Climate warming `backward´

The last 100 Million years

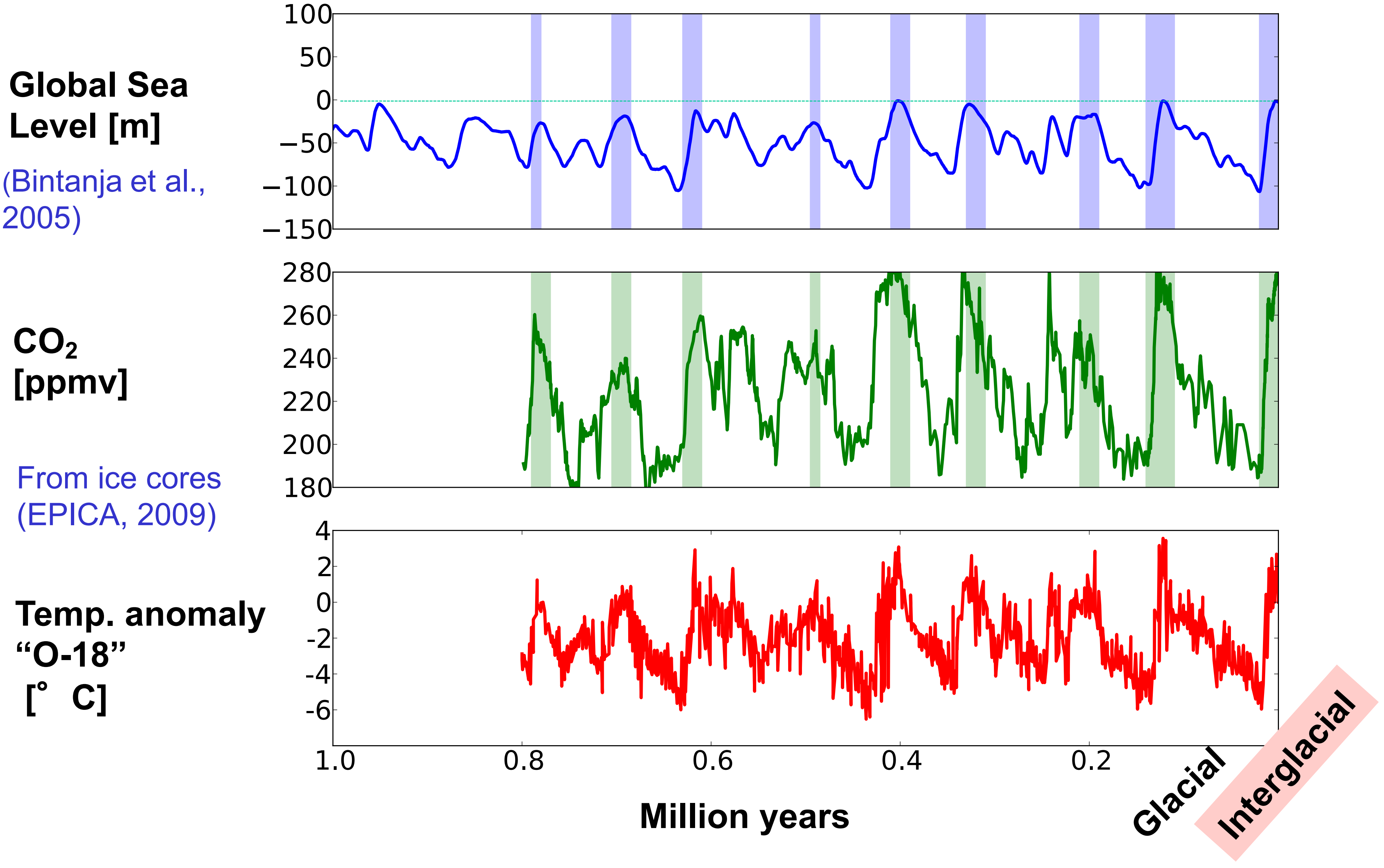
Transitions from Greenhouse to Icehouse Climate

Climate System II

Gerrit Lohmann

with Christian Stepanek

Glacial-Interglacial variability



Glacial-Interglacial variability

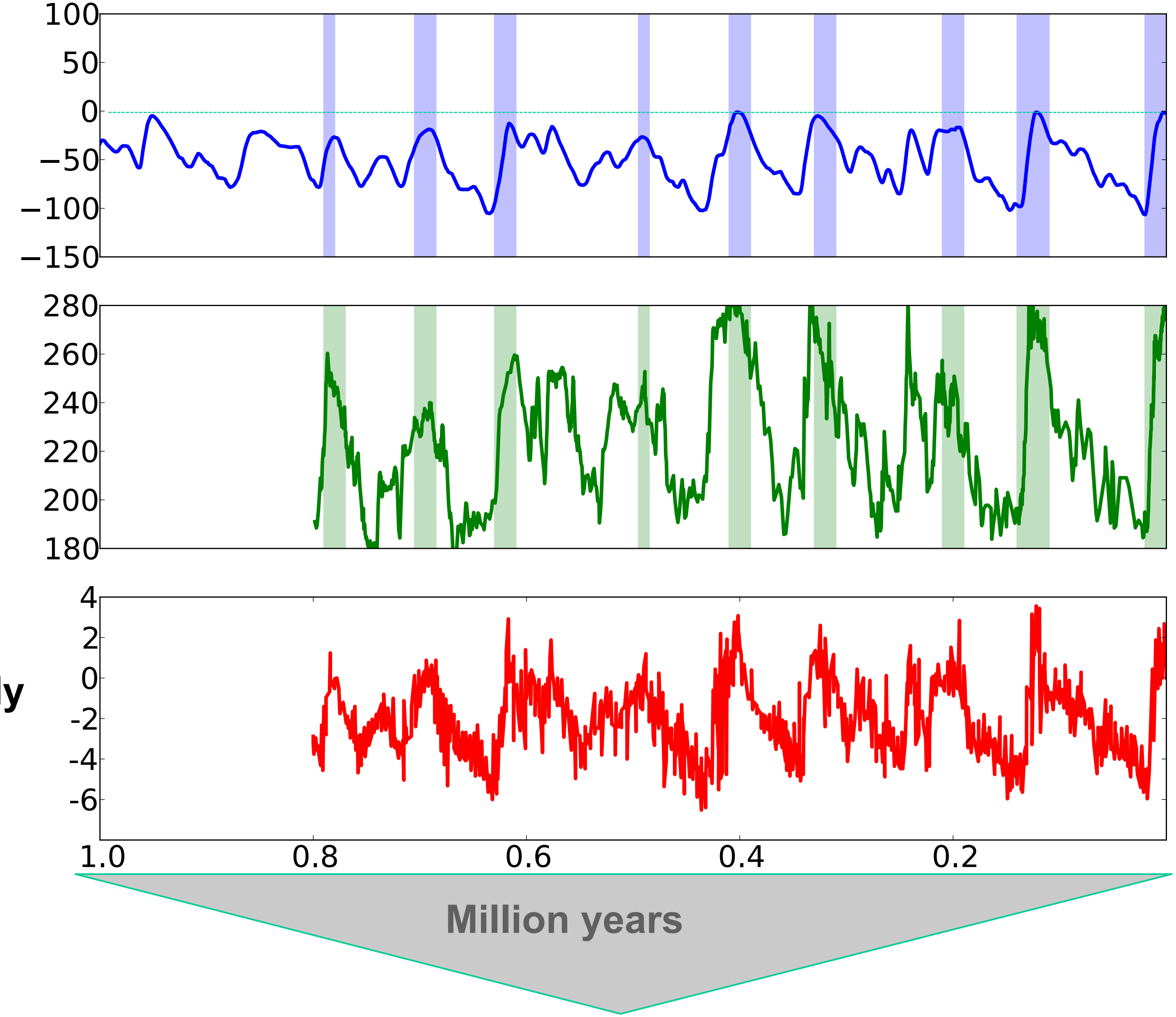
Global Sea Level [m]

(Rohling et al., 2009)

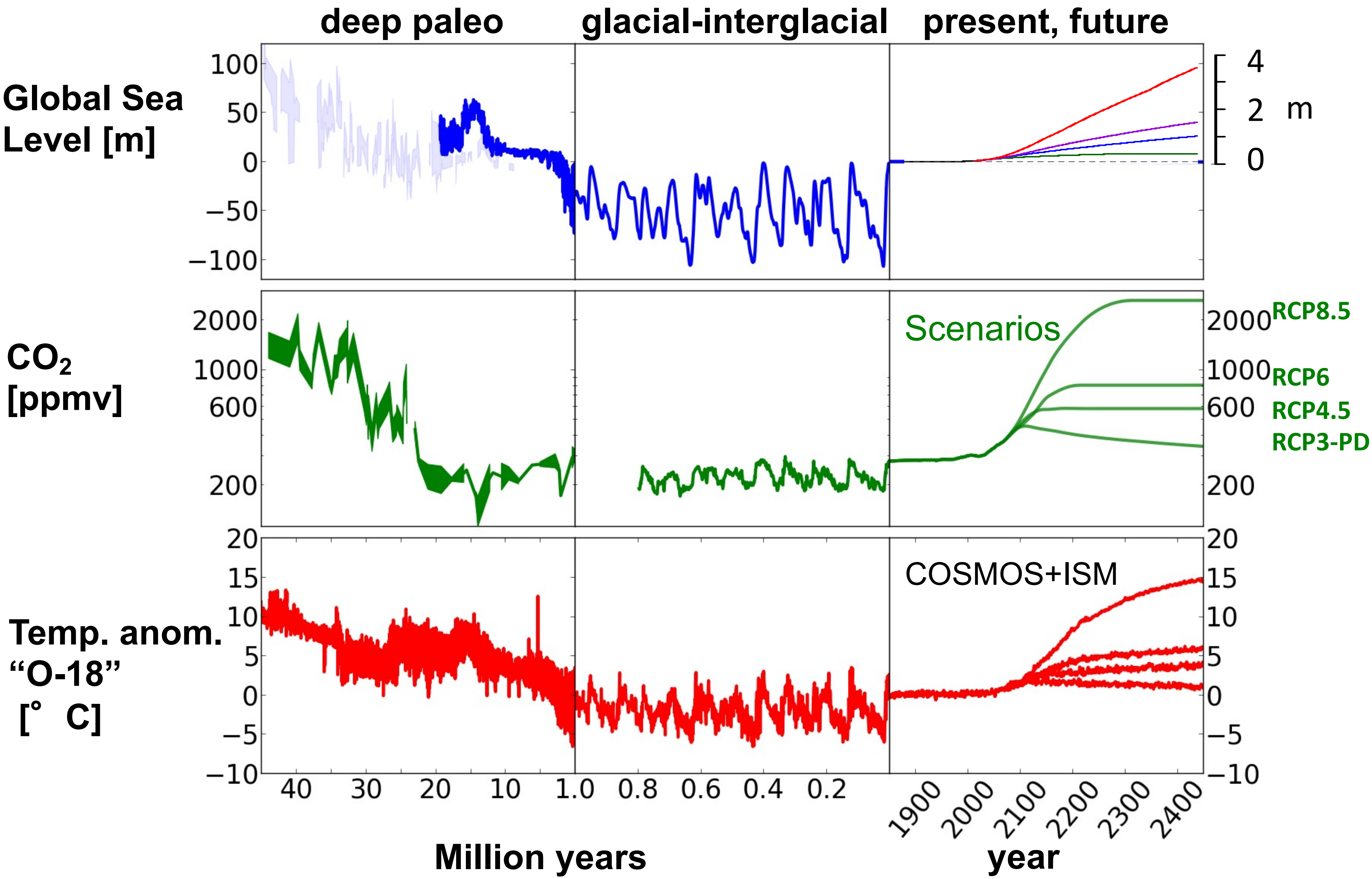
CO_2 [ppmv]

From ice cores (EPICA, 2009)

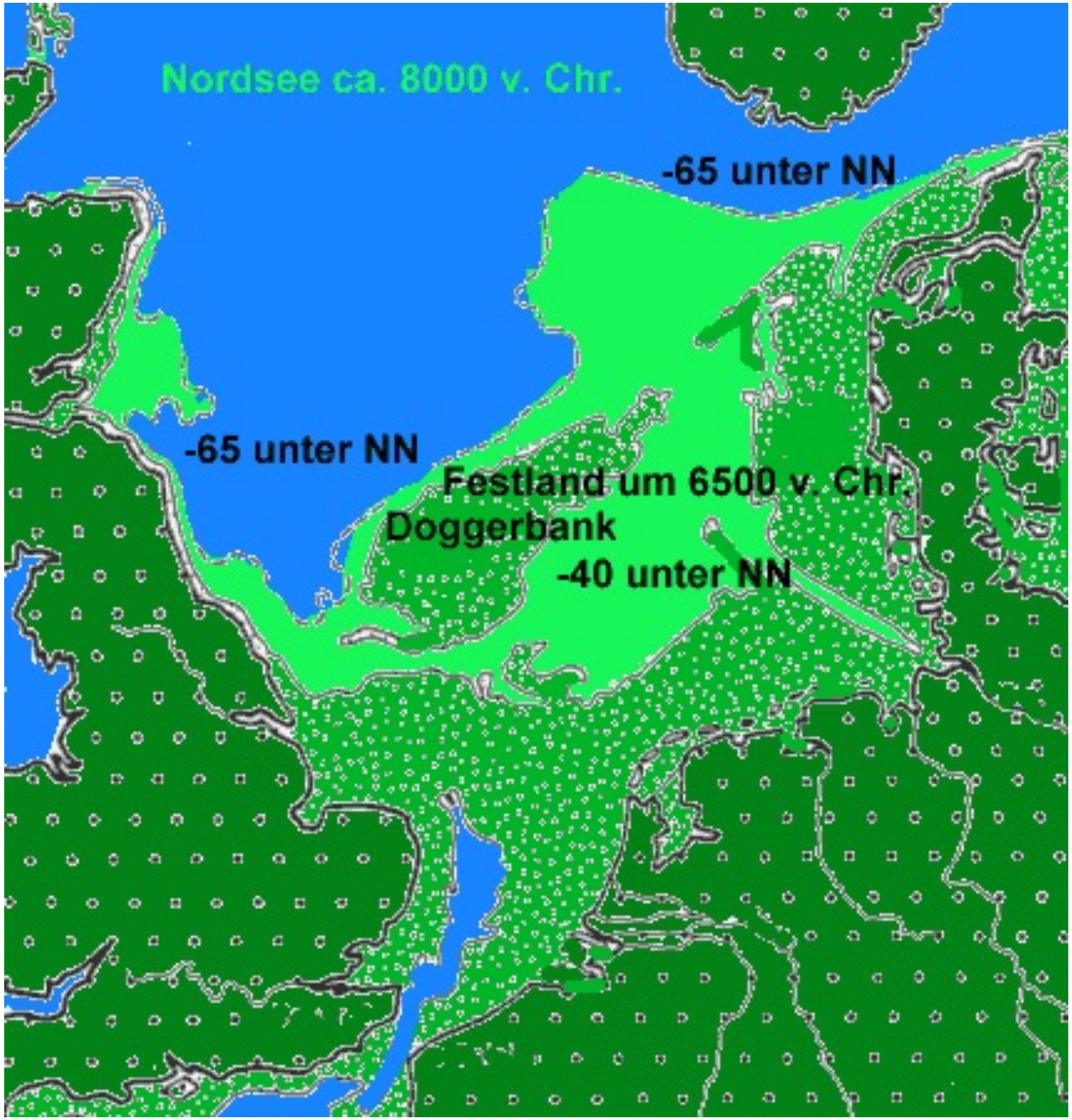
Temp. anomaly "O-18" [° C]



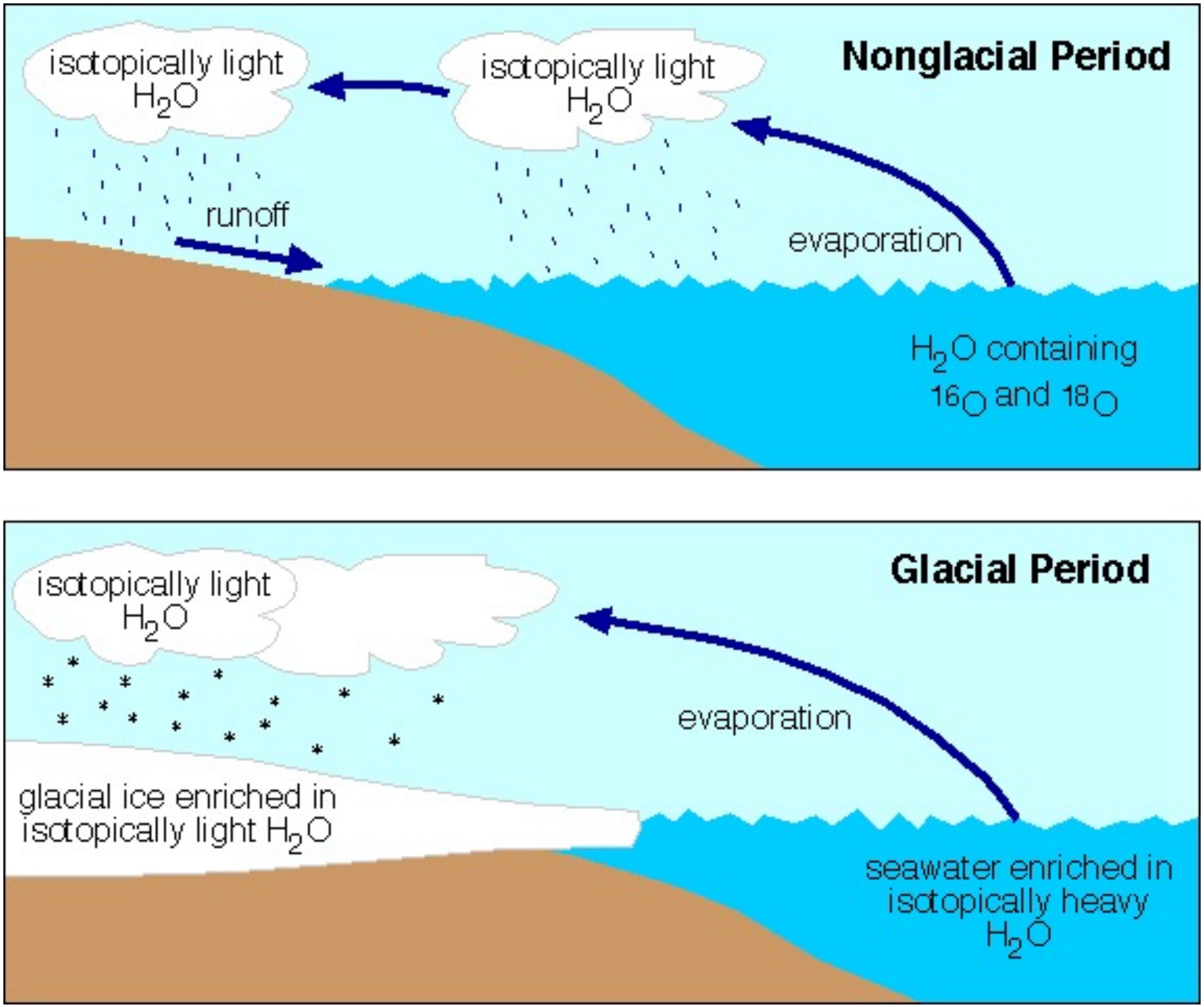
Natural variability and perturbed climate



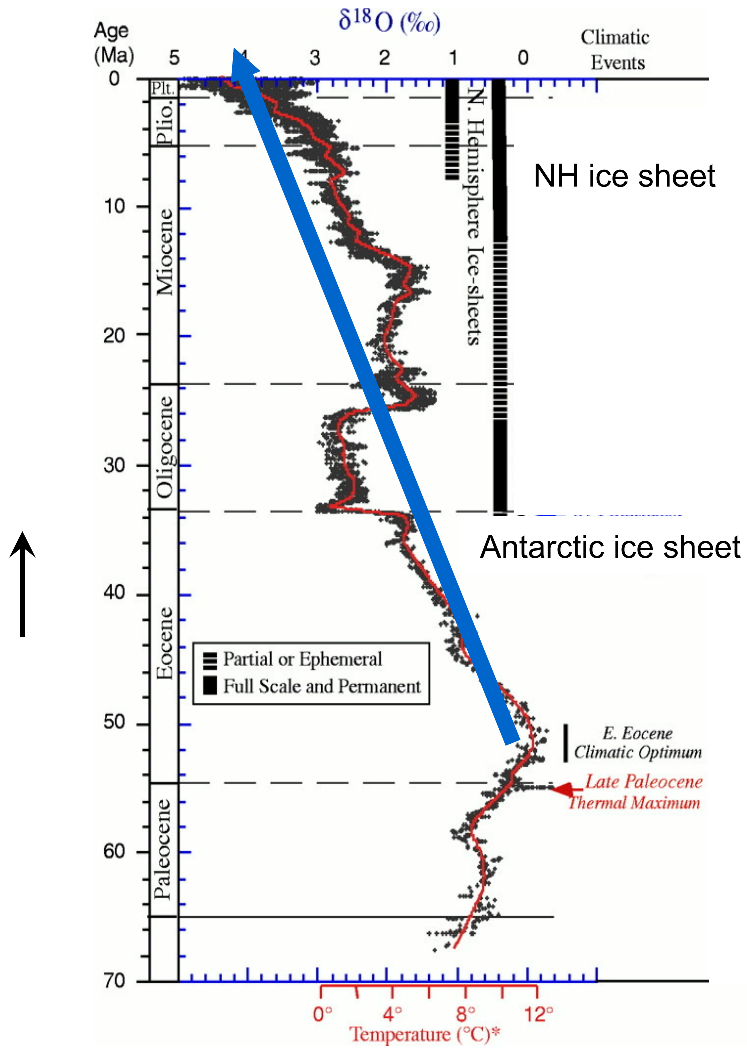
(Kominz et al., 2008; Pagani et al., 2009; Kramer et al., 2011; Crowley & Kim 1995, Wei & Lohmann,) Sea level: 10 ky BP



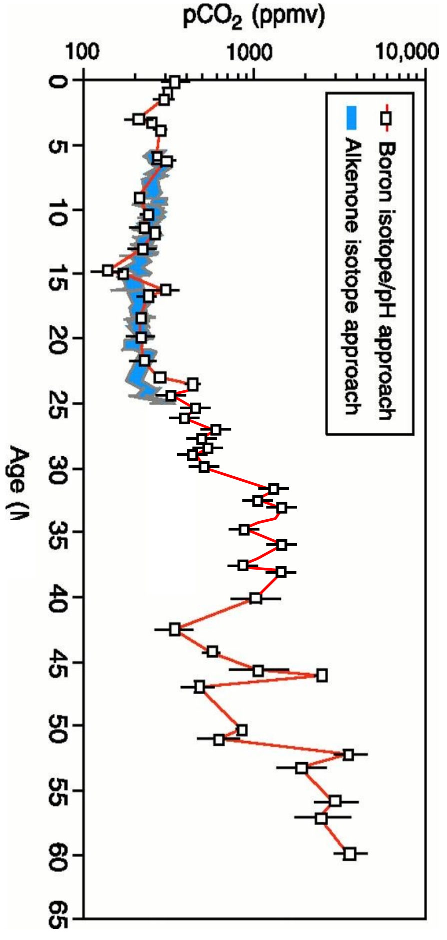
O-18 and sea level



Transitions from Greenhouse to Icehouse Climate: Evidence from Marine Sediments



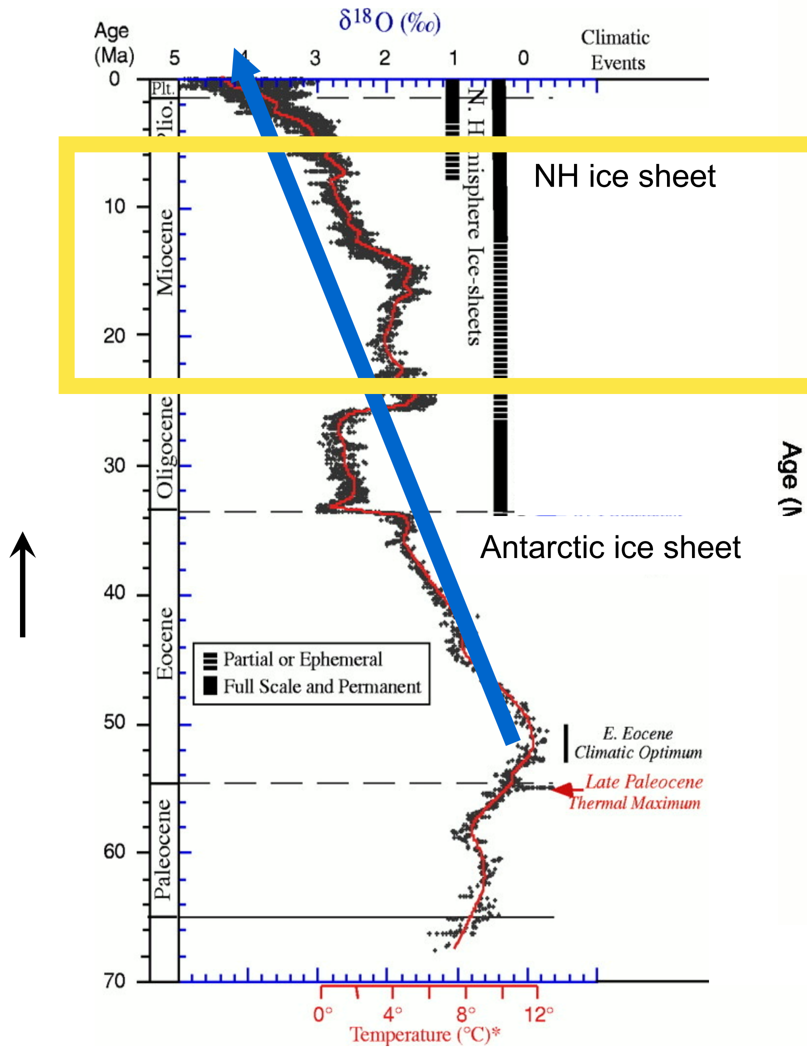
Global deep-sea O-18
(Zachos et al. 2001)

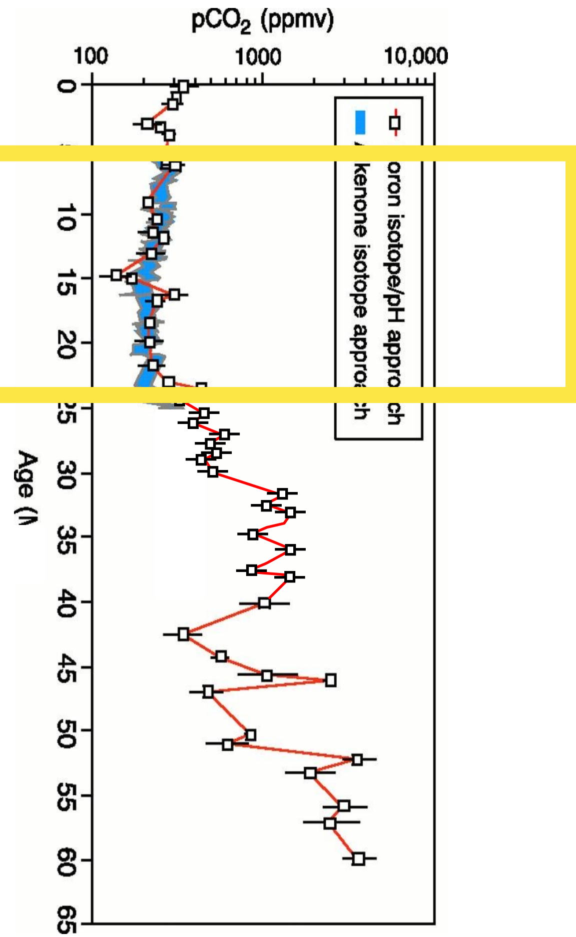


Proxy estimates of atmospheric pCO2 *(Pearson & Palmer 2000; Pagani et al. 1999, 2005)*

Integrative approach
Data-Modelling

Transitions from Greenhouse to Icehouse Climate: Evidence from Marine Sediments



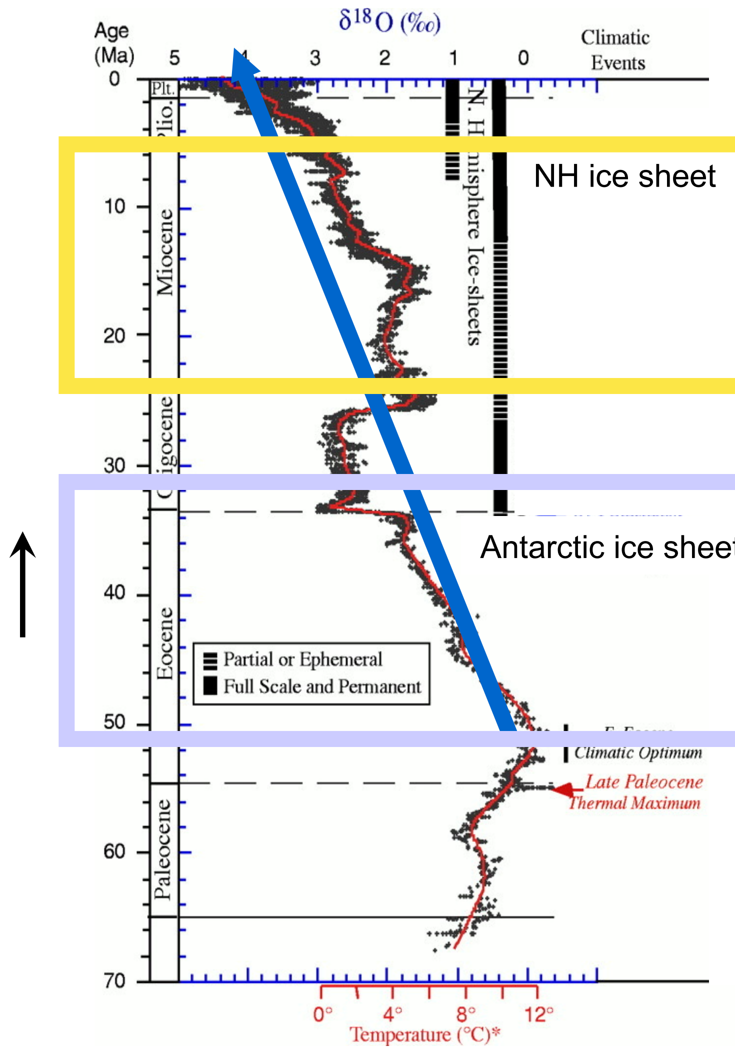


Miocene

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

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

Transitions from Greenhouse to Icehouse Climate: Evidences from Marine Sediments



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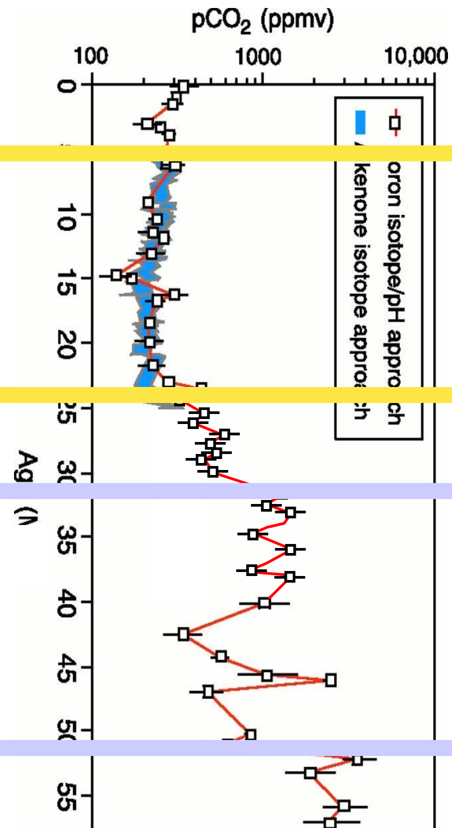
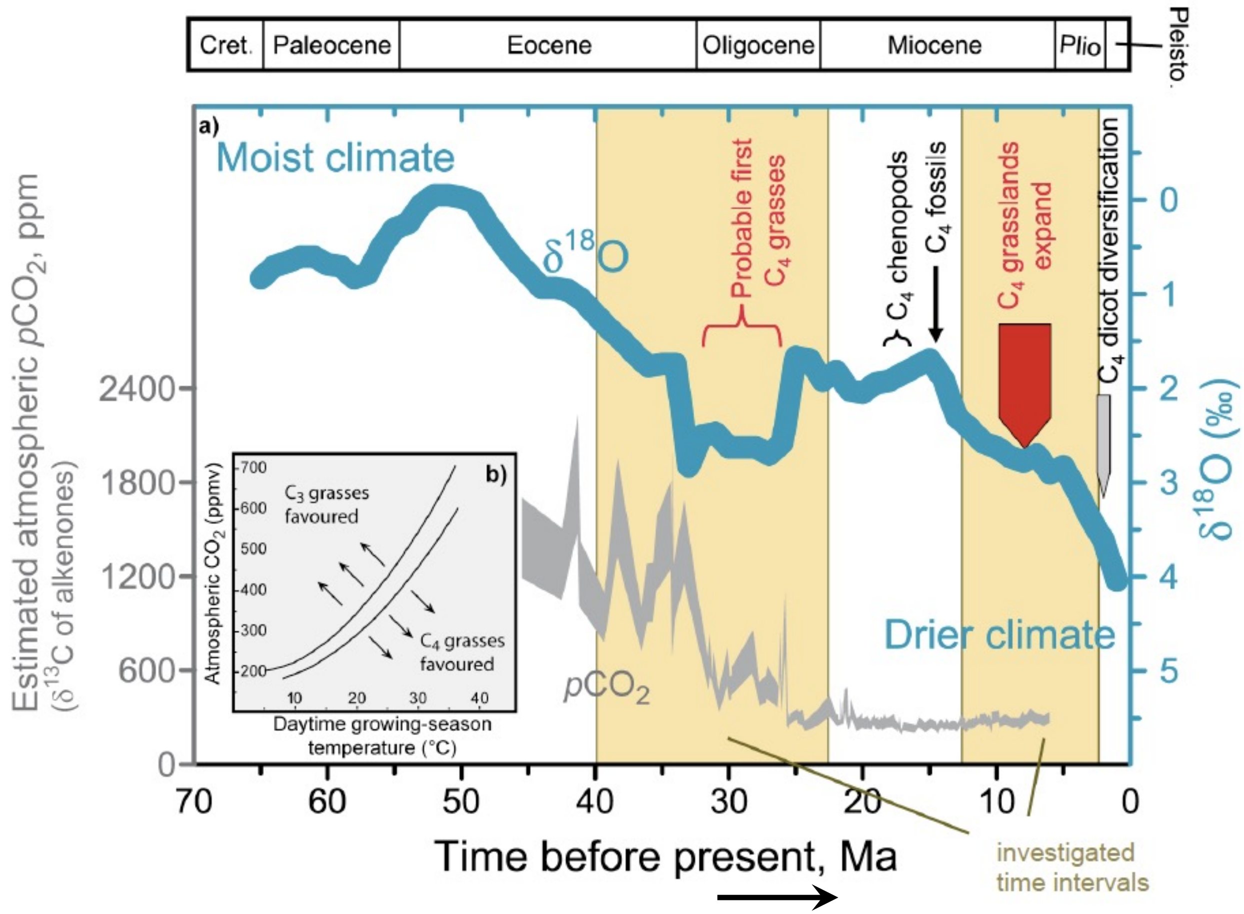


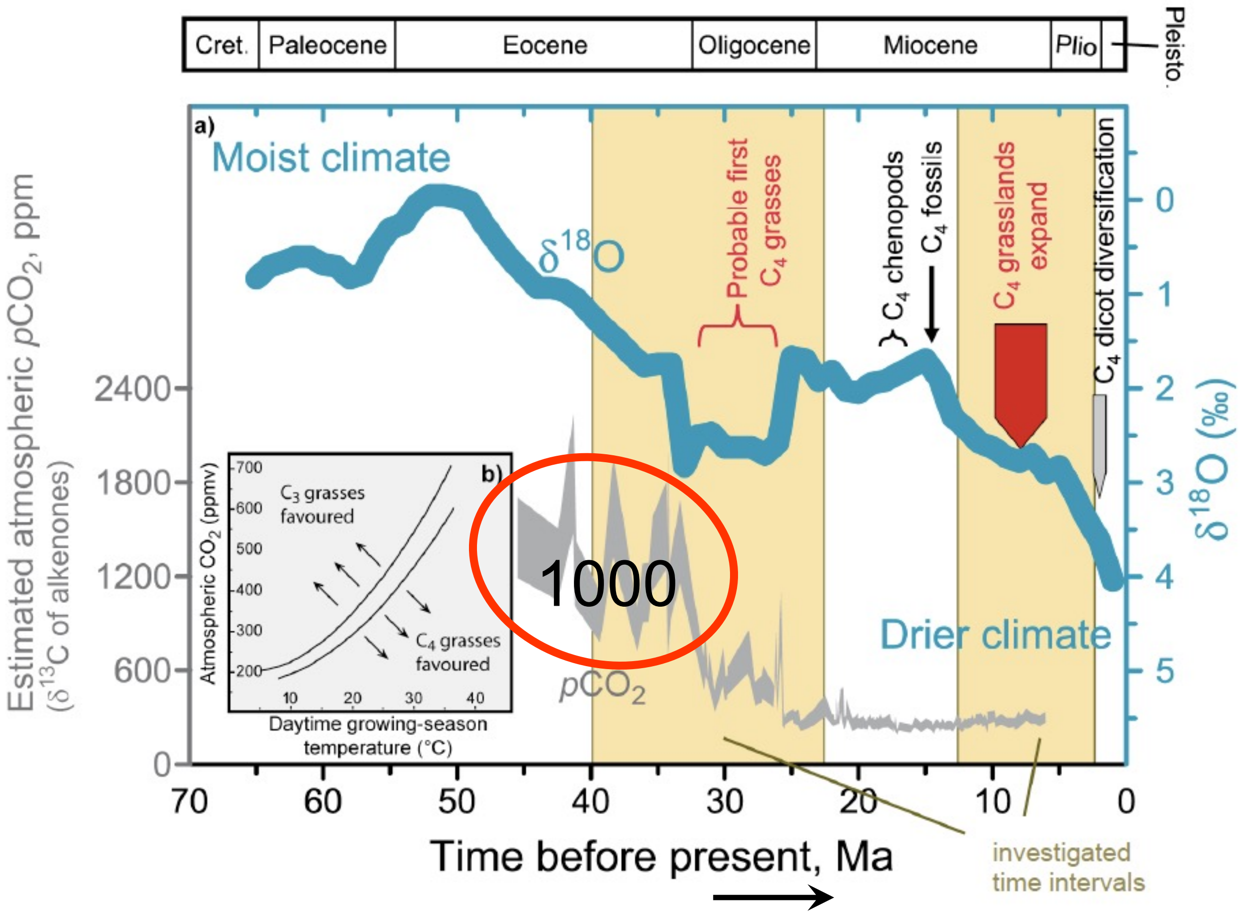
Proxy estimates of atmospheric pCO2 *(Pearson & Palmer 2000; Pagani et al. 1999, 2005)*

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

Climate warming `backward´

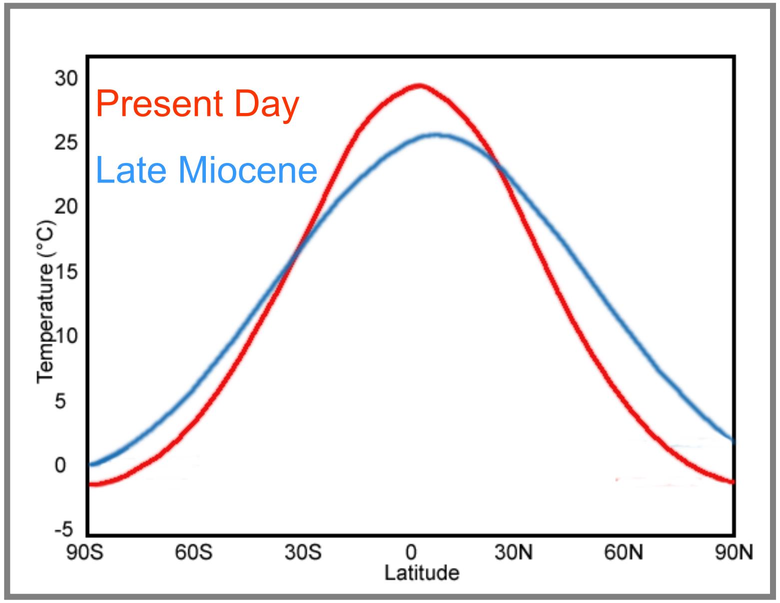


Climate warming `backward´



Flat Temperature Gradient

Reason?

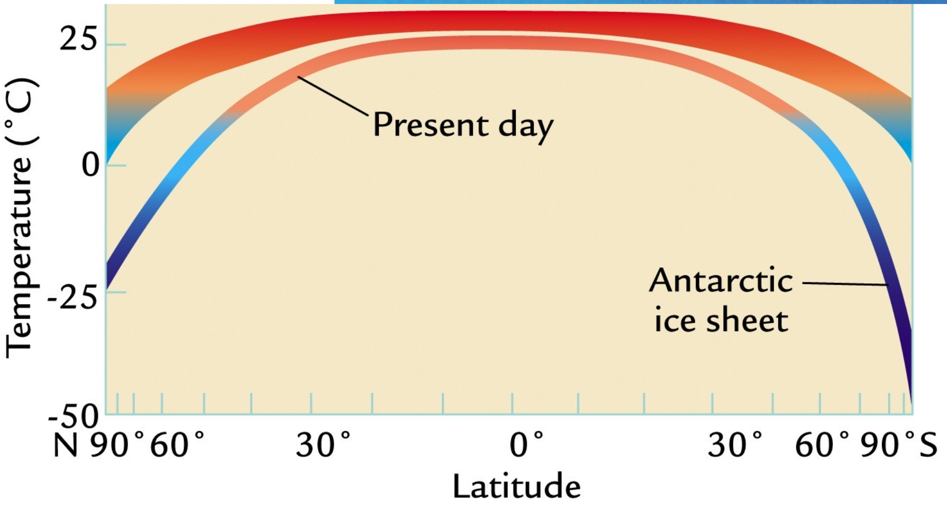


Crowley

Steppuhn et al., 2006

Many authors


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


25
0
-25
-50
Temperature (°C)
Present day
Antarctic ice sheet
N 90° 60°
30°
0°
30°
60° 90°S
Latitude

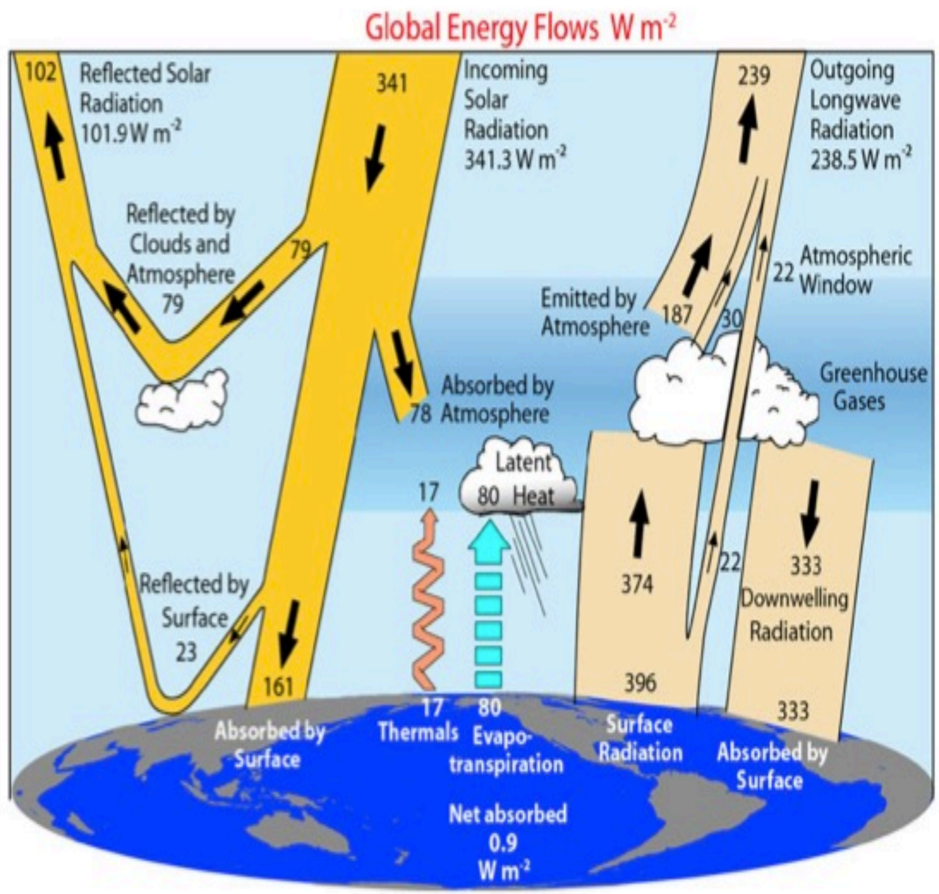

Evidence for a temperate rainforest near the South Pole 90 million years ago
High stakes at sea
Will treaty to protect ocean resources hamper research?
Chemical switch
Light turns neutral radical into powerful reducing agent
Behind your back
Visualization of the clock that governs spine formation

Energy Budget

- In steady state, energy follows energy balance model:

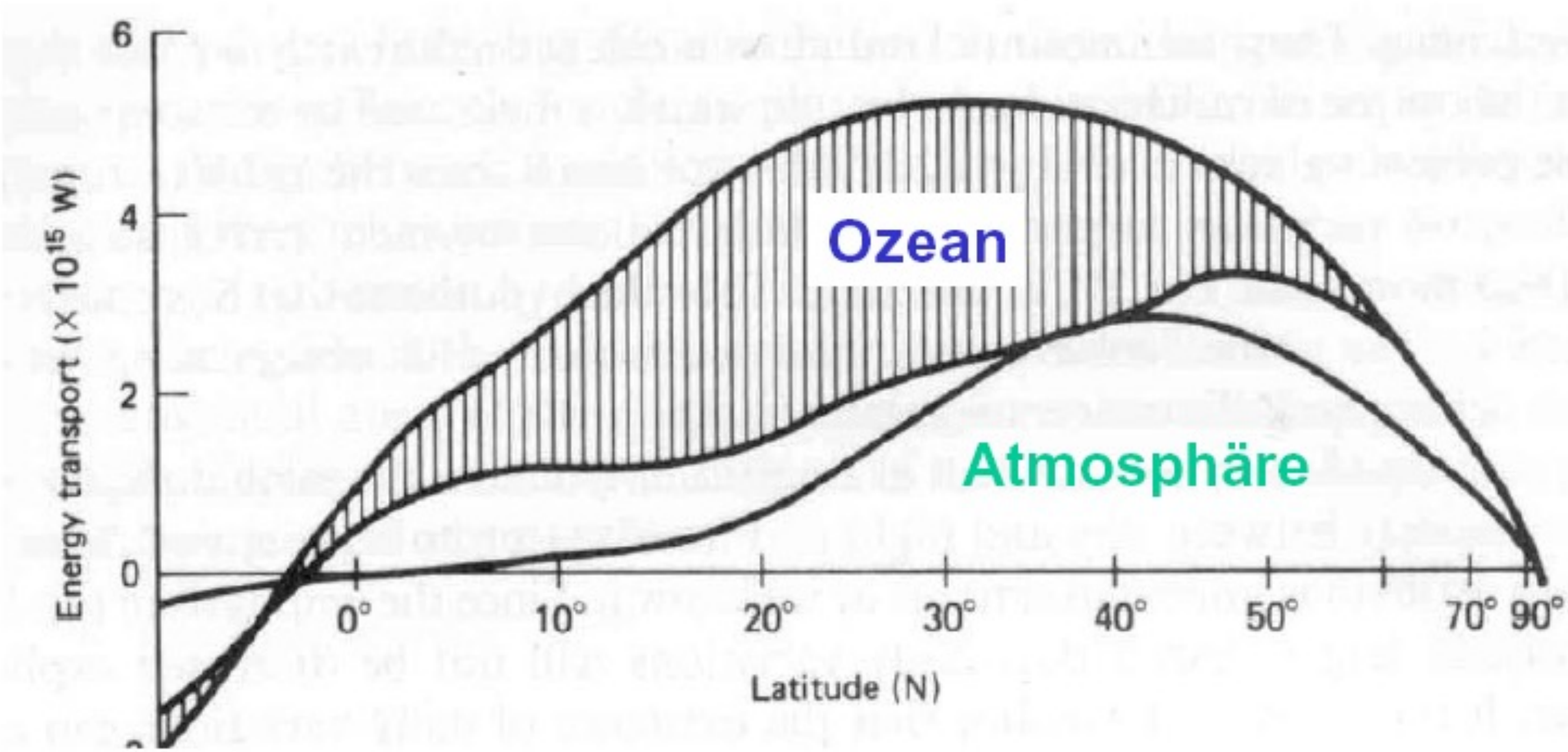
CHANGE IN STORAGE = IN – OUT

- many papers discuss an imbalance in this equation, which results in missing energy



(Trenberth & Fasullo, 2012)

Northward Heat Transport



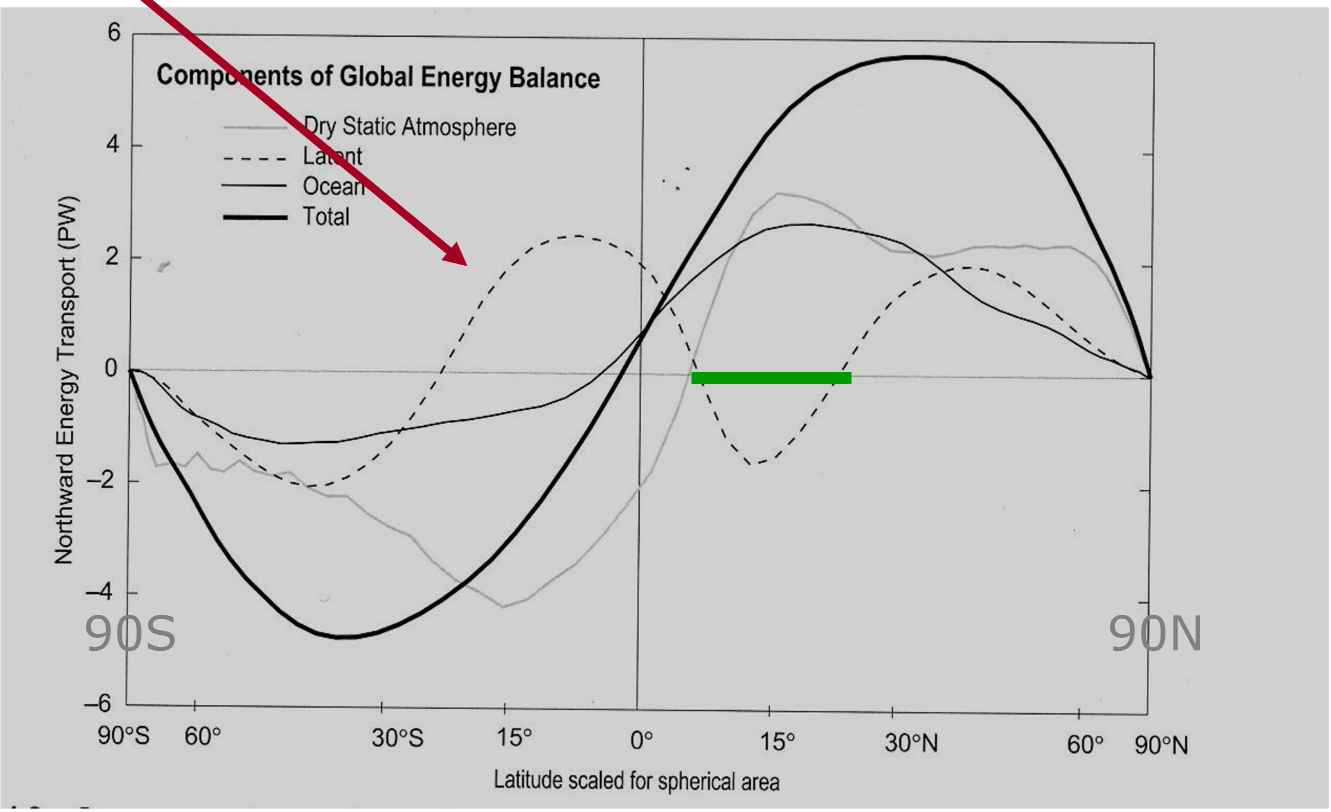
nach Von der Haar & Ort; Quelle: Gill

Global meridional heat transport divides roughly equally into 3 modes:

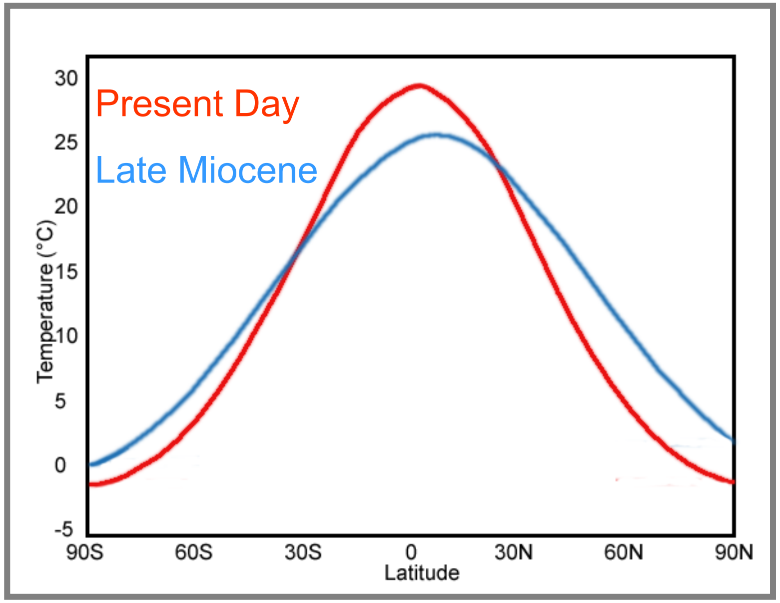
1. atmosphere (dry static energy)
2. ocean (sensible heat)
3. water vapor/latent heat transport

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

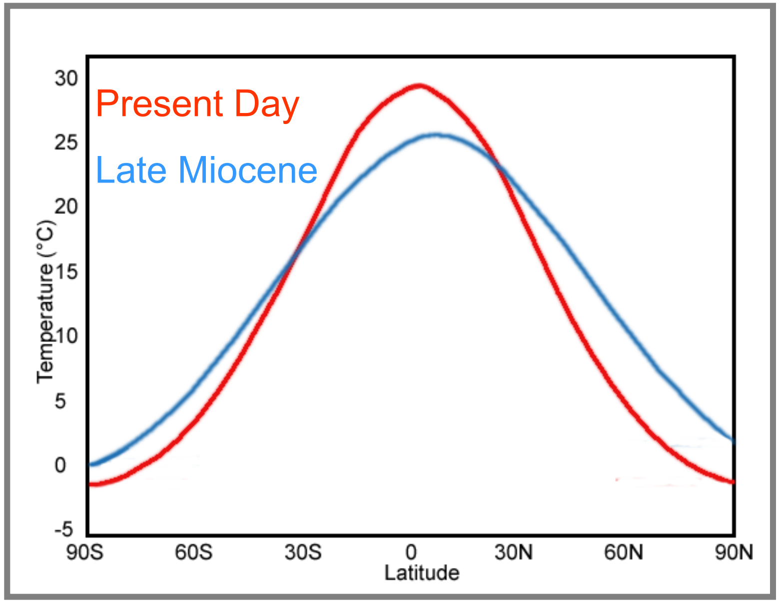
Steppuhn et al., 2006

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



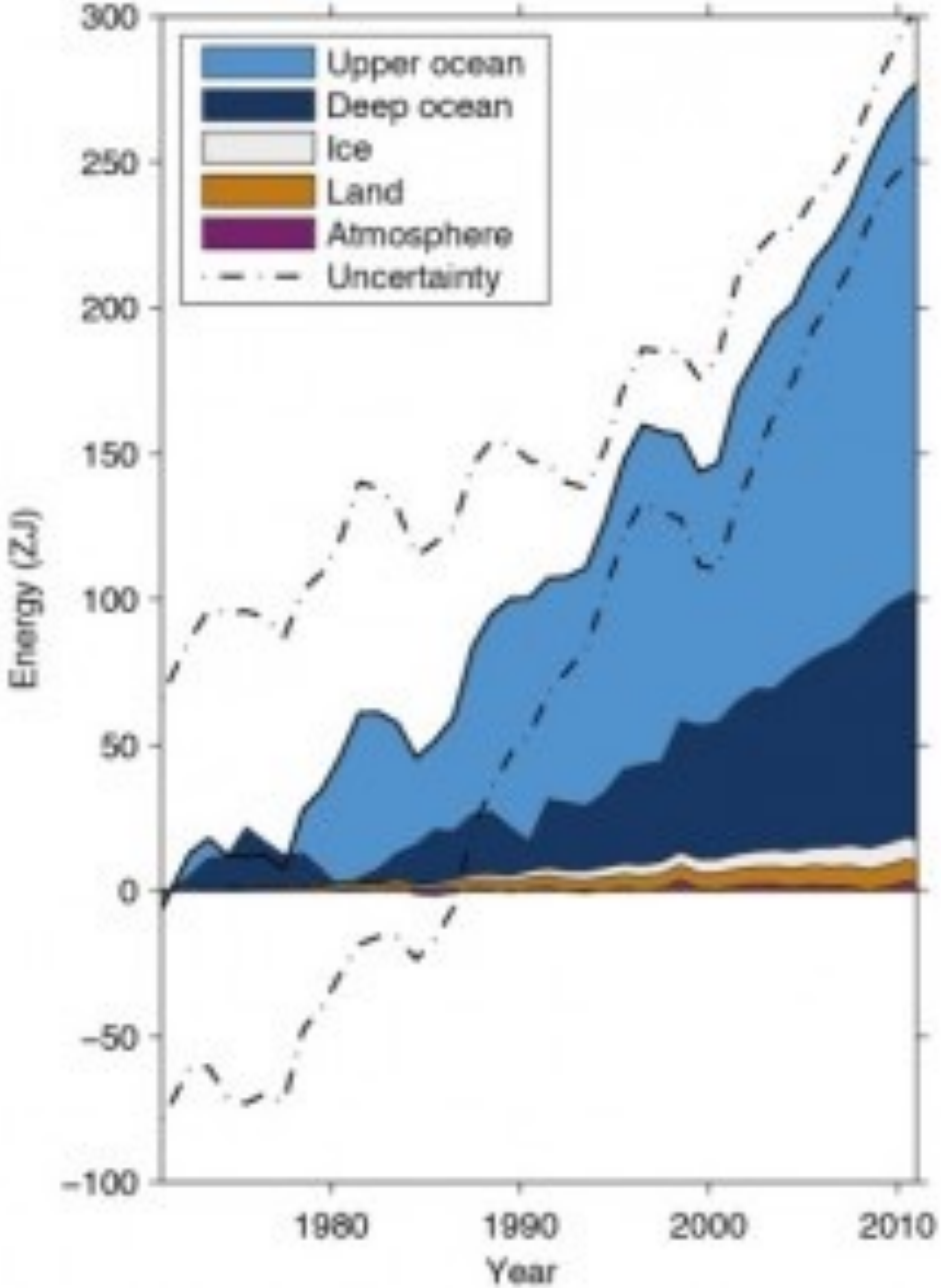
Crowley

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?**



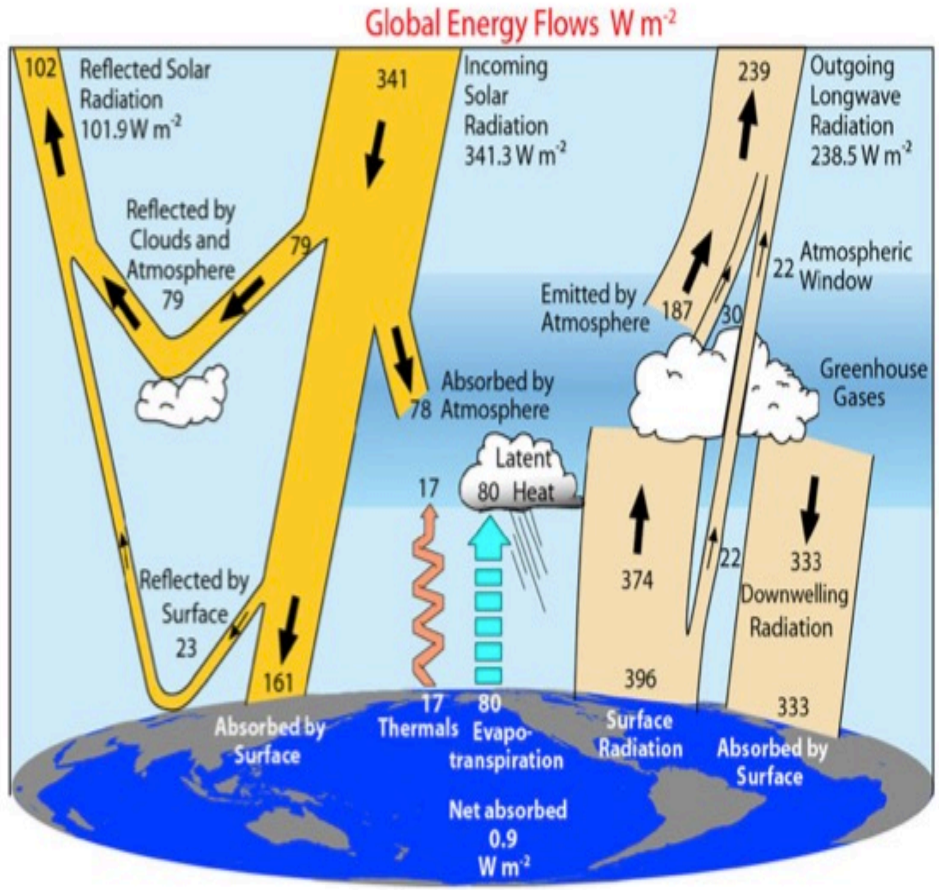
Our current warming

boring for the hundredth time

Energy Budget

CHANGE IN STORAGE = IN – OUT

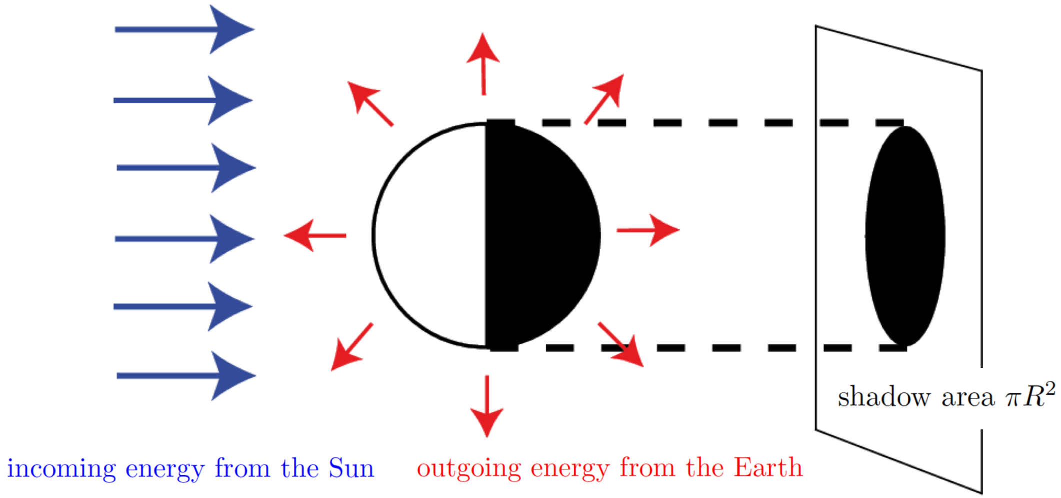
- many papers discuss an imbalance in this equation, which results in missing energy



(Trenberth & Fasullo, 2012)

Energy balance model

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



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

boring for the hundredth time, but …

$$C_p \partial_t T = \nabla \cdot HT + (1-\alpha)S(\varphi, t) - \epsilon\sigma T^4$$

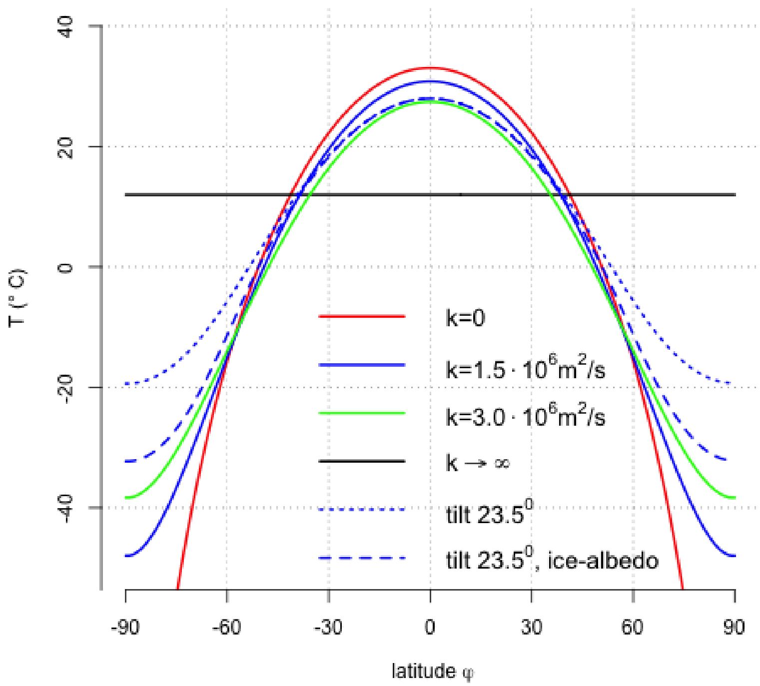
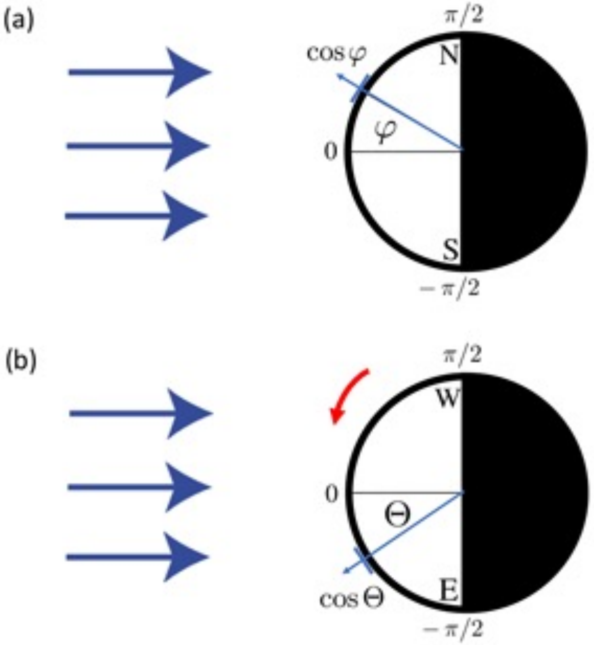


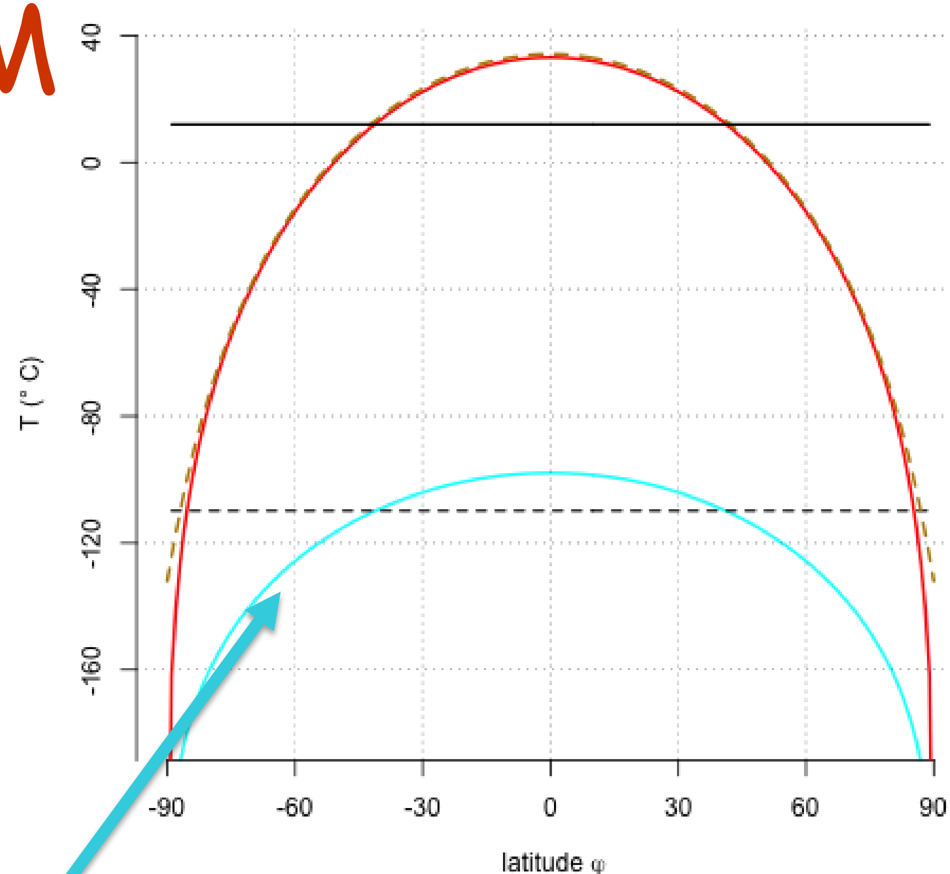
Figure 4. Equilibrium temperature of (15) using different diffusion coefficients. The blue lines use $1.5 \cdot 10^6 m^2/s$ with no tilt (solid line), a tilt of 23.5° (dotted line), and as the dashed line a tilt of 23.5° and ice-albedo feedback using the respresentation of Sellers (1969). Except for the dashed line, the global mean values are identical to the value calculated in (12). Units are °C.

$$HT = -k\nabla T$$

In the exercise, long-wave radiation as A + BT



EBM



$$\overline{T} = \frac{1}{2}\int_{-\pi/2}^{\pi/2} T(\varphi)\cos\varphi\, d\varphi$$

$$= \frac{1}{2}\frac{\Gamma(5/8)}{\sqrt{2\pi}\,\Gamma(9/8)}\cdot\sqrt[4]{\frac{(1-\alpha)S}{4\epsilon\sigma}}\underbrace{\int_{-\pi/2}^{\pi/2}(\cos\varphi)^{5/4}d\varphi}_{\sqrt{\pi}\,\Gamma(9/8)/\Gamma(13/8)}$$

$$= \underbrace{\frac{1}{2}\frac{1}{\sqrt{2}}\frac{\Gamma(5/8)}{\Gamma(13/8)}}\cdot\sqrt[4]{\frac{(1-\alpha)S}{4\epsilon\sigma}}.$$

$$\frac{\sqrt{2}}{4}\frac{8}{5} = 0.4\sqrt{2}$$

Heat capacity of the climate system

Fast rotation

Lohmann, 2020

https://esd.copernicus.org/articles/11/1195/2020/esd-11-1195-2020.pdf

Practical Jan 11, 2022

Exercise

EBM analysis

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