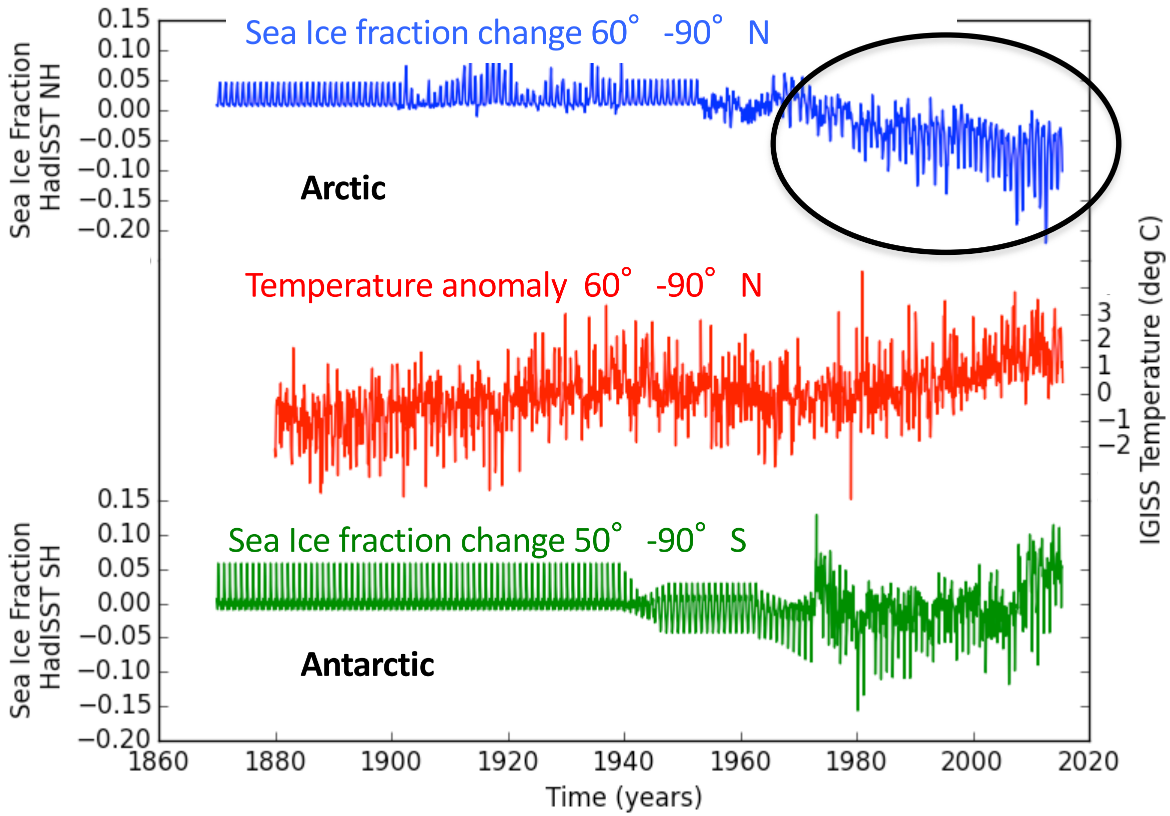
Climate System II course 2022 (4th lecture)

G. Lohmann & M. Werner

Orbital Theory, Ice Ages, Climate change

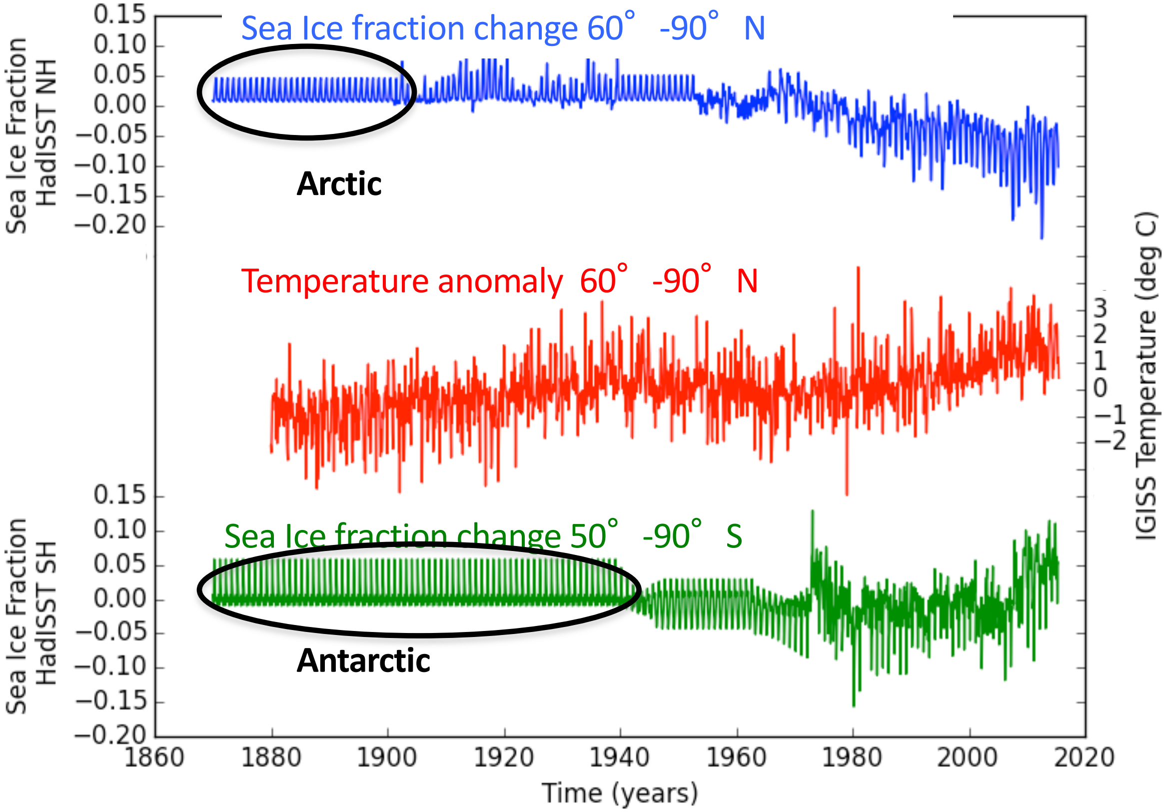
Gerrit Lohmann

Arctic Sea Ice retreat



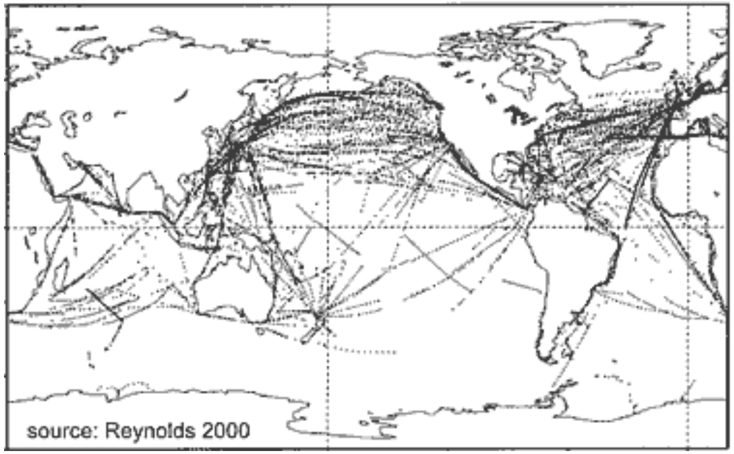
Arctic Sea Ice retreat

Missing Information about Sea Ice



The "Climate dilemma"

- Instrumental data are **sparce**



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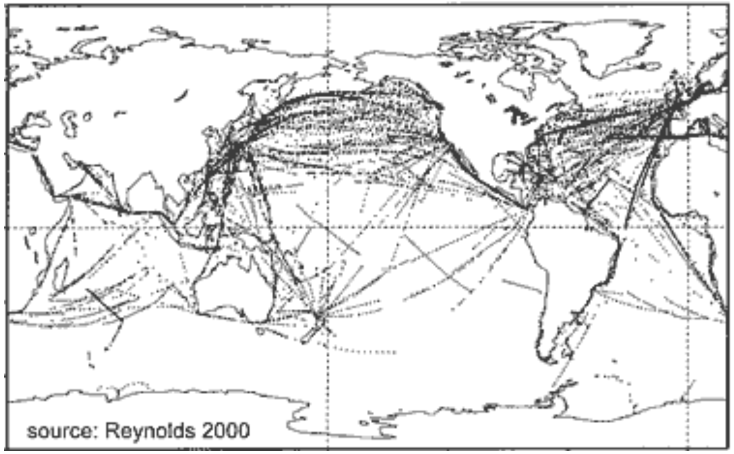

- The records of direct temperature measurements are **short** and already fall in the phase of strong **human influence**.

