

# Paleoclimate: An Introduction

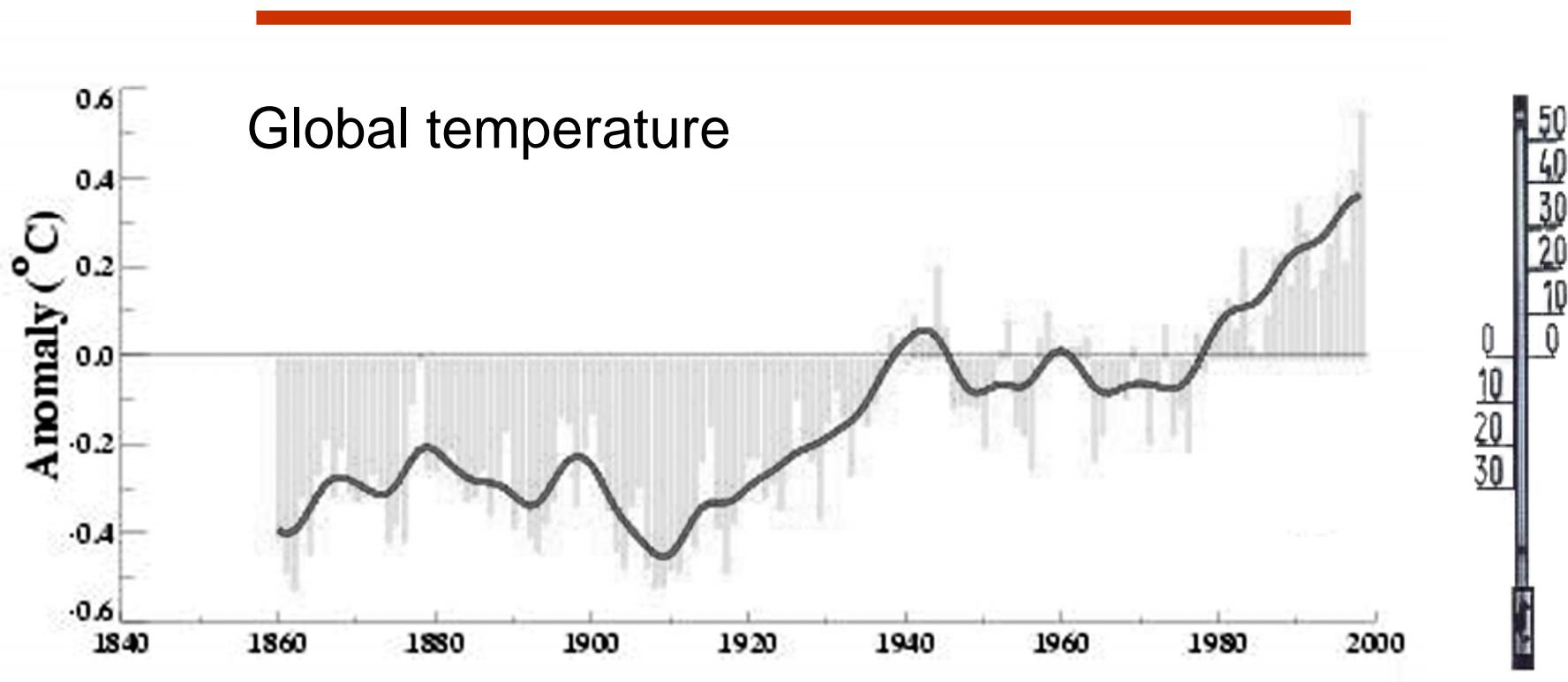
*Seminar, 15th March 2009  
University of Gothenburg*

Gerrit Lohmann  
Alfred Wegener Institute for Polar and Marine Research



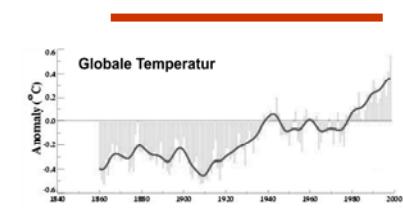
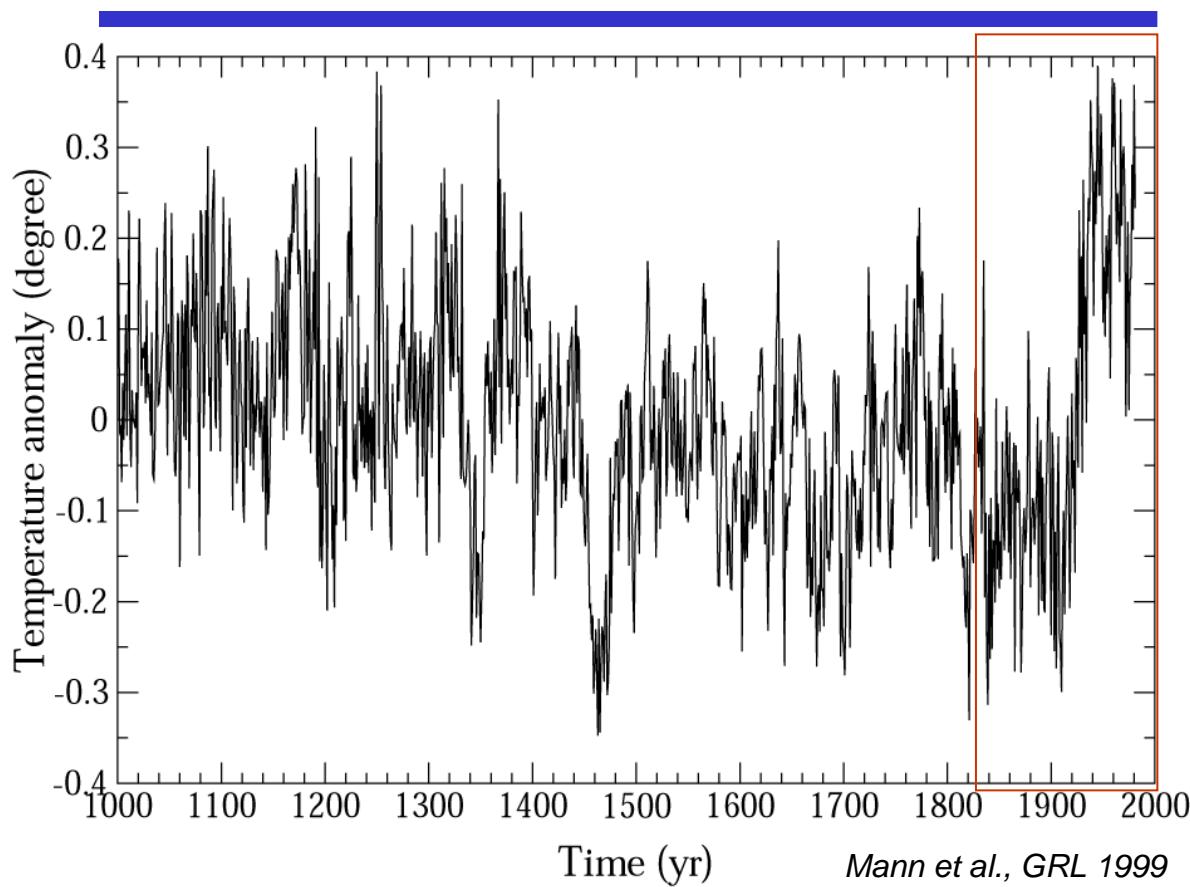
# Climate Trends at different Timescales

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

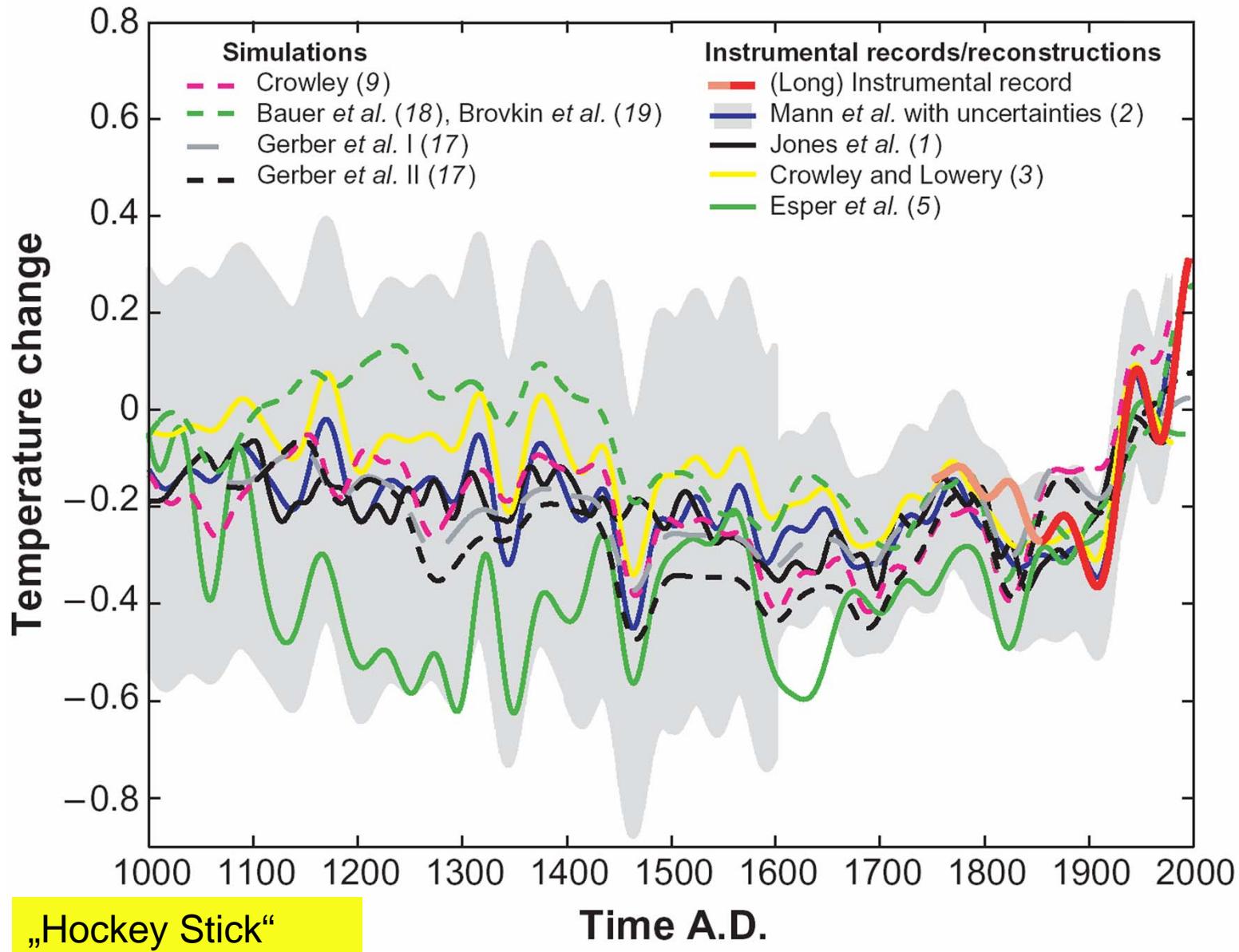


# Climate Trends at different Timescales

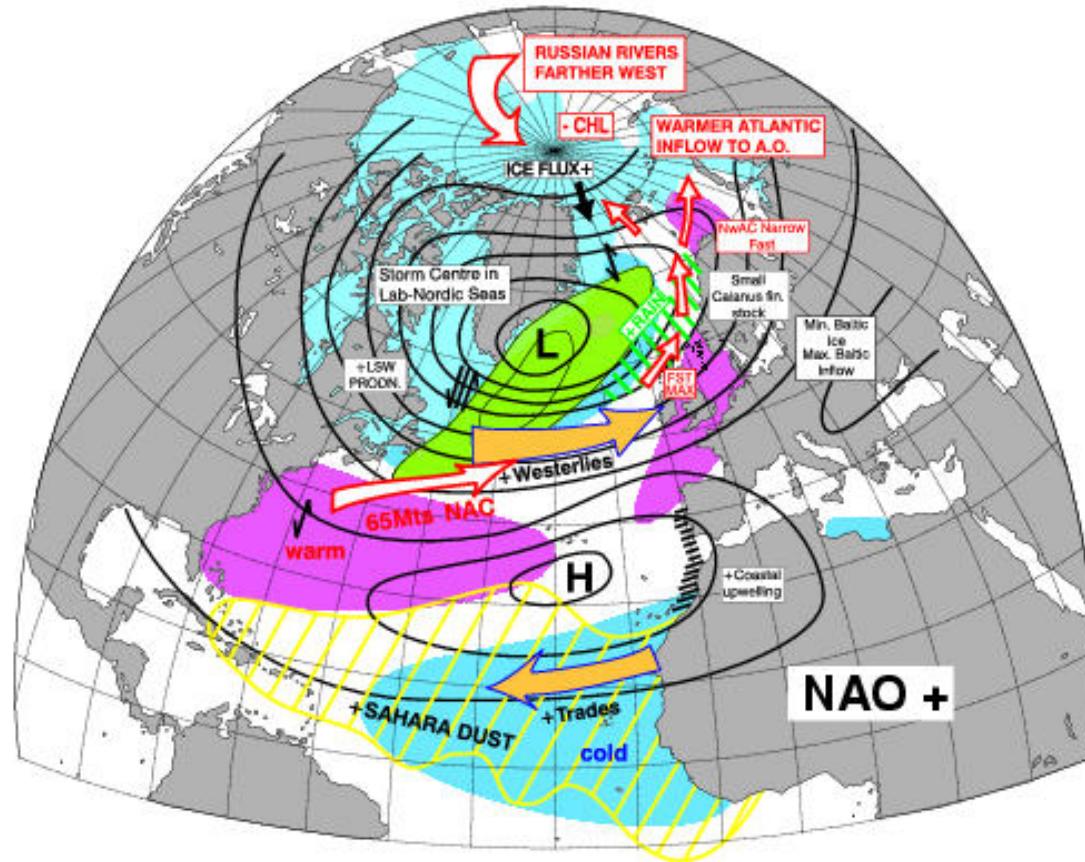
Temperature of the last **1000 years**



# Temperature of the last 1000 years



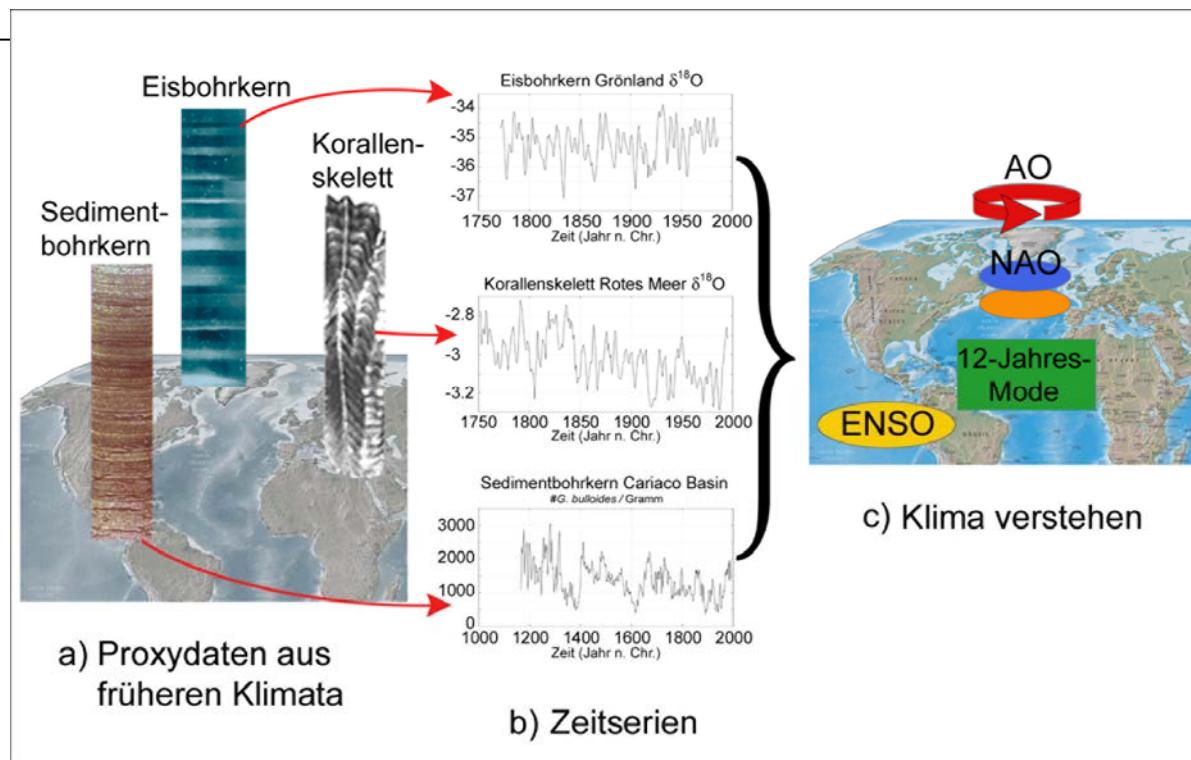
# The Phases of the North Atlantic Oscillation



