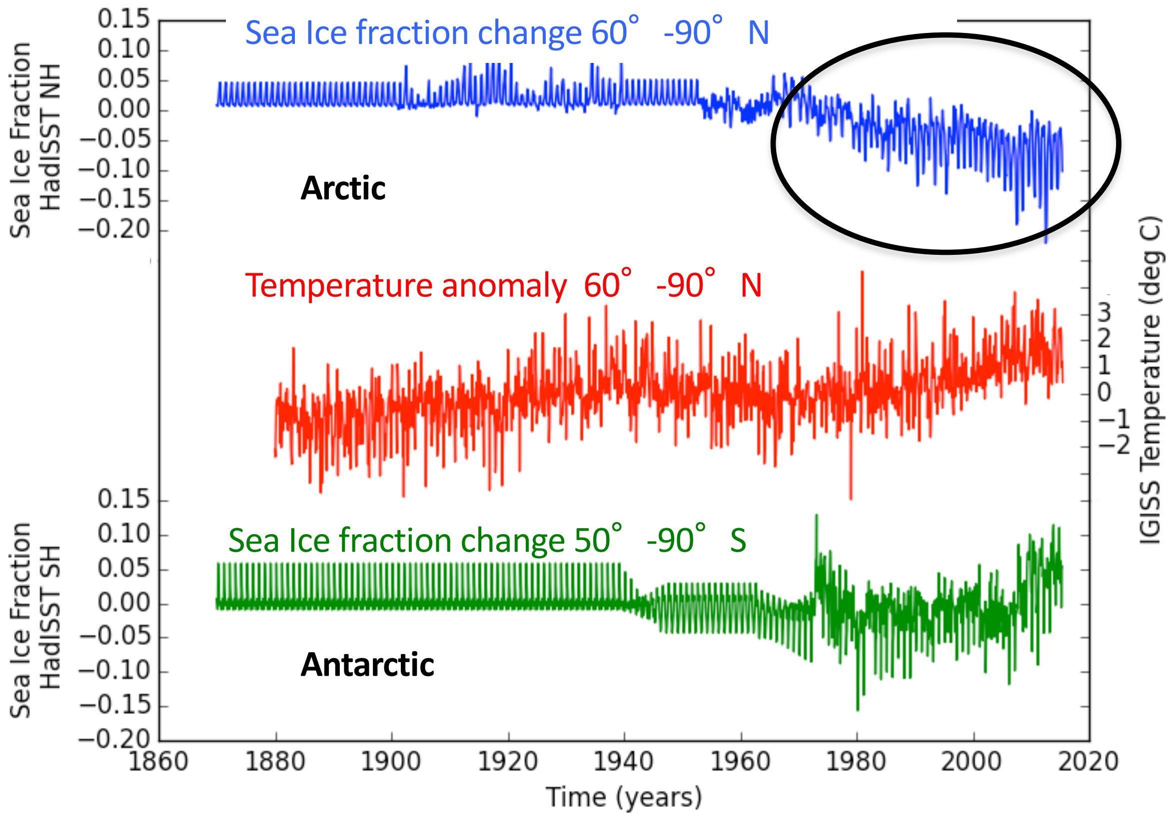
Climate System II course 2023 (5th lecture)

G. Lohmann & M. Werner

Orbital Theory, Ice Ages, Climate change

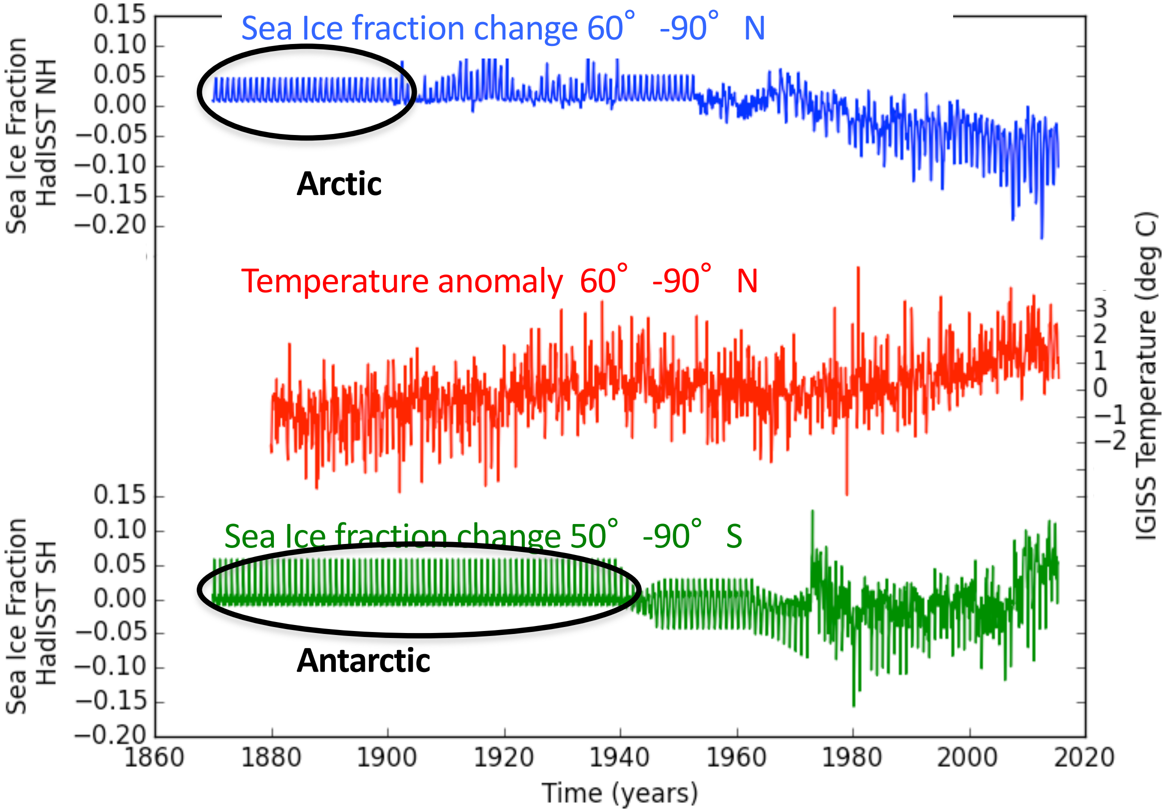
Gerrit Lohmann

Arctic Sea Ice retreat



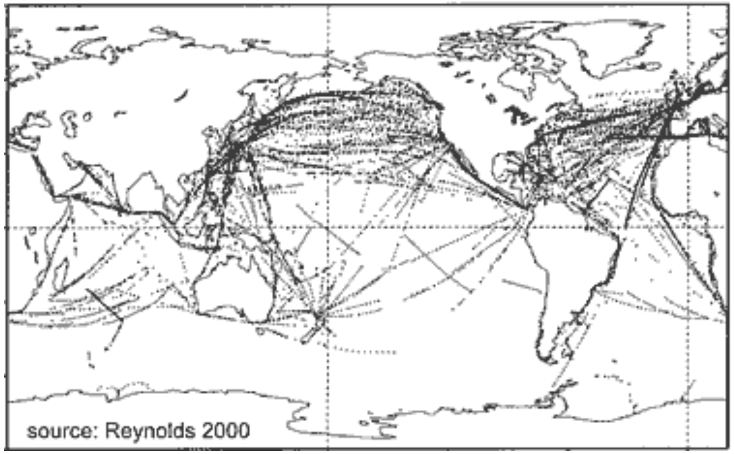
Arctic Sea Ice retreat

Missing Information about Sea Ice



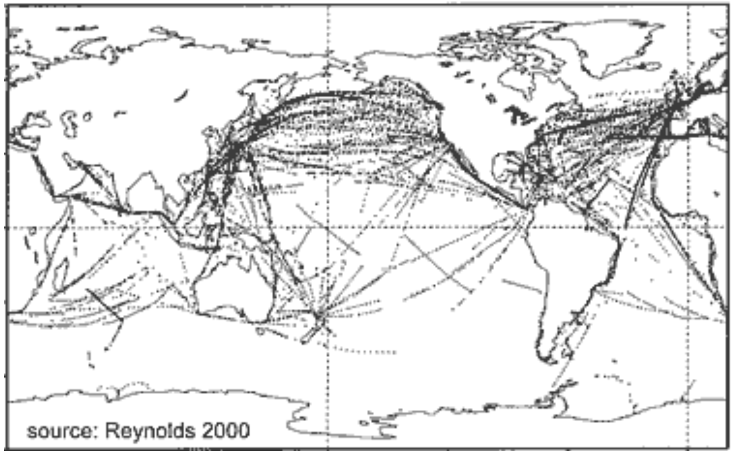
The “Climate dilemma“

- Instrumental data are **sparce**



The “Climate dilemma“

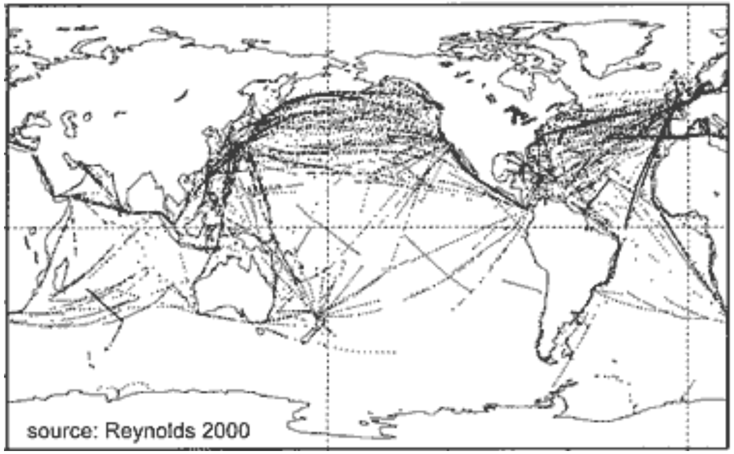
- Instrumental data are **sparce**



- The records of direct temperature measurements are **short** and already fall in the phase of strong **human influence**.