The “Climate dilemma“

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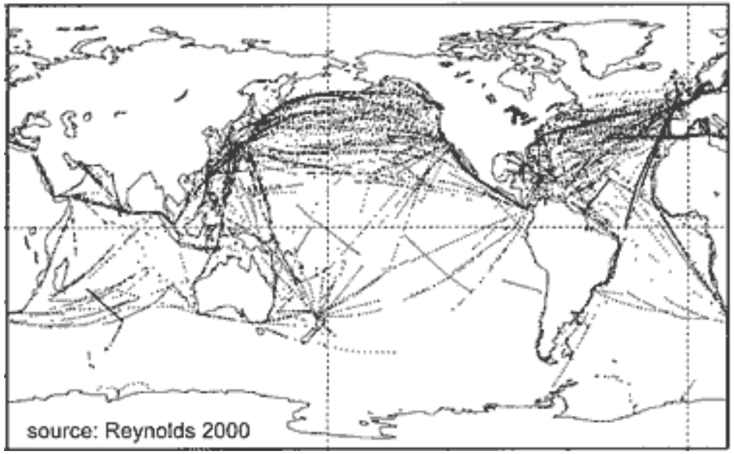
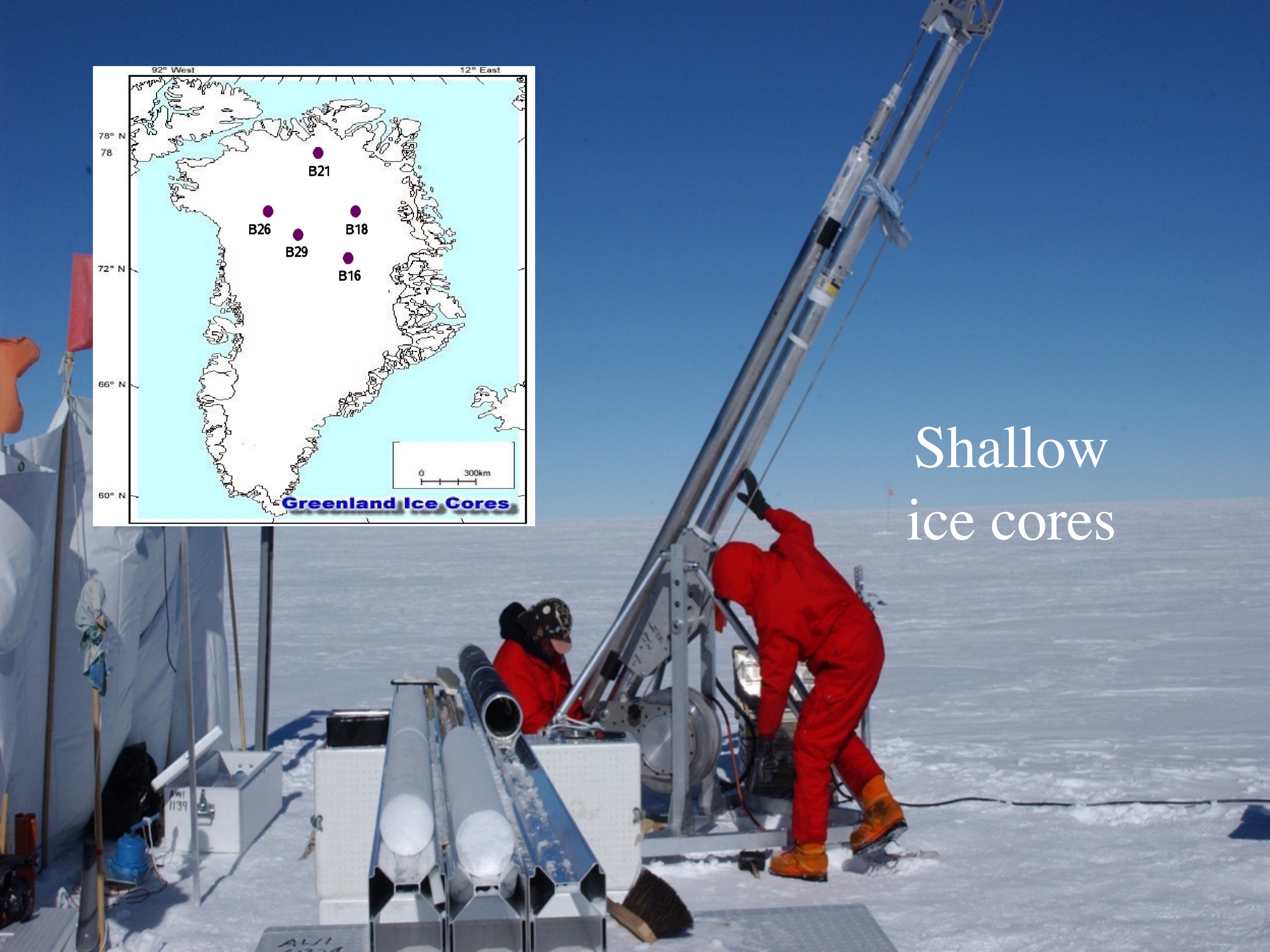


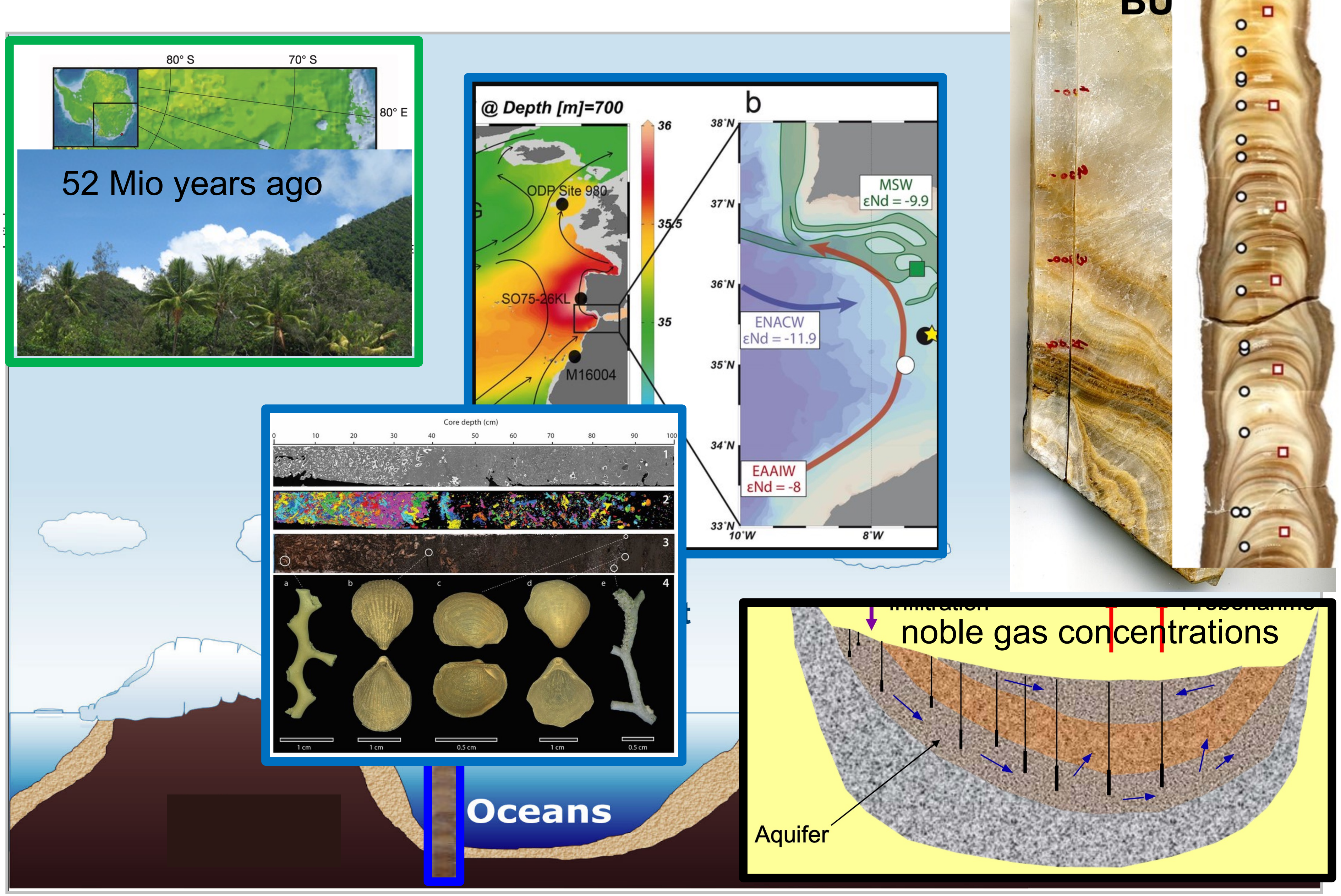
- The records of direct temperature measurements are **short** and already fall in the phase of strong **human influence**.

