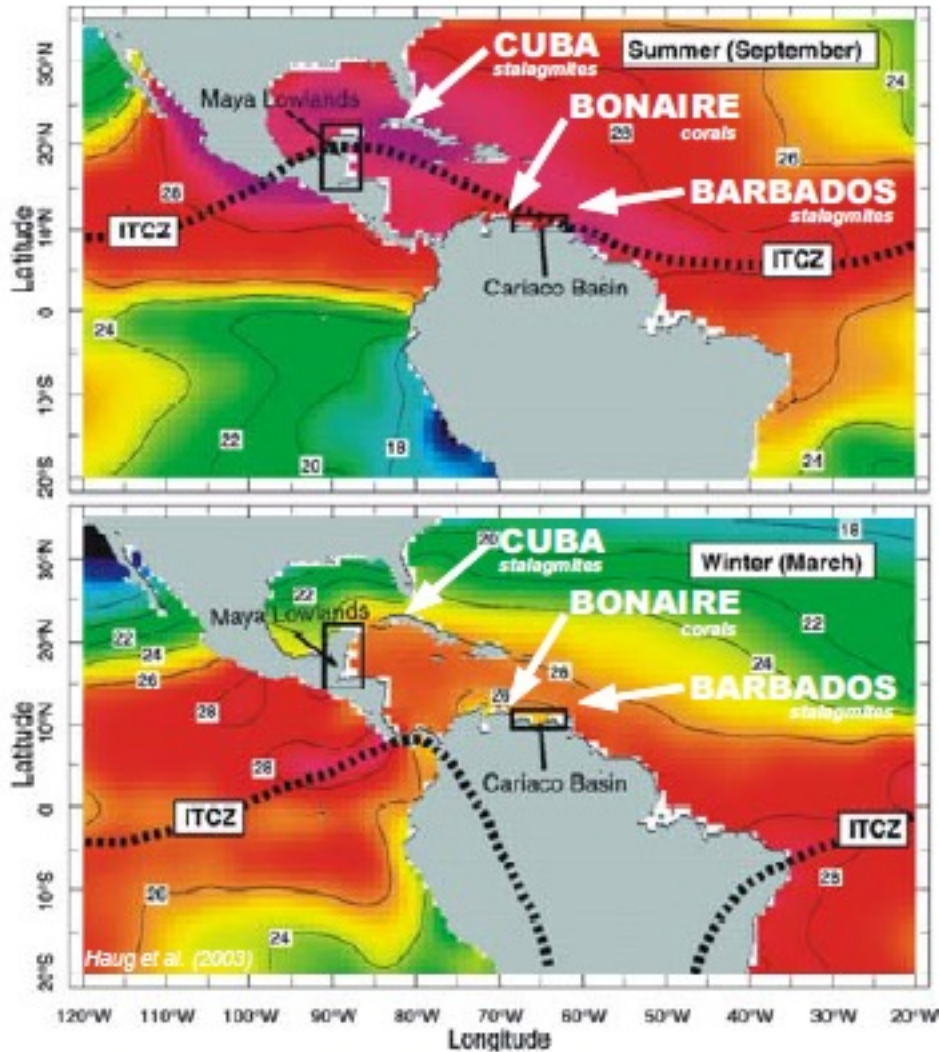


Figure 1. Seasonal variations in the mean position of the Intertropical Convergence Zone (ITCZ) over the Caribbean region, illustrated for typical summer (September) (**top**) and winter (March) (**bottom**) conditions. These variations control the pattern and timing of regional rainfall. Numbers and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

Monsoon

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".