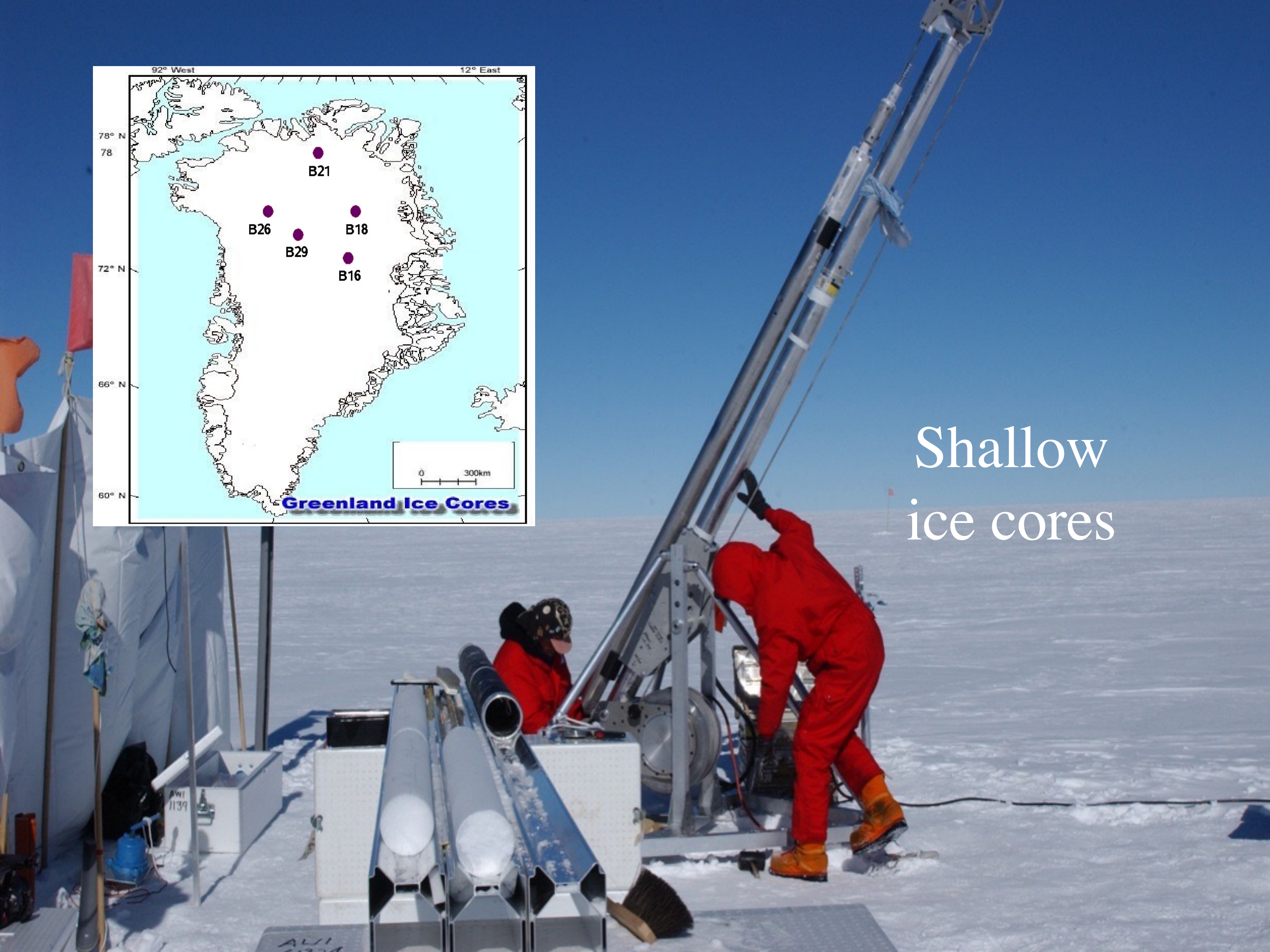
The “Climate dilemma“

- Instrumental data are **sparce**

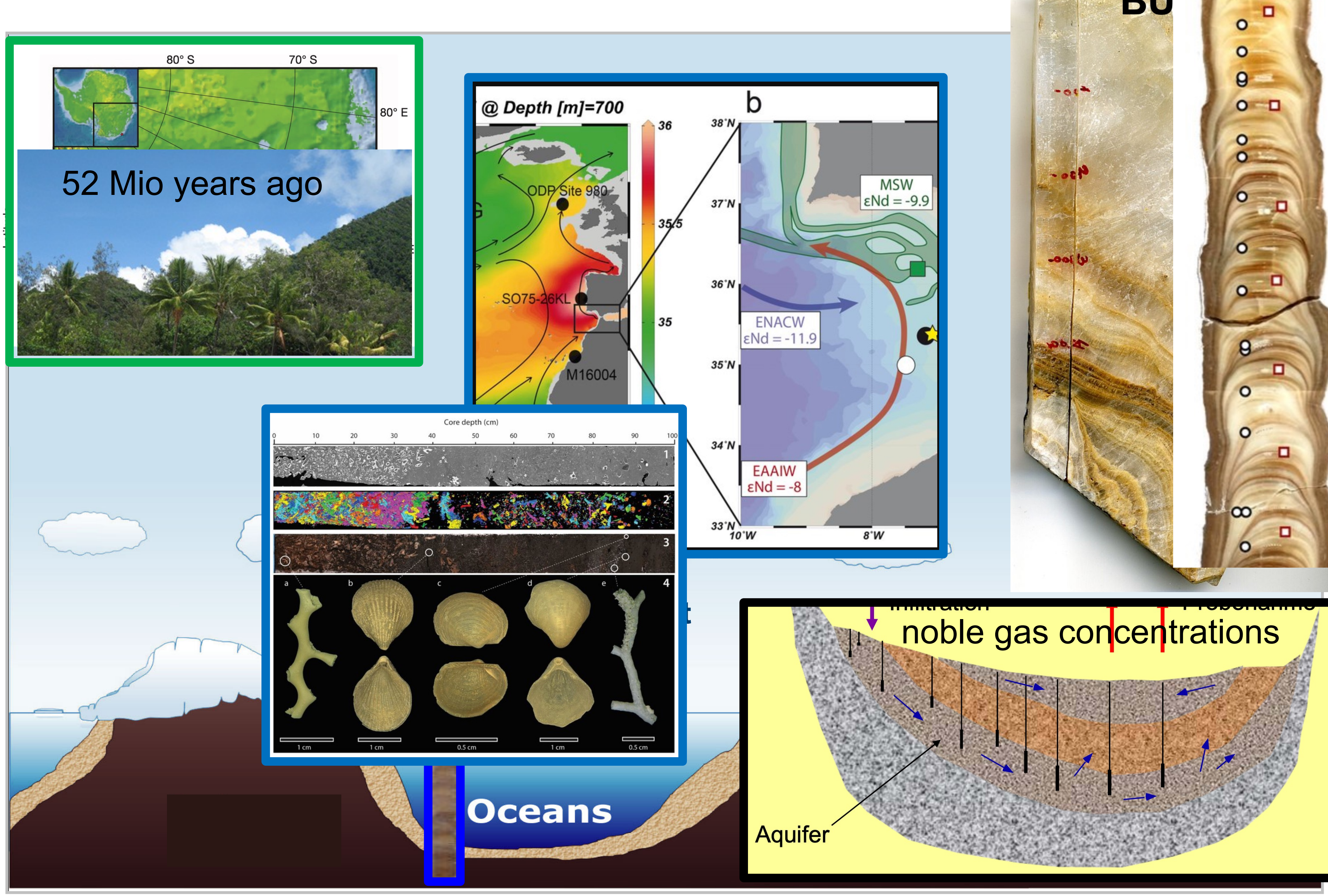


- The records of direct temperature measurements are **short** and already fall in the phase of strong **human influence**.

- **For the time before instrumental records, one has to rely on information from proxy data and modeling.**


92° West
12° East
78° N
78
72° N
66° N
60° N
B21
B26
B18
B29
B16
0
300km
Greenland Ice Cores
Shallow
ice cores

Earth System: Reconstructions

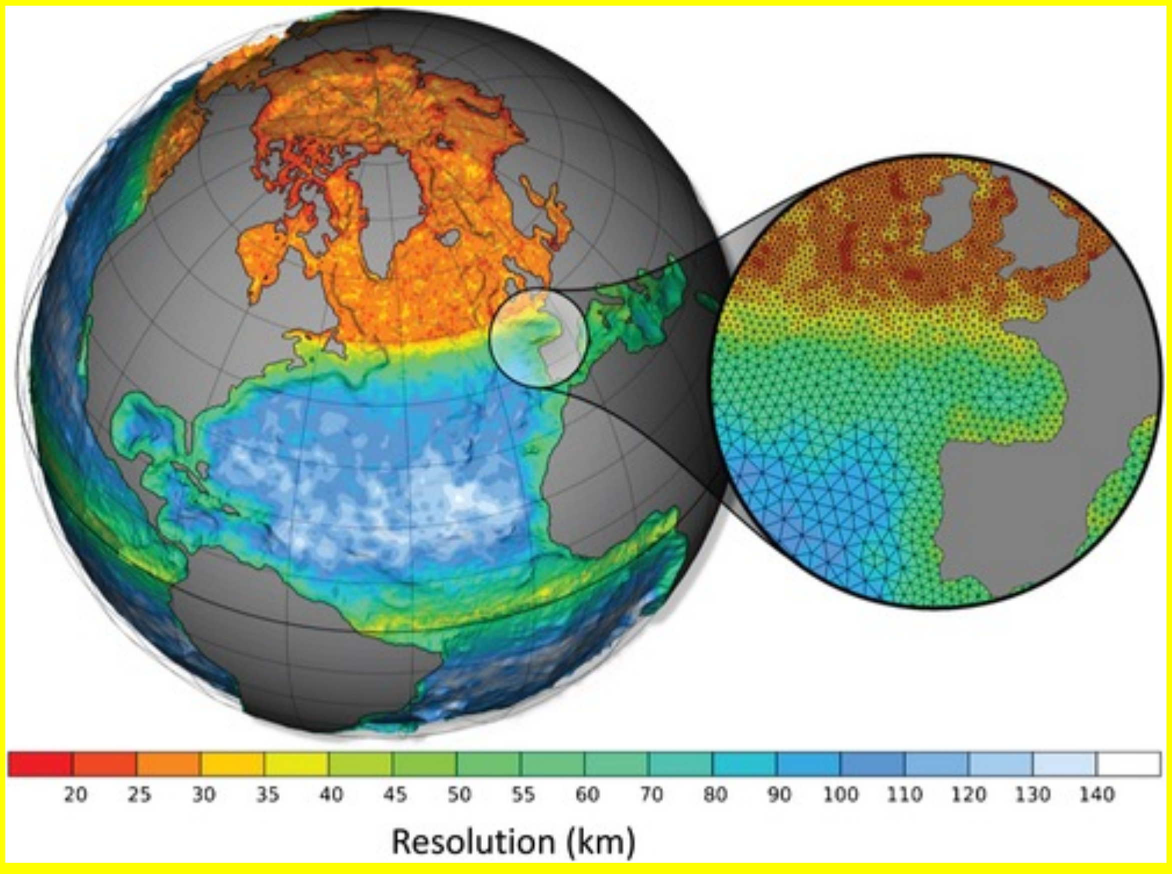


Earth System Analysis: Models

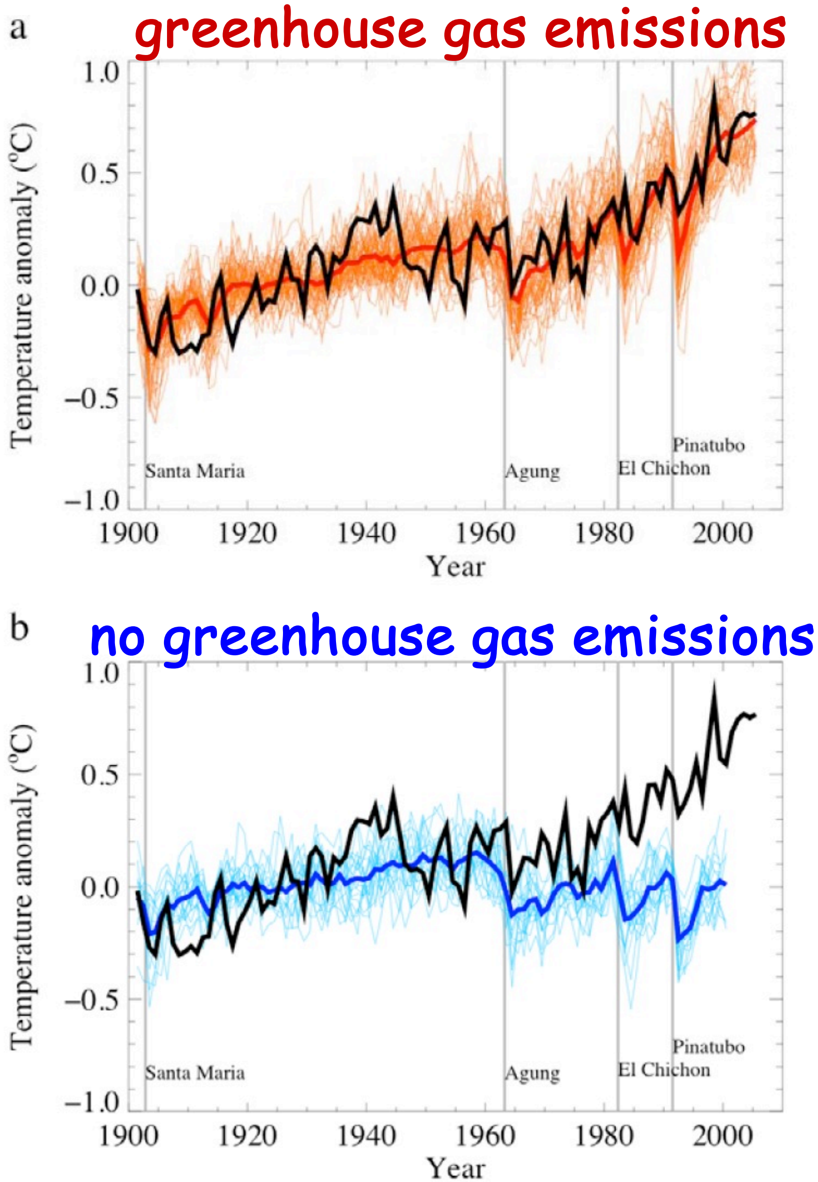
$$\frac{\partial \mathbf{v}}{\partial t} + \mathbf{v} \cdot \nabla \mathbf{v} = -2\Omega \times \mathbf{v} - \frac{1}{\rho}\nabla p + \mathbf{g} + \mathbf{F}$$

$$\frac{\partial \rho}{\partial t} + \nabla \cdot \rho \mathbf{v} = 0$$

$$\frac{\partial T}{\partial t} + \mathbf{v} \cdot \nabla T - \frac{p}{\rho^2}\frac{d\rho}{dt} = Q$$