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

Shallow ice cores



Earth System: Reconstructions

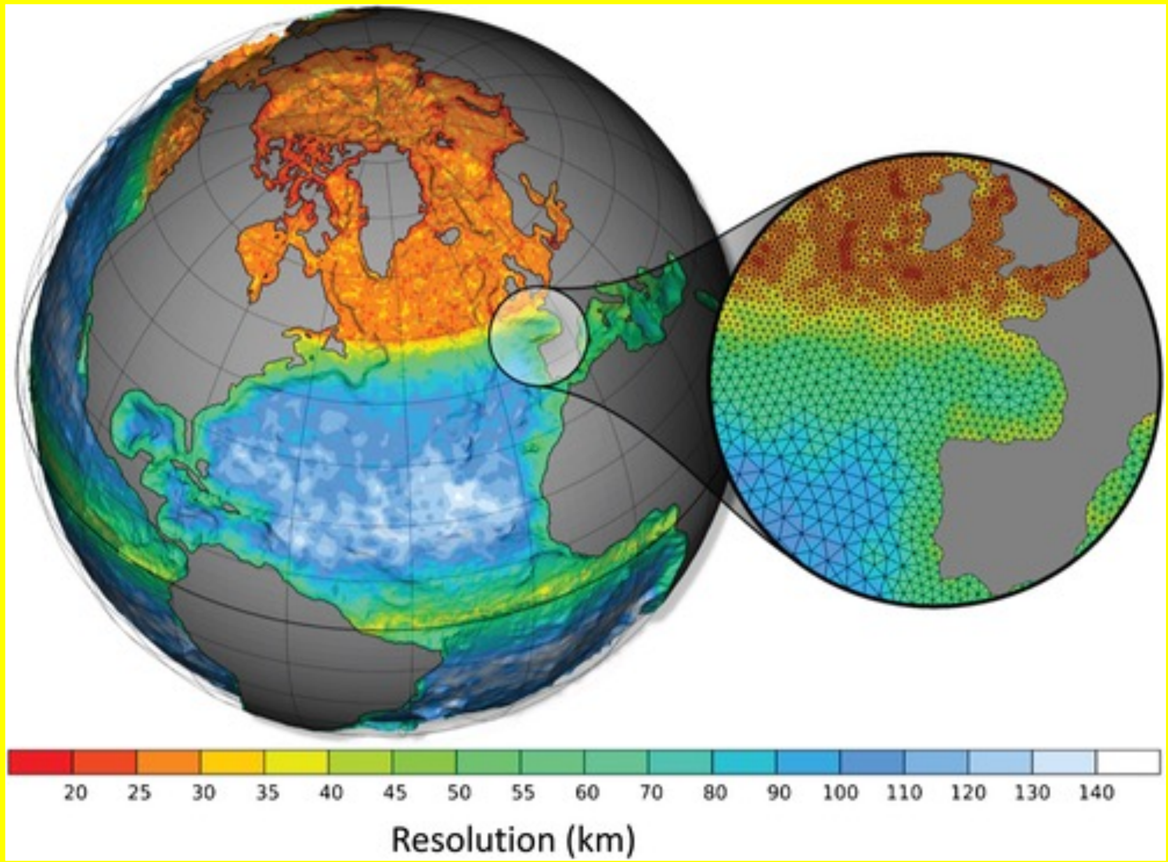


Earth System Analysis: Models

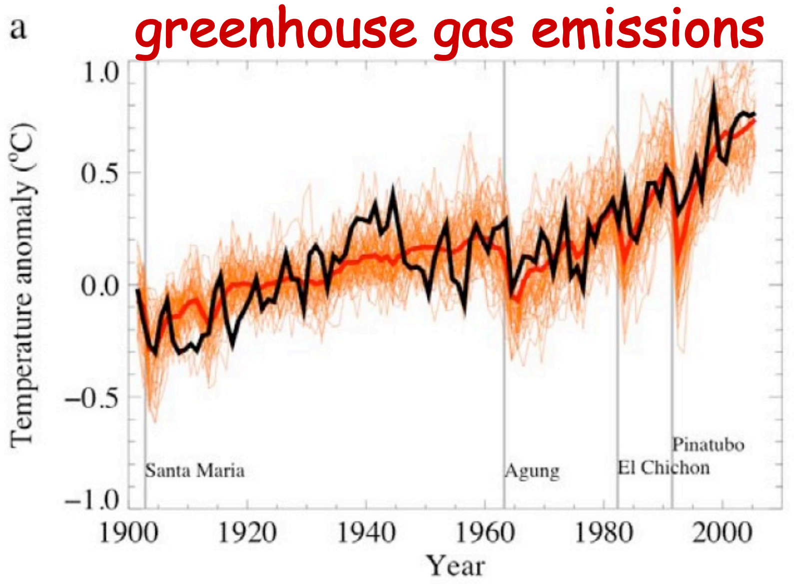
$$\frac{\partial \mathbf{v}}{\partial t} + \mathbf{v} \cdot \nabla \mathbf{v} = -2\Omega \times \mathbf{v} - \frac{1}{\rho}\nabla p + \mathbf{g} + \mathbf{F}$$

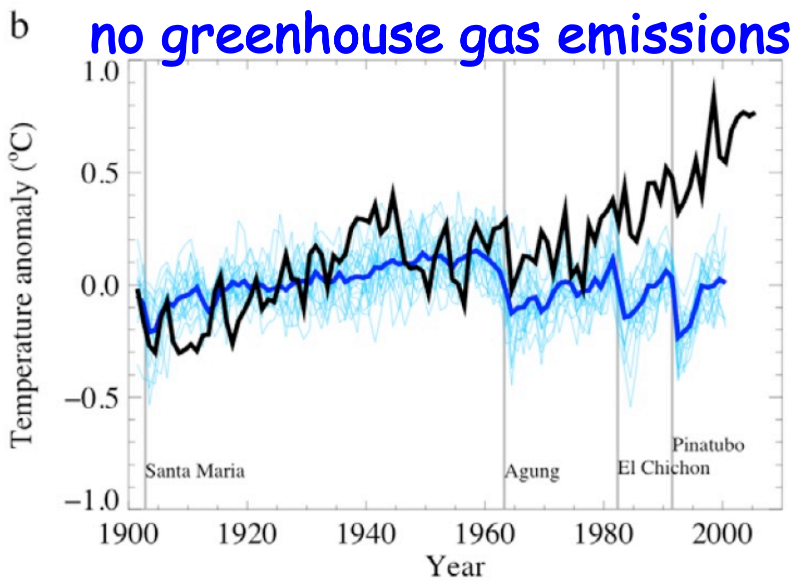
$$\frac{\partial \rho}{\partial t} + \nabla \cdot \rho \mathbf{v} = 0$$

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



Attribution (model world)

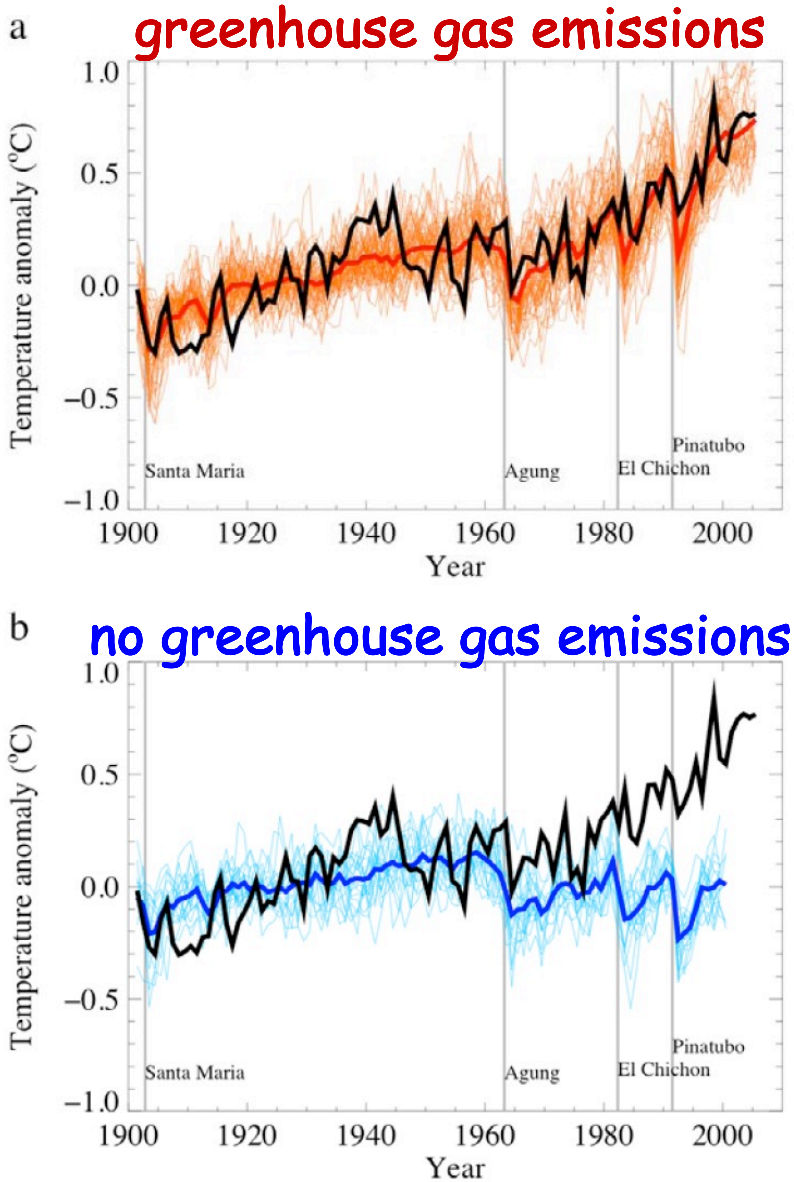




observed changes are consistent with modeled response to external forcing, inconsistent with alternative explanations

Nobel Price, 2021

Attribution (model world)

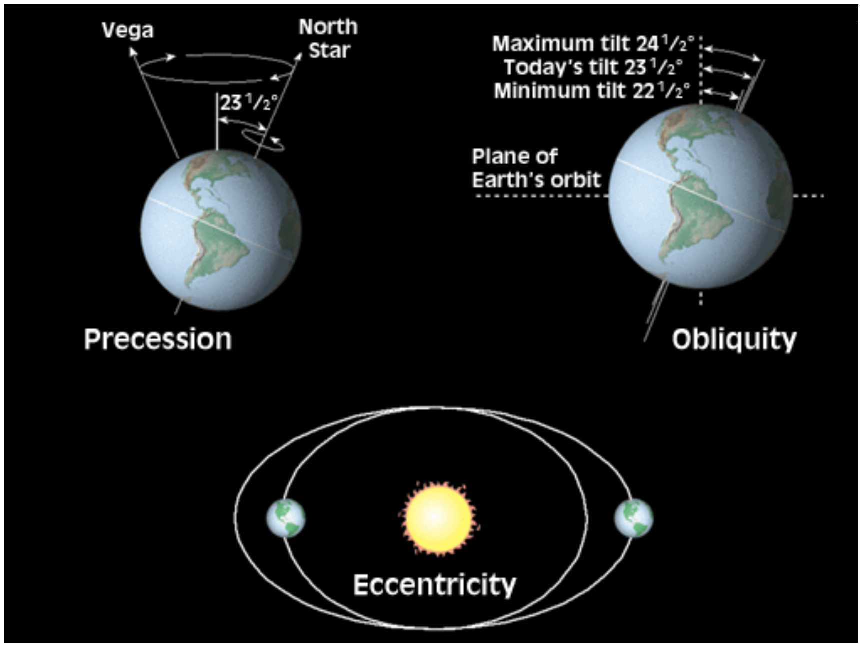


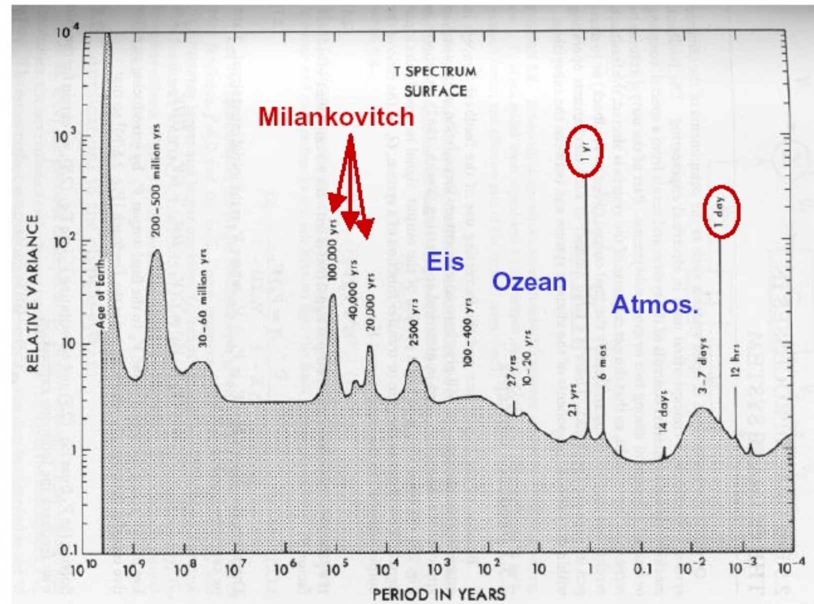
observed changes are consistent with modeled response to external forcing, inconsistent with alternative explanations

Critics:

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

Previous Lecture: Orbital forcing

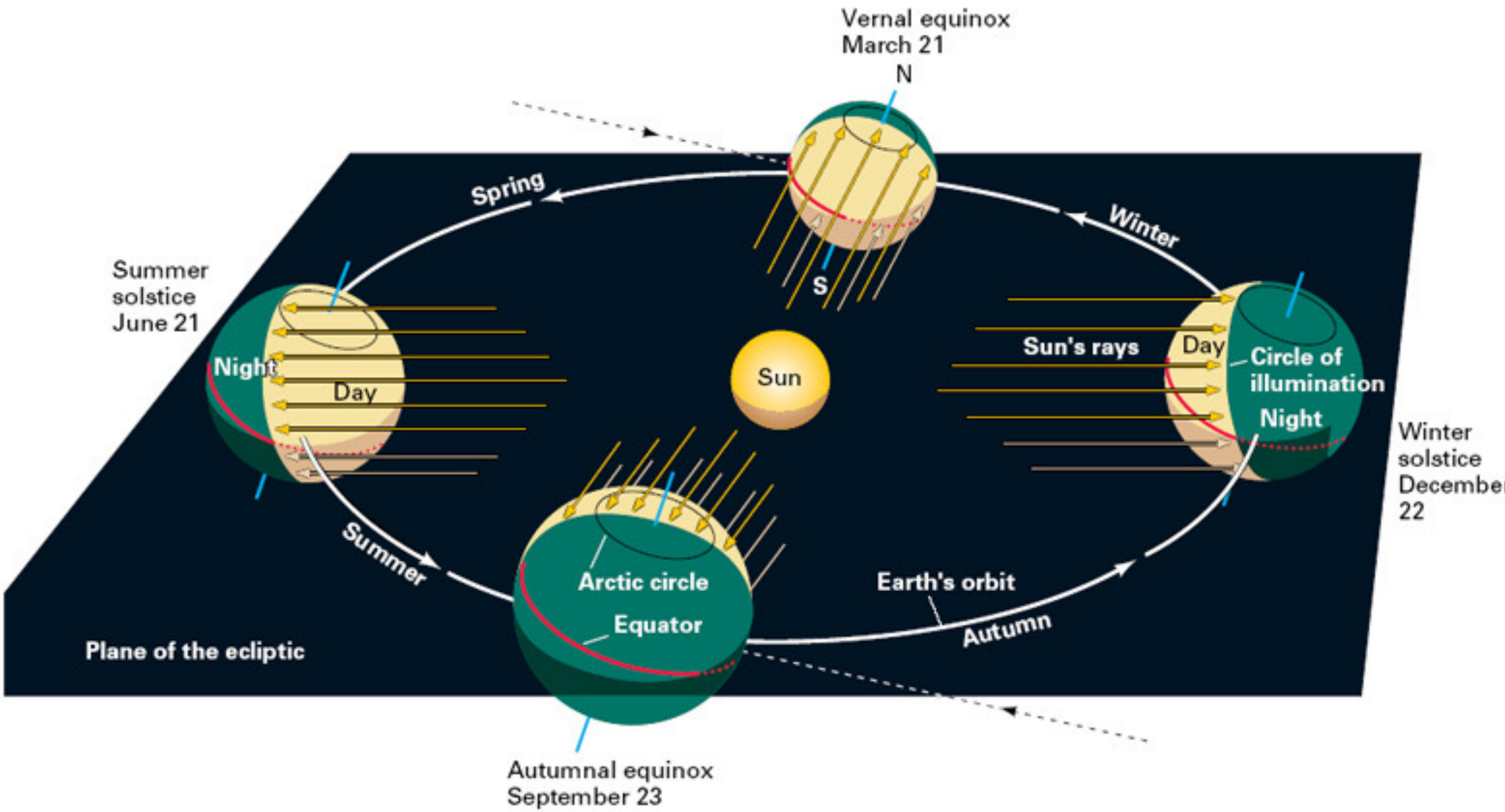




Quelle: Peixoto & Oort

- ~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

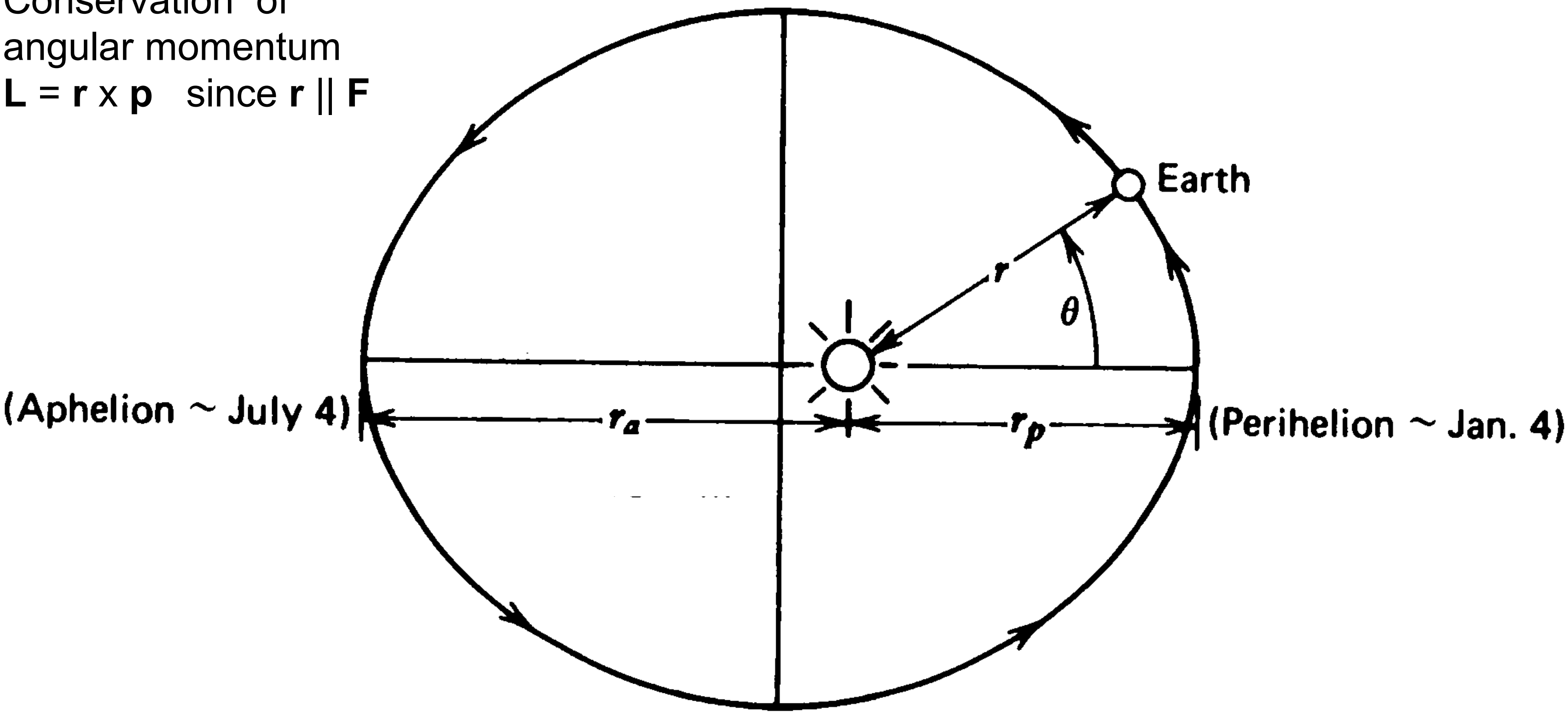
Keppler

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

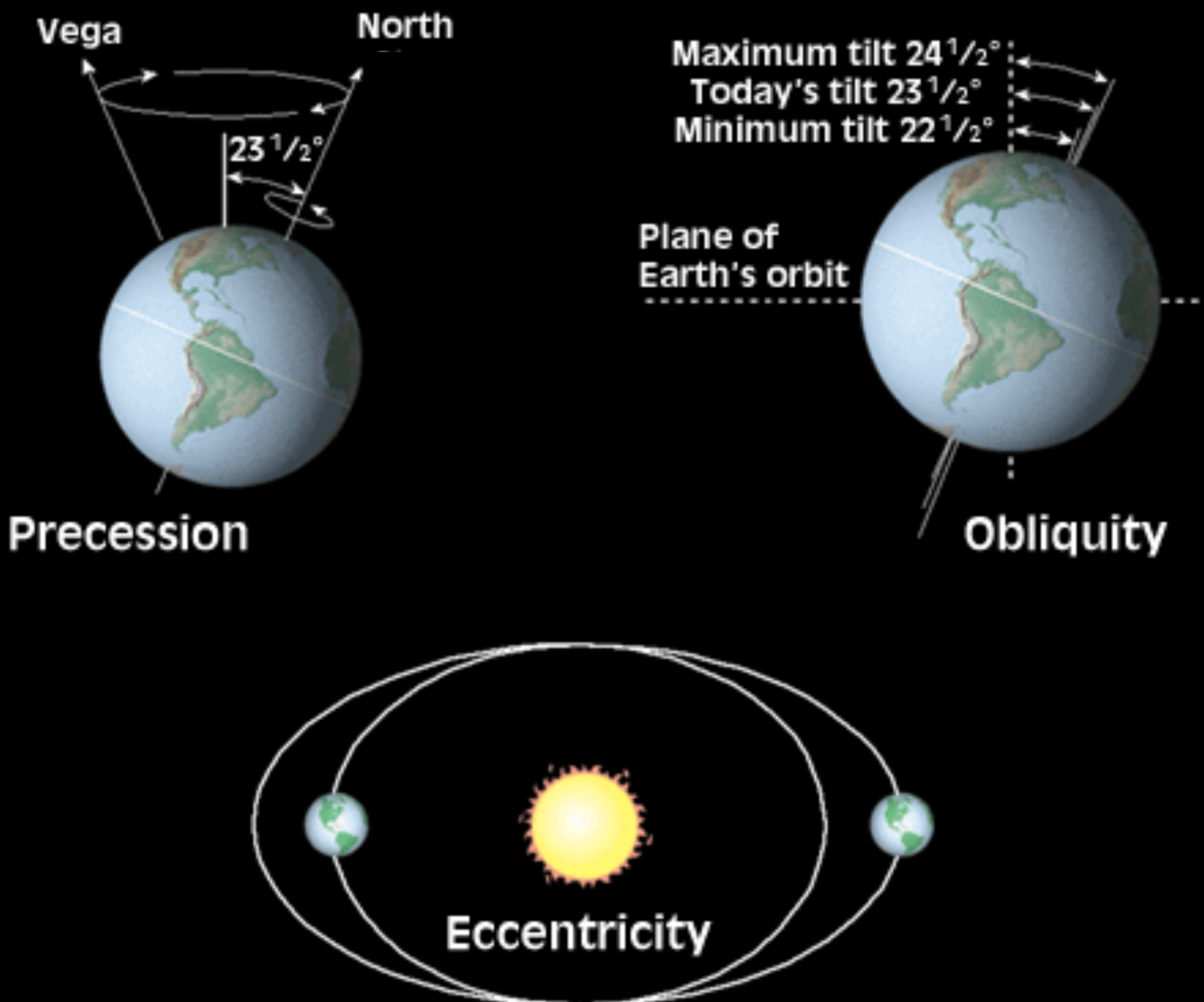
r = a +/- 2%

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

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



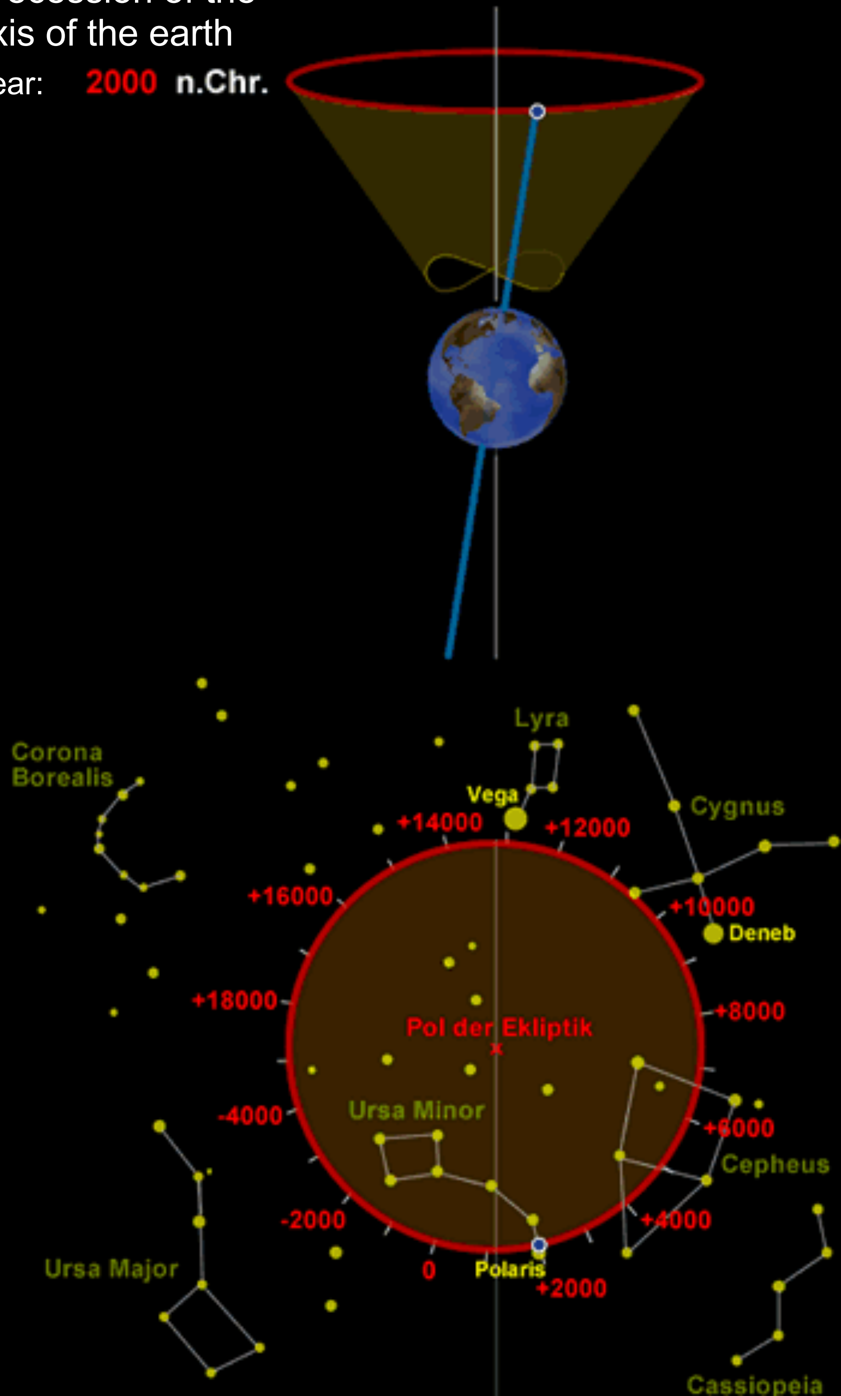