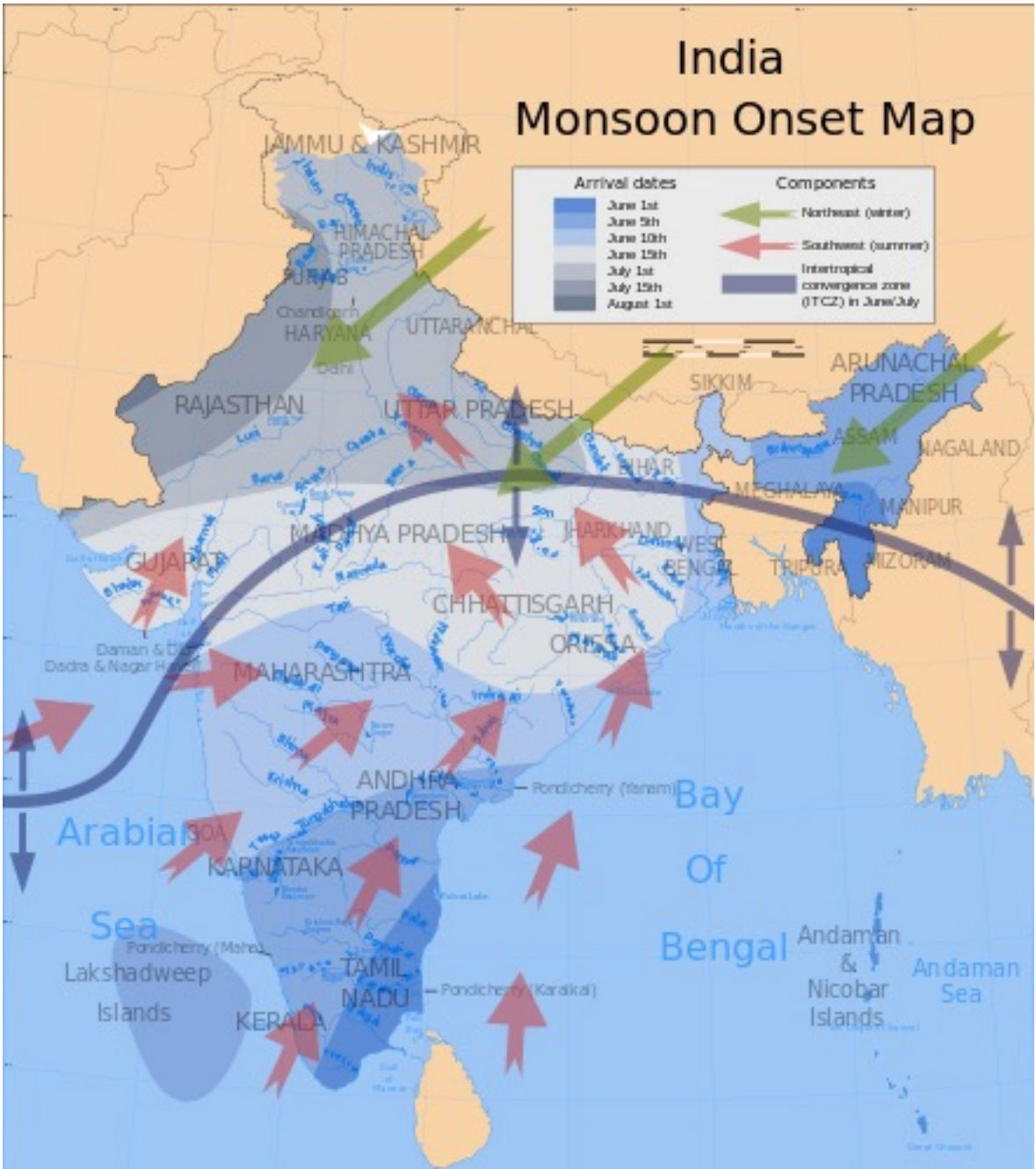
During warmer months sunlight heats the surfaces of both land and oceans, but land temperatures rise more quickly.

water heat capacity ($4.2 \text{ J g}^{-1} \text{ K}^{-1}$)