Attribution (model world)

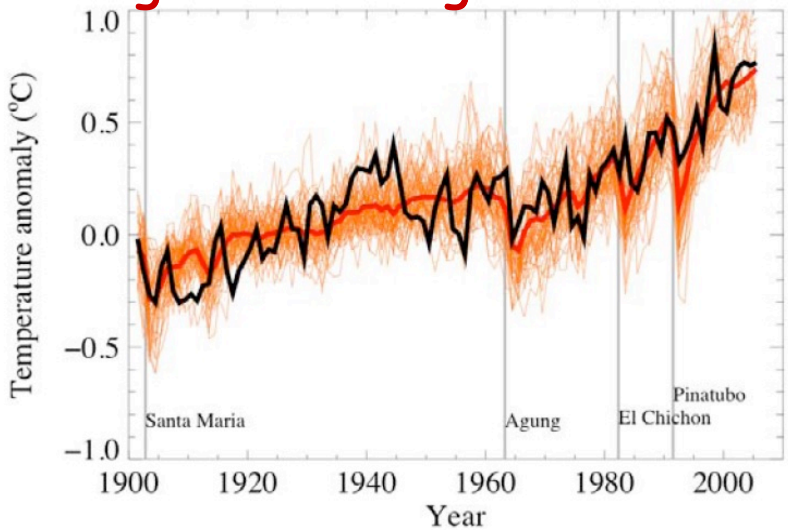


observed changes are consistent with modeled response to external forcing, inconsistent with alternative explanations

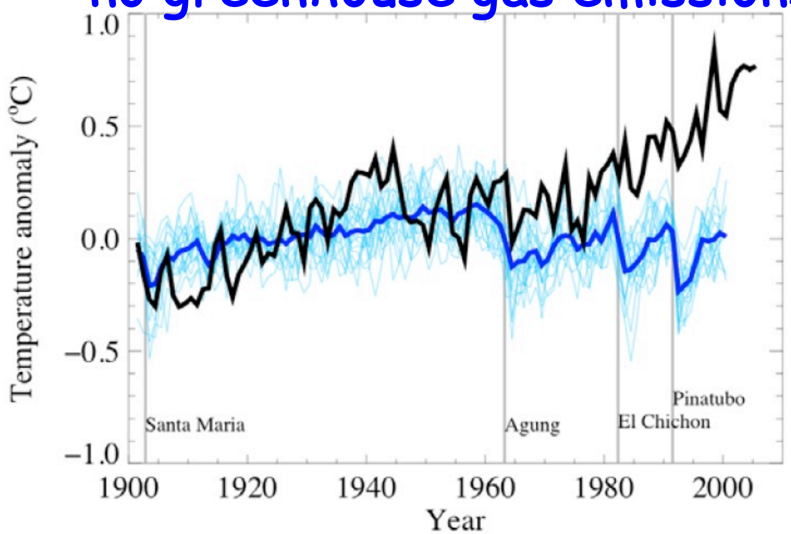
Nobel Price, 2021

Attribution (model world)

a greenhouse gas emissions



b no greenhouse gas emissions

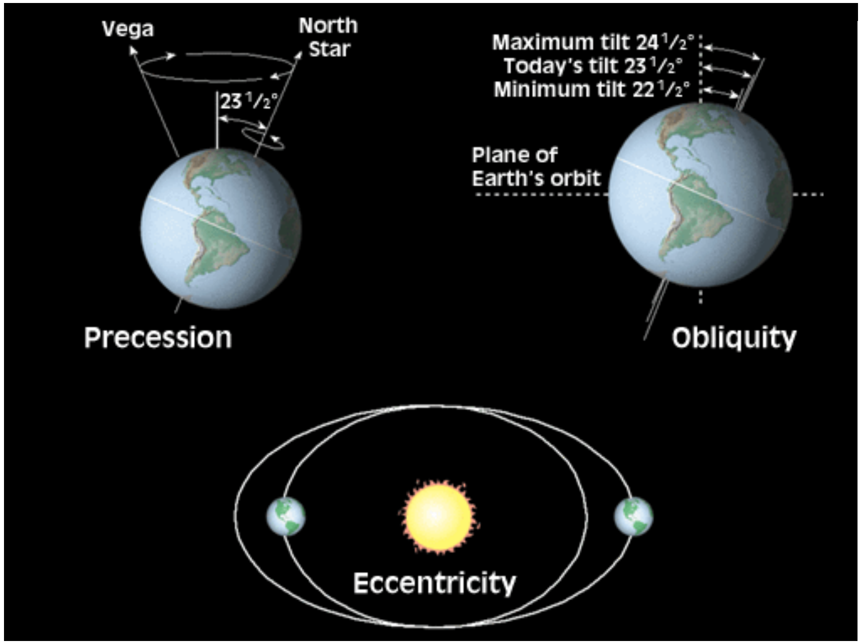


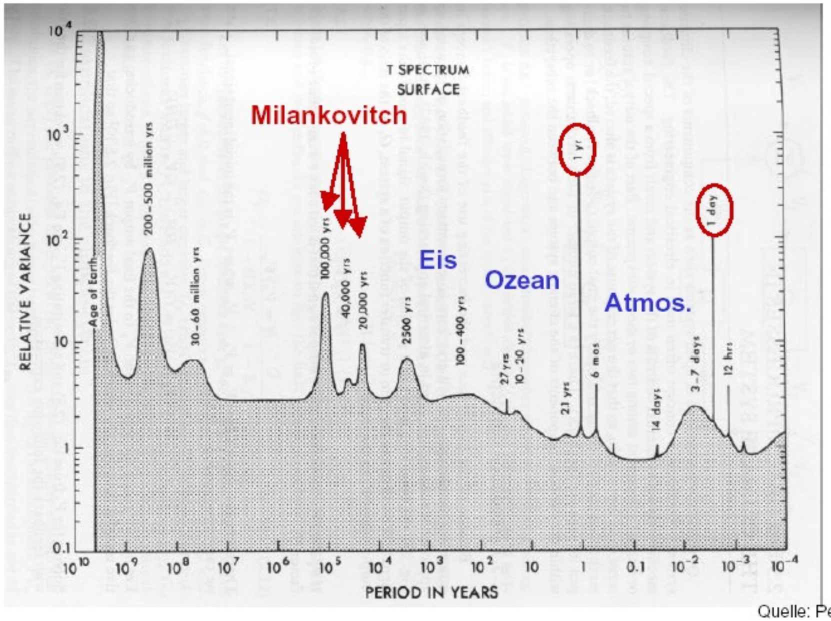
observed changes are consistent with modeled response to external forcing, inconsistent with alternative explanations

Critics:

- **Time series too short**
- **Estimates of natural variability based only on models**

Previous Lecture: Orbital forcing

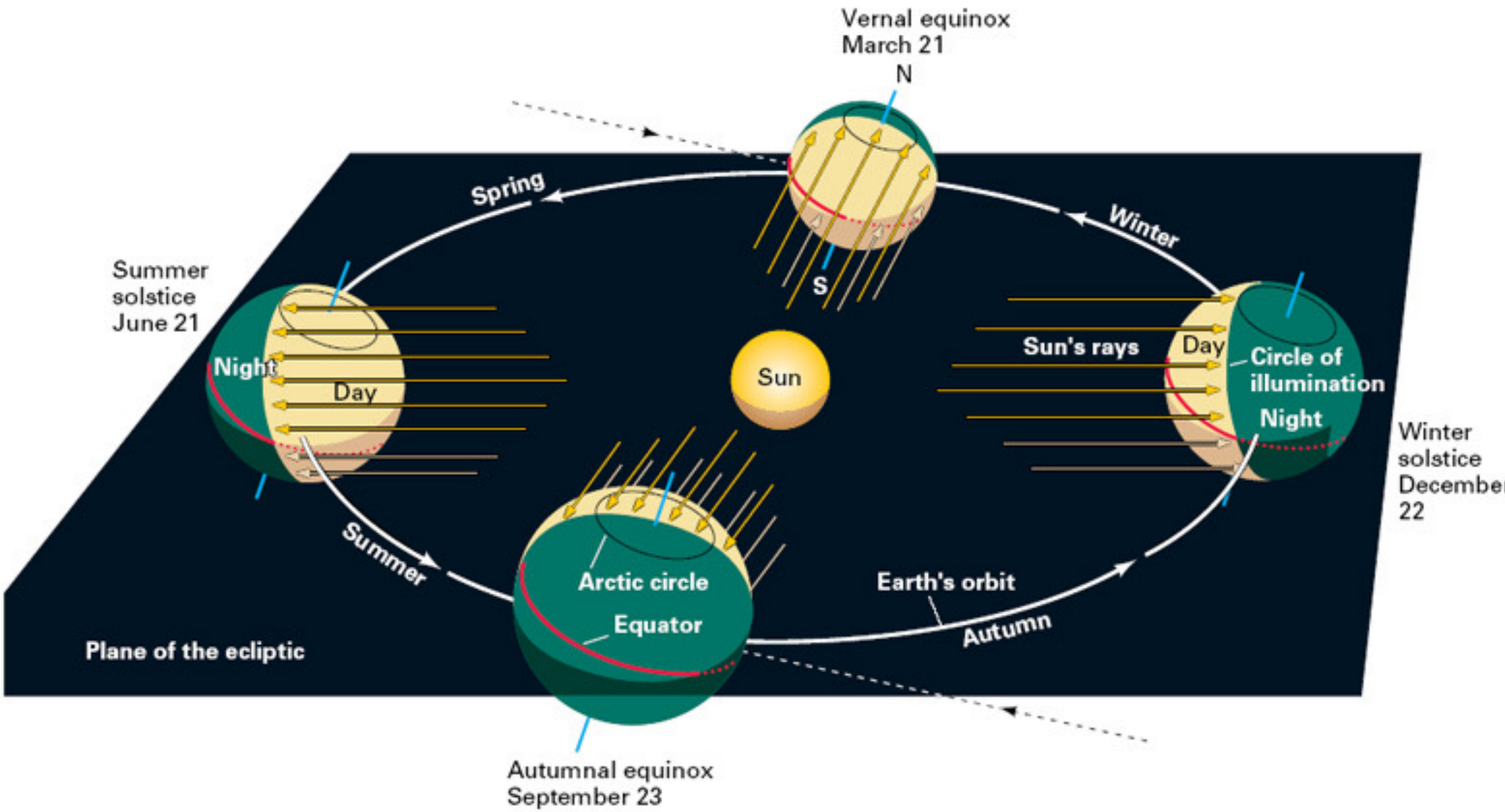




Quelle: Peixoto & Oort

- ~20,000, ~40,000, ~100,000 years
- 0.5, 1 year
- Tides
- **Geometry of the Sun-Earth configuration (& Moon)**

