

# Climate Changes: Data, Order of Magnitudes, Models

Zoltán RÁCZ

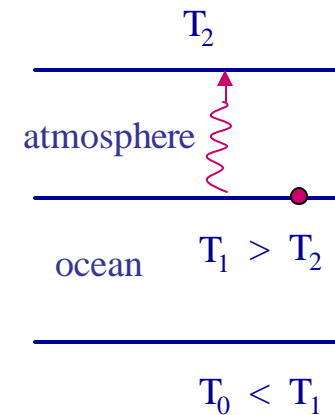
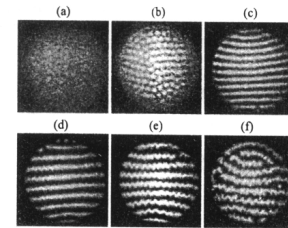
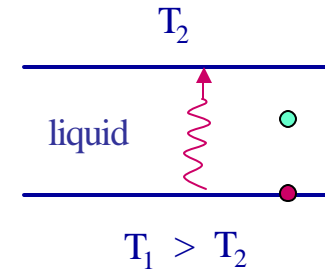
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Homepage: <http://cgl.elte.hu/~racz>

**Problem:** What is climate and how does it change?  
Mixing of scientific and social problems (witches).

**Questions:** What do we know from the past (time series)?  
Relevant time- and spatial scales  
What drives the climatic processes?  
Energy- és energy-flux scales

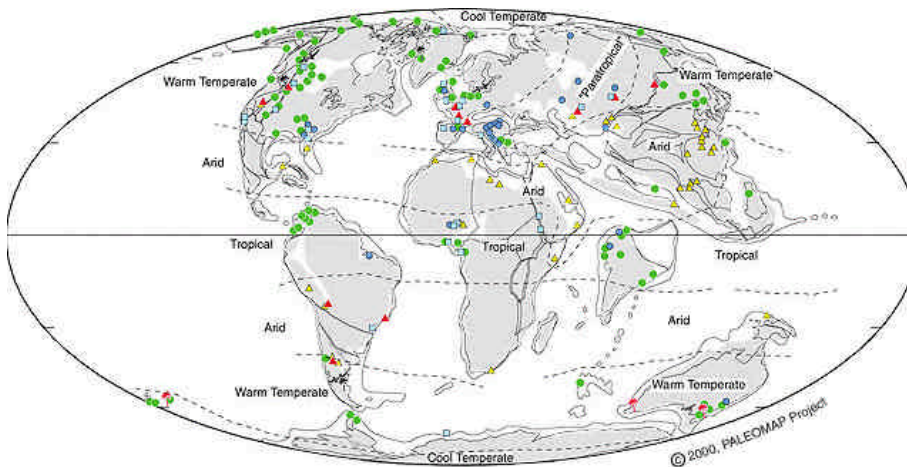
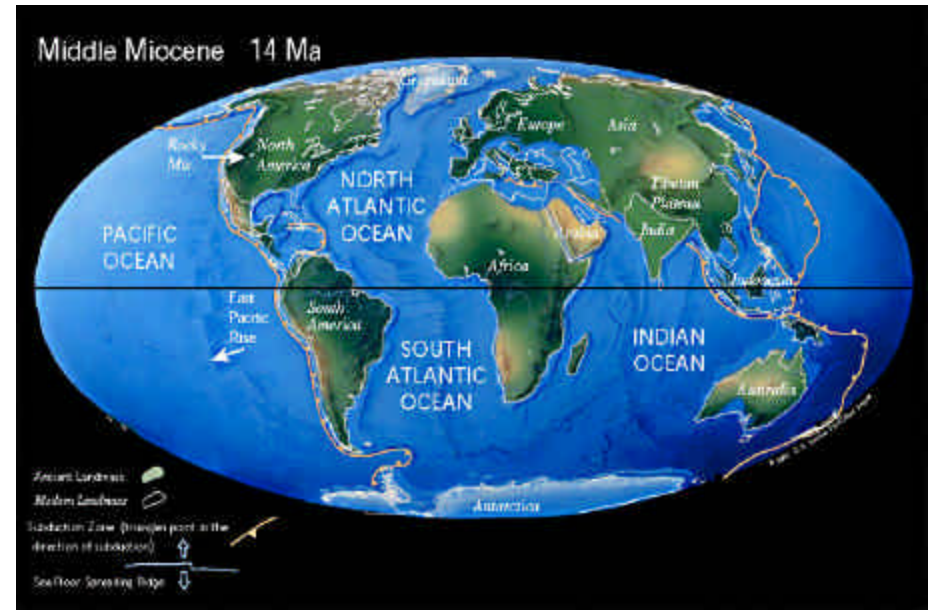
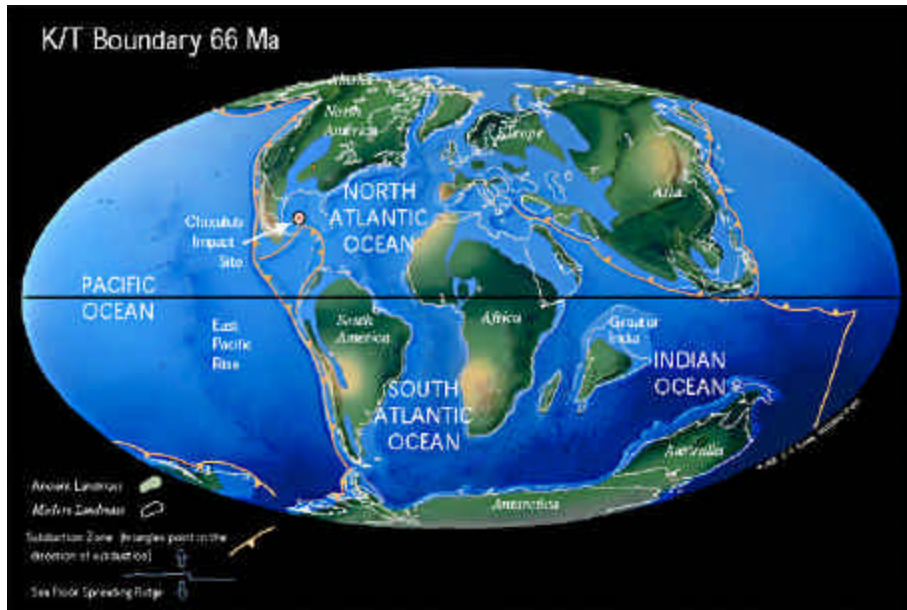
**Models:** Importance of spatial structures  
Is there a possibility for sudden change?  
Mixing of distant energy scales  
Greenhouse effect