Wieder, 1982

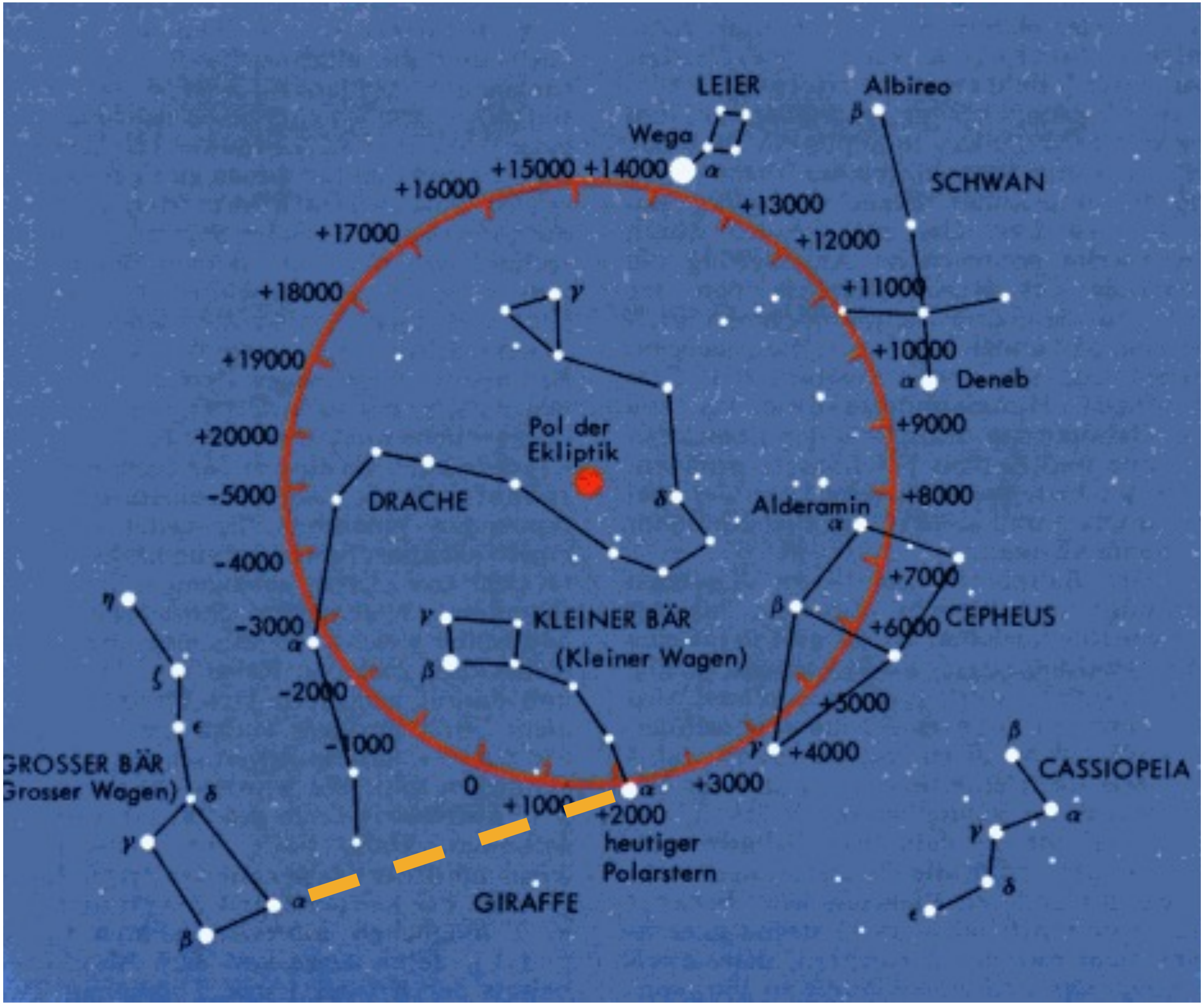


Vega
North
23 1/2°
Precession
Maximum tilt 24 1/2°
Today's tilt 23 1/2°
Minimum tilt 22 1/2°
Plane of
Earth's orbit
Obliquity
Eccentricity

Precession of the axis of the earth

Year: 2000 n.Chr.





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

Universität Bremen

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

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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

