Climate warming `backward´

The last 100 Million years

Transitions from Greenhouse to Icehouse Climate

Climate System II

Gerrit Lohmann

with Christian Stepanek

Glacial-Interglacial variability

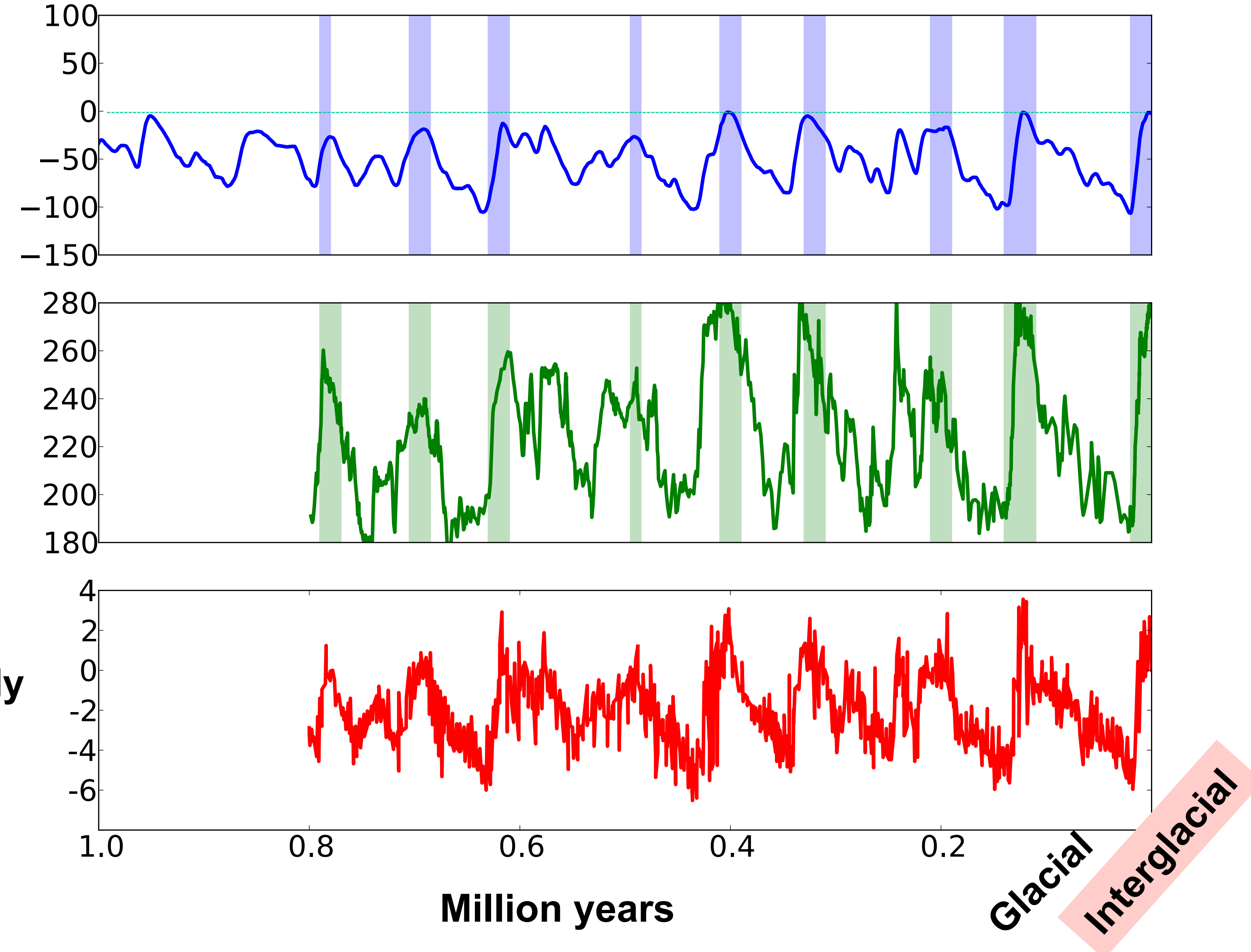
Global Sea Level [m]

(Bintanja et al., 2005)

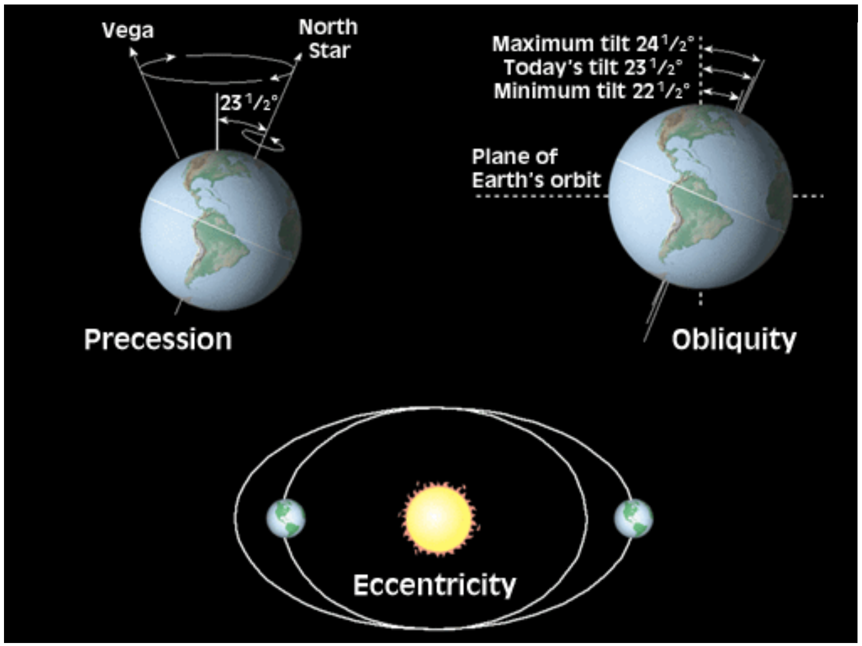
CO_2 [ppmv]

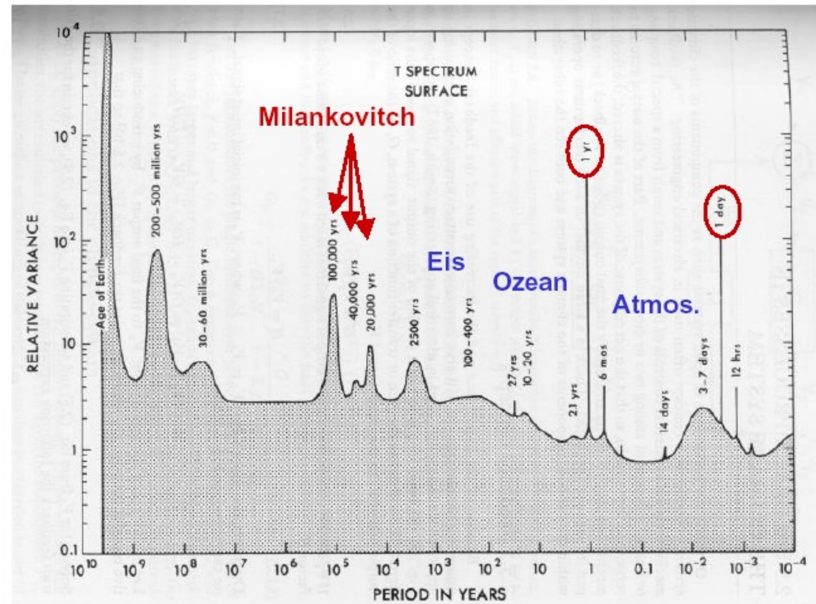
From ice cores (EPICA, 2009)

Temp. anomaly "O-18" [° C]



