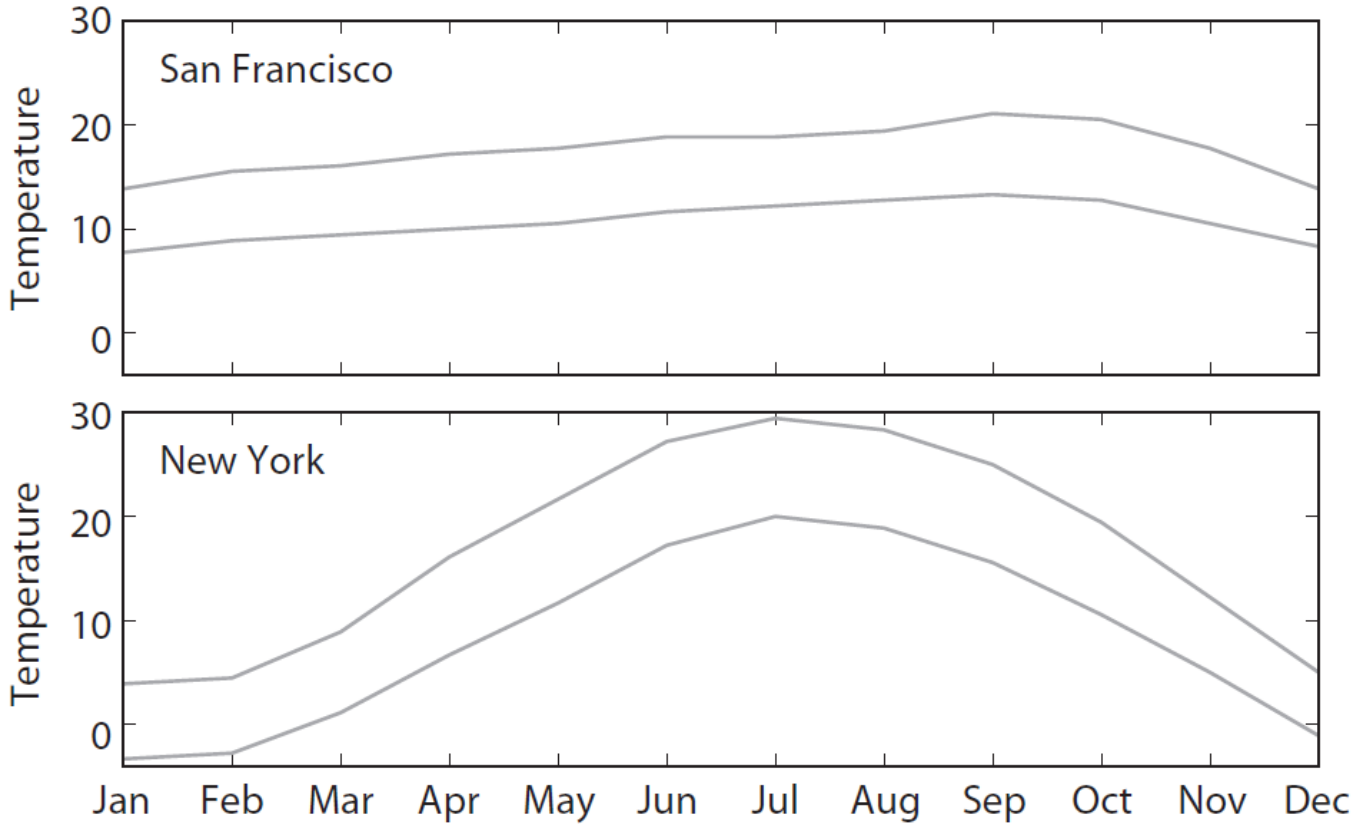
The ocean‘s overall role in climate

- moderates climate in time (diurnally, annually)
- redistributes heat spatially in the large-scale ocean circulation
- lower albedo (sea ice higher albedo)
- dry atmosphere has no clouds (smaller greenhouse effect)

The oceans moderates climate

- **The heat capacity of the ocean is 100 times greater than that of land**
- **Effective heat capacity of the ocean (atmosphere) is that of a water body of 50-100 m (3 m) depth**

Two coastal cities: San Francisco 38ºN, New York 41ºN



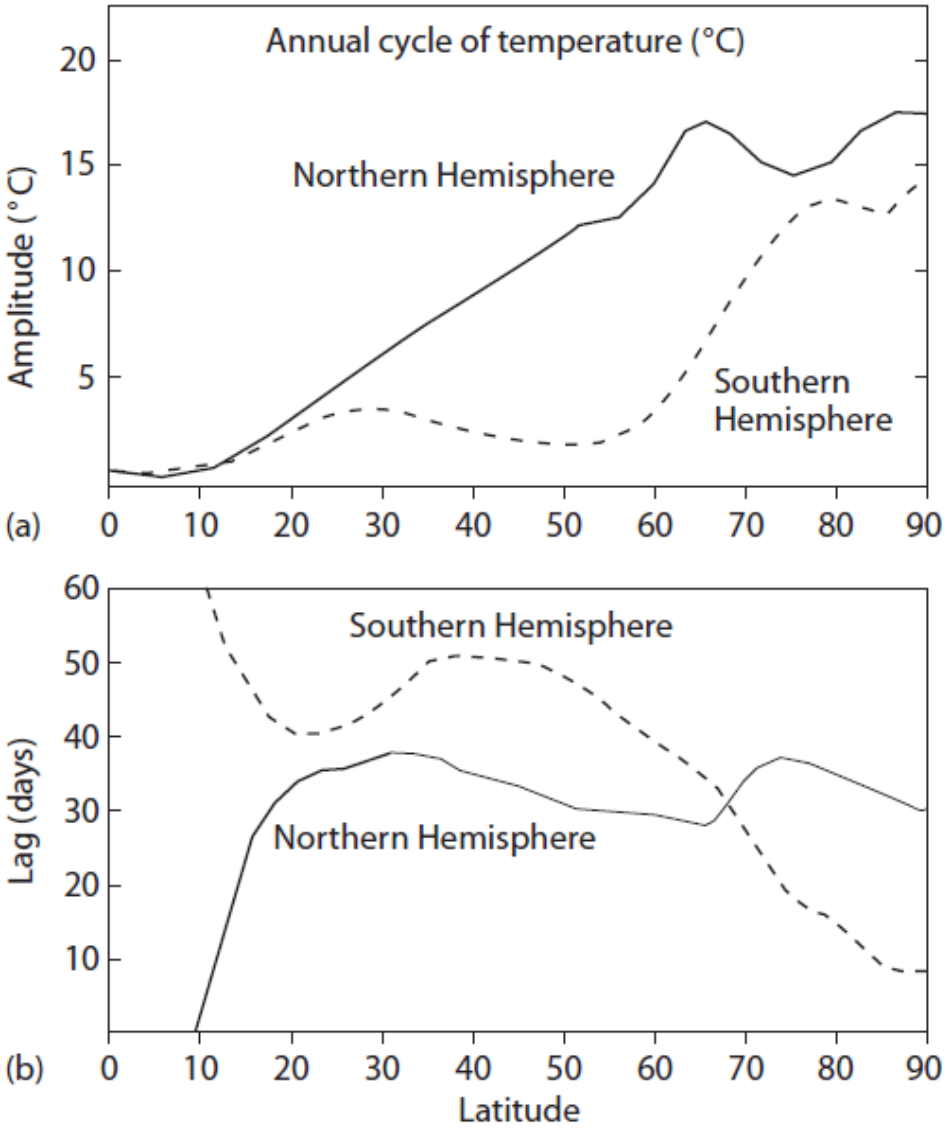


Figure 5.2. Amplitude and lag of the annual cycle in the Northern and Southern hemispheres, as a function of latitude. The lag is the time, in days, from the maximum solar insolation to the maximum temperature. Source: Trenberth, 1983.

NH 60% oceans
SH 80% oceans

Damping of climate variability of the ocean

Ocean heat transport

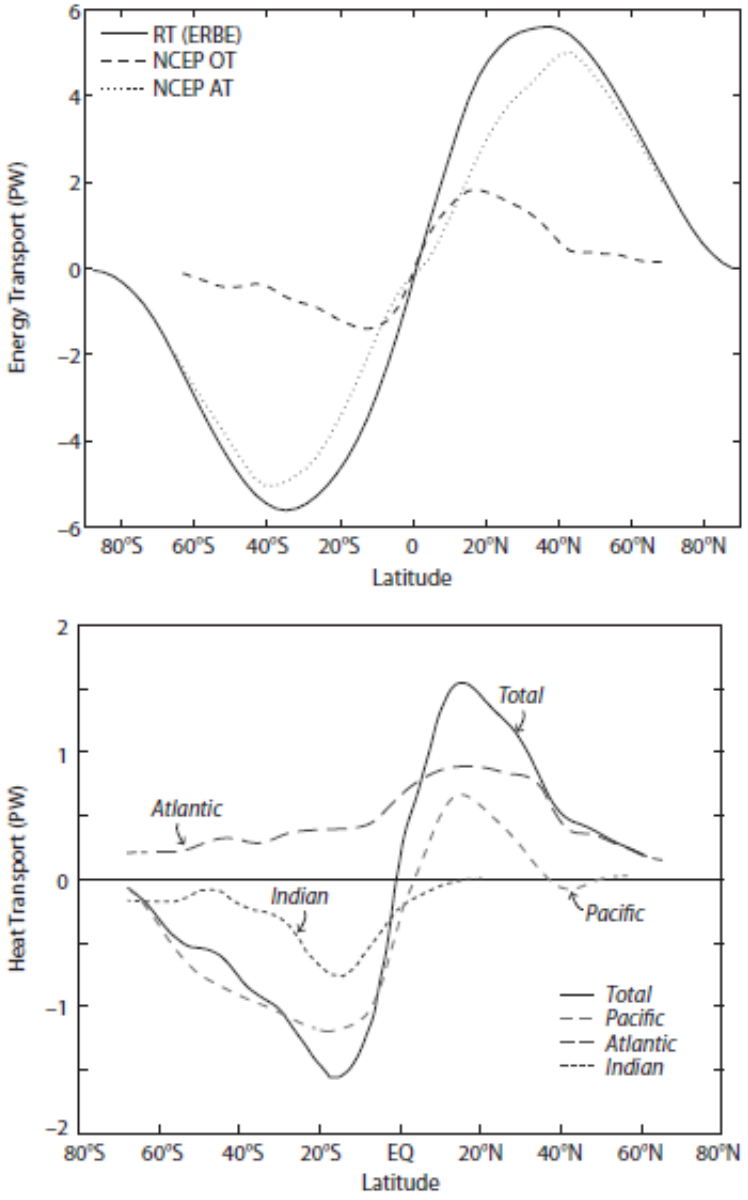
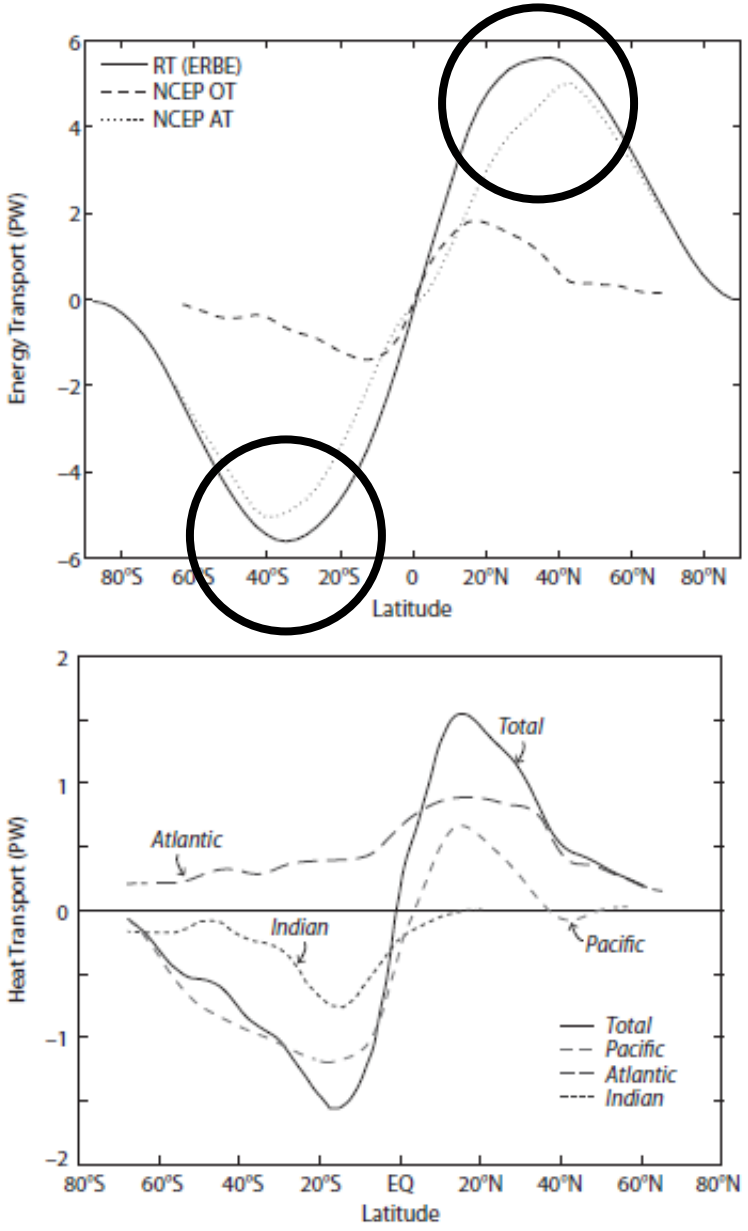


Figure 5.3. Upper panel: Heat transport in the total atmosphere–ocean system (solid line), in the ocean (dashed line), and in the atmosphere (dotted line). Lower panel: Oceanic heat transport, subdivided into the various basins. Source: Trenberth and Caron, 2004.

Ocean heat transport



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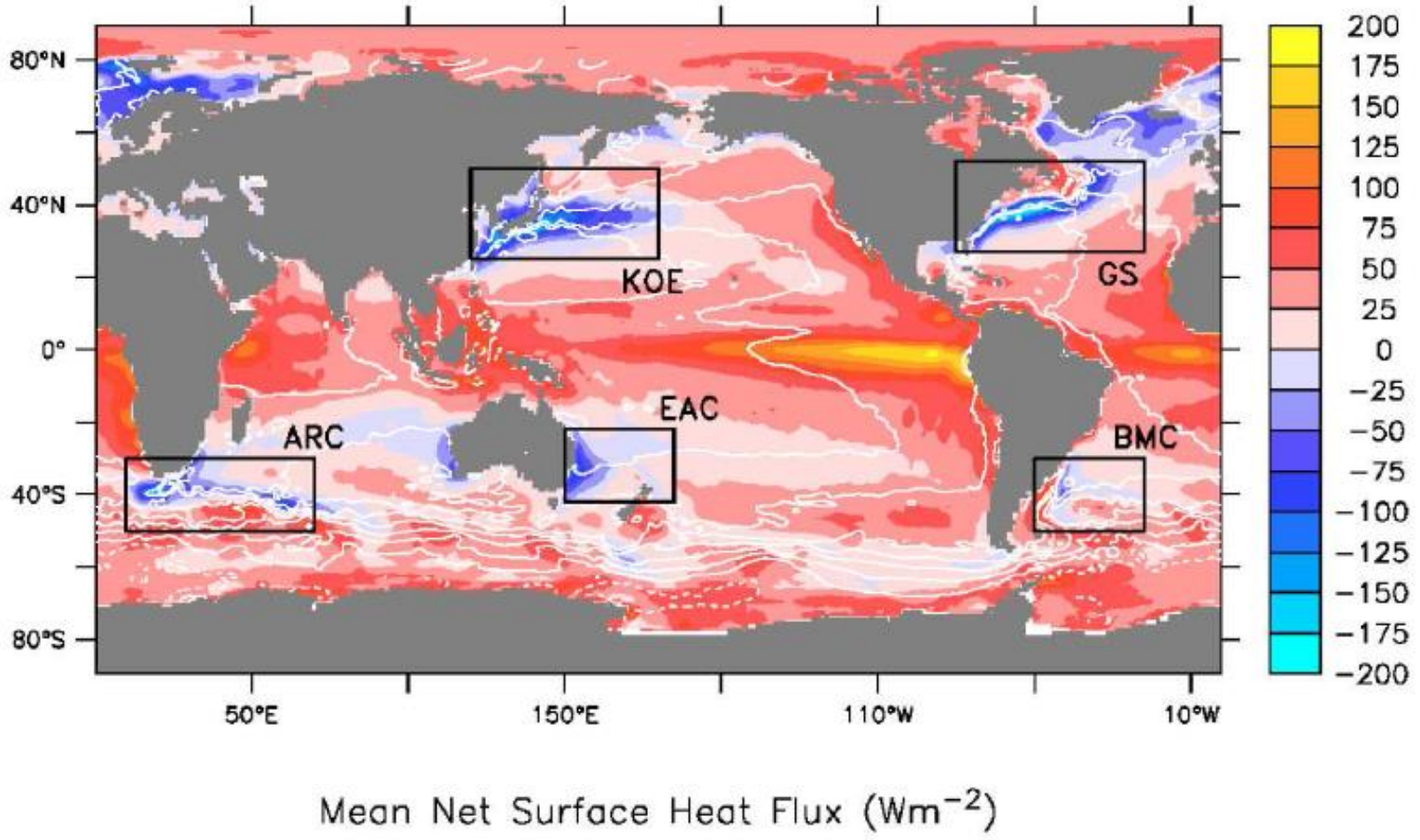


Source: Dommenget (2014)

Ocean heat transport

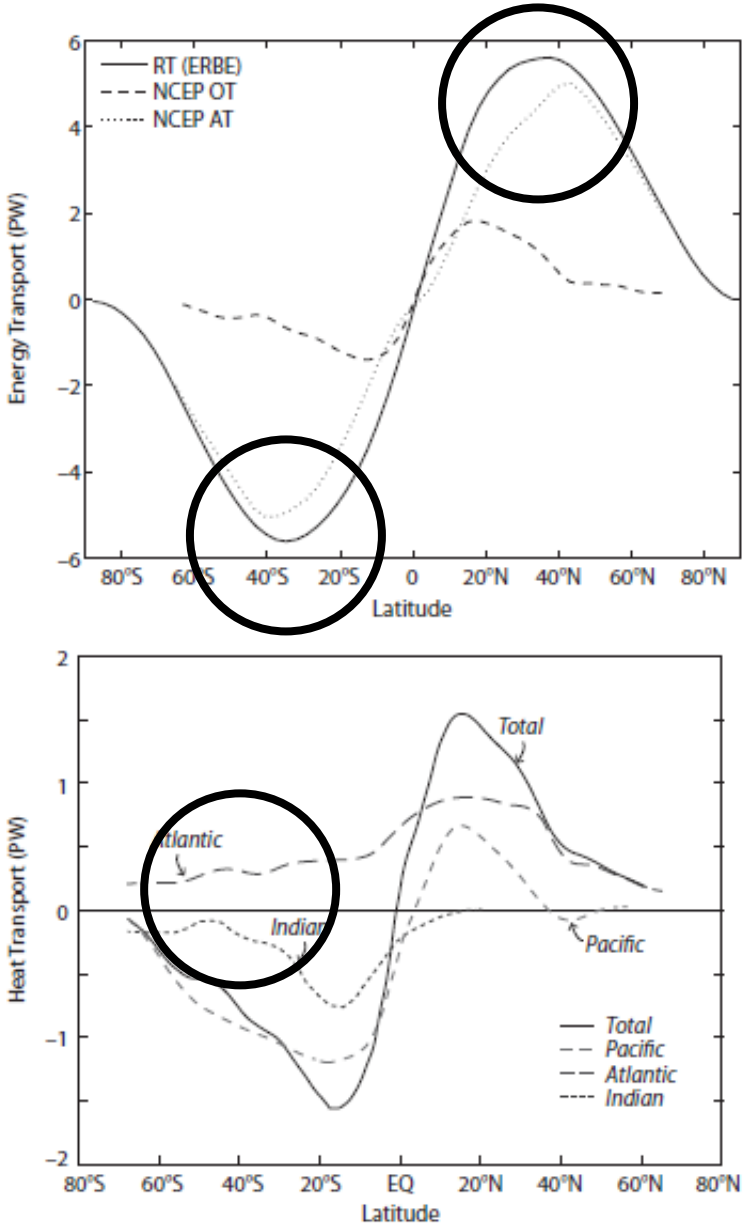
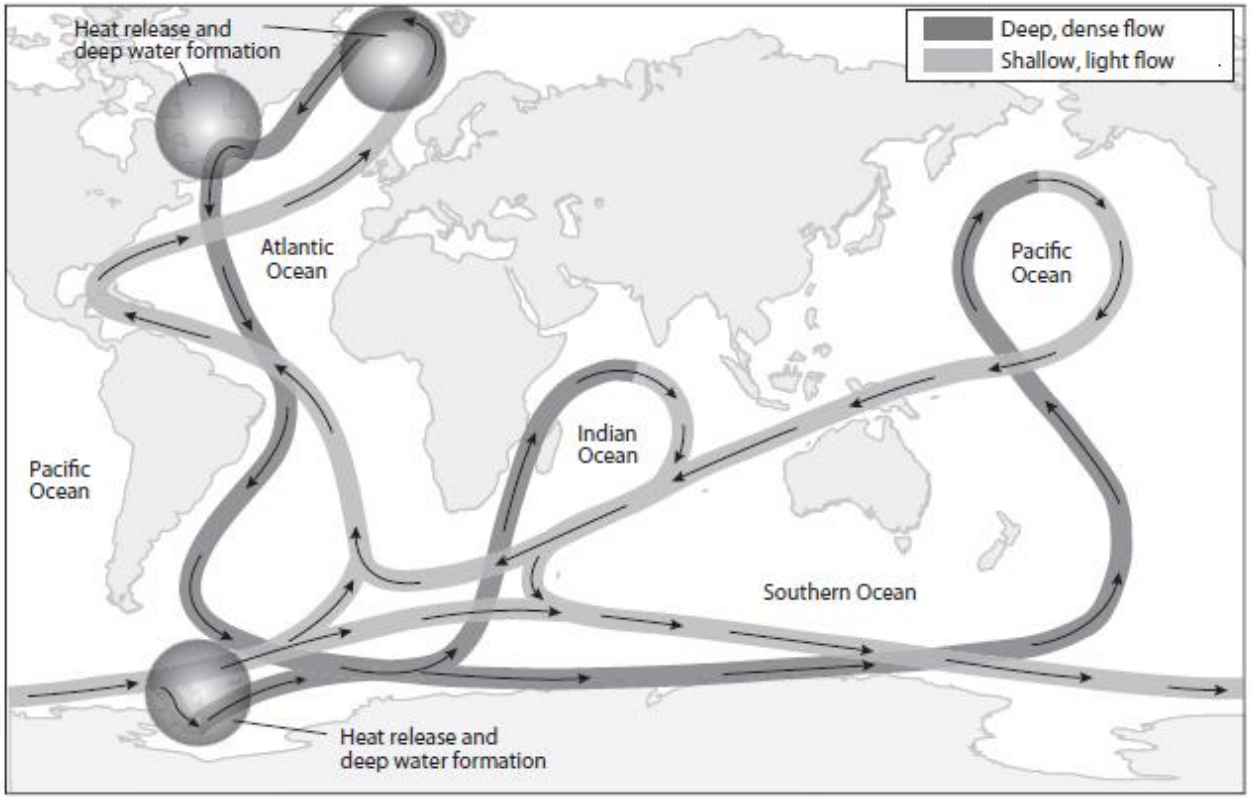


Figure 5.3. Upper panel: Heat transport in the total atmosphere–ocean system (solid line), in the ocean (dashed line), and in the atmosphere (dotted line). Lower panel: Oceanic heat transport, subdivided into the various basins. Source: Trenberth and Caron, 2004.