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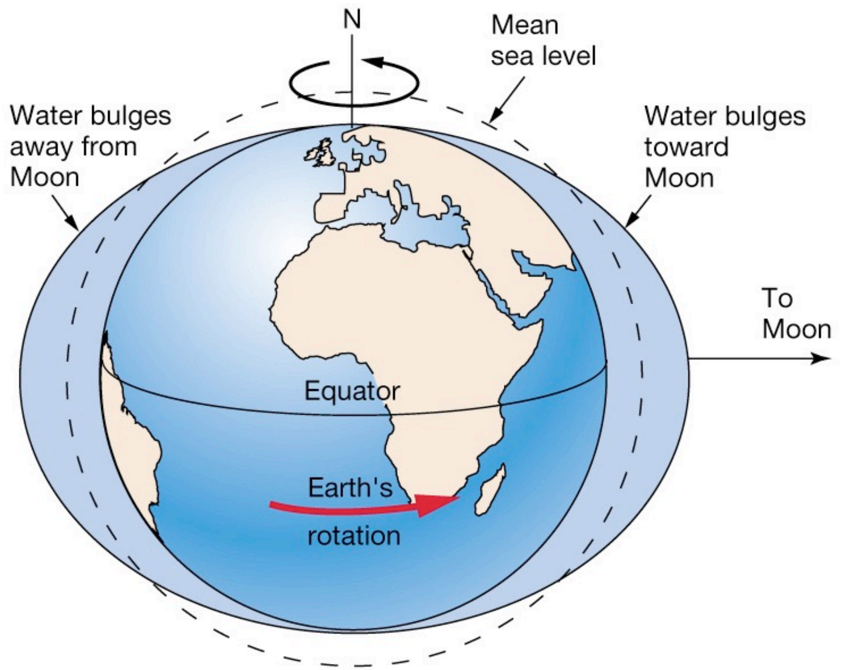
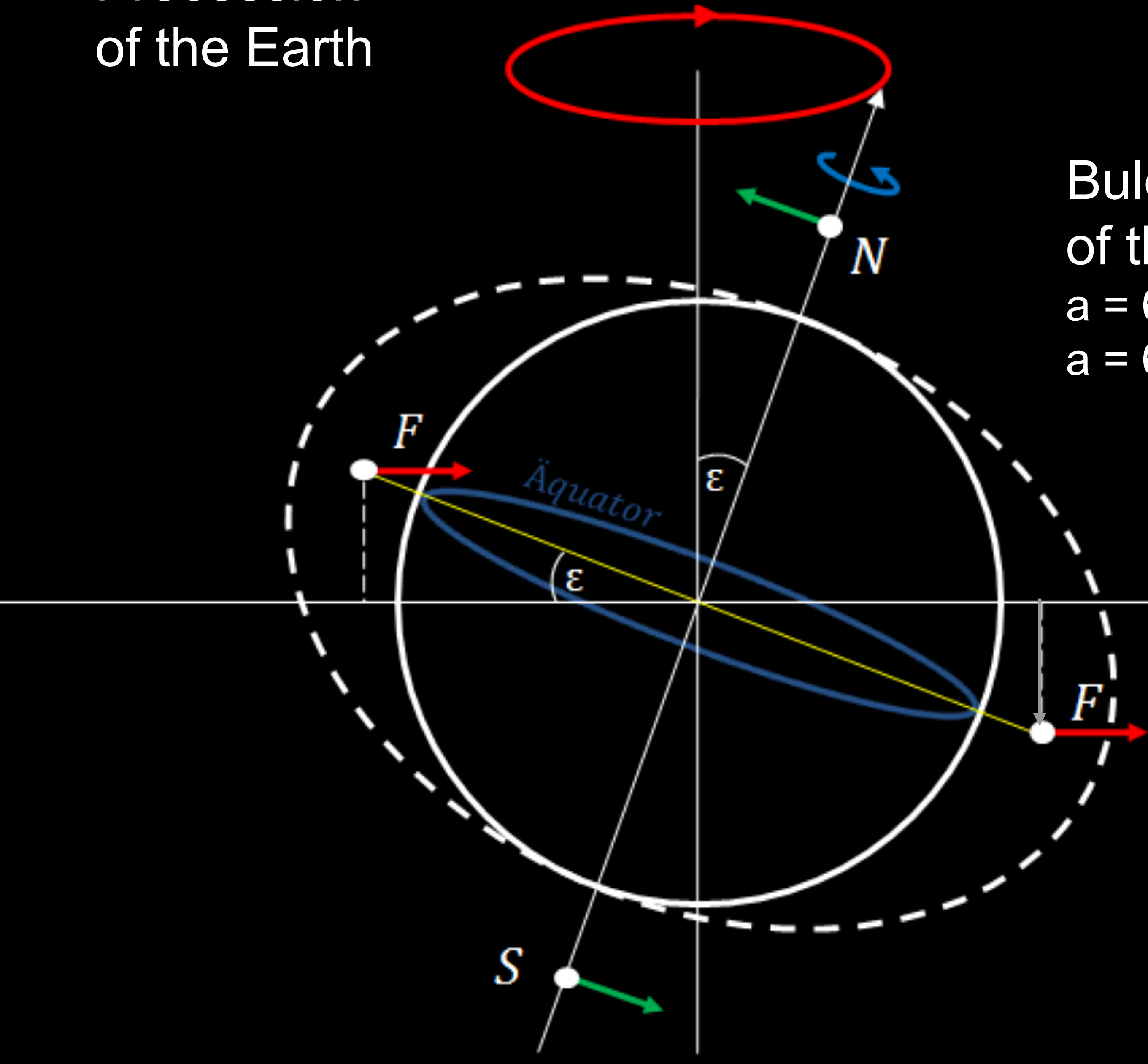
https://www.uni-bremen.de/physika/versuche/mechanik

Tidal bulges

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



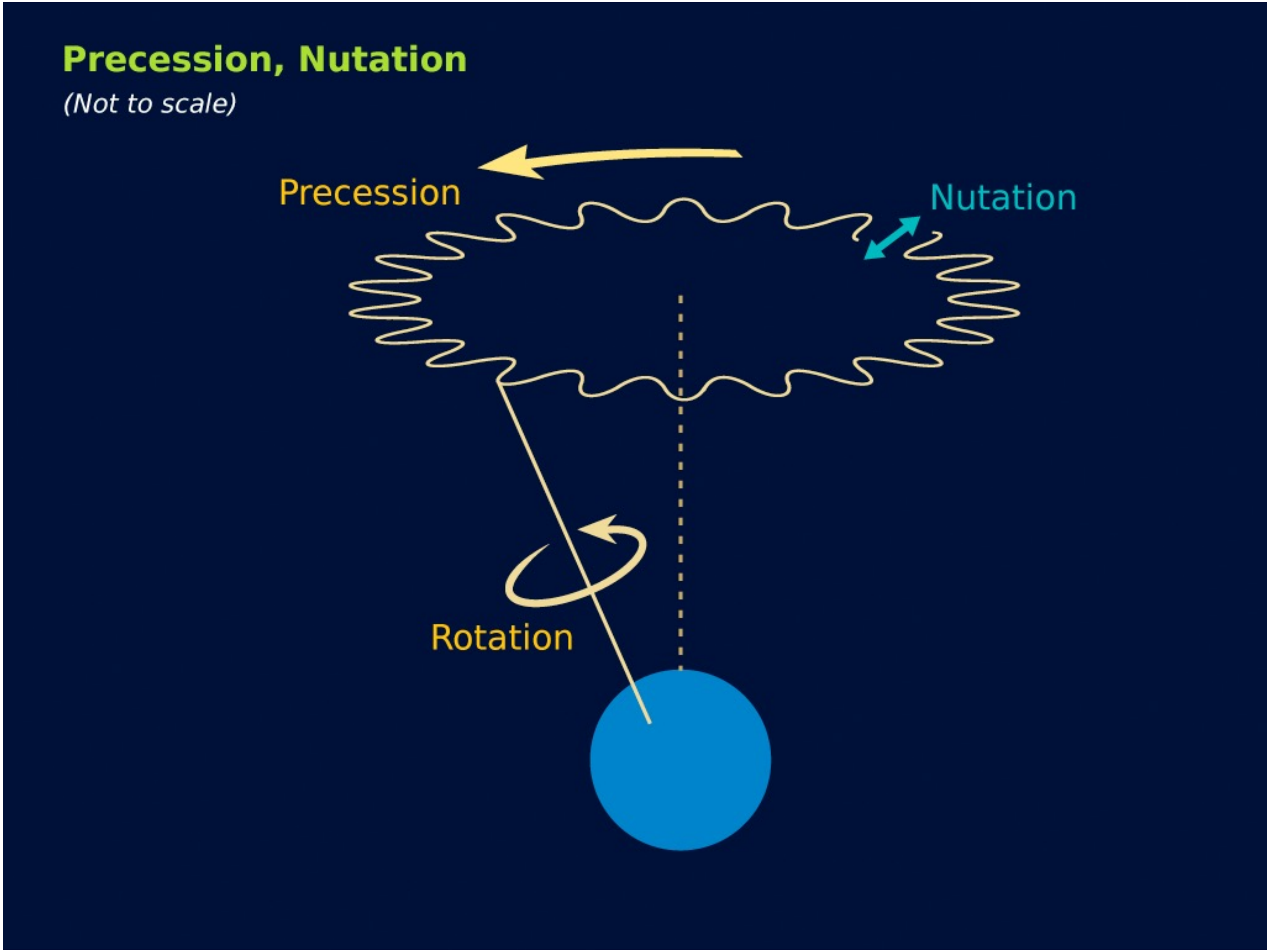
Precession of the Earth



Buldge of the Earth:

a = 6378 km equator

a = 6357 km poles


Precession, Nutation
(Not to scale)
Precession
Nutation
Rotation

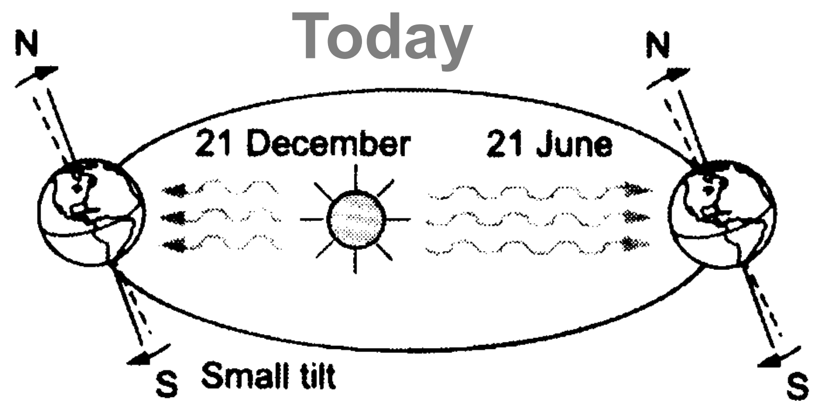
Sunspots Photo: Nasa

Configuration of the Earth‘s orbit: Examples

Perihelion (closest point)

in January

Tilt of the earth‘s axis: **23.5°**



Kutzbach (1992)

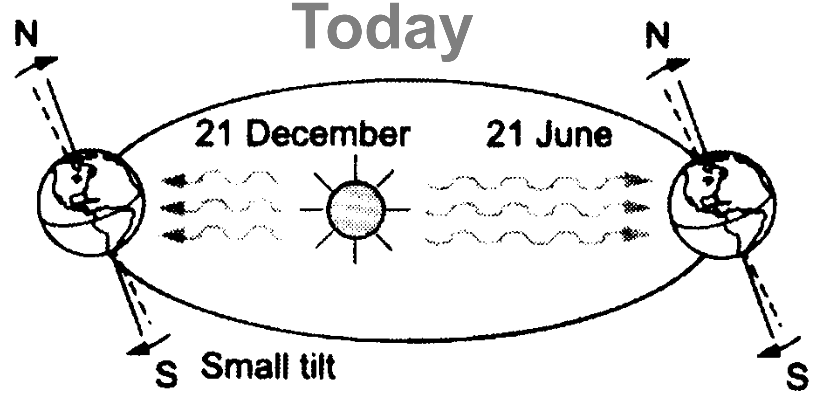
Configuration of the Earth‘s orbit: Examples