**Epilogue:** Probability of change of opinion: Do witches exist?

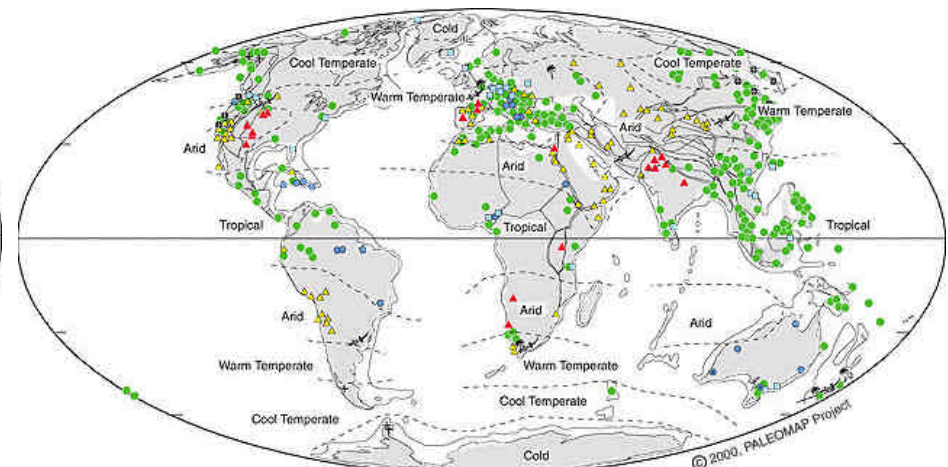


Acknow.: Z. Horvath, G. Gyorgyi, I. Janosi, and T. Tel (Eotvos U.)

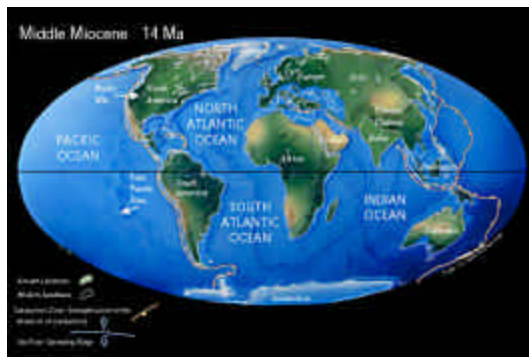
# Motion of continents and changes of climate



Paleocene



Miocene

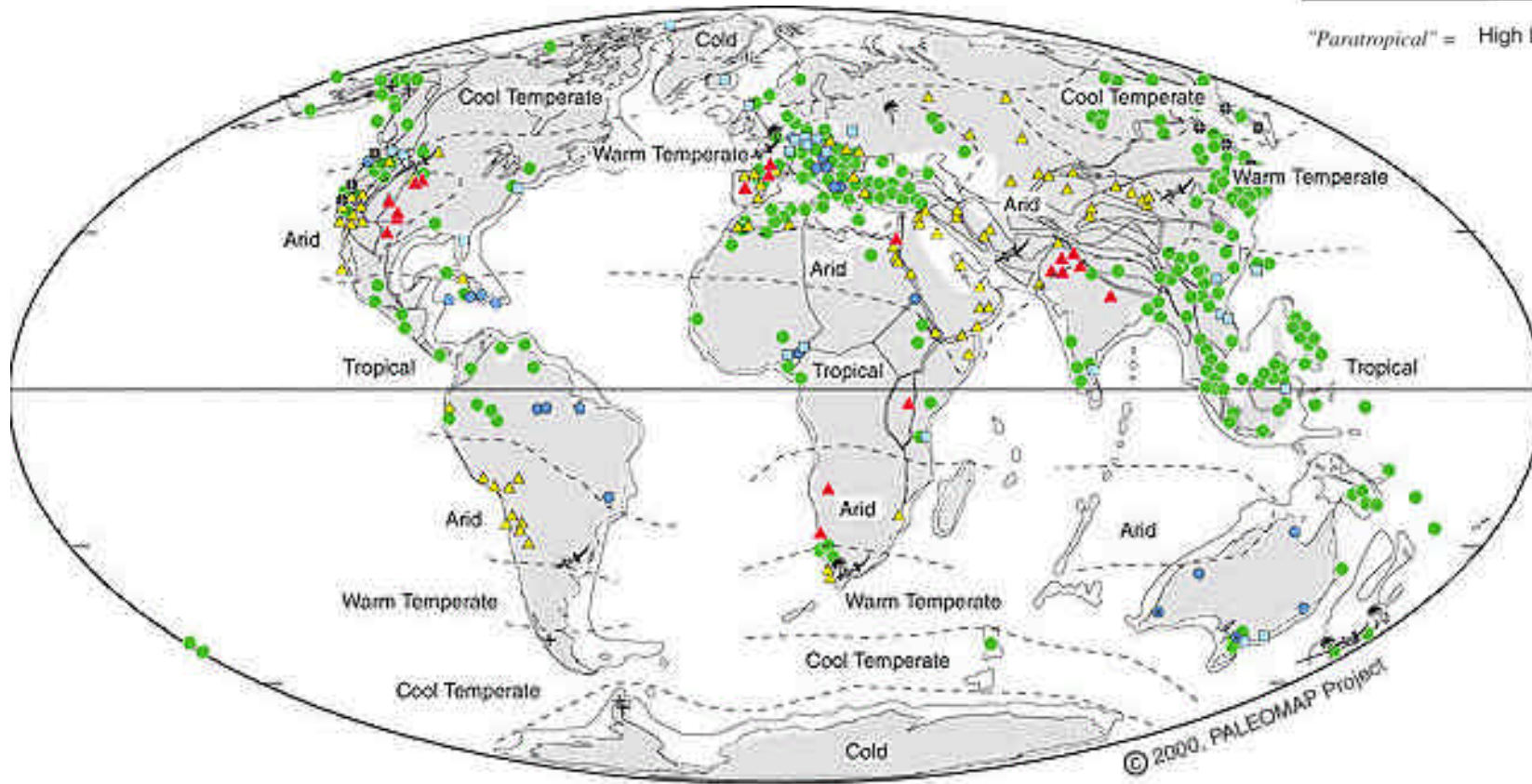


-14 million years

### LEGEND

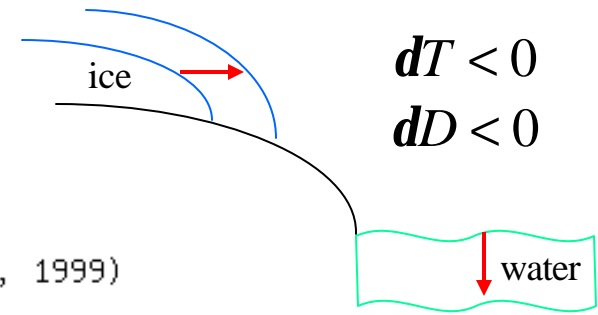
		WARM	COOL
WET	Tropical	● Coal ● Bauxite ● Laterite	● Coal & Tillites
	Warm Temperate	■ Kaolinite (& coal & evaporite) 🌴 Crocodiles 🌴 Palms & Mangroves	
DRY	Arid	▲ Evaporite ▲ Calcrete	⊕ Tillite ⊕ Dropstone ● Glendonite