Orbital forcing

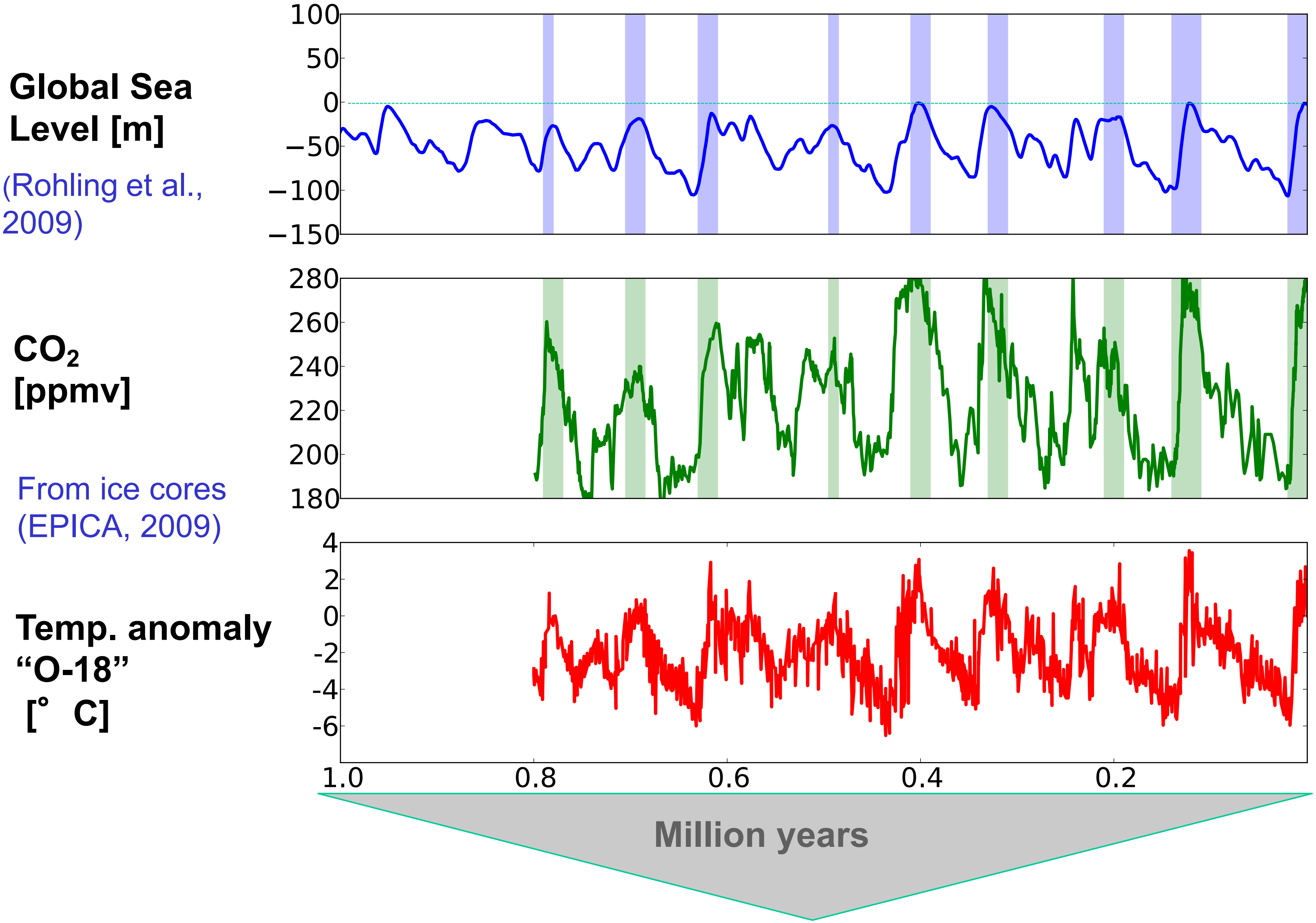




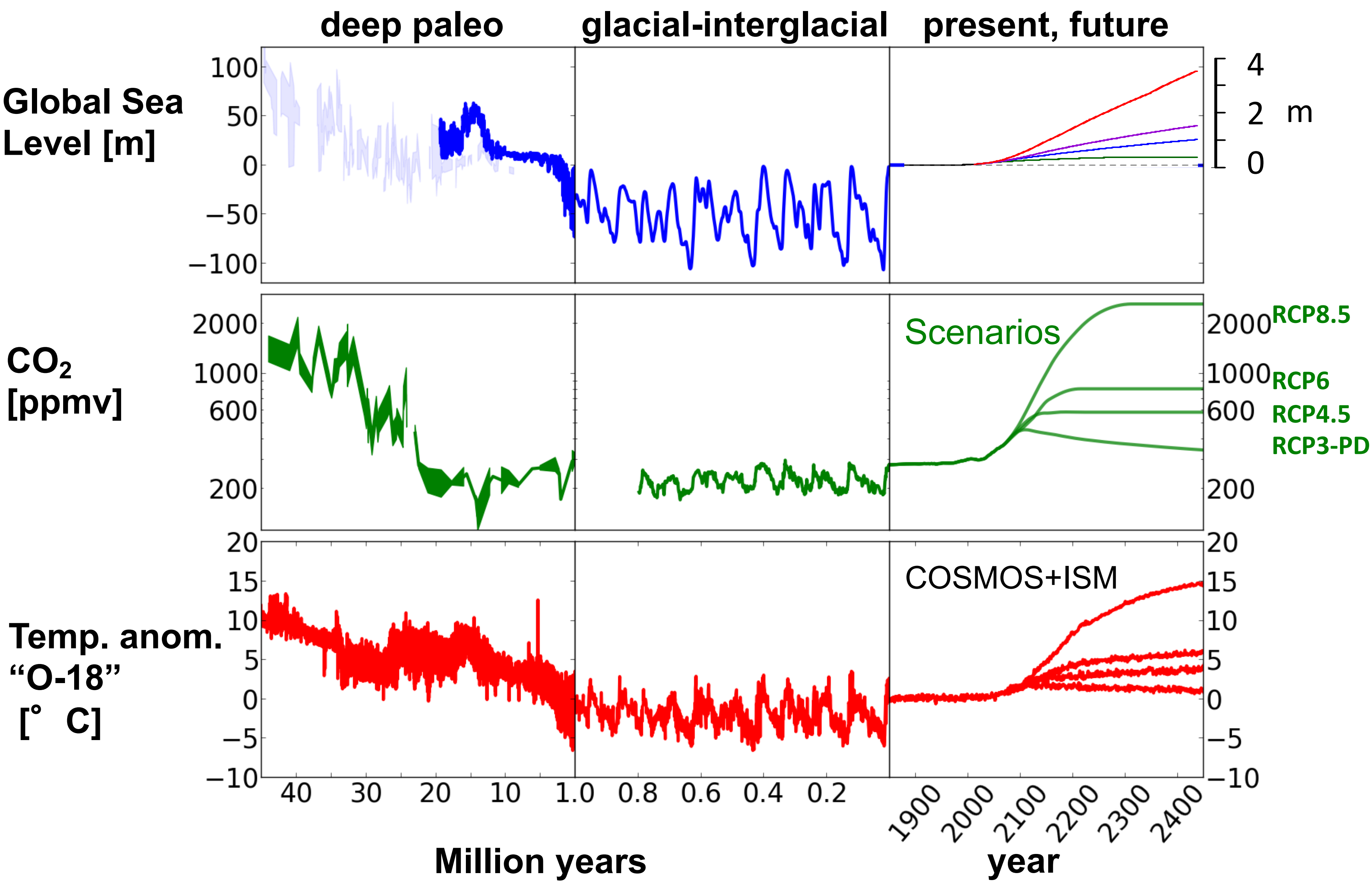
Quelle: Peixoto & Oort

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

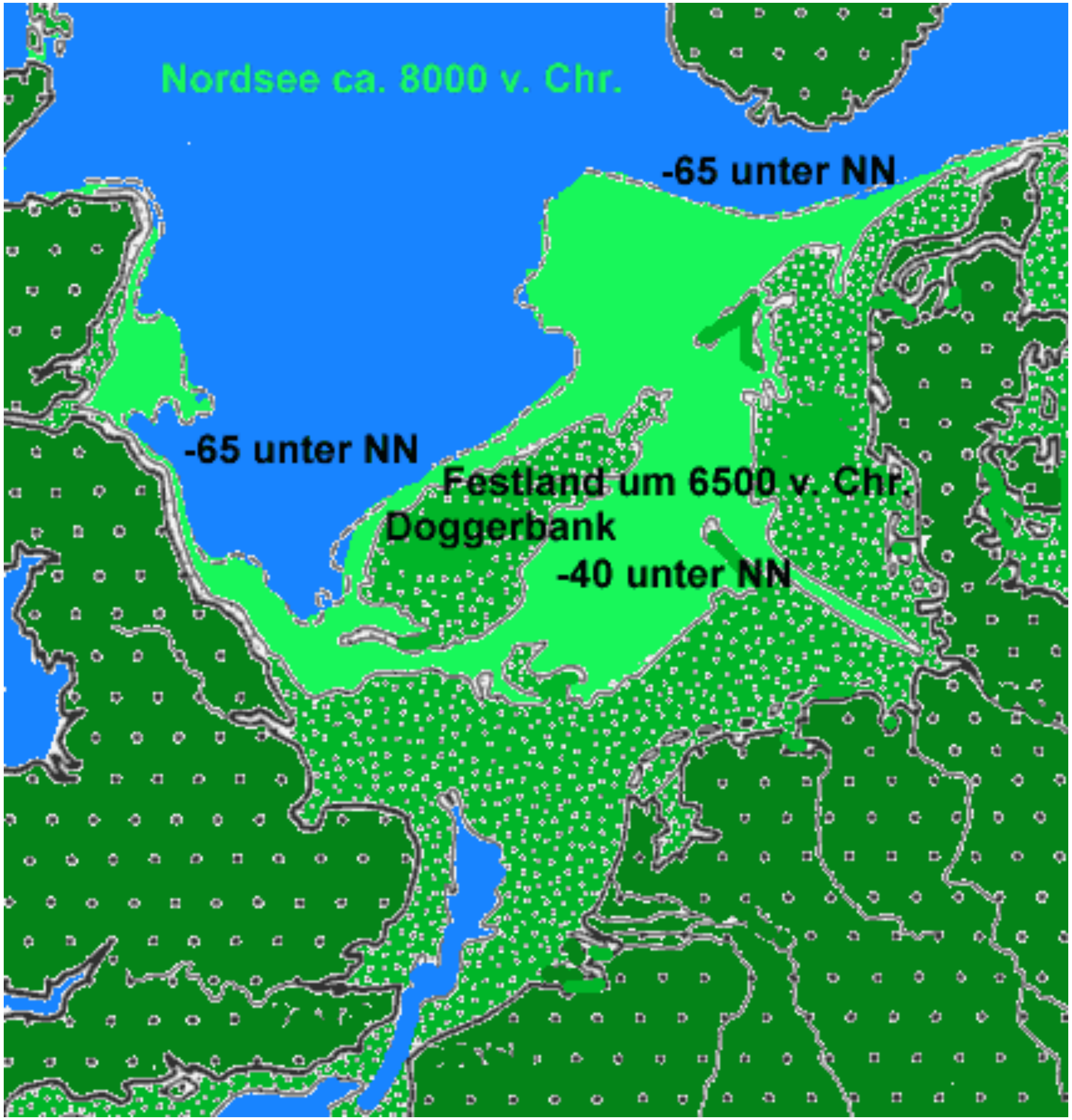
Glacial-Interglacial variability



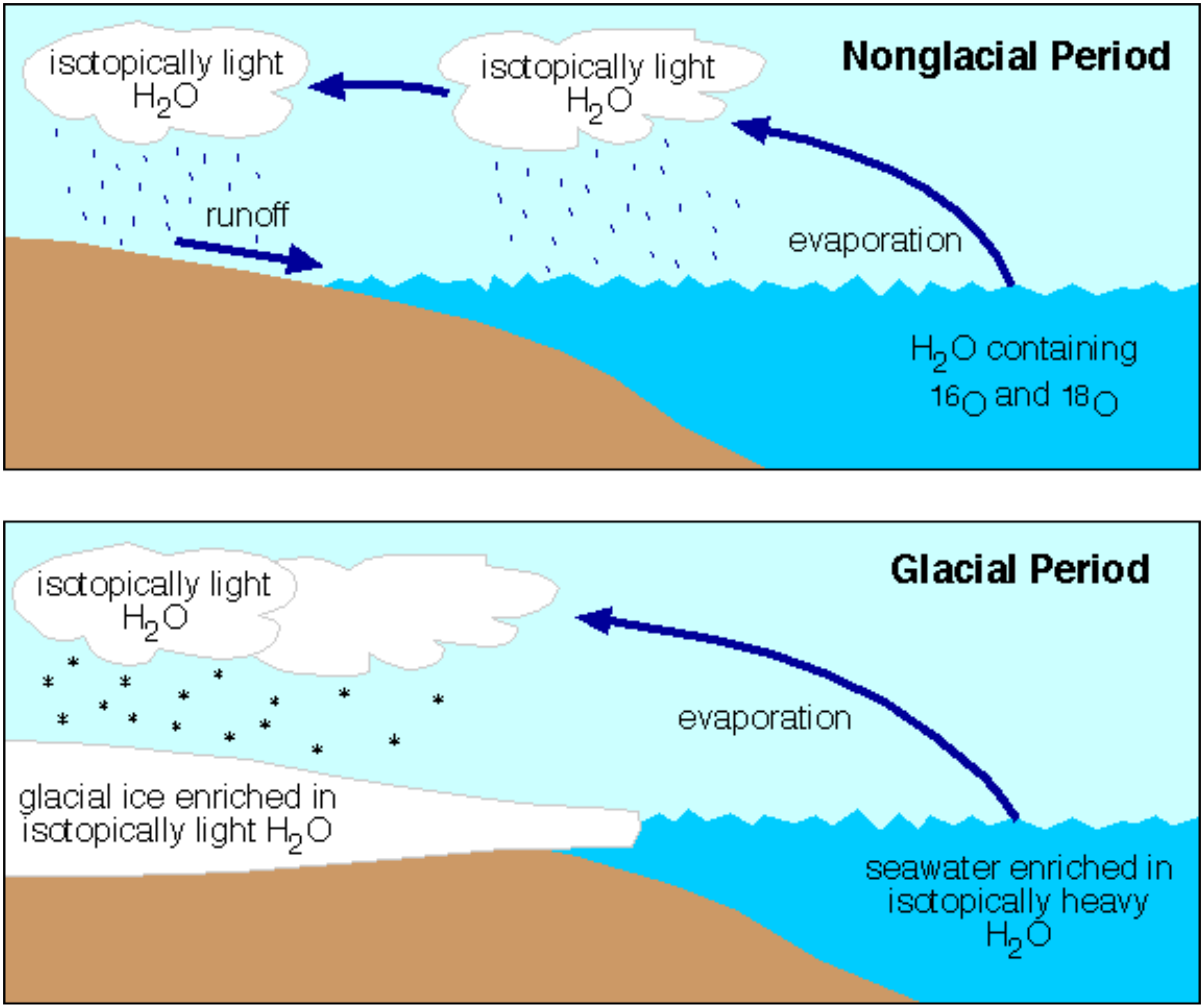
Natural variability and perturbed climate



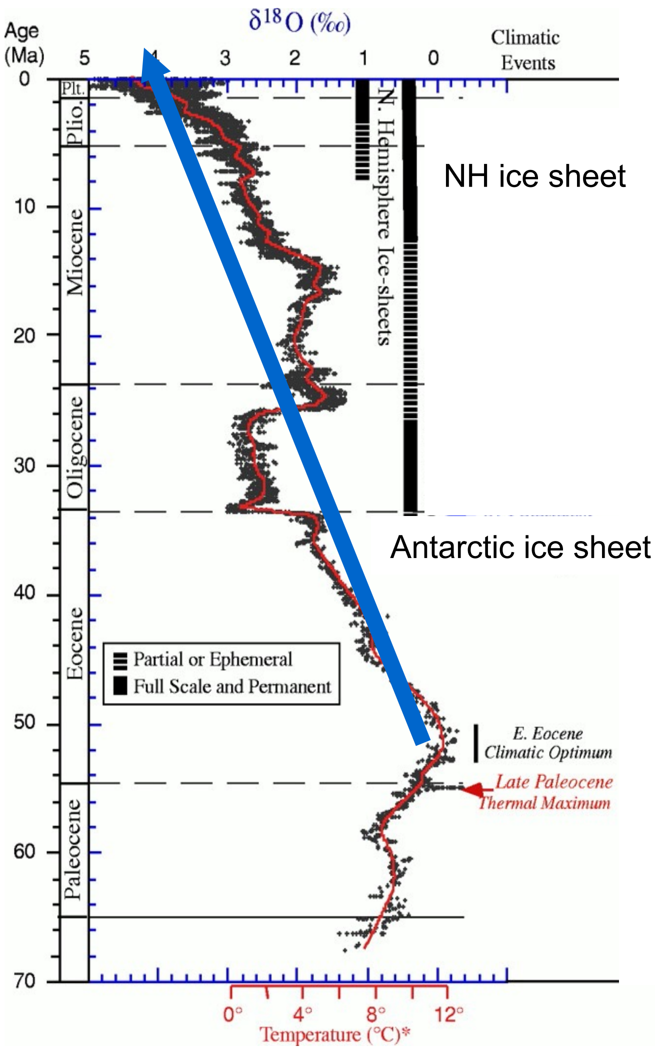