Perihelion (closest point)

in January

Tilt of the earth‘s axis: **23.5°**

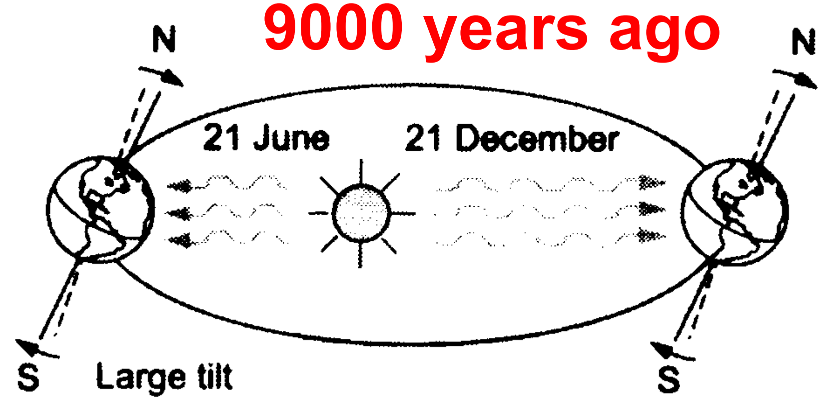
Today



Perihelion in July

Tilt of the earth‘s axis: **24.0°**

9000 years ago

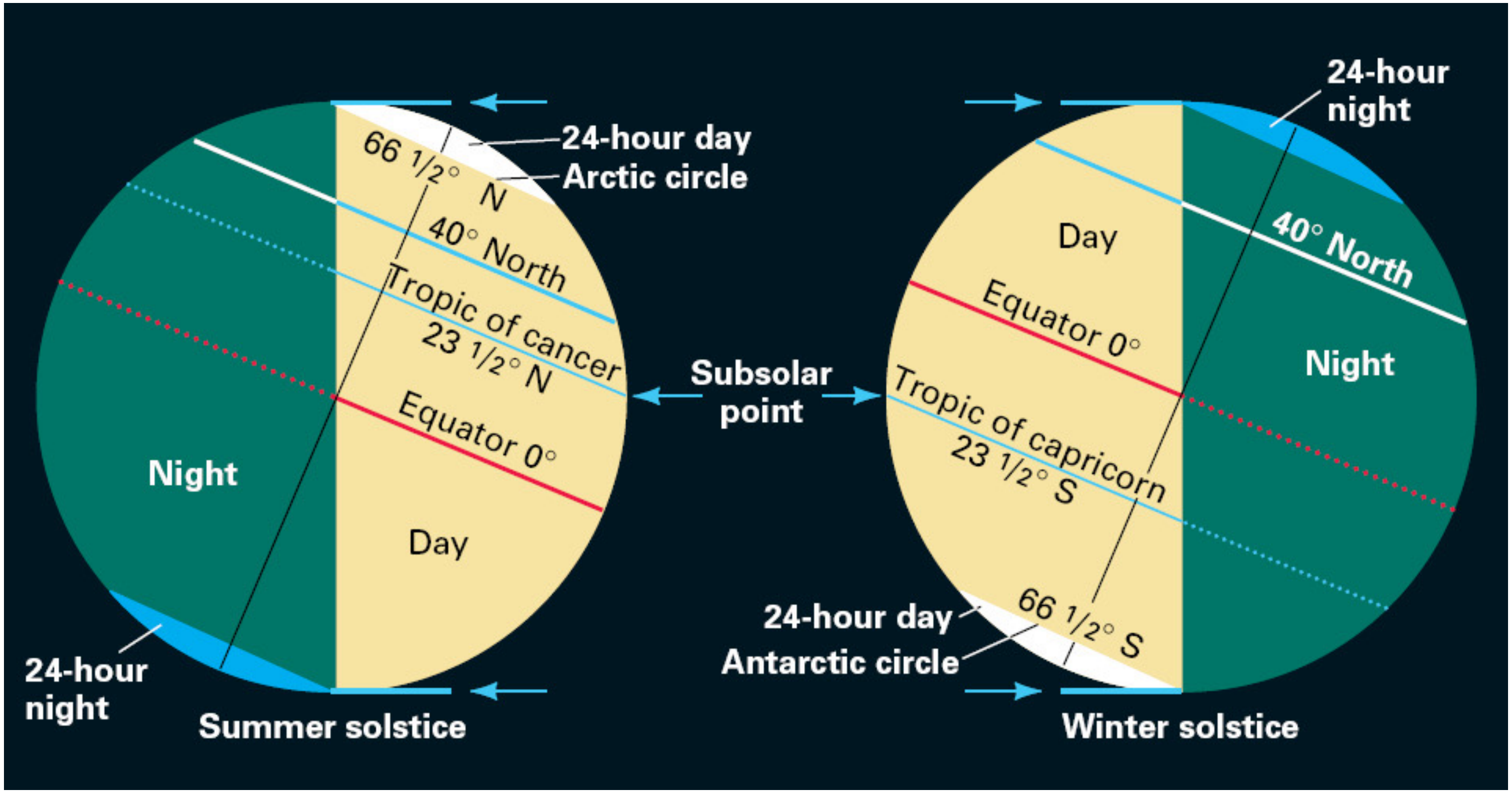


The incoming solar energy in the northern hemisphere 7 % greater in July and correspondingly less in January.

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=?

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

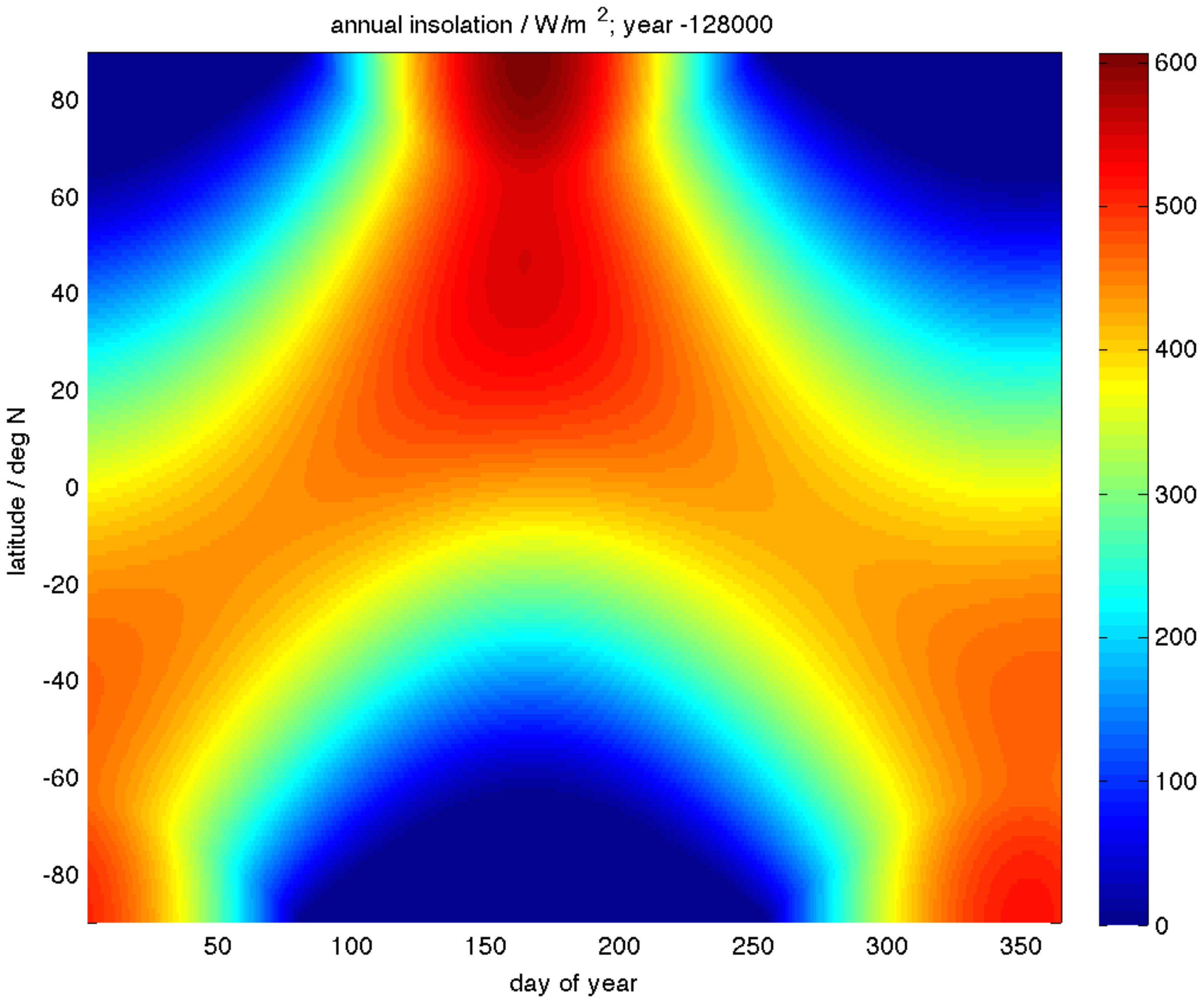
$$\Delta\Phi_{year} = \frac{\Delta\Phi_{tot}}{T/2} = \frac{2\Delta\Phi_{tot}}{T} = \frac{4.8°}{41,000 \text{ years}} = 0.000117°$$