"Paratropical" = High Latitude Bauxites

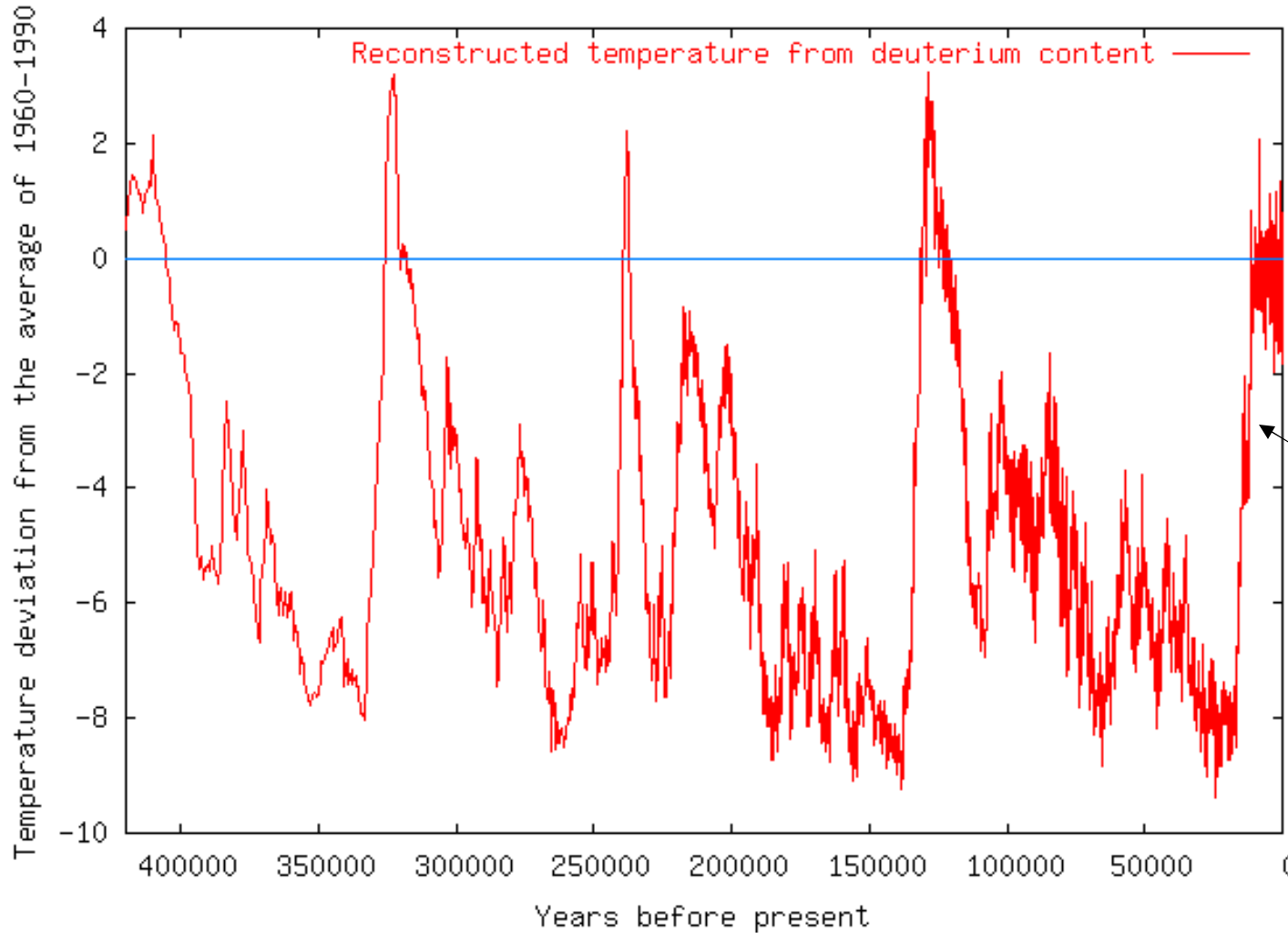


Miocene

# The last 430 thousand years



Vostok Ice Core Data (Petit et al., Nature 399, 429-436, 1999)



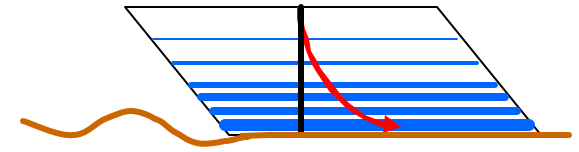
Fast increase  
(starting from  
low T-s!)

$$\Delta T > 6^\circ C / 50y$$

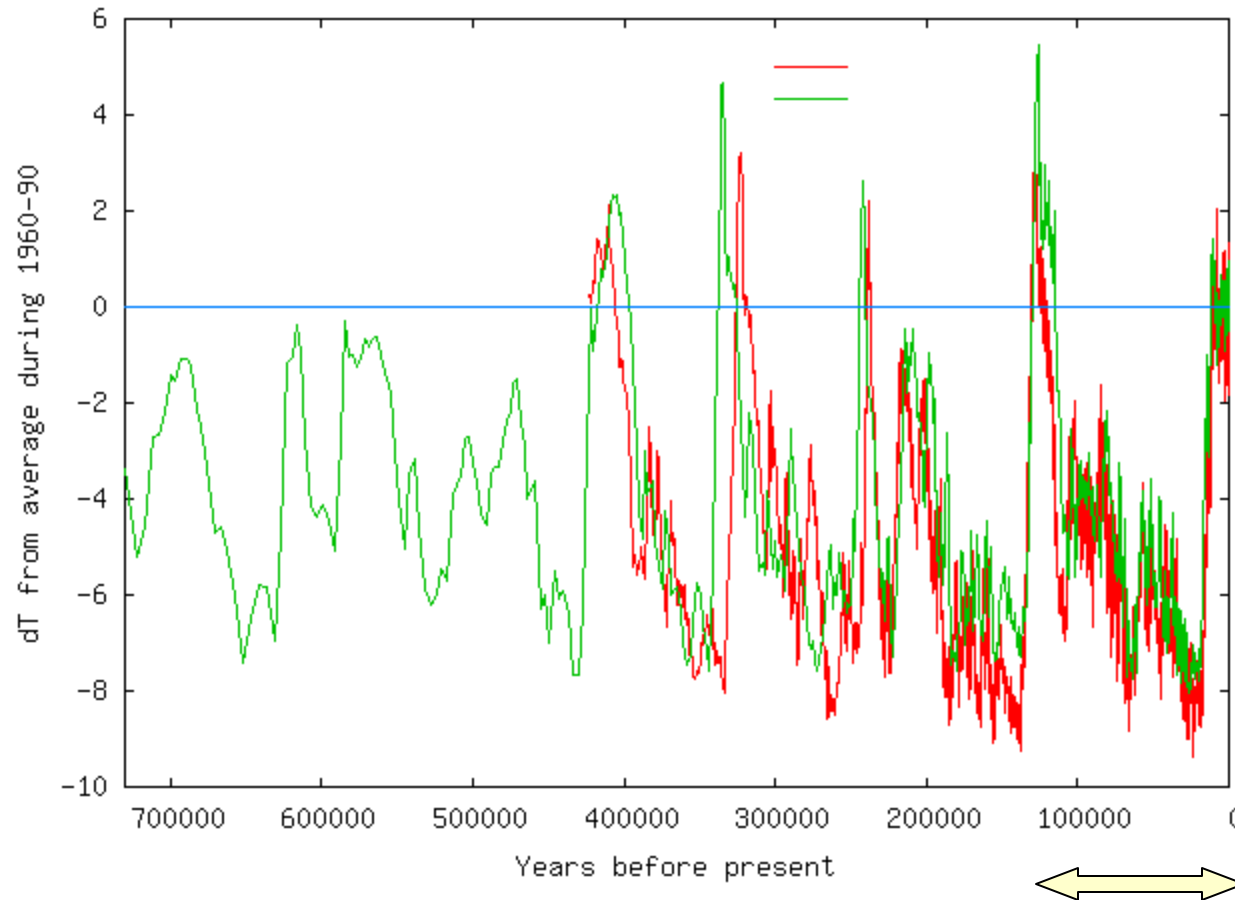
Slow cooling

# Last 725 thousand years

Accuracy of data:

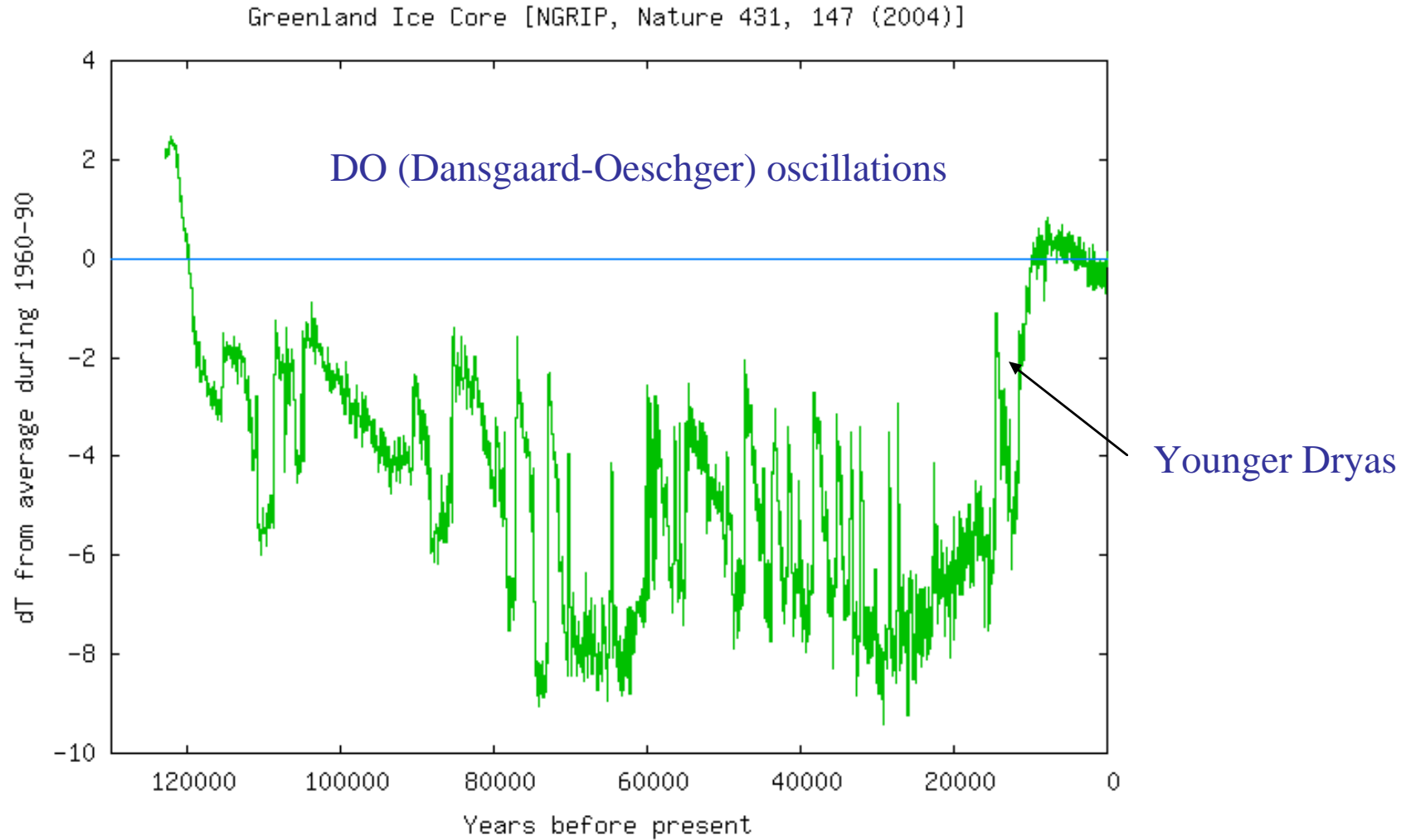


Antarctic Ice Cores compared

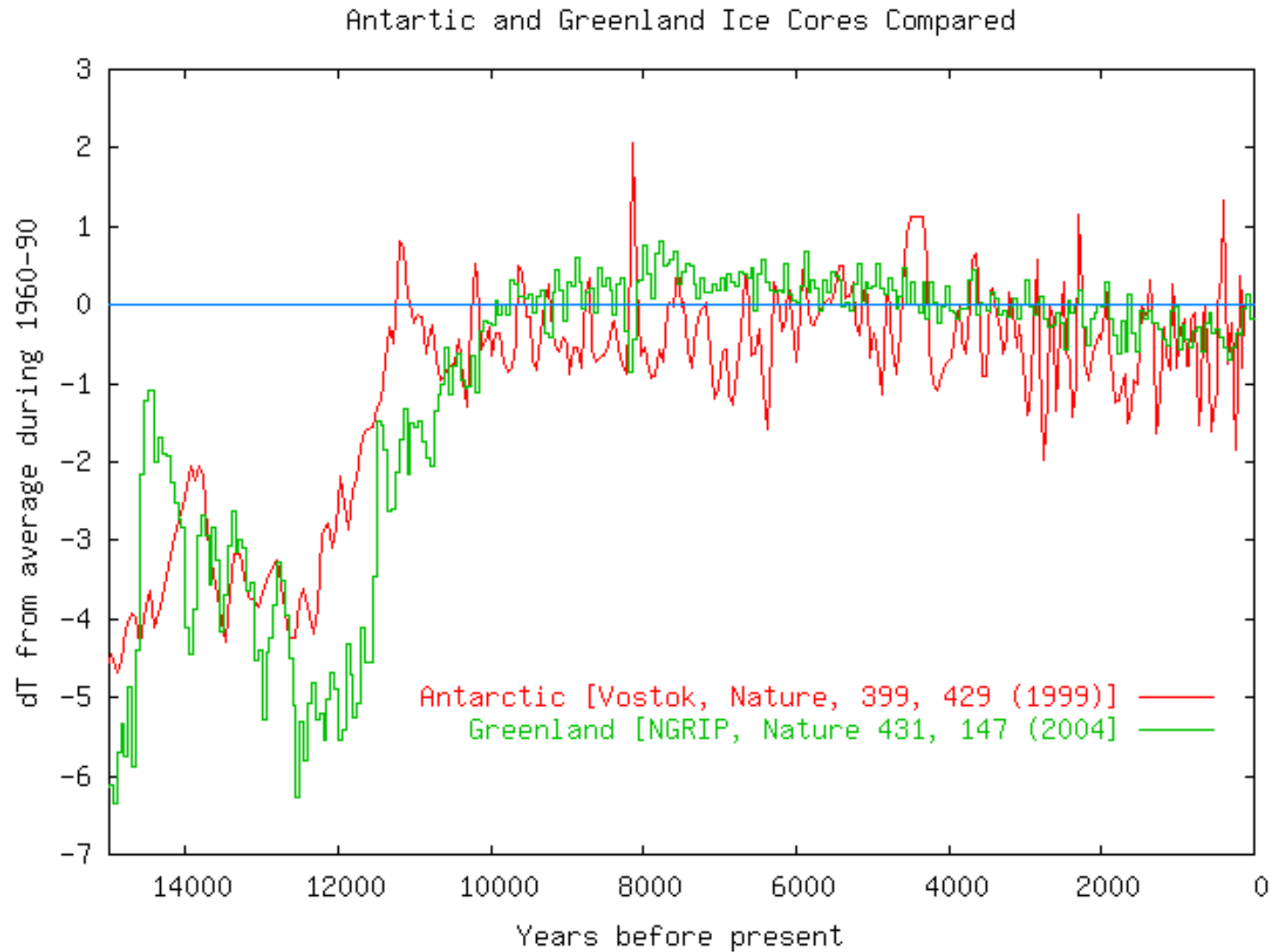


pressure  
shear  
roughness

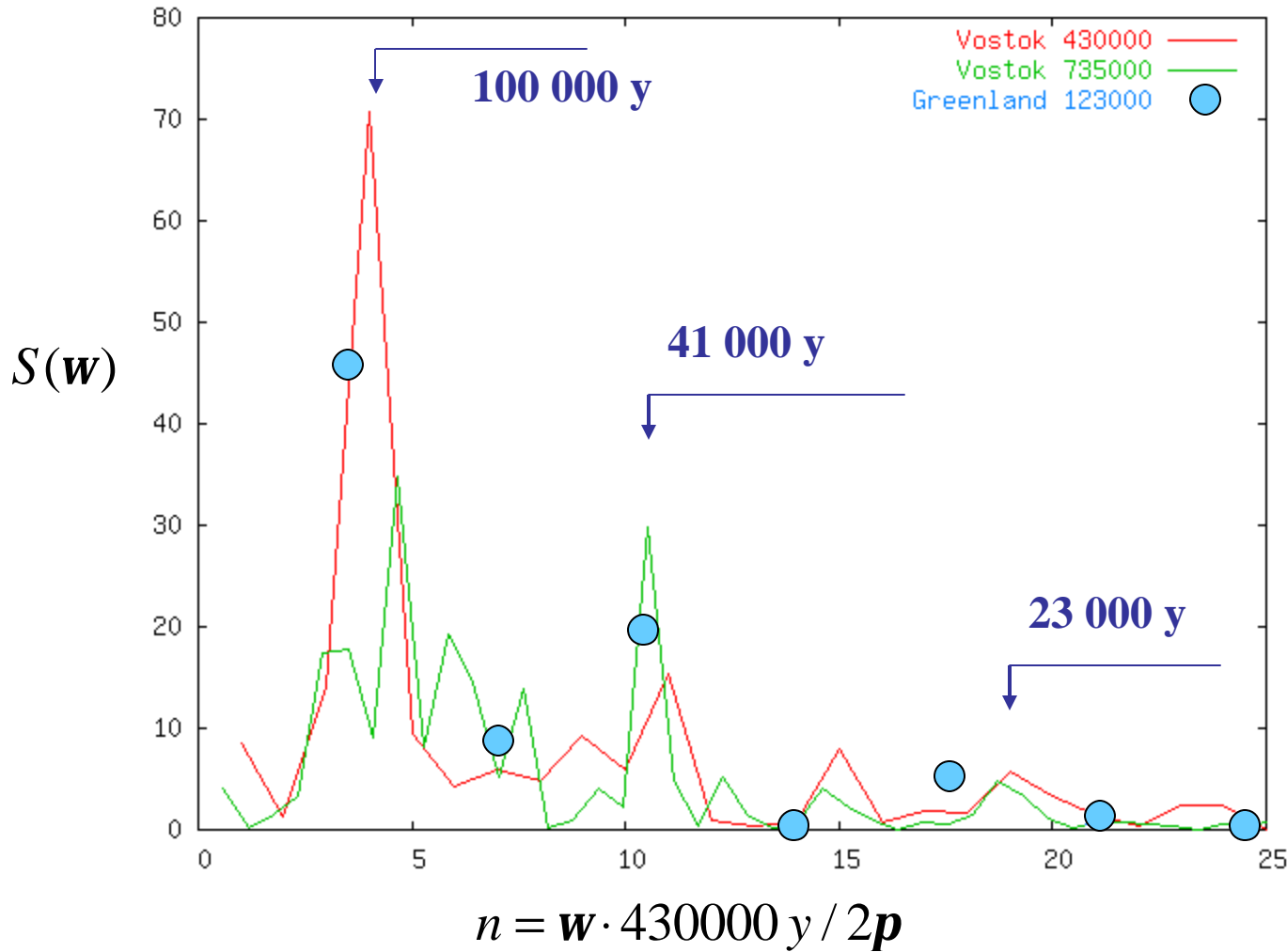
# Last 123 000 years: Fine structure of the ice age



# Last 15 000 years: Differences between north and south



# Power spectrum of fluctuations



Periods related to the Earth's orbital motion:

Excentricity:

**100 000 y**

Change in angle of inclination:

**41 000 y**

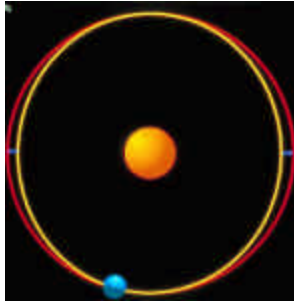
Precession of the axis of rotation:

**23 000 y**

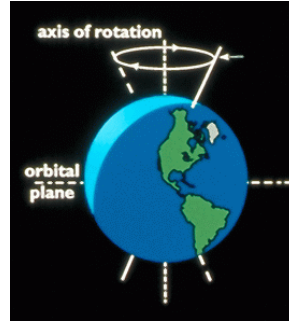


# Periods of Earth: (Milankovich 1920)

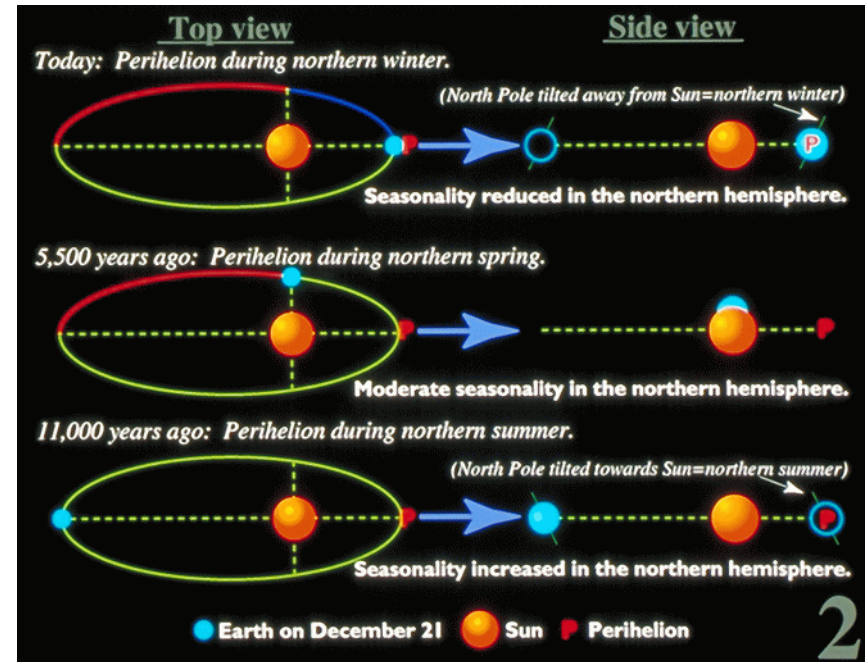
G. Bacsák



Excentricity (100000 y)  
small effect – 0.1%

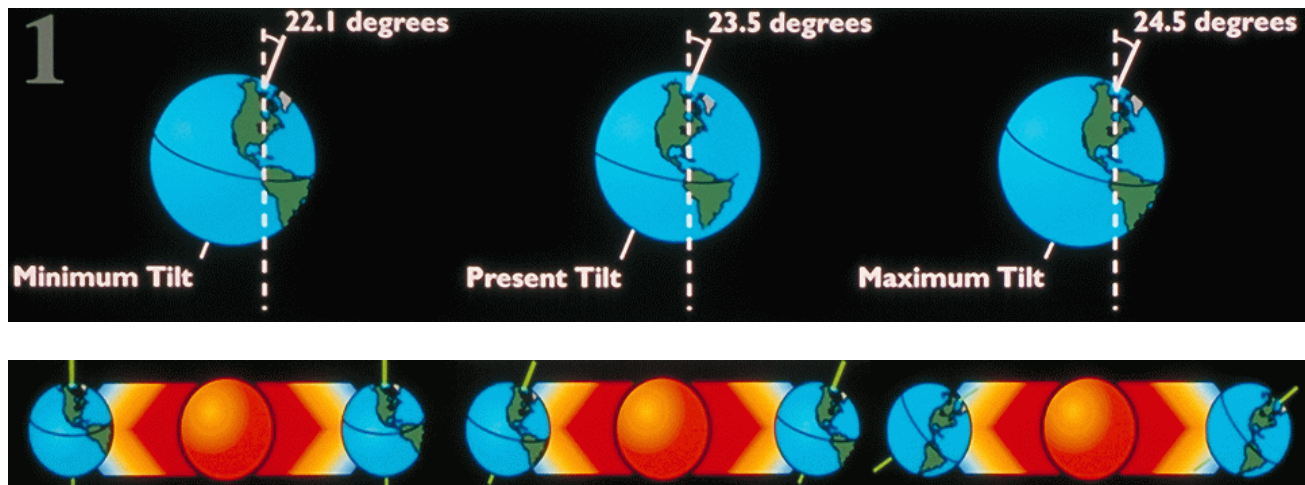


Precession of axis of rotation:  
(23000 y)



Affects intensity of seasons.

Angle of inclination (41000 y)



Changes distribution of insolation.

Insolation at North Pole:

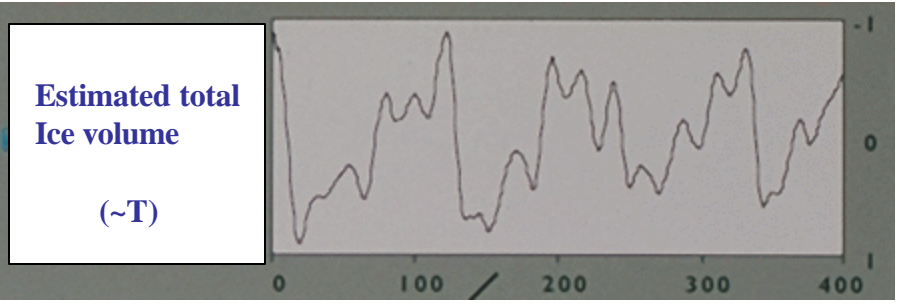
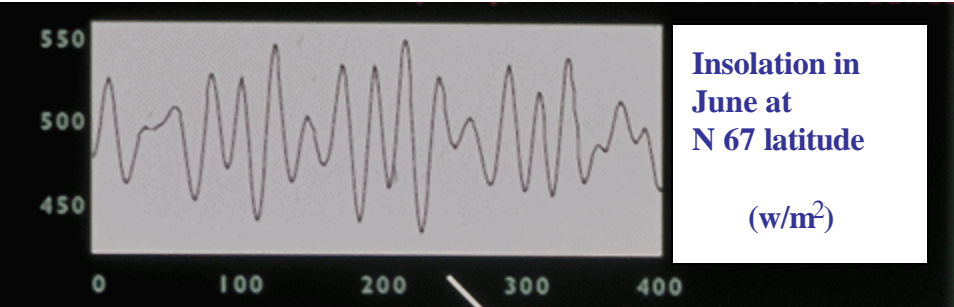
max      min  
90°      0°