(Kominz et al., 2008; Pagani et al., 2009; Kramer et al., 2011; Crowley & Kim 1995, Wei & Lohmann,) Sea level: 10 ky BP



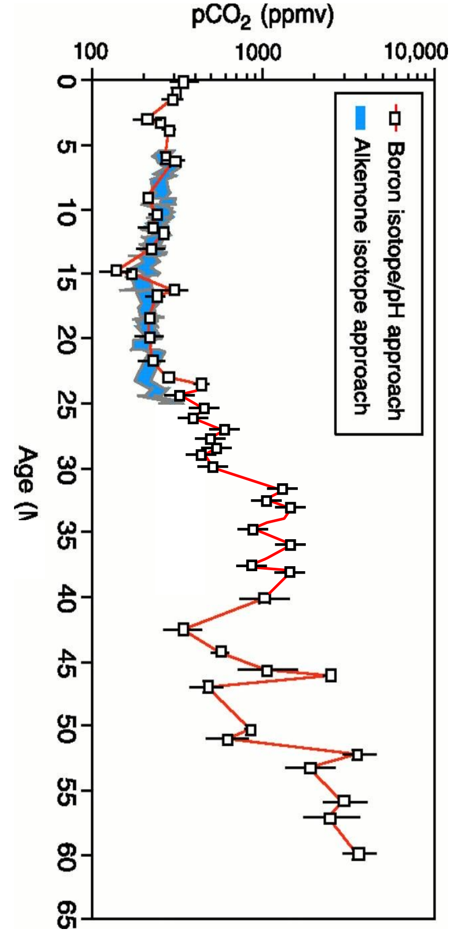
O-18 and sea level



Transitions from Greenhouse to Icehouse Climate: Evidence from Marine Sediments



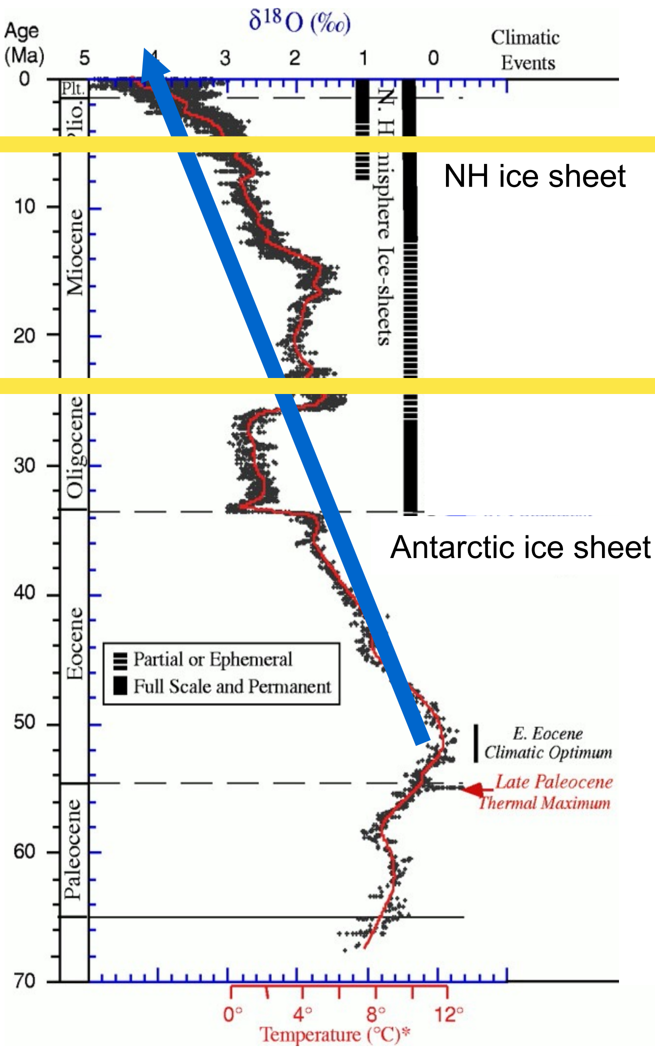
Global deep-sea O-18
(Zachos et al. 2001)