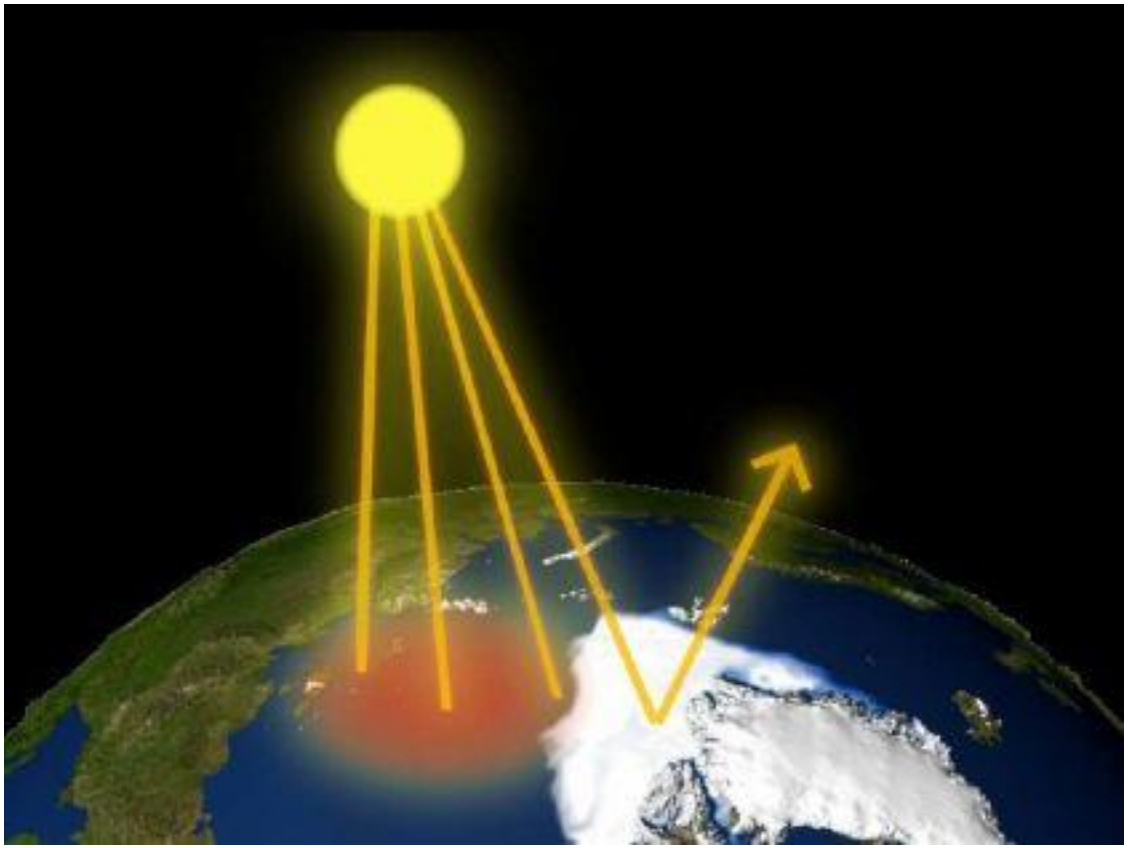
Ocean conveyor belt



Source:Vallis (2012) Climate and the oceans

Atmosphere heat transport

- **Low latitudes Hadley Cell**
- **Midlatitudes weather systems**



Forced and unforced climate variability

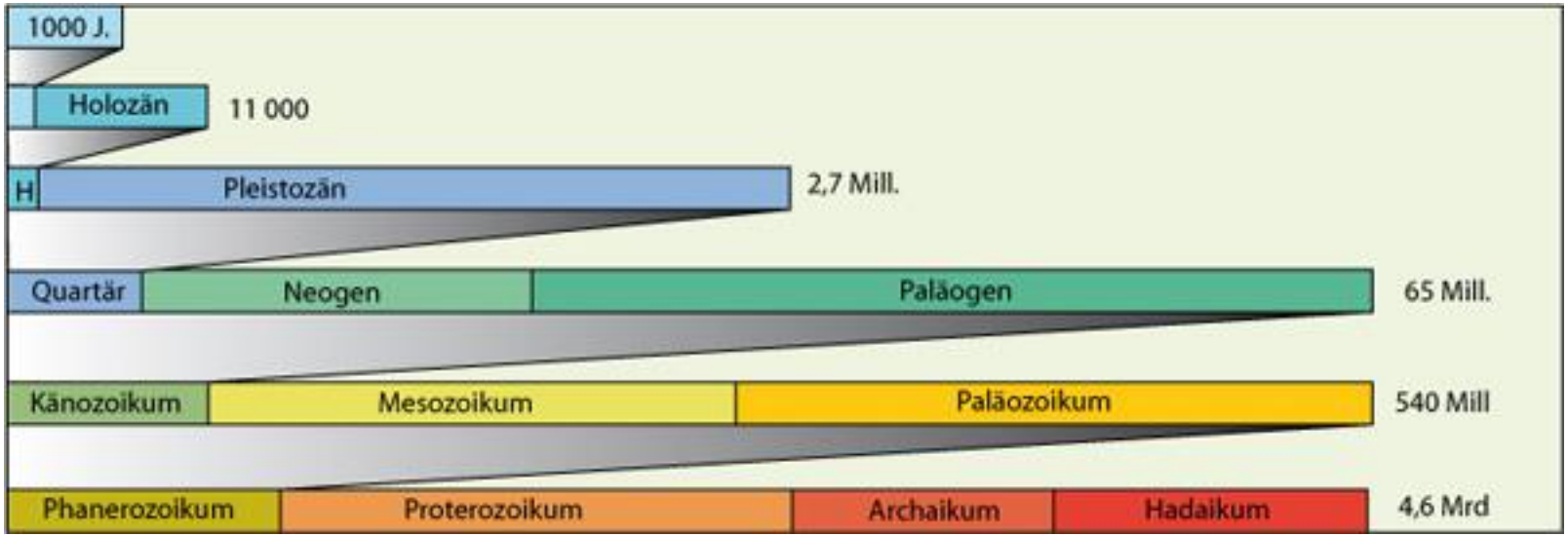
1. Paleo climate variability (ice ages)

Natural climate variability

- Volcanic eruptions (forced)
- Aerosols and greenhouse gases (forced)
- Solar variability (Sunspot activity, orbital parameters) (forced)
- Tectonic changes
- Internal (=unforced) variability generated by the non-linear dynamics of the climate system

Anthropogenic impact on climate

- Anthropogenic emission of greenhous gases and aerosols (forced)



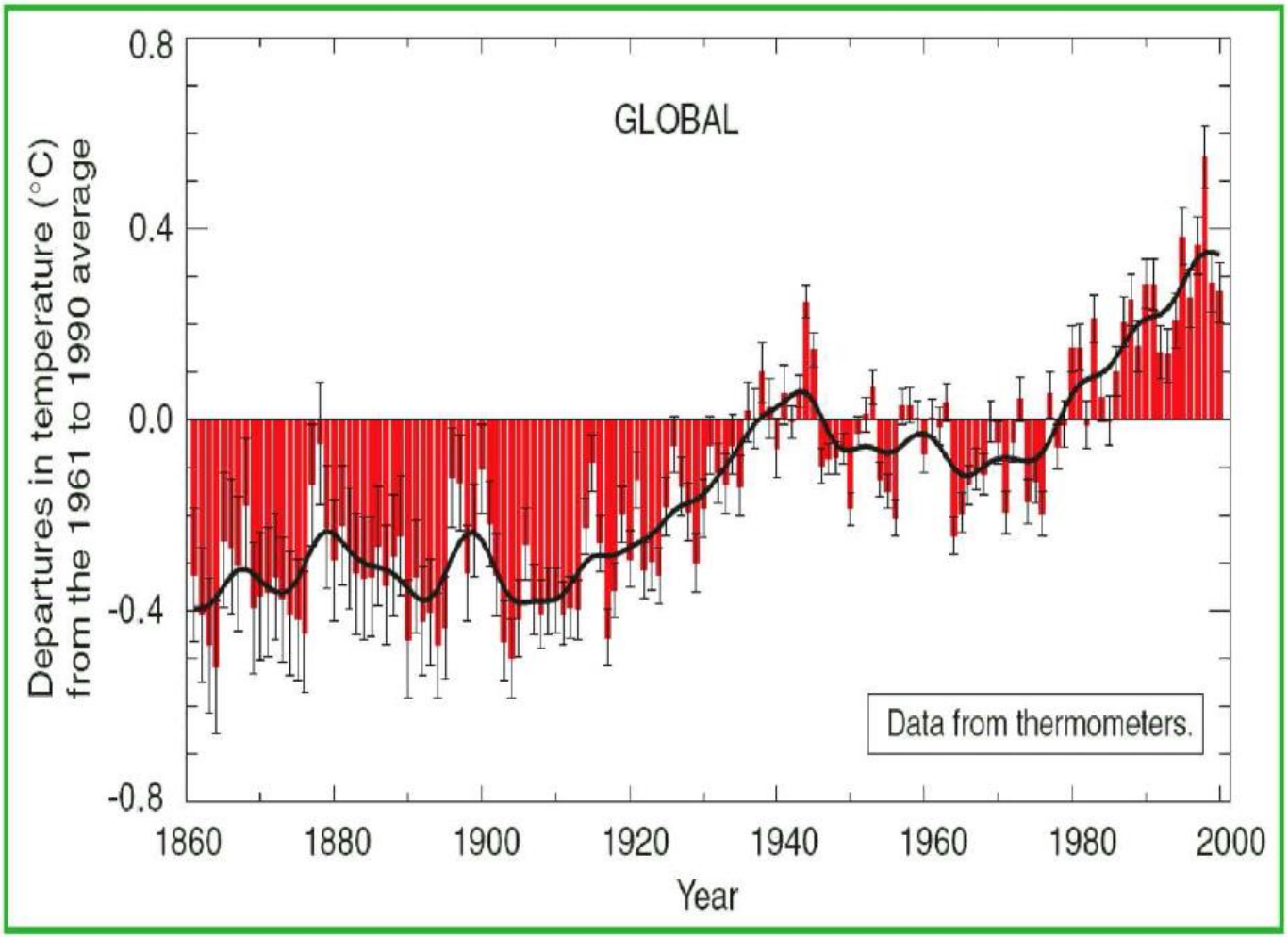
Präkambrium

3.5 Mrd first forms of life

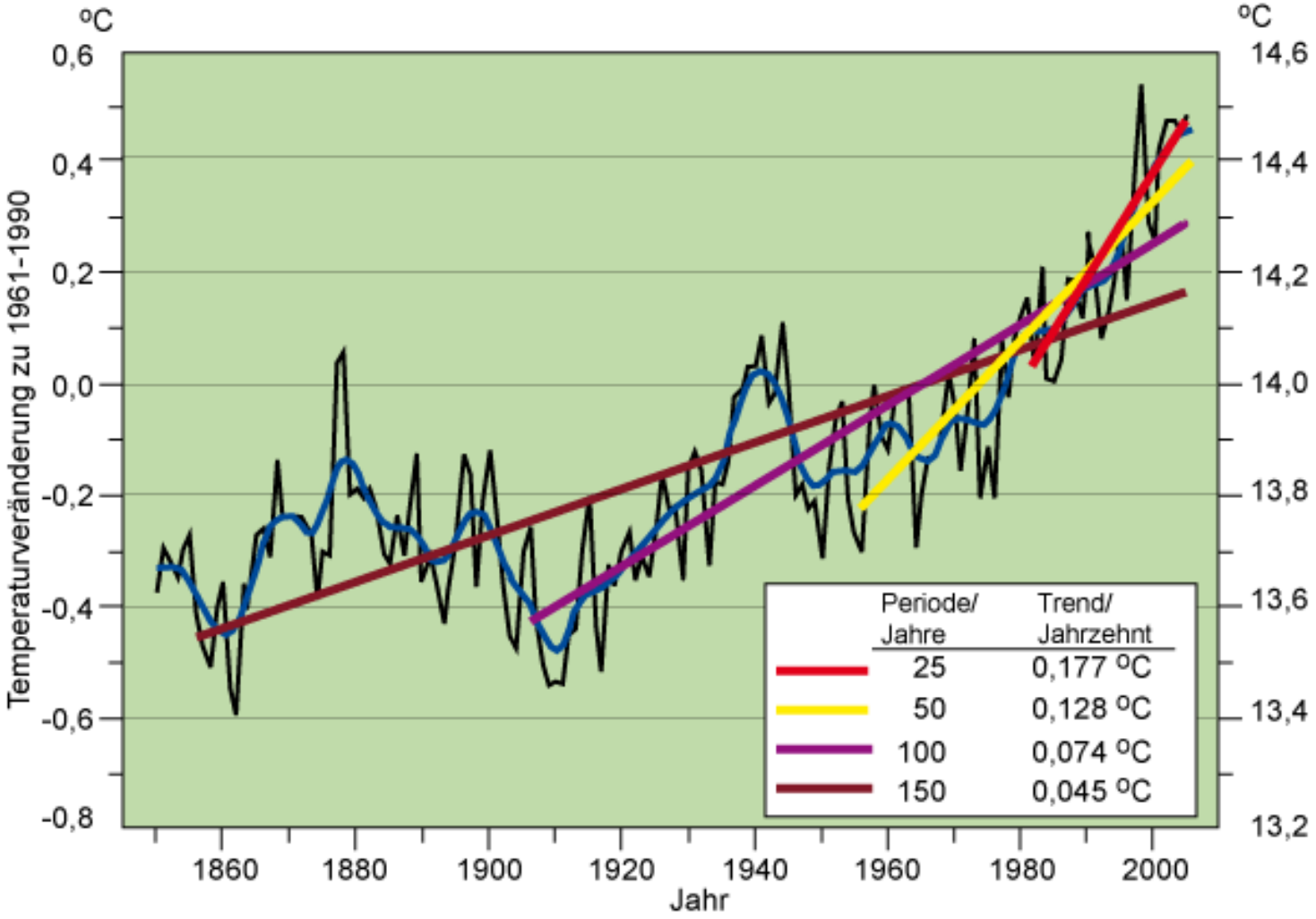
Source: http://bildungsserver.hamburg.de/klimawandel/

Climate (proxy) data

1. Thermometer measurements



Source: Dommenget (2014)



Source: Dommenget (2014)

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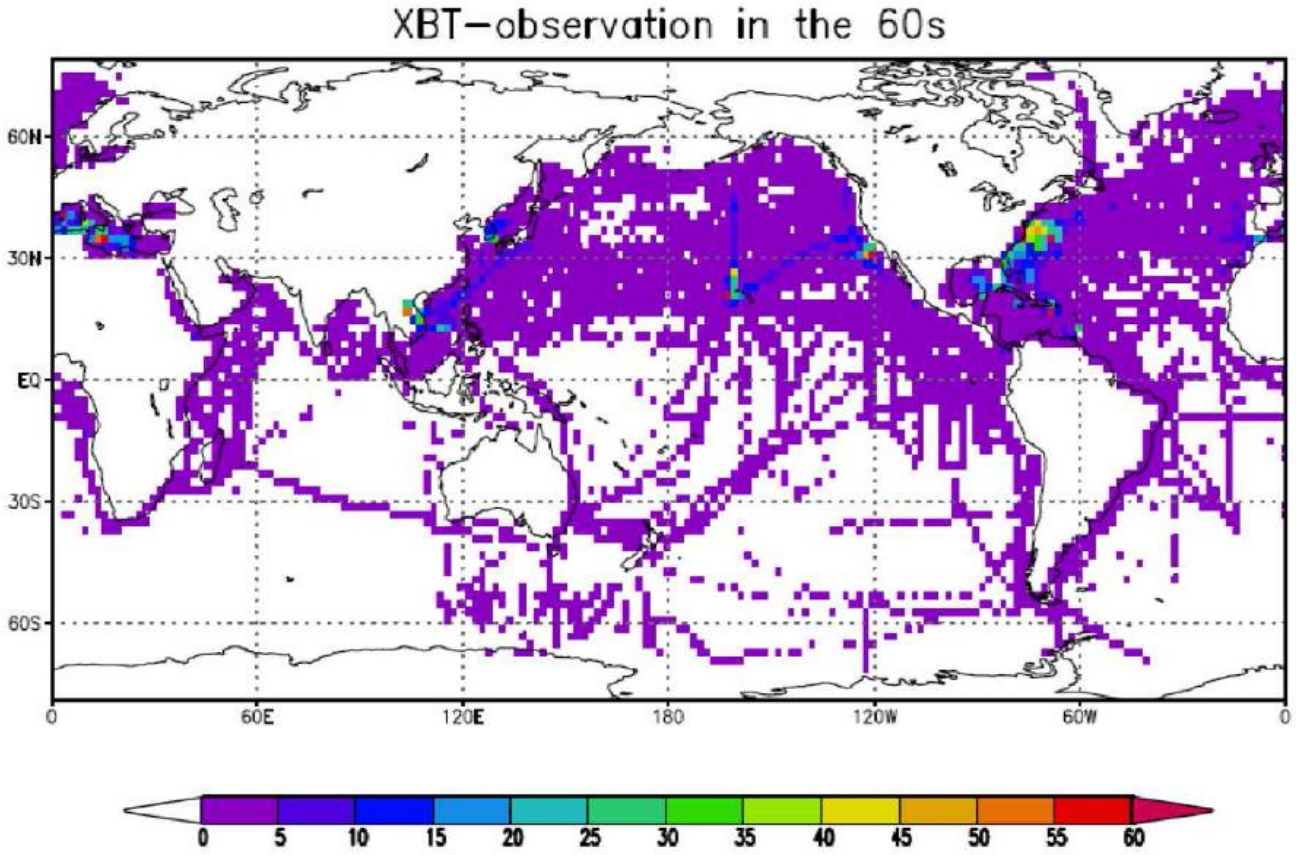

Source: Dommenget (2014)

Climate (proxy) data

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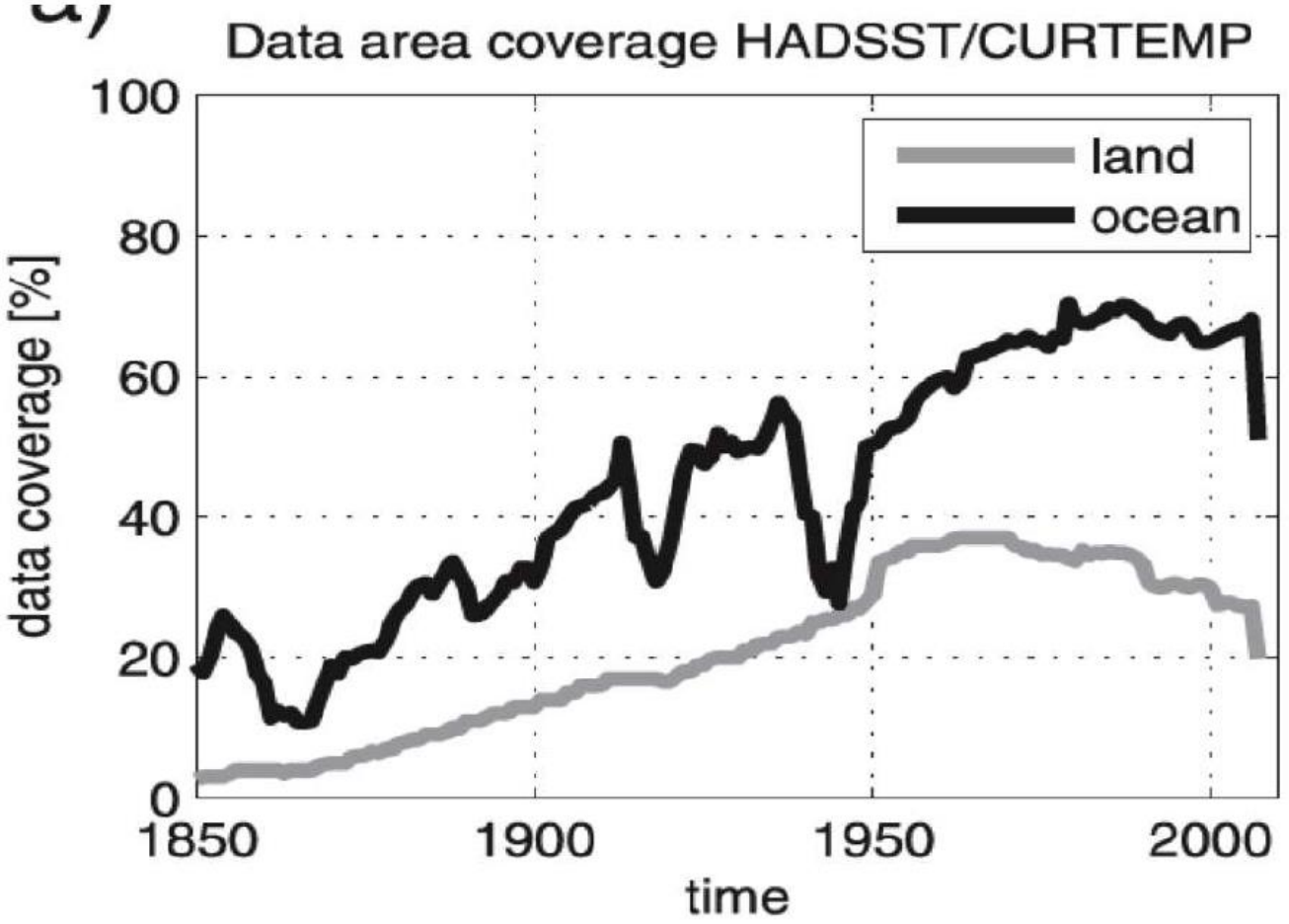
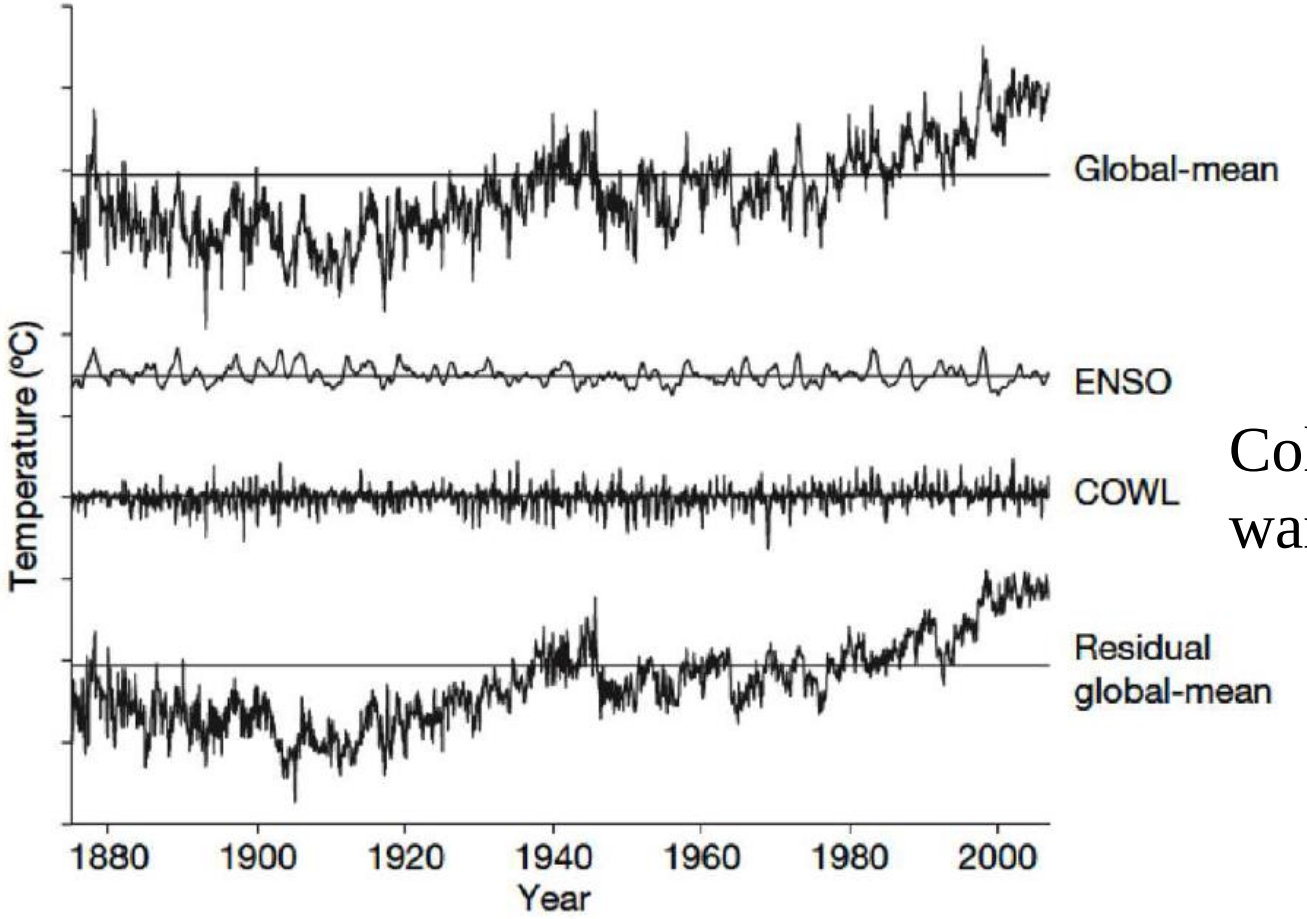


Data area coverage over land (CRUTEMP) and oceans (HADISST)
Source: Dommenget (2014)

Climate (proxy) data

1. Thermometer measurements

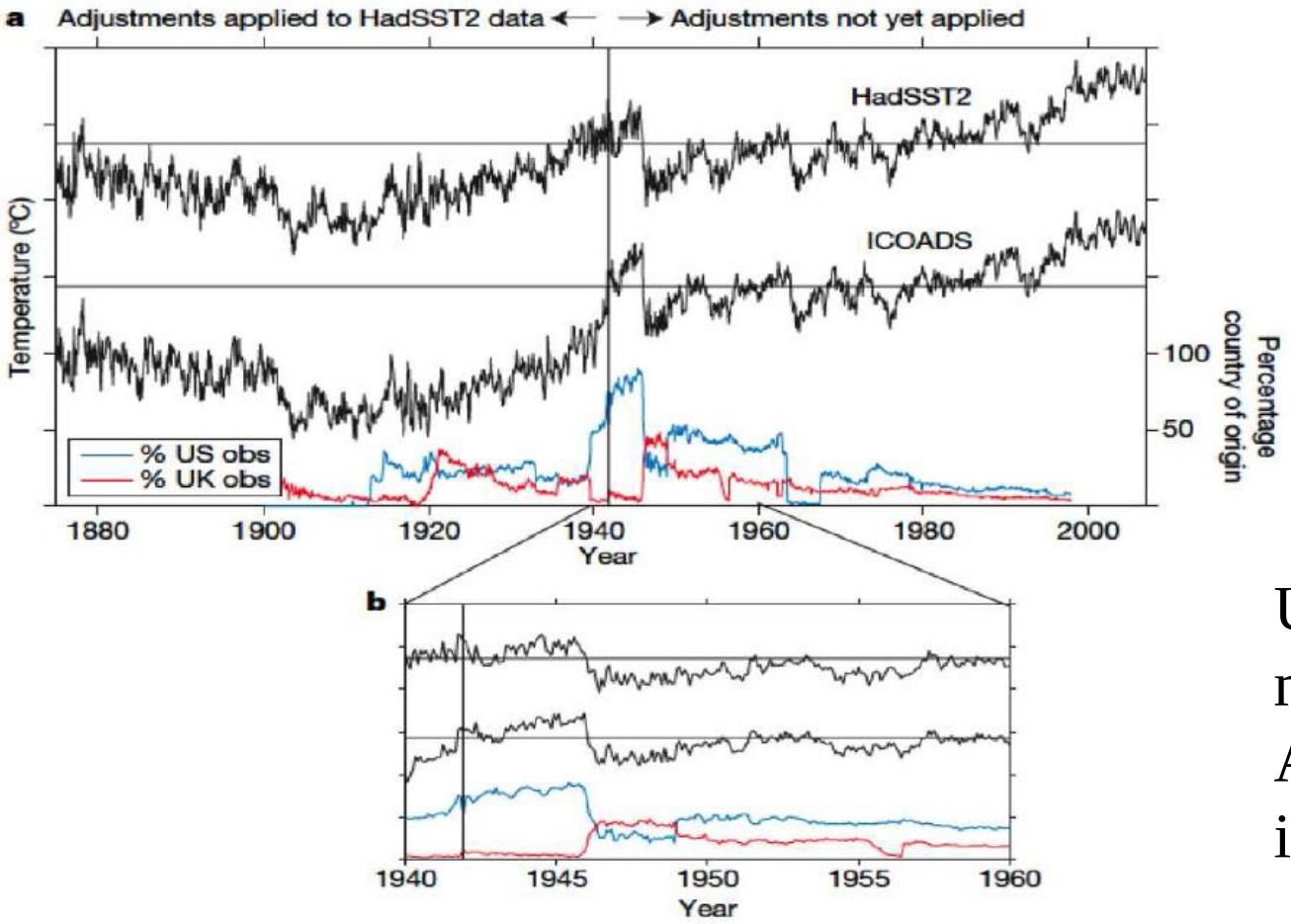


Cold ocean –
warm land pattern

Source: Dommenget (2014)