The seasons



Strahler, 2002

The Earth's orbit

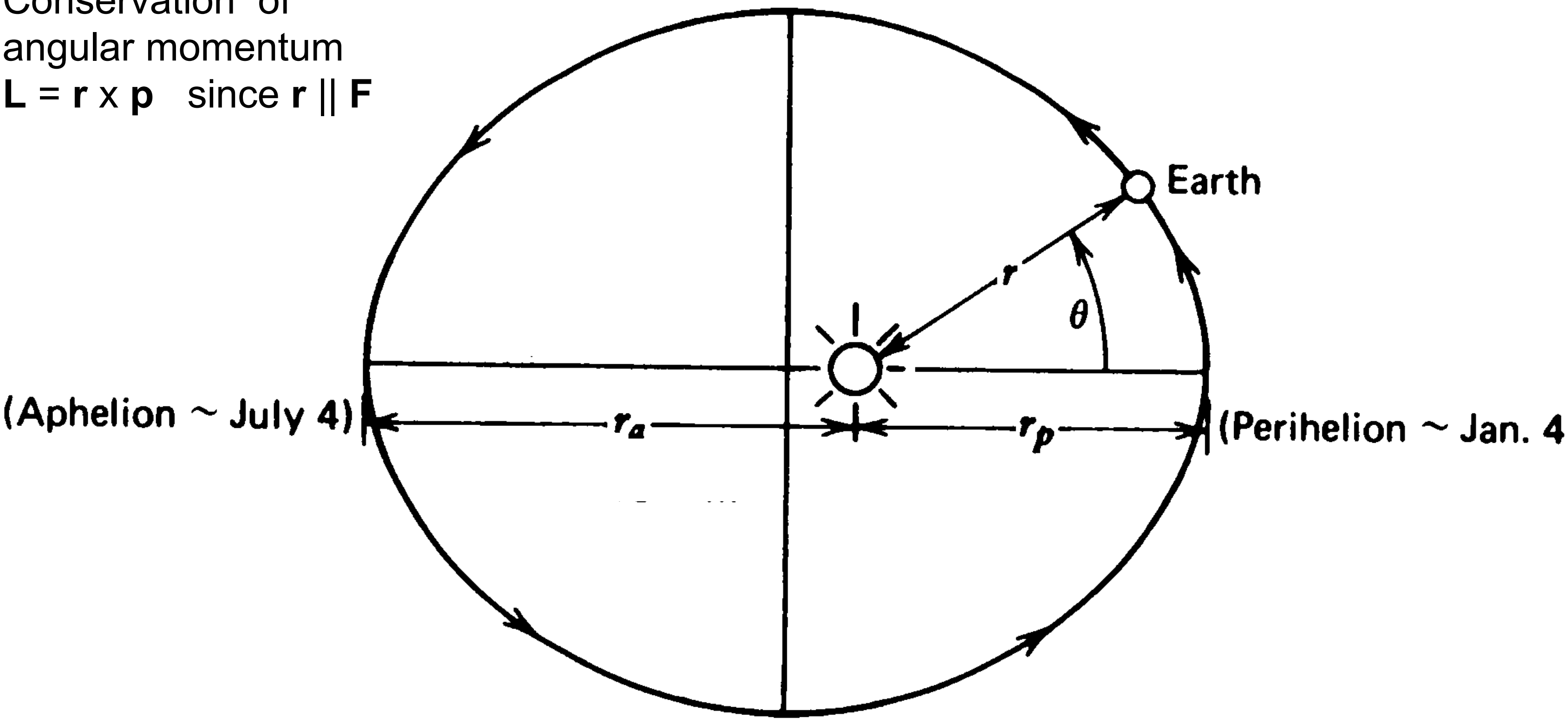
Keppler

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

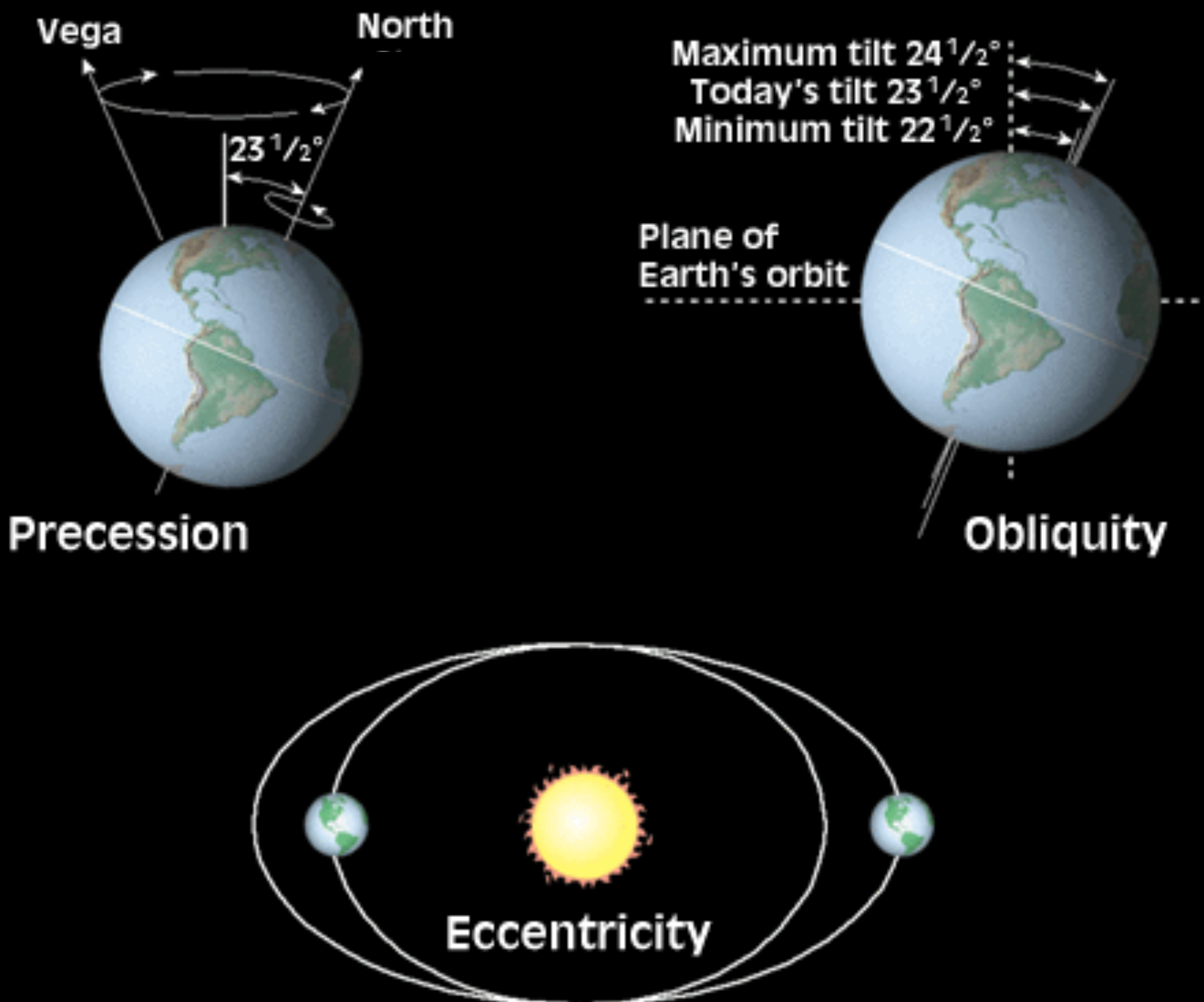
r = a +/- 2%

mean orbital distance	**a = 150 Mio km**
eccentricity	**ε = 0.0167** (shown exaggerated)