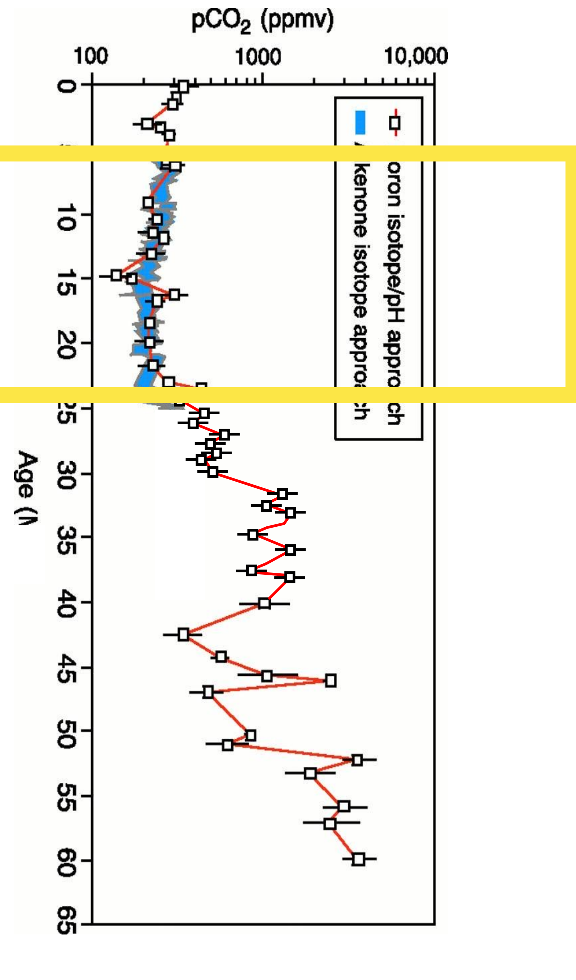
Proxy estimates of atmospheric pCO_2 *(Pearson & Palmer 2000; Pagani et al. 1999, 2005)*

Integrative approach
Data-Modelling

Transitions from Greenhouse to Icehouse Climate: Evidence from Marine Sediments



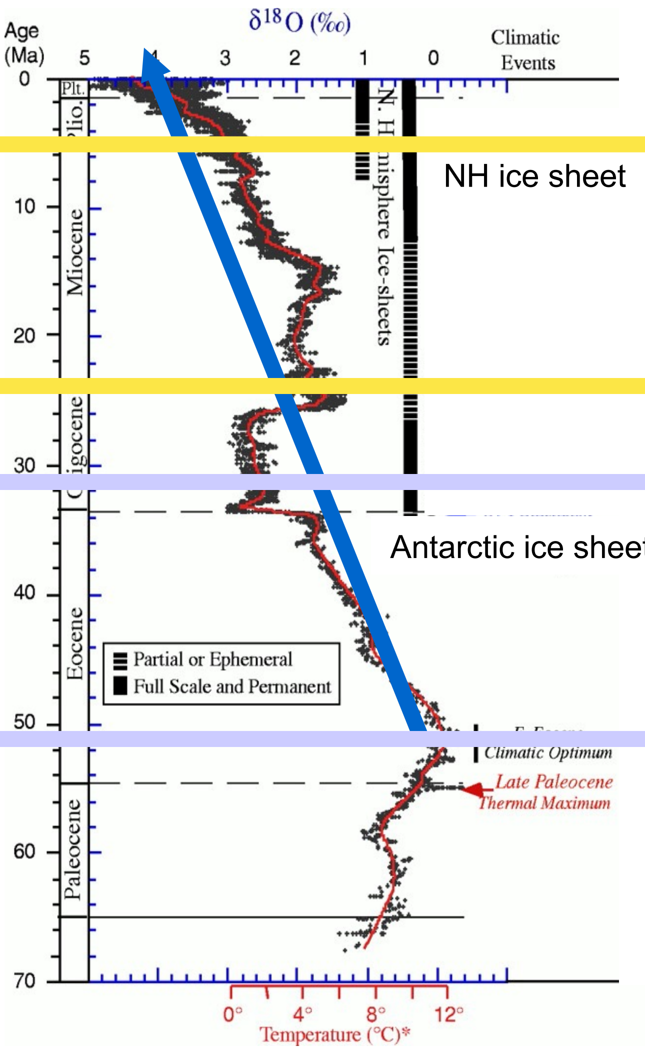
Global deep-sea O-18
(Zachos et al. 2001)



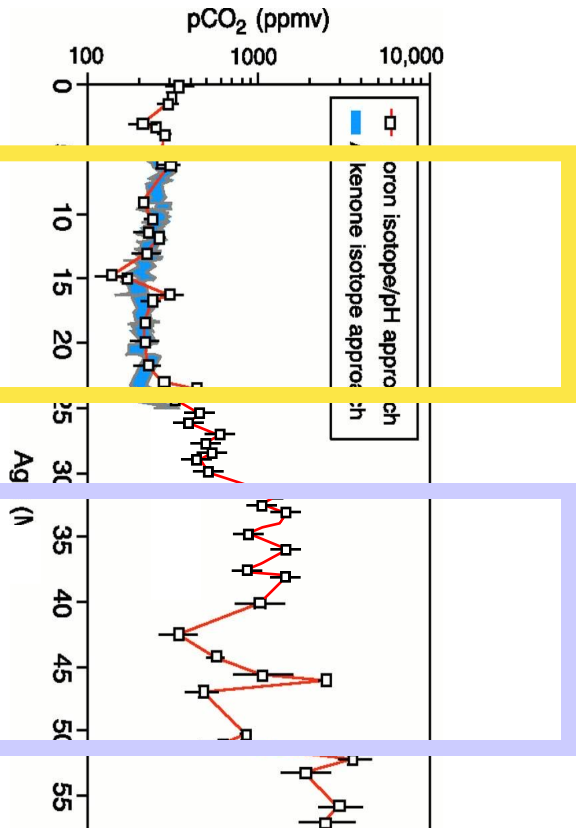
Miocene

Proxy estimates of atmospheric pCO_2 *(Pearson & Palmer 2000; Pagani et al. 1999, 2005)*

Transitions from Greenhouse to Icehouse Climate: Evidences from Marine Sediments



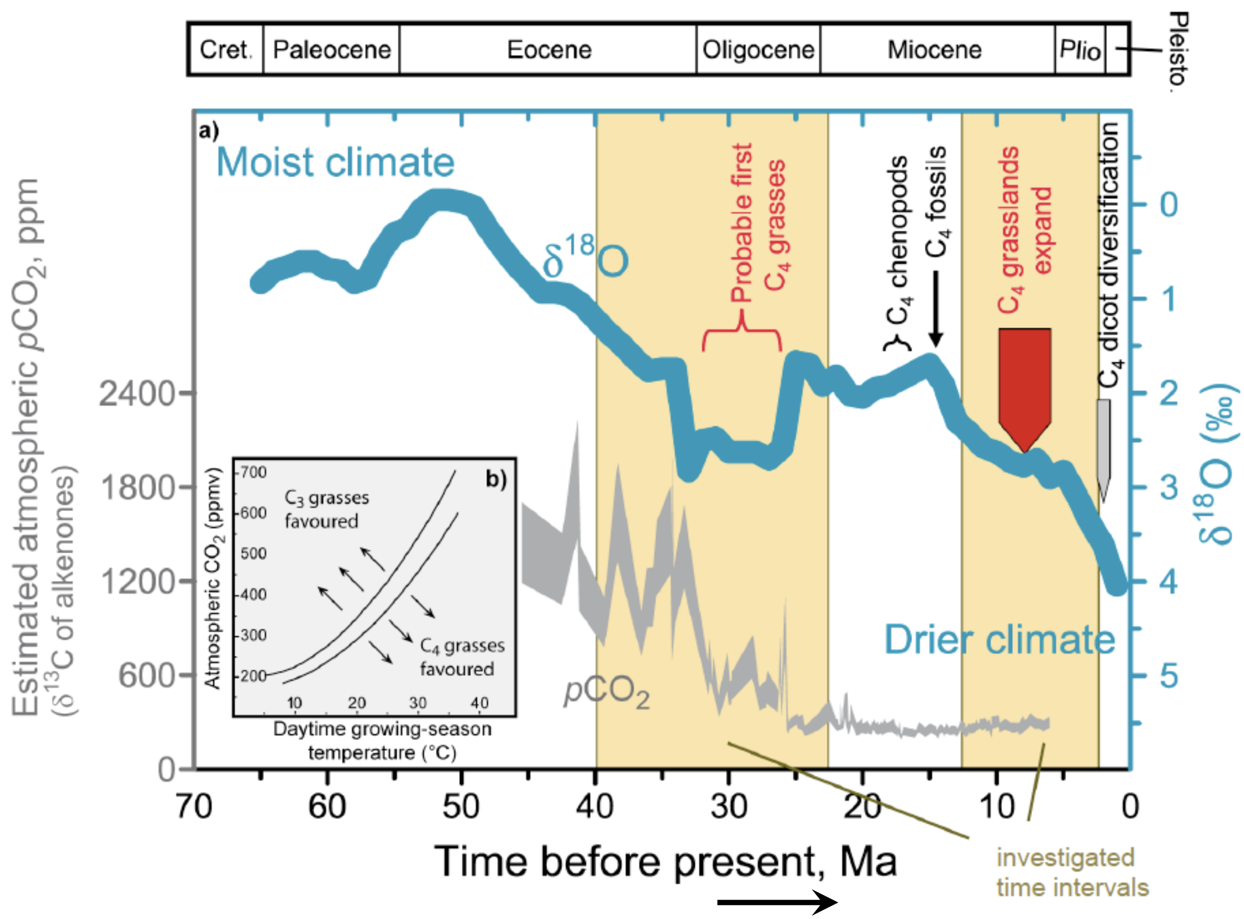
Global deep-sea O-18
(Zachos et al. 2001)