Climate (proxy) data

1. Thermometer measurements



UK ships measured in the Atlantic, US ships in the Pacific

Source: Dommenget (2014)

Climate (proxy) data

2. Climate proxies: tree rings

Summer temperature, dependence on the region

Source: Dommenget (2014)

Climate (proxy) data

3. Climate proxies: ice cores δ O 18

Antarctic ice sheet (4 km) very old (1 mio years), O18 isotope ratios depend on the water masses (surrounding oceans) and atm temperatures that produce the precip, air bubbles (atm chem composition)

Source: Dommenget (2014)

Climate (proxy) data

4. Climate proxies: corals

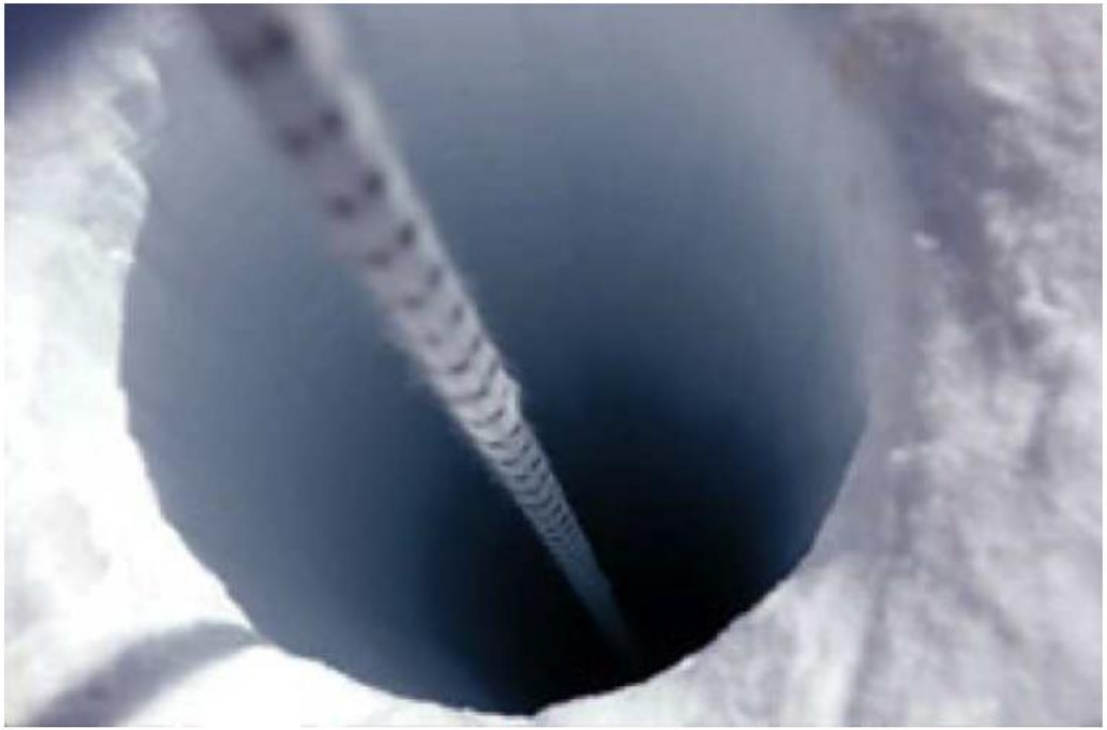
Proxy of SST in shallow waters < 5m, many thousand years

Source: Dommenget (2014)

Climate (proxy) data

5. Climate proxies: ice borehole temperatures

Temp from the days when the ice layer is formed, many thousand years



Source: Dommenget (2014)

Climate (proxy) data

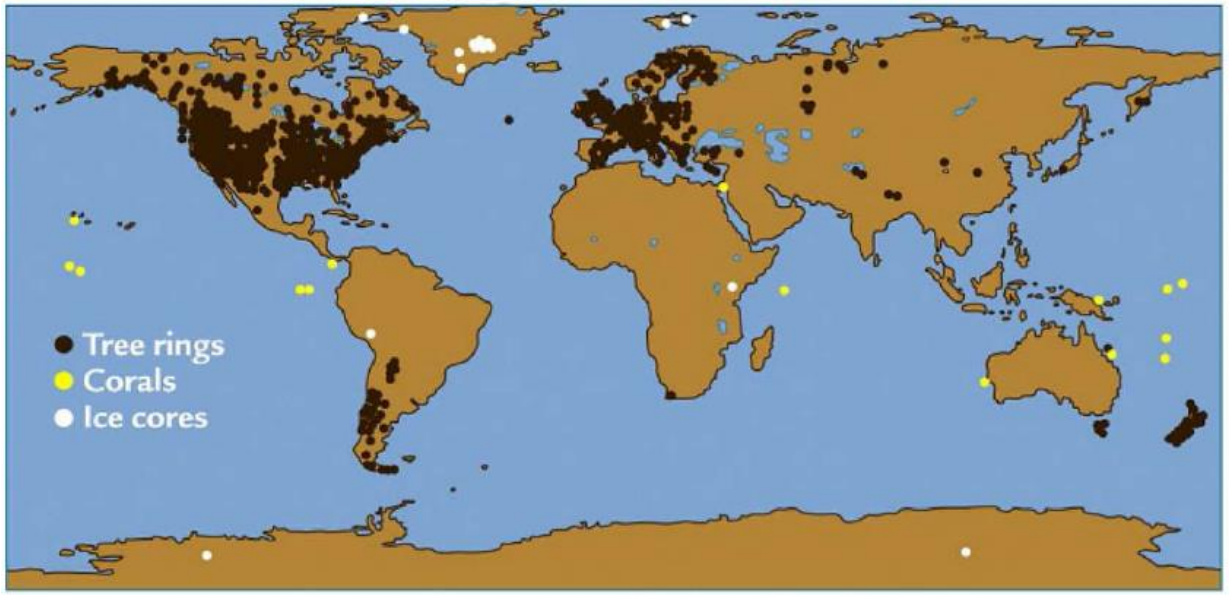
6. Climate proxies: sediments

Several climate indicators, track fossils, many million years

Source: Dommenget (2014)

Climate (proxy) data

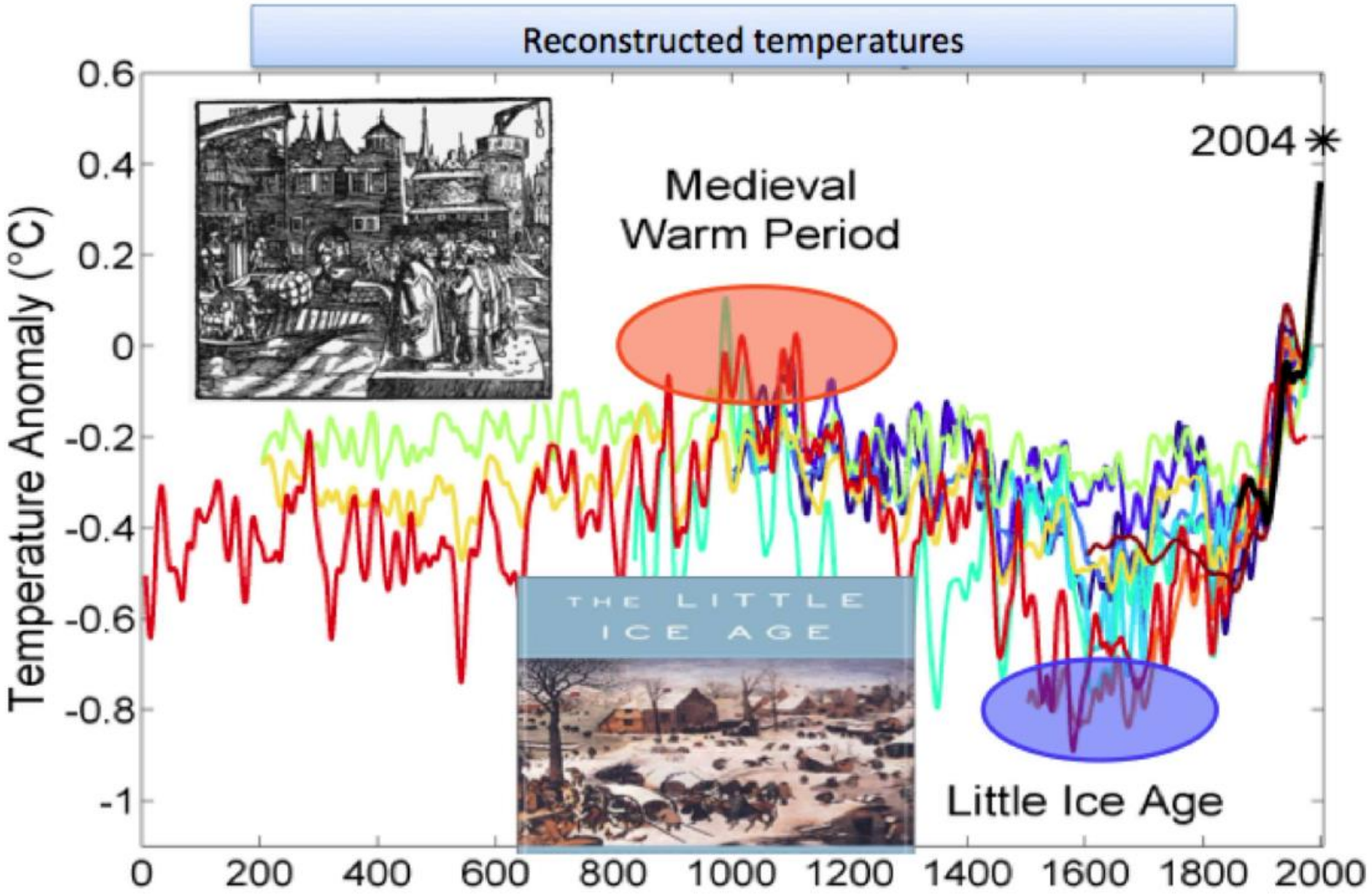
Distribution of climate proxy data



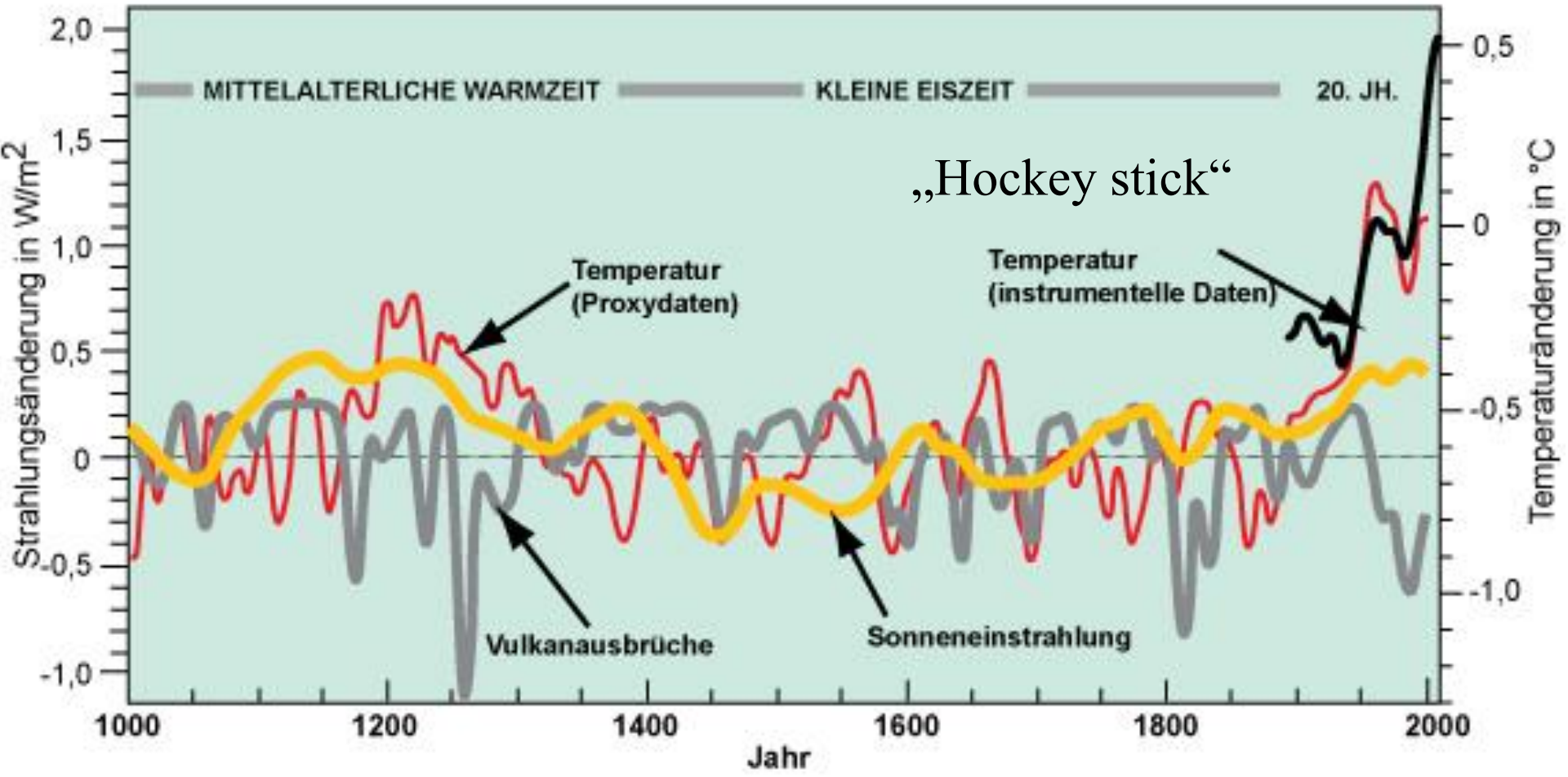
Source: Dommenget (2014)

Climate history

1. The last 2000 years



Source: Dommenget (2014)



Climate of the past 2000 years relatively stabile, variability caused by internal variability with some impact of sun spot and volcanic activities

Source: http://bildungsserver.hamburg.de/klimawandel/

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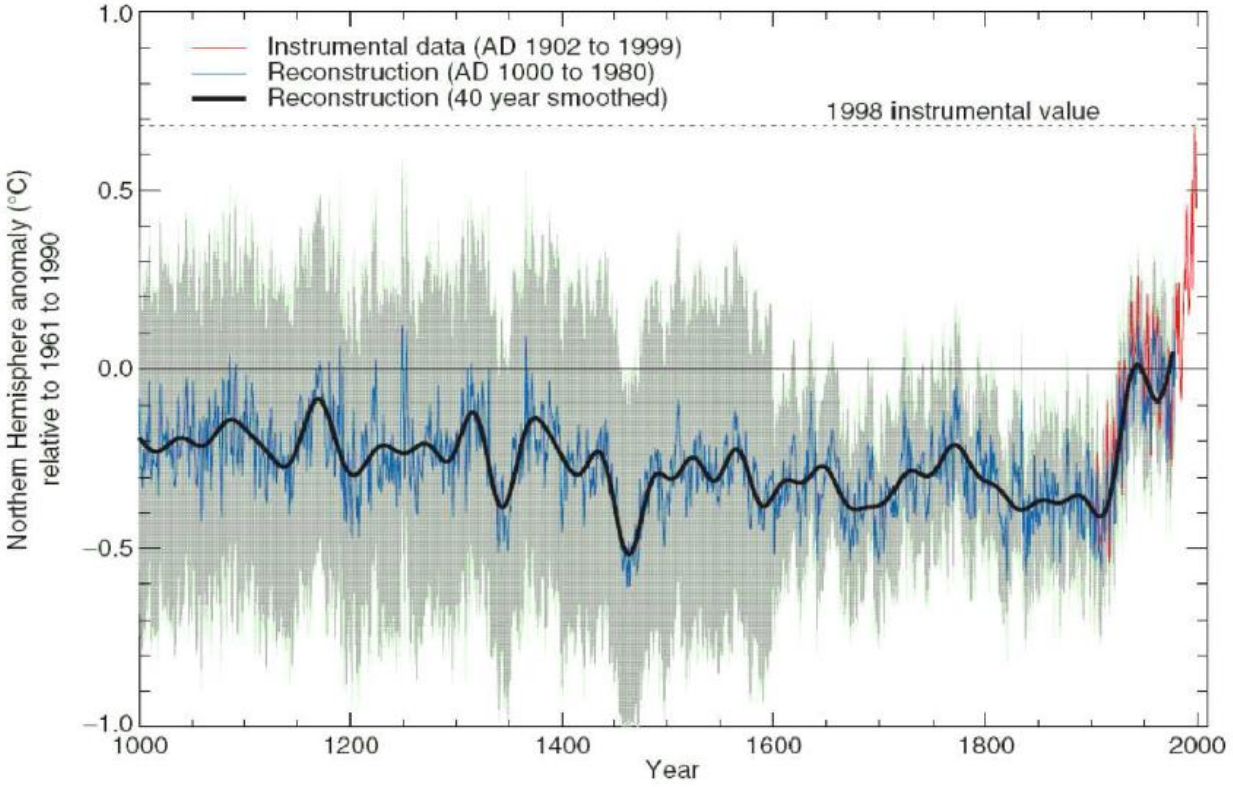
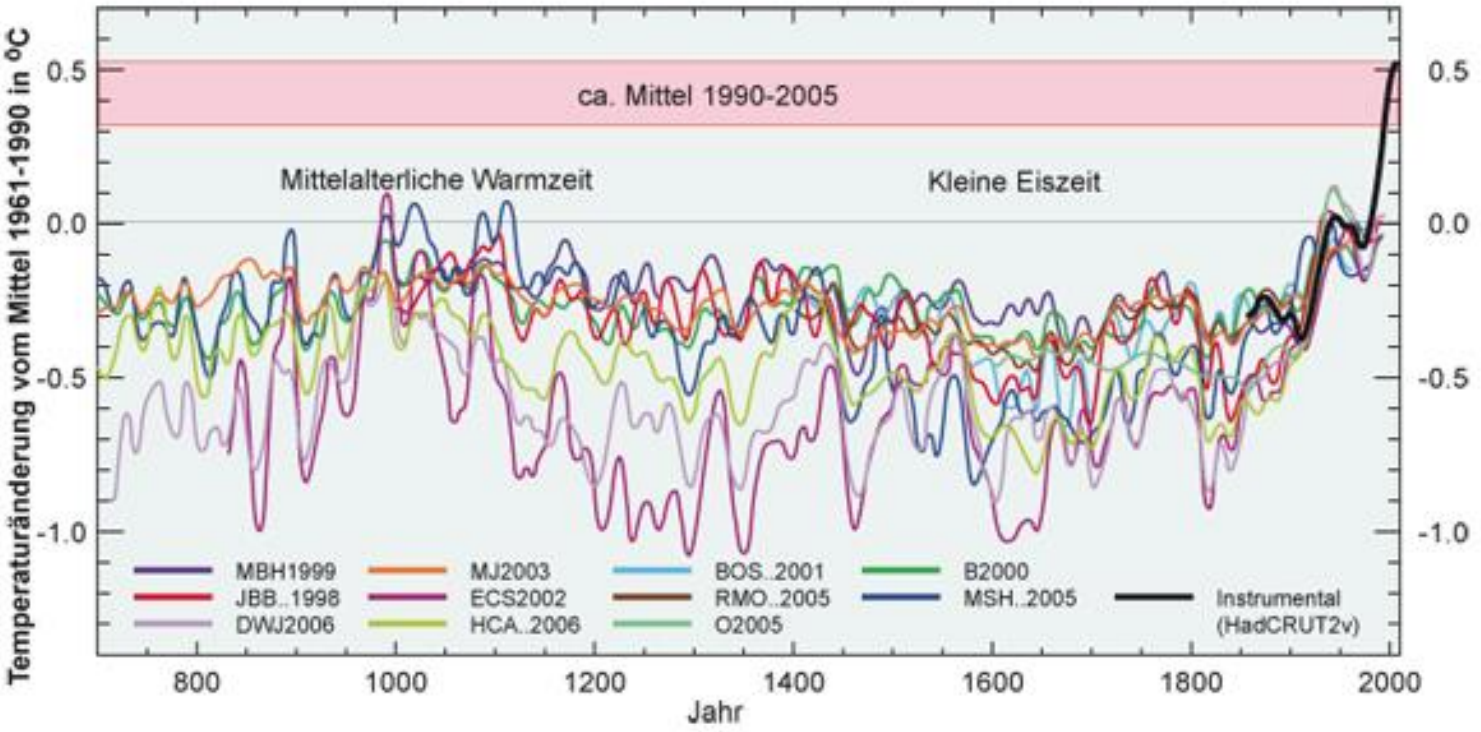
Climate history

1. The last 2000 years



Reconstruction of the northern hemisphere temperature

Source: Dommenget (2014)



Source: http://bildungsserver.hamburg.de/klimawandel/

Climate history

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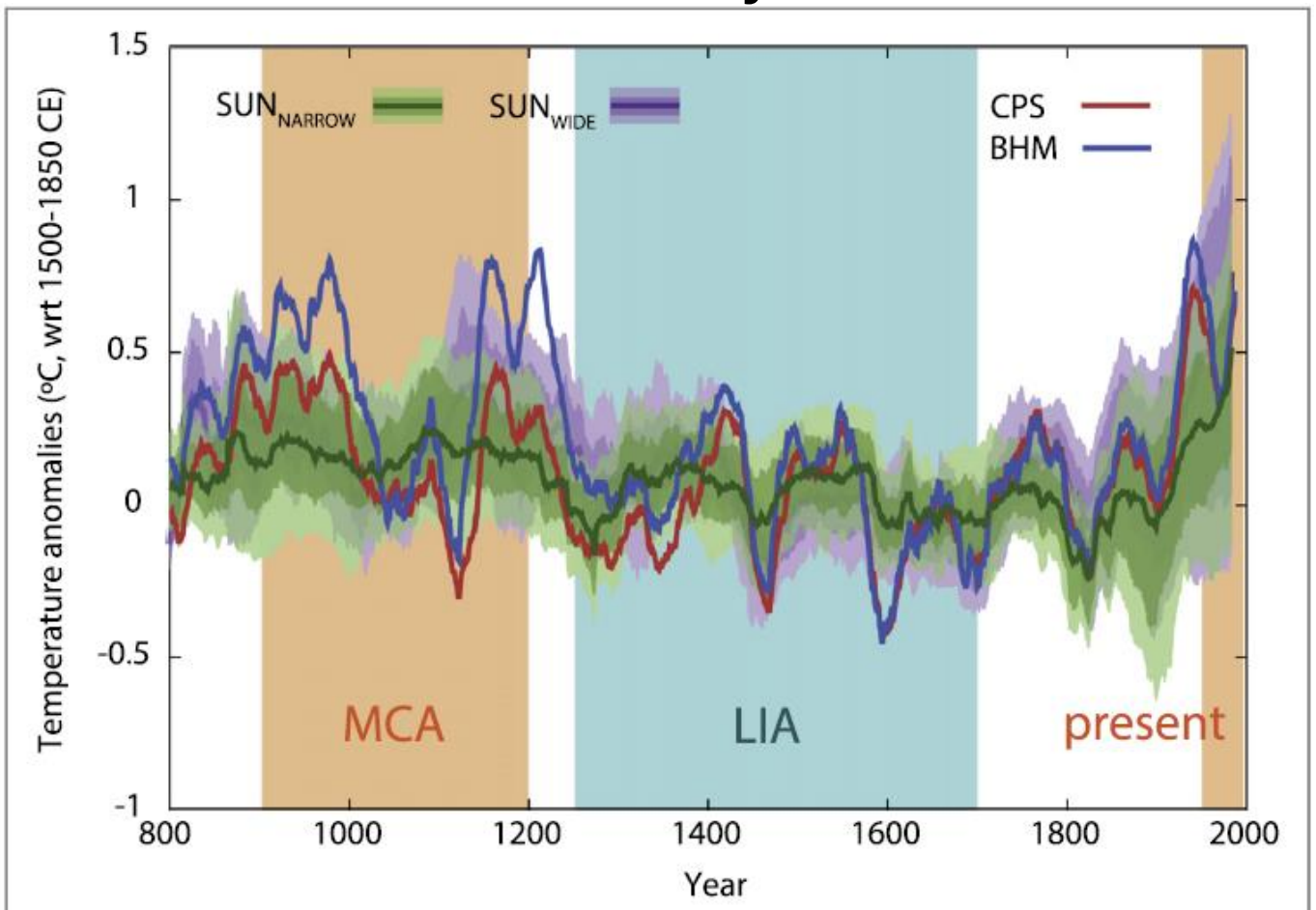
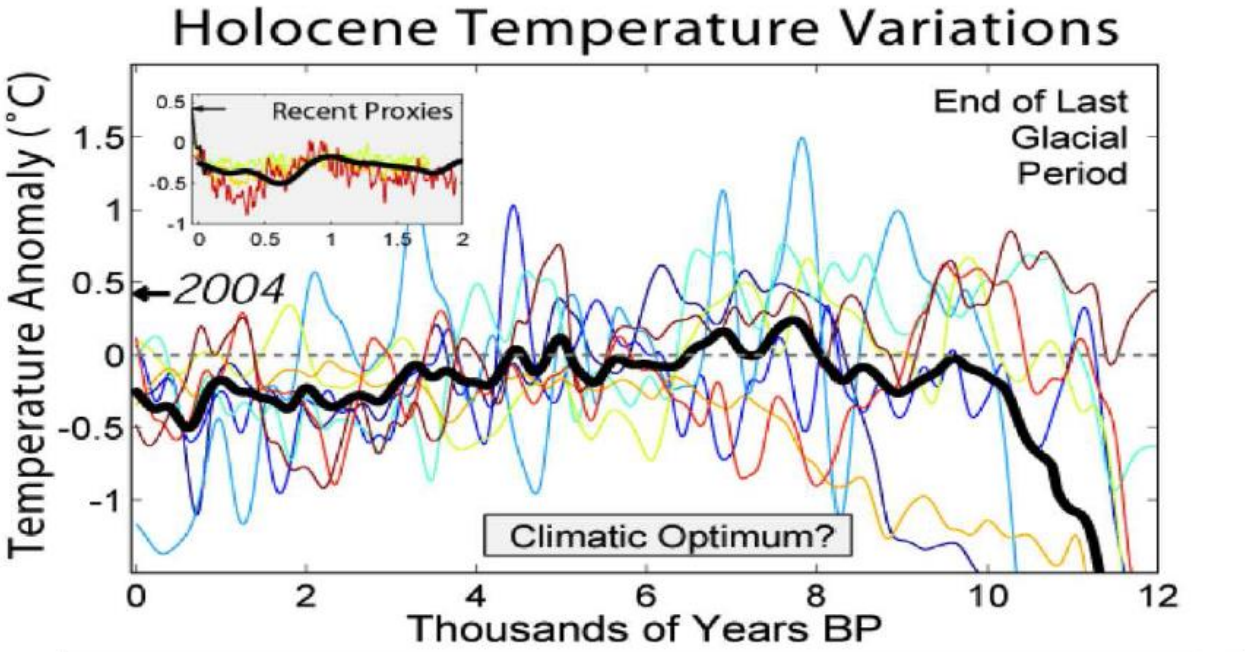


Figure 3. Simulated and reconstructed European summer land temperature anomalies (with respect to 1500–1850 CE) for the last 1200 yr, smoothed with a 31 yr moving average filter. BHM (CPS) reconstructed temperatures are shown in blue (red) over the spread of model runs. Simulations are distinguished by solar forcing: stronger (SUN_{WIDE}, purple; TSI change from the LMM to present >0.23%) and weaker (SUN_{NARROW}, green; TSI change from the LMM to present <0.1%). The ensemble mean (heavy line) and the two bands accounting for 50% and 80% (shading) of the spread are shown for the model ensemble (see SOM for further details).