Conservation of angular momentum
L = **r** x **p** since **r** \|\| **F**

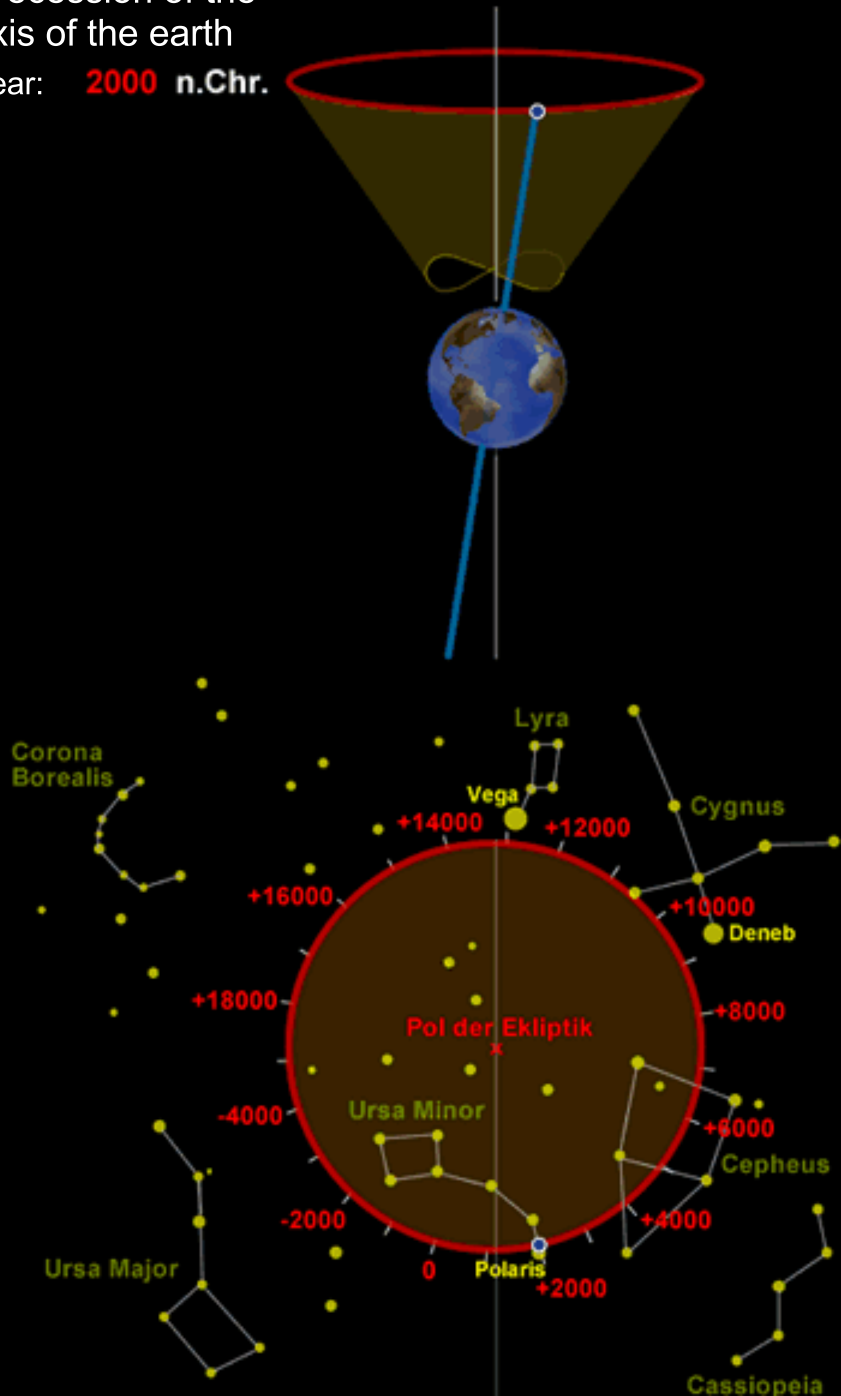


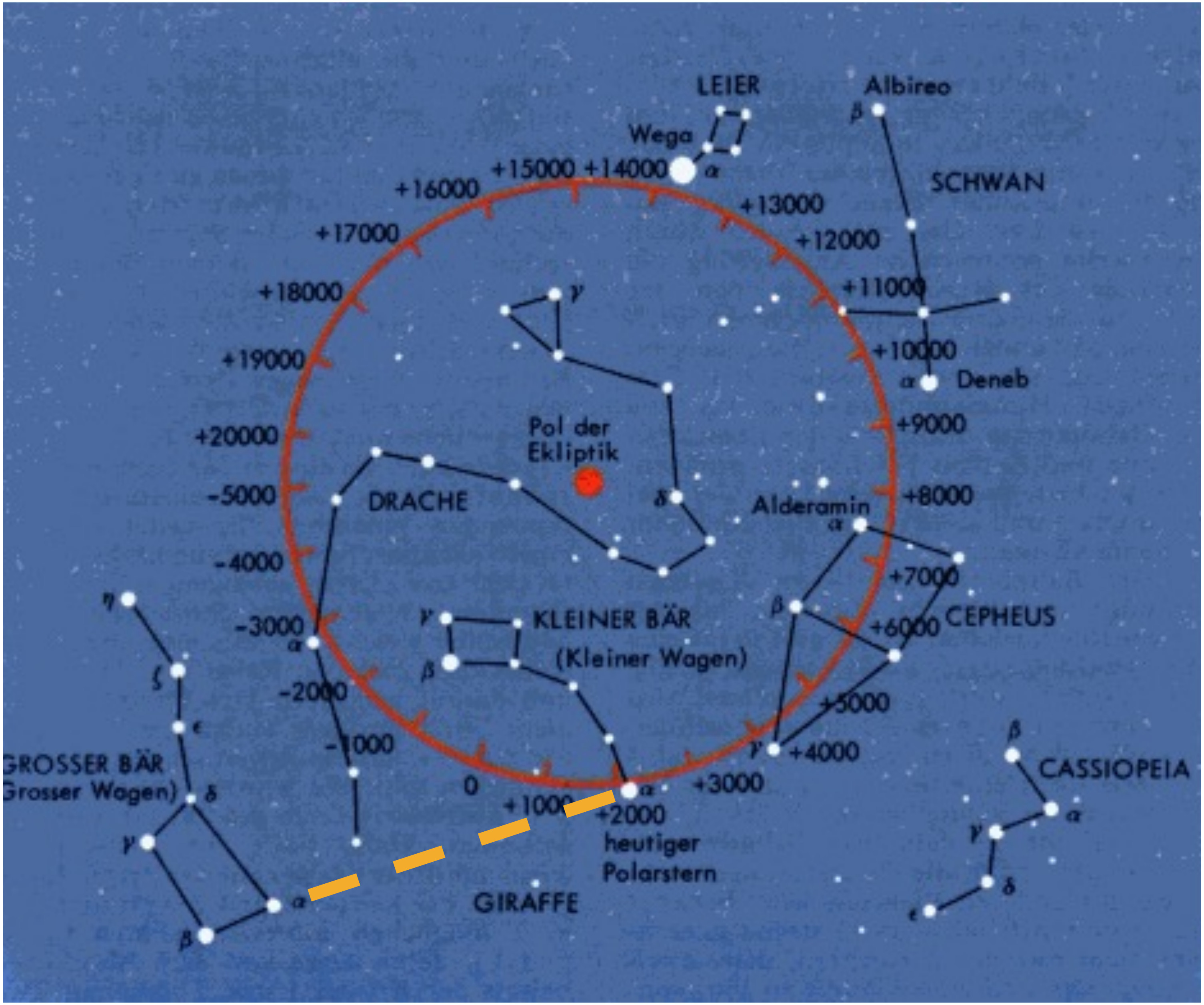
Wieder, 1982


Vega
North
23 1/2°
Precession
Maximum tilt 24 1/2°
Today's tilt 23 1/2°
Minimum tilt 22 1/2°
Plane of
Earth's orbit
Obliquity
Eccentricity

Precession of the axis of the earth

Year: 2000 n.Chr.




LEIER
Albireo
Wega
SCHWAN
Deneb
Pol der Ekliptik
DRACHE
Alderamin
CEPHEUS
KLEINER BÄR
(Kleiner Wagen)
GROSSER BÄR
(Grosser Wagen)
heutiger Polarstern
GIRAFFE
CASSIOPEIA
+15000
+14000
+16000
+13000
+17000
+12000
+18000
+11000
+19000
+10000
+20000
+9000
-5000
+8000
-4000
+7000
-3000
+6000
-2000
+5000
-1000
+4000
0
+1000
+2000
+3000

Universität Bremen

verschiedenen Dämpfungen, Messwerterfassung und Auswertung mit CASSY-Computersystem, chaotisches Verhalten, Phasenraumdarstellung

© C.Windzio / PHYSIKA

Versuchsskript: m9_erzwungene_schwingungen_13_04_11.pdf

M11 Kreisel

Überprüfung des Zusammenhangs zwischen Präzessionsdauer, Rotationsfrequenz, Schwerpunktlage, Trägheitsmoment / Stoppuhr

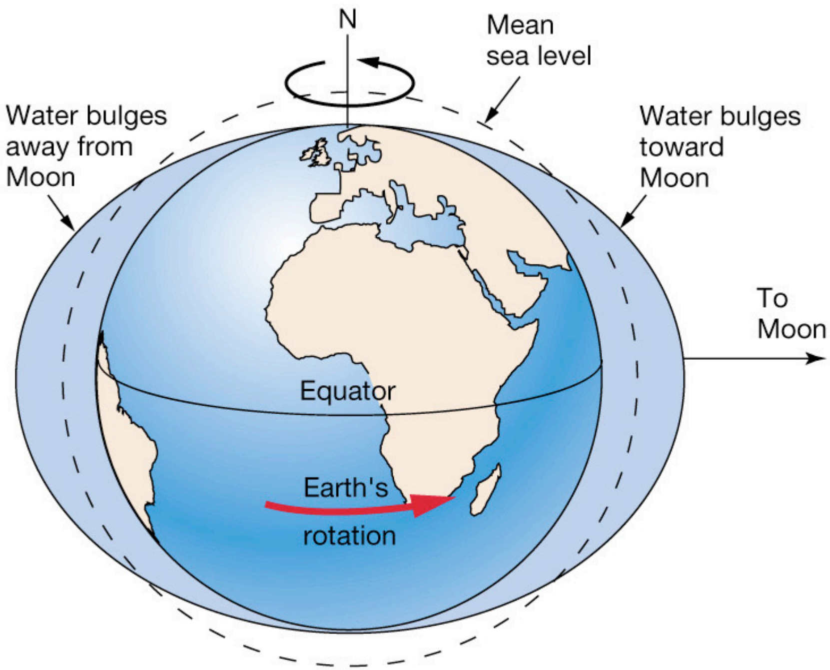
Versuchsskript: M11_Kreisel_04_10_17.pdf

© C.Windzio / PHYSIKA

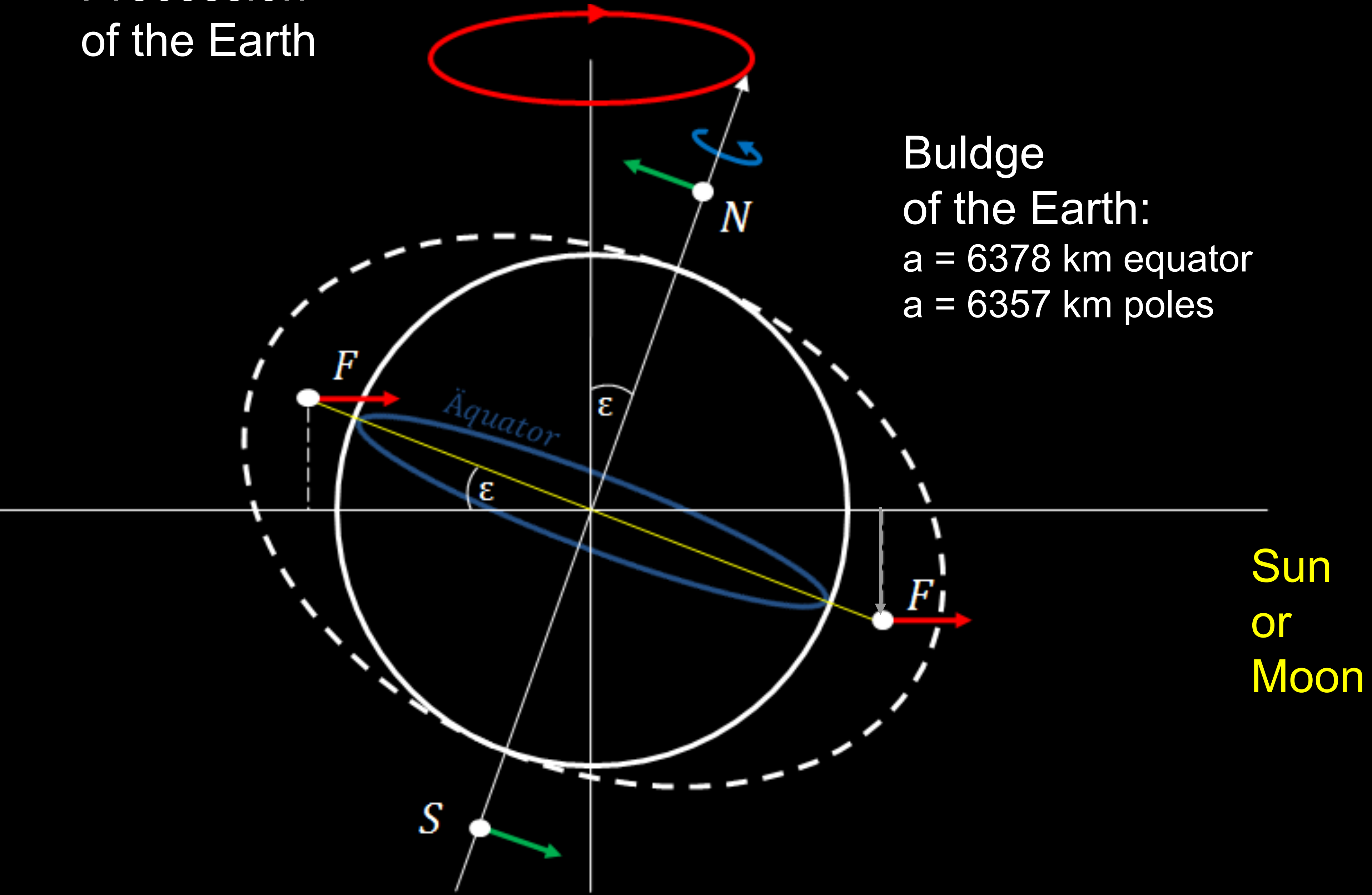
https://www.uni-bremen.de/physika/versuche/mechanik