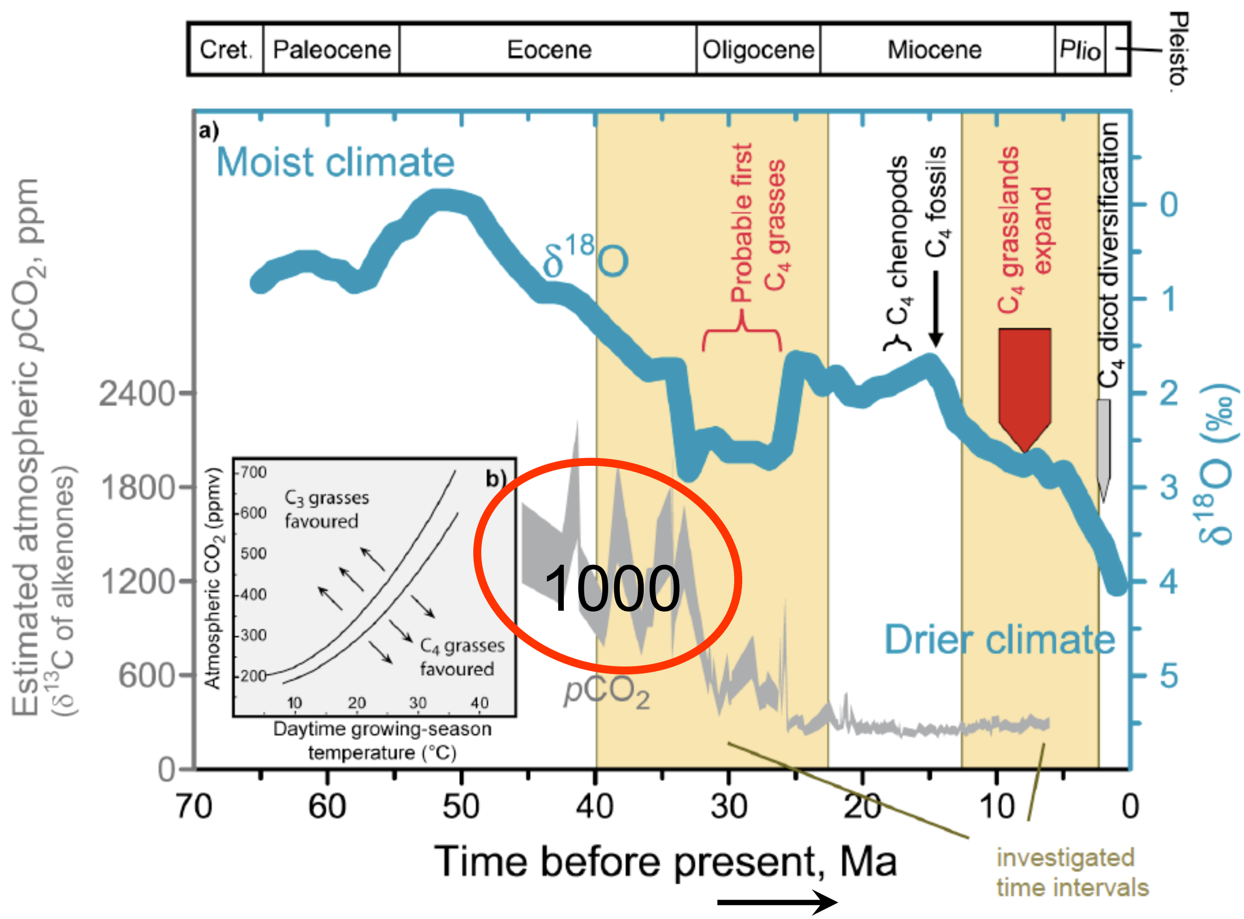
Proxy estimates of atmospheric pCO2 *(Pearson & Palmer 2000; Pagani et al. 1999, 2005)*

- Eocene long-term climate cooling
- Eocene/Oligocene glaciation of Antarctica; drop in pCO2
- Compare to the Miocene/Pliocene cooling; low pCO2

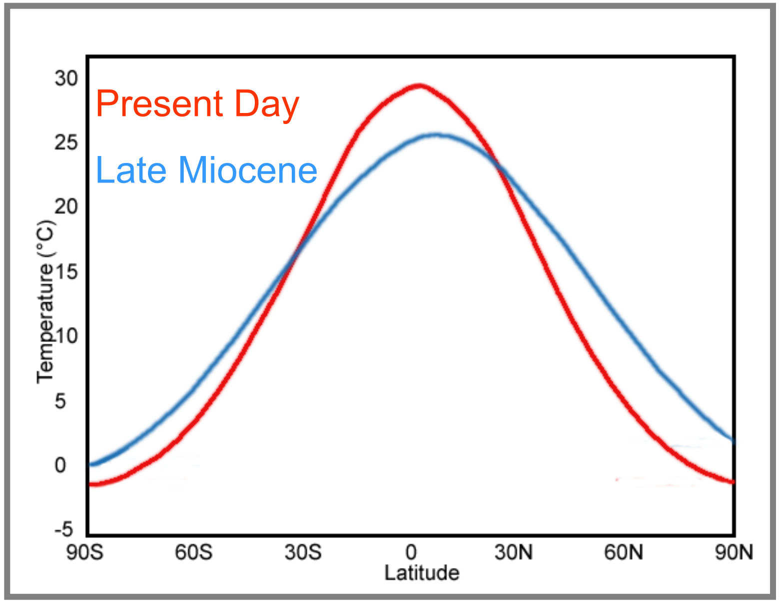
Climate warming `backward´



Climate warming `backward'