<http://www.ncdc.noaa.gov/paleo/>

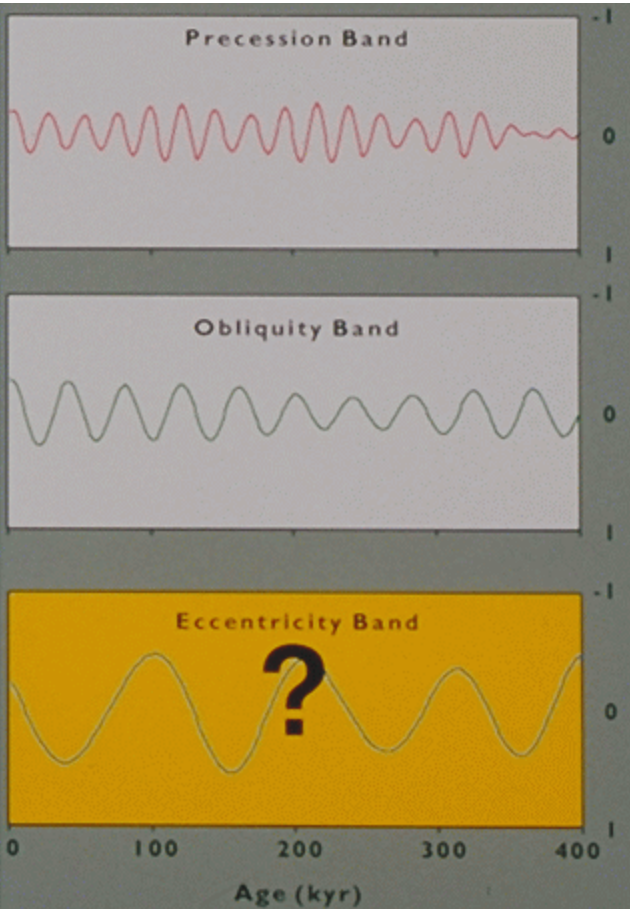
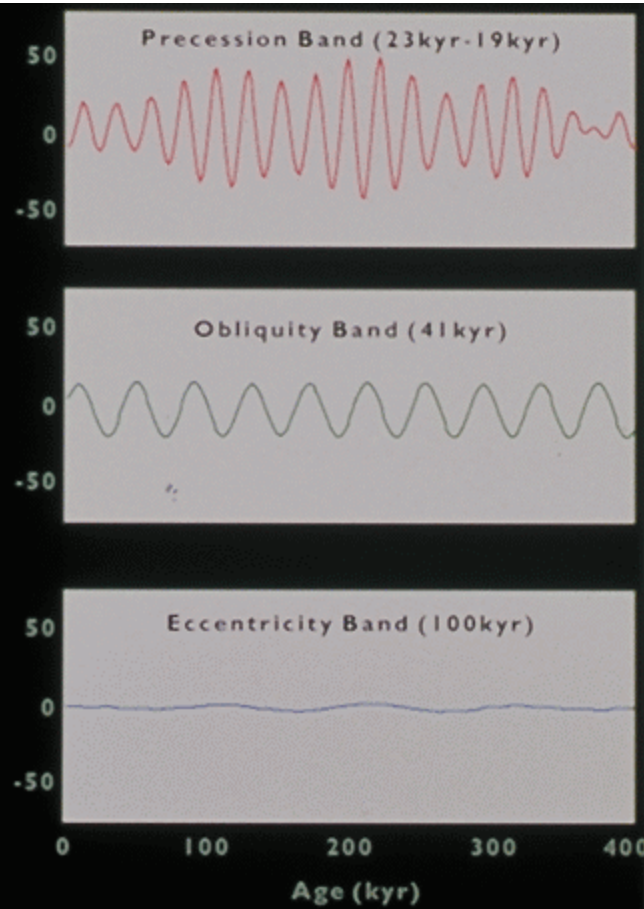
# Periods of Earth's motion

$$J_E + dJ_E \approx a(T_F + dT_F)^4$$

$$\frac{dT_F}{T_F} \approx \frac{1}{4} \frac{dJ_E}{J_E}$$



0.1  
 $dT_F \approx 7C^\circ$



0.001

0.02

0.02

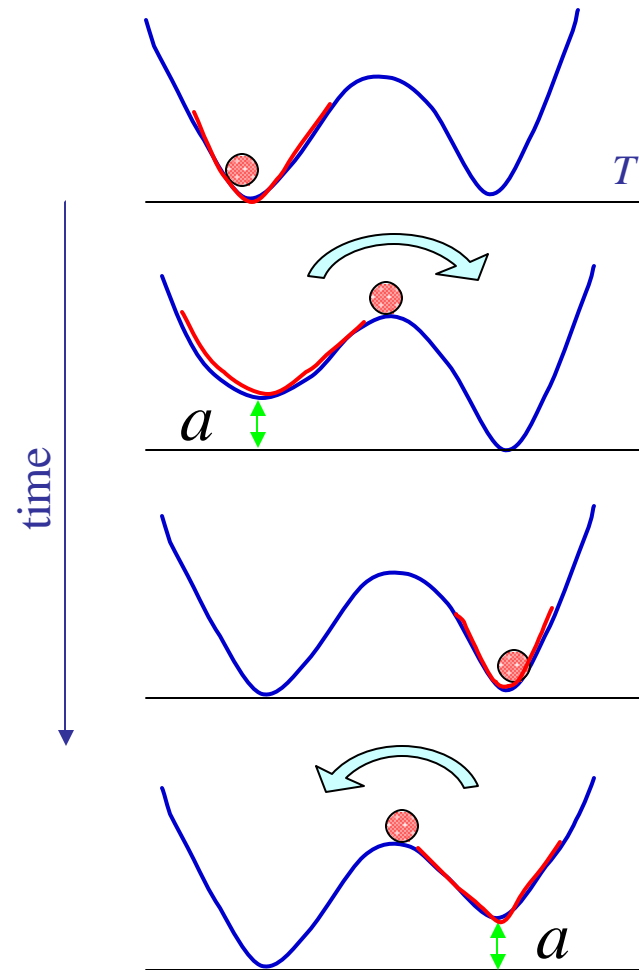
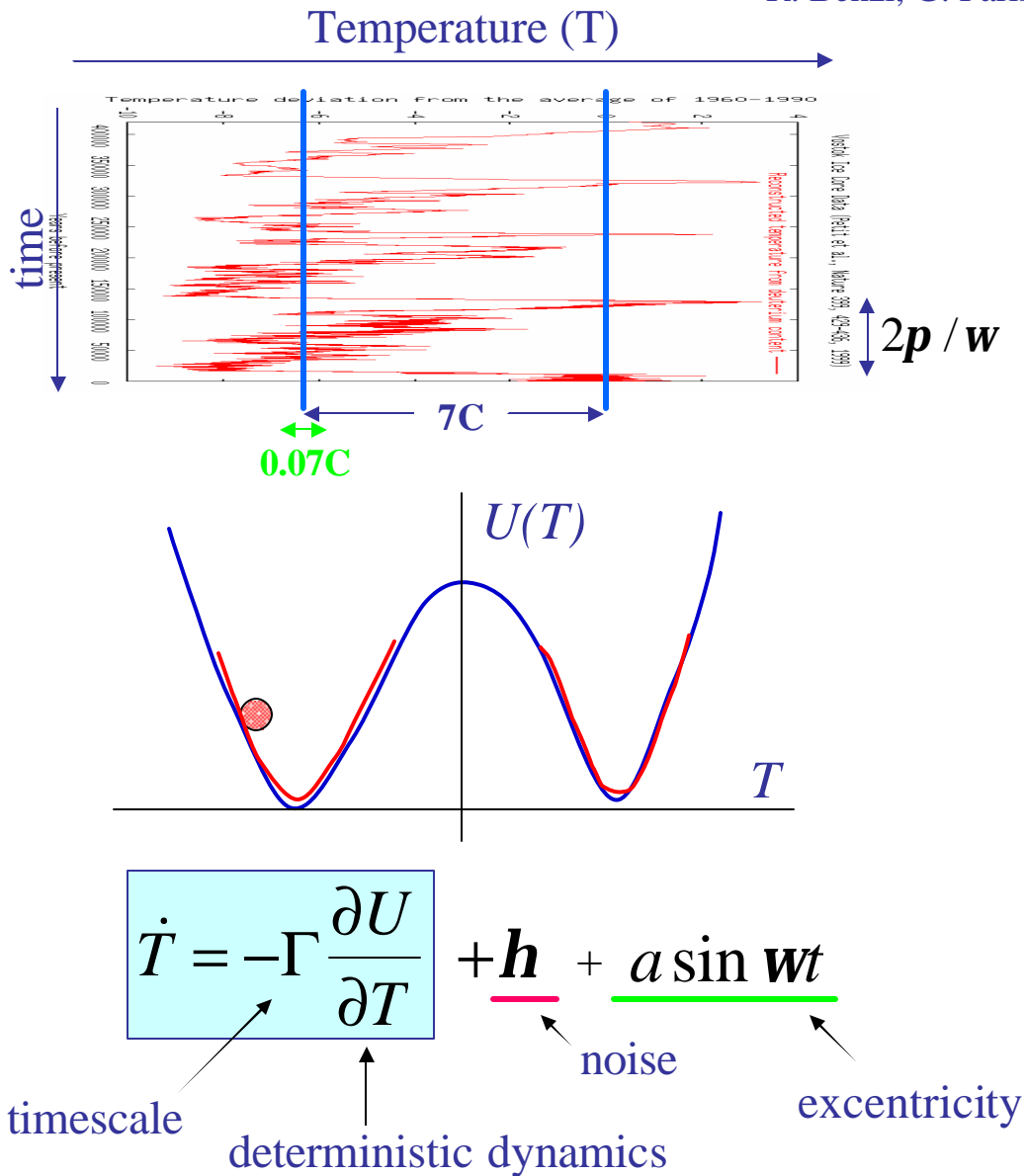
0.001