Tidal bulges

1. Away from Moon on side of Earth opposite Moon
2. Toward Moon on side of Earth facing Moon



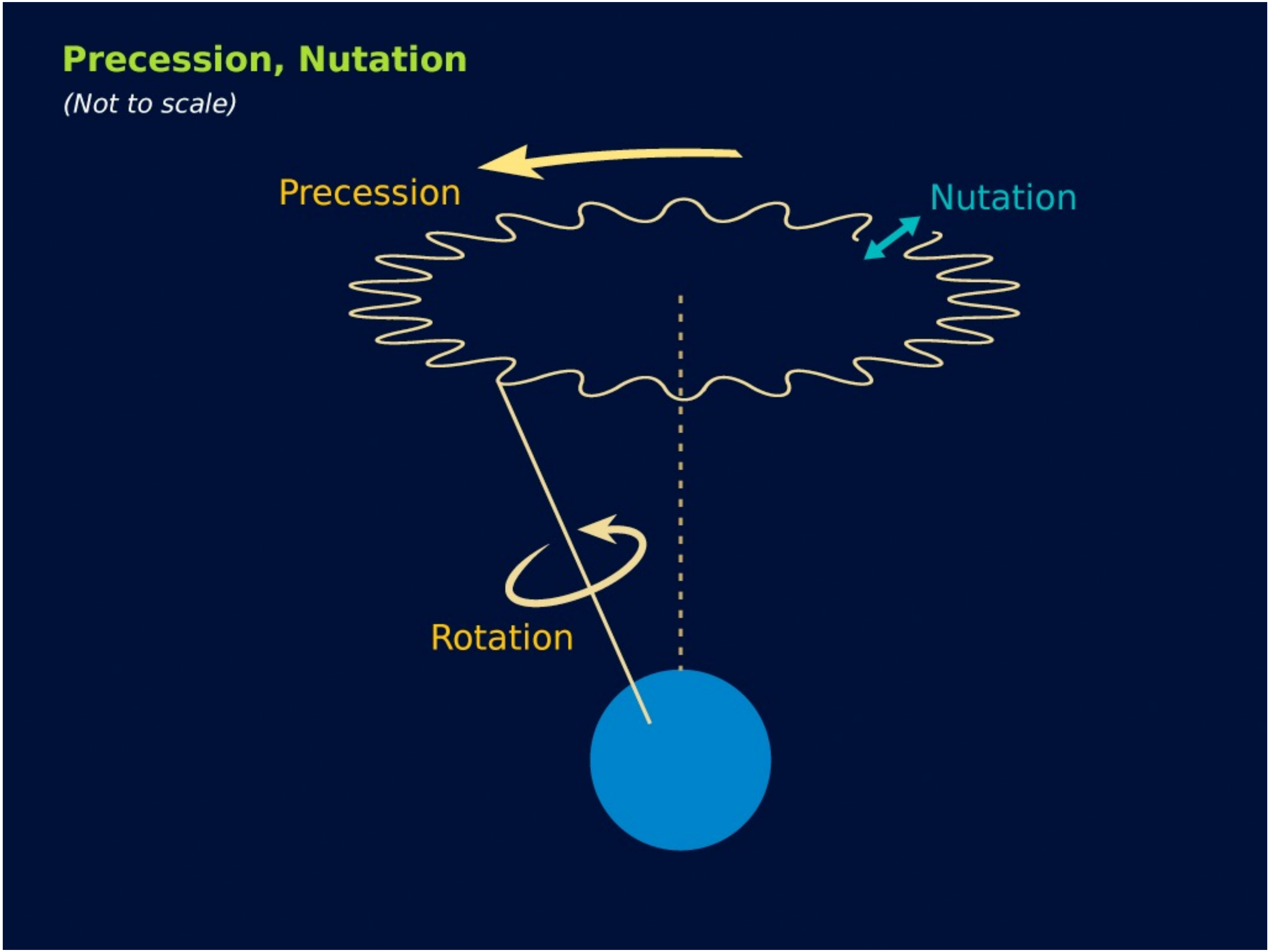
Precession of the Earth



Buldge of the Earth:

a = 6378 km equator

a = 6357 km poles


Precession, Nutation
(Not to scale)
Precession
Nutation
Rotation

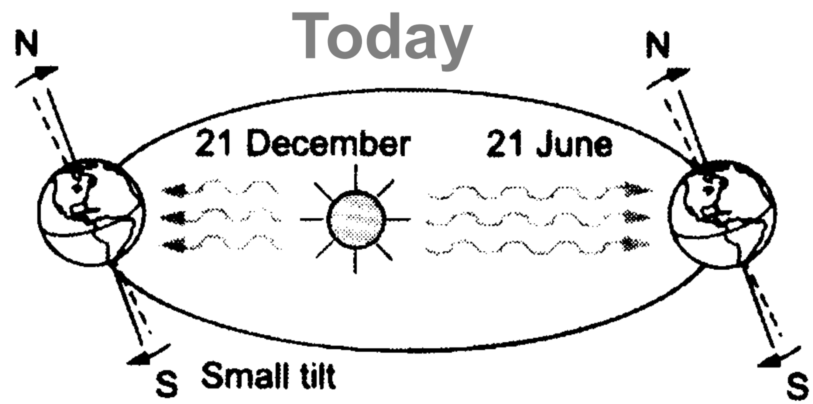
Sunspots Photo: Nasa

Configuration of the Earth‘s orbit: Examples

Perihelion (closest point)

in January

Tilt of the earth‘s axis: **23.5°**



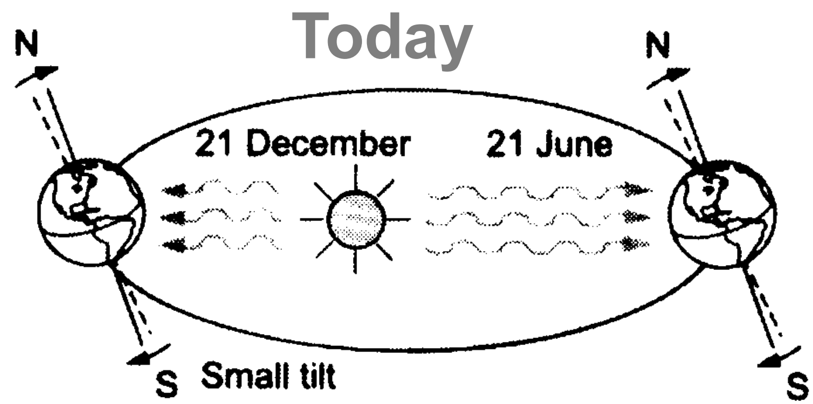
Kutzbach (1992)

Configuration of the Earth‘s orbit: Examples

Perihelion (closest point)

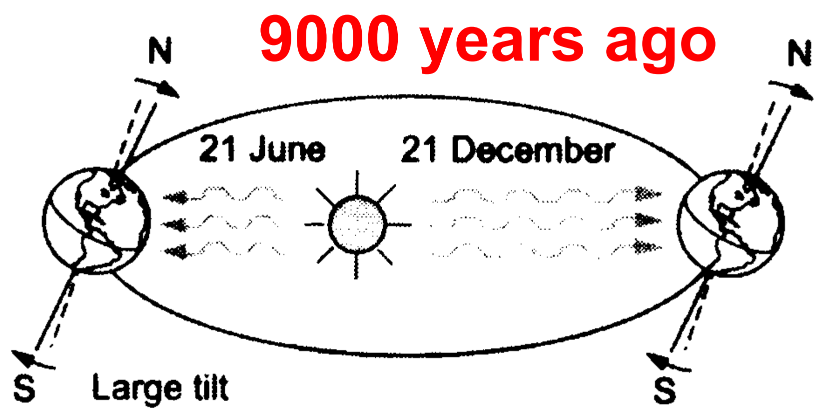
in January

Tilt of the earth‘s axis: **23.5°**



Perihelion in July

Tilt of the earth‘s axis: **24.0°**

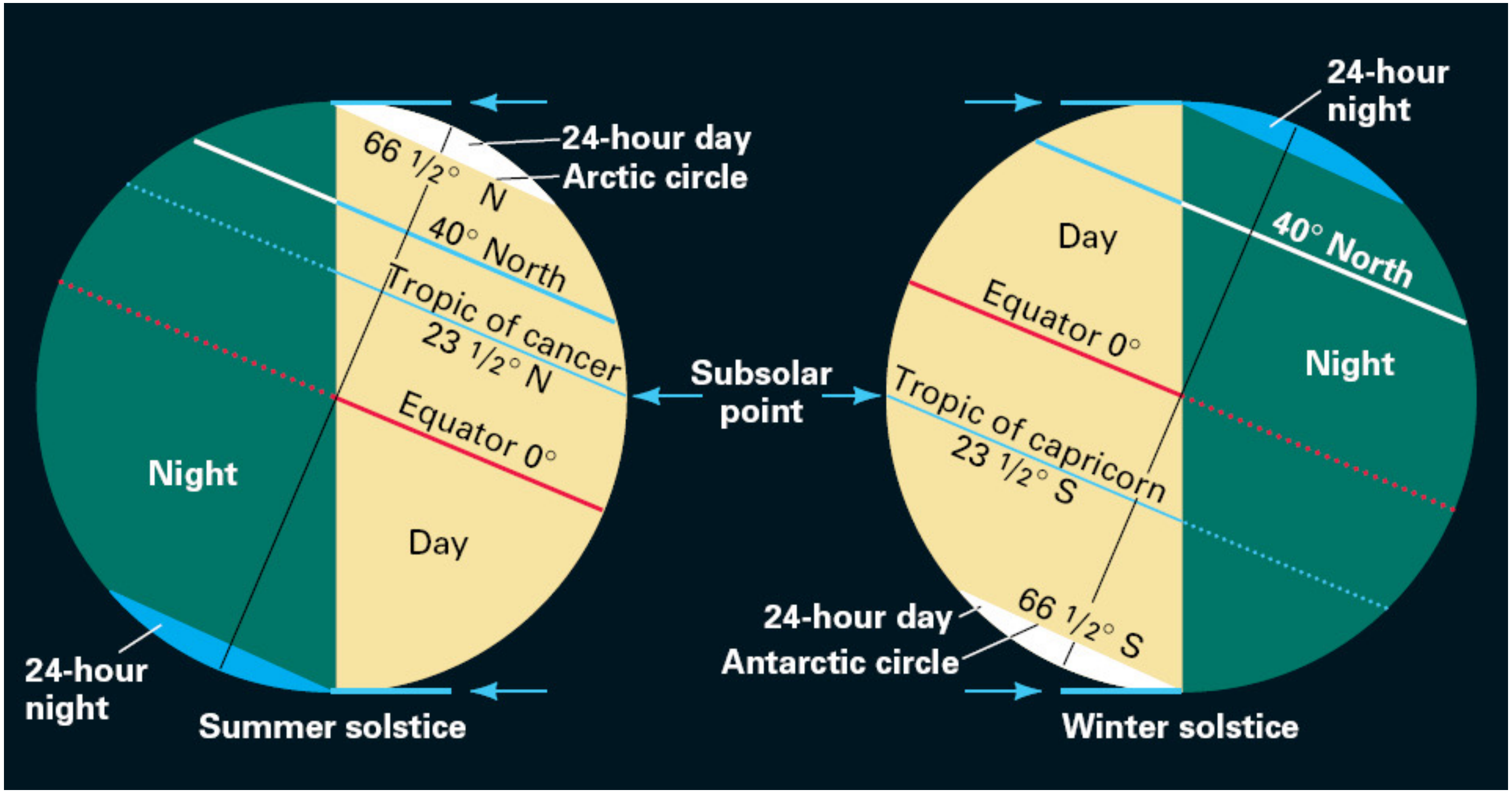


The incoming solar energy in the northern hemisphere 7 % greater in July and correspondingly less in January.

Kutzbach (1992)

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)



Strahler, 2002

Effect of **obliquity** on the **position Tropic of Cancer**

Highway in Mexico

How many meters per year?