Flat Temperature Gradient



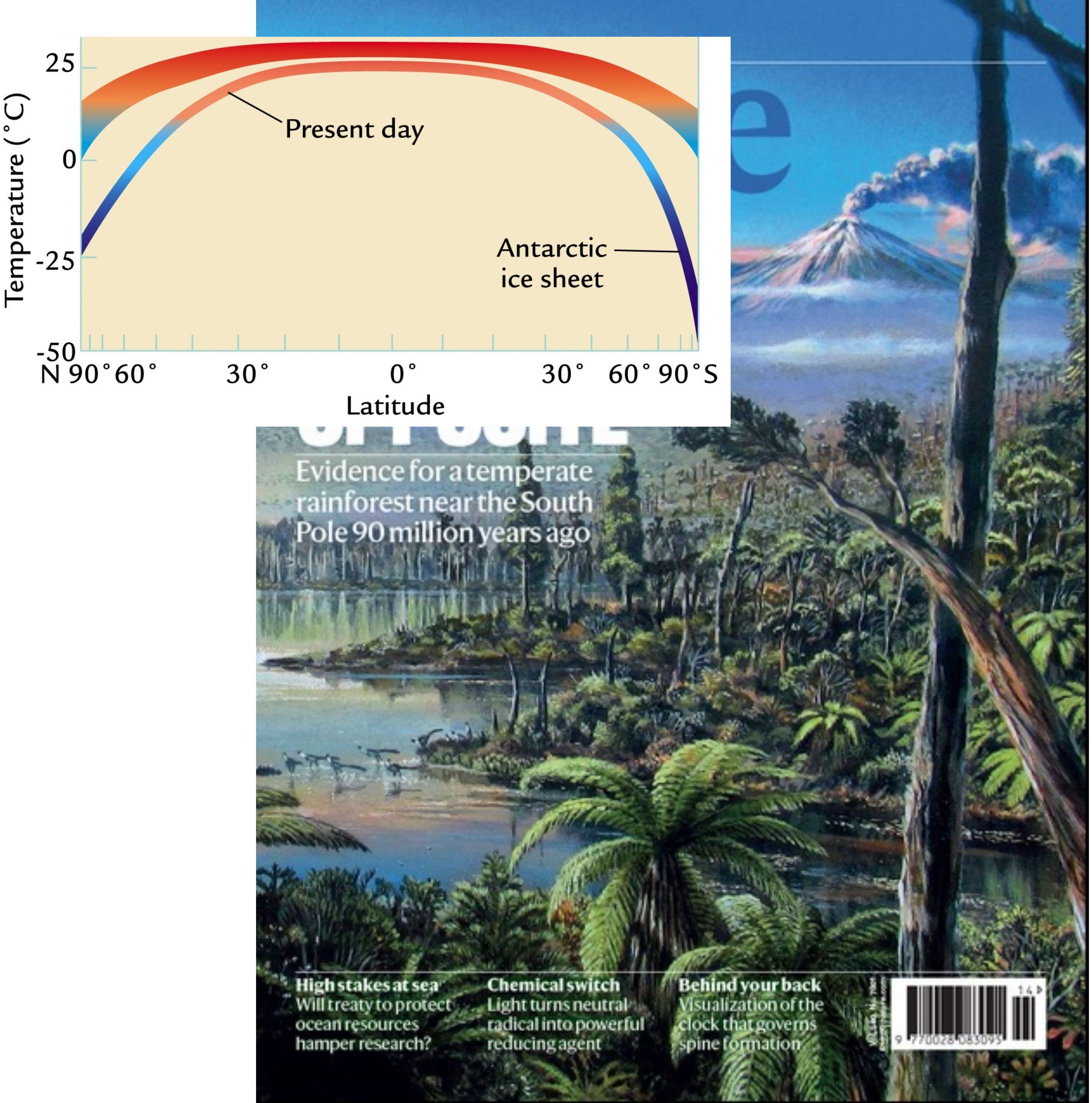
Crowley

Steppuhn et al., 2006

Many authors

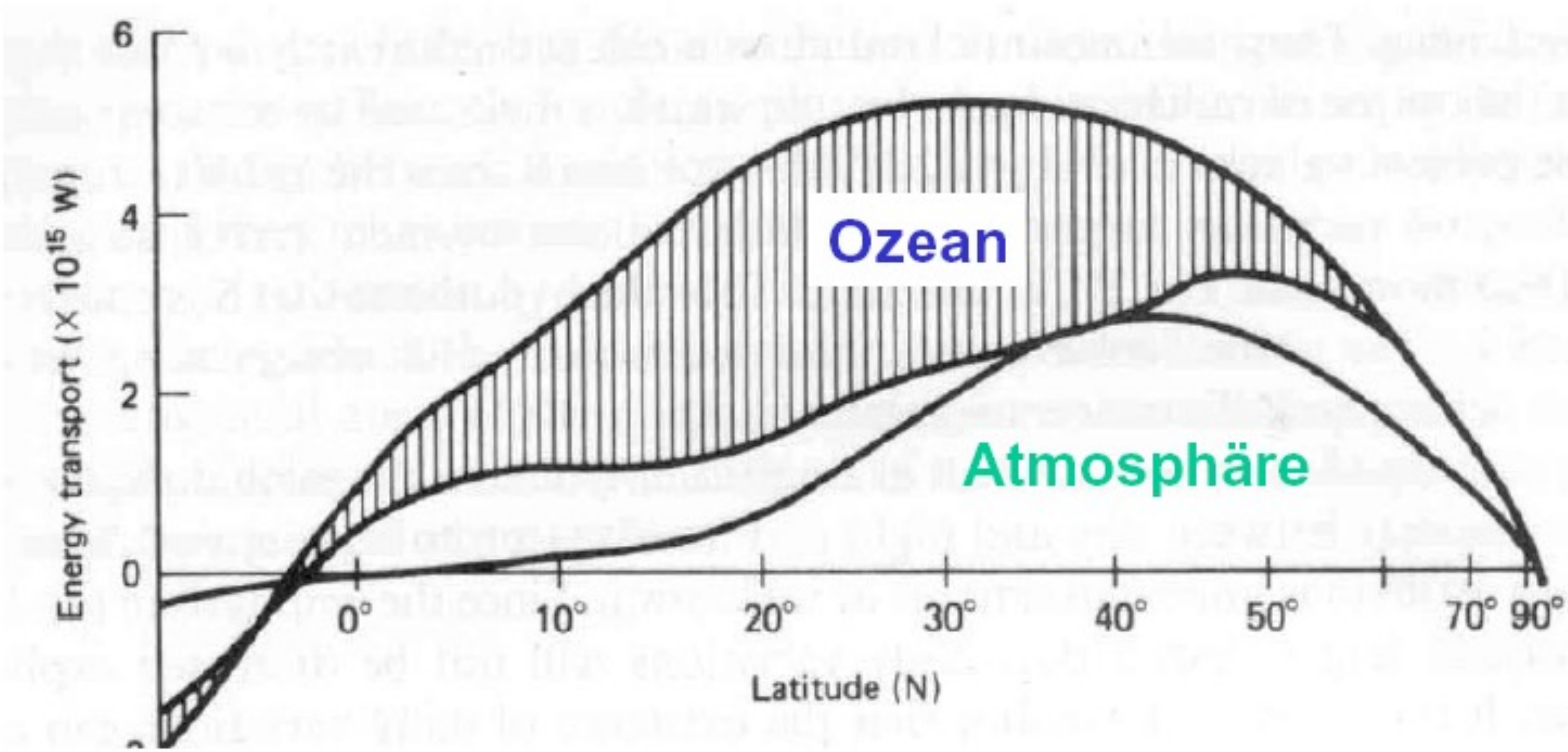
Reason?


The international journal of science / 2 April 2020
nature
POLAR OPPOSITE
Evidence for a temperate rainforest near the South Pole 90 million years ago
High stakes at sea
Will treaty to protect ocean resources hamper research?
Chemical switch
Light turns neutral radical into powerful reducing agent
Behind your back
Visualization of the clock that governs spine formation
14
9 770028 083095



Evidence for a temperate rainforest near the South Pole 90 million years ago
High stakes at sea
Will treaty to protect ocean resources hamper research?
Chemical switch
Light turns neutral radical into powerful reducing agent
Behind your back
Visualization of the clock that governs spine formation
Temperature (°C)
25
0
-25
-50
Present day
Antarctic ice sheet
N 90° 60° 30° 0° 30° 60° 90° S
Latitude

Northward Heat Transport

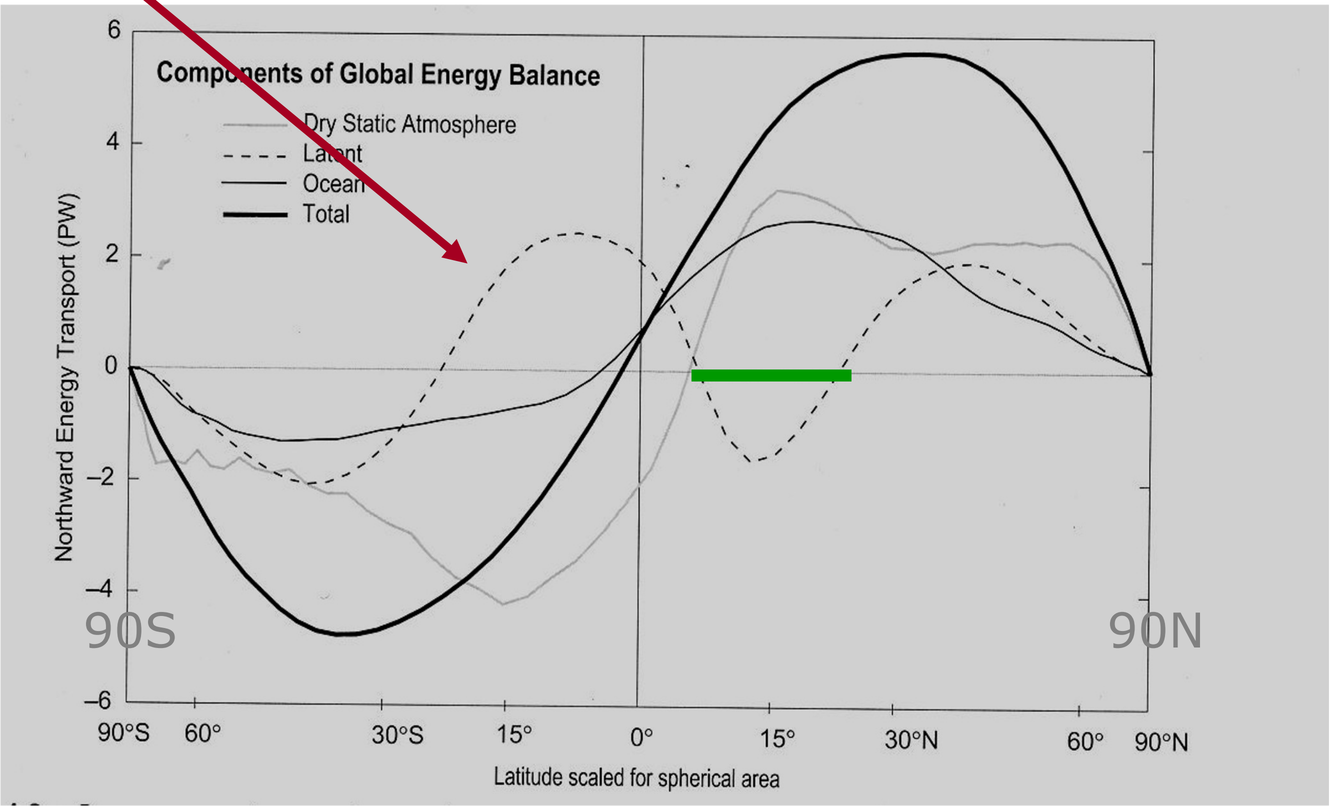


nach Von der Haar & Ort; Quelle: Gill

Global meridional heat transport divides roughly equally into 3 modes:

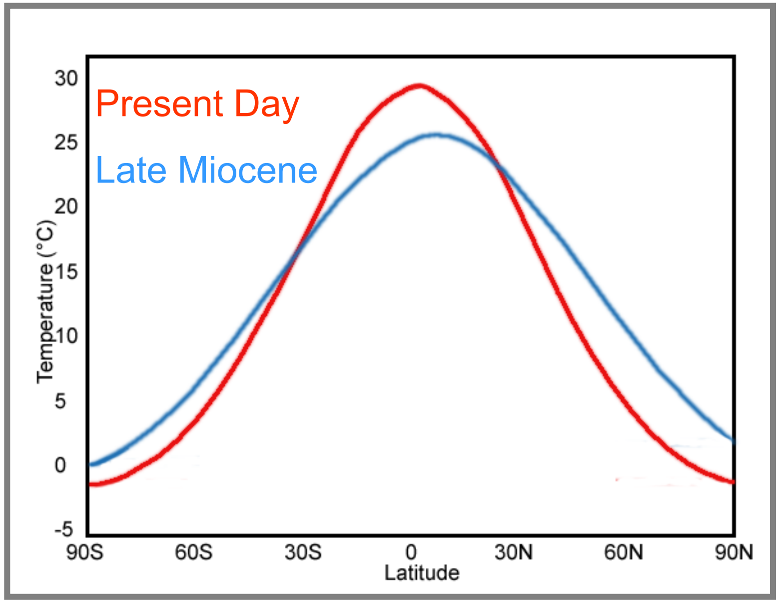
1. atmosphere (dry static energy)
2. ocean (sensible heat)
3. water vapor/latent heat transport

The three modes of poleward transport are comparable in amplitude, and distinct in character (sensible heat flux divergence focused in tropics, latent heat flux divergence focus in the subtropics)



(residual method, TOA radiation 1985-89 and ECMWF/NMC atmos obs)

Flat Temperature Gradient



Crowley

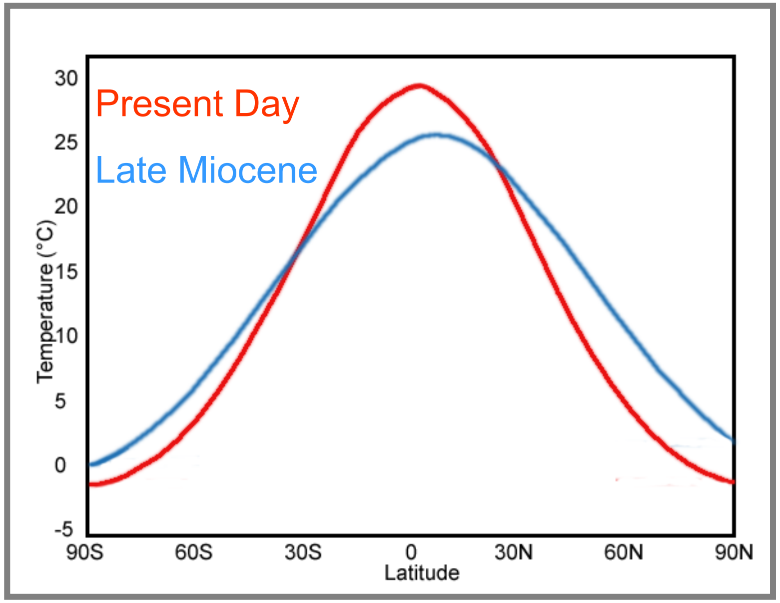
Steppuhn et al., 2006

Many authors

Reason?

- **Sensible heat transport**
- **Latent heat transport**
- **Ocean heat transport**
- **Orography** → **Greenland: high latitude warming**
- **Changes in the land surface cover**
- **Other effects?**

Flat Temperature Gradient



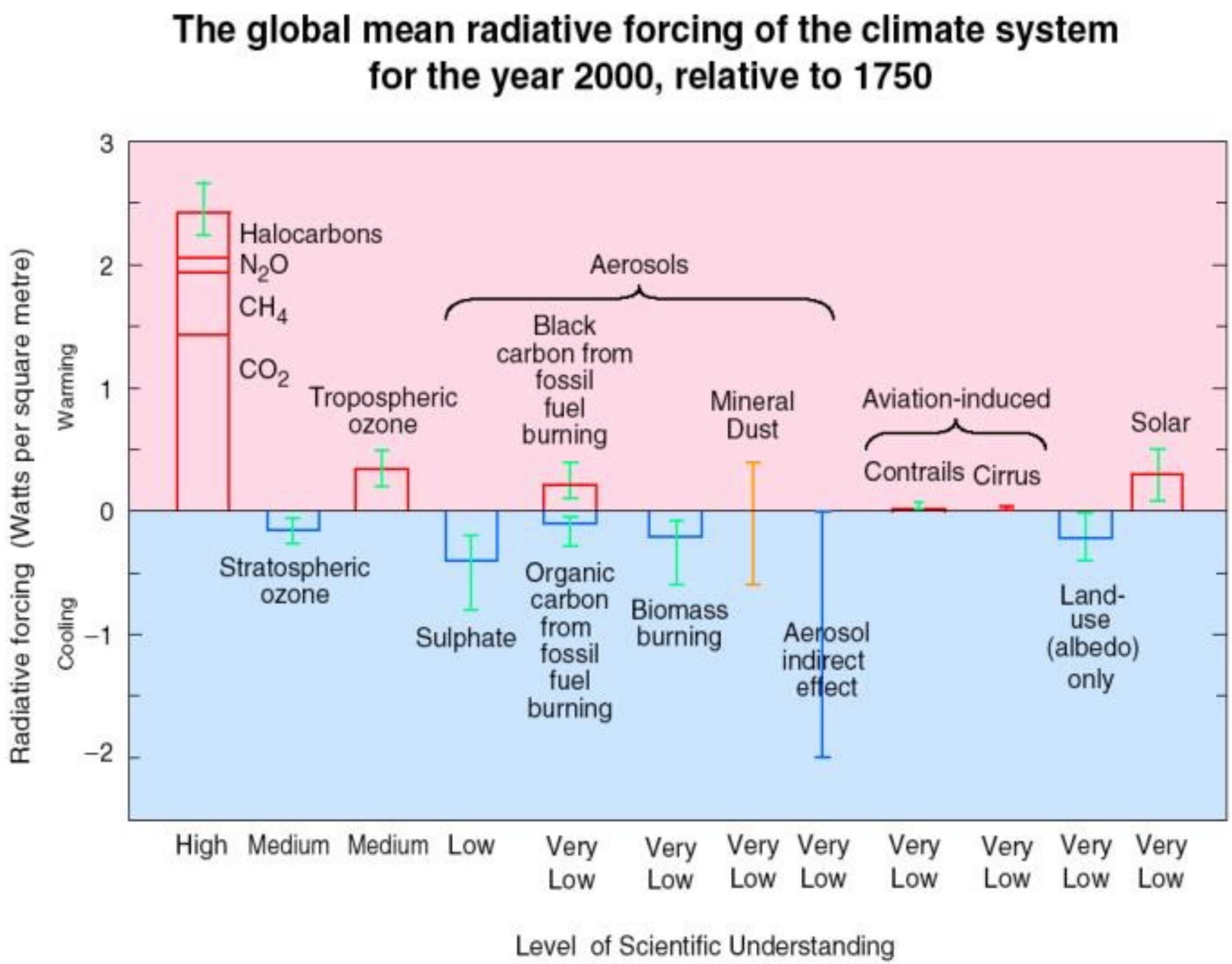
Crowley

Steppuhn et al., 2006

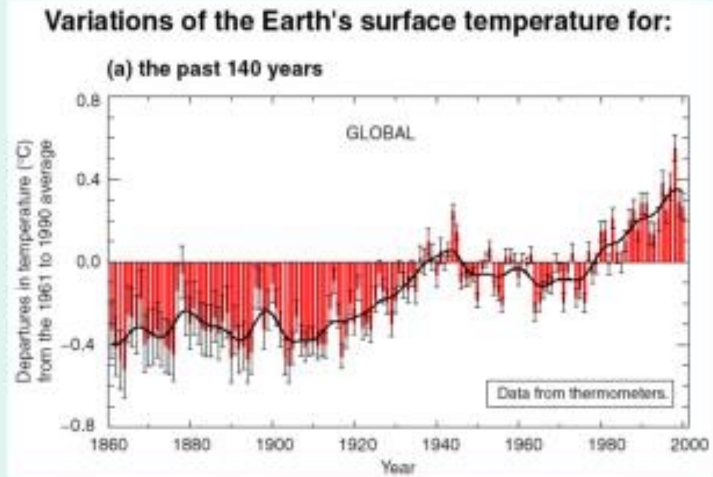
Many authors

Reason?

- **Sensible heat transport** ~ ΔT ↘ EBMs, ……
- **Latent heat transport** ~ $\Delta T \frac{\partial q}{\partial T}$ → *Caballero & Langen*
- **Ocean heat transport** ↘ Panama Gateway, Atlantic salinity reduction
- **Orography** ⟶ **Greenland: high latitude warming**
- **Changes in the land surface cover**
- **Other effects?**


The global mean radiative forcing of the climate system
for the year 2000, relative to 1750
Radiative forcing (Watts per square metre)
Warming
Cooling
3
2
1
0
−1
−2
Halocarbons
N_2O
CH_4
CO_2
Aerosols
Tropospheric ozone
Stratospheric ozone
Black carbon from fossil fuel burning
Organic carbon from fossil fuel burning
Mineral Dust
Sulphate
Biomass burning
Aerosol indirect effect
Aviation-induced
Contrails
Cirrus
Land-use (albedo) only
Solar
High
Medium
Medium
Low
Very Low
Very Low
Very Low
Very Low
Very Low
Very Low
Very Low
Very Low
Level of Scientific Understanding

To Project future climates by using the observed record of climate over the past century, we need to know three things to interpret the temperature time series:



$$\Delta Q = C\frac{\Delta T}{\Delta t} + \frac{1}{\lambda}\Delta T$$

Climate Forcing = ΔQ (Wm^{-2})

Heat capacity = C ($J\ {}^{o}K^{-1}\ m^{-2}$)

Climate sensitivity = λ (${}^{o}K$ per Wm^{-2})

Energy Equation:

$$\Delta Q = C\frac{\Delta T}{\Delta t} + \frac{1}{\lambda}\Delta T$$

Climate =	**Heat**	**+**	**Heat**
Forcing	**Storage**		**Loss**

In Equilibrium, temperature is constant with time and so,

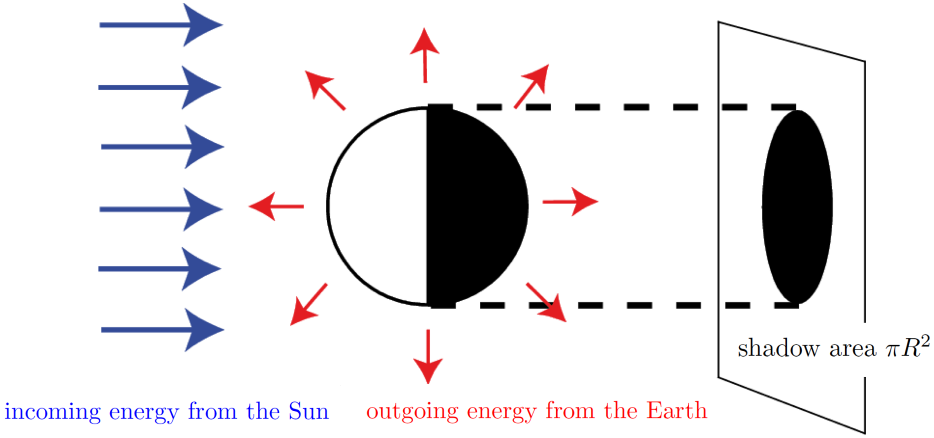
$$\Delta T = \lambda \cdot \Delta Q$$

λ is a measure of climate sensitivity;
K per Wm^{-2} of climate forcing

Energy balance model: Concepts of climate

$$(1-\alpha)S\pi R^2 = 4\pi R^2 \epsilon\sigma T^4$$

$$T = \sqrt[4]{\frac{(1-\alpha)S}{4\epsilon\sigma}}$$



Heat capacity of the climate system

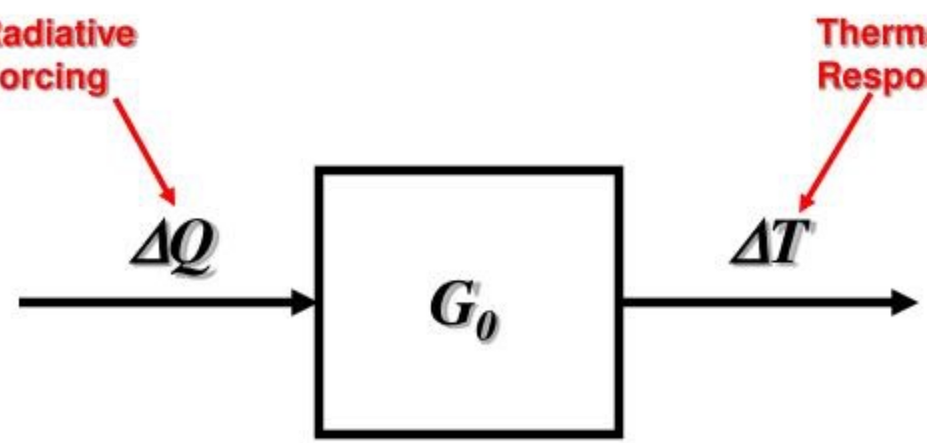
Fast rotation

Lohmann, 2020
doi:10.5194/esd-11-1195-2020

A Simple Question

- If we alter Earth's radiation balance by 1 W m^{-2} and allow the climate system to fully adjust, how much will the global average temperature change?
- This is a fundamental question in climate dynamics, and is relevant to both past and future climate change.

Schematic Diagram of Zero-Dimensional Climate Model



$$\Delta T = G_0 \Delta Q$$

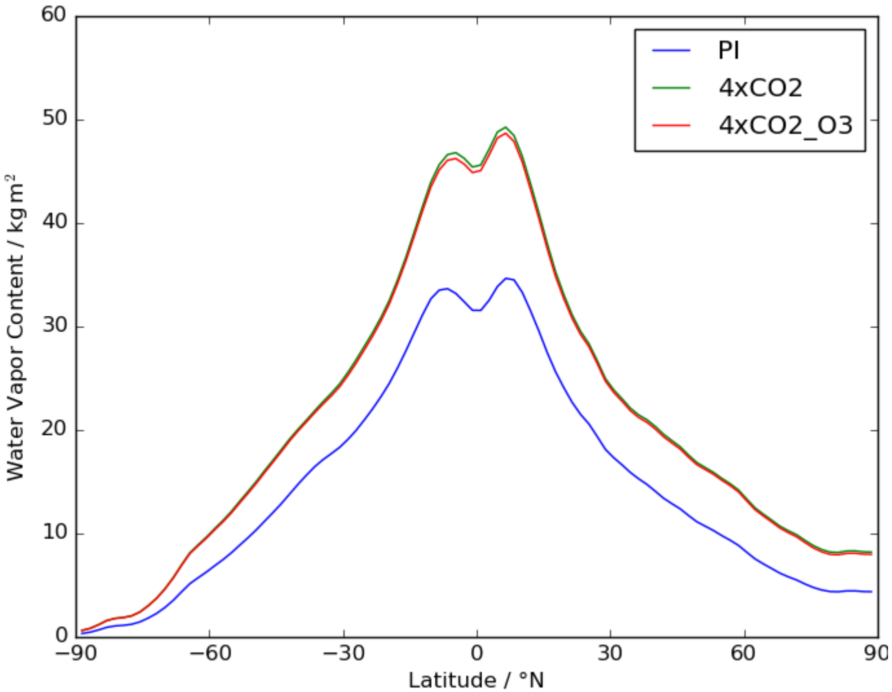
Snow-Ice-Albedo Feedback

- In a warmer climate, snow cover and sea ice extent are reduced.
- Reduced snow cover and sea ice extent decrease the surface albedo of the earth, allowing more solar radiation to be absorbed.
- Increased absorption of solar radiation leads to a further increase in temperature.
- This is a positive feedback.

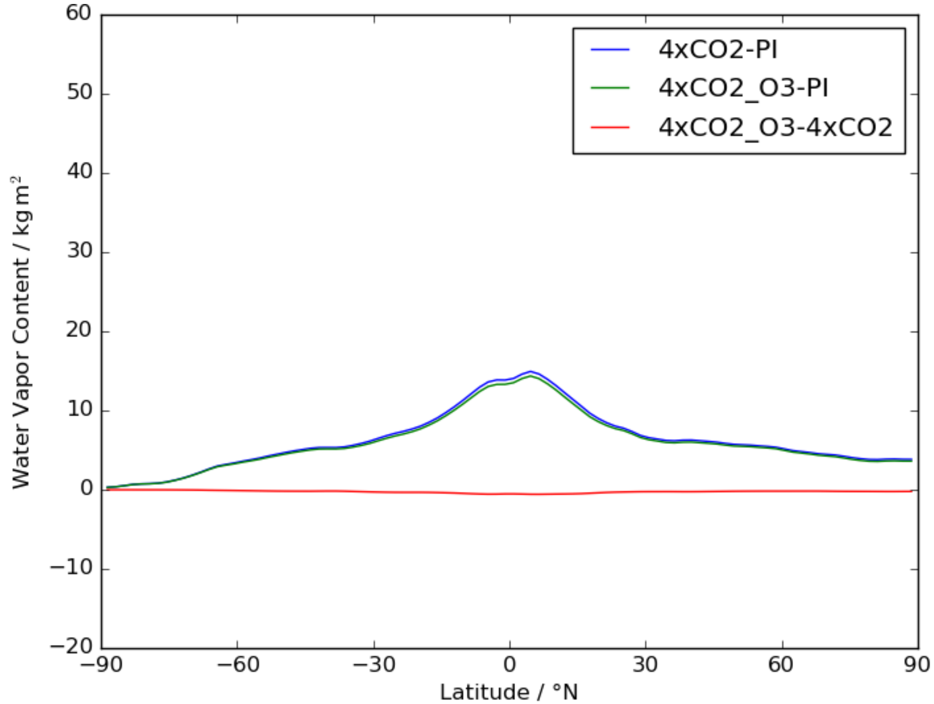
Water Vapor Feedback

- In a warmer climate, increases in saturation vapor pressure allow water vapor to increase.
- Increased water vapor increases the infrared opacity of the atmosphere.
- The reduction in outgoing longwave radiation leads to a further increase in temperature.
- This is a positive feedback.

Water vapor



PI
4xCO2
4xCO2_O3
Water Vapor Content / kg m^{2}
Latitude / °N
60
50
40
30
20
10
0
−90
−60
−30
0
30
60
90



4xCO2-PI
4xCO2_O3-PI
4xCO2_O3-4xCO2
Water Vapor Content / kg m^{2}
Latitude / °N
60
50
40
30
20
10
0
−10
−20
−90
−60
−30
0
30
60
90

Water Vapor Feedback

Effect on long-term response to doubled CO_2

$$\Delta T = \lambda \cdot \Delta Q$$

λ is a measure of climate sensitivity;
^{o}K per Wm^{-2} of climate forcing

λ_o = for fixed absolute humidity = 0.25 $^{o}K/(Wm^{-2})$

λ_{RH} = for fixed relative humidity = 0.50 $^{o}K/(Wm^{-2})$

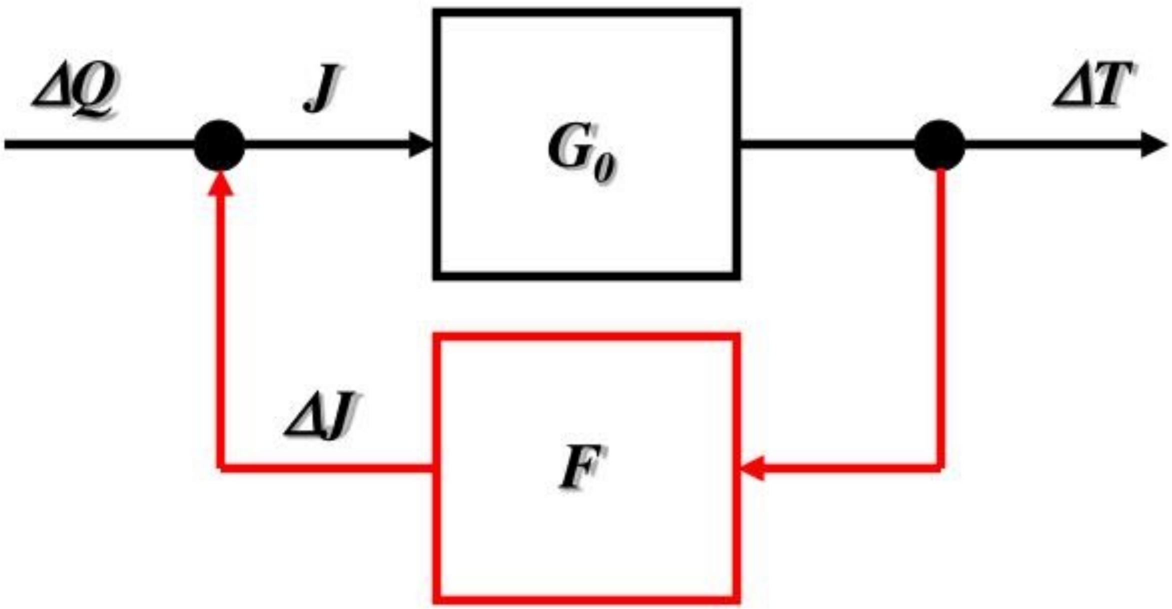
$$\lambda_{RH}^{-1} = 2.0 \pm 0.5 Wm^{-2} K^{-1}$$

(NRC, 1979, still good?)

$$\Delta Q_{2\times CO_2} = 4Wm^{-2} \quad gives$$

$$1.6C < \Delta T < 2.7C$$

Zero-Dimensional Climate Model With Feedbacks



$$\Delta T = G_0 J = G_0\left(\Delta Q + F\Delta T\right)$$

$$\Delta T = G_0\left(\Delta Q + F\Delta T\right)$$

Solving for ΔT:

$$\Delta T = \frac{G_0}{1-f}\Delta Q \qquad\qquad f \equiv G_0 F$$

This can also be written as

$$\Delta T = G_f \Delta Q \qquad\qquad G_f \equiv \frac{G_0}{1-f}$$

Larger positive F → larger G_f → larger ΔT

Climate sensitivity is sometimes expressed in terms of the equilibrium warming that would result from a doubling of atmospheric CO_2:

$$\Delta T_{2x} = G_f \Delta Q_{2x}$$

$$\Delta Q_{2x} \approx 4 W\, m^{-2}$$

Practical Jan 10, 2023

Exercise

EBM analysis

- https://1drv.ms/u/s!AnZSDMNwdkDMgccDeuhjFFrmQHaqvw?e=ZaHqPA