During the high phase of the NAO westerlies in the North Atlantic are enhanced, resulting in mild and wet winter conditions over Northern Europe.  
(Courtesy of CEFAS, UK)

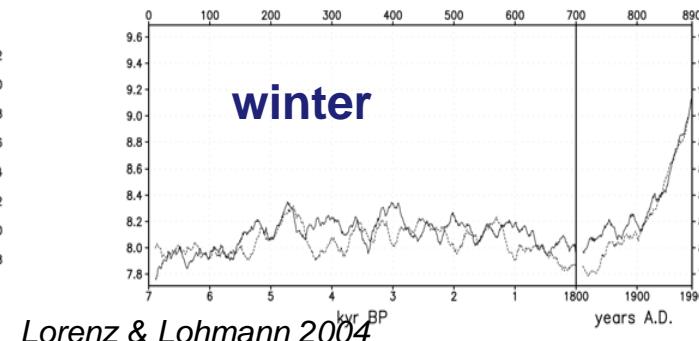
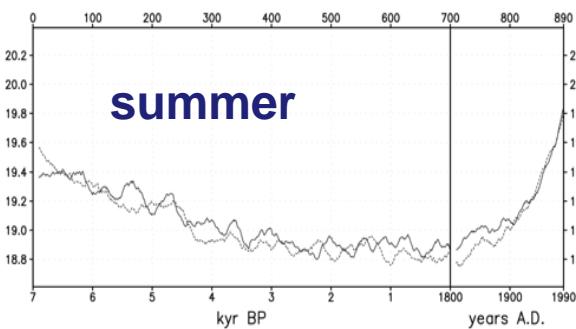
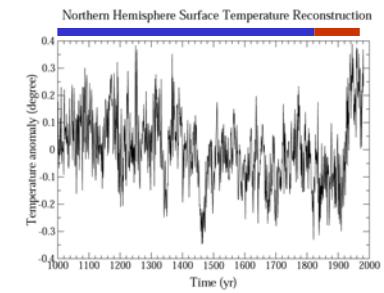
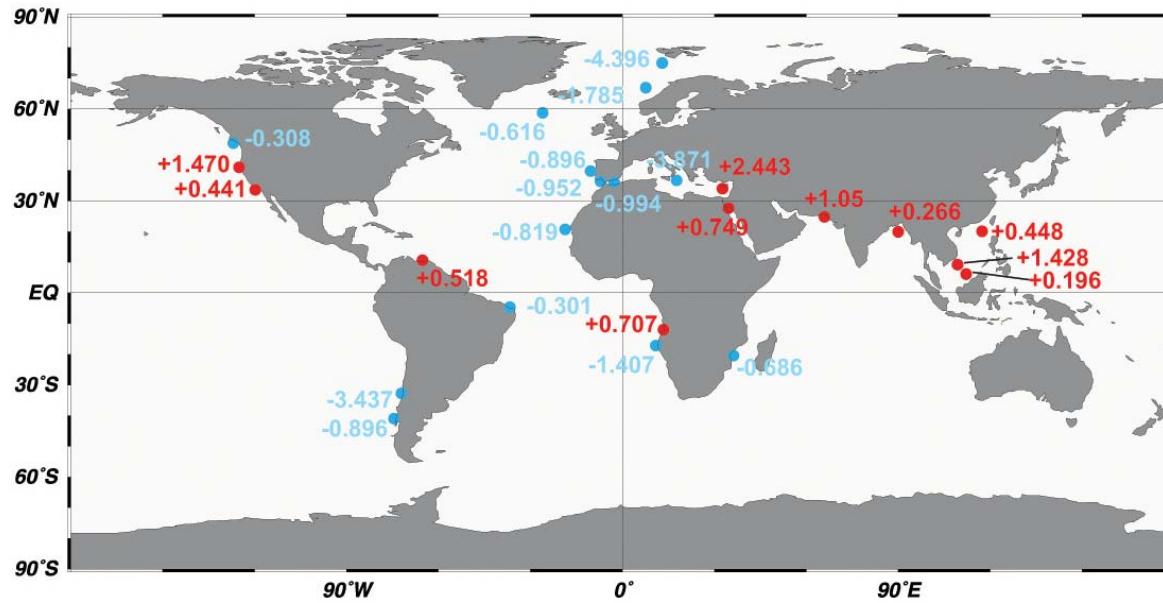
# Proxy Data

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

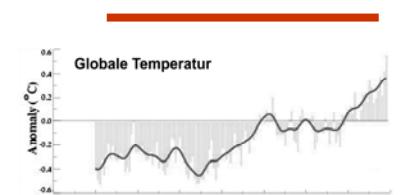


# Climate Trends at different Timescales

## Holocene: Temperature proxy for the last 7000 years

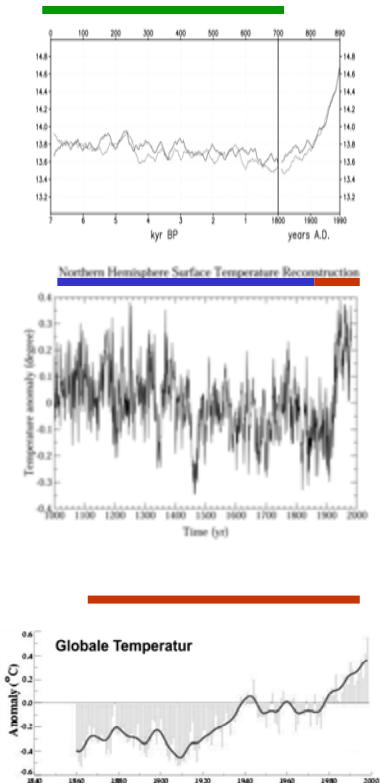
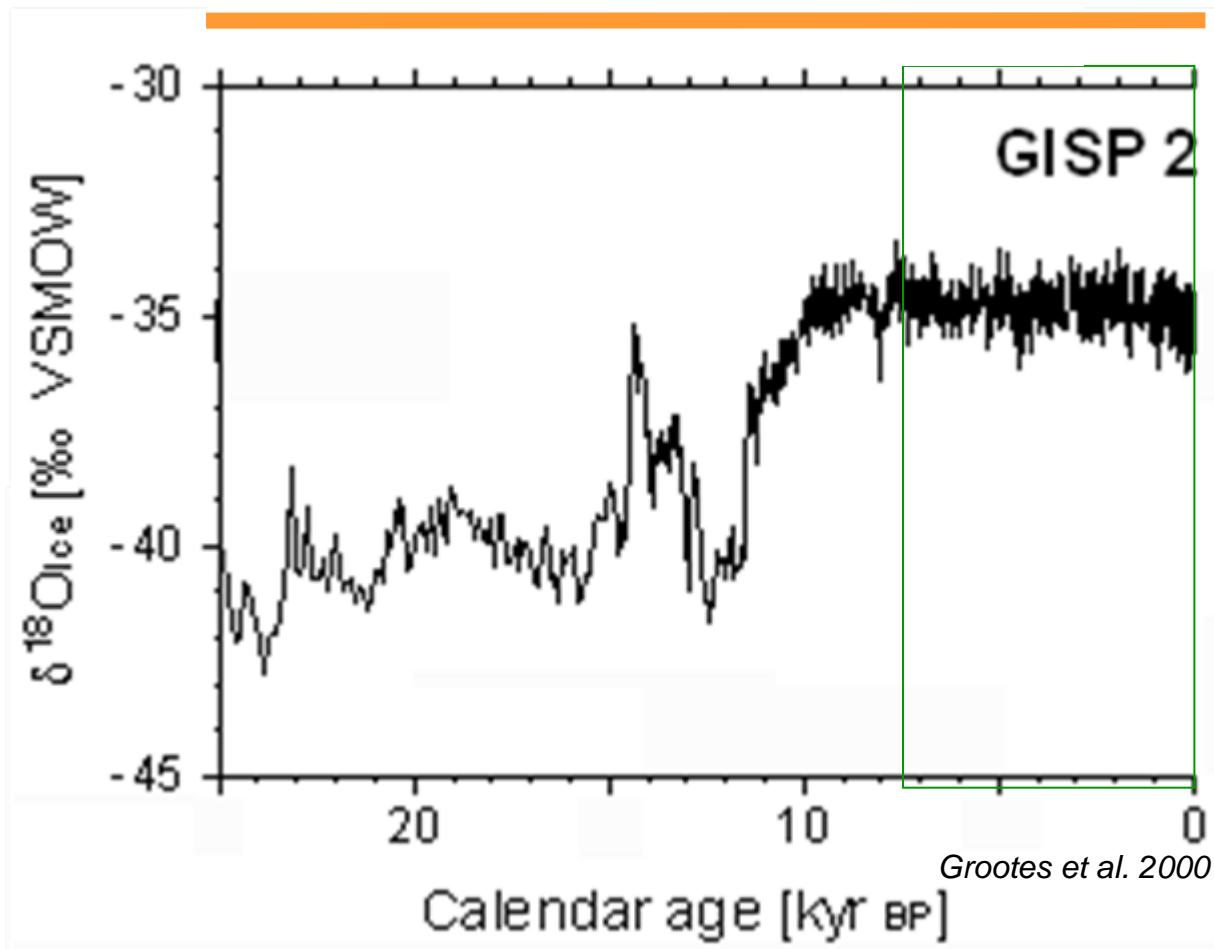