Earth's obliquity oscillates between 22.1° and 24.5° on a 41,000-year cycle.
The Earth radius a=6371

Exercise 1 - Climate System II

1 Evaluation of the effect of obliquity on the movement of the Tropic of Cancer

Minimal obliquity: $\Phi_{min} = 22.1°$
Maximal obliquity: $\Phi_{max} = 24.5°$
Period of oscillation: $T = 41,000$ years
Earth radius: $R = 6,371$ km
Movement per year of the Tropic of Cancer due to obliquity changes: d=?

$$\Delta\Phi_{tot} = \Phi_{max} - \Phi_{min} = 24.5° - 22.1° = 2.4°$$

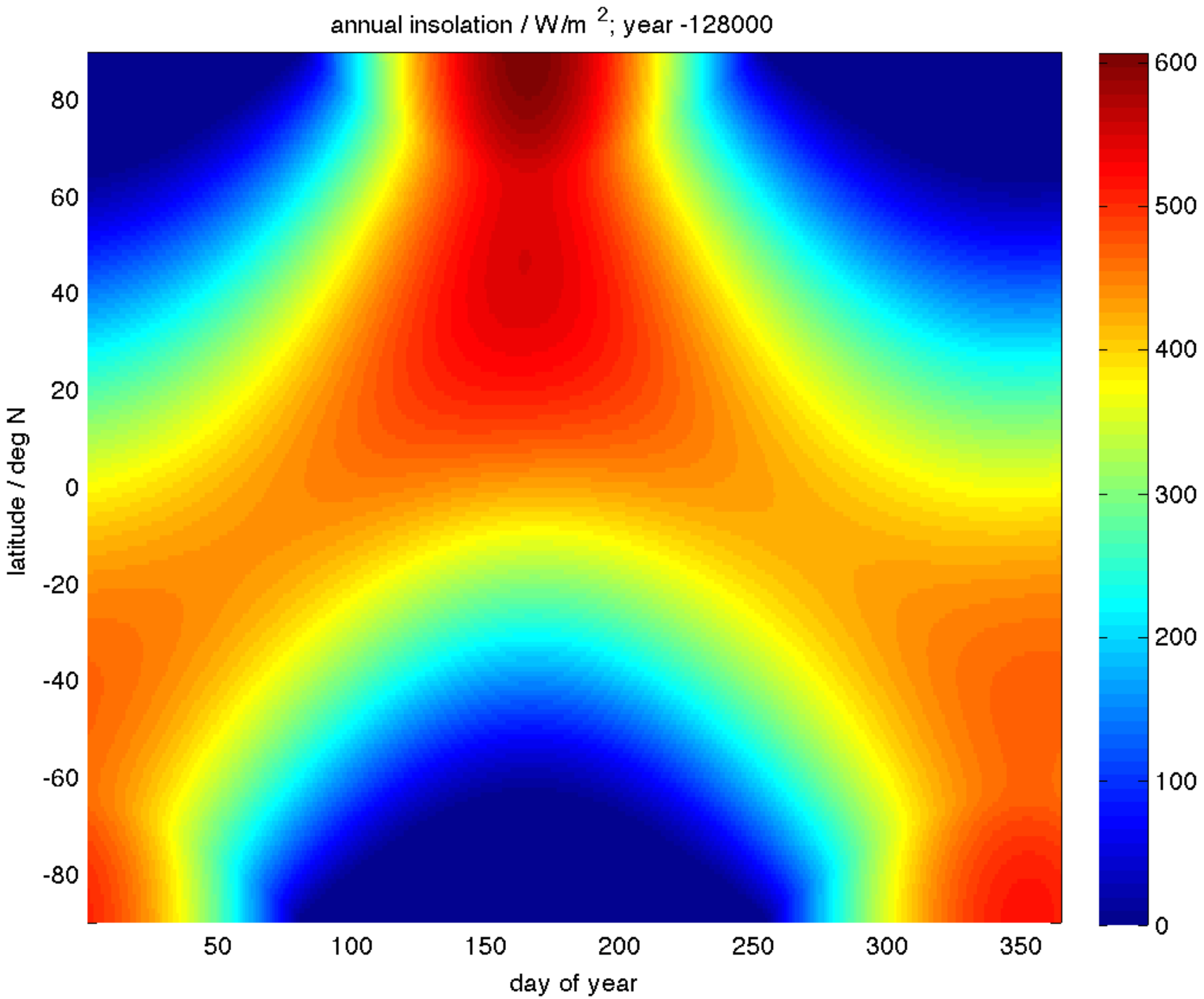
$$\Delta\Phi_{year} = \frac{\Delta\Phi_{tot}}{T/2} = \frac{2\Delta\Phi_{tot}}{T} = \frac{4.8°}{41,000 \text{ years}} = 0.000117°$$

$$d = \Delta\Phi_{year} \cdot 111 \text{ km} = 0.000117° \cdot 111 \cdot 10^3 \text{ m} = 13 \text{ m}$$

where we used the fact that one degree of latitude corresponds to 111 km, in fact:

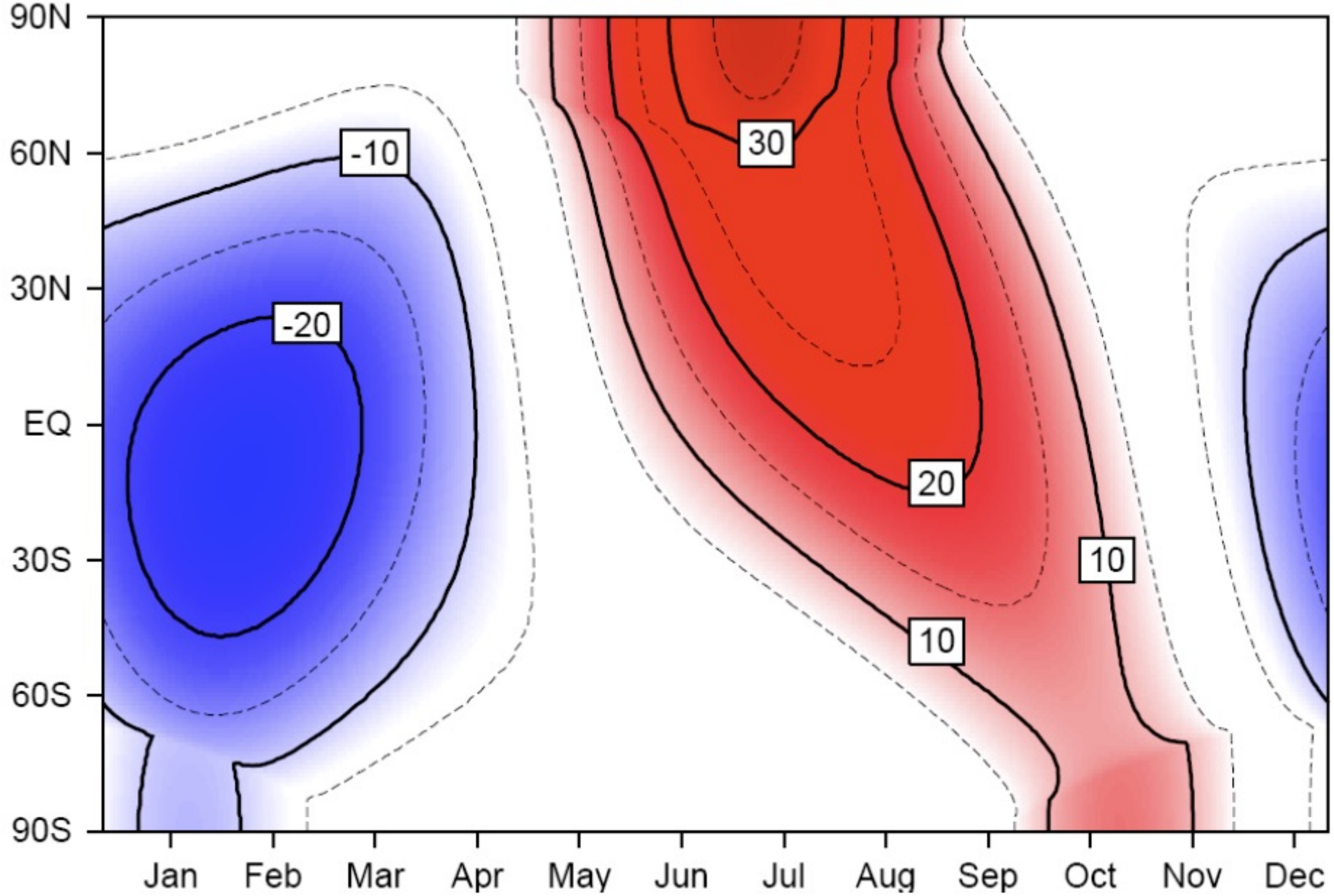
$$\frac{2 \cdot \pi \cdot R}{360°} = 111 km/degree$$

Insolation



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

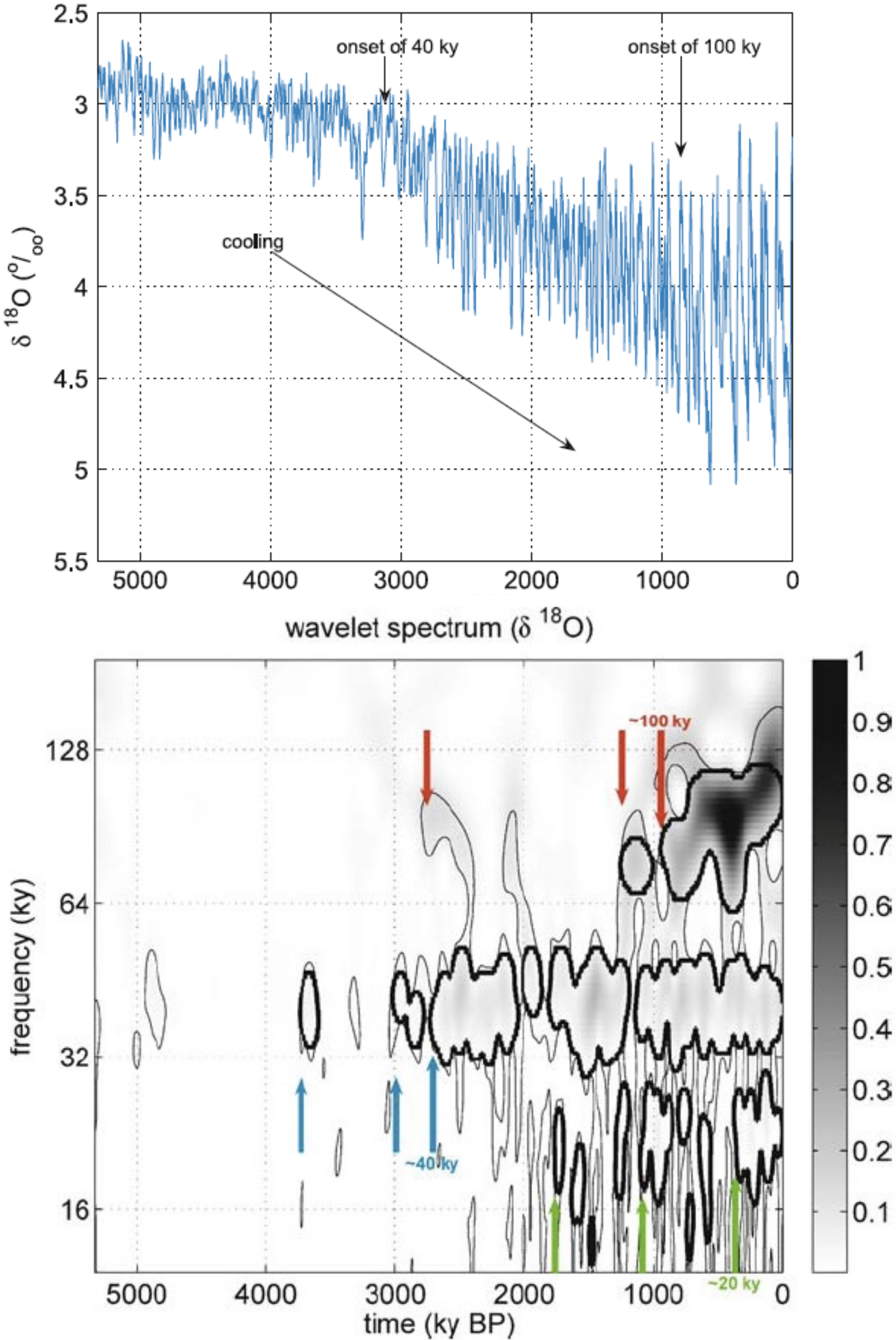
Insolation (6k minus present)



https://www.awi.de/fileadmin/user_upload/AWI/Forschung/Klimawissenschaft/Dynamik_des_Palaeoklimas/OrbitalTheoryOfIceAges/index.html