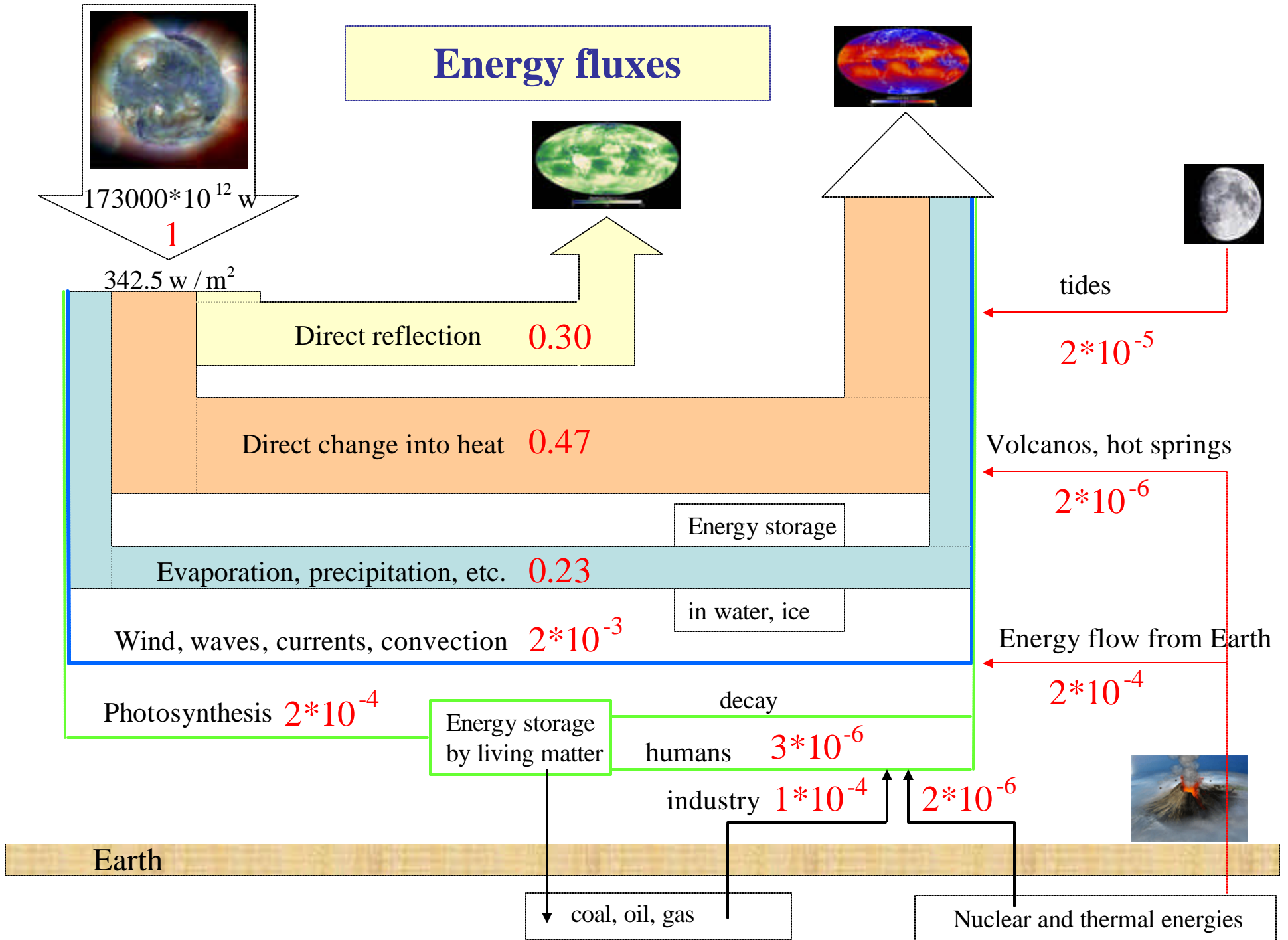
0.1

$dT_F \approx 0.07C^\circ$

# Stochastic resonance and the 100 000 year period

R. Benzi, G. Parisi, A. Sutera, and A. Vulpiani, Tellus 34, 16 (1982)





# Energies and energy fluxes: Characteristic times

relaxation time  
of perturbation

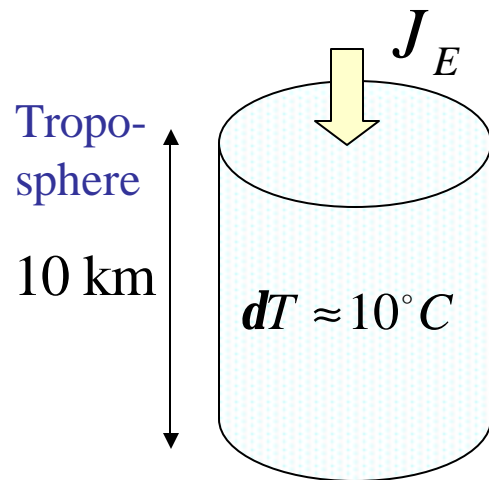
$$t \approx \frac{dE}{J_E}$$

← energy perturbation

← energy flux through the system

$$\approx 342.5 \text{ w / m}^2$$

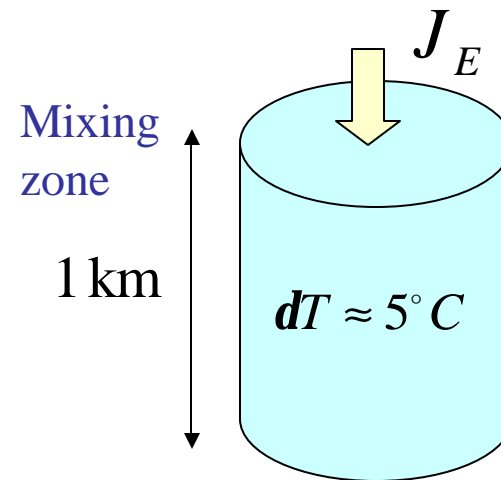
atmospheric perturbations



$$t \approx 5 \text{ days}$$

$$dE \approx 2 \cdot 10^8 \text{ J / m}^2$$

oceanic perturbations