Lorenz & Lohmann 2004

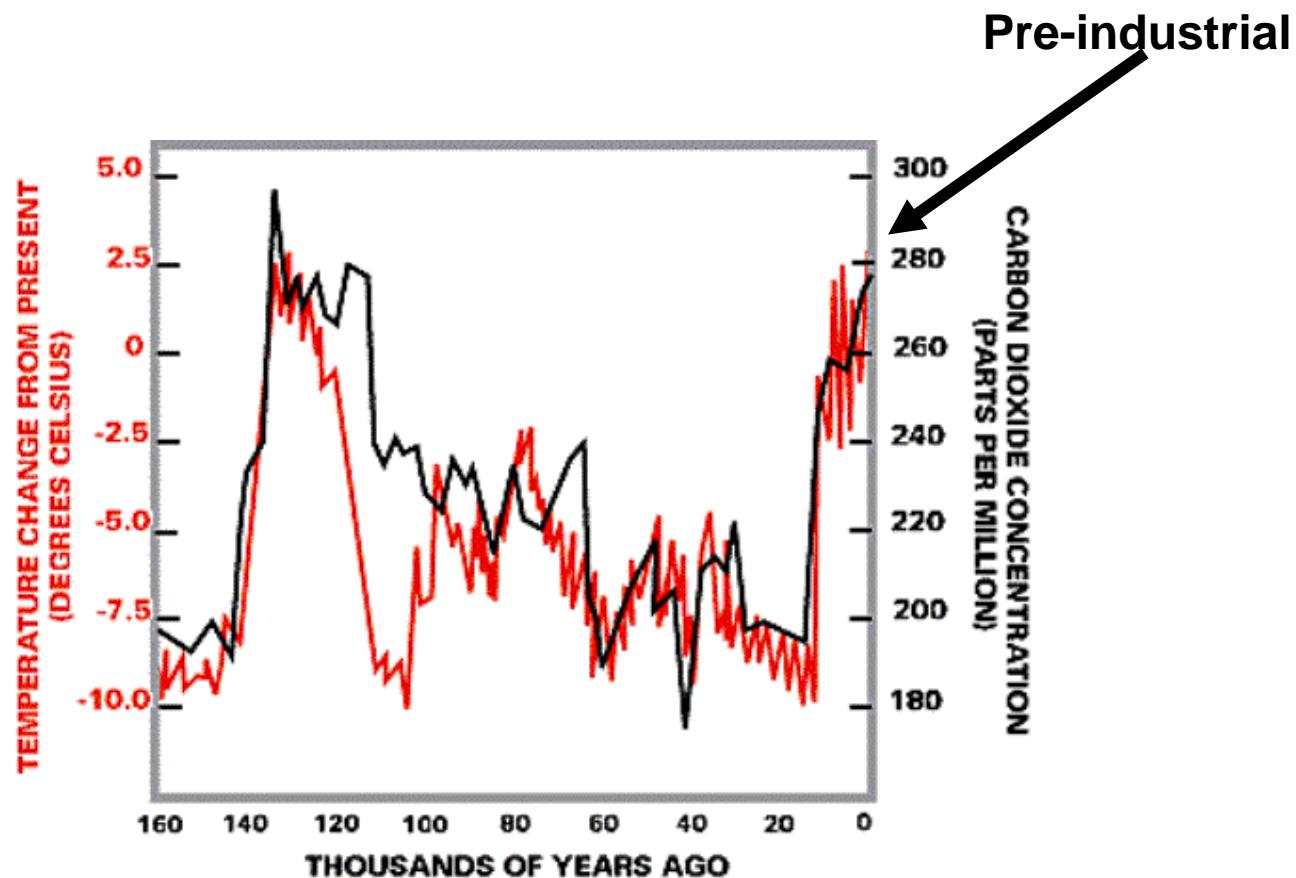


# Climate Trends at different Timescales

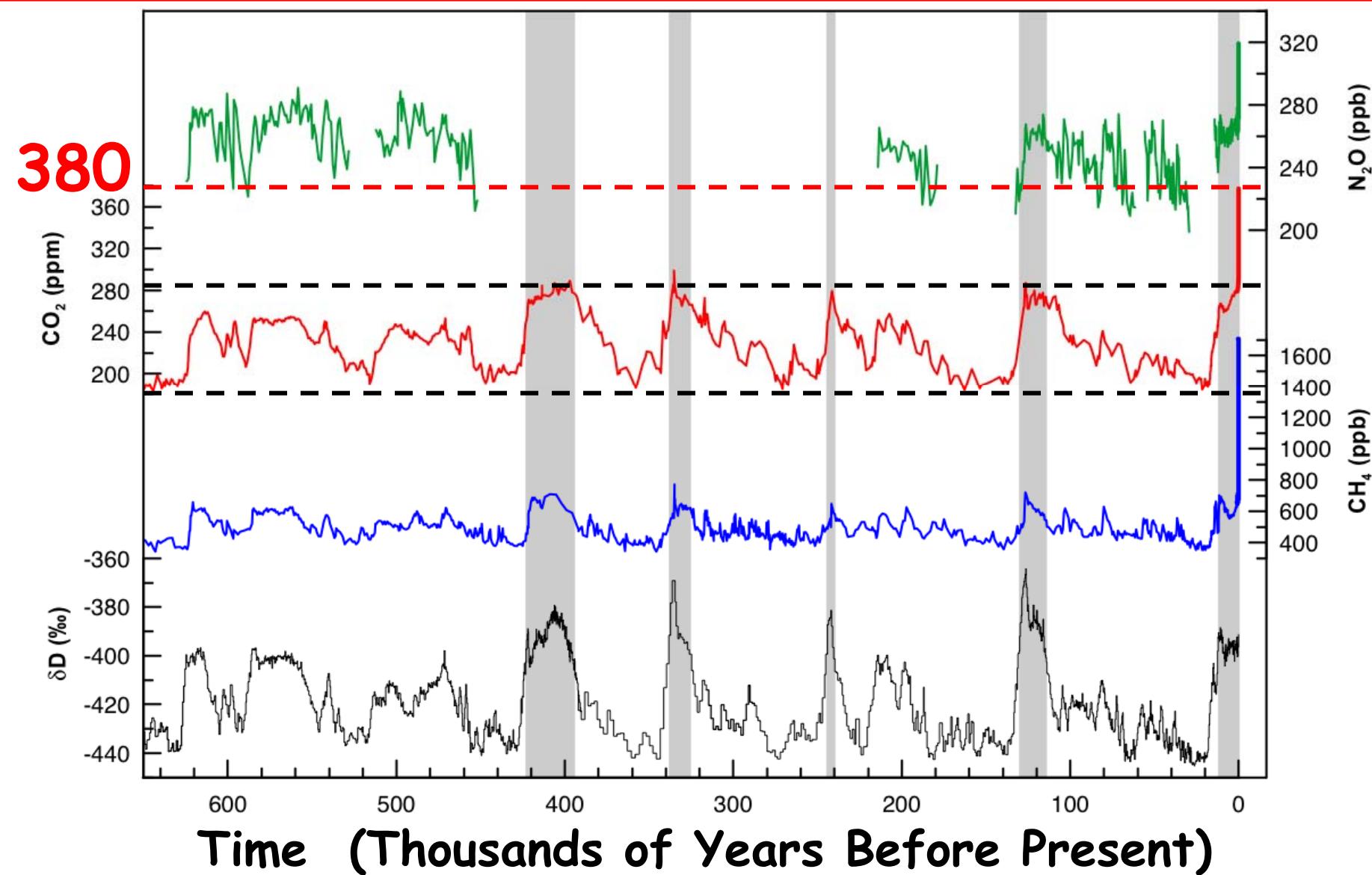
Deglaciation – Greenland ice core



# $\text{CO}_2$ and temperature



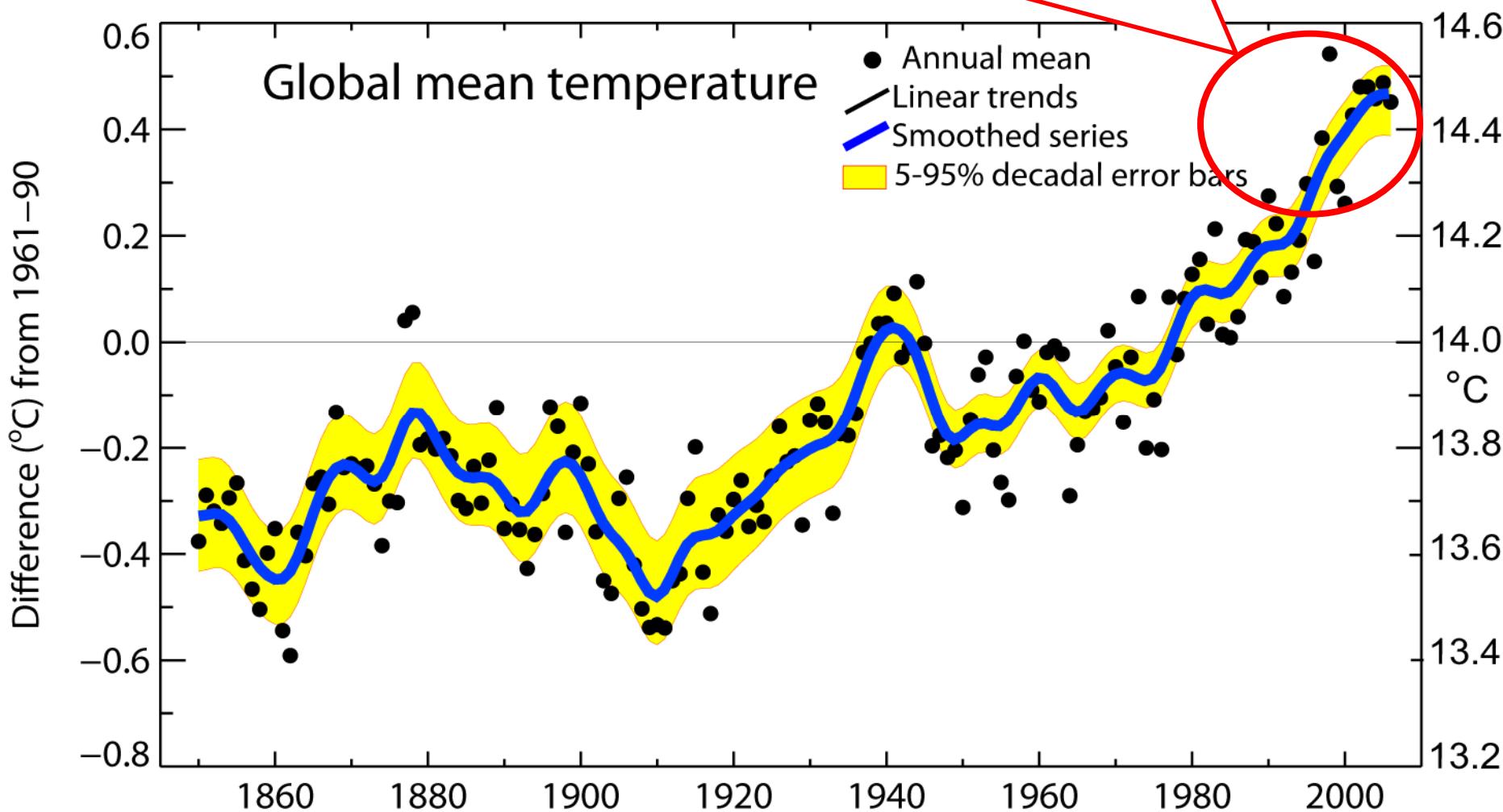
# Atmospheric Gas Concentrations from Ice Cores



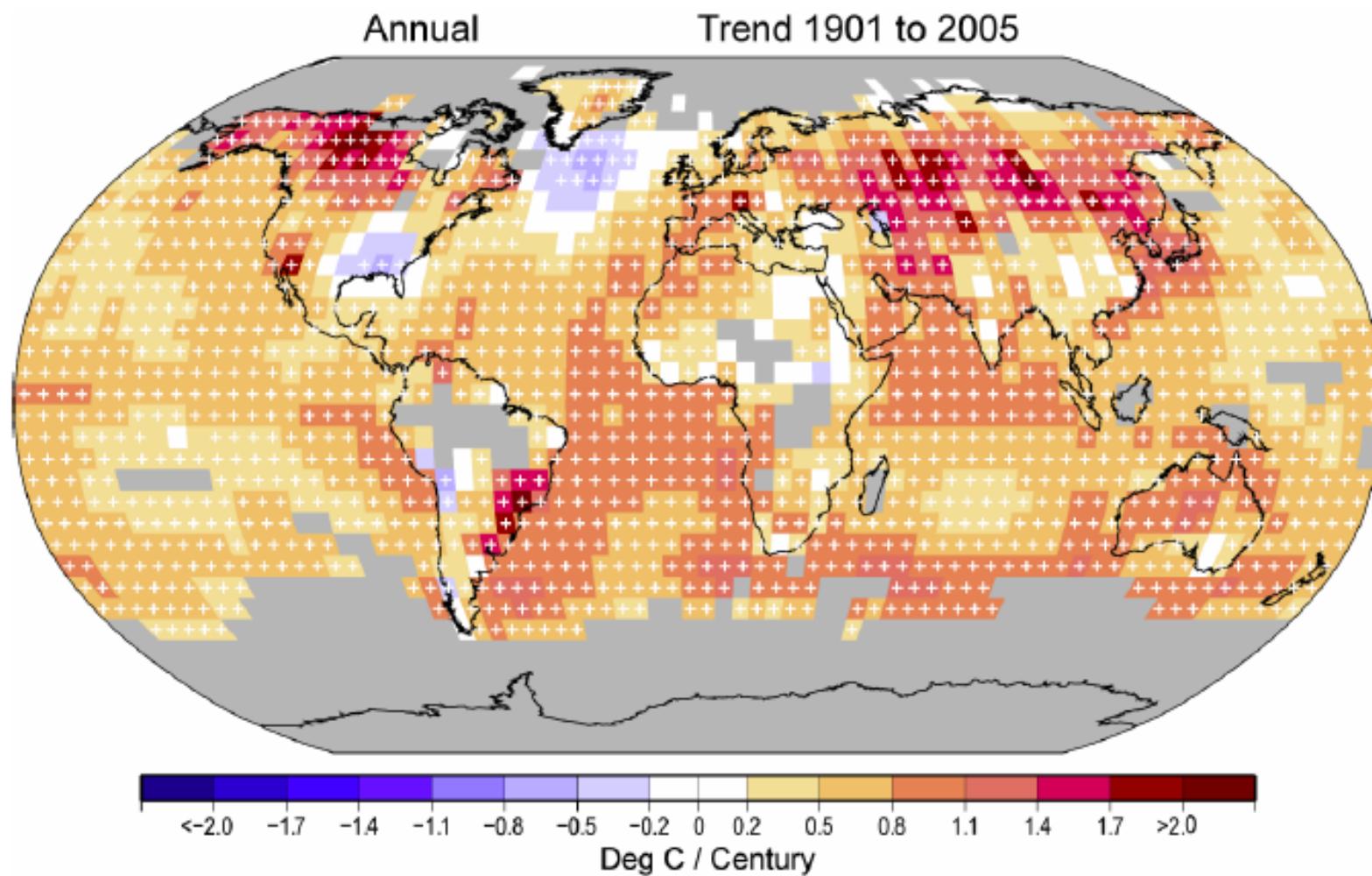
# Global mean temperatures

Warmest 12 years:

1998, 2005, 2003, 2002, 2004, 2006,  
2001, 1997, 1995, 1999, 1990, 2000

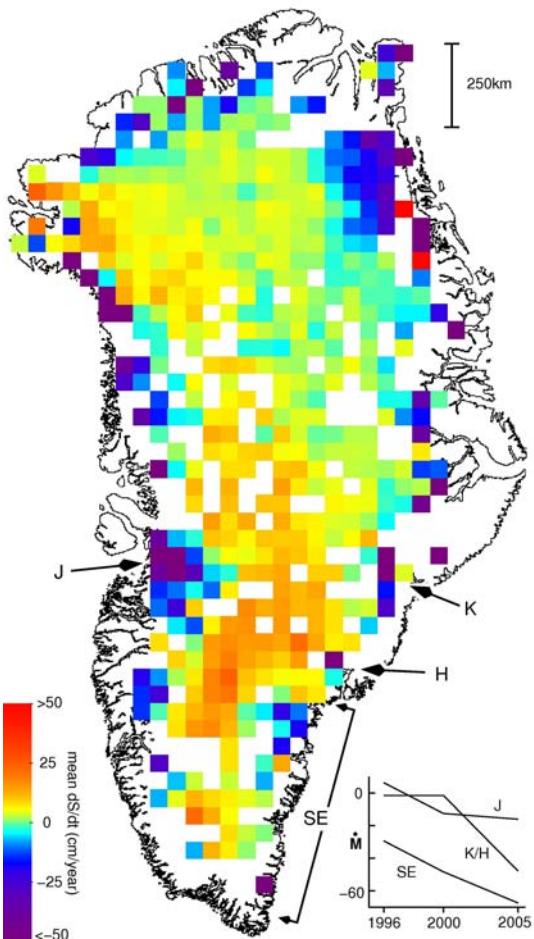


# Observations: Temperature trend since 1901

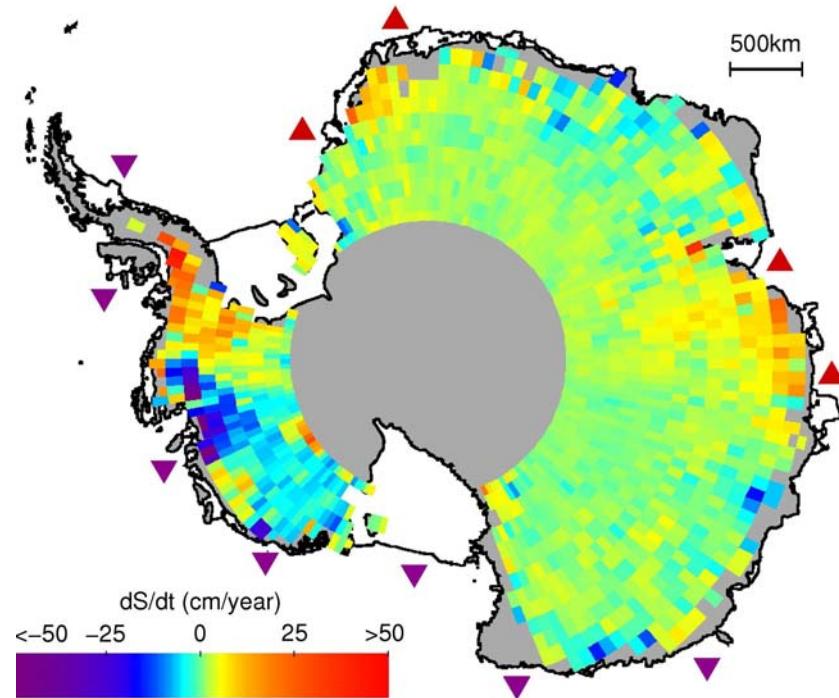


How is this related to past changes?