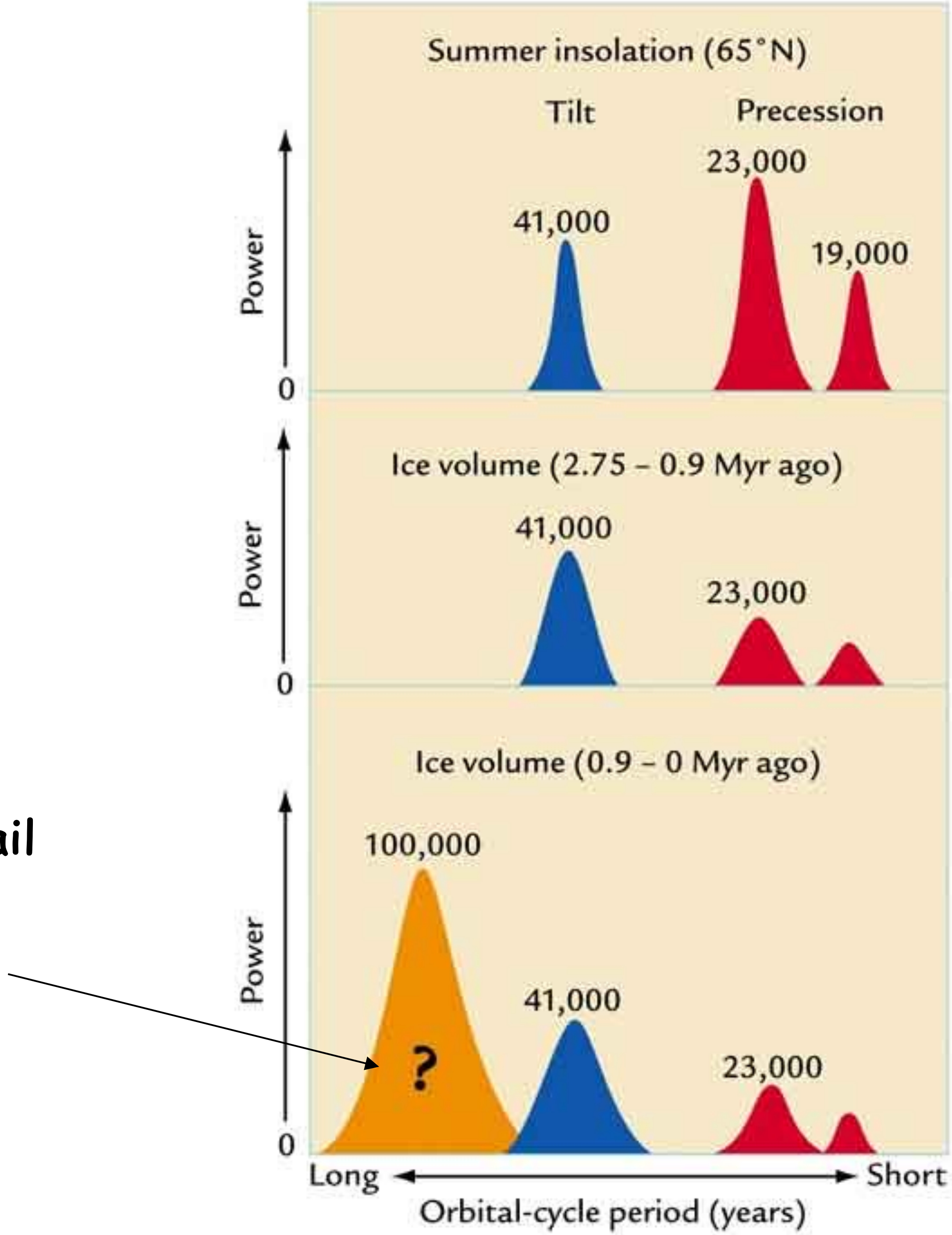
https://paleodyn.uni-bremen.de/study/climate2023_24.html

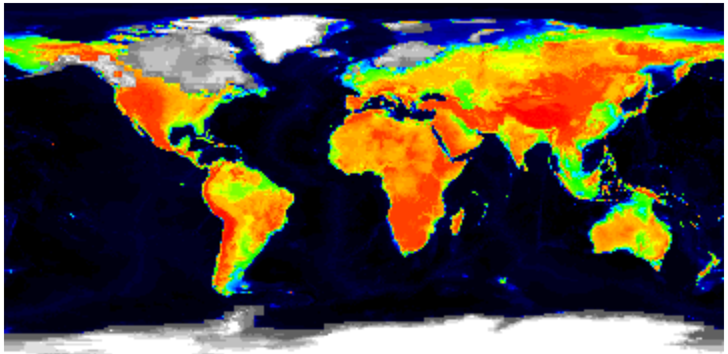
Ice ages

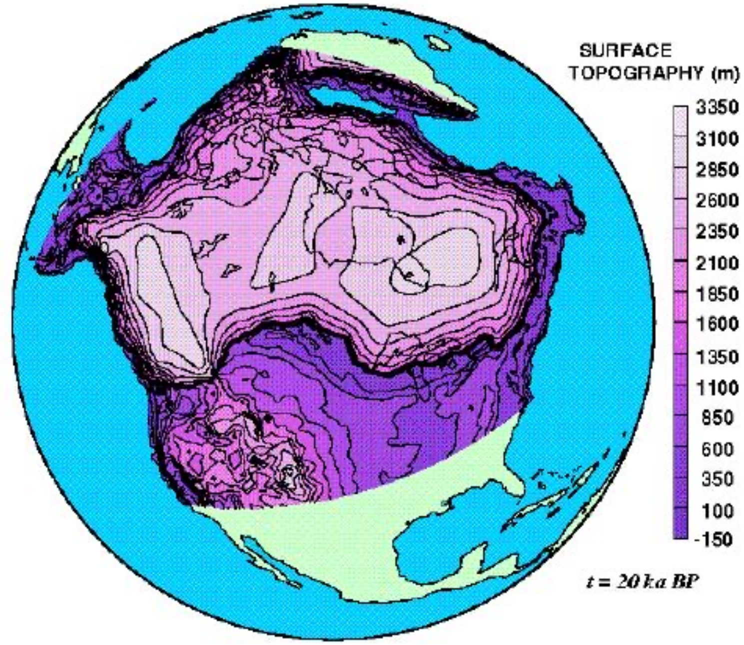


2.5
3
3.5
4
4.5
5
5.5
δ 18O (o/oo)
onset of 40 ky
onset of 100 ky
cooling
5000
4000
3000
2000
1000
0
wavelet spectrum (δ 18O)
~100 ky
~40 ky
~20 ky
128
64
32
16
frequency (ky)
time (ky BP)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1

A holy grail

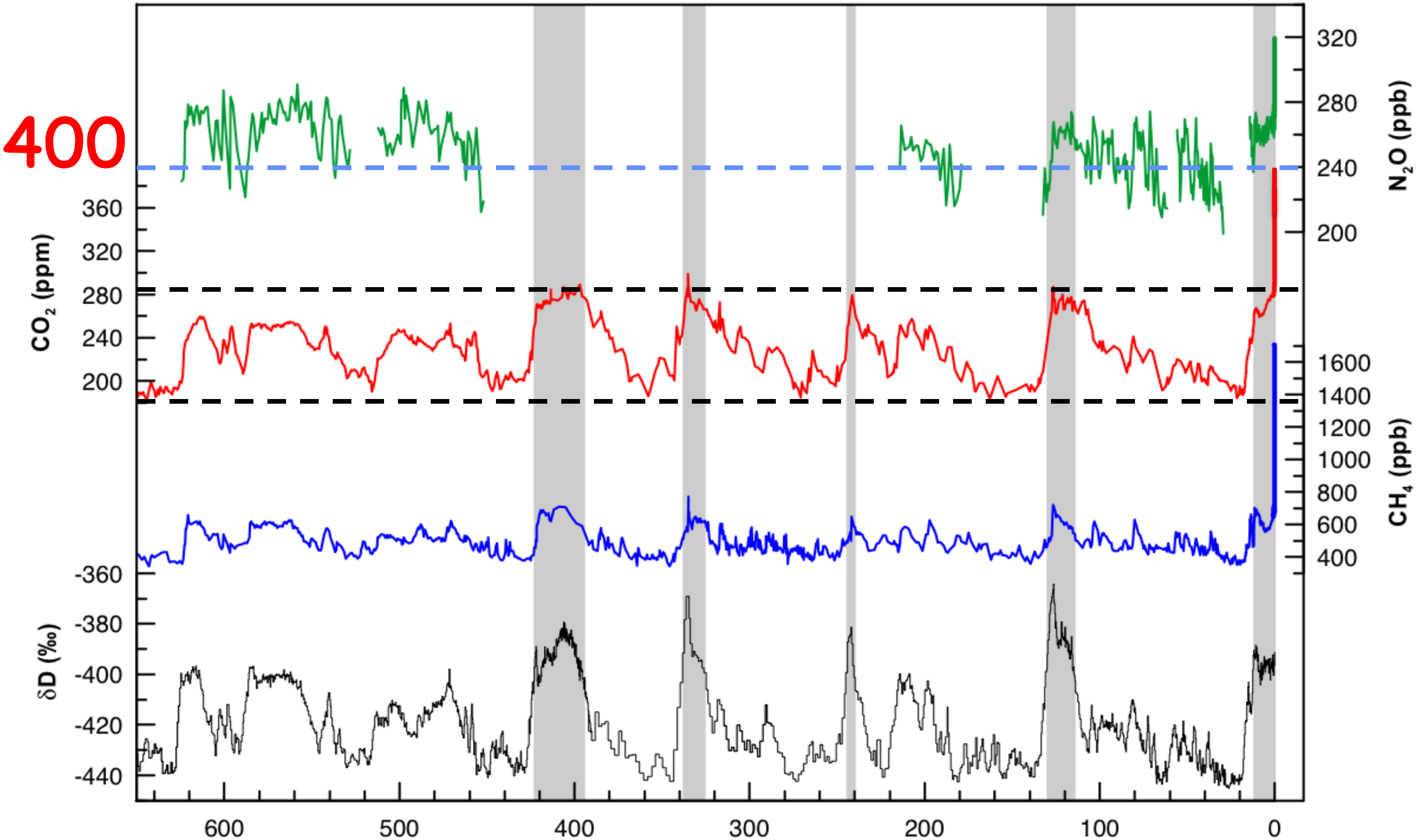

Summer insolation (65°N)
Tilt
Precession
23,000
41,000
19,000
Power
0
Ice volume (2.75 – 0.9 Myr ago)
41,000
23,000
Power
0
Ice volume (0.9 – 0 Myr ago)
100,000
?
41,000
23,000
Power
0
Long
Short
Orbital-cycle period (years)





Deglaciation

Atmospheric Gas Concentrations from Ice Cores



Time (Thousands of Years Before Present)

EPICA 2008

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, CO2, stochastic

Amplifiers: thresholds, rectification