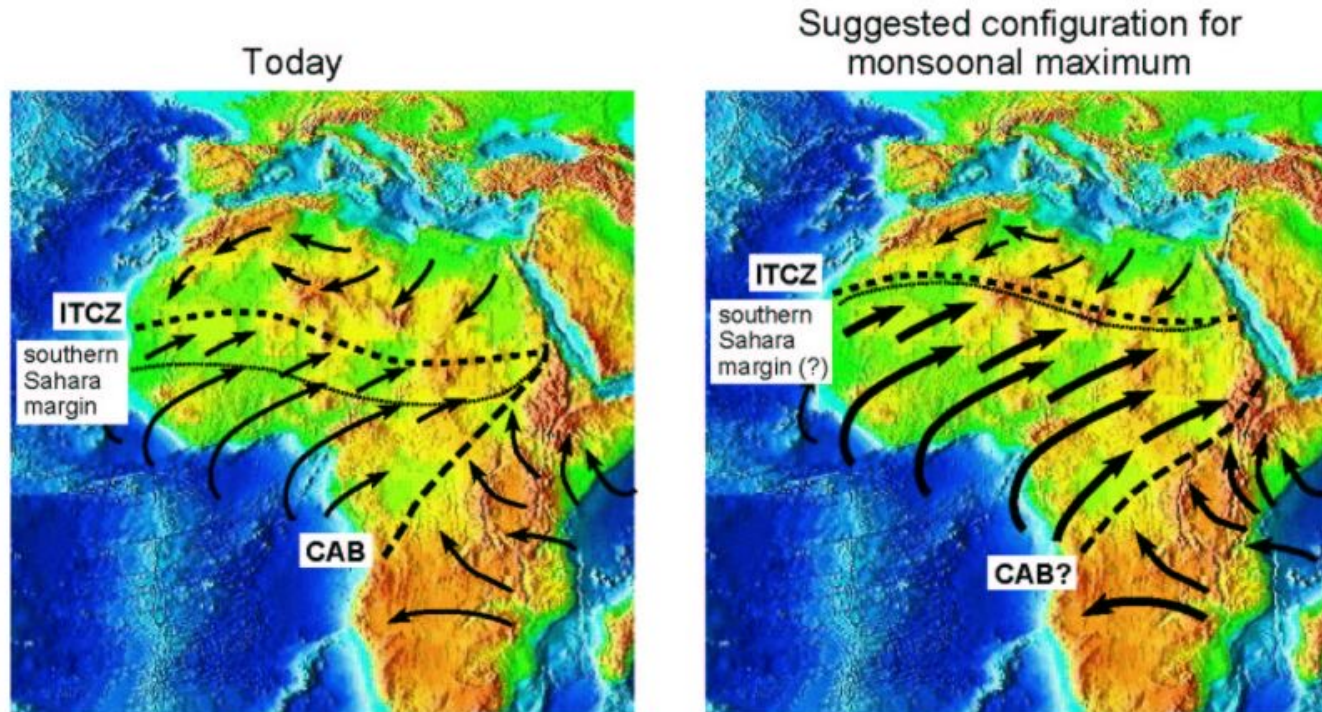
dirt, sand, and rocks heat capacities (0.19 to $0.35 \text{ J g}^{-1} \text{ K}^{-1}$)