(Source: Luterbacher et al. 2016)

Climate history

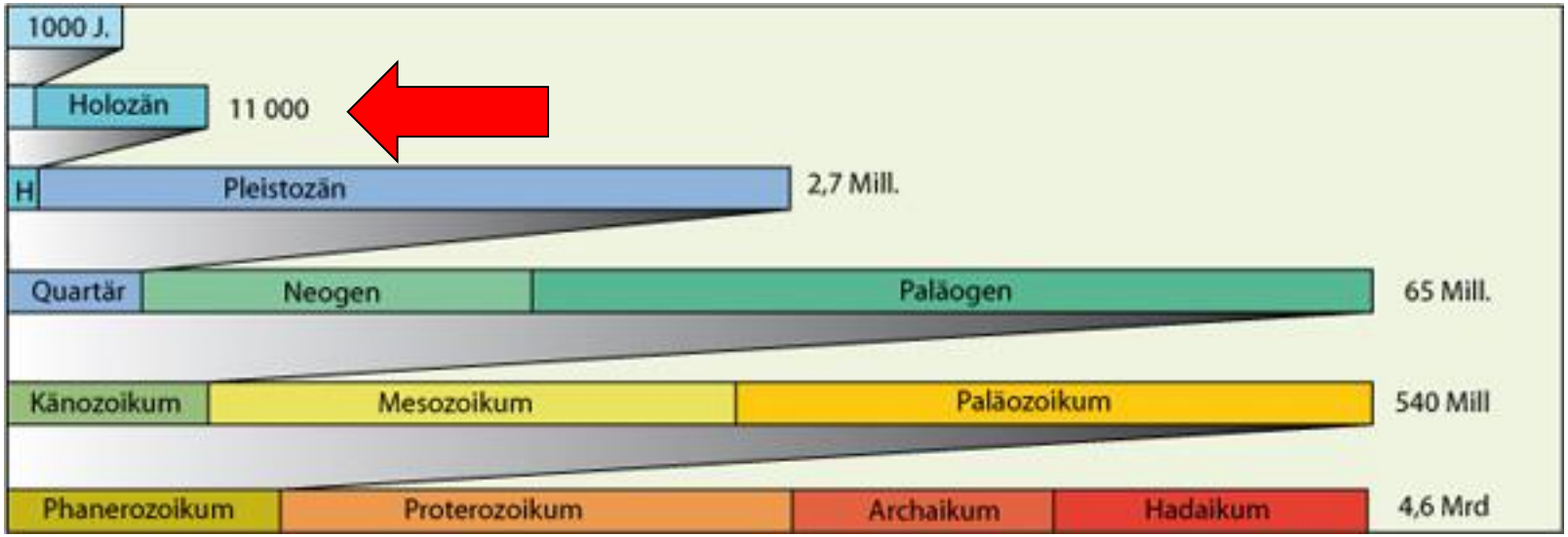
2. The last 10 000 years



Data Sources:

1. (dark blue) Sediment core ODP 658, interpreted sea surface temperature, Eastern Tropical Atlantic:
2. (blue) Vostok ice core, interpreted paleotemperature, Central Antarctica
3. (light blue) GISP2 ice core, interpreted paleotemperature, Greenland:
4. (green) Kilimanjaro ice core, $\delta^{18}O$, Eastern Central Africa.
5. (yellow) Sediment core PL07-39PC, interpreted sea surface temperature, North Atlantic: .
6. (orange) Pollen distributions, interpreted temperature, Europe:
7. (red) EPICA ice core, interpreted site temperature, Central Antarctica:
8. (dark red) Composite sediment cores,

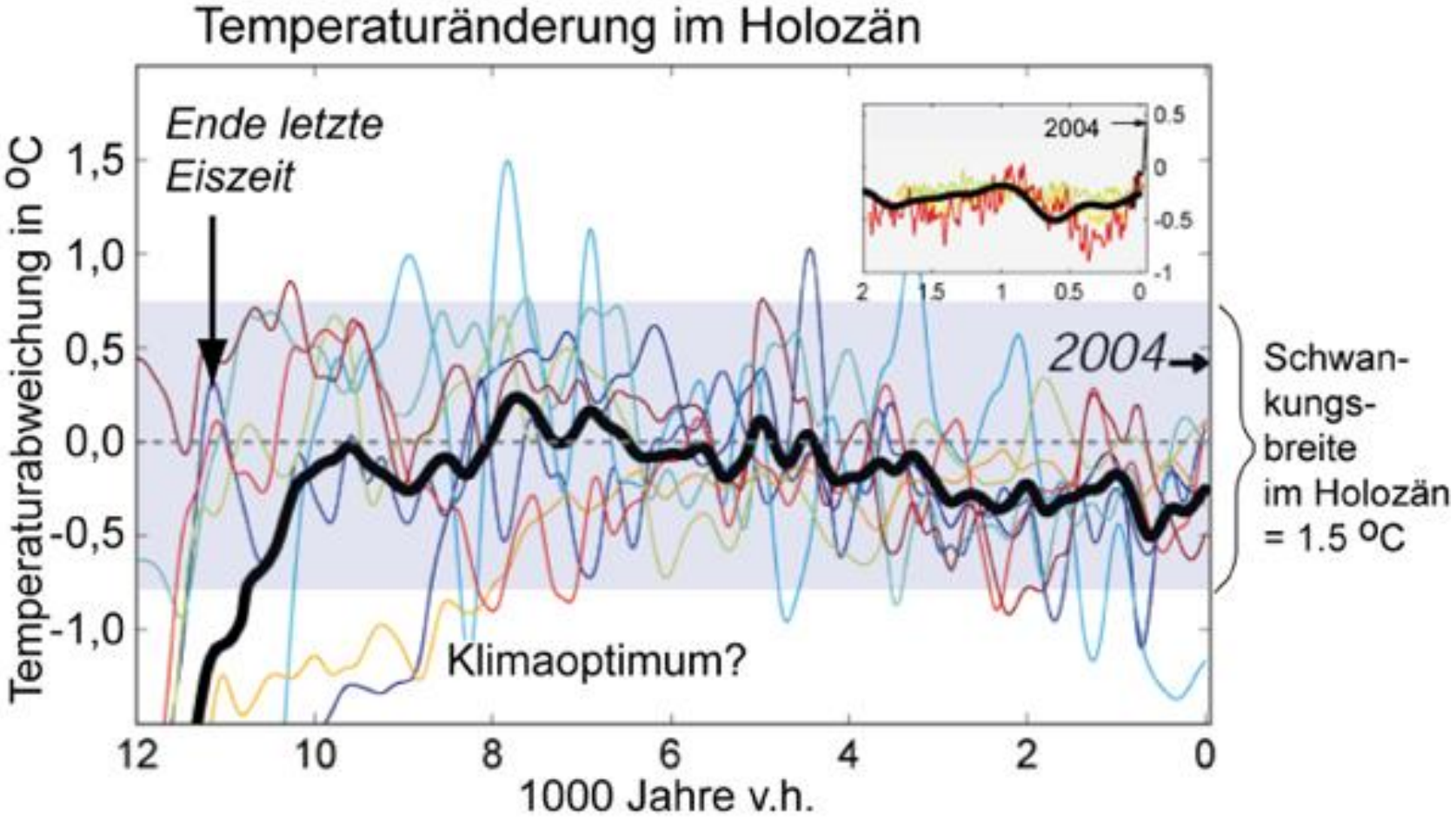
Source: Dommenget (2014)



Präkambrium

3.5 Mrd first forms of life

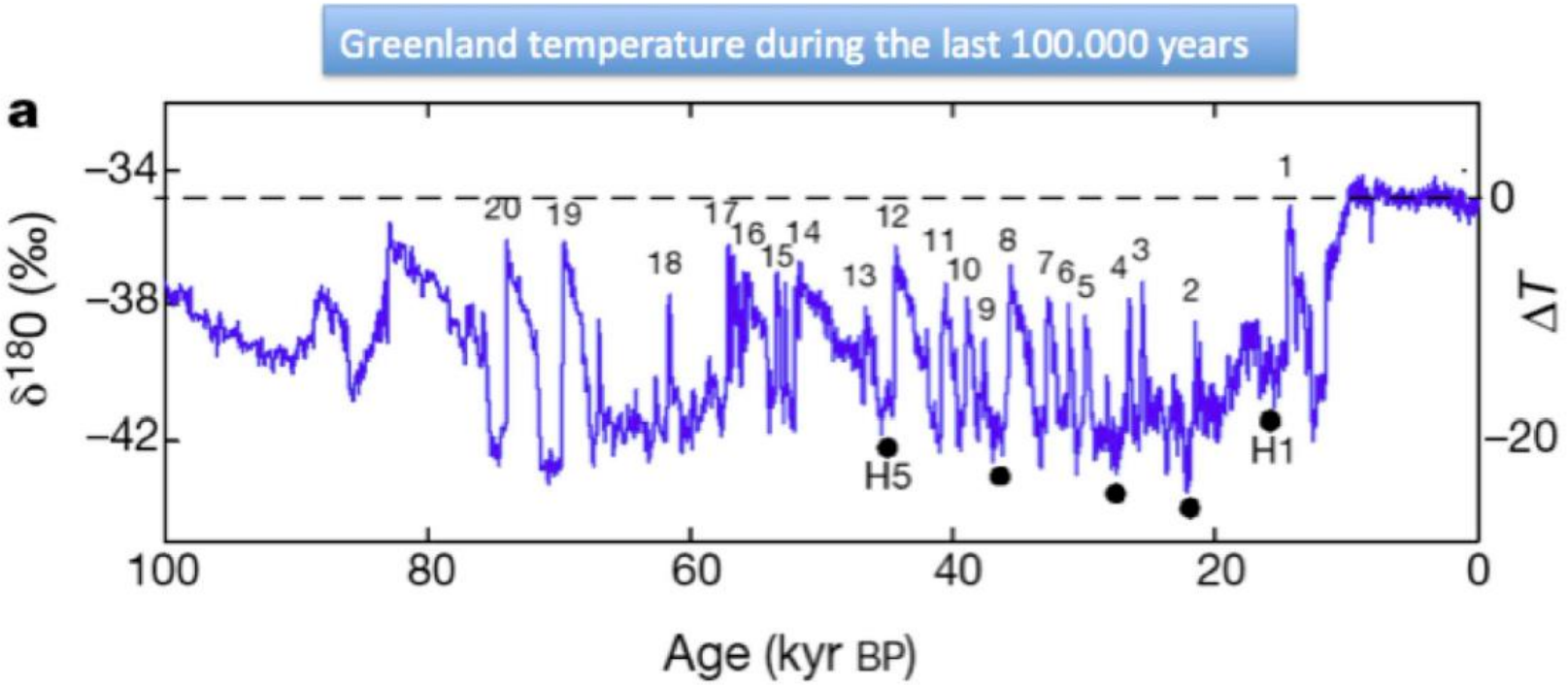
Source: http://bildungsserver.hamburg.de/klimawandel/



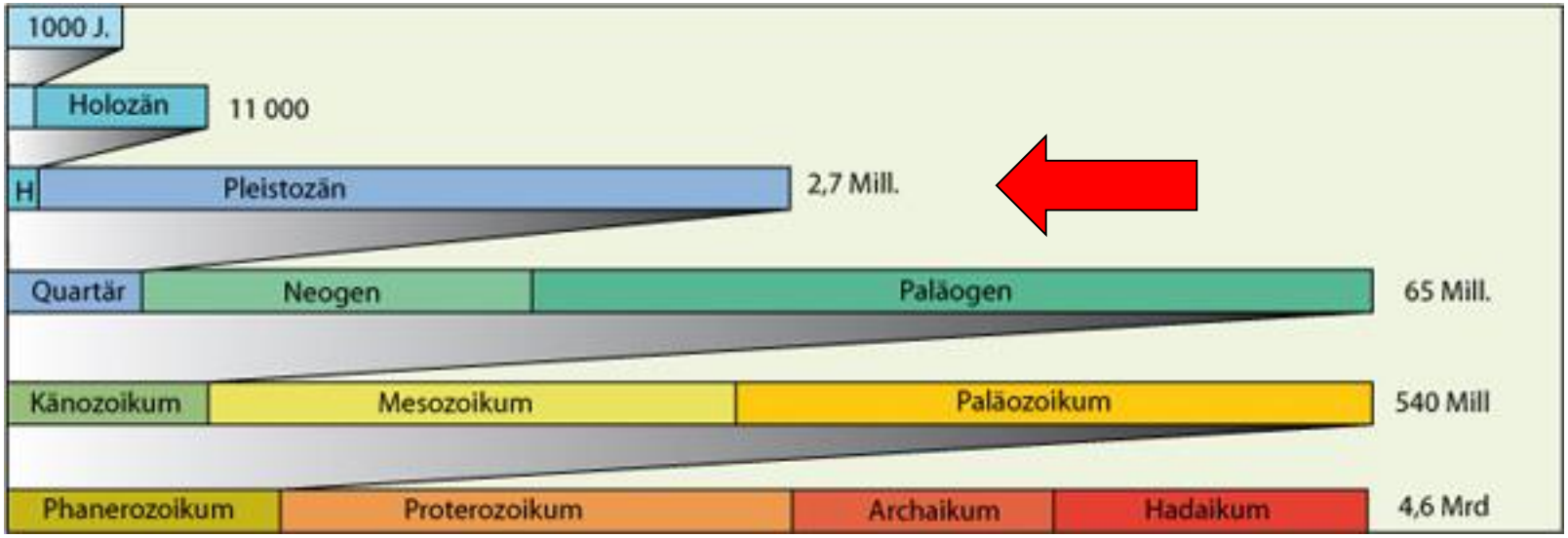
Source: http://bildungsserver.hamburg.de/klimawandel/

Climate history

3. The last 500 000 years (ice ages, Milankovitch cycles)



Source: Dommenget (2014)



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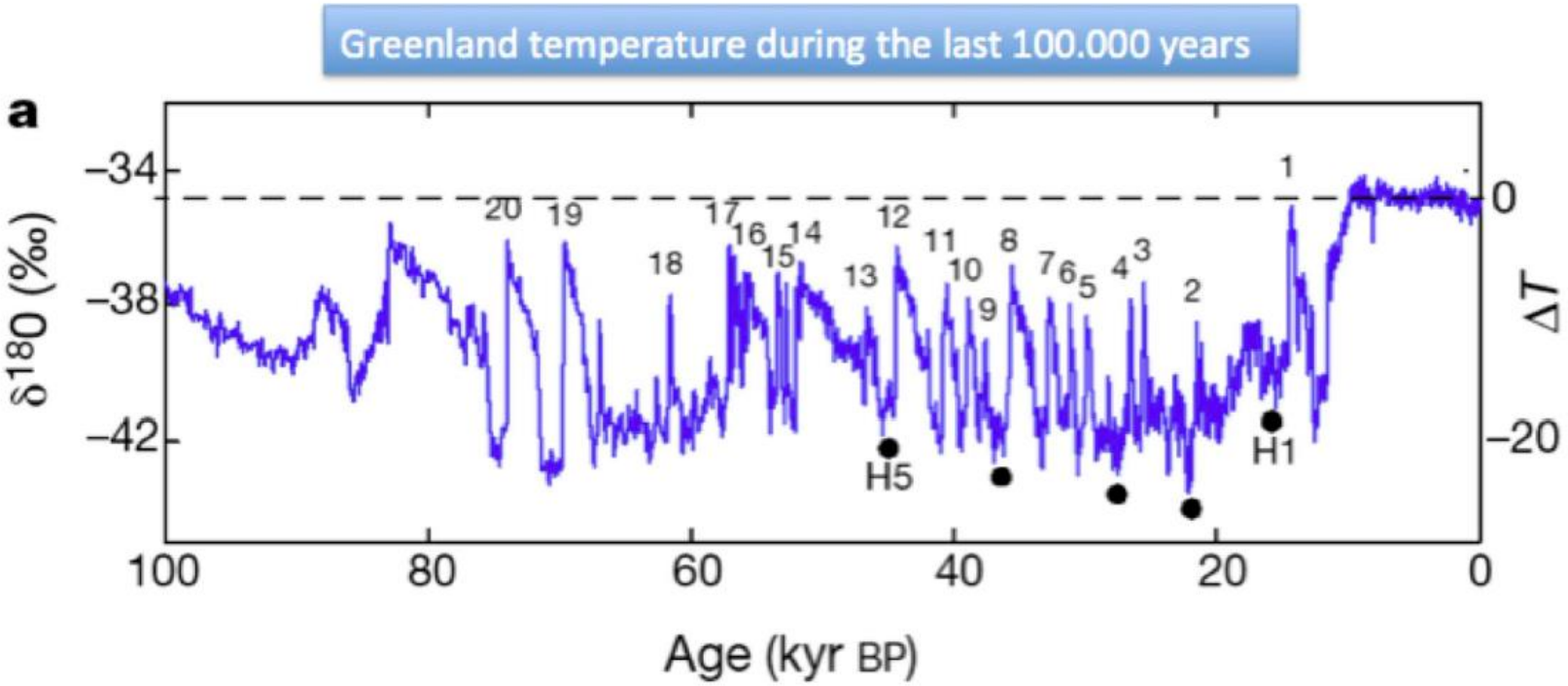
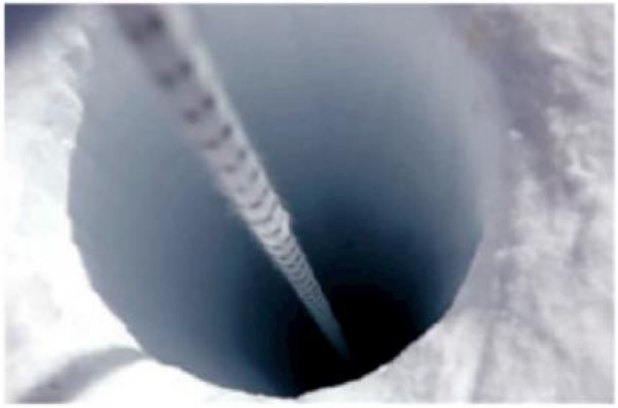


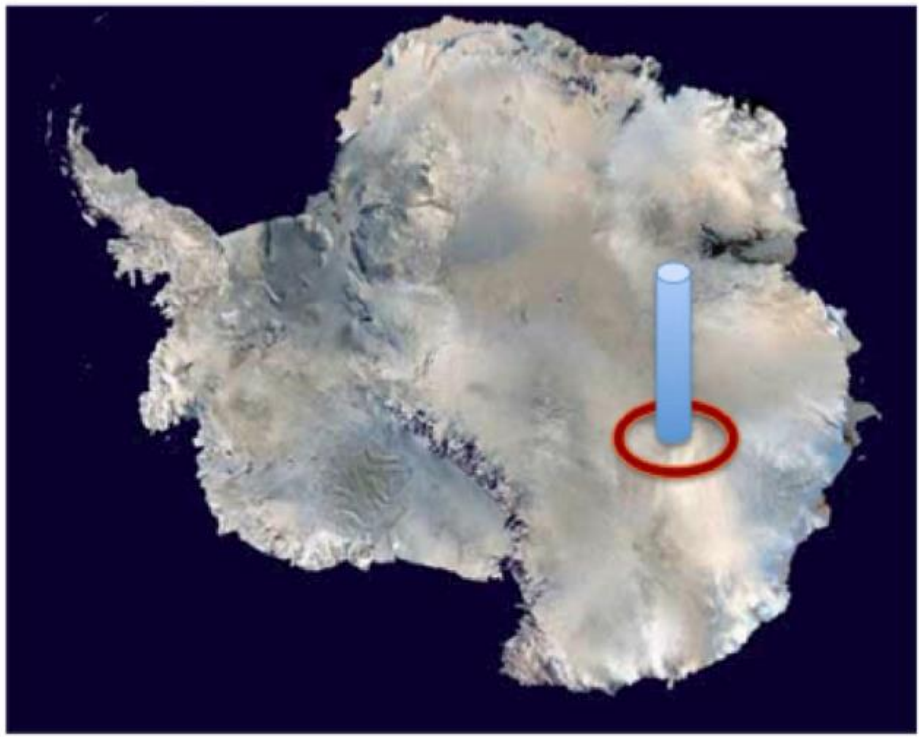
Dominated by big ice age cycles (short interglacials, long glacials), global extent, global temp difference 3K, some periods are 1-2 K warmer than today

Source: Dommenget (2014)

Climate history

Vostock ice core drilling site



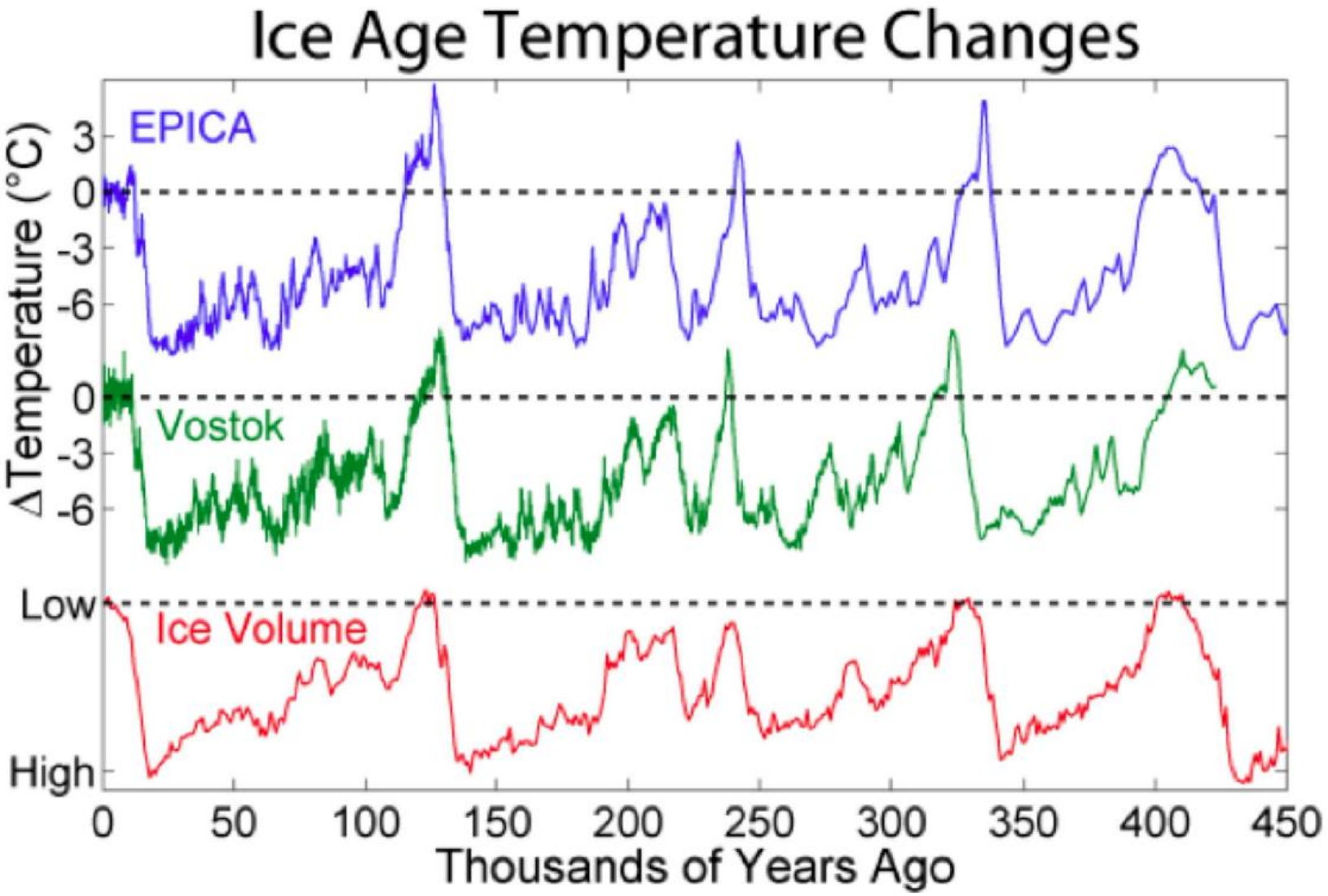


Thickest ice sheet, no drift, no snow, oldest ice

Source: Dommenget (2014)

Climate history

3. The last 500 000 years (ice ages, Milankovitch cycles)



Source: Dommenget (2014)

Climate history

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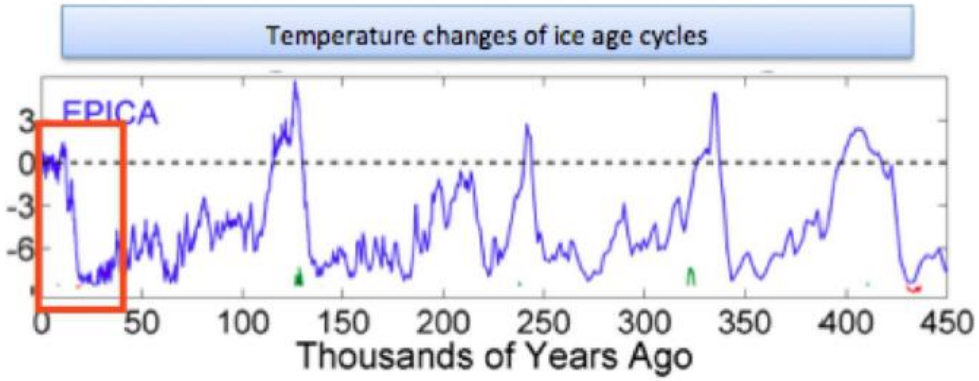
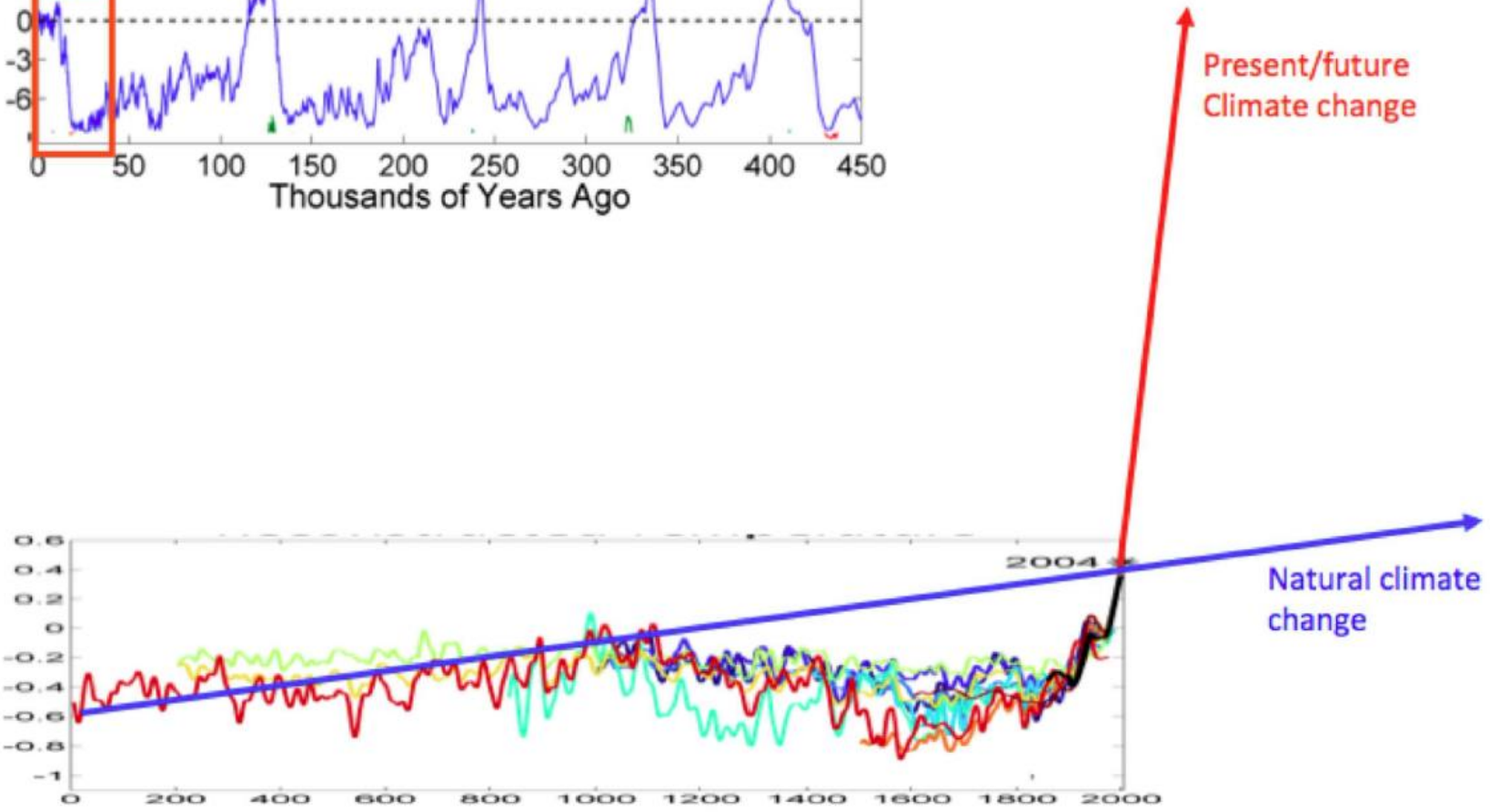
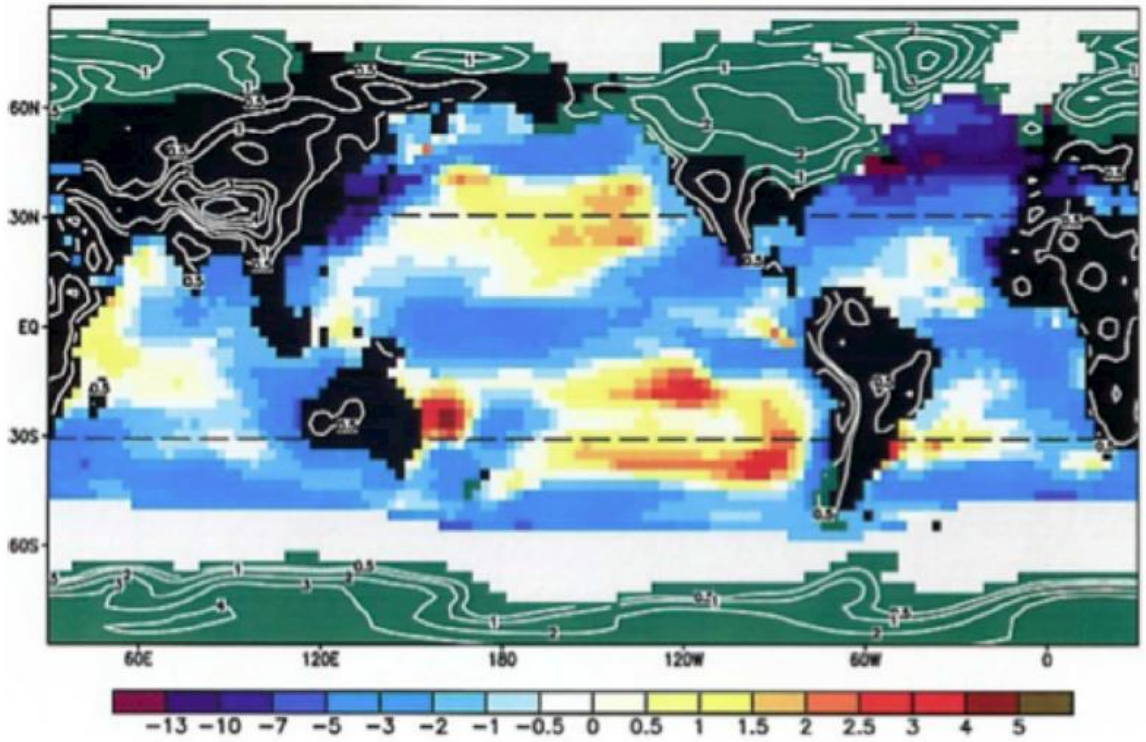




Source: Dommenget (2014)

Causes of ice ages



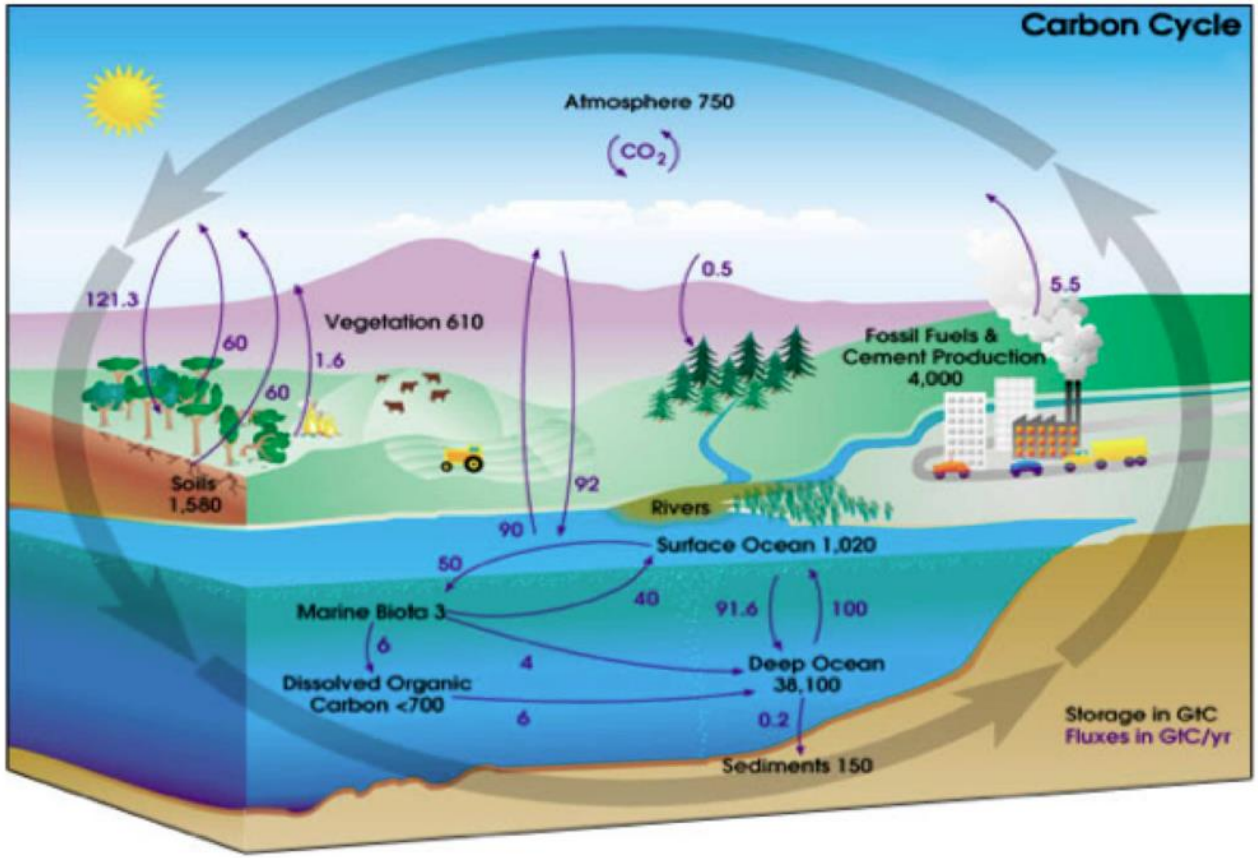
Reconstruction of the global temperatures during the last ice age maximum

Source: Dommenget (2014)

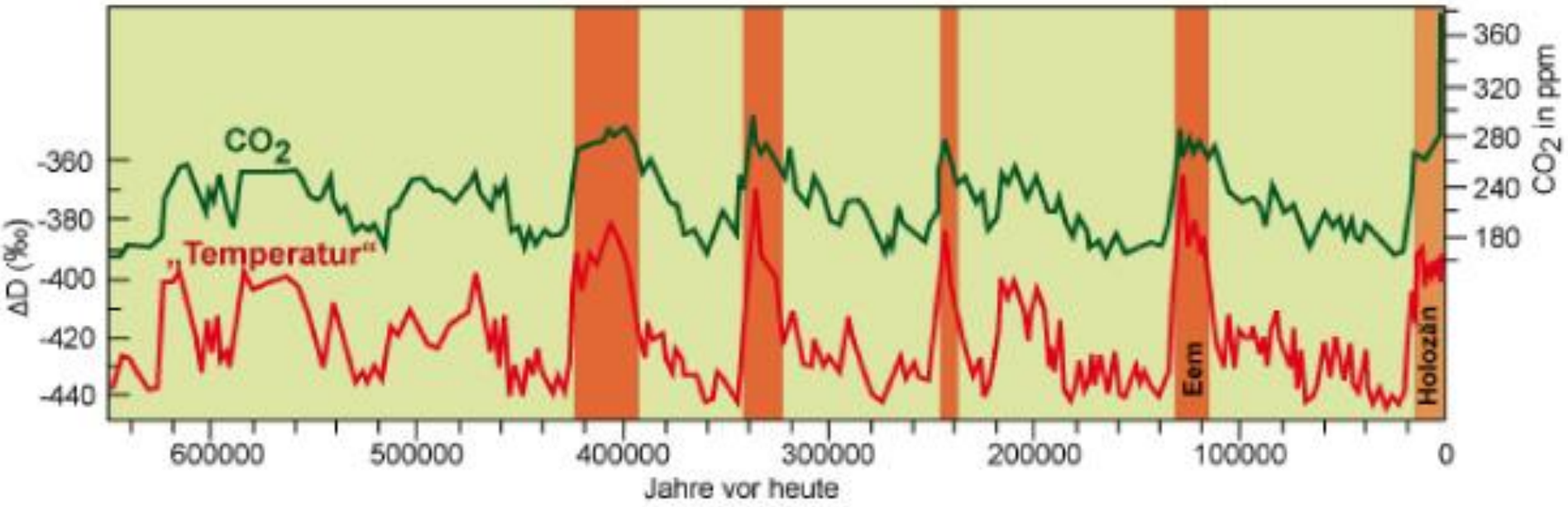
Causes of ice ages

- Partly internal natural and external climate variabilty, including some important feedbacks
- Most important driver: variations in the Earth‘s orbit (Milankovitch cycles)
- Glacier feedbacks (ice albedo, water vapor, altitude cooling, atmospheric circulation)
- Other feedbacks: CO_2 uptake (cold oceans can take up more CO_2), land vegetation

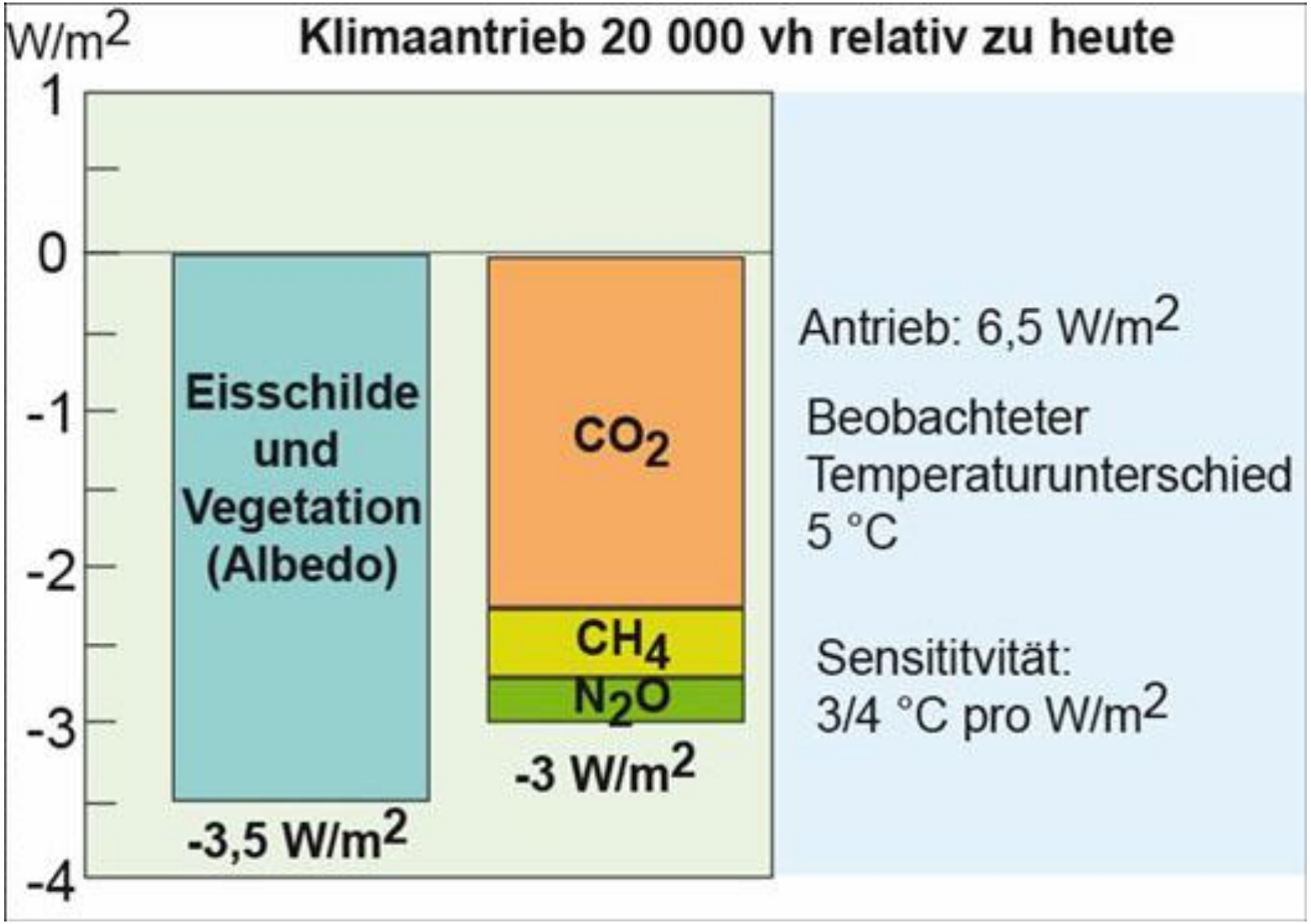
Causes of ice ages



Source: Dommenget (2014)



Source: http://bildungsserver.hamburg.de/klimawandel/

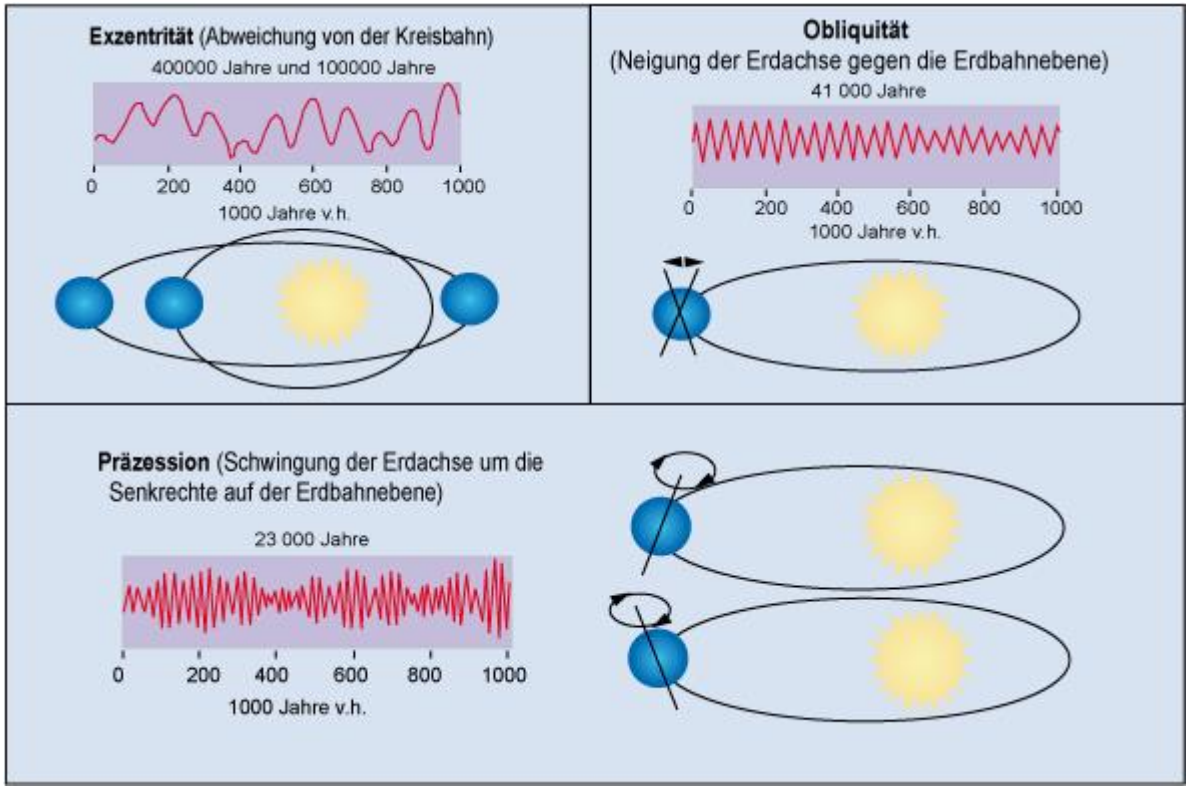


Source: http://bildungsserver.hamburg.de/klimawandel/

Causes of ice ages: orbital forcings (Milankovitch Cycles)

cause mostly a redistribution of incoming radiation between latitudes and seasons (regional changes up to 50 Wm^{-2} over 10 kyr)

S_0=0.7 Wm^{-2}



21.16-24.5°

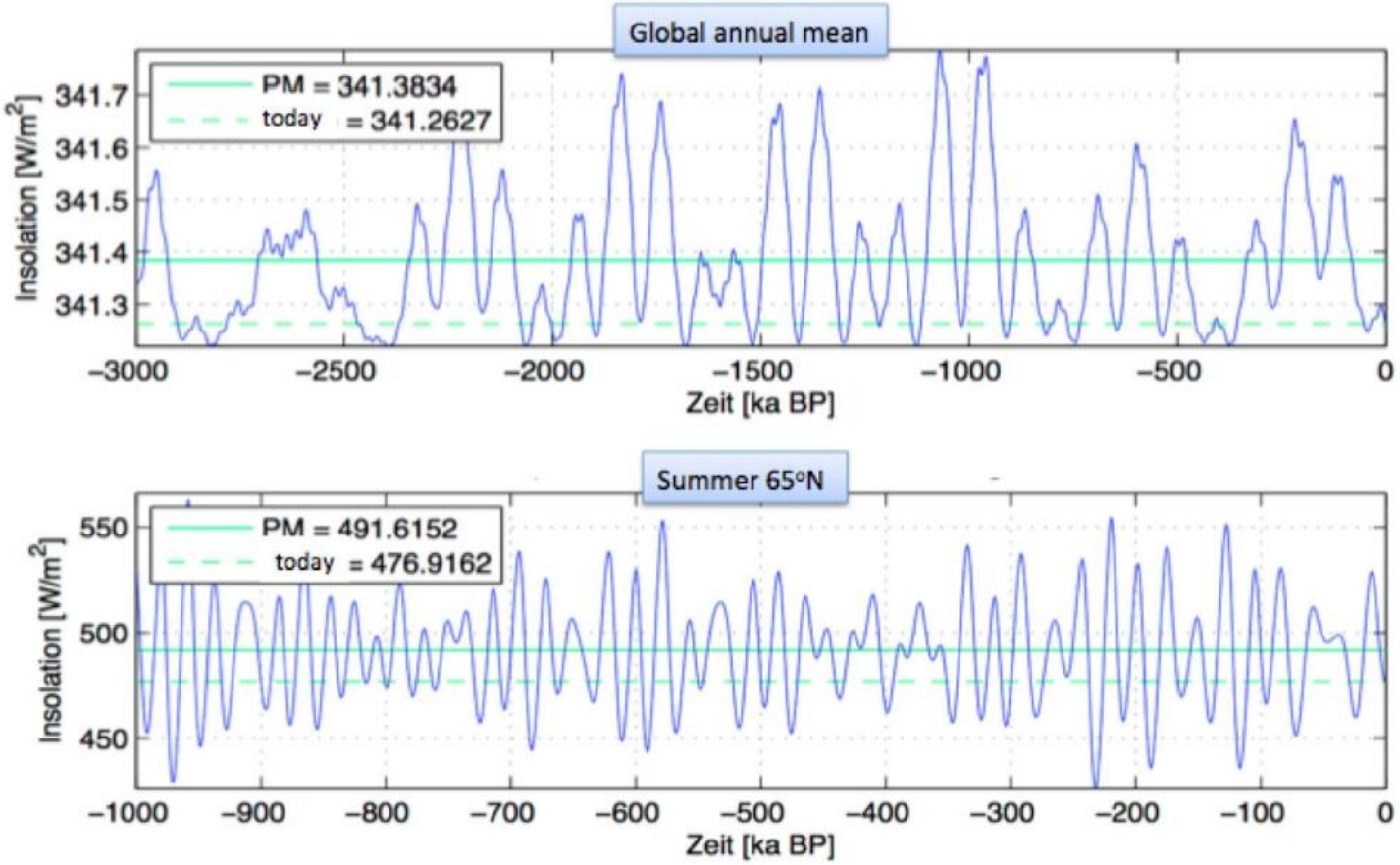
No effect if there is no excentricity and obliquity

Source: http://bildungsserver.hamburg.de/klimawandel/

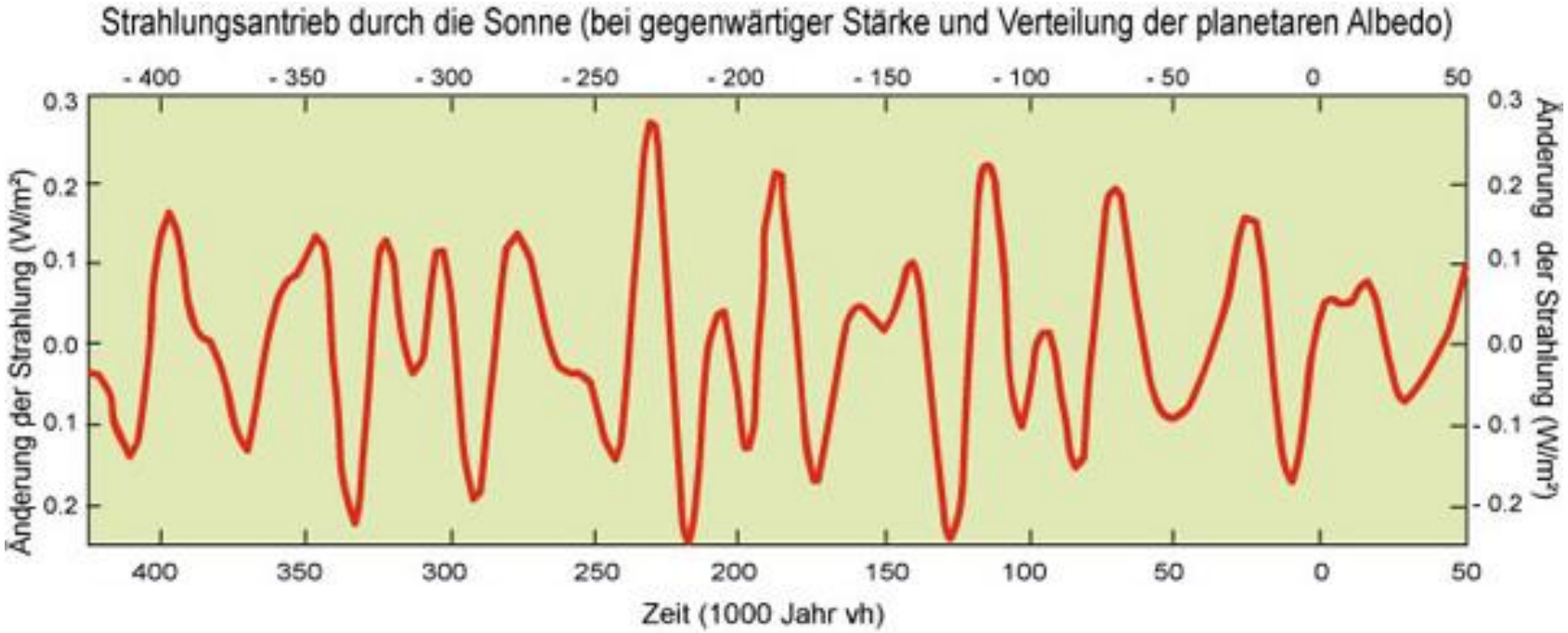
Causes of ice ages

Source: http://bildungsserver.hamburg.de/klimawandel/

Causes of ice ages



Source: Dommenget (2014)



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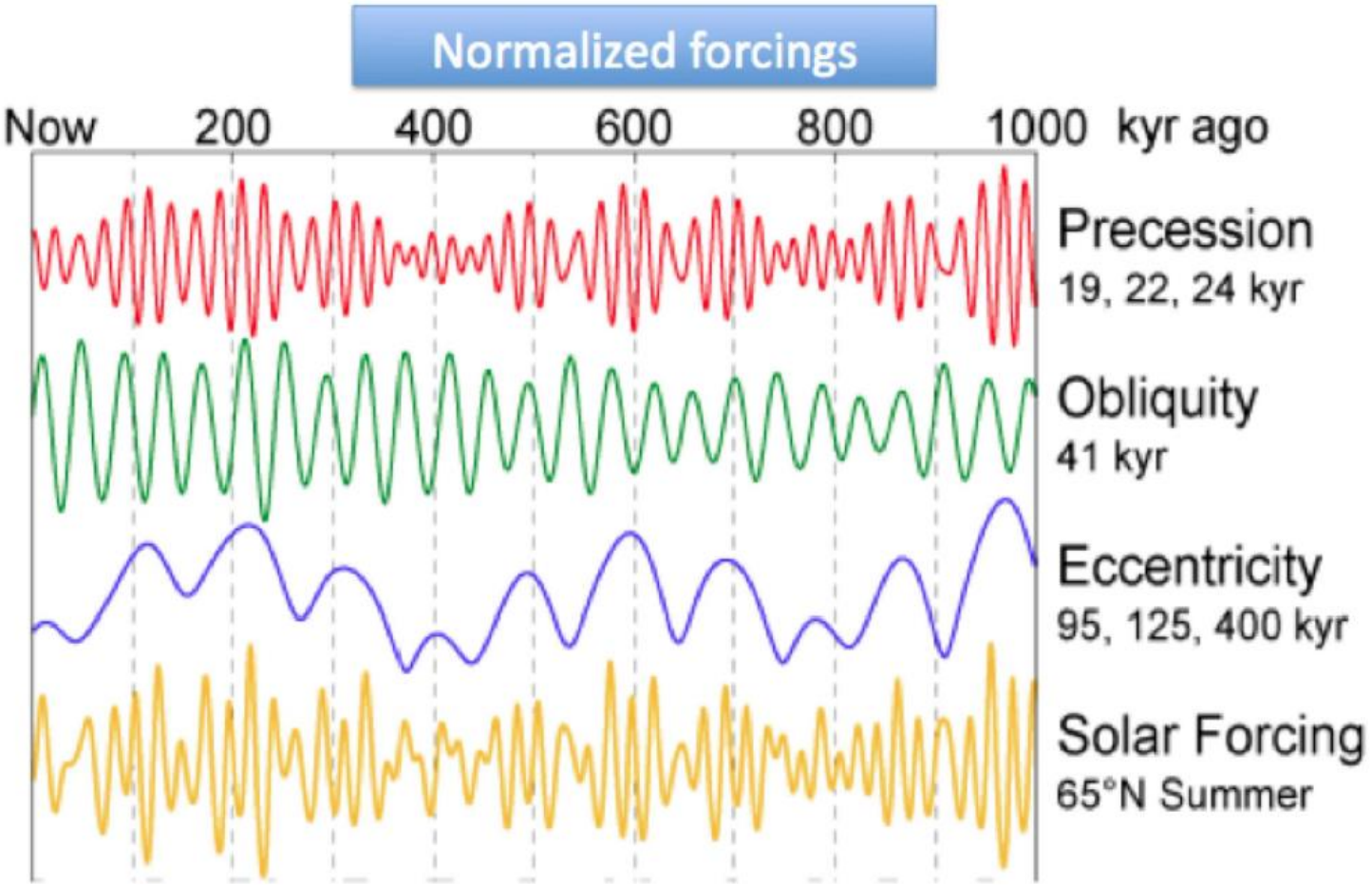
Causes of ice ages



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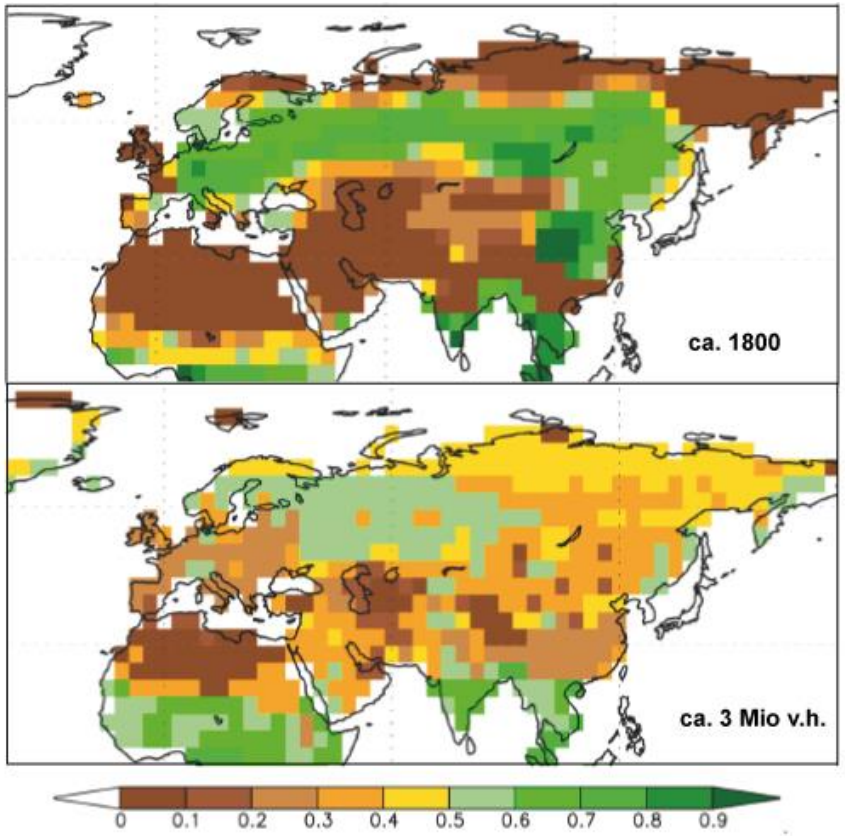
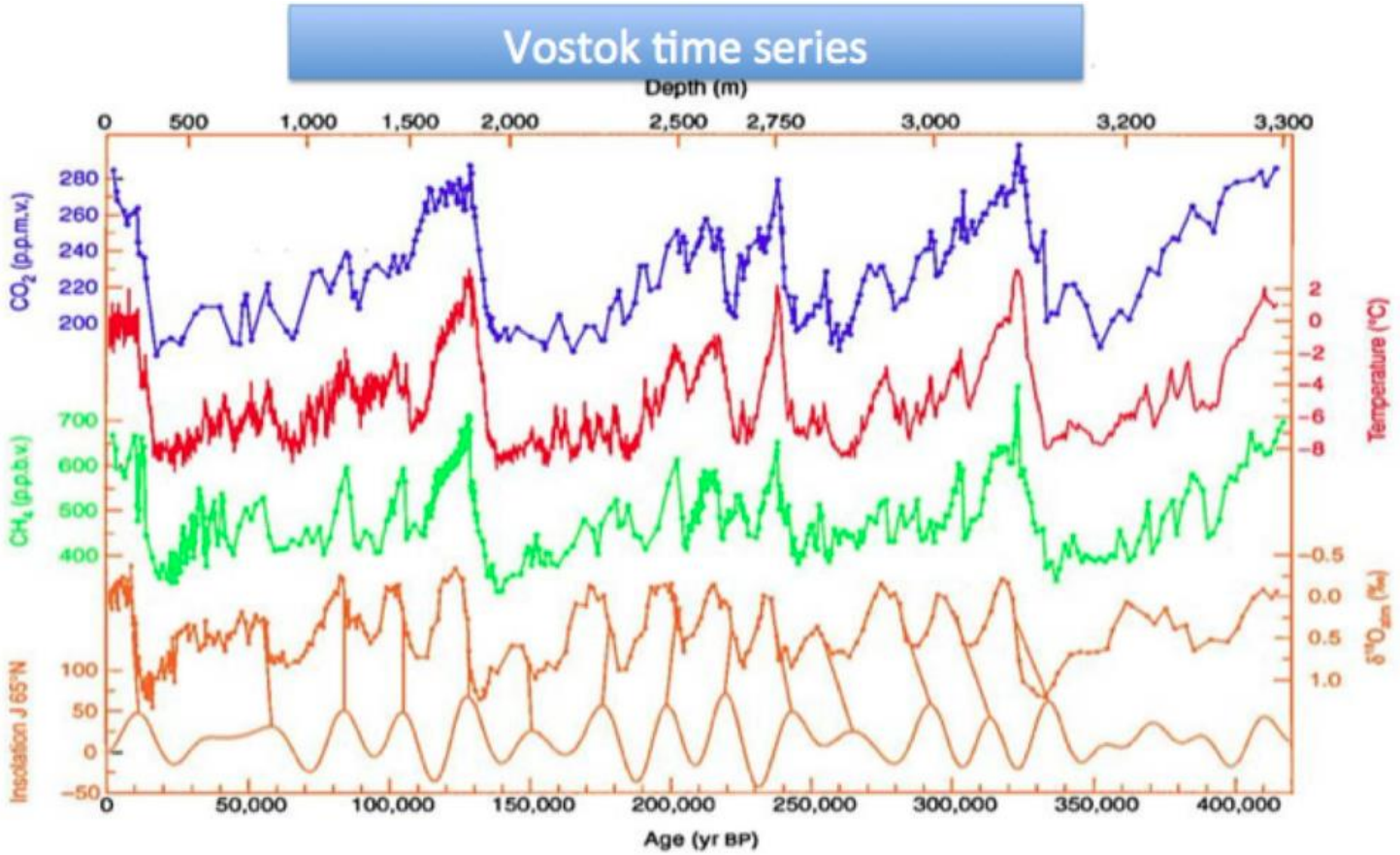


Waldanteil in vorindustrieller Zeit (oben) und im mittleren Pliozän (unten) nach Modellberechnungen

Open questions

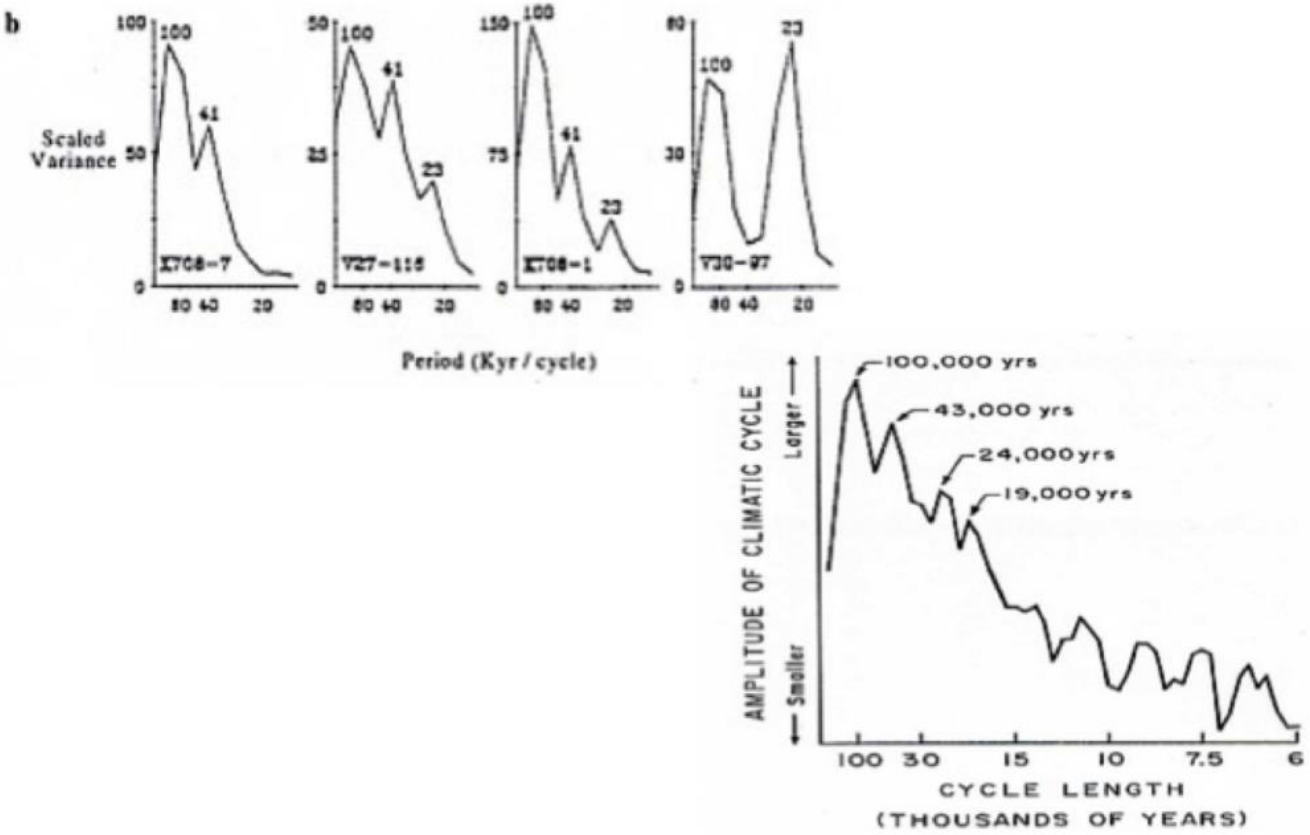
- **Shift**
- **Why is the 100 000 year period soo strong and other frequencies not?**
- **Temperature spectrum looks like red noise**

Causes of ice ages



Source: Dommenget (2014)

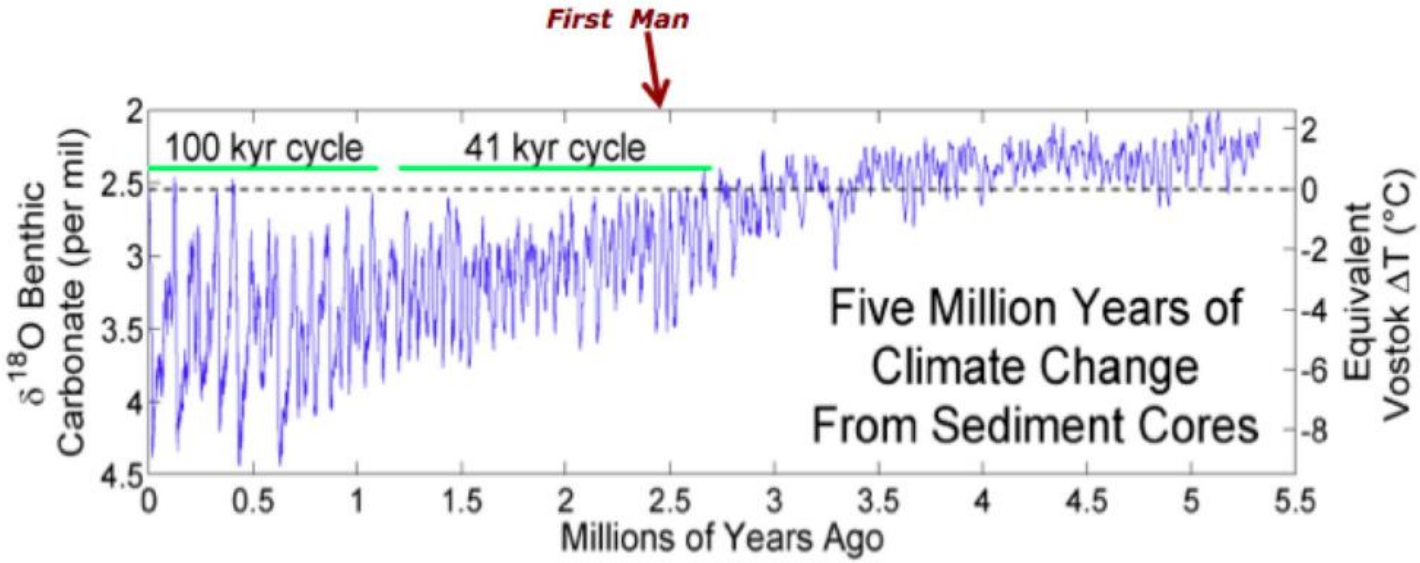
Cause of ice ages



Power spectrum of different ice core records

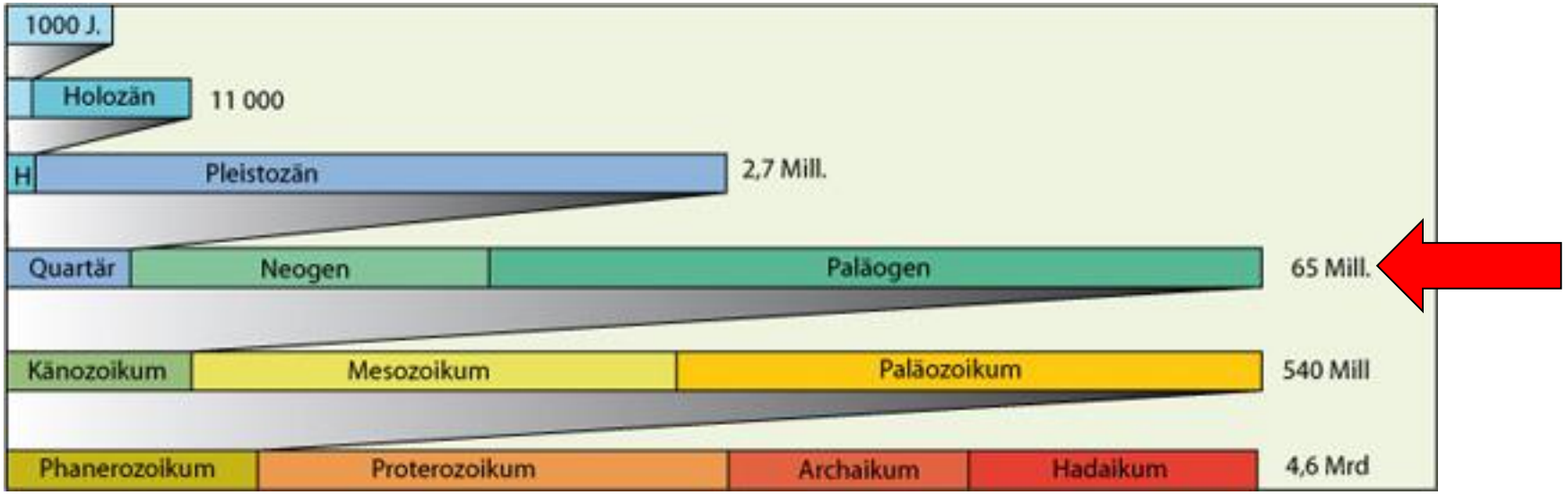
Climate history

4. The last 500 million years



On time scales longer than 1 million years ago geography starts to vary (most recent event: south polar position of Antarctica, cooling)

Source: Dommenget (2014)



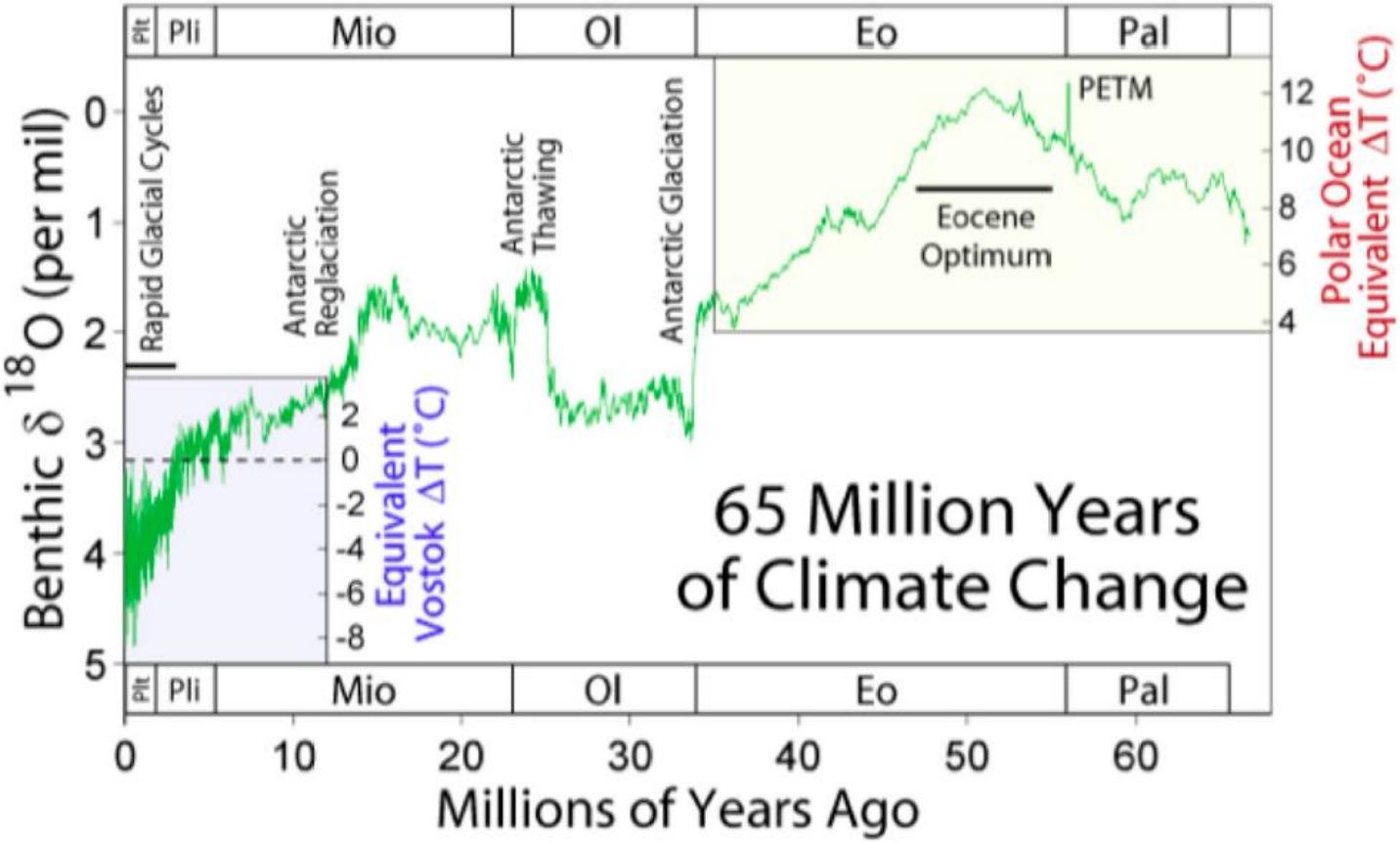
Präkambrium

3.5 Mrd first forms of life

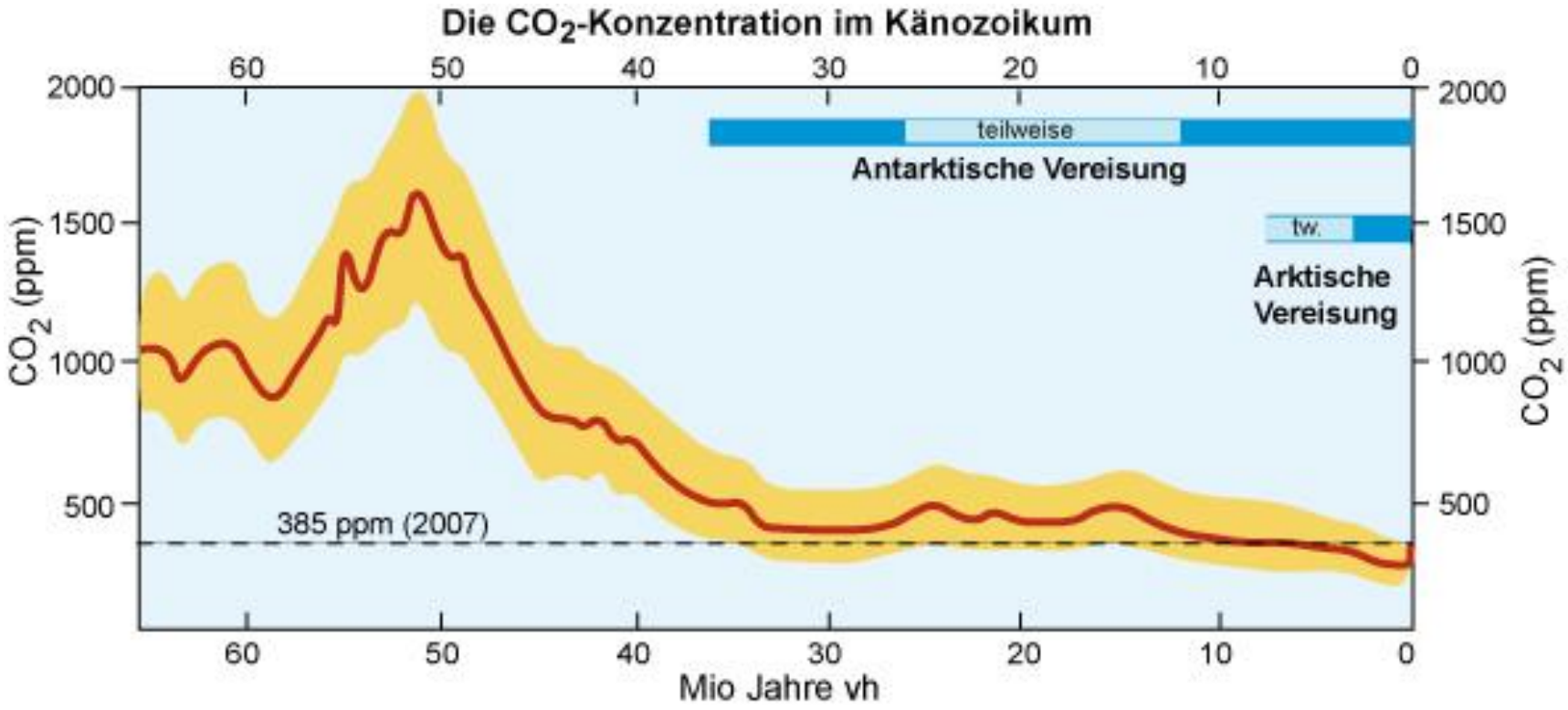
Source: http://bildungsserver.hamburg.de/klimawandel/

Climate history

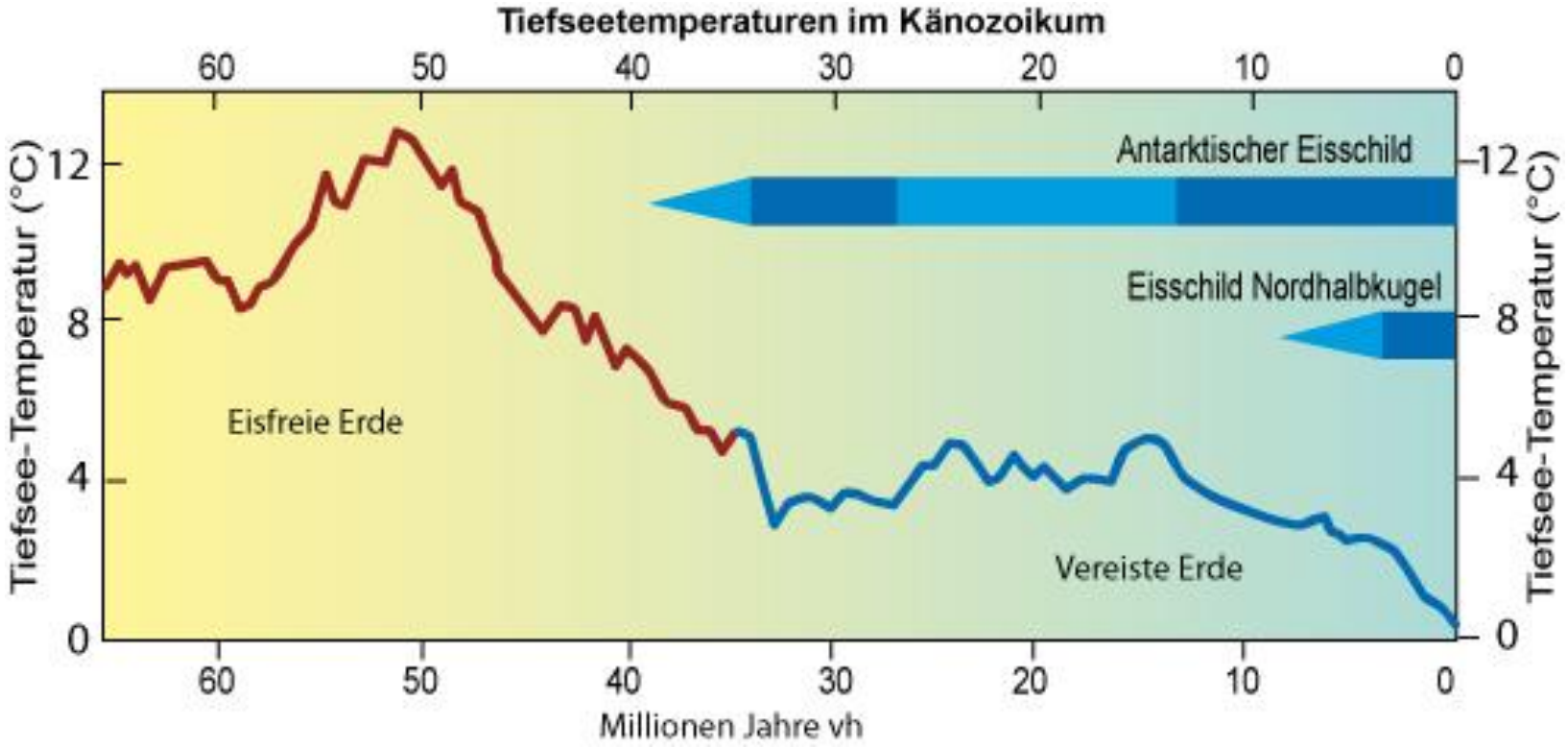
4. The last 500 million years



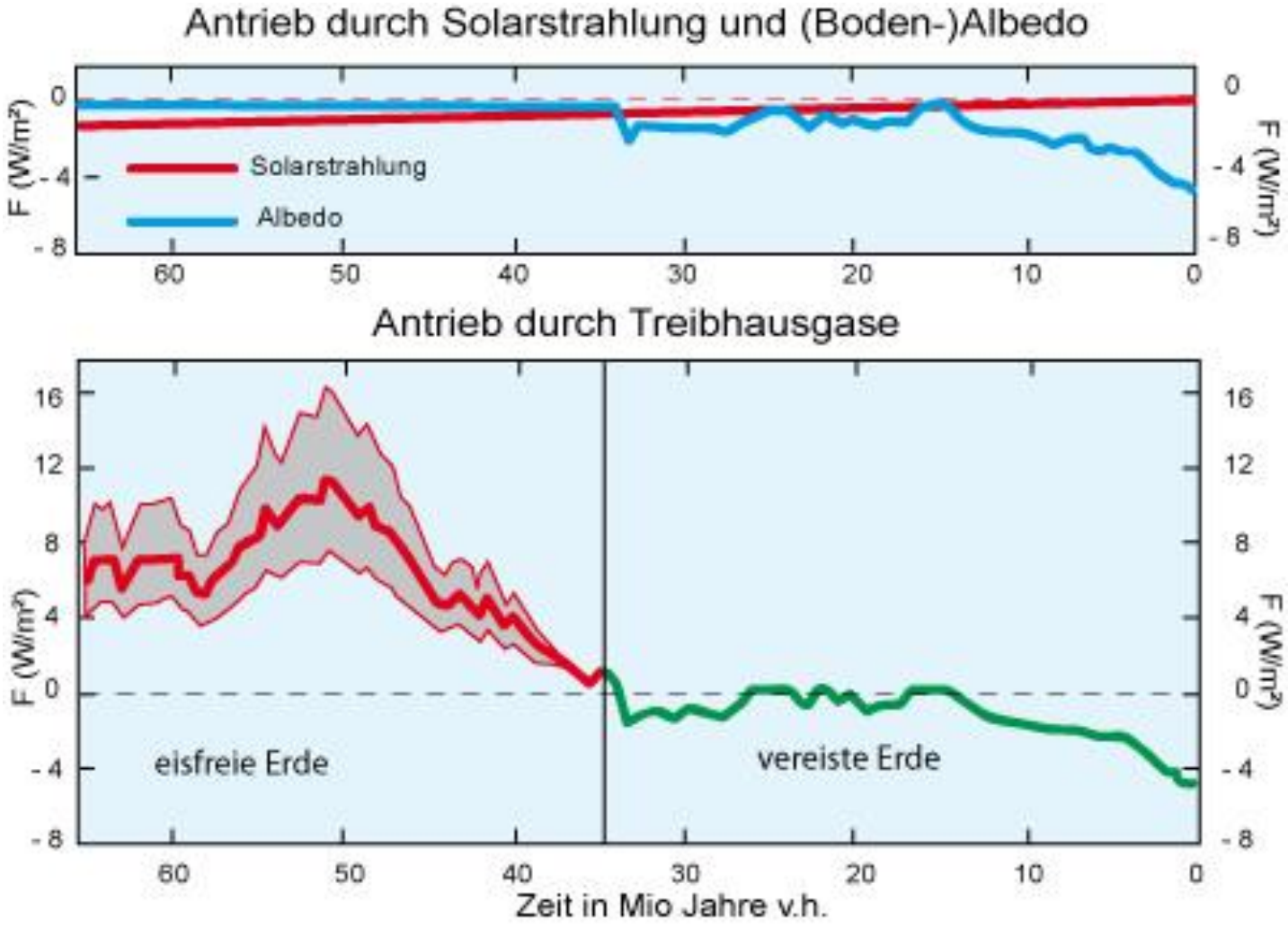
Source: Dommenget (2014)

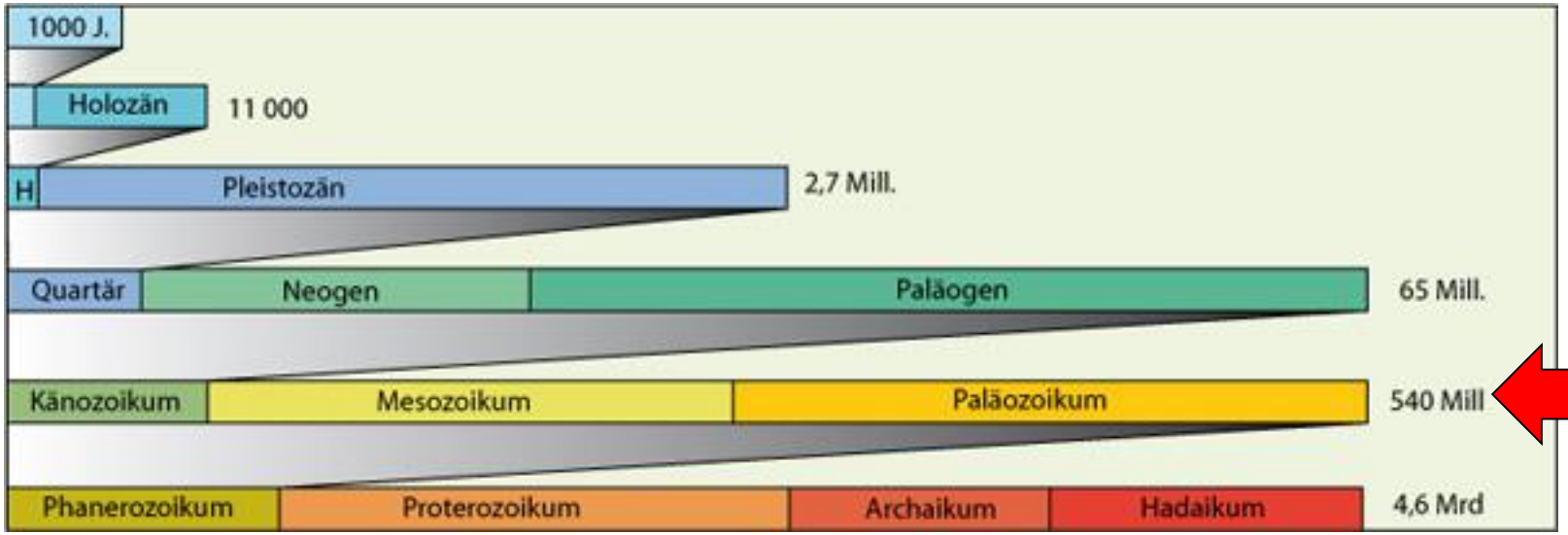


Source: http://bildungsserver.hamburg.de/klimawandel/



Source: http://bildungsserver.hamburg.de/klimawandel/


Antrieb durch Solarstrahlung und (Boden-)Albedo
F (W/m²)
0
- 4
- 8
Solarstrahlung
Albedo
60
50
40
30
20
10
0
Antrieb durch Treibhausgase
16
12
8
4
0
- 4
- 8
eisfreie Erde
vereiste Erde
Zeit in Mio Jahre v.h.



Präkambrium

3.5 Mrd first forms of life

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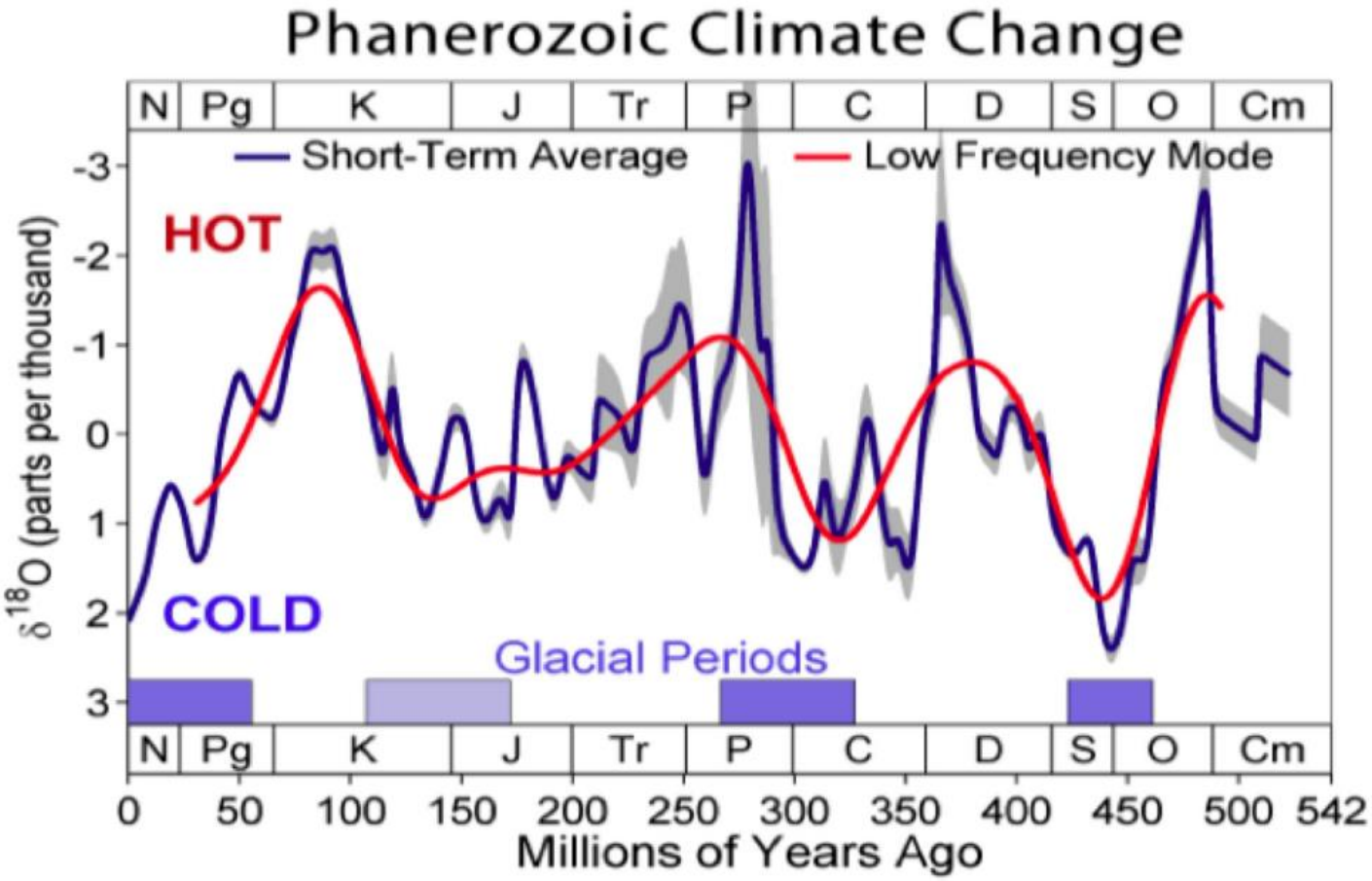
Climate history

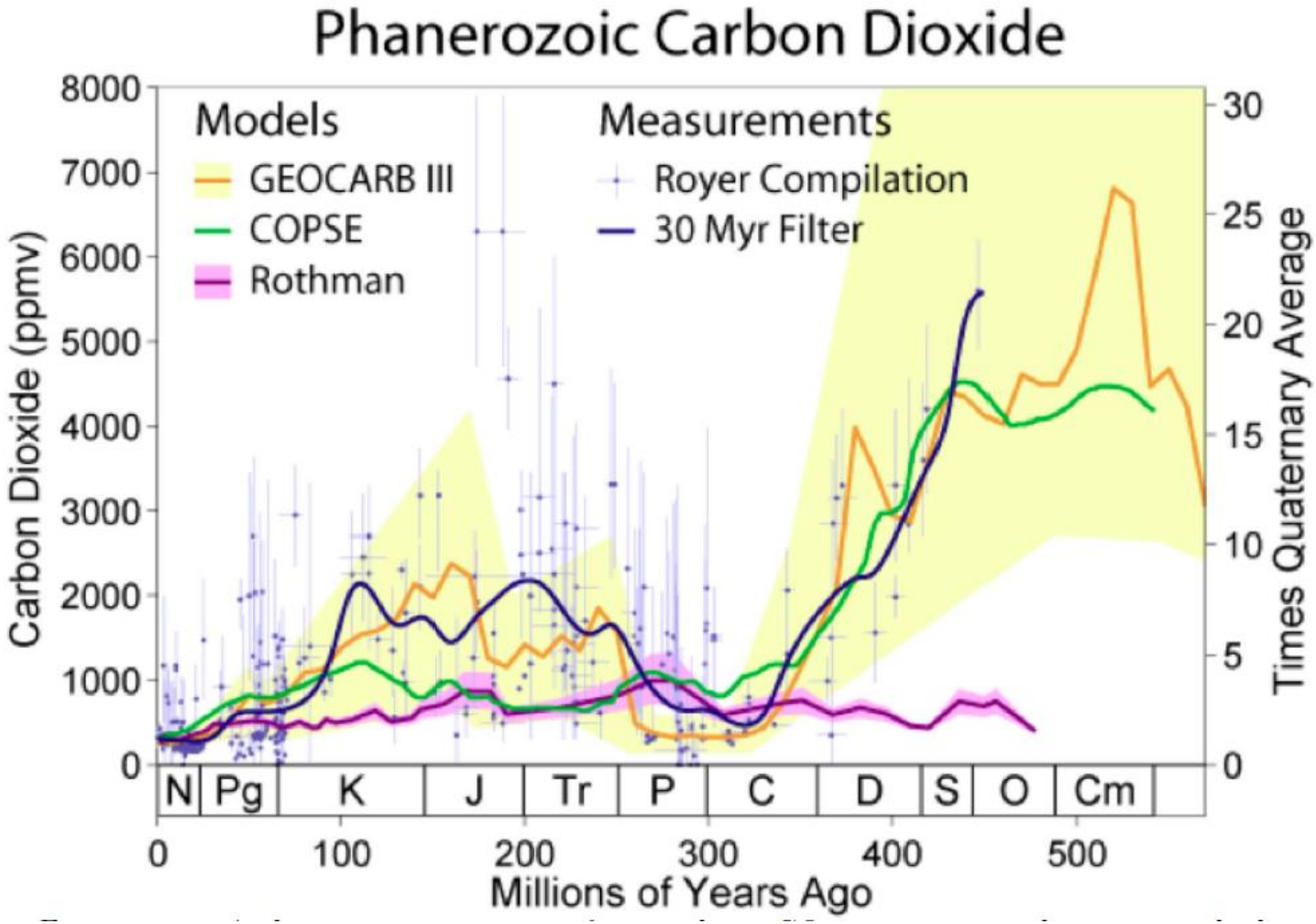
4. The last 500 million years



Source: Dommenget (2014)

Climate history

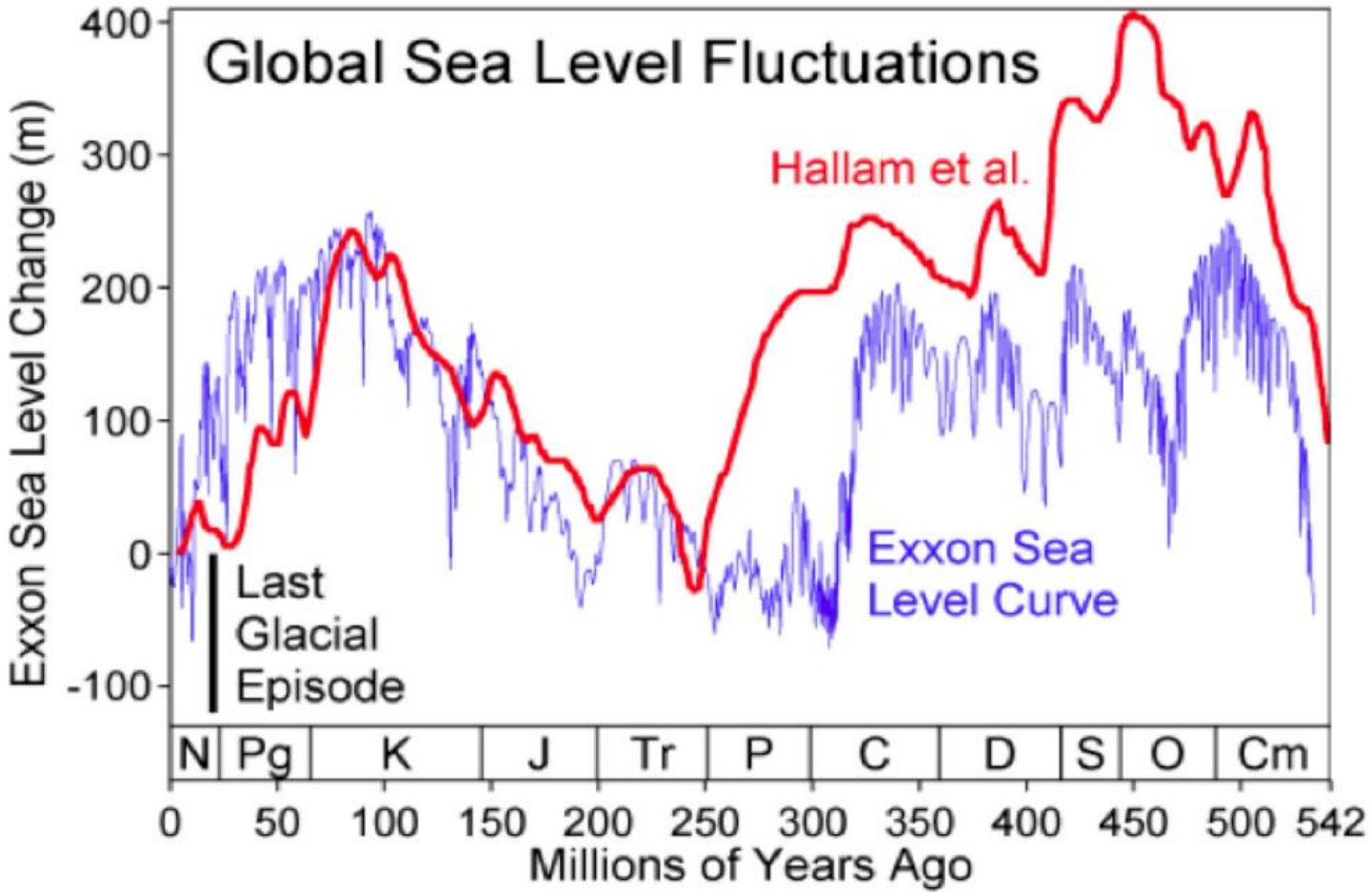
4. The last 500 million years



Source: Dommenget (2014)

Climate history

4. The last 500 million years



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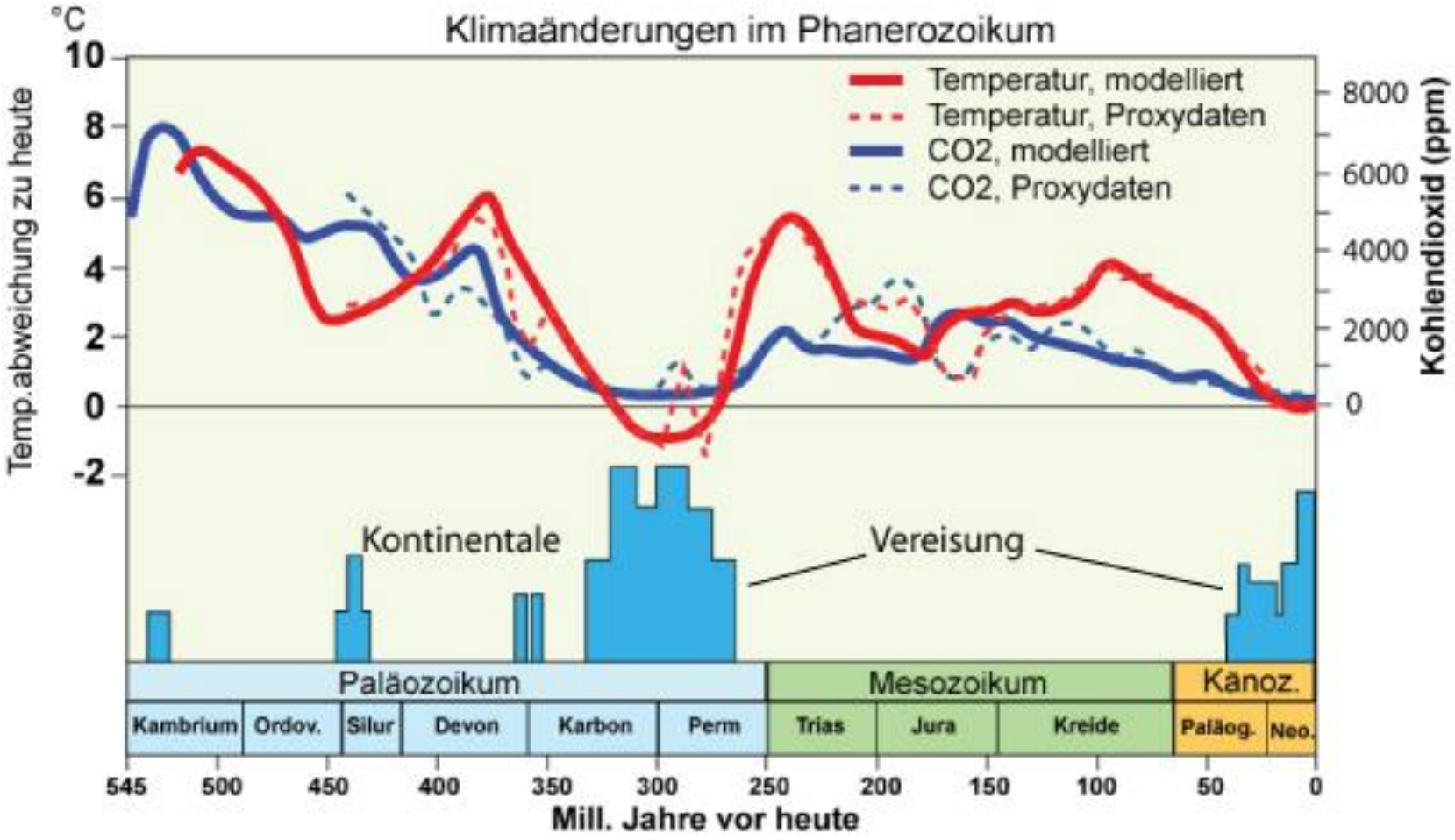
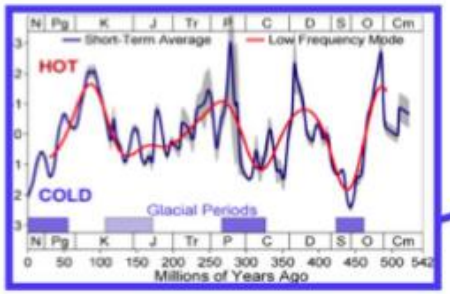


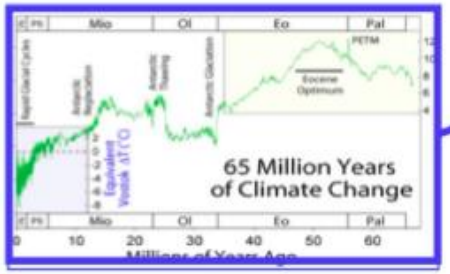
Source: http://bildungsserver.hamburg.de/klimawandel/

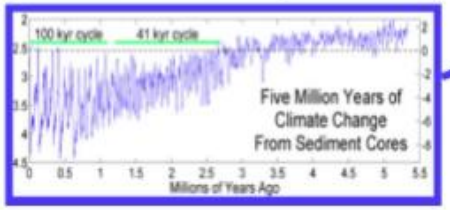
Climate history

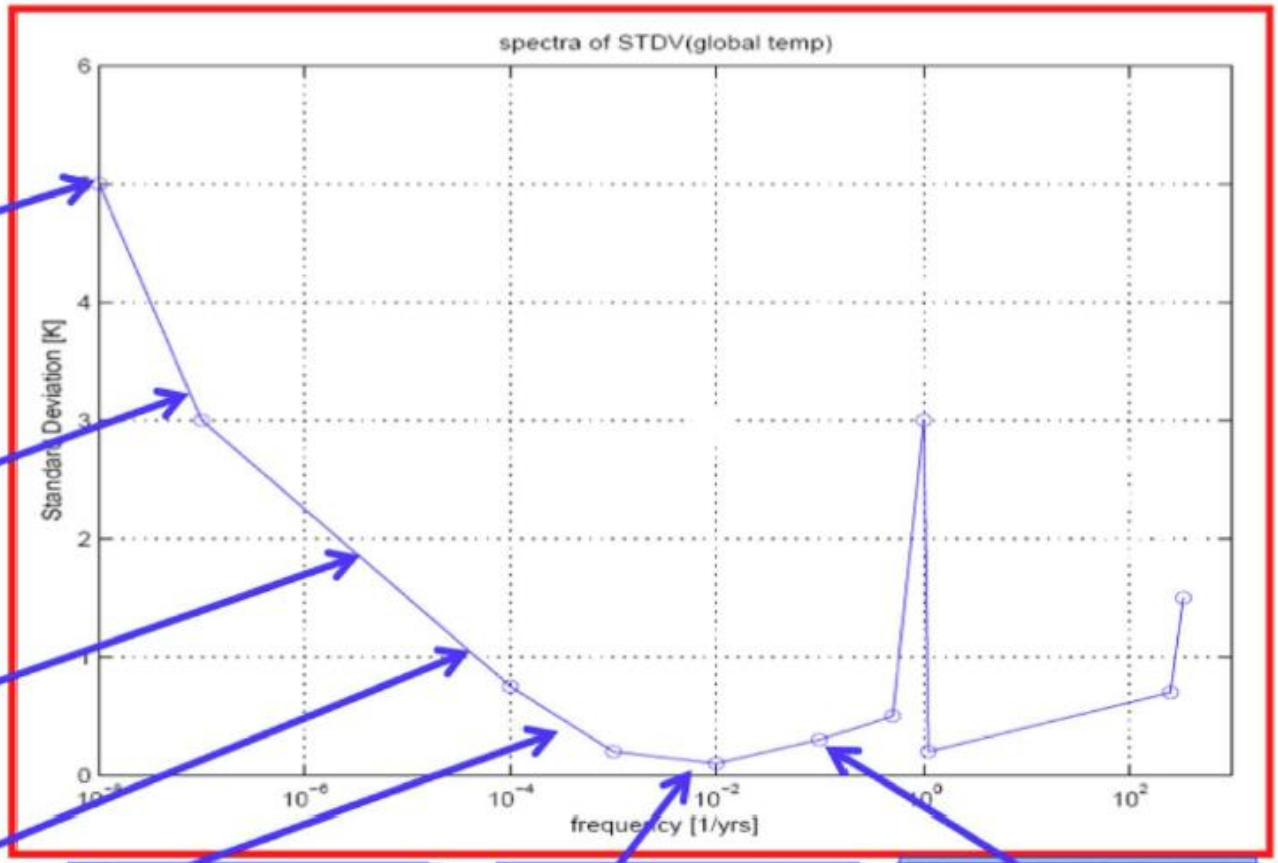
Source: Dommenget (2014)

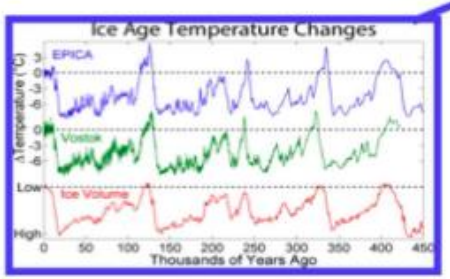
4. The last 500 million years

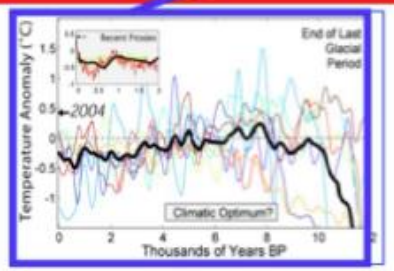


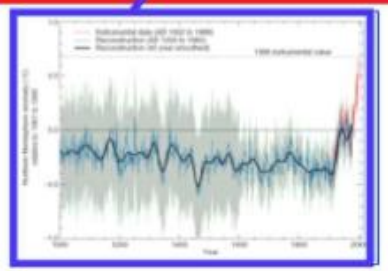


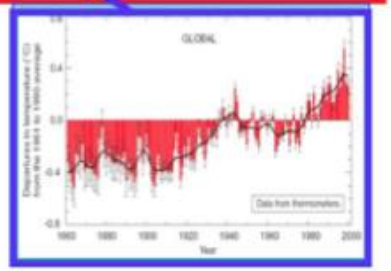






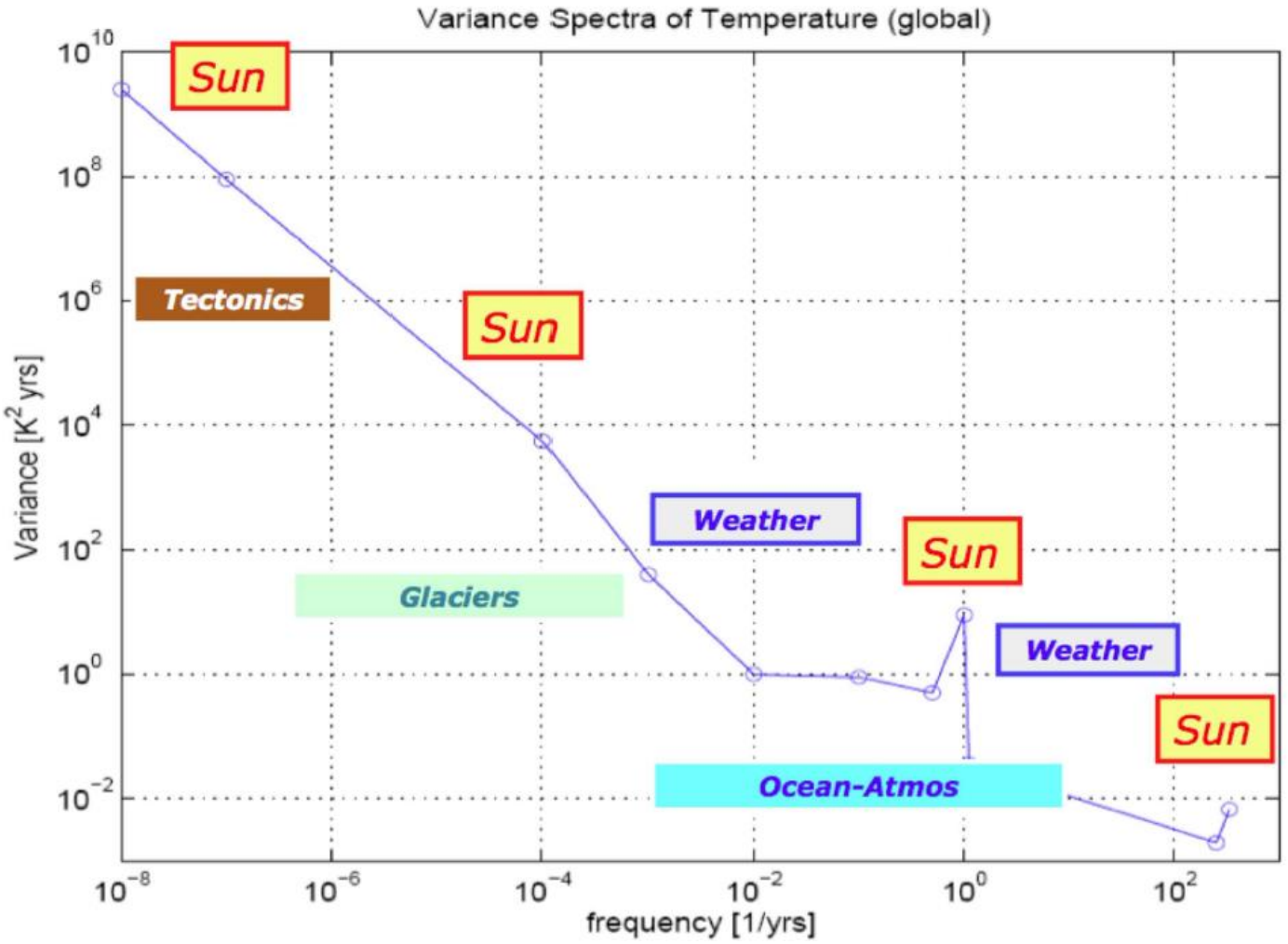




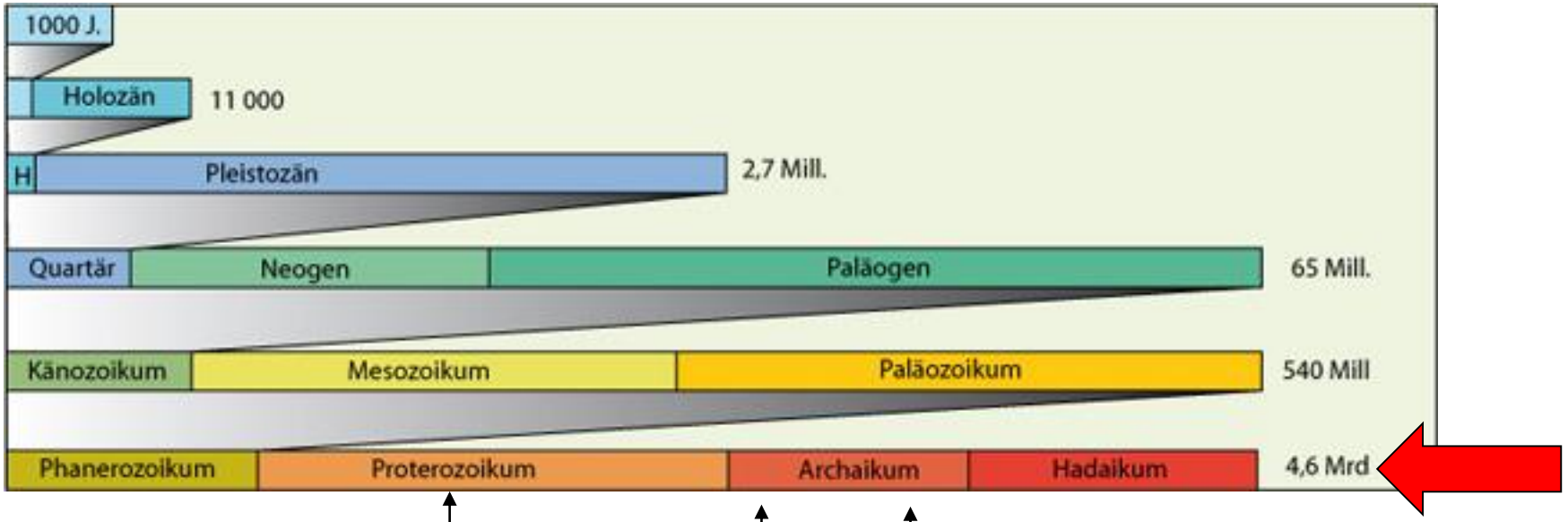


Climate history

4. The last 500 million years



Source: Dommenget (2014)



Präkambrium

Schneeball-Erde- Vereisung, Großkontinent „Rodina“, Verwitterung

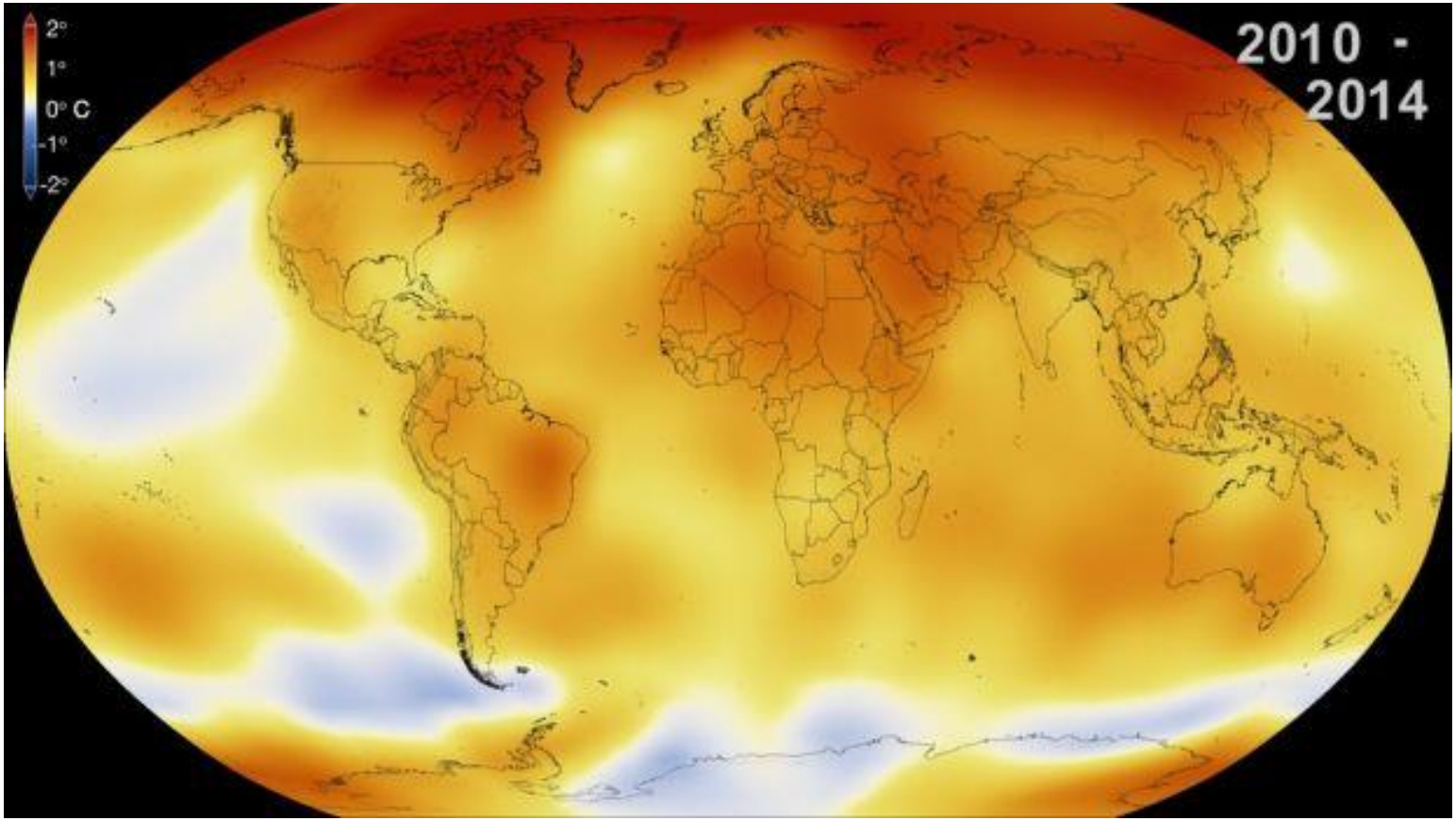
2.9 Mrd Pangoa ice age 3.5 Mrd first forms of life

Source: http://bildungsserver.hamburg.de/klimawandel/

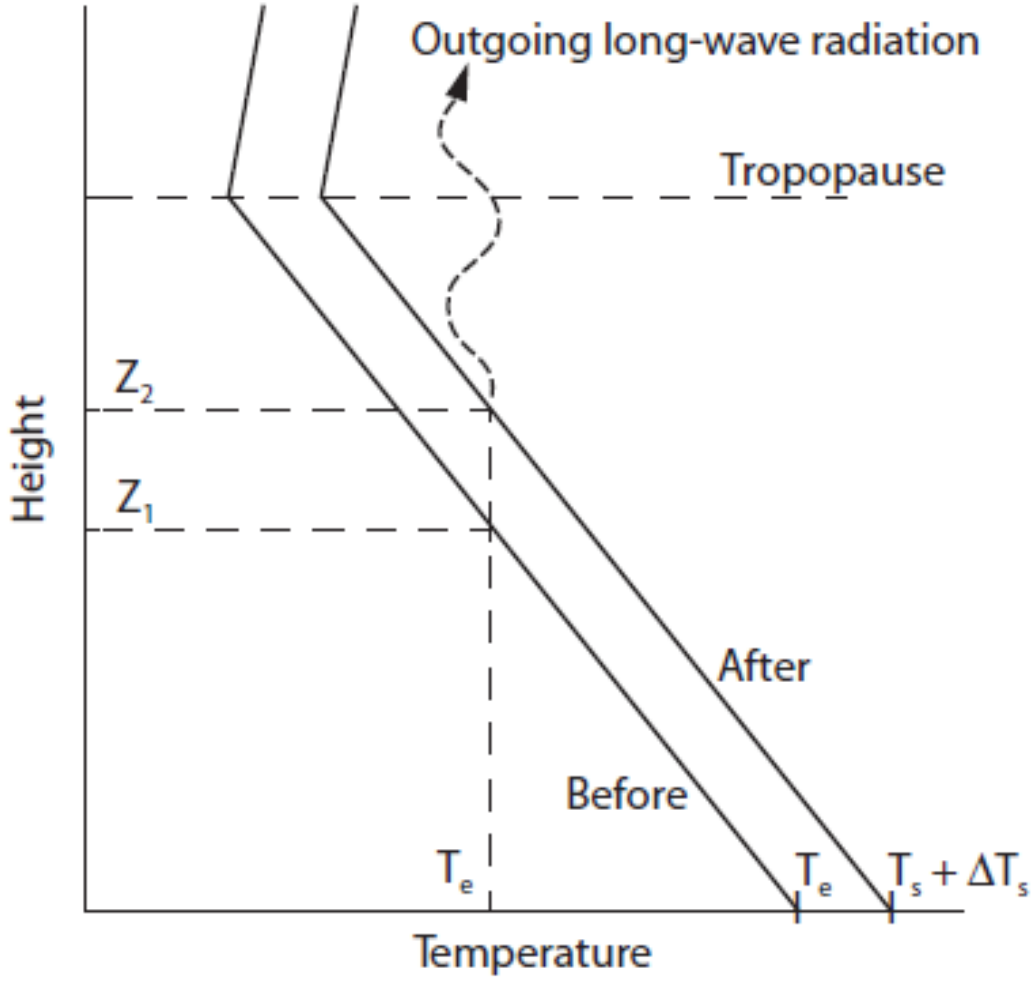
Forced and unforced climate variability

2. Global warming caused by anthropogenic greenhouse gas emissions

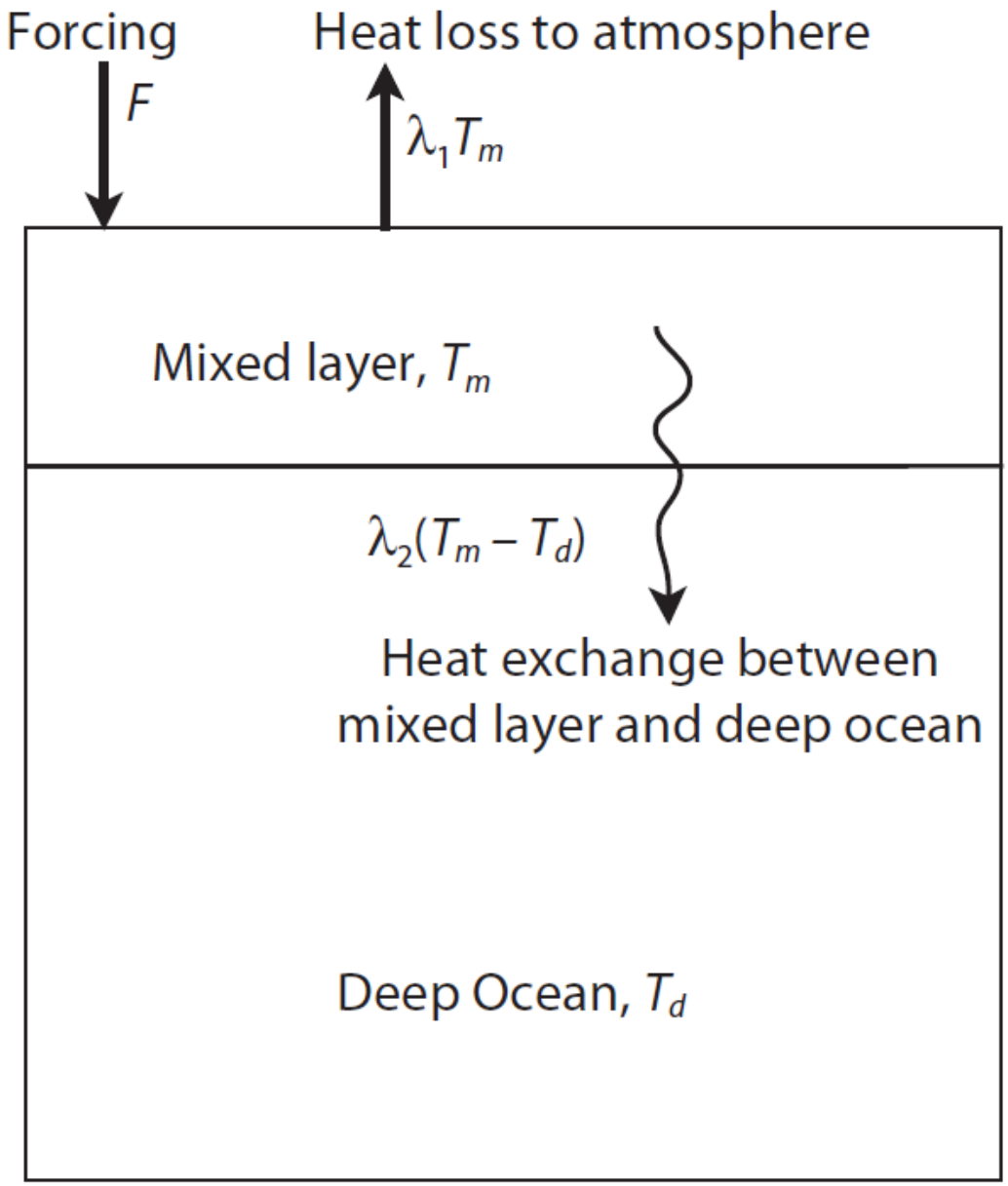
Change in mean temperature 2010-2014 compared to 1951-1980



Source: http://bildungsserver.hamburg.de/klimawandel/



Source:Vallis: Climate and the oceans (2012)



Source:Vallis: Climate and the oceans (2012)