# The big ice sheets



Greenland gains mass in the interior, but loses more at the margins



Antarctic ice sheet loses mass mostly through increased glacier flow

# Climate Change: Observations & Models



Detection



Understanding

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1911

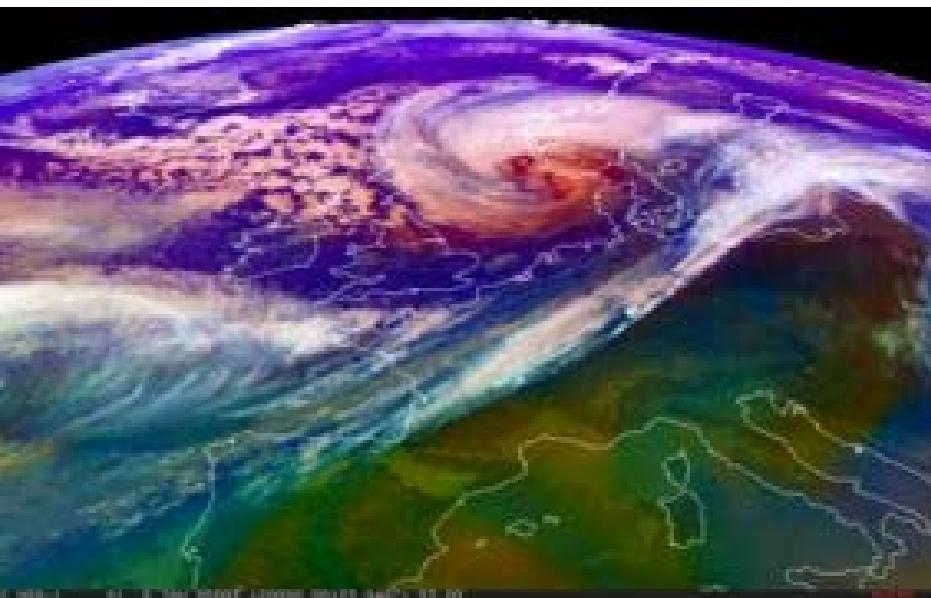


2001



mountain glaciers (Morteratsch)

# Economic damage: European windstorms during winter



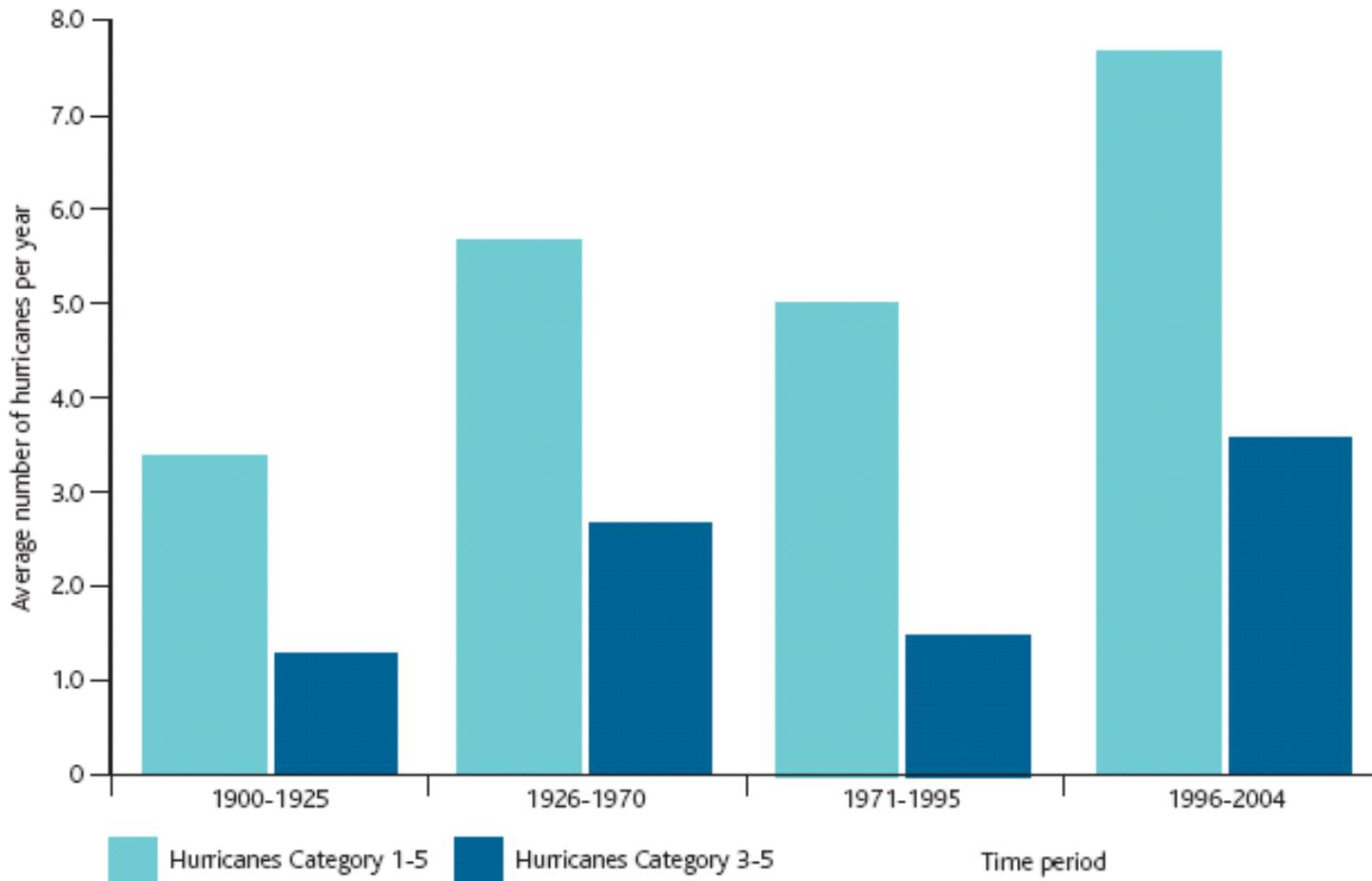
**Economic damage: €1.9 billion per year,  
insurance losses: €1.4 billion per year  
(1990-1998).**

**Second highest cause of global natural  
catastrophe insurance loss after U.S.  
hurricanes.**



# Hurricane formation in the North Atlantic

(a) Changes in relation to warm and cold phases

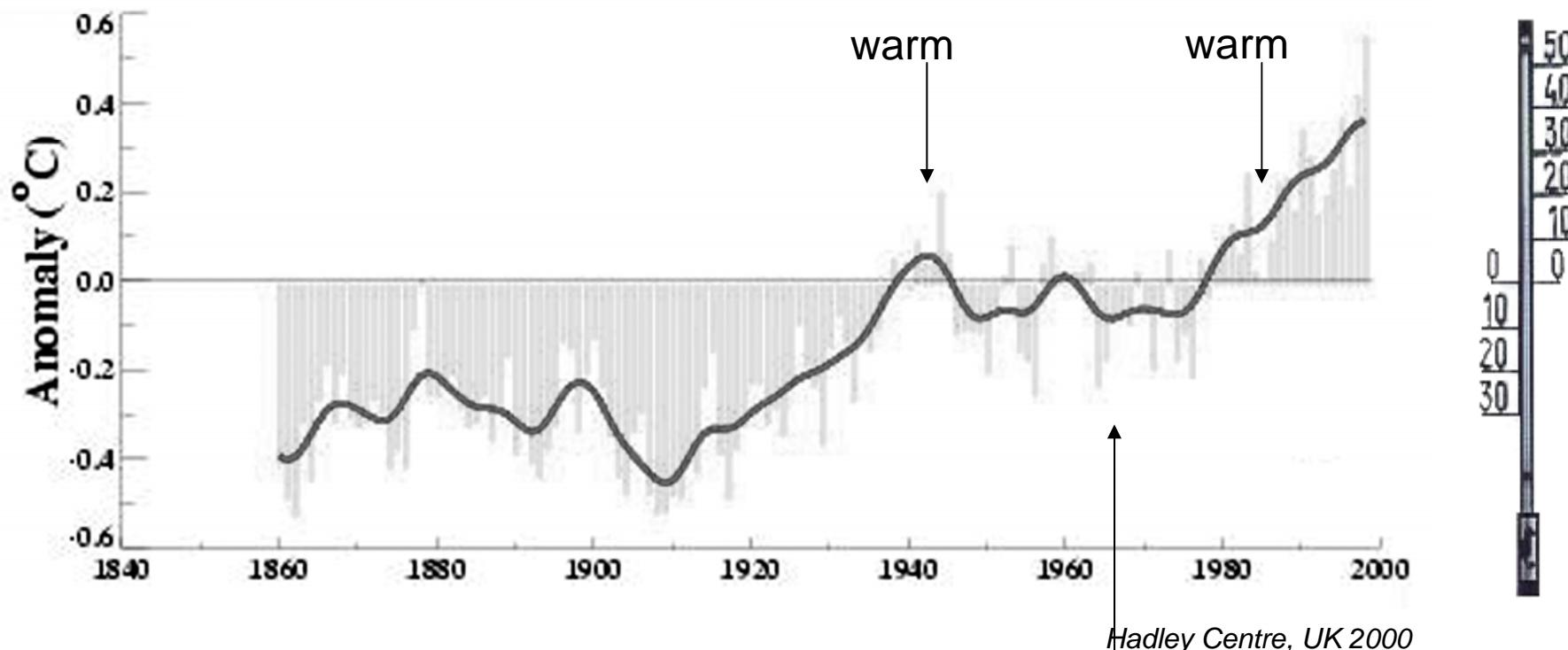


Note: Category 5 represents the most severe class of hurricane.

Source: Based on data from the National Oceanic Atmospheric Administration (NOAA) National Hurricane Centre.

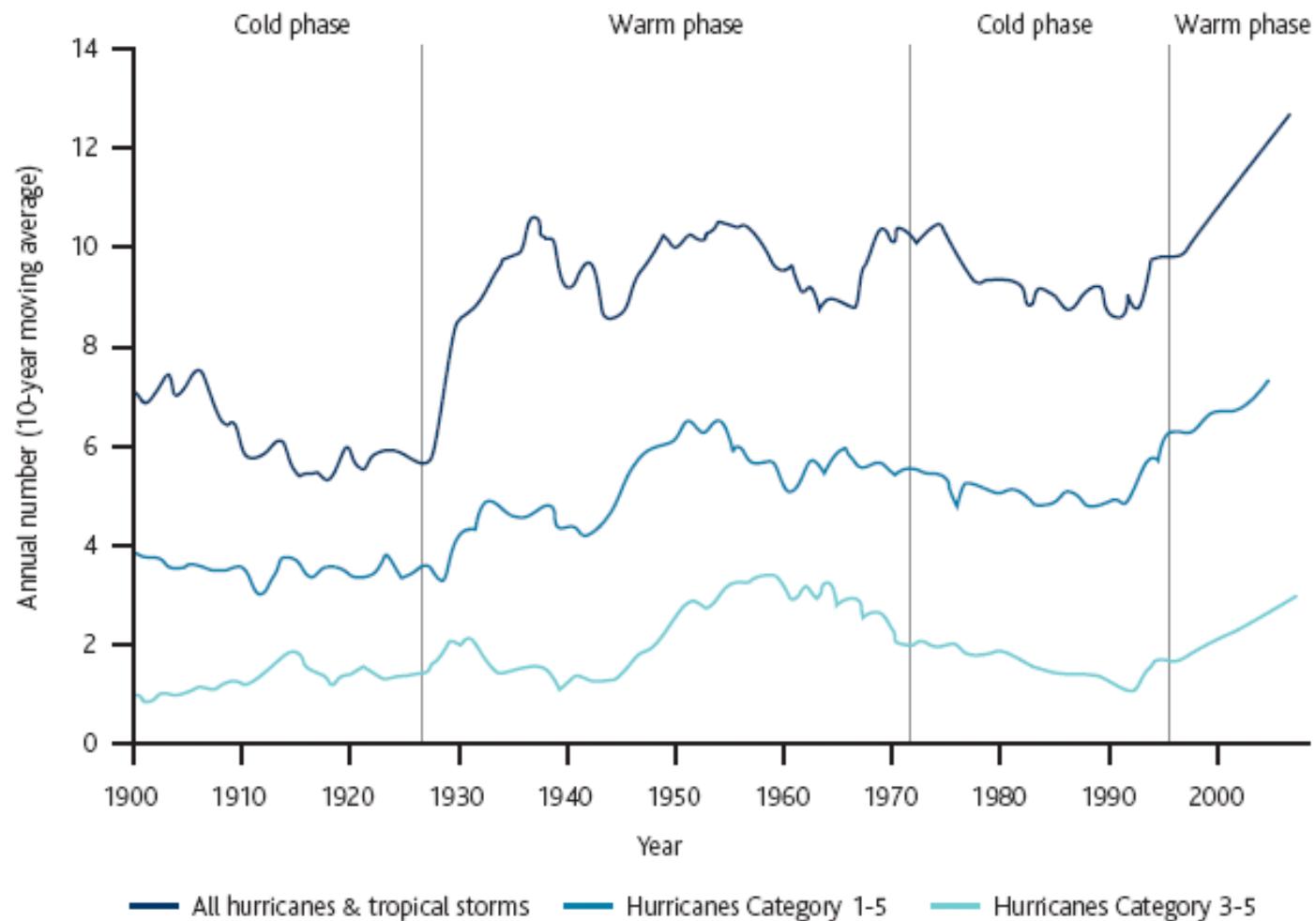
Temperature of the last **150 years** (instrumental data)

## Global temperature



# # Hurricanes: Decadal Oscillations plus trend

(b) Ten-year moving average for tropical cyclones formed in the North Atlantic Basin





# Modelling

## Circulation Models

### Fluid dynamical equations

Momentum equations:

$$\begin{aligned} u_t + \text{Adv}(u) - \left( f + \frac{u \tan \phi}{a} \right) v &= -\frac{1}{a \cos \phi} \left( \frac{p}{\rho_0} \right)_\lambda + F^\lambda \\ v_t + \text{Adv}(v) + \left( f + \frac{u \tan \phi}{a} \right) u &= -\frac{1}{a} \left( \frac{p}{\rho_0} \right)_\phi + F^\phi \\ 0 &= -\left( \frac{p}{\rho_0} \right)_z - g\rho \end{aligned}$$

Continuity equation:

$$\frac{1}{a \cos \phi} \left[ (u)_\lambda + (v \cos \phi)_\phi \right] + (w)_z = 0$$

Equation for tracers  $\chi$ , temperature  $T$ , salinity (humidity)  $S$ :

$$\chi_t + \text{Adv}(\chi) = A_{HH} \nabla^2 \chi + A_{HV} \chi_{zz} \quad ,$$

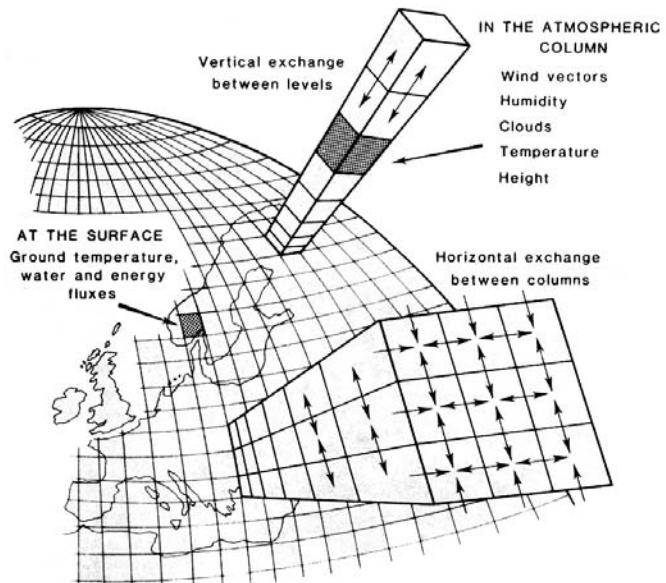
Equation of state:

$$\rho = \rho(\Theta, S, z) \quad .$$

The equations are "coarse grained" in space and time.

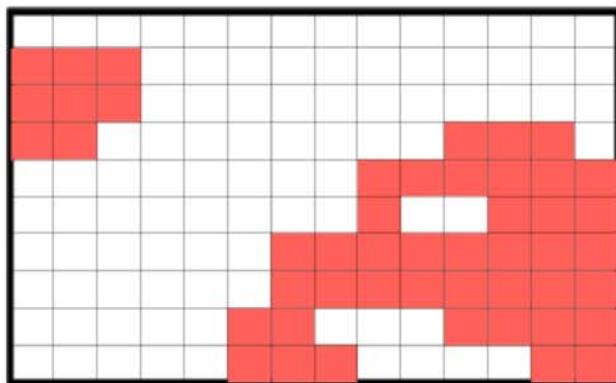
Subgrid scale processes are **parameterized** by diffusive mixing.

### Cartesian Grid GCM



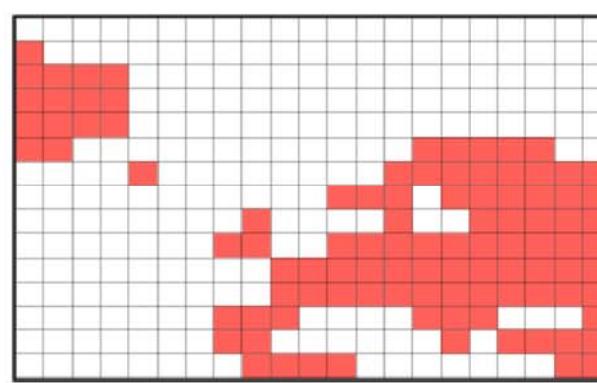
# Grid resolution

T 21



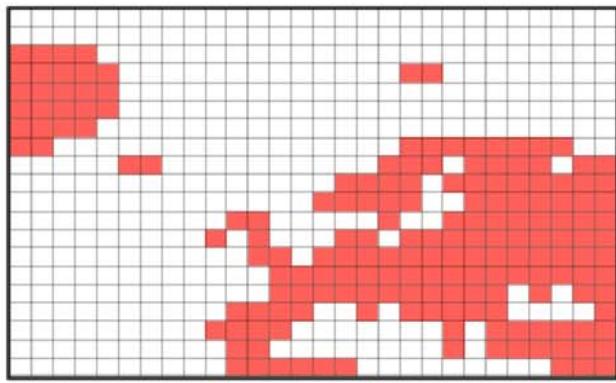
ca. 500 km Gitterabstand

T 42



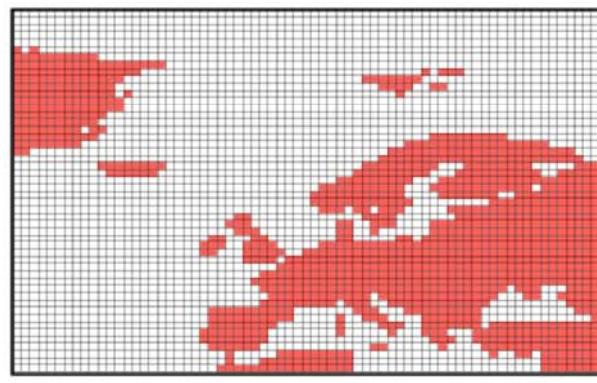
ca. 250 km Gitterabstand

T 63

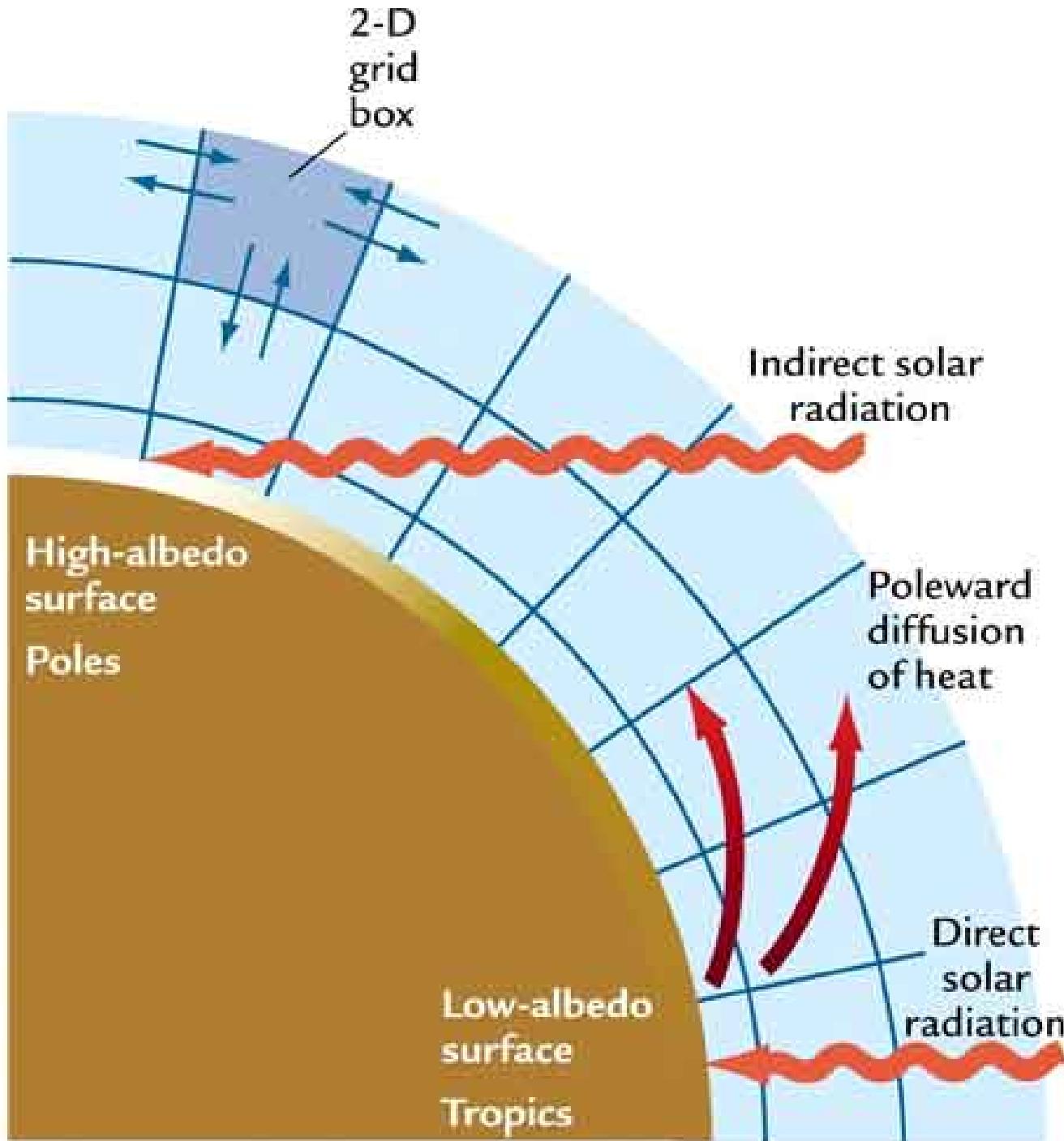


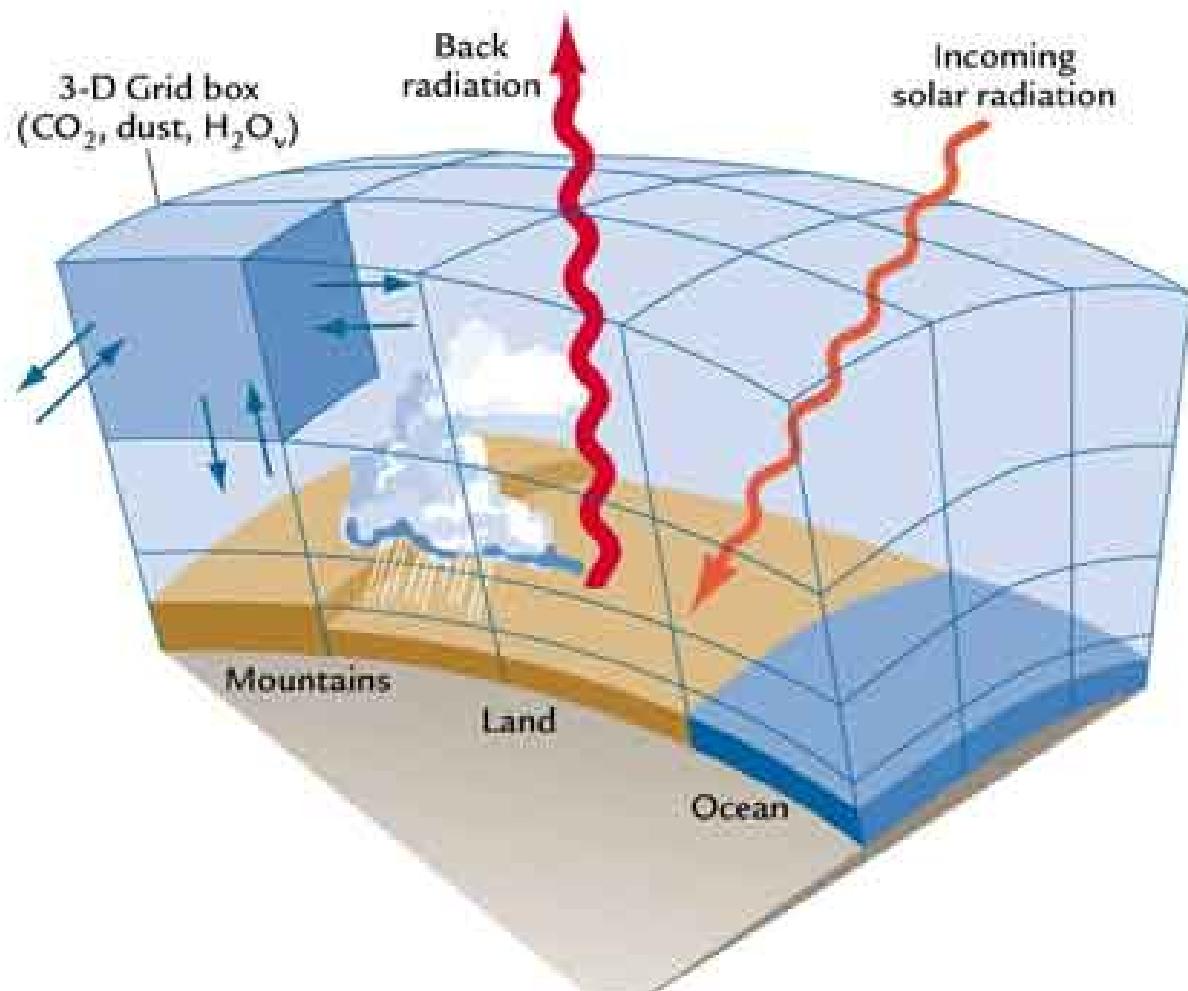
ca. 180 km Gitterabstand

T 106



ca. 110 km Gitterabstand





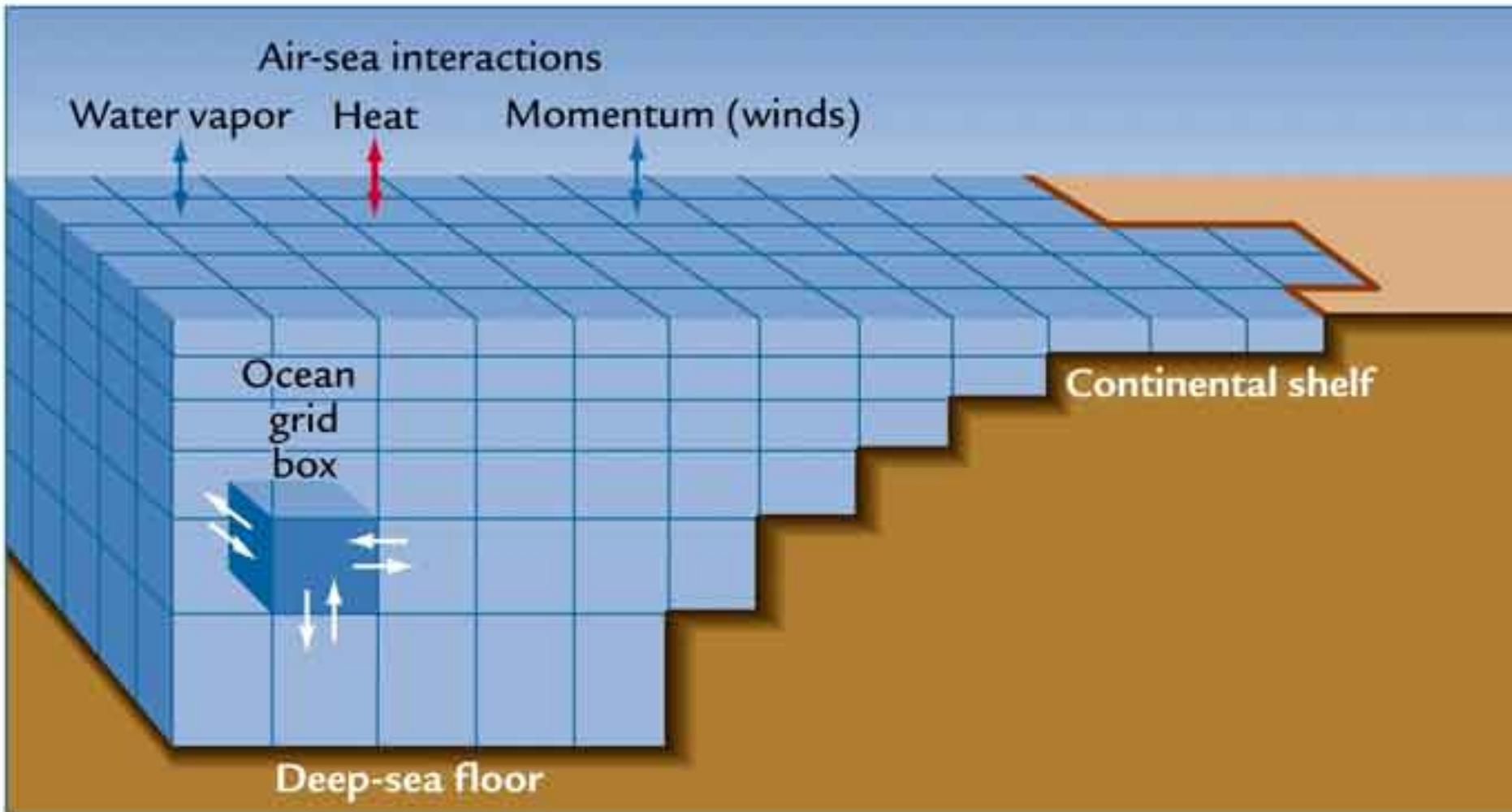
### Air-sea interactions

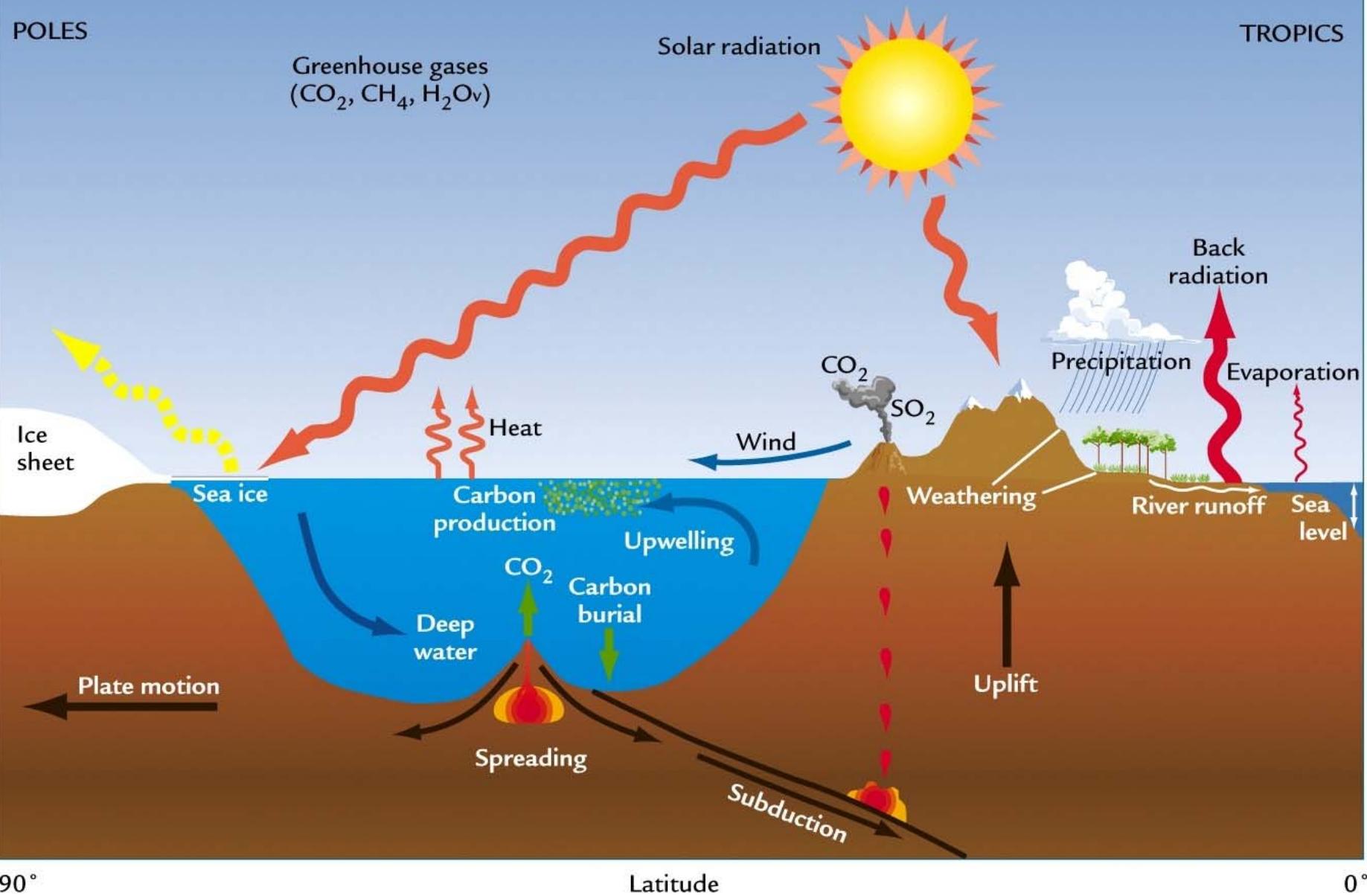
Water vapor      Heat      Momentum (winds)

Ocean  
grid  
box

Continental shelf

Deep-sea floor

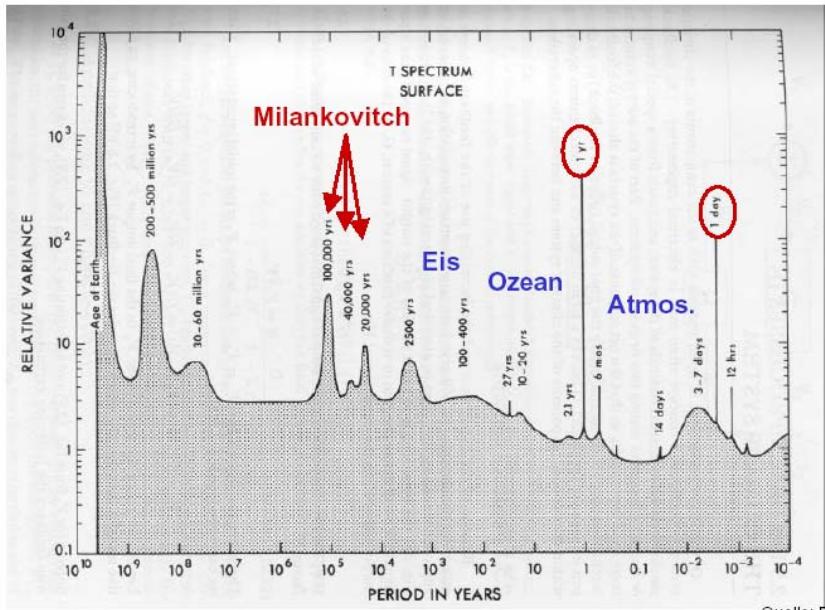




- 2nd
- Forcings

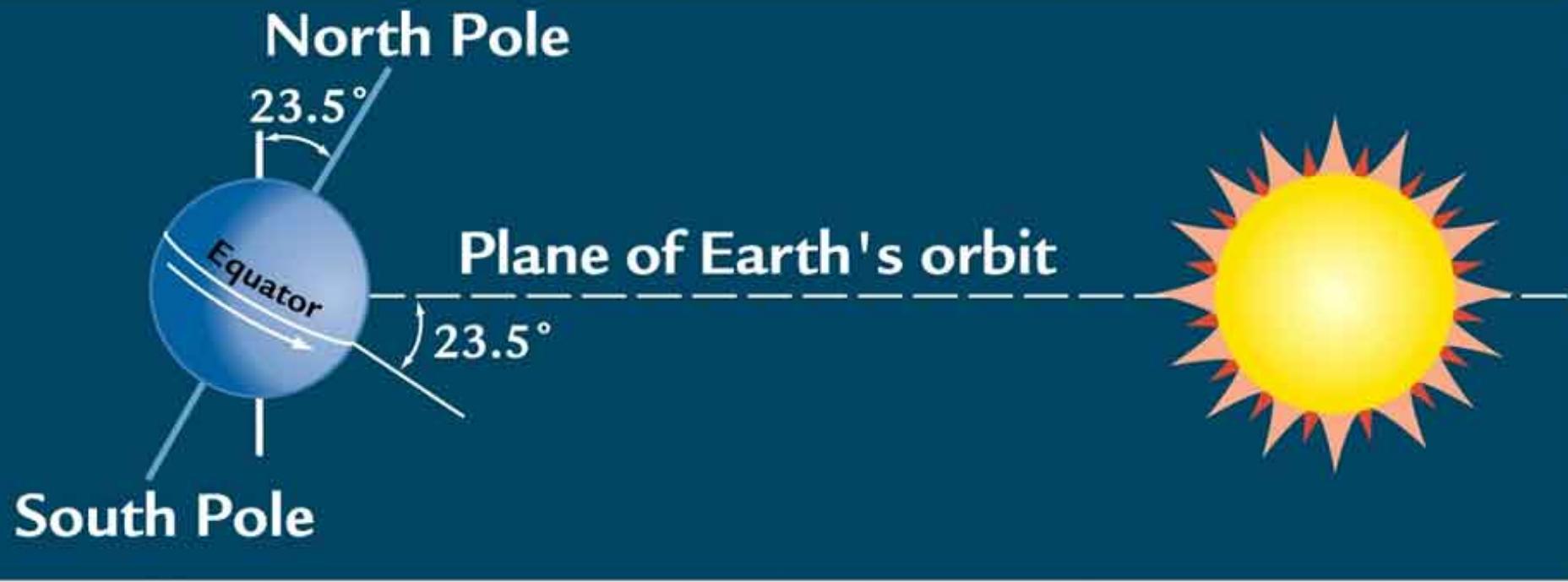
# Solar - Orbital focusing

- 20000, 40000, 100000 years
- 0.5, 1 year
- Geometry of the Sun-Earth configuration



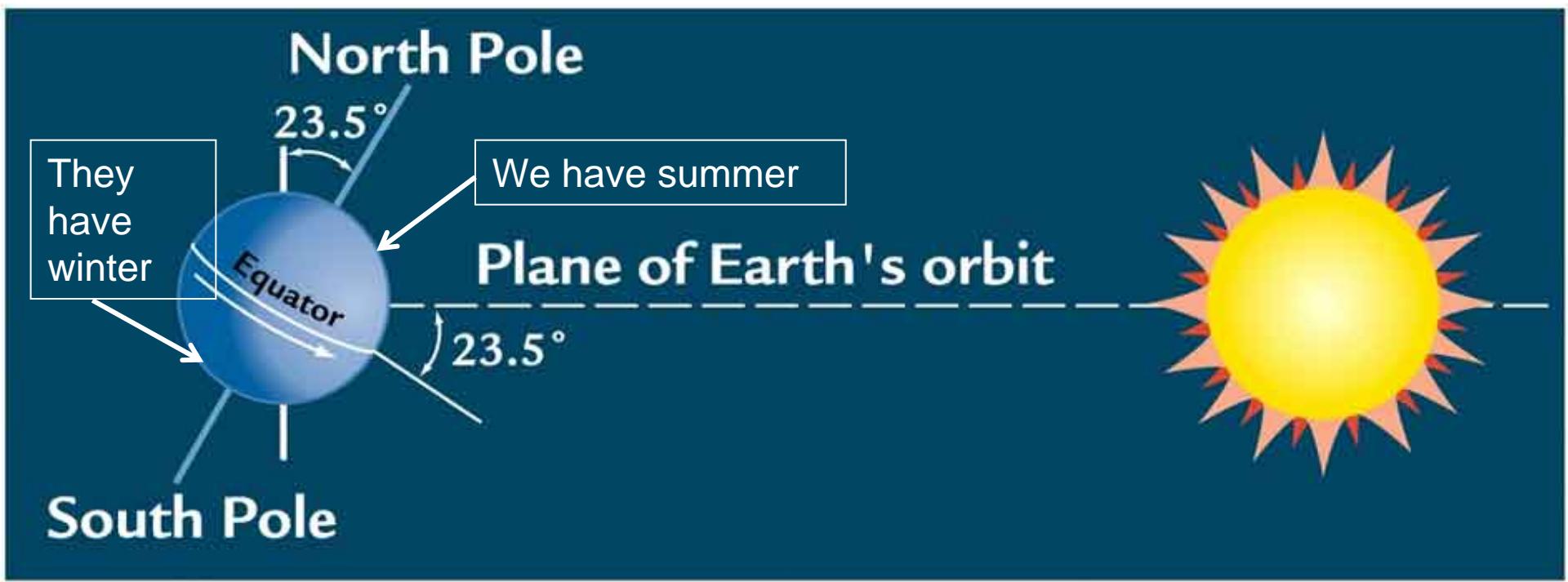
Quelle: Peixoto & Oort

# Annual Cycle



**Northern Hemisphere Summer**  
**Boreal Summer**

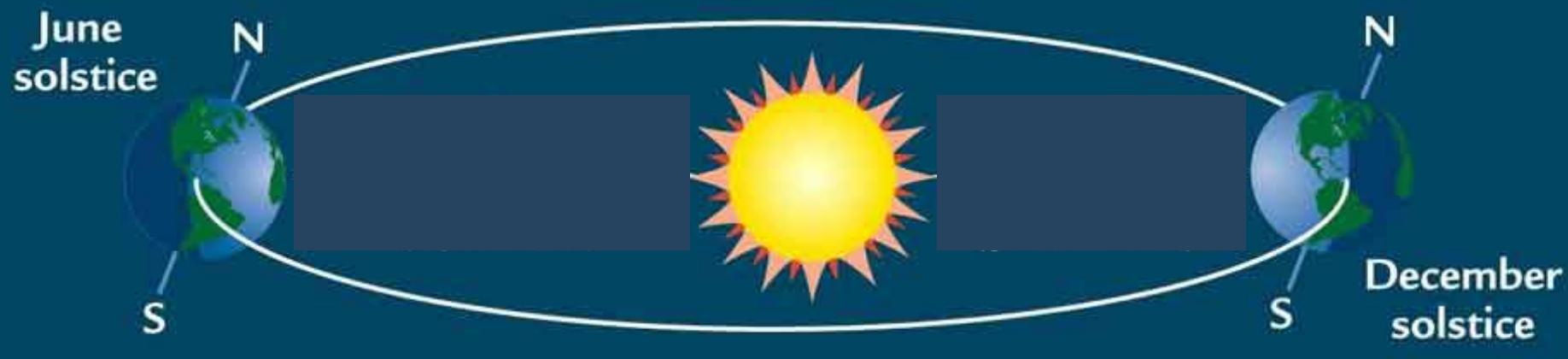
# Annual Cycle



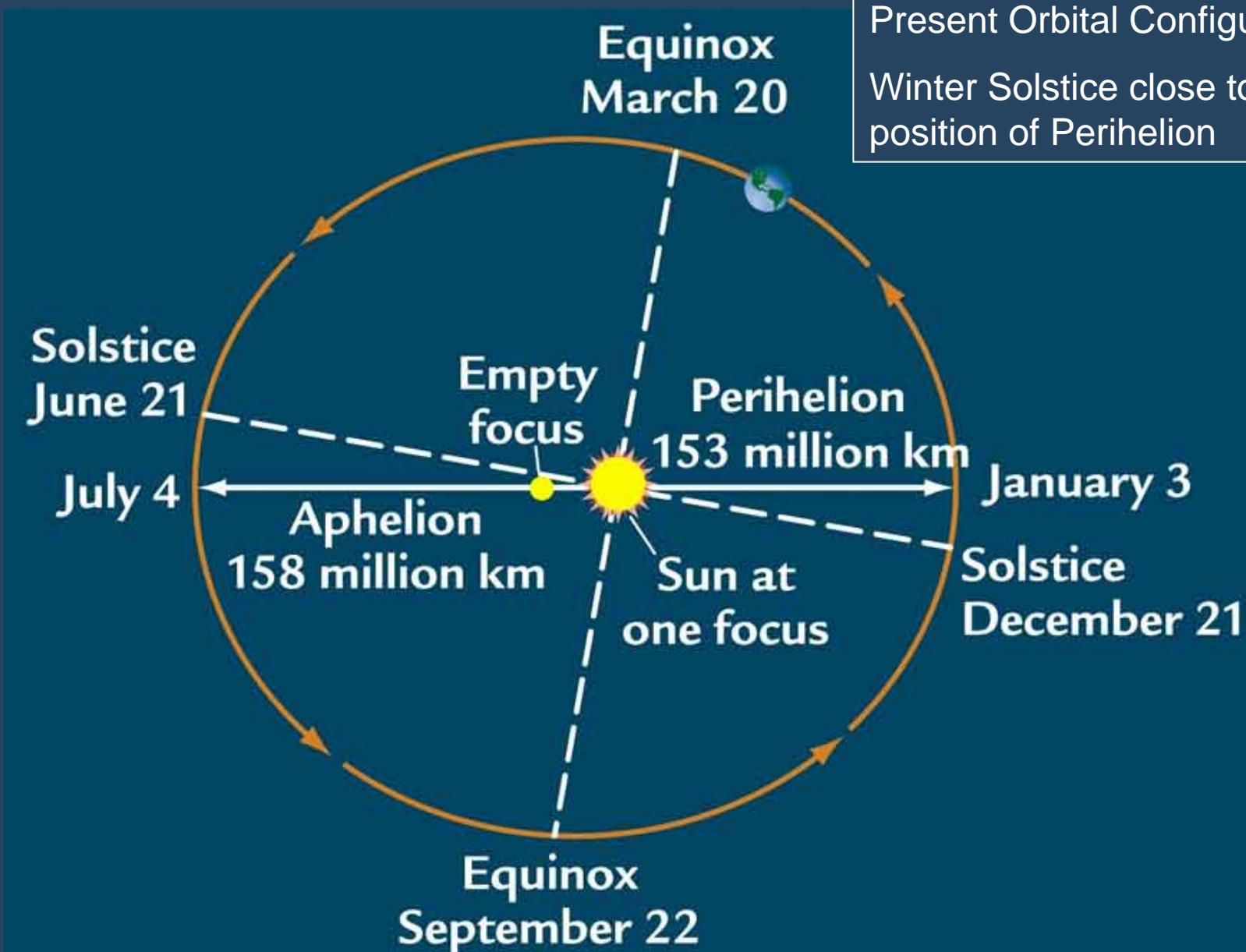
**Northern Hemisphere Summer**  
**Boreal Summer**

# Annual Cycle

## Fixed axis of Earth rotation



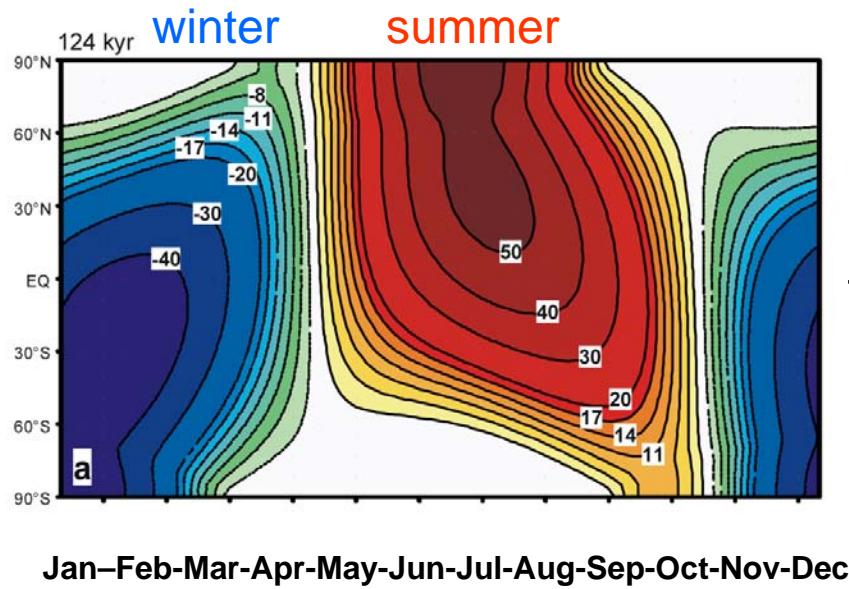
# Precession & Eccentricity



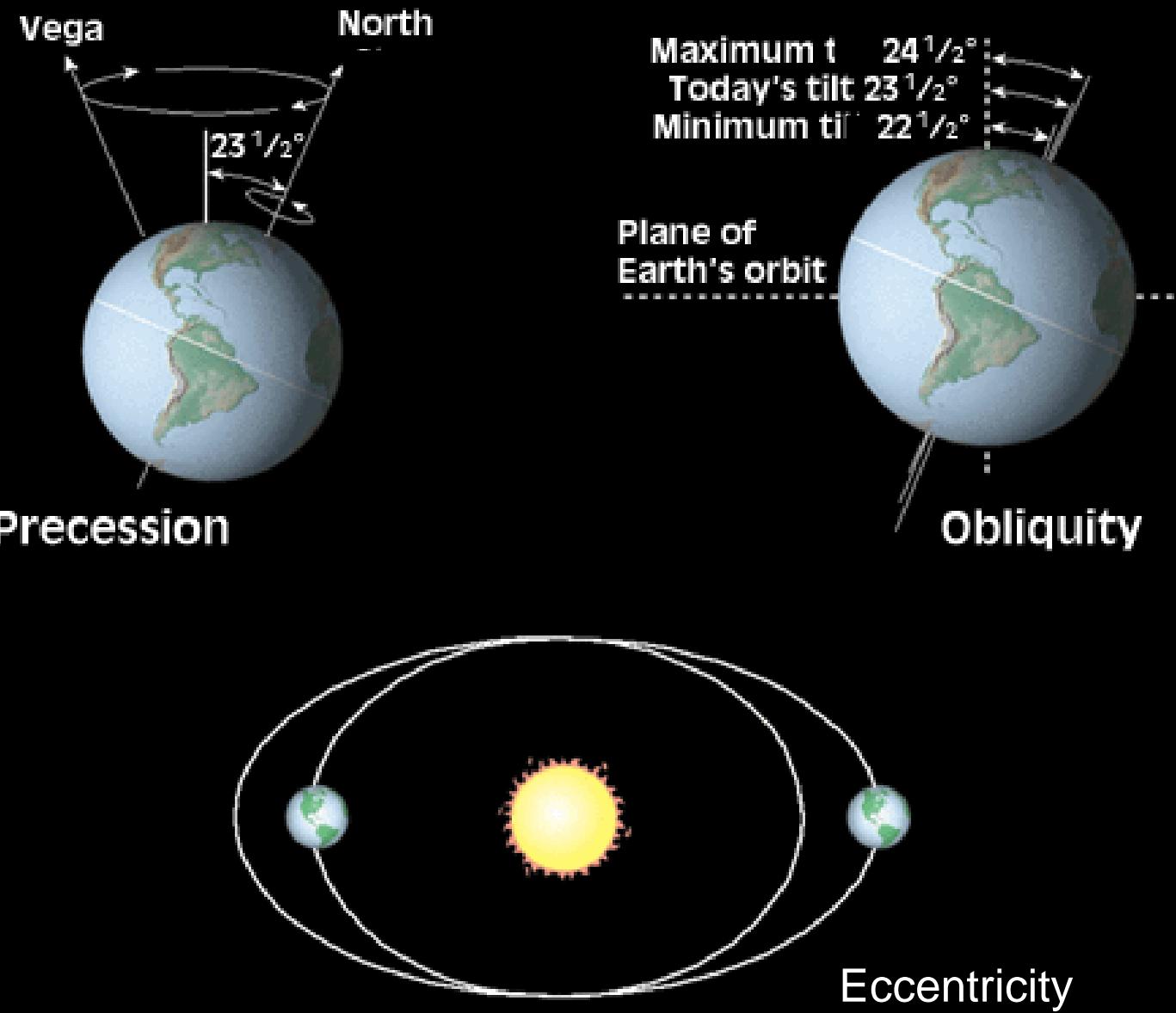
Present Orbital Configuration:  
Winter Solstice close to the  
position of Perihelion

# Example for Milankovitch forcing

The Eemian climate (the last interglacial, 124 000 years)

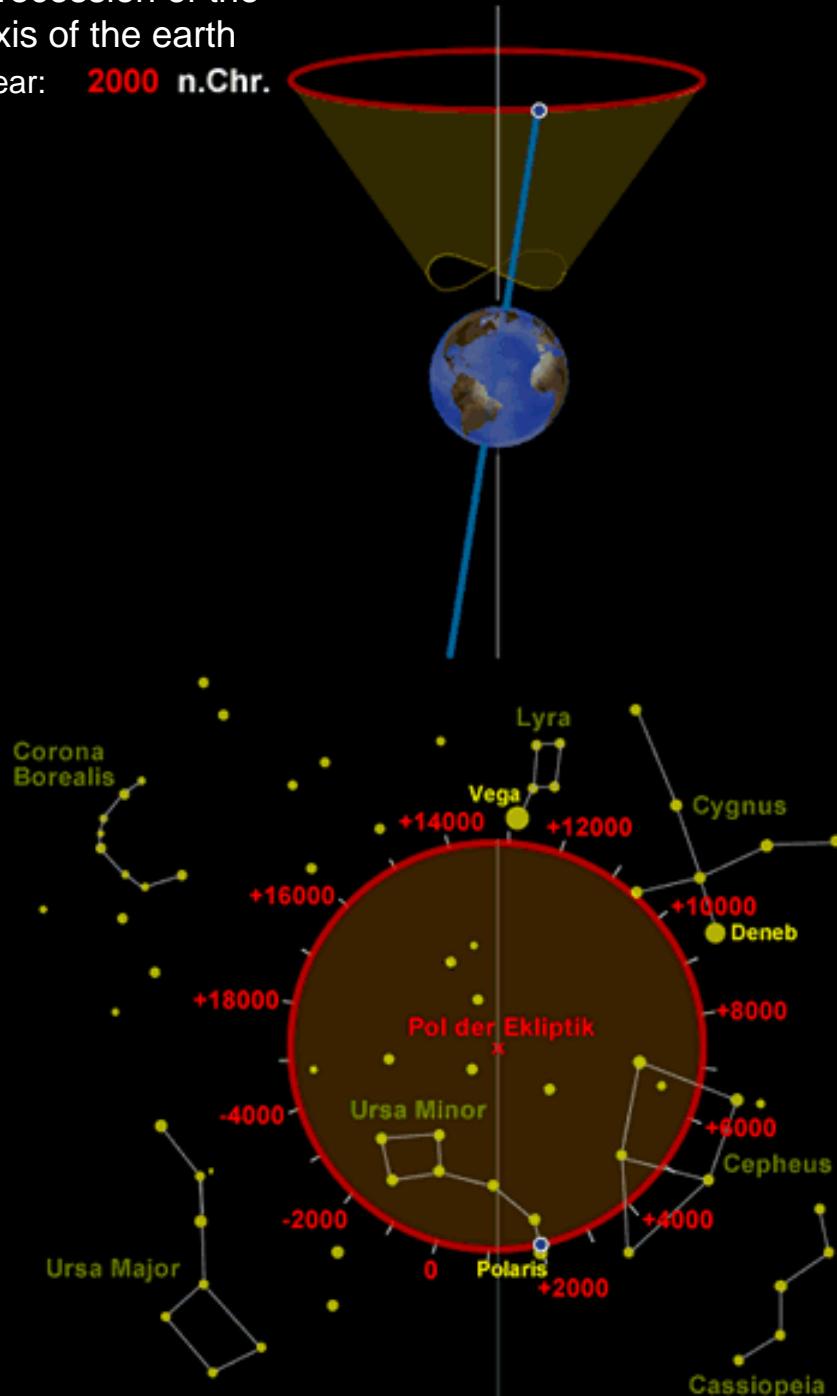


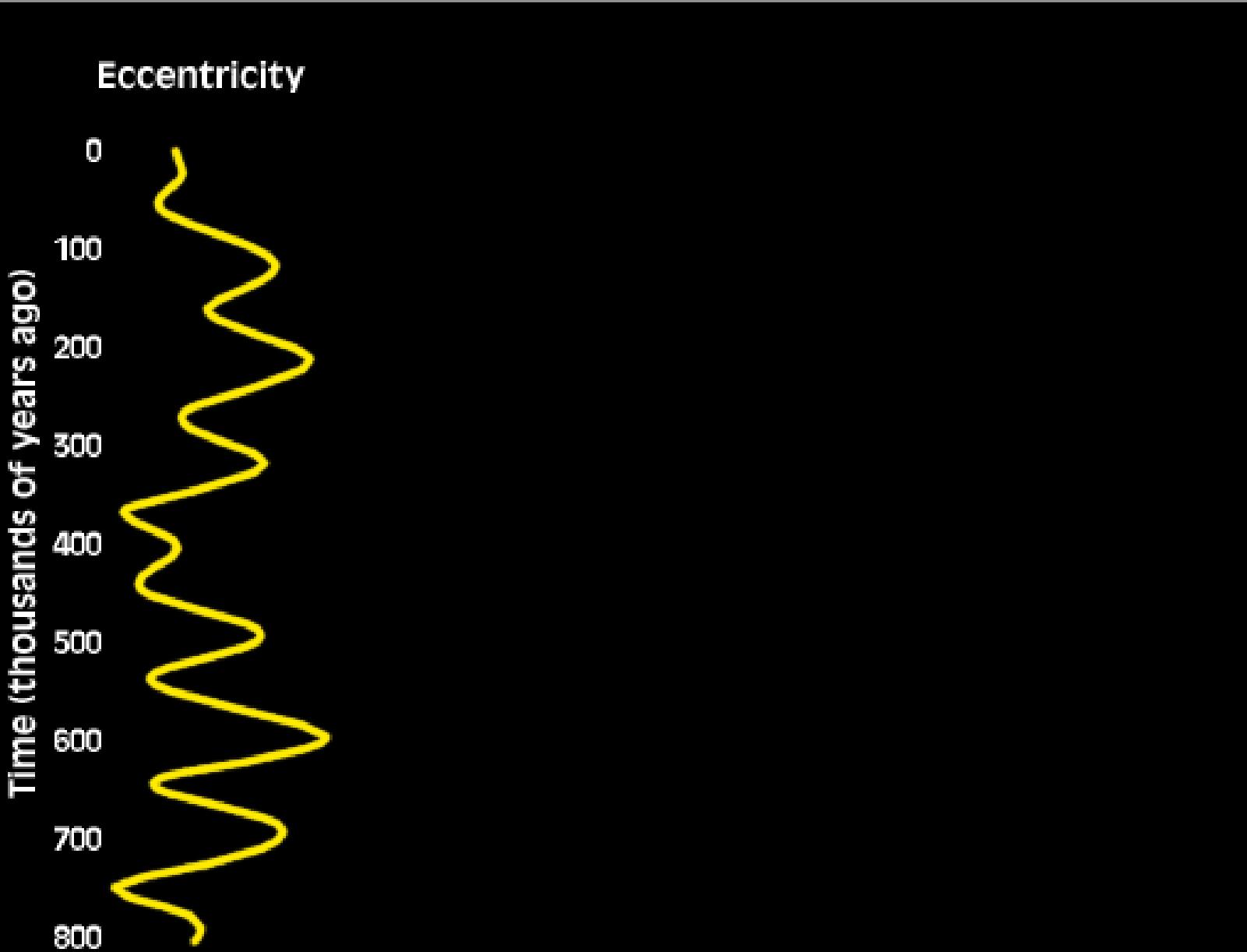
insolation  
anomaly  
form today

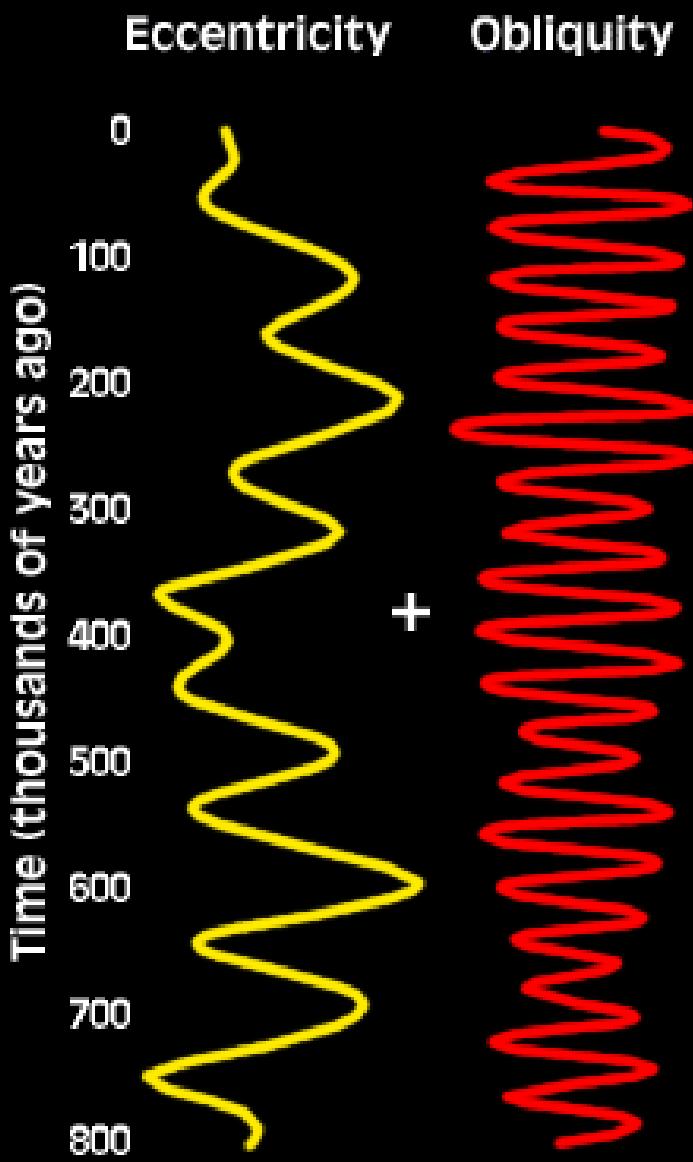


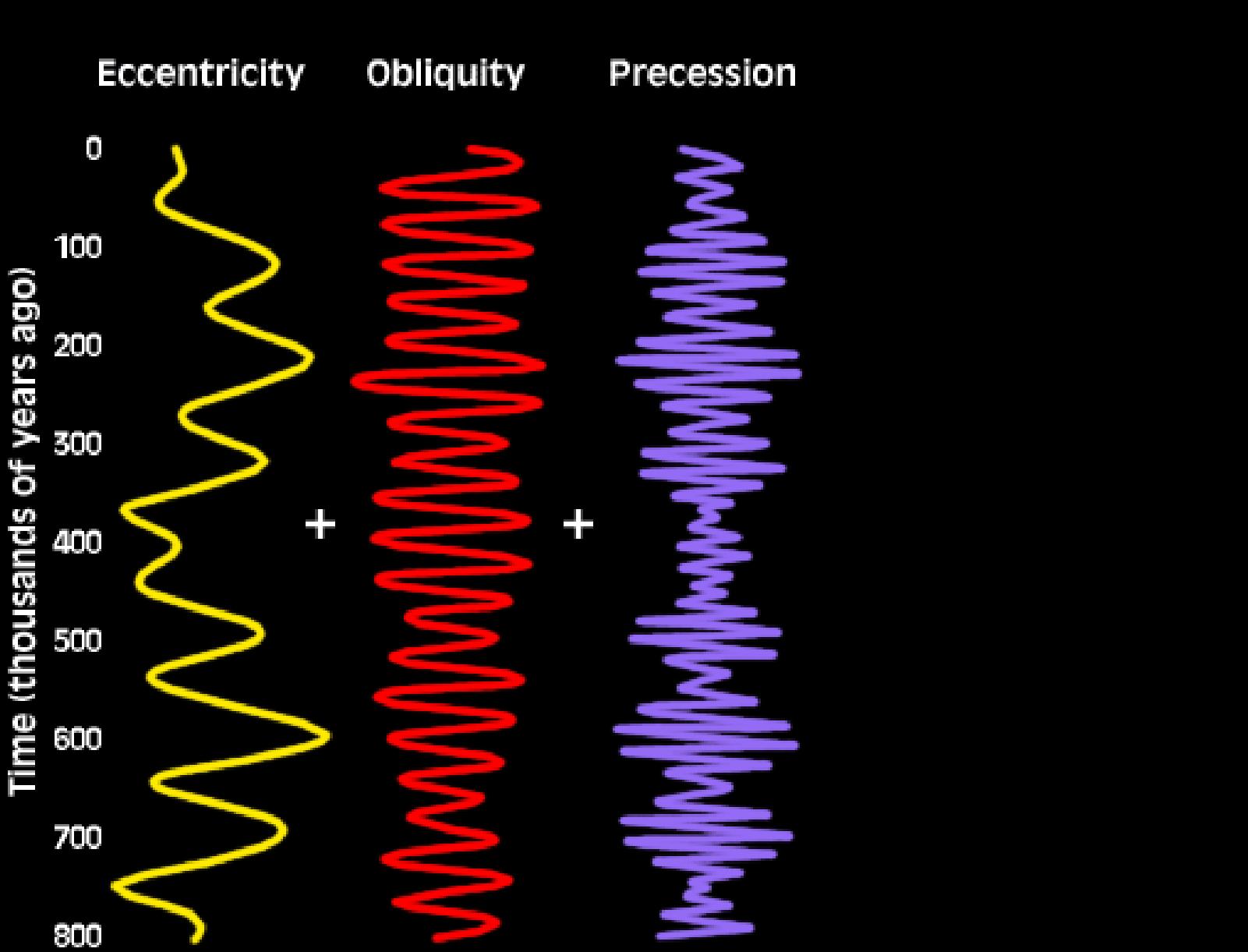
# Precession of the axis of the earth

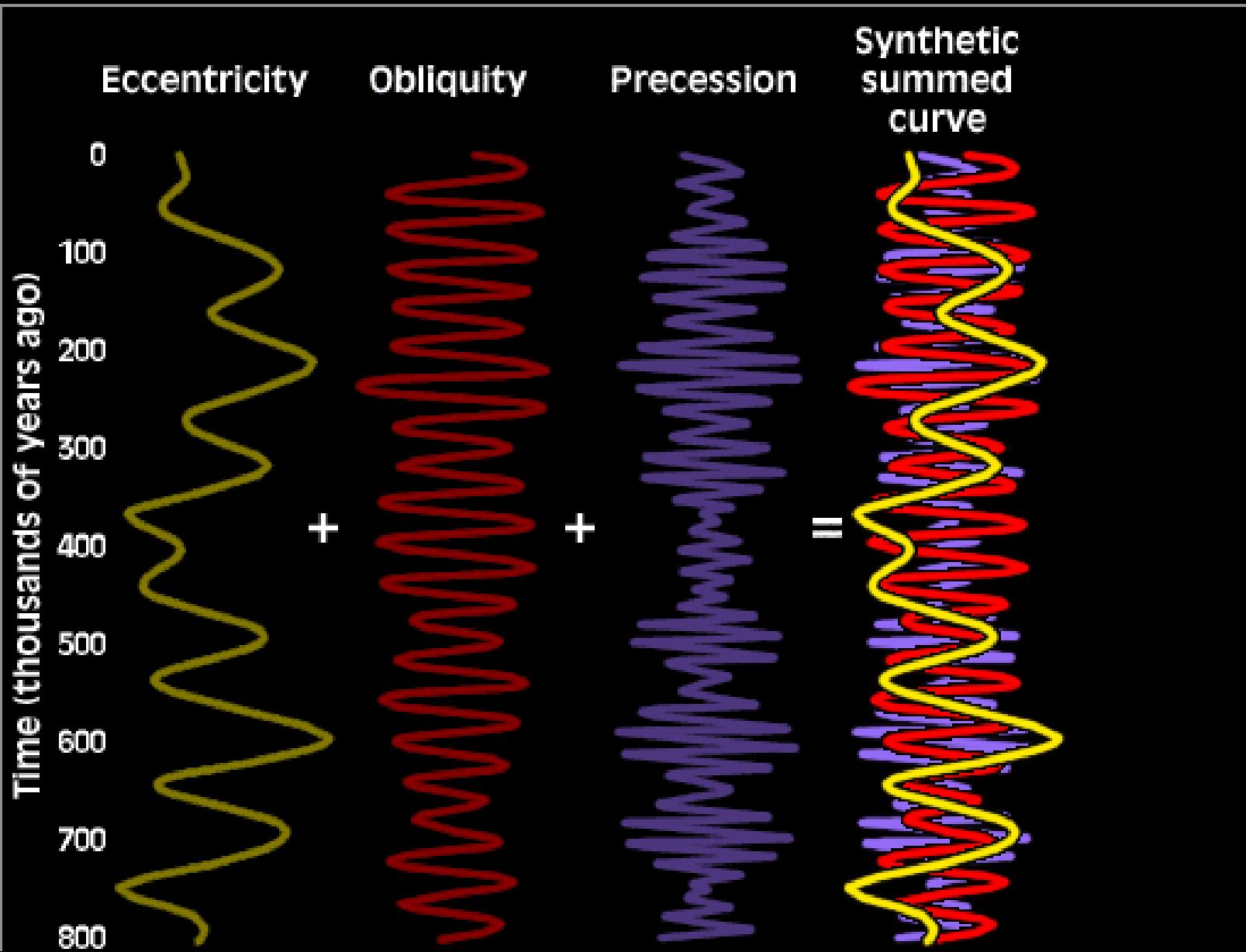
Year: **2000** n.Chr.

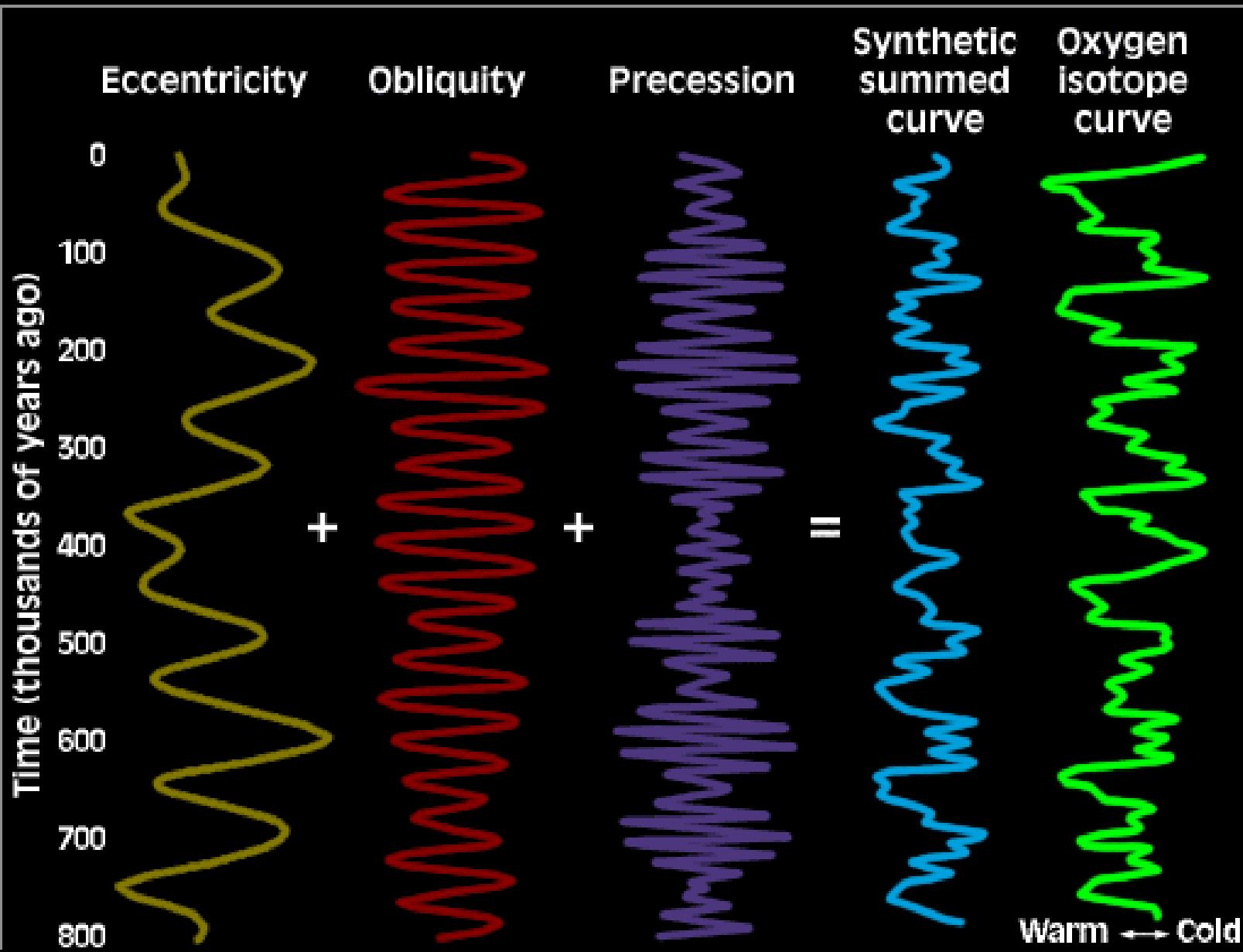














Sunspots

Photo: Nasa