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

India Monsoon Onset Map

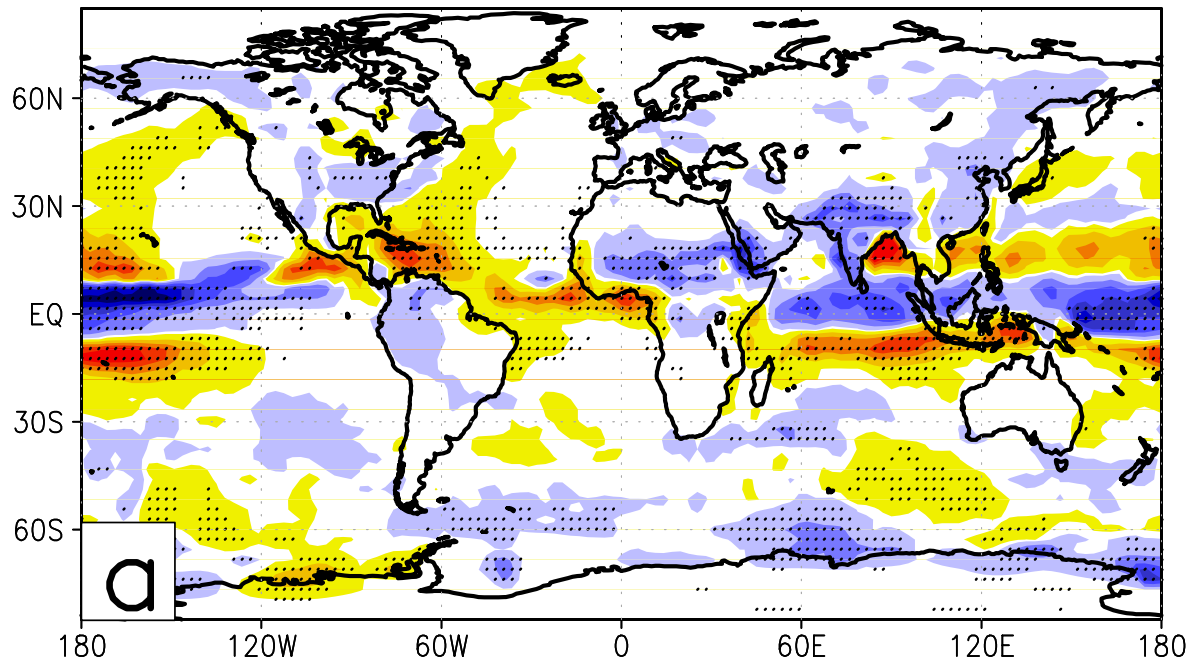


Precession: Effect on climate



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

Holocene 6K- PI, precipitation JJA



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



Paintings

Older than 7000 years



2002 Archäologen Massimo & Jacopo Foggini, Ahmed Mestikawi



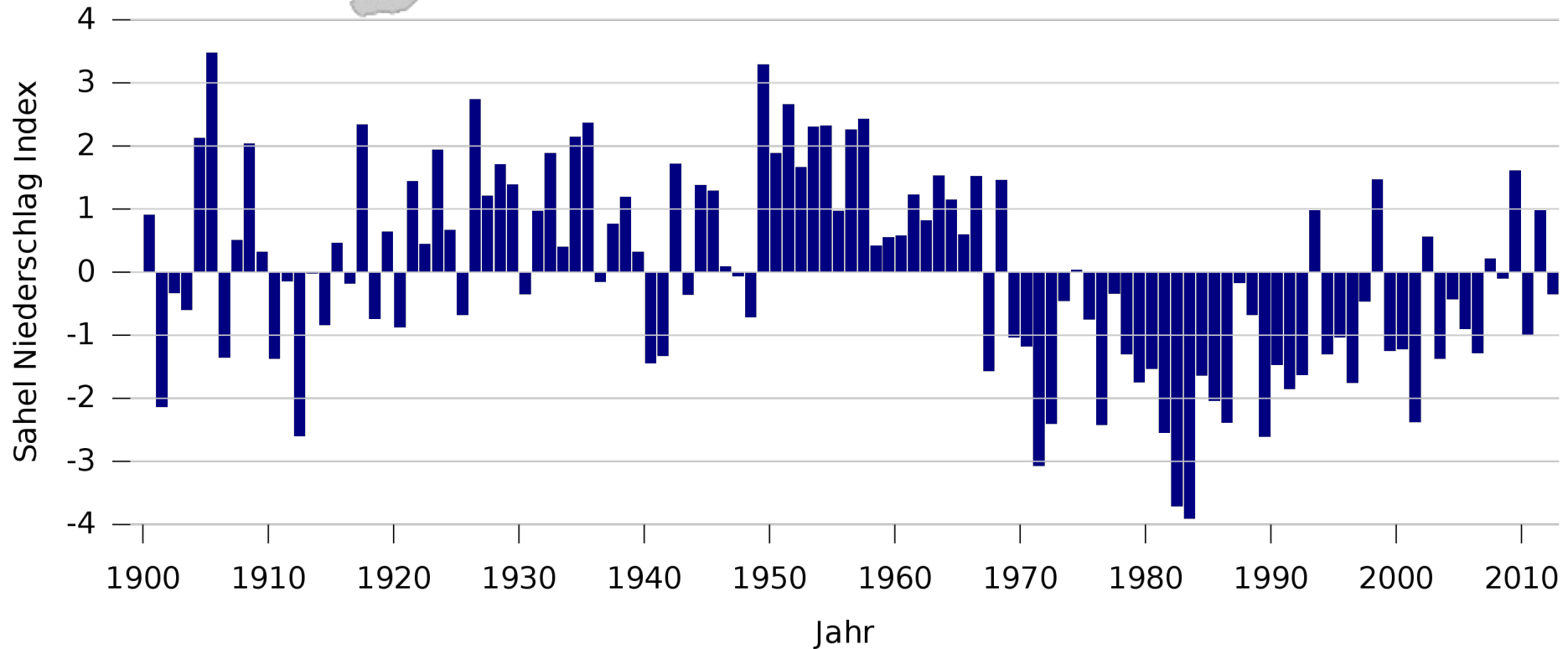


Agadez in Niger.

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