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

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

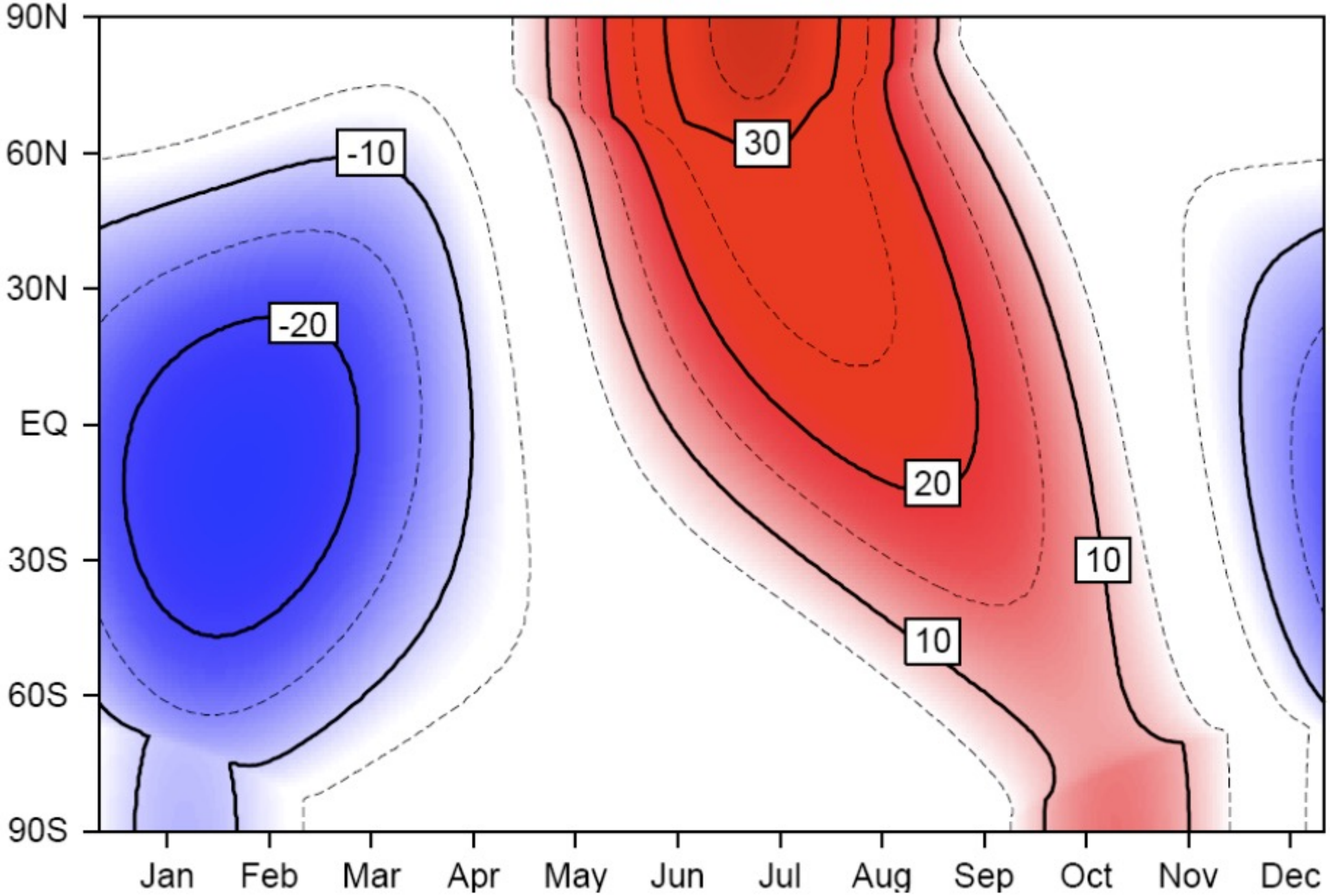
$$\frac{2 \cdot \pi \cdot R}{360°} = 111 km/degree$$

Insolation



annual insolation / W/m 2; year -128000
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

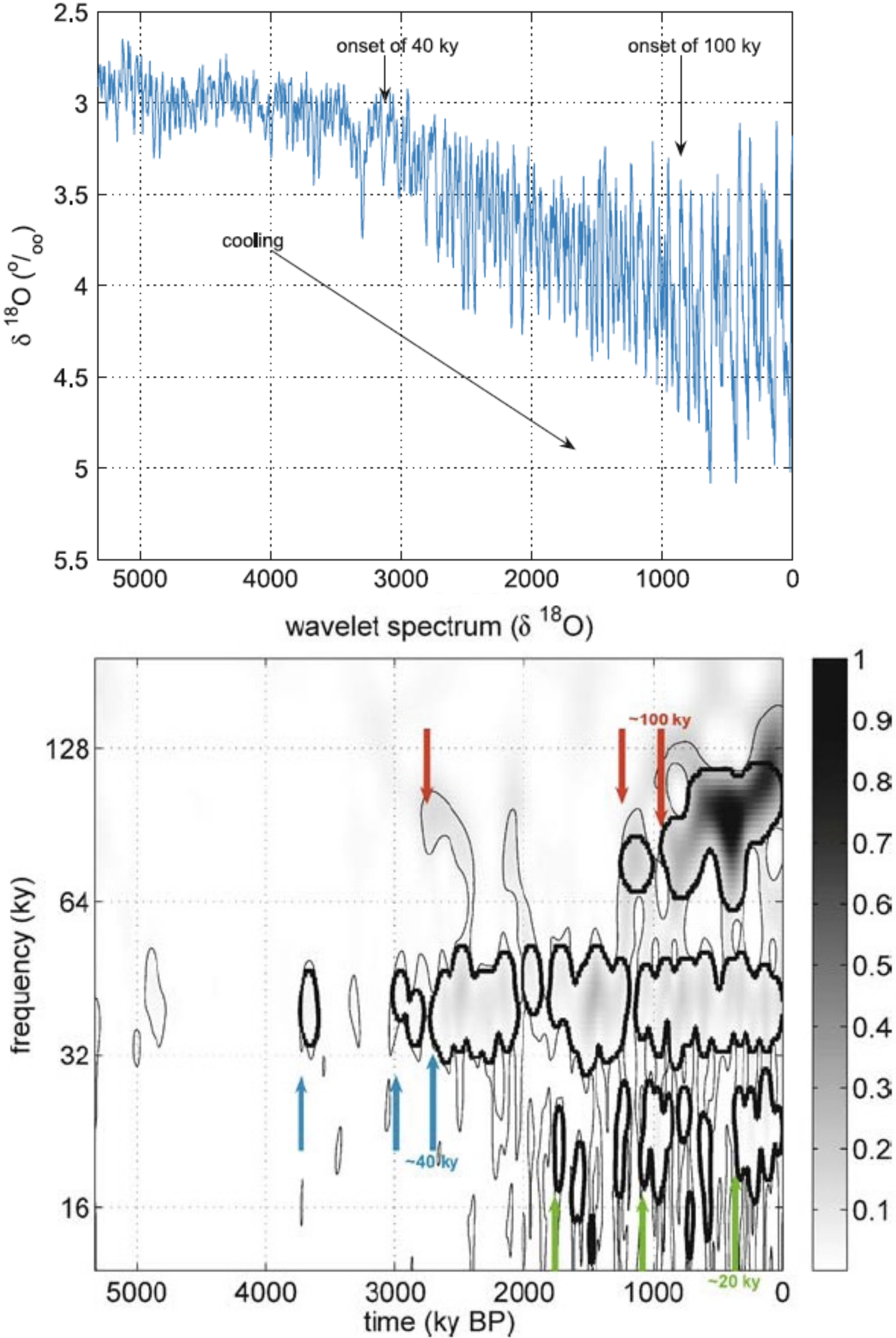
Insolation (6k minus present)



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

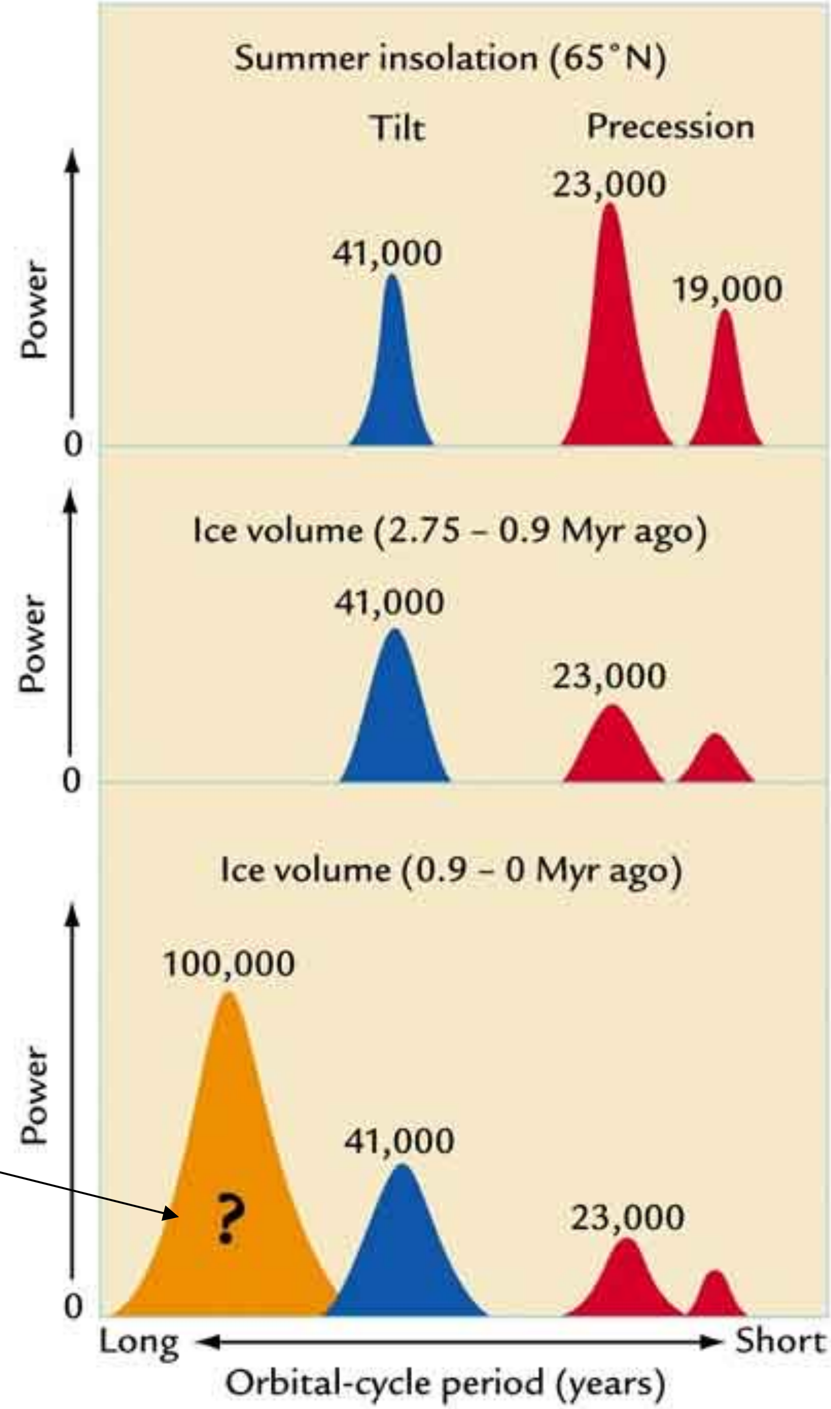
https://paleodyn.uni-bremen.de/study/climate2022_23.html

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, CO2, stochastic

Amplifiers: thresholds, rectification