Climate science

Climate variability across time scales: challenges from limited data & modeling

MarData course 2020

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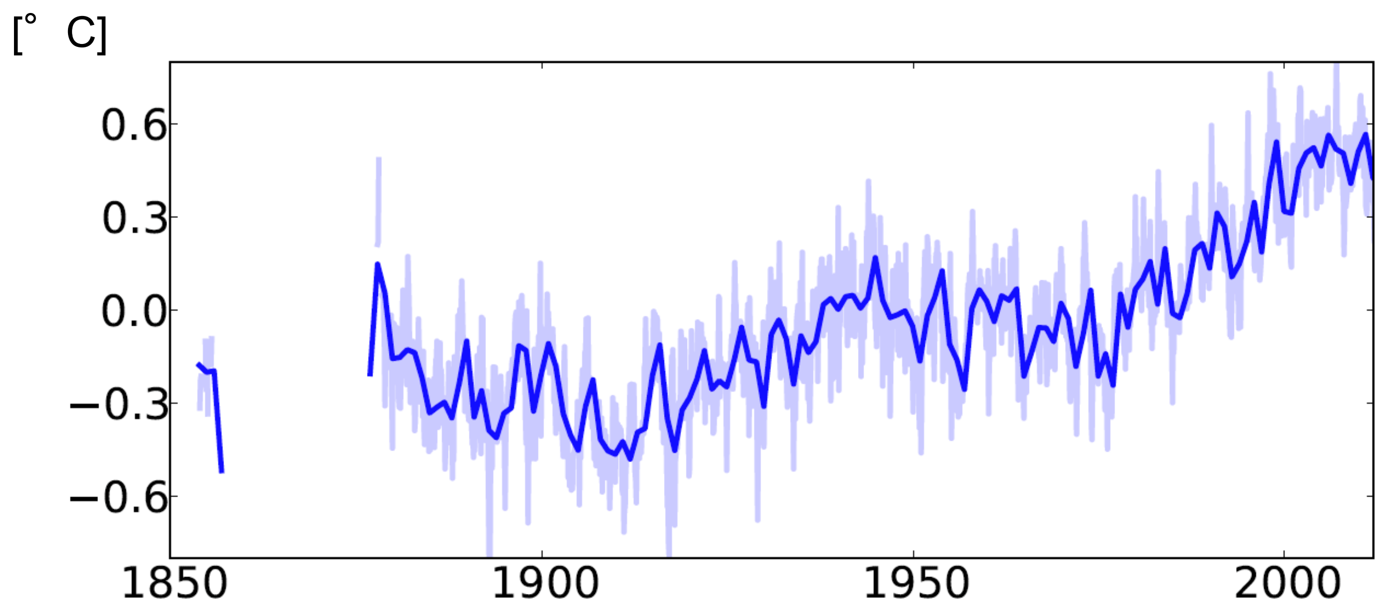
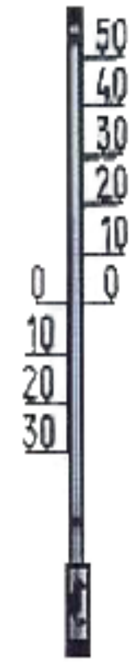
Climate Trends at different Timescales

Temperature of the last **150 years** (instrumental data)

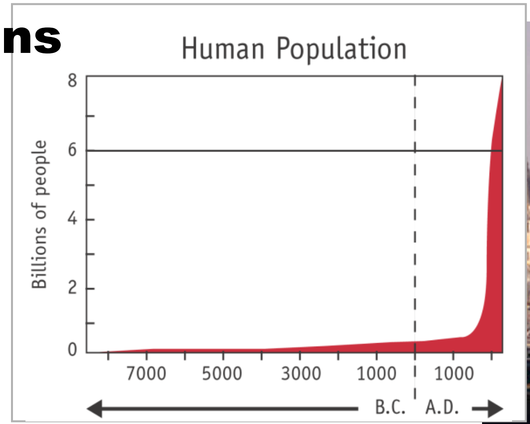
Northern Hemisphere Temp. anomaly

HadCRU



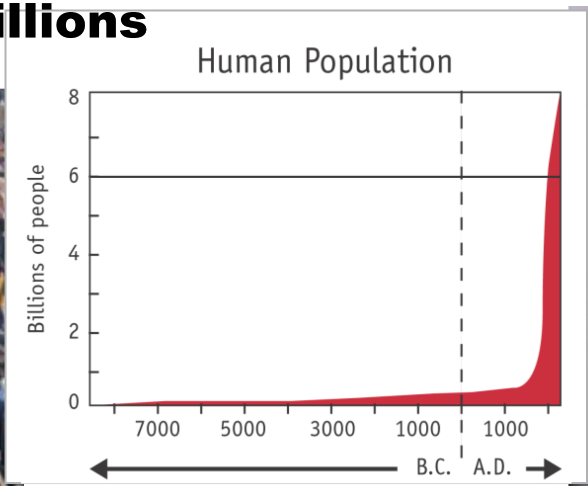


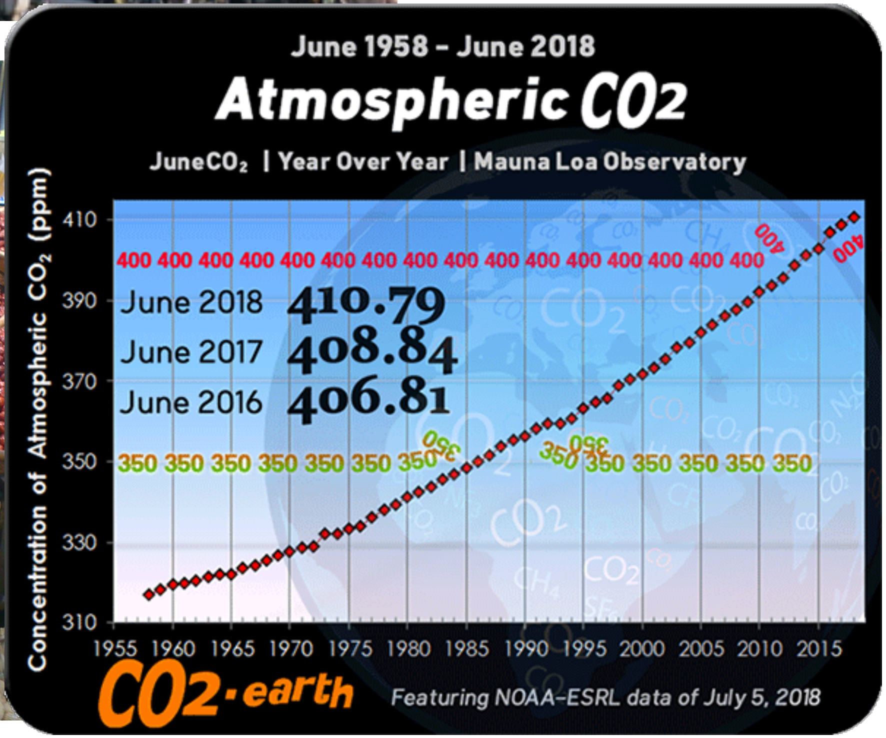
Human Population: 7 billions



Challenges: Food, Energy, Climate

Human Population: 7 billions



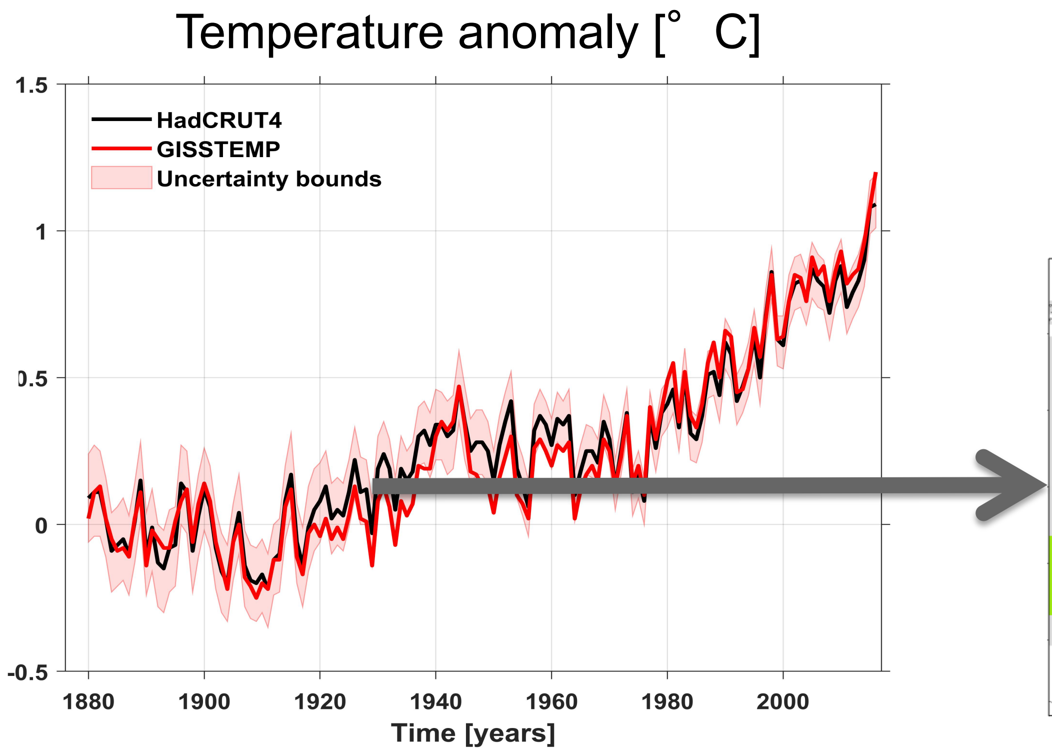


CO_2 Increase:

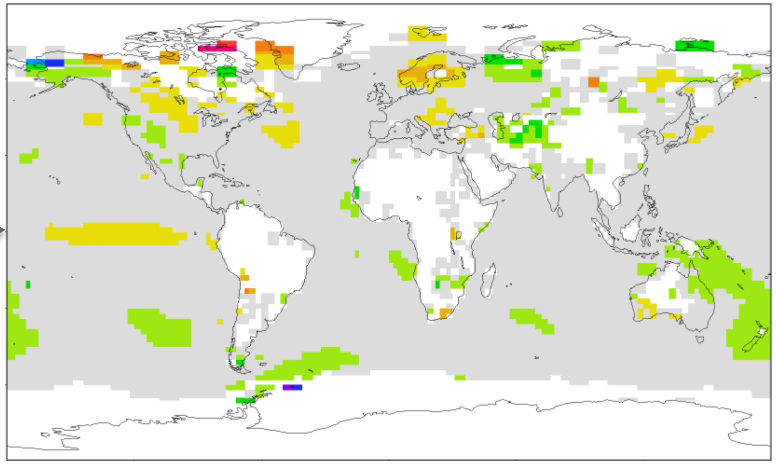
Land cover: 22%

CO_2-Emissions: 78%

Motivation: Observational Record

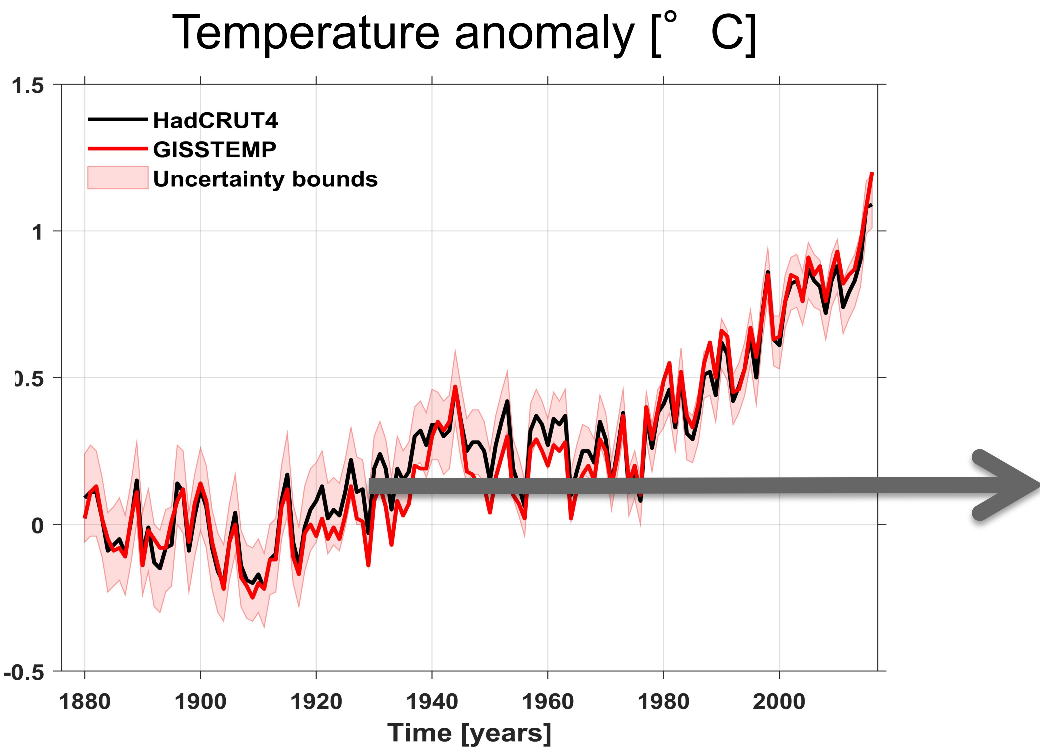


Uncertainty largely due to missing information at high latitudes

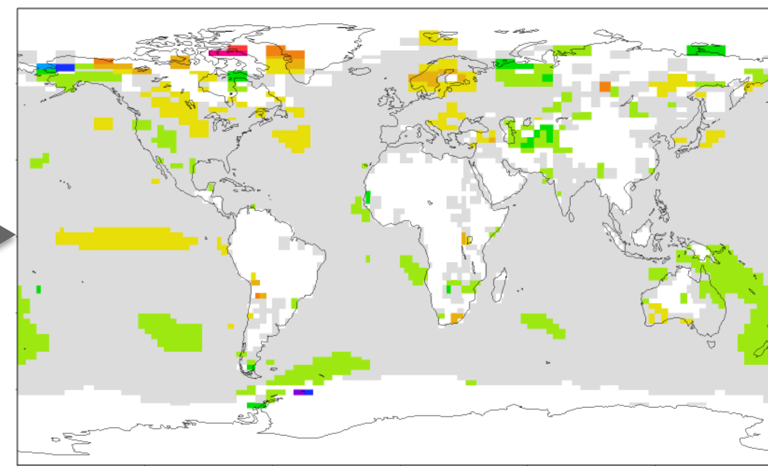


Temperature Anomaly 1930
White areas: not enough data

Motivation: Observational Record

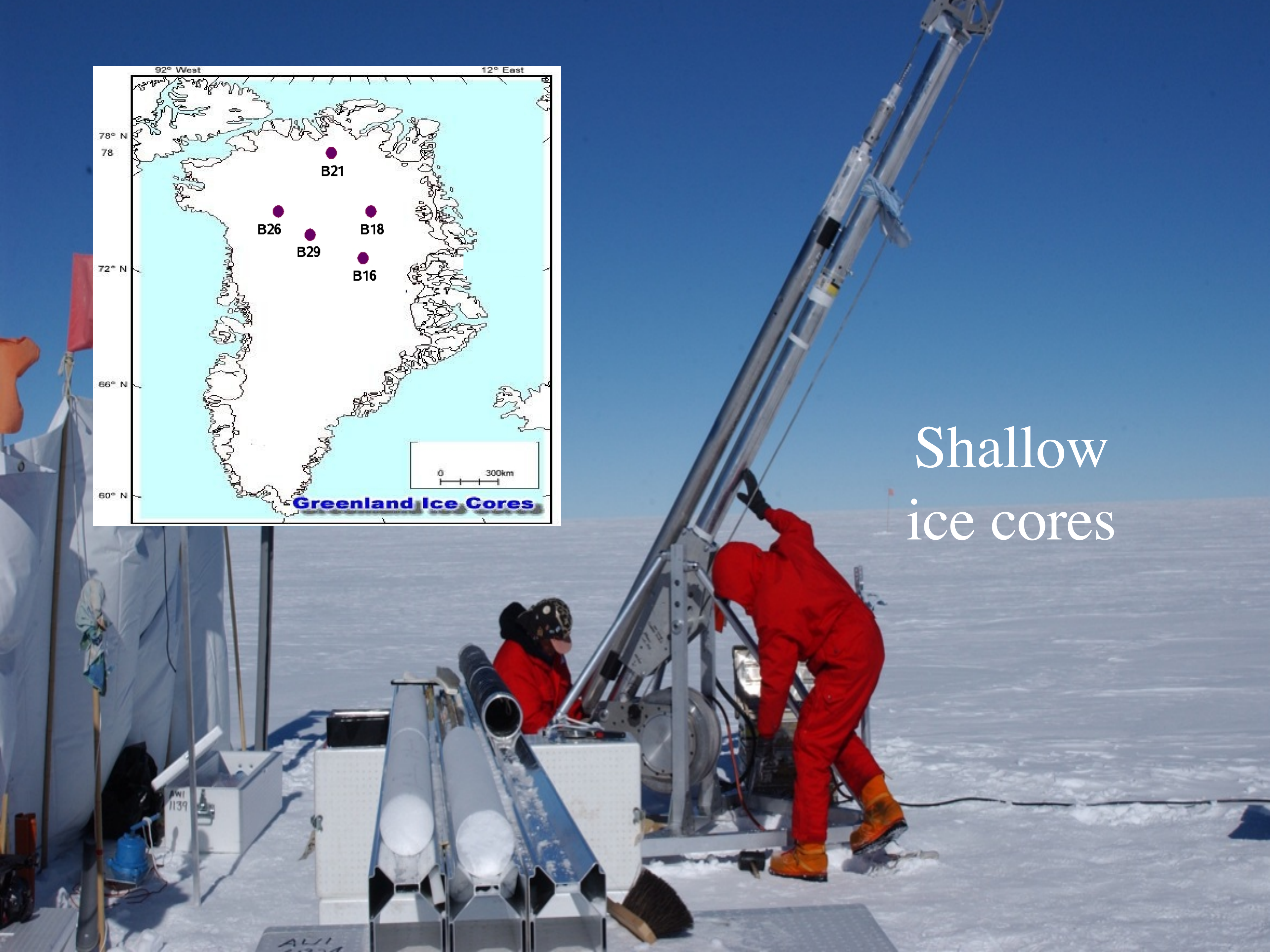


Uncertainty largely due to missing information at high latitudes



Temperature Anomaly 1930
White areas: not enough data

Climate variability beyond the instrumental record: Decadal, centennial, millennial


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
AWI
1139

History

last **1000 Years**

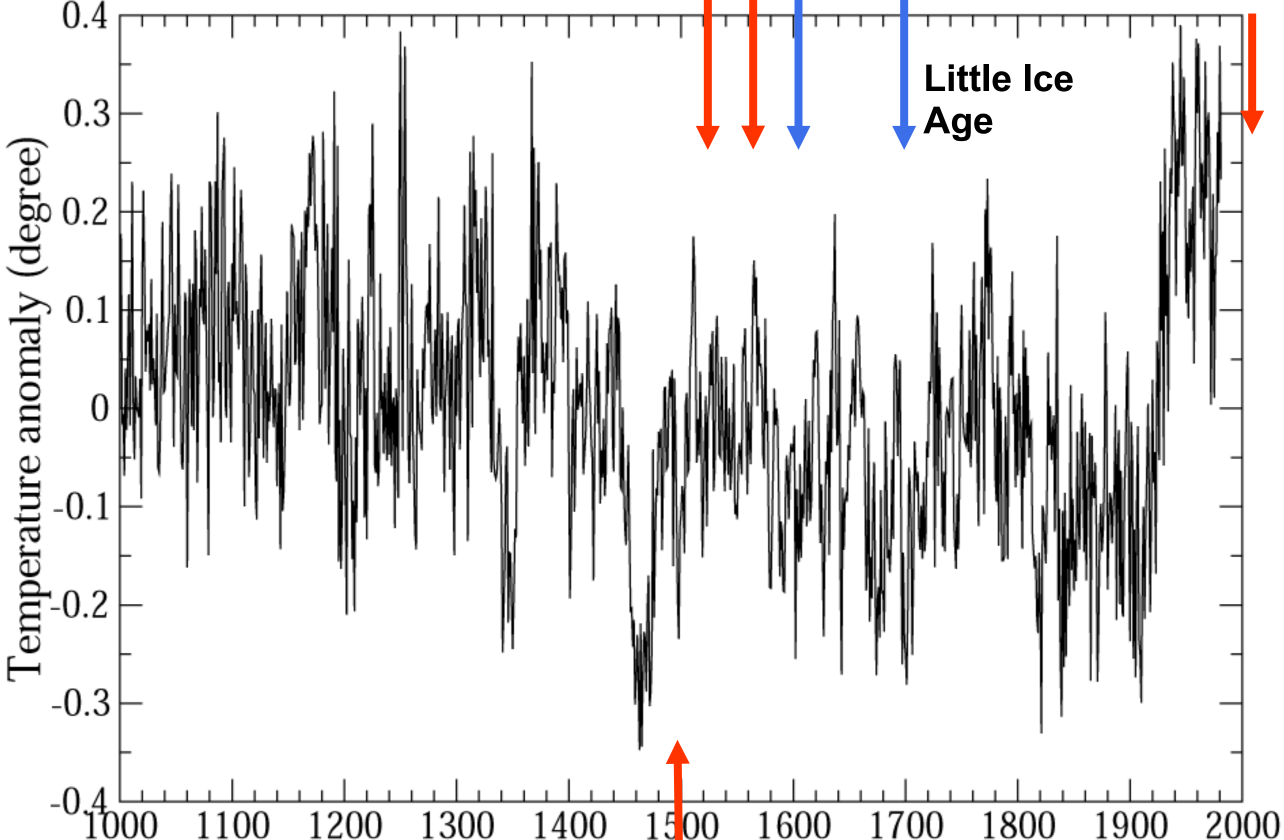
Thermometer

Barometer (Torricelli)

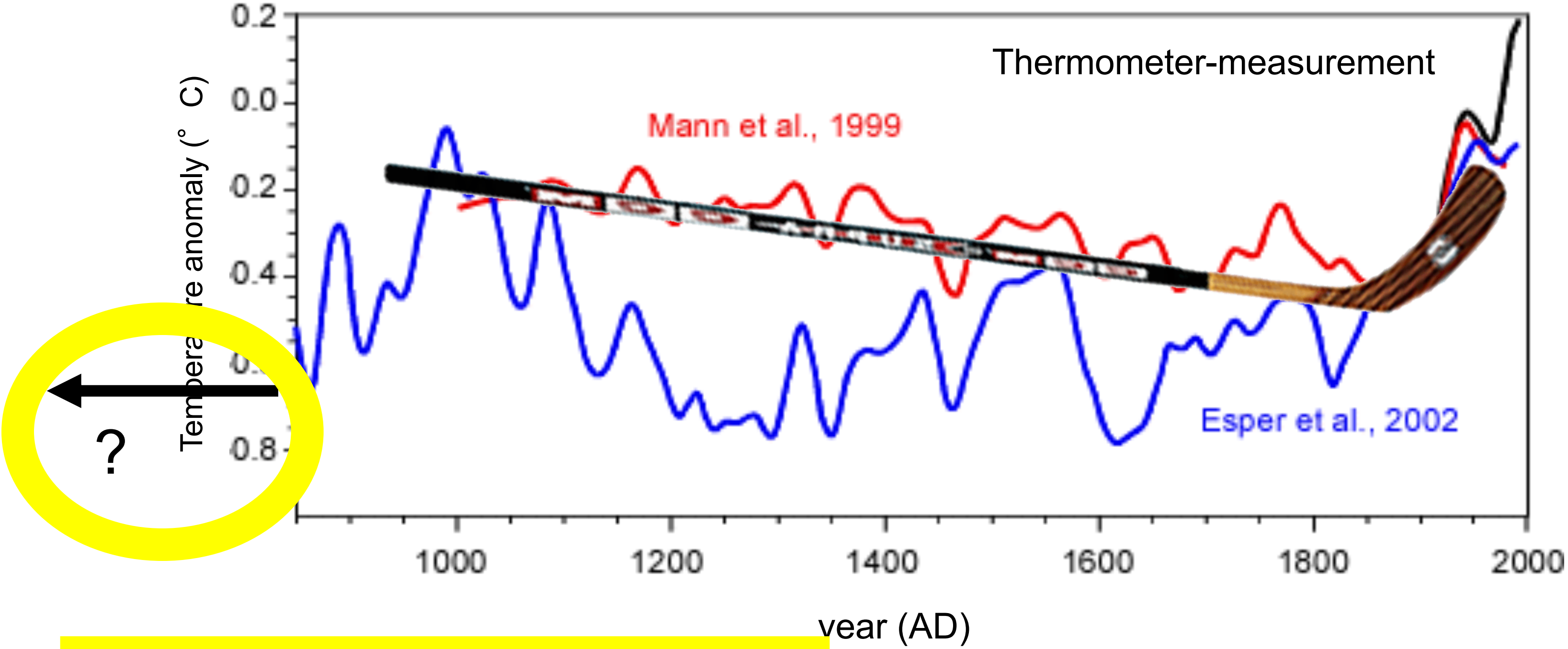
Pieter Breughel d.Ä.

Little Ice Age

present



Nicolaus Kopernikus



Further back in time?

Proxy Data

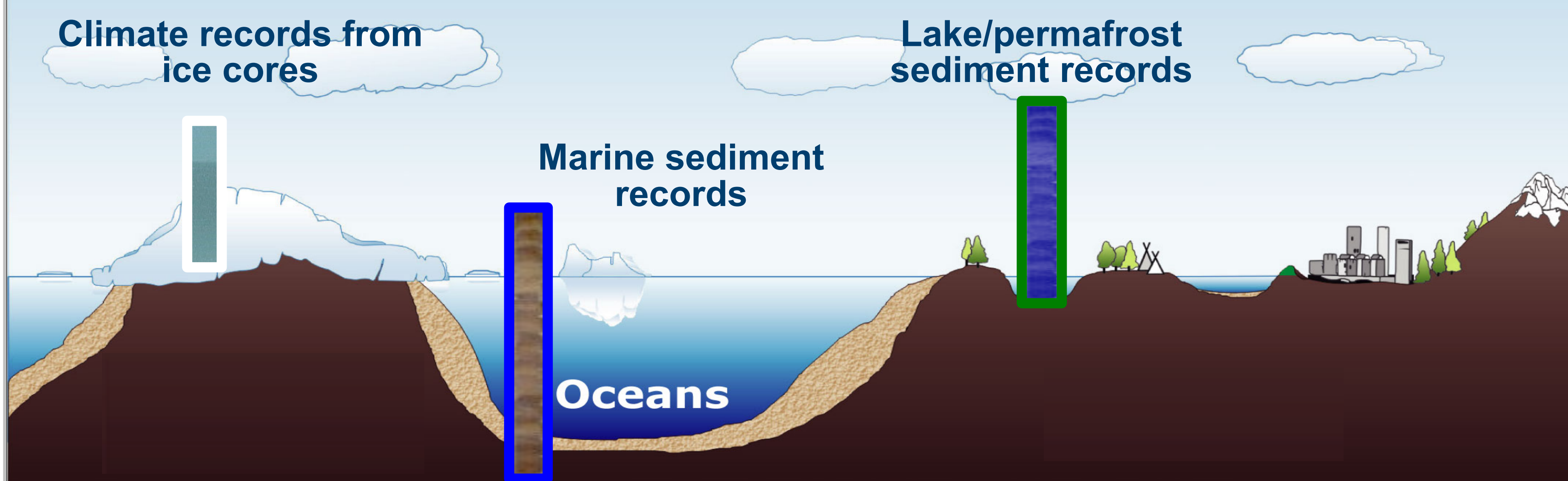
- Indirect data, often qualitative
- Long time series from archives
- Information beyond the instrumental record

Data in the Earth System

Ice drilling camp, 2009

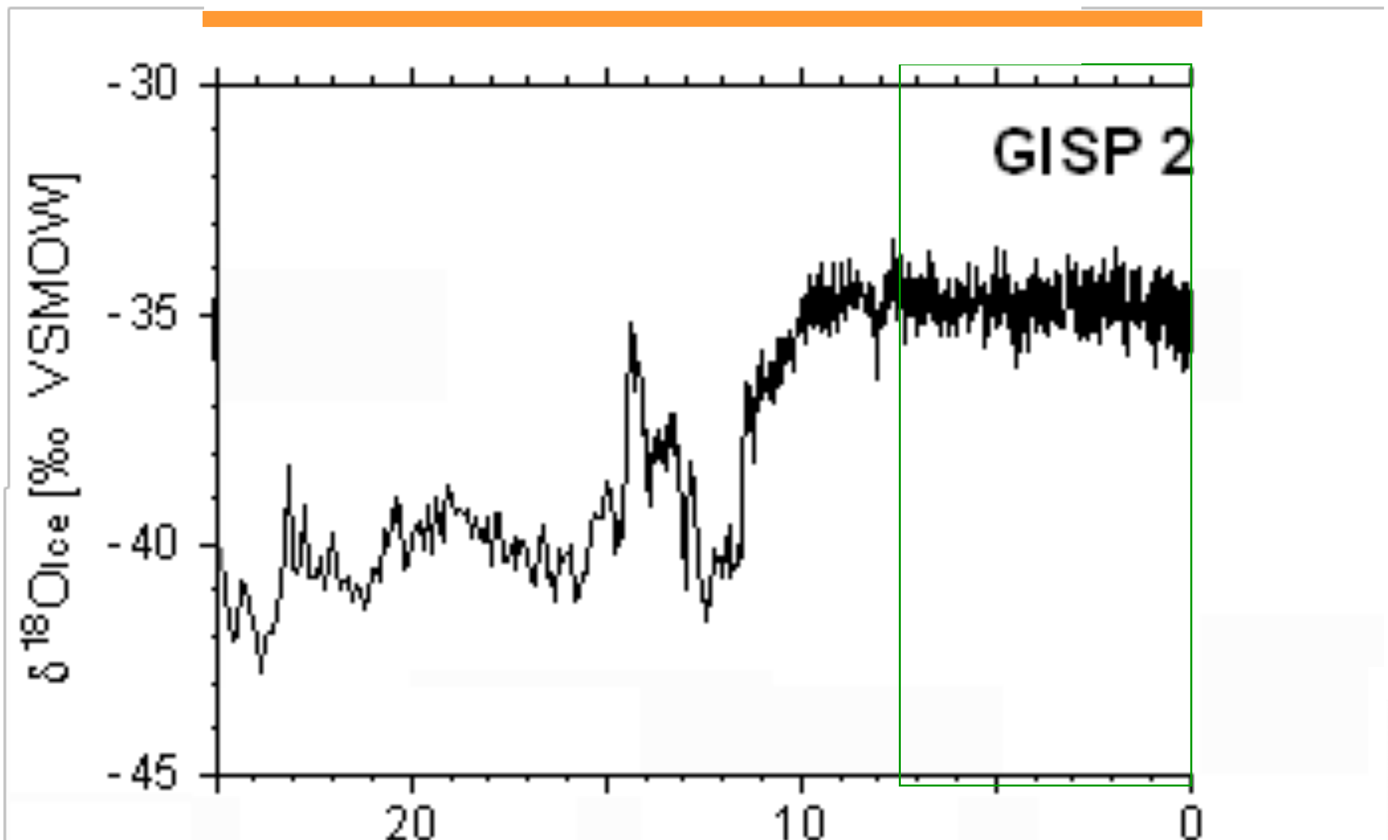
Polarstern, marine sediments

Lake/permafrost sediments

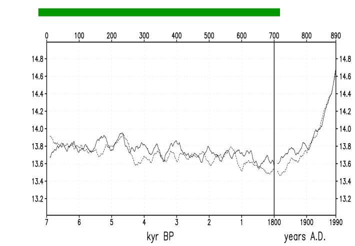


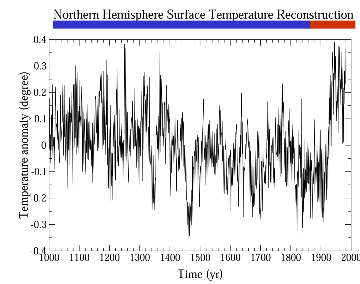
Climate Trends at different Timescales

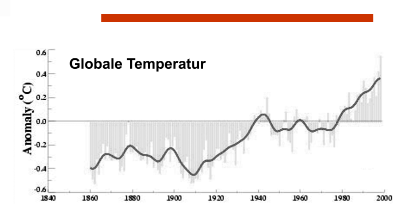
Deglaciation – Greenland ice core

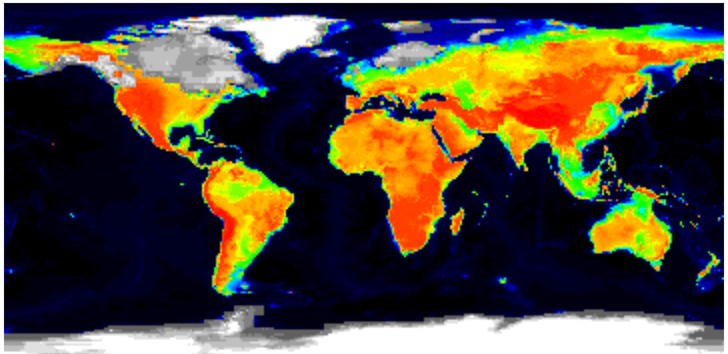


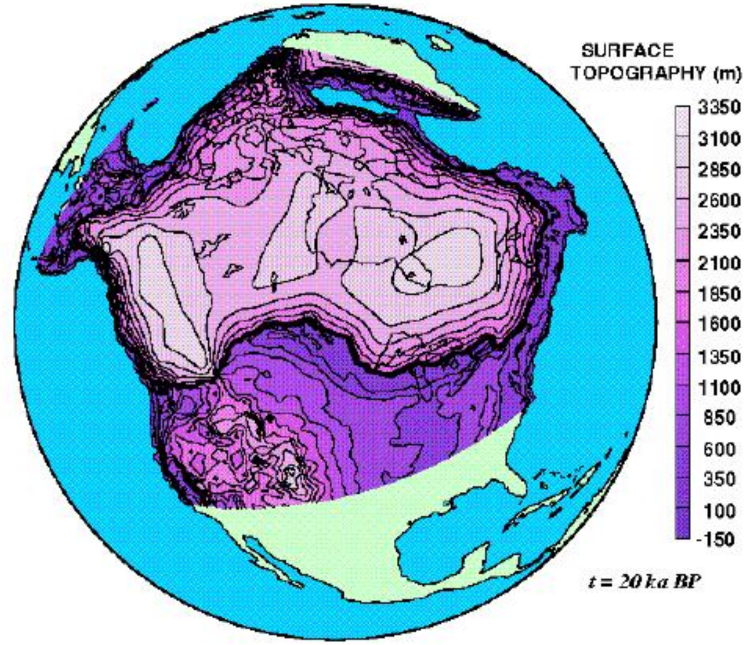
Grootes et al. 2000





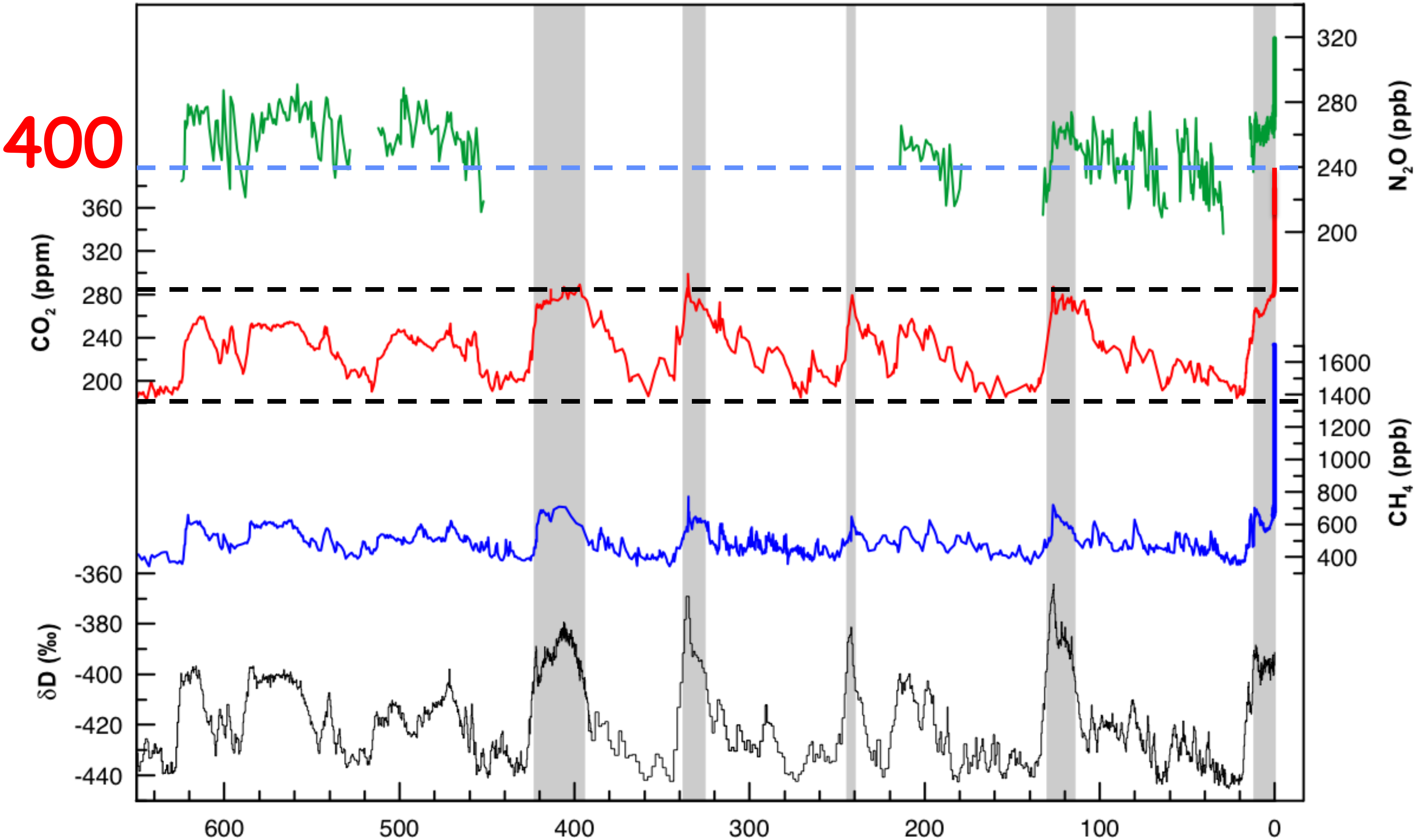






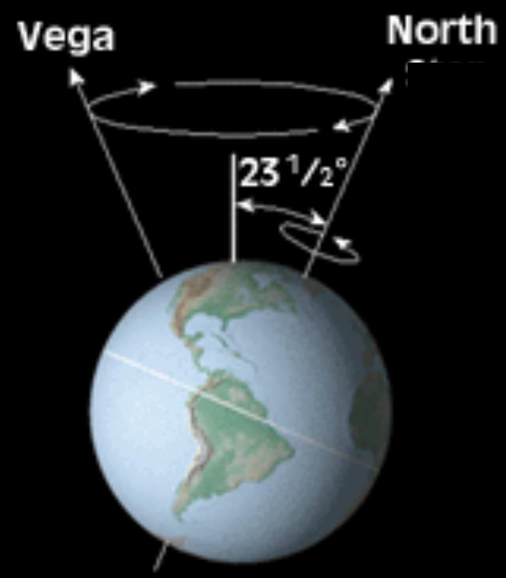
Deglaciation

Atmospheric Gas Concentrations from Ice Cores

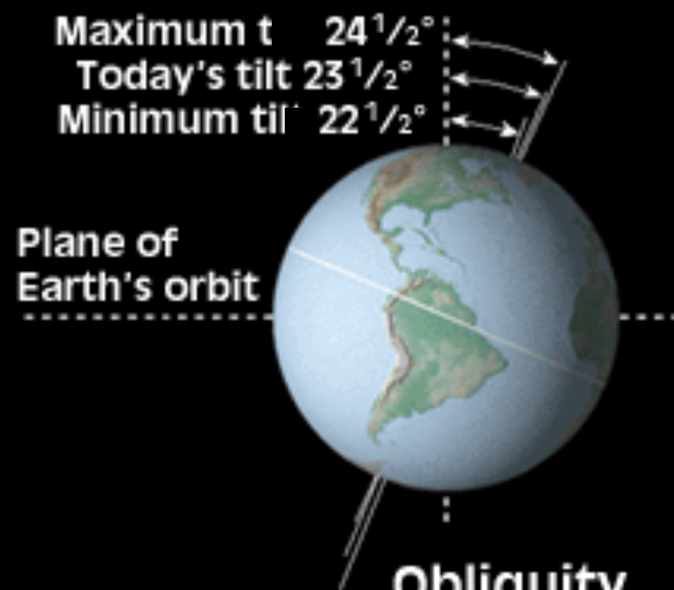


Time (Thousands of Years Before Present)

EPICA 2008



Precession



Obliquity

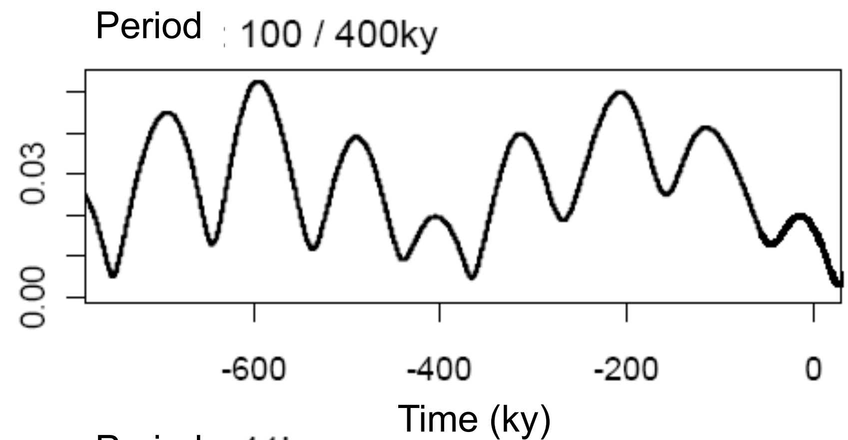
Eccentricity

Questions

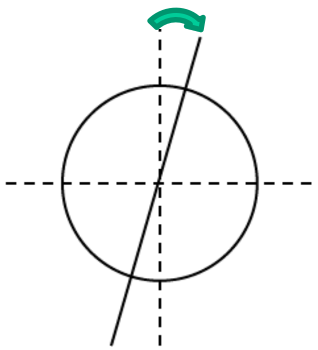
- Response of climate models to forcing?
- Common pattern of data and models?
- Climate sensitivity and variability

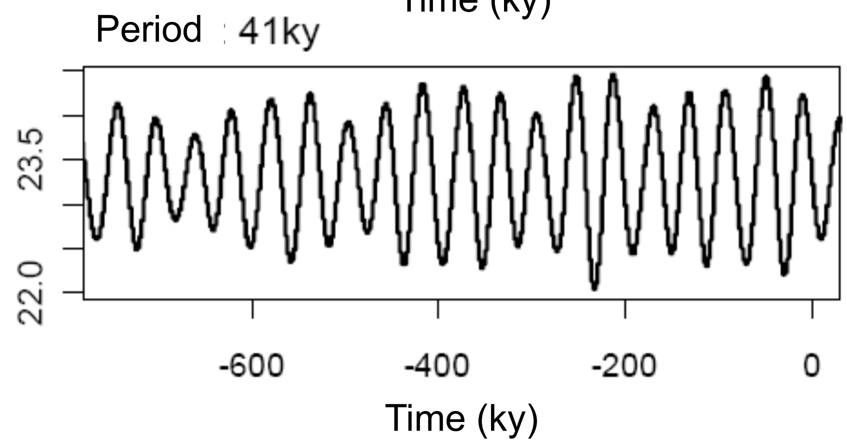
Orbital parameters

Excentricity

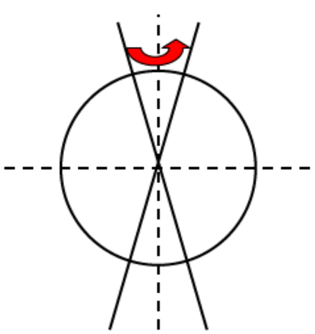


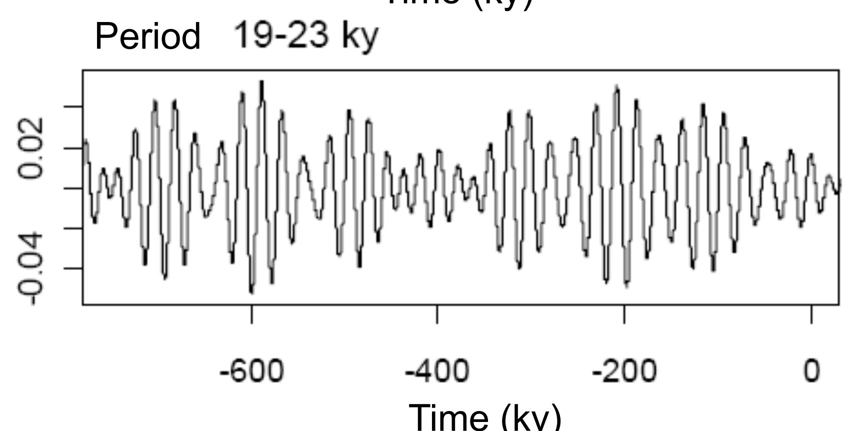
Obliquity





Precession

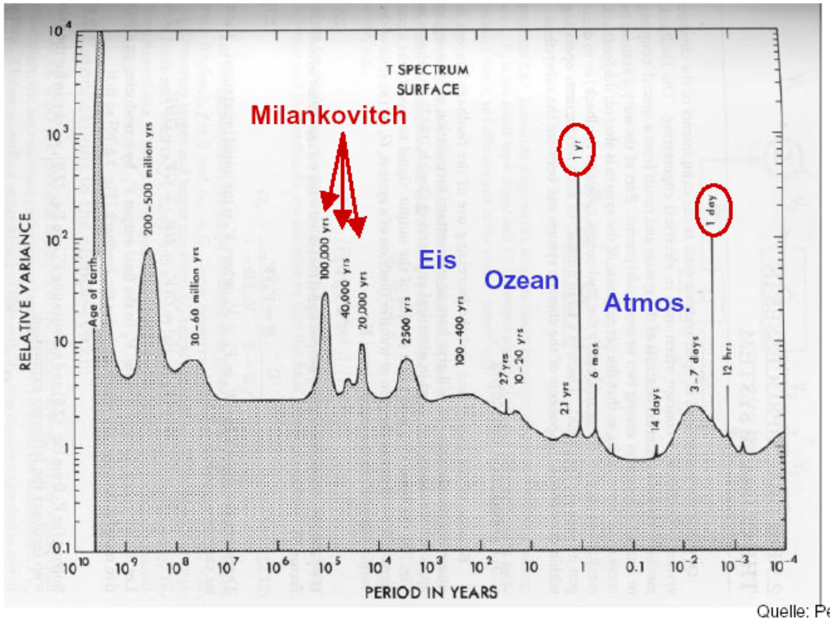




Orbital focing

- ~20.000, ~40.000, ~100.000 years
- 0.5, 1 year

- Geometry of the Sun-Earth configuration

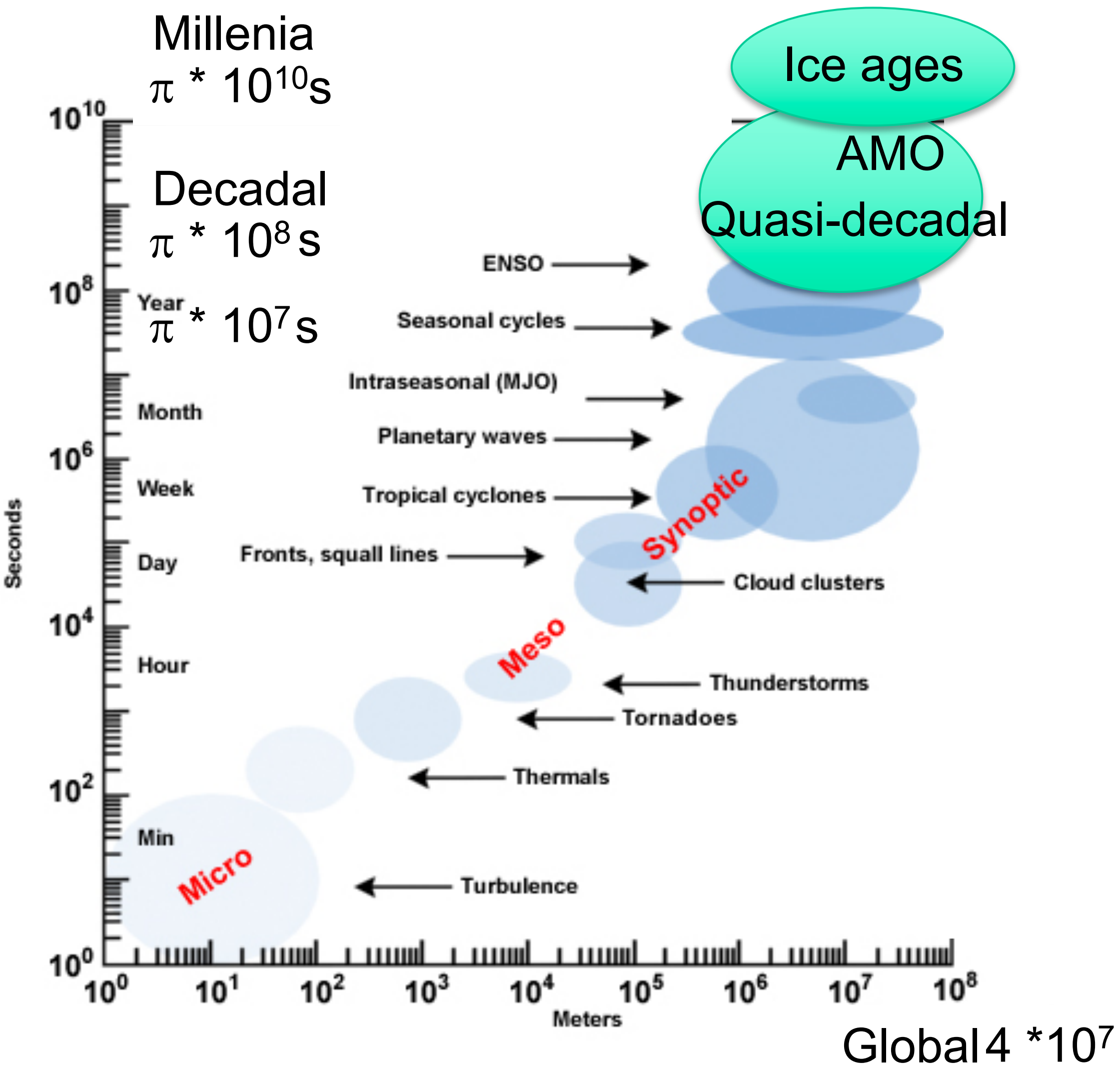


Quelle: Peixoto & Oort

Sunspots Photo: Nasa

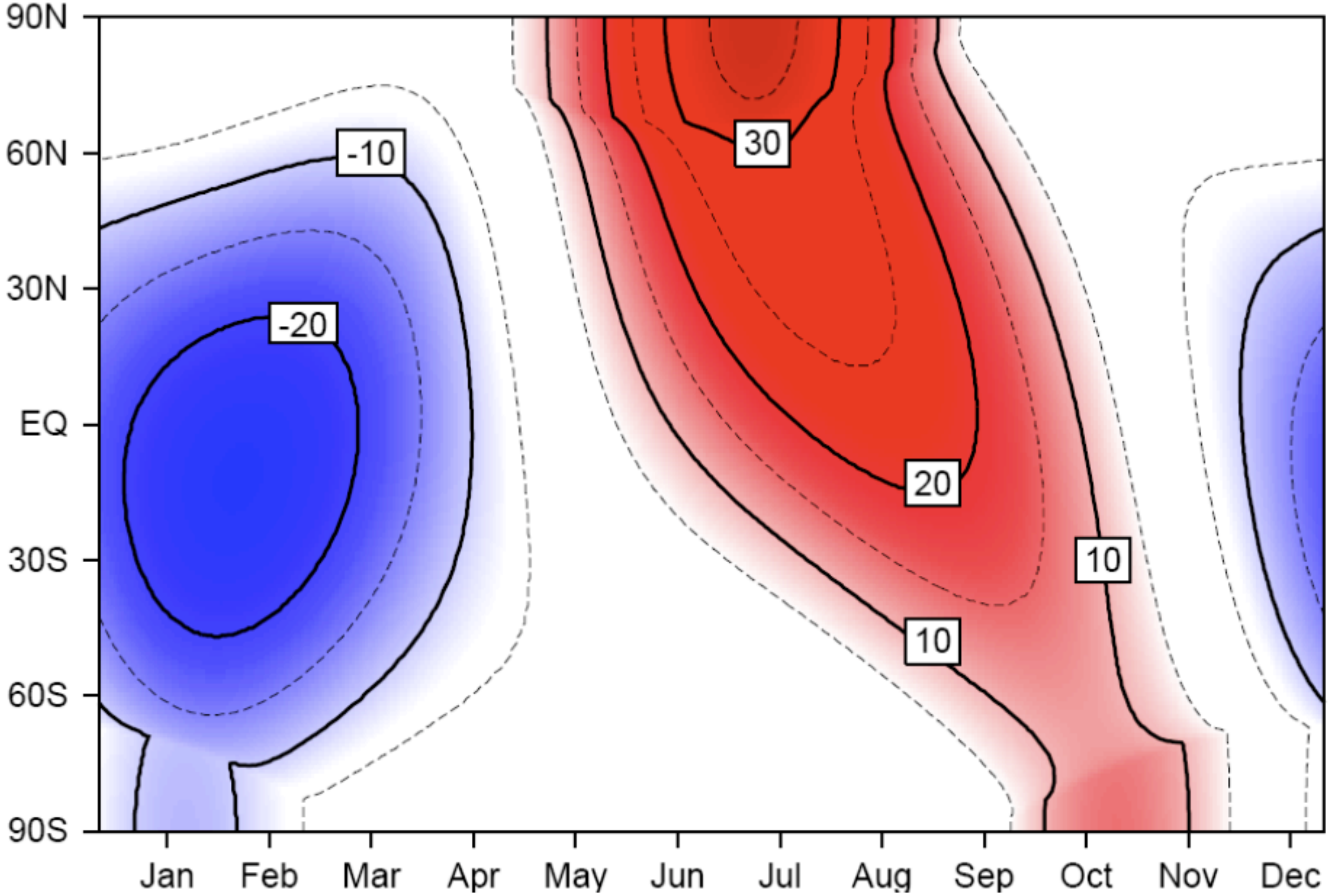
Spatio-Temporal Scales

Dissipative Systems (as atmosphere & ocean) cannot maintain large gradients on long time scales



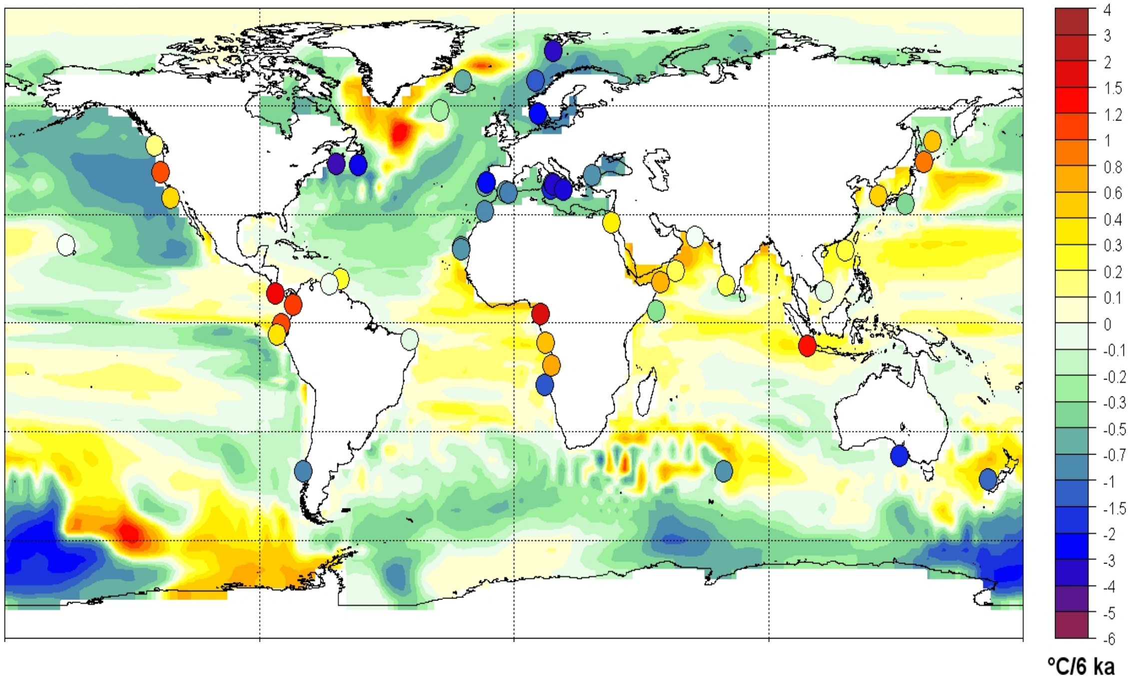
Spatial || temporal Scales

Insolation (6k minus present)



Marine temperature trends (last 6000 years)

Annual mean sea surface temperature trends

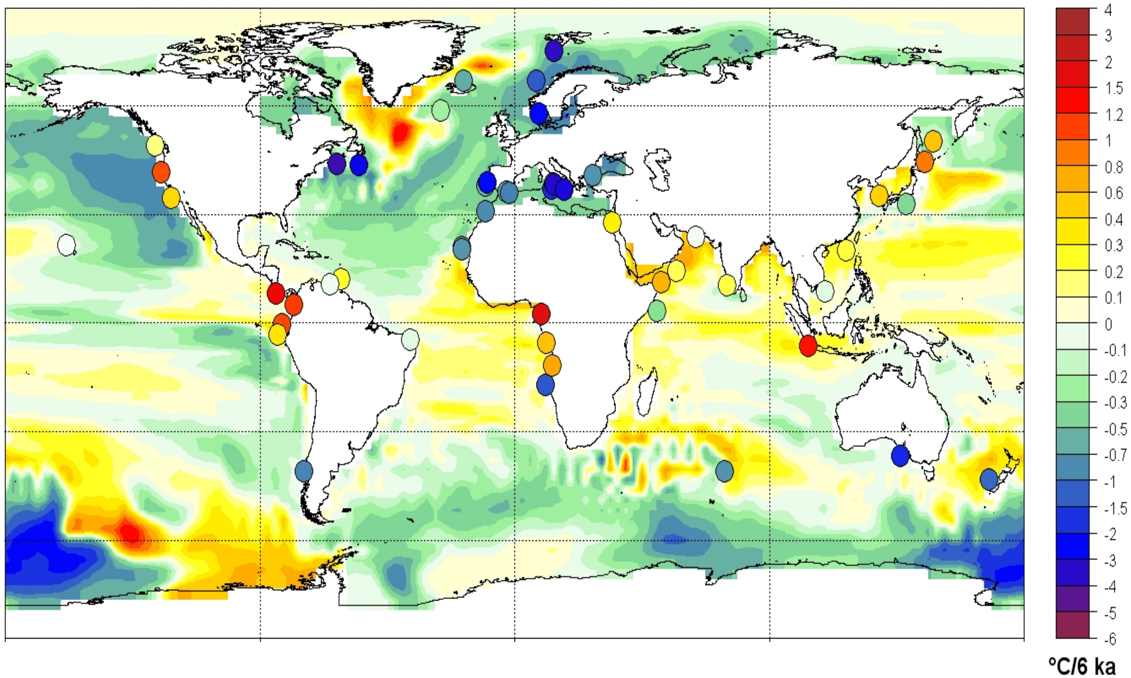


Alkenone-based temperature trends

Lohmann et al., 2013, CP

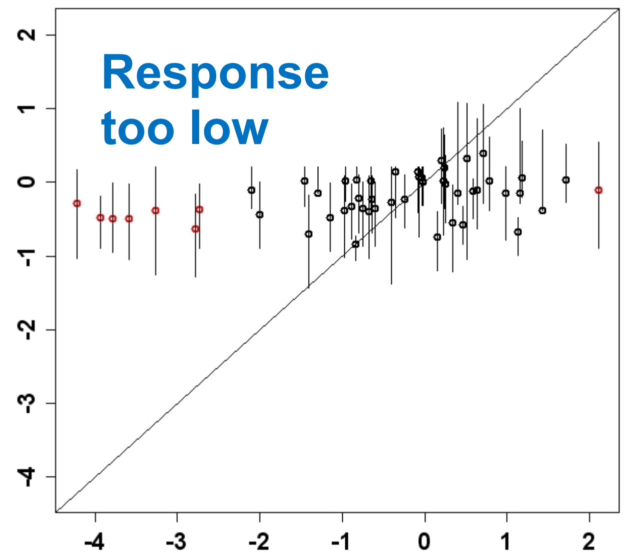
Marine temperature trends (last 6000 years)

Annual mean sea surface temperature trends



Alkenone-based temperature trends

ΔT



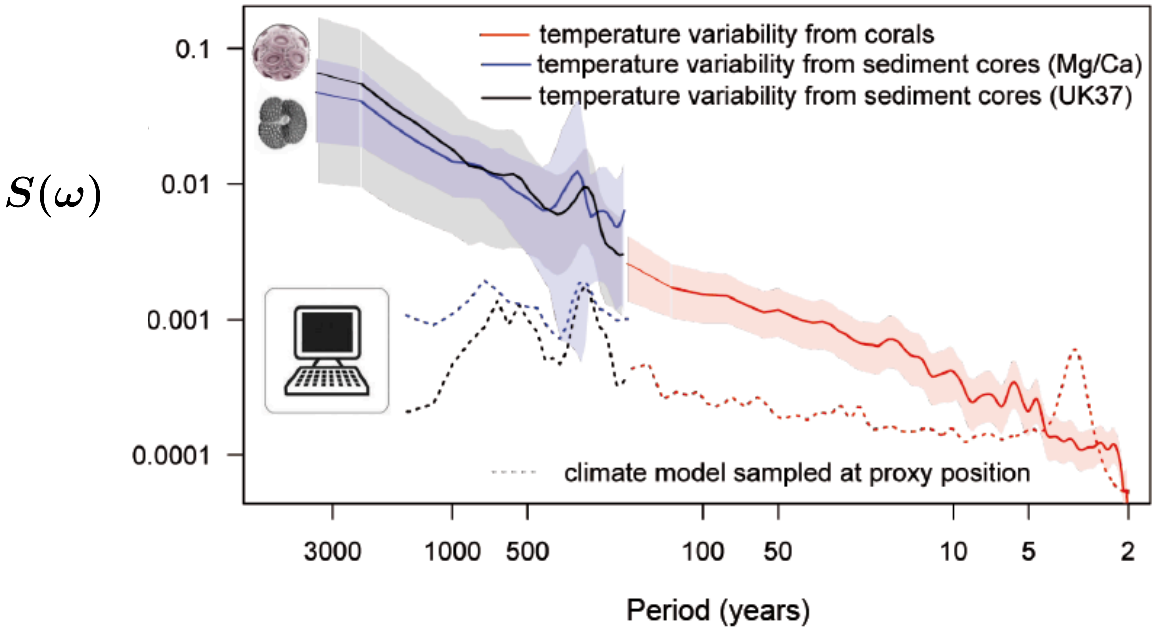
ΔT

Lohmann et al., 2013, CP

Marine temperature variability

(annual to millennial time scales)

Power spectrum



Current climate models seem to underestimate long-term variability

Laepple and Huybers, 2014; GRL, PNAS

Climate variability and sensitivity are related

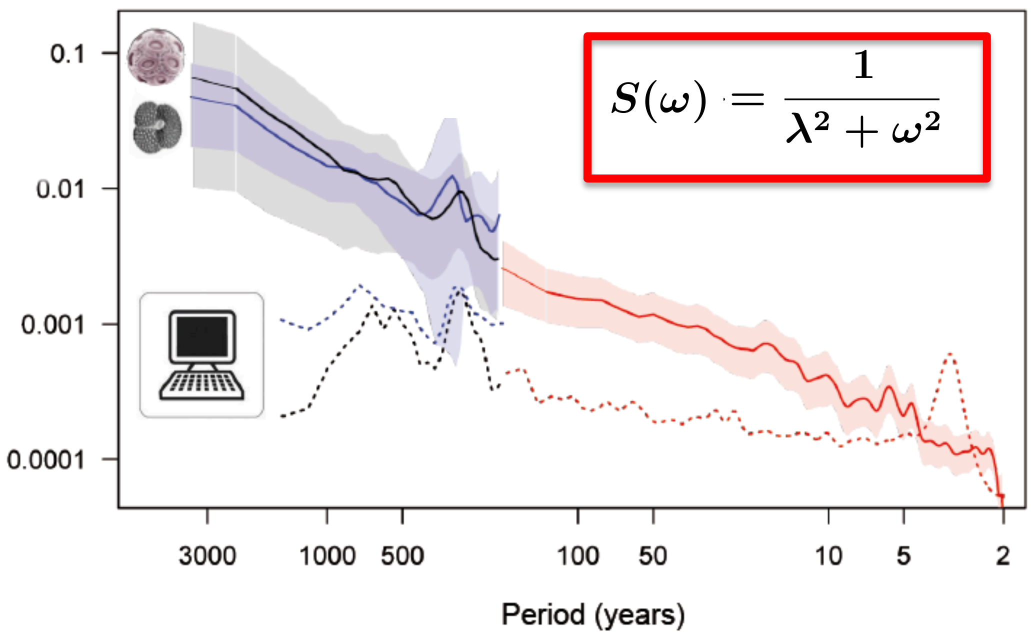
Stochastic climate model

$$\frac{dT}{dt} = -\lambda T + \text{Noise} + \text{Forcing}$$

$$\Delta T = \frac{\text{Forcing}}{\lambda}$$

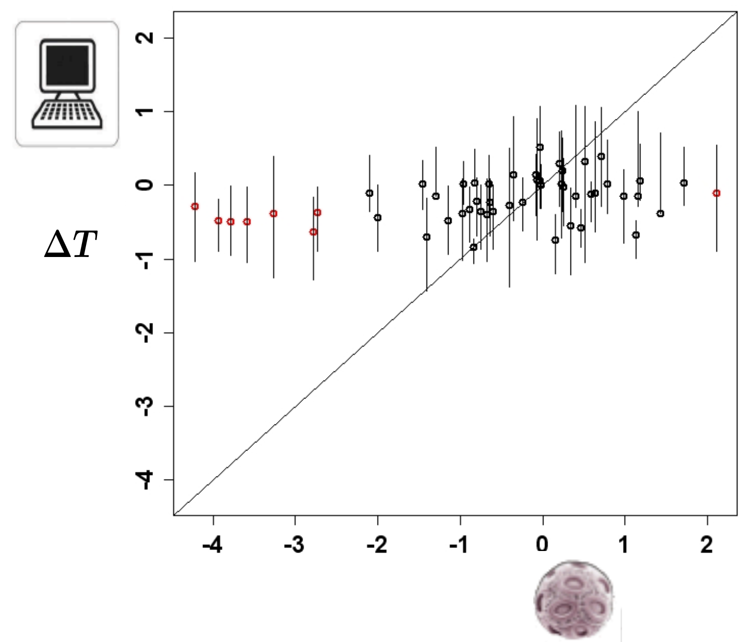
Power spectrum

$$S(\omega) = \frac{1}{\lambda^2 + \omega^2}$$



Variance too low

Response too low



Damping λ too high

(Fluctuation Dissipation Theorem)

Lohmann 2018

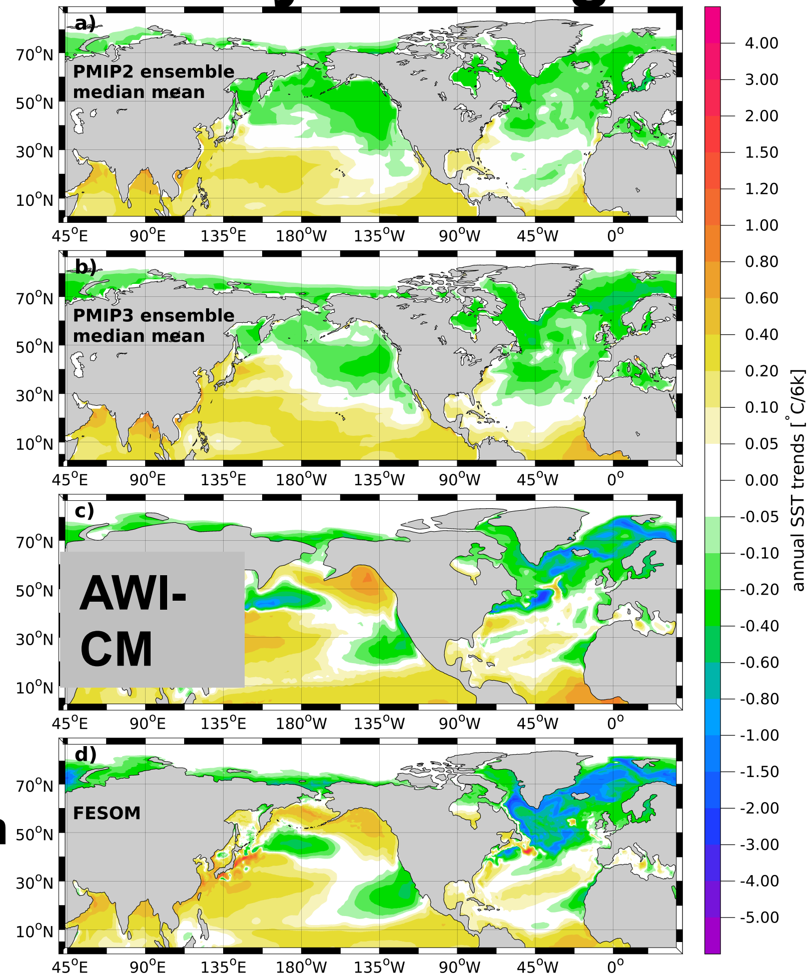
Holocene SST -Trends 6000 years: high resolution

PMIP2, ~3° resol

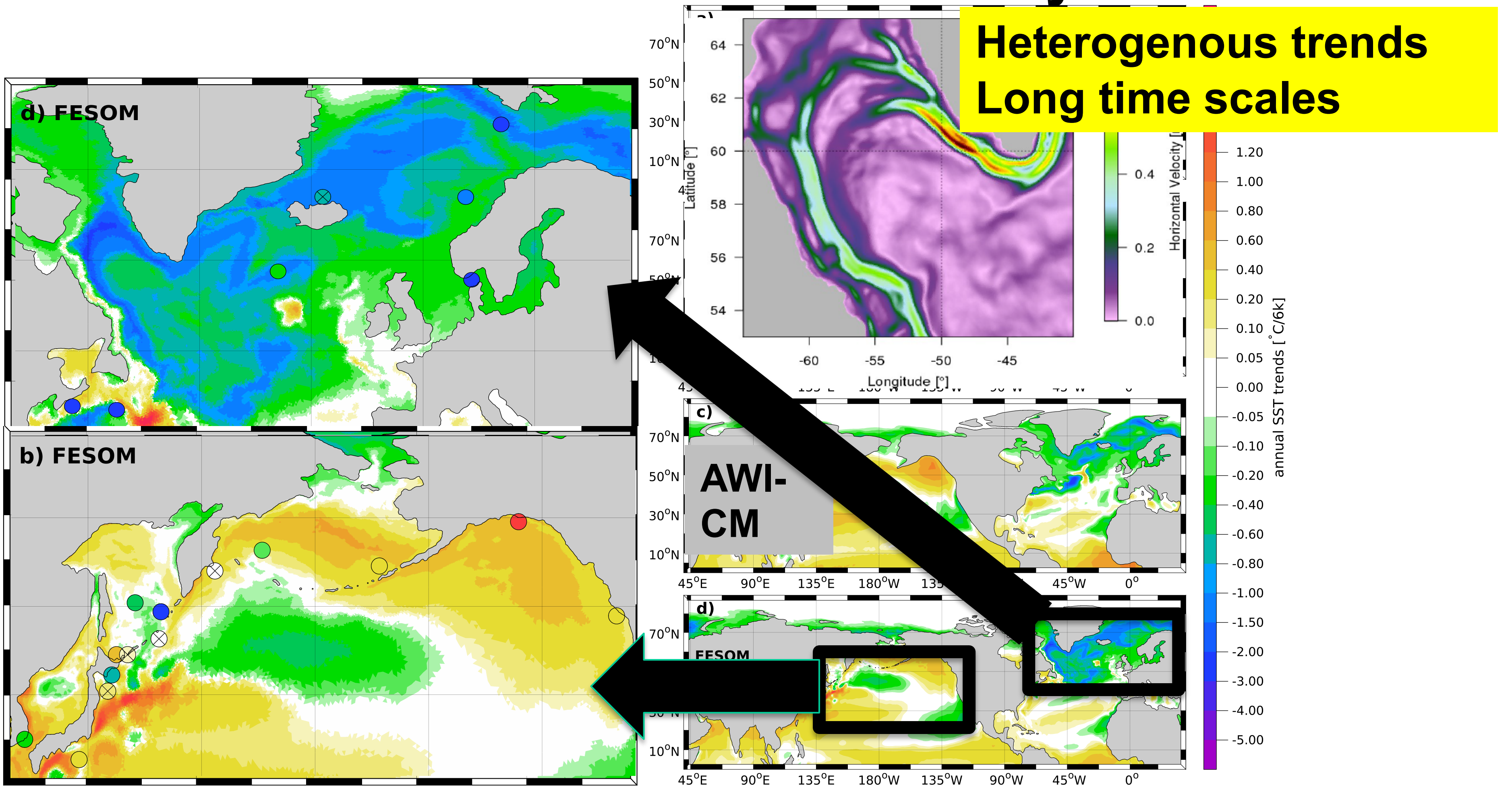
PMIP3, ~2° resol

Climate model ECHAM6-FESOM

Downscaling Ocean



Holocene SST -Trends 6000 years



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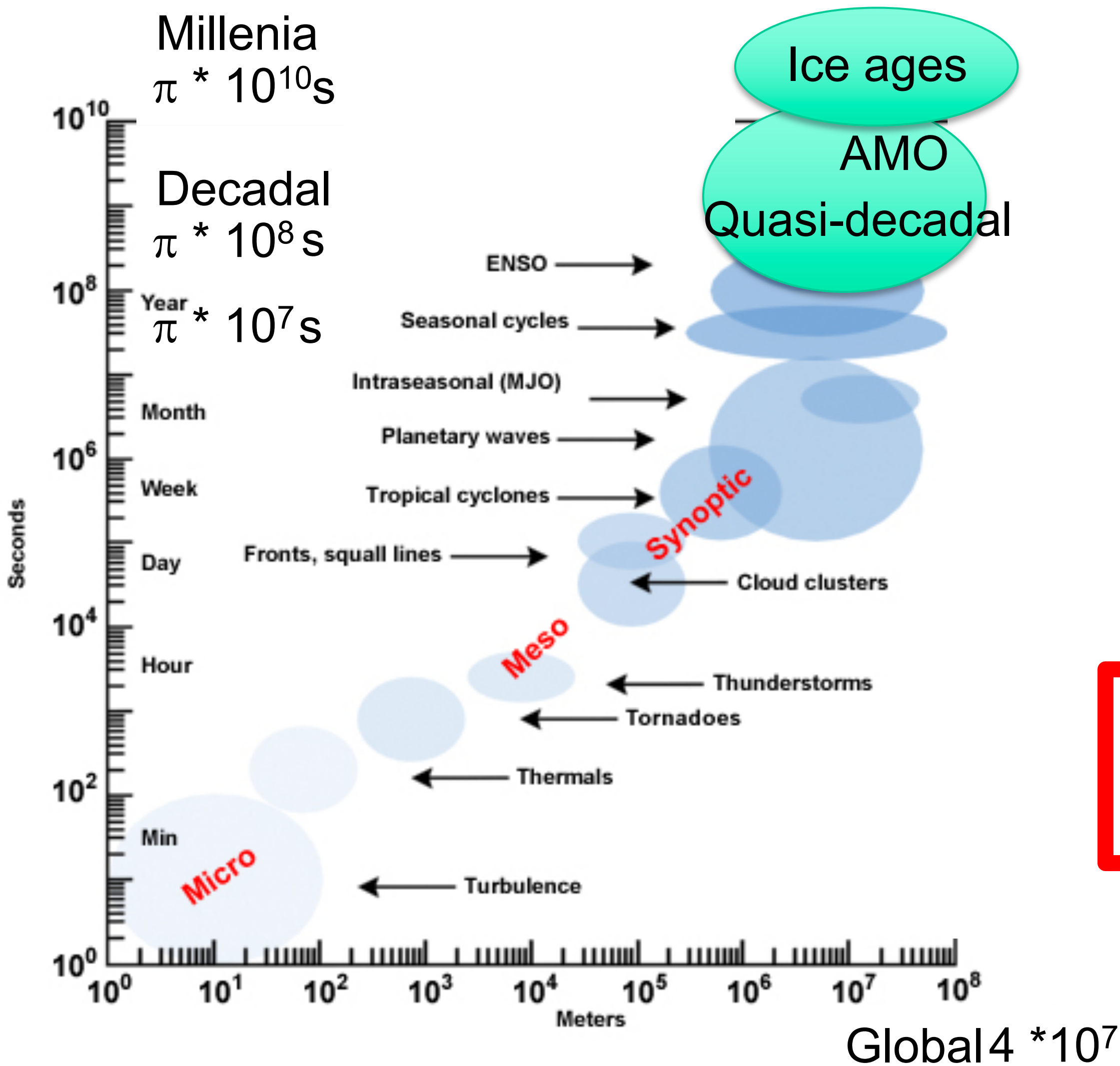


Spatial || temporal Scales

<u>No:</u>
Persistence Jets, atm. dyn, Western BC, sea ice

Momentum equations

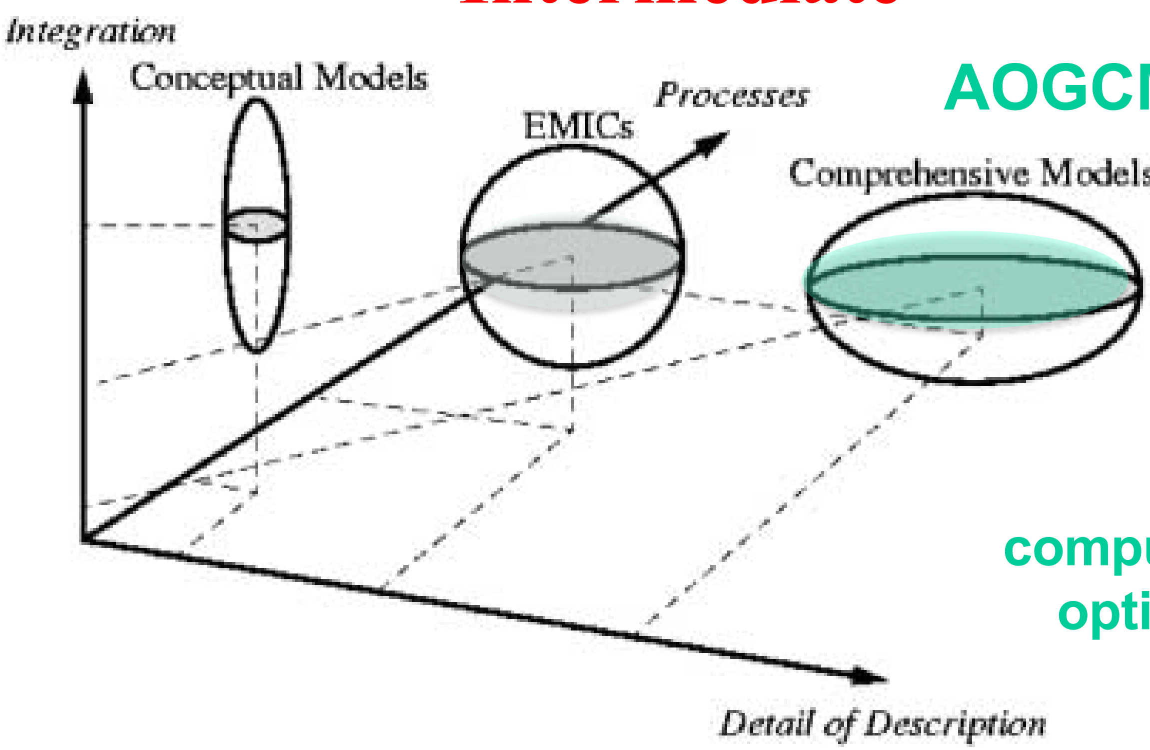
$$\frac{\partial u}{\partial t} + \mathbf{v} \cdot \nabla u - \frac{uv\tan\varphi}{a} - \frac{uw}{a} = -\frac{1}{\rho}\frac{\partial p}{\partial x} + fv - f^{(2)}w + \nu\nabla^2 u$$

$$\frac{\partial v}{\partial t} + \mathbf{v} \cdot \nabla v - \frac{u^2\tan\varphi}{a} - \frac{vw}{a} = -\frac{1}{\rho}\frac{\partial p}{\partial y} - fu + \nu\nabla^2 v$$

Model Strategy

Intermediate

AOGCMs



computer power,
optimisation

Pictorial definition of EMICs (Claussen et al. 2002)

Energy balance model

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

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

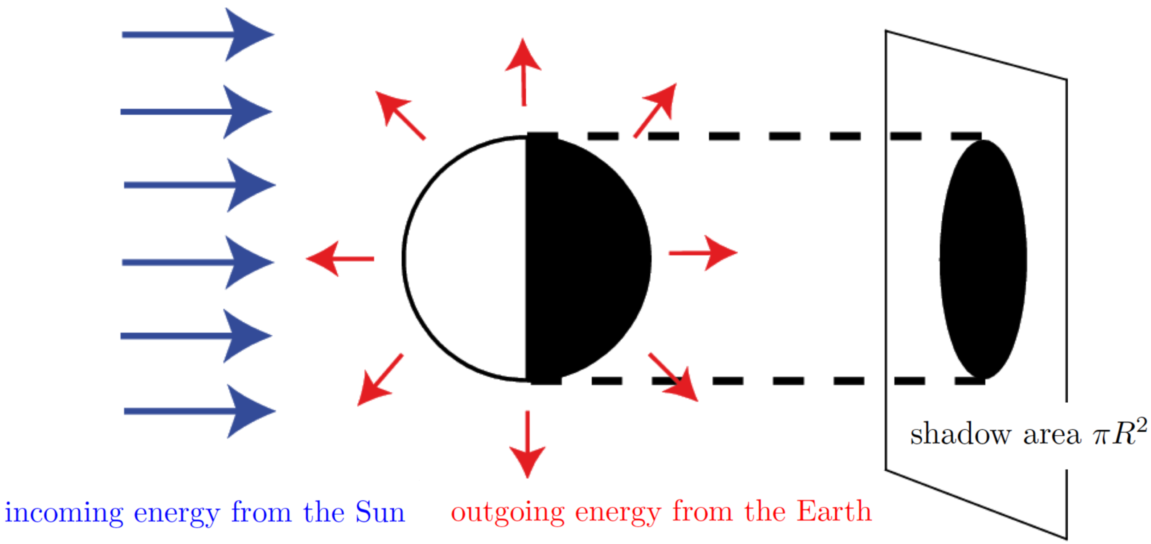
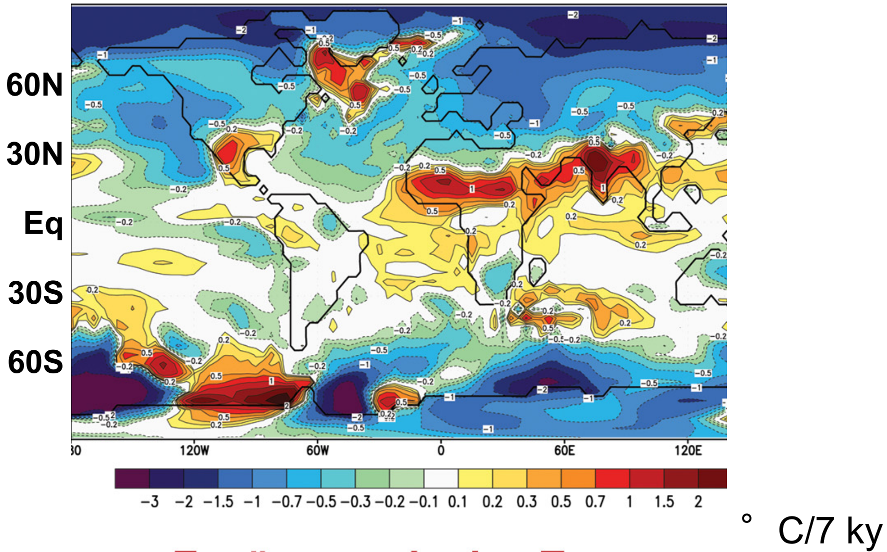


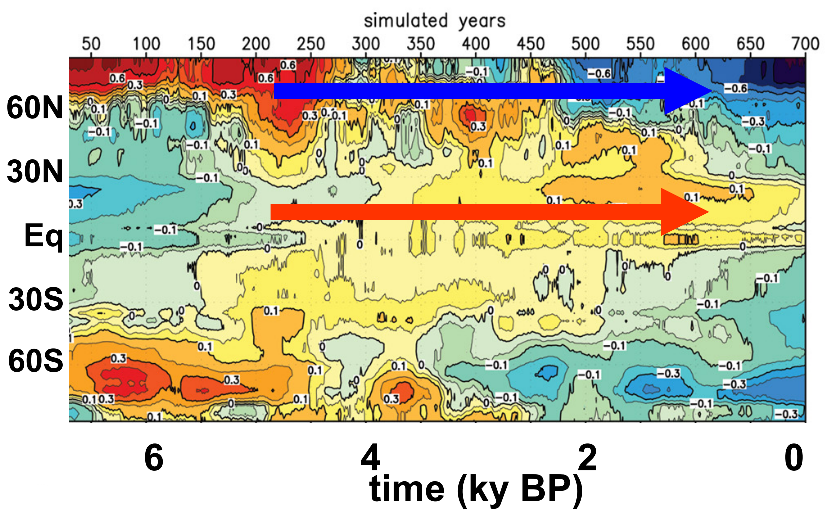
Figure 1. Schematic view of the energy absorbed and emitted by the Earth following (1). Modified after Goose (2015).

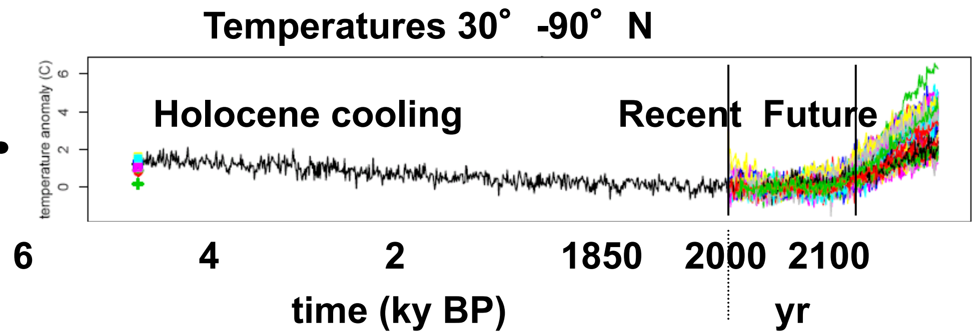
last 7000 years: Models & Data



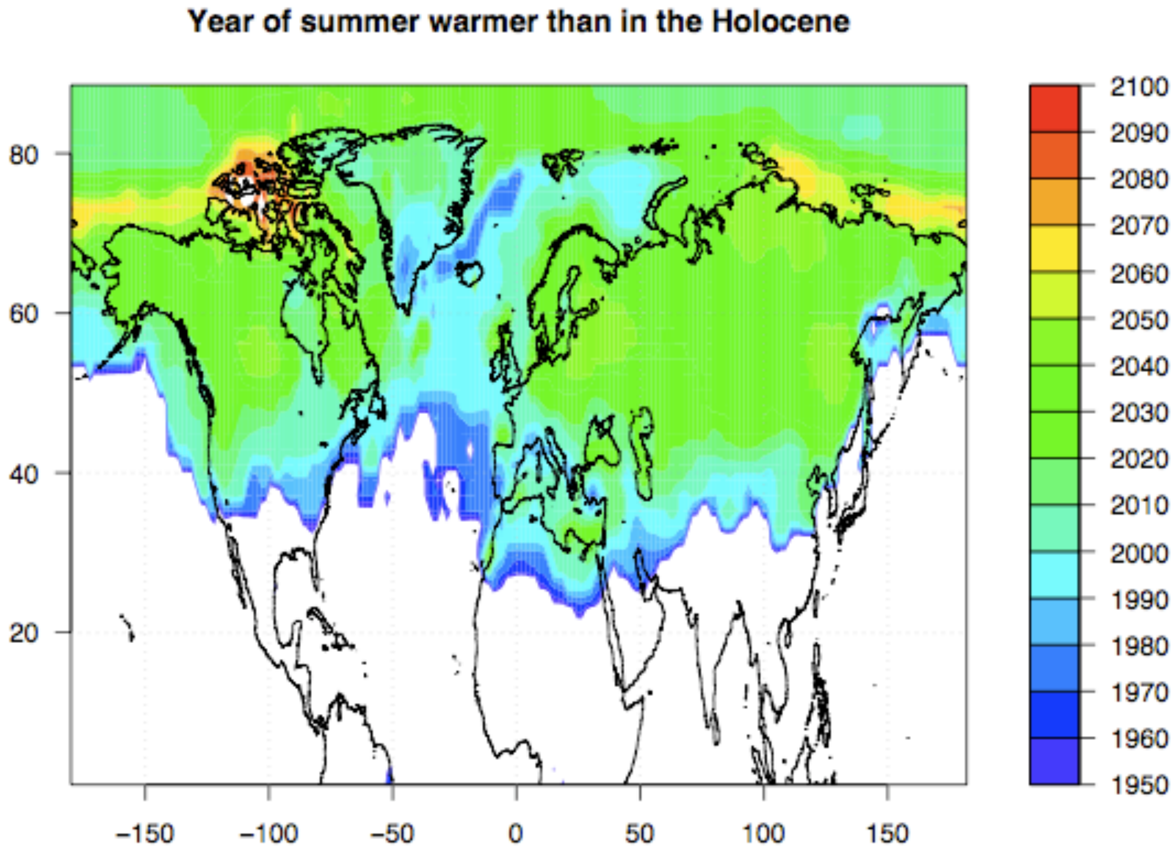
Holocene temperature trend

Erwärmung in den Tropen
Abkühlung in hohen Breiten



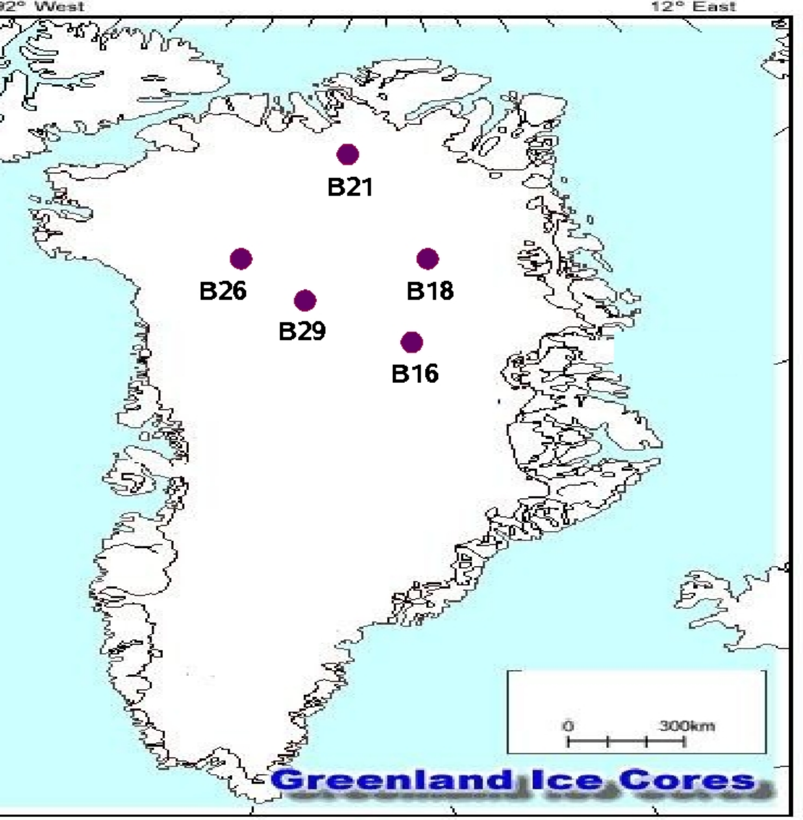


When do we reach the temperature level of 6000 years before present (climate optimum)?



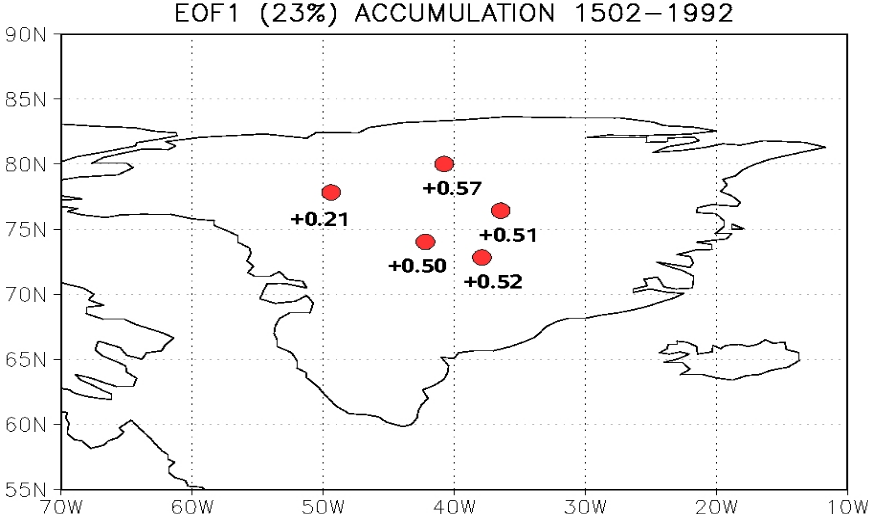
5300 year old man
Ötztaler Alpen 3210m H

Shallow ice cores

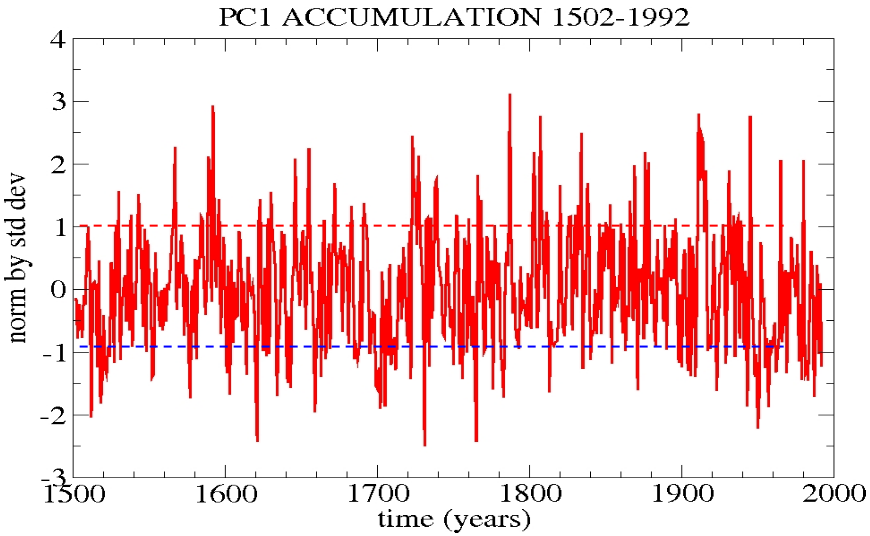


Atmospheric Blocking Circulation

Greenland Shallow Ice Core Positions



Variability of Accumulation Rate



Rimbu and Lohmann 2009

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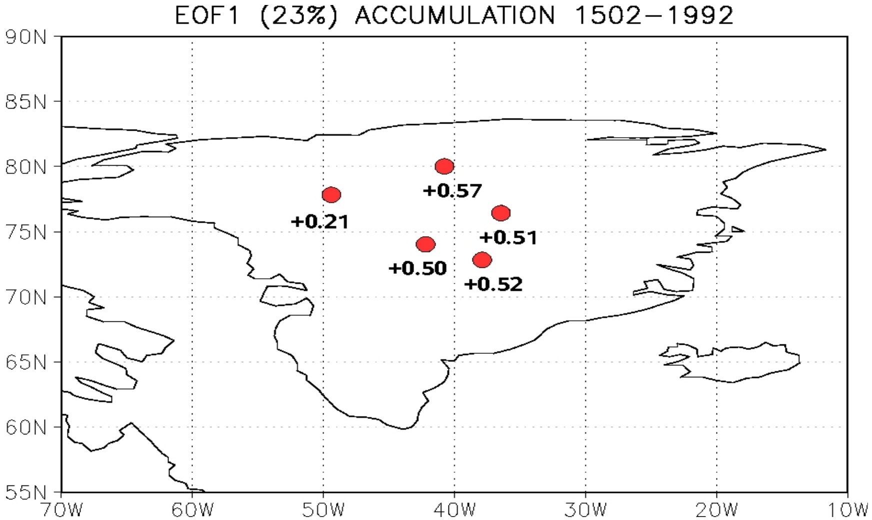

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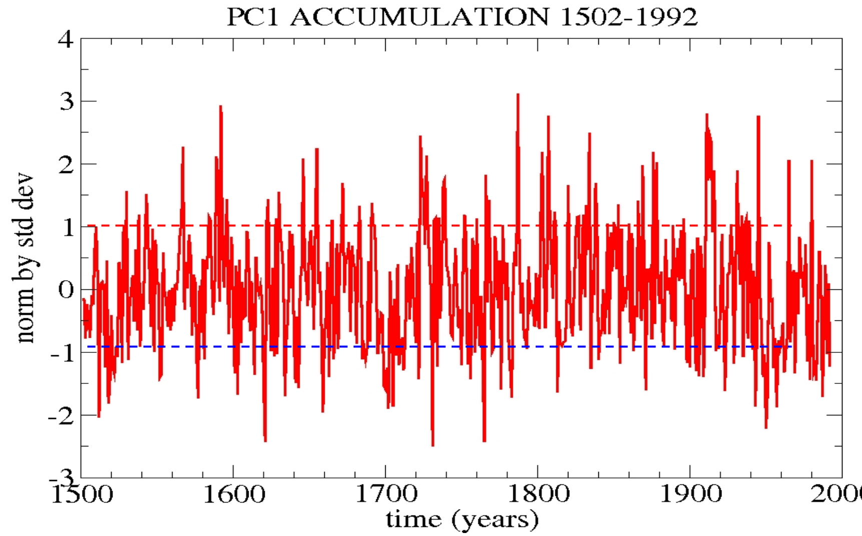
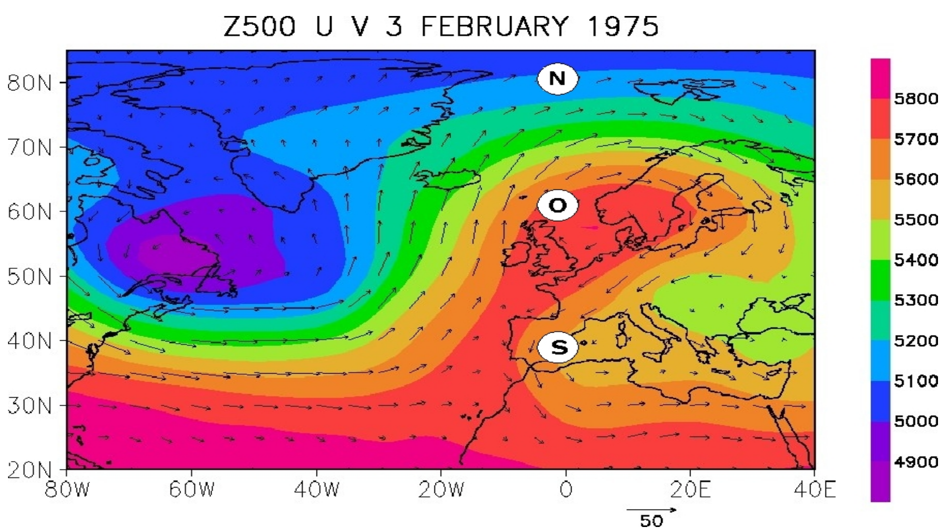
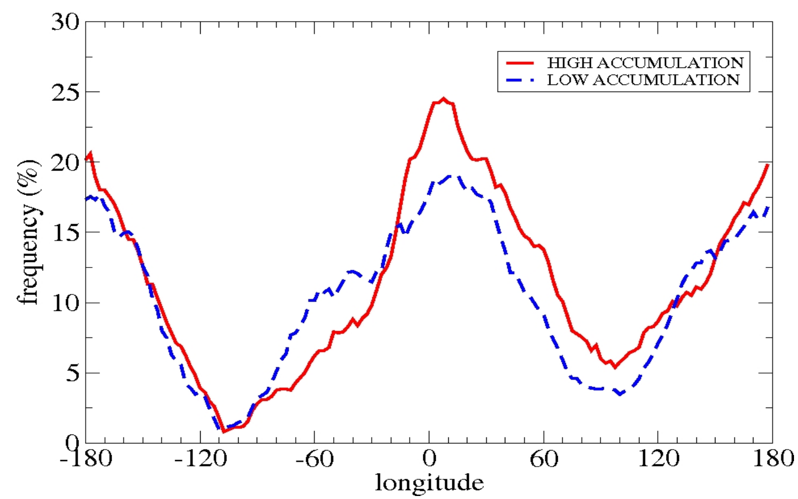


Synoptic Scale Blocking Situation

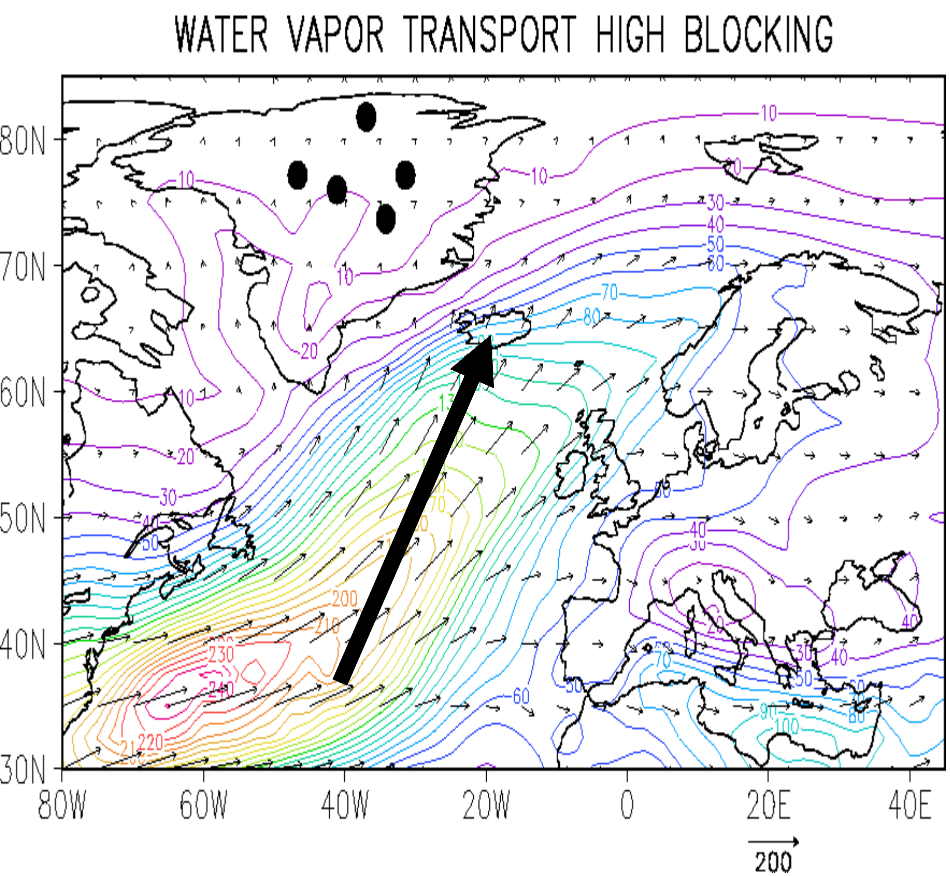


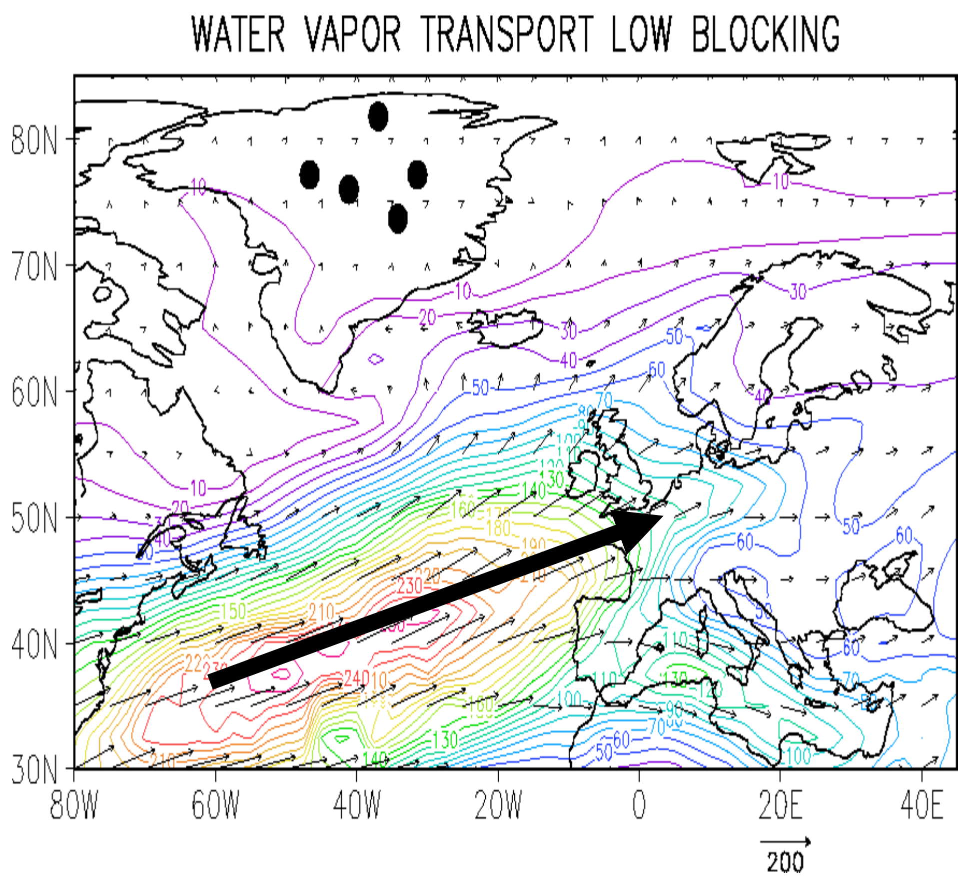
Blocking Frequency for 1948-1992



Rimbu and Lohmann 2009

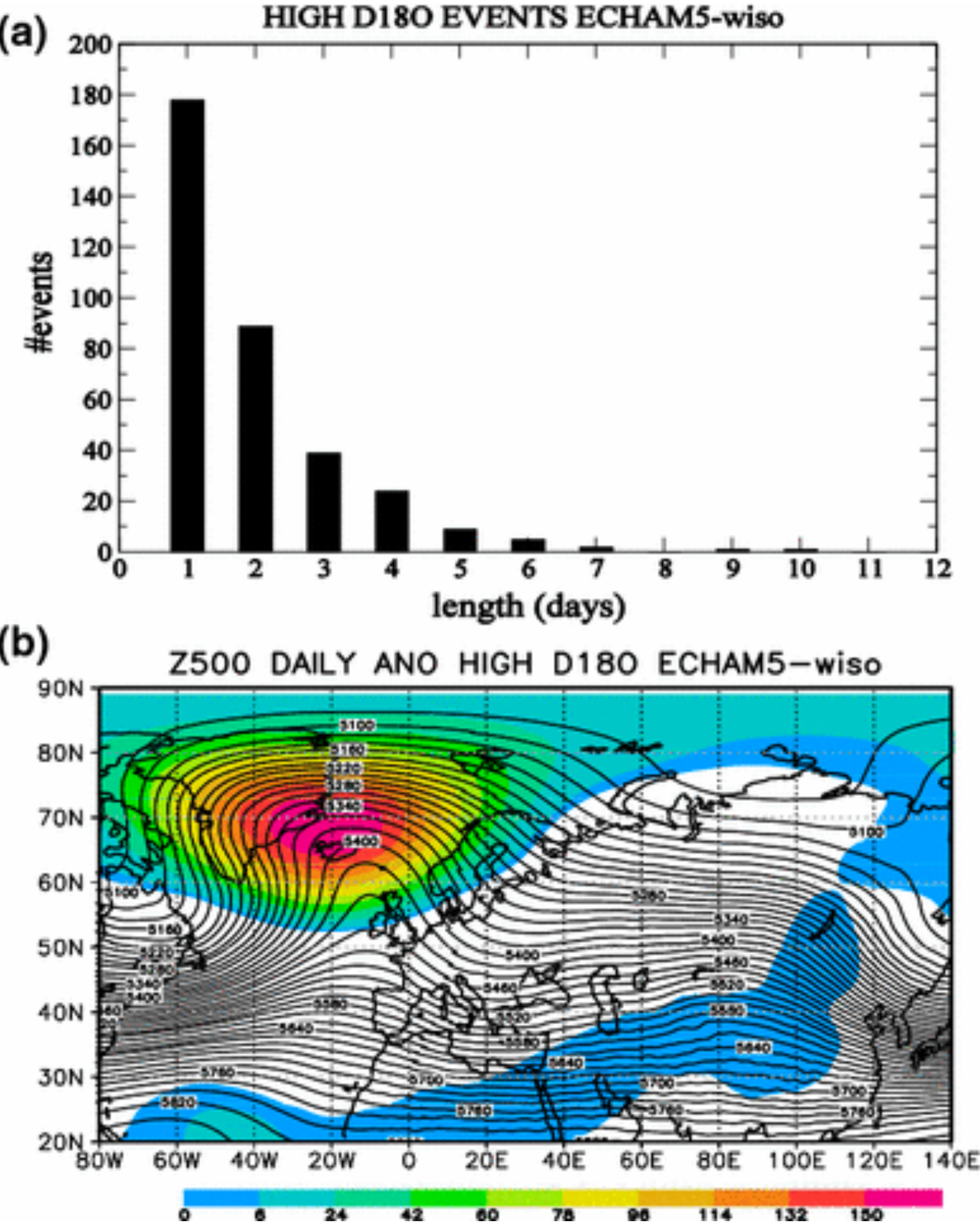
WATER VAPOR TRANSPORT

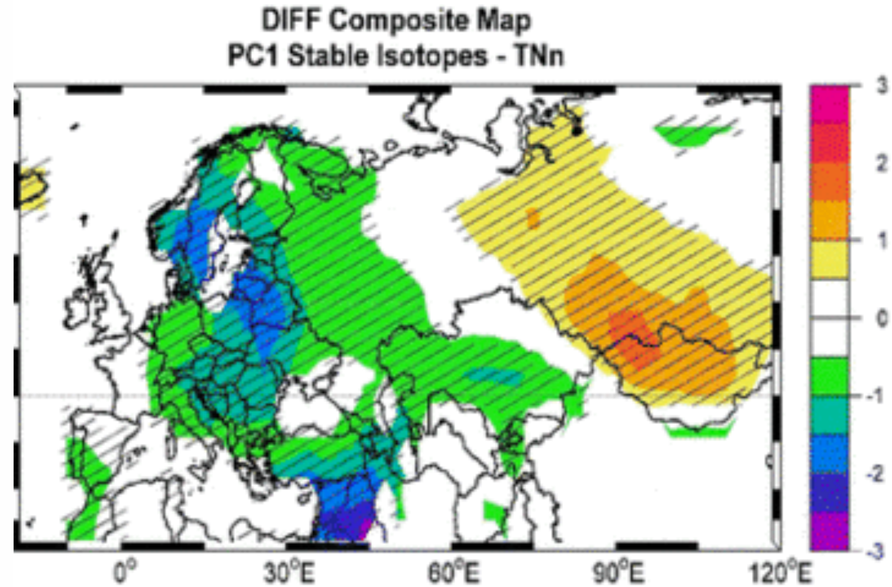




Enhanced moisture transport during high blocking activity

minimum value of daily minimum temperature (TNn)





Climate variability across time scales: challenges from limited data & modeling

Past climates help us to understand the climate system as a whole

To elaborate processes (first and second order)

Test hypotheses by scenarios and comparing model results to data

Climate variability across time scales: challenges from limited data & modeling

Past climates help us to understand the climate system as a whole

To elaborate processes (first and second order)

Test hypotheses by scenarios and comparing model results to data

Holocene: High latitude cooling, low-latitude warming
Models and data disagree in amplitude & variability (fdt)

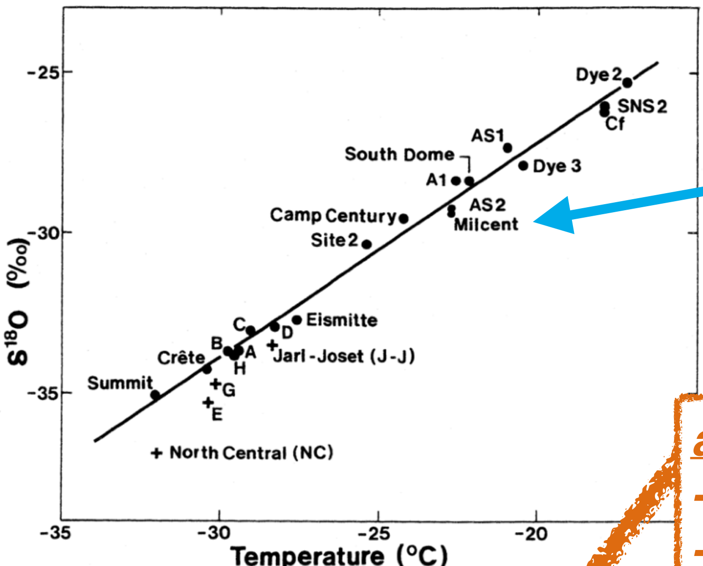
Dynamics: Heterogeneities in temperature,
large gradients can persist on long time scales

Interpretation of proxy data:
Bring the current climate into a long-term context, extremes

The use of of δ18O in precipitation as a temperature proxy

Modern spatial relation between δ18O and surface temperature (on Greenland):

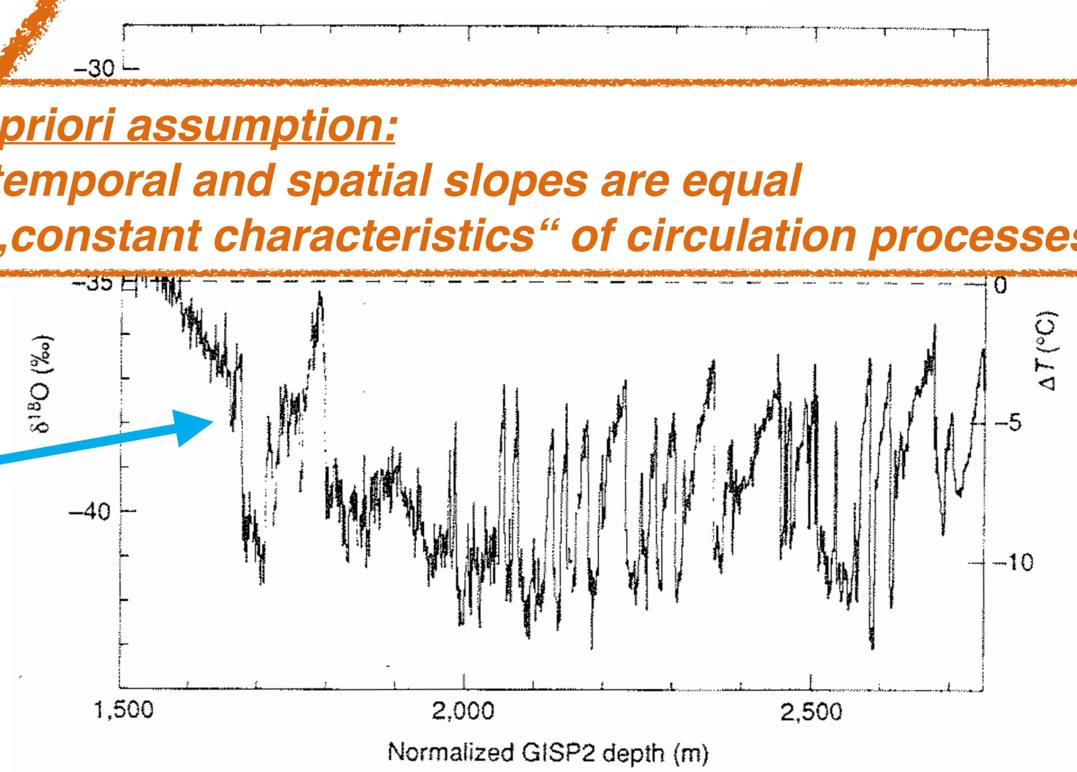
$$\delta^{18}O = 0.67 \cdot T_{surf}$$



[Johnsen et al., Tellus, 1989]

__a priori assumption:__

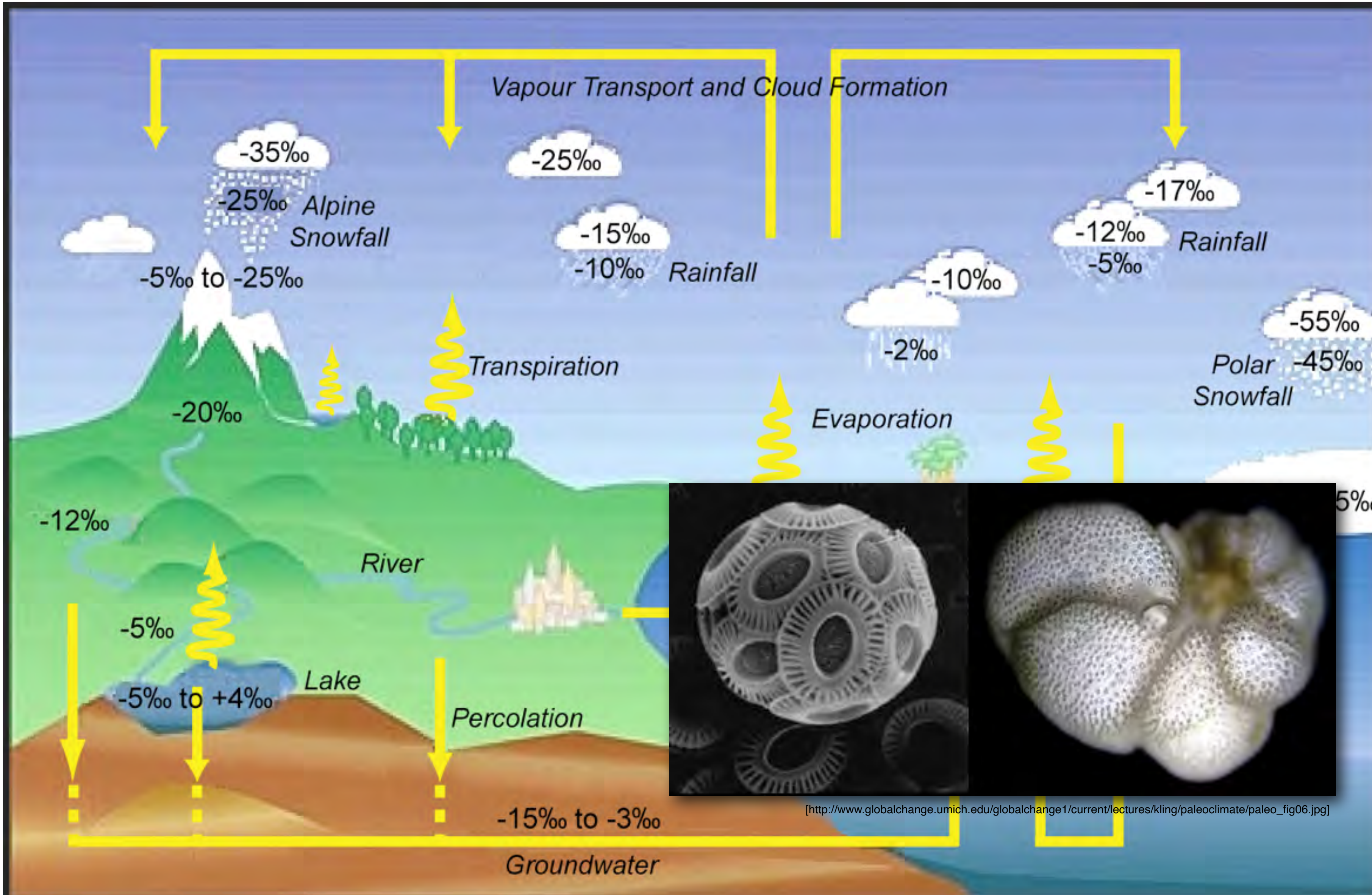
- ***temporal and spatial slopes are equal***
- ***„constant characteristics" of circulation processes***



[Grootes et al., Nature, 1993]

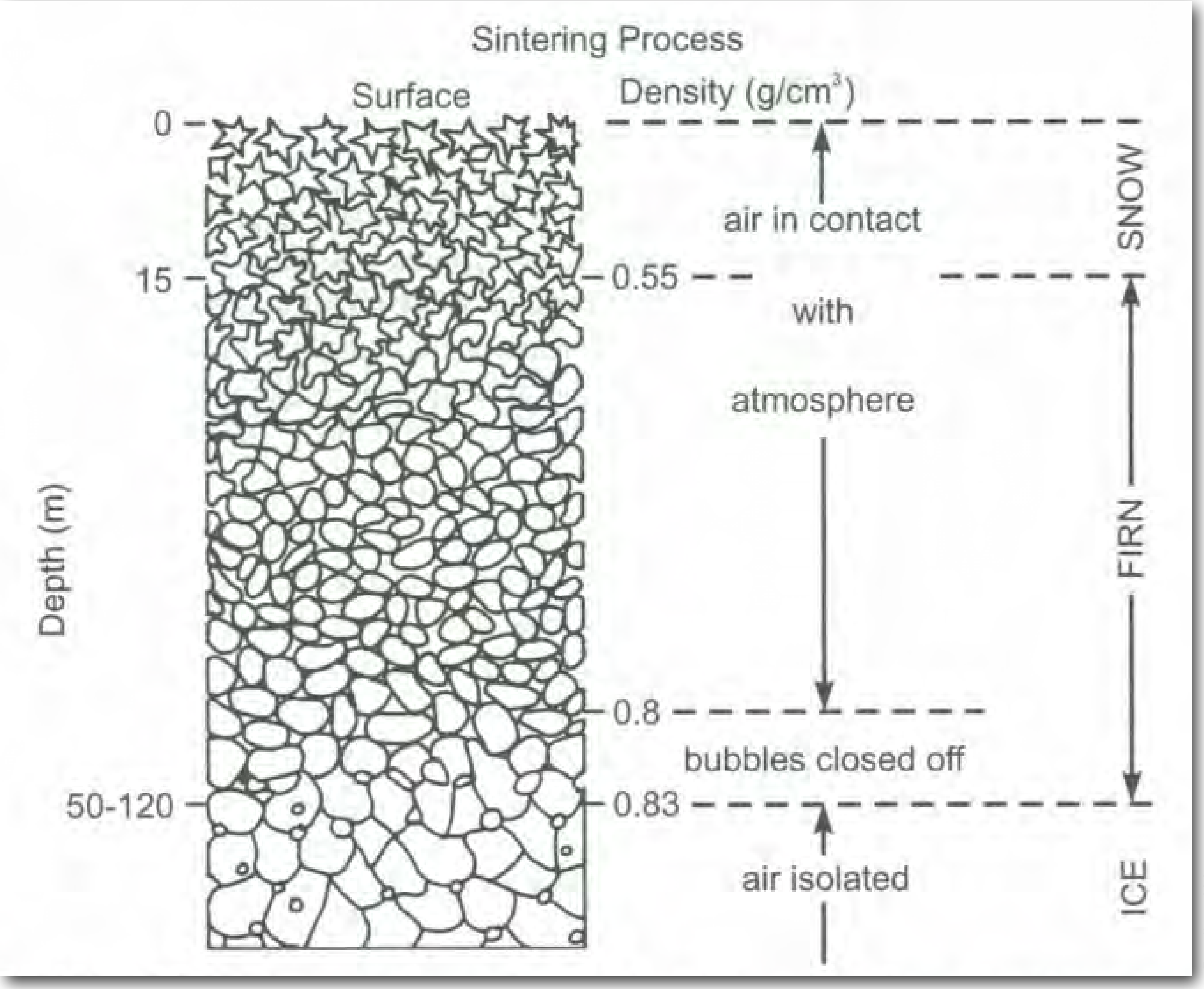
Converting temporal changes of δ18O into past temperature changes

The δ18O signal in marine sediment cores



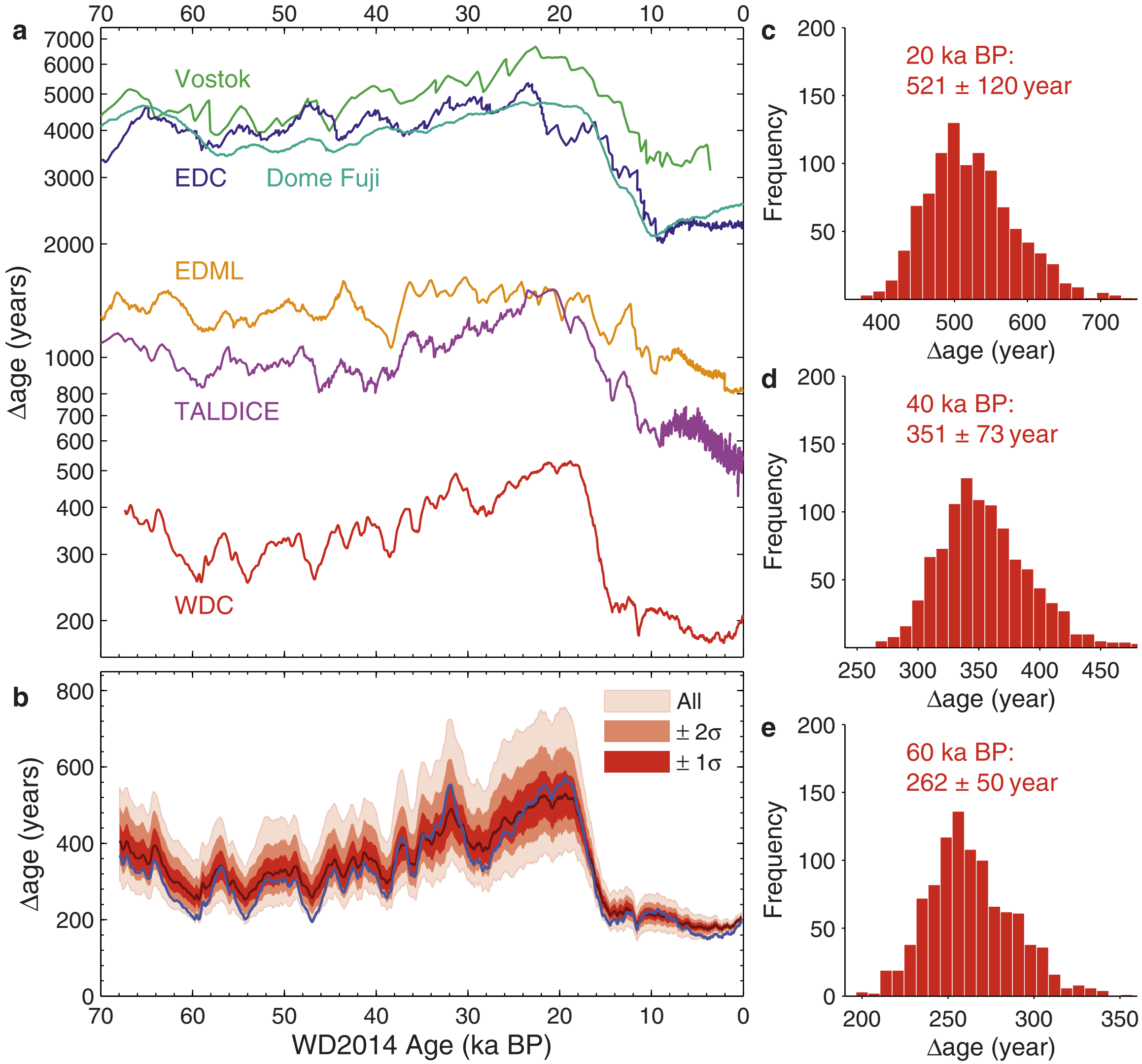
[plot adapted from the GNIP brochure, IAEA, 1996]

Transformation of snow to ice



Bradley, Abb. 5.30

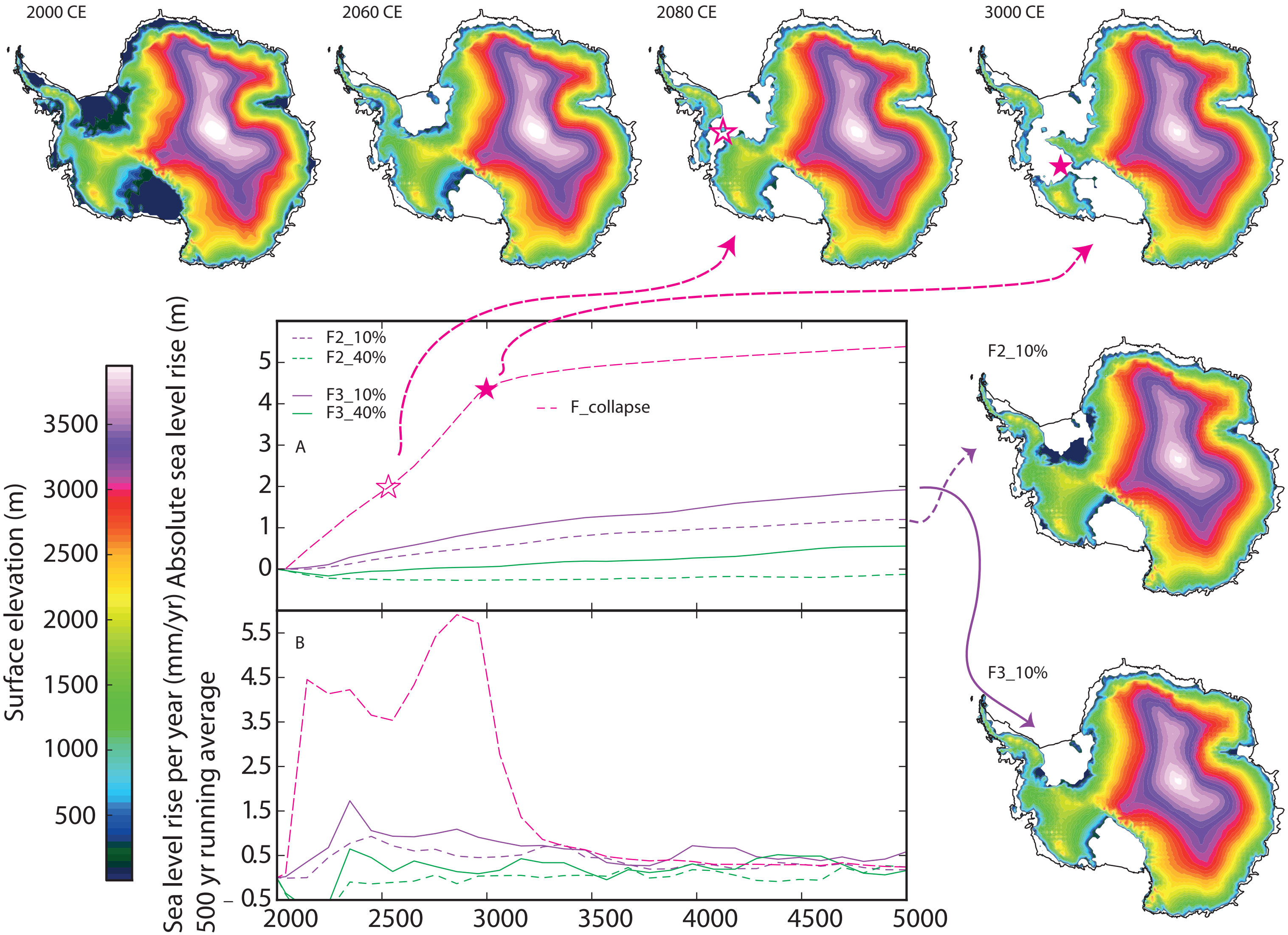
Example: difference between ice age and gas age



Extended Data Figure 1 | Difference between gas age and ice age (Δage) at WAIS Divide. **a**, Comparison of WDC Δage with other Antarctic cores. Ice core abbreviations: EDC, EPICA Dome Concordia; EDML, EPICA Dronning Maud Land; TALDICE, Talos Dome; WDC, WAIS Divide. Δage values are taken from refs 23, 63–65. The vertical axis is on a logarithmic scale. **b**, Δage uncertainty bounds obtained from an ensemble of 1,000 alternative Δage scenarios; details are given elsewhere[23]. A Δage scenario obtained with an alternative densification model (ref. 39 instead of ref. 38) is shown in blue. **c–e**, Histograms of the 1,000 Δage scenarios at 20 kyr BP (**c**), 40 kyr BP (**d**) and 60 kyr BP (**e**); stated values give the distribution mean ± the 2σ standard deviation.

WAIS Divide Project Members, Nature, 2015

Future

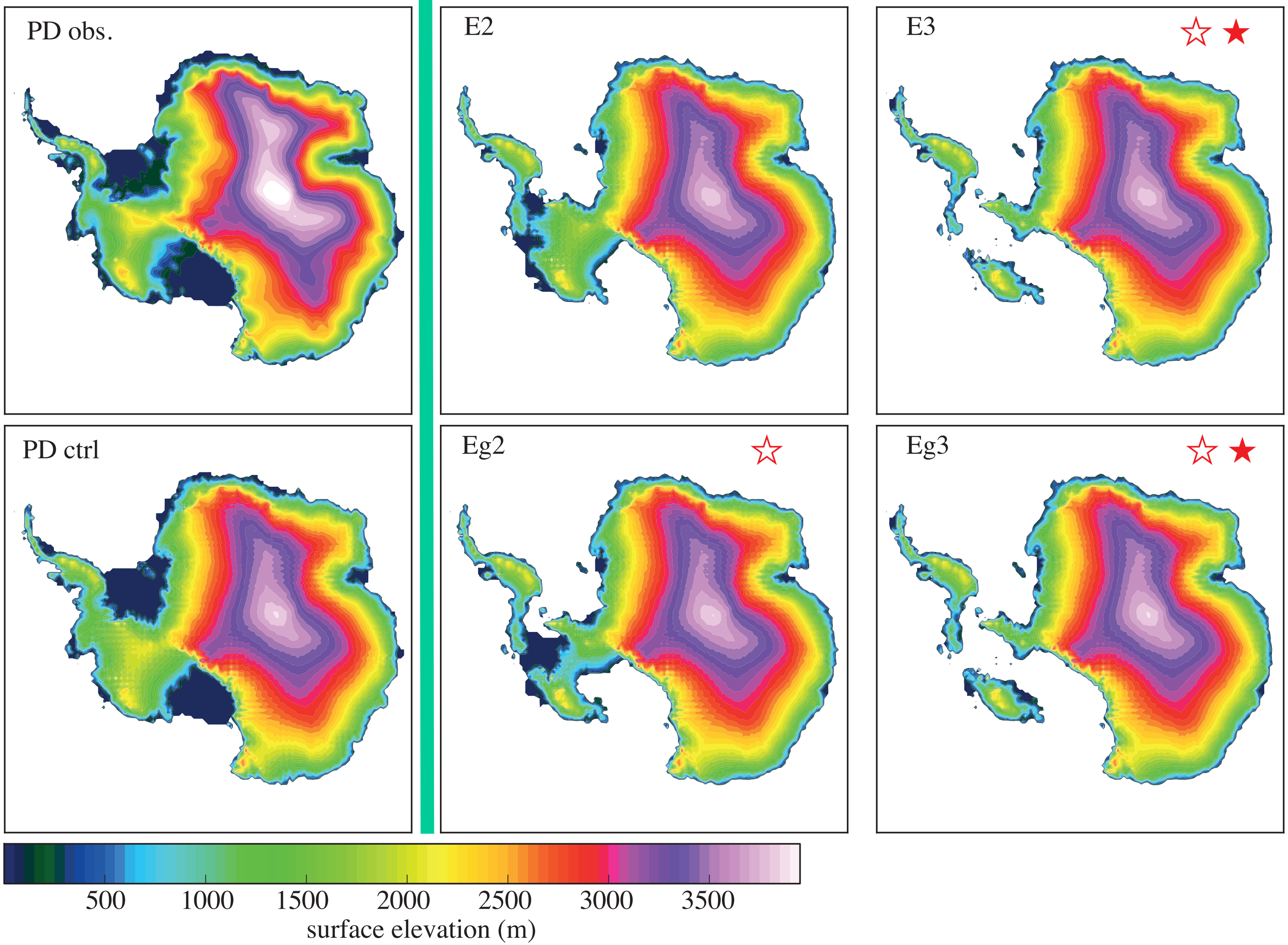


2000 CE
2060 CE
2080 CE
3000 CE
F2_10%
F3_10%
Surface elevation (m)
3500
3000
2500
2000
1500
1000
500
Absolute sea level rise (m)
Sea level rise per year (mm/yr)
500 yr running average
F2_10%
F2_40%
F3_10%
F3_40%
F_collapse
A
B
5
4
3
2
1
0
5.5
4.5
3.5
2.5
1.5
0.5
– 0.5
2000
2500
3000
3500
4000
4500
5000

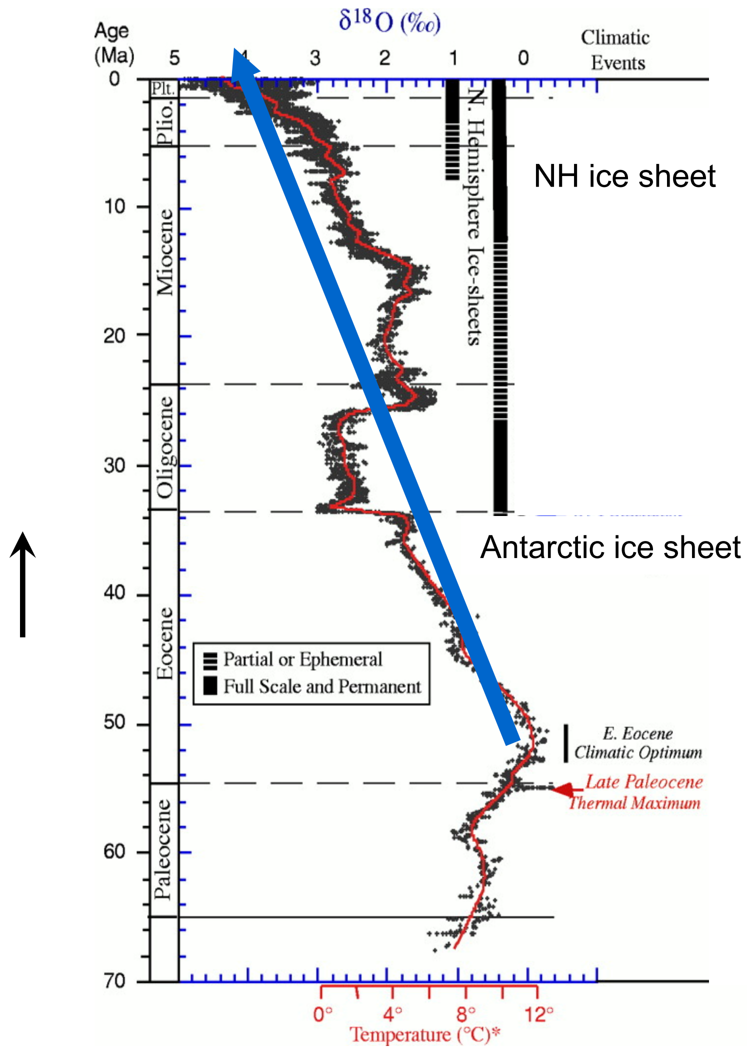
Present

LIG + 2° C
SL: 2-3 m

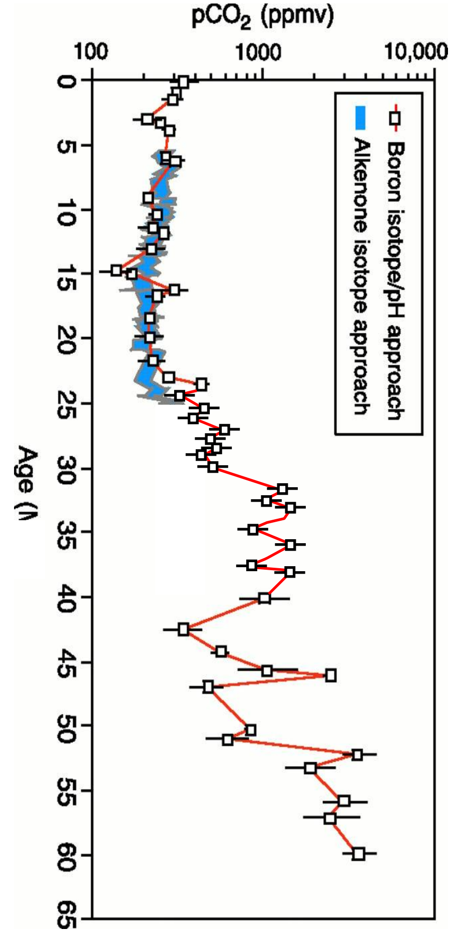
LIG + 3° C
SL: 3-5 m



Transitions from Greenhouse to Icehouse Climate: Evidence from Marine Sediments



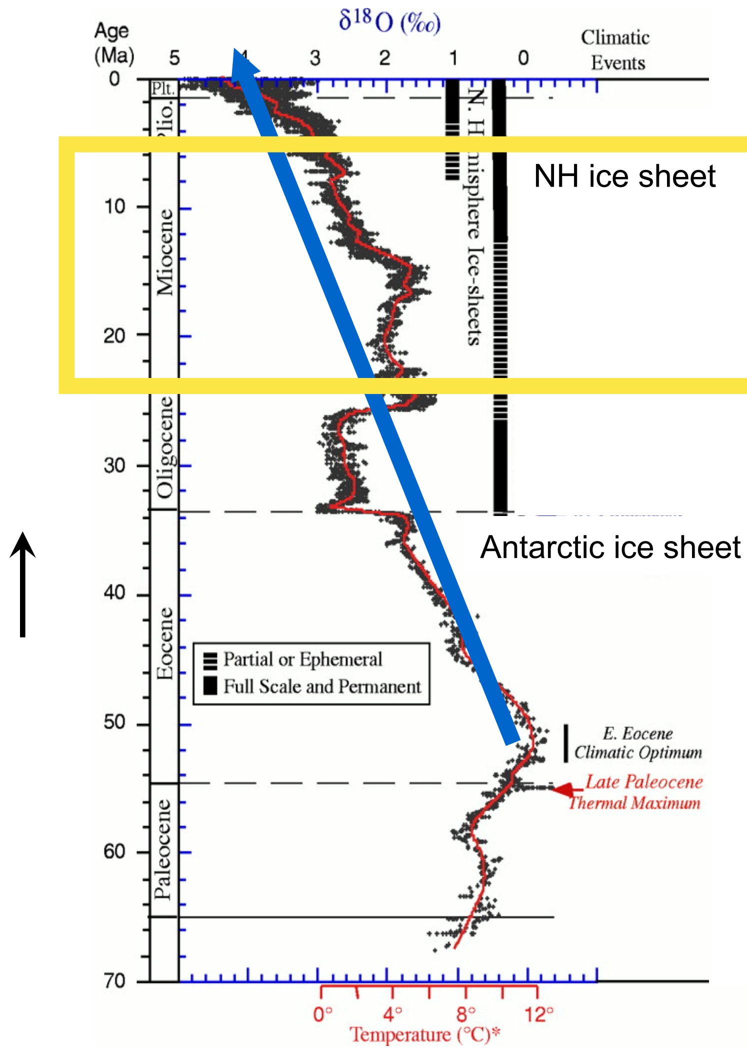
Global deep-sea O-18
(Zachos et al. 2001)



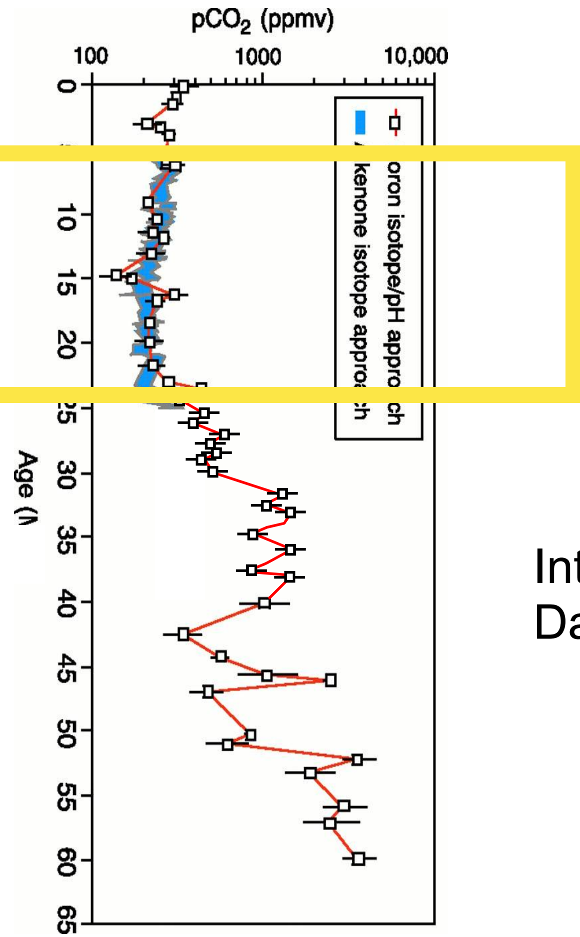
Proxy estimates of atmospheric pCO2 *(Pearson & Palmer 2000; Pagani et al. 1999, 2005)*

Integrative approach
Data-Modelling

Transitions from Greenhouse to Icehouse Climate: Evidence from Marine Sediments



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

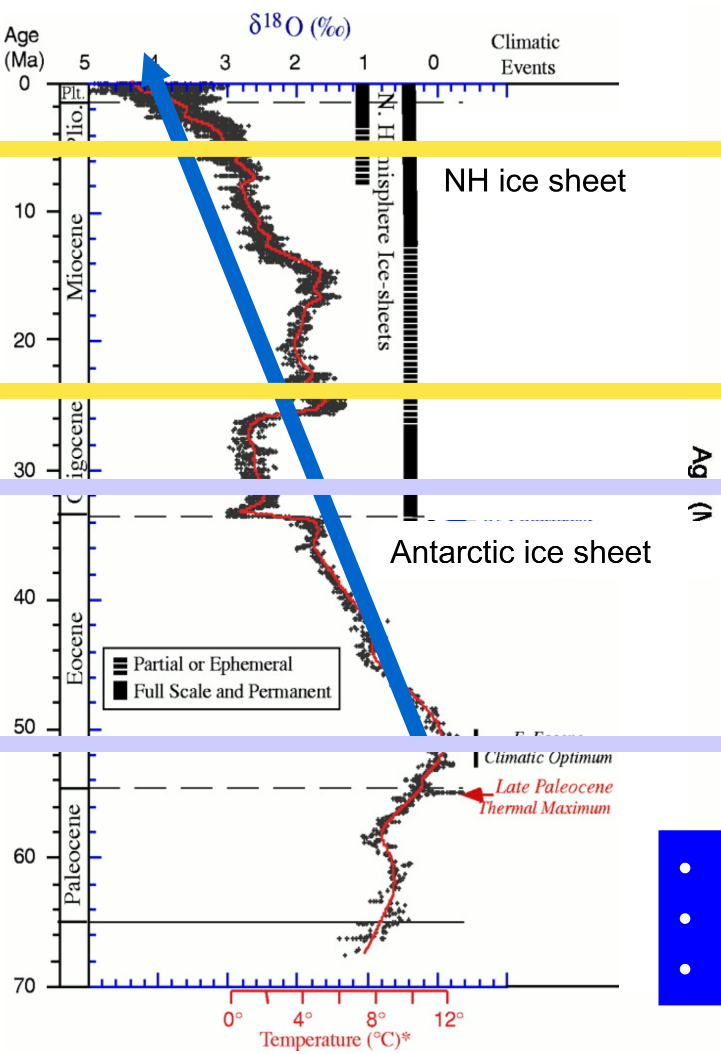


Proxy estimates of atmospheric pCO2 *(Pearson & Palmer 2000; Pagani et al. 1999, 2005)*

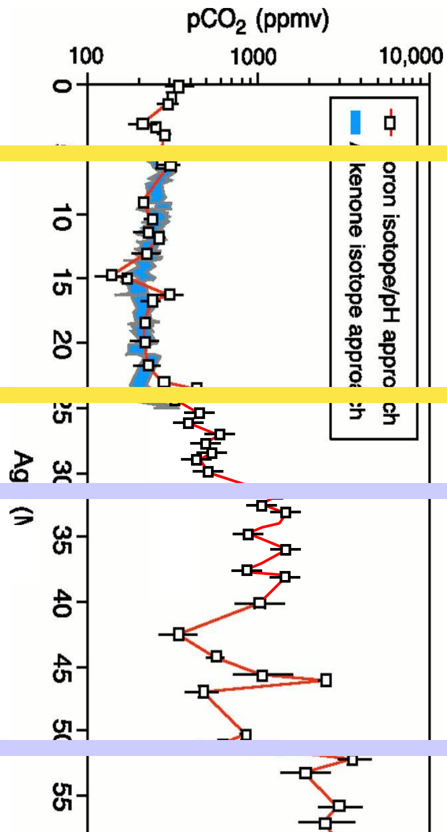
Miocene

Integrative approach
Data-Modelling

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)*

Miocene

Eocene/Oligocene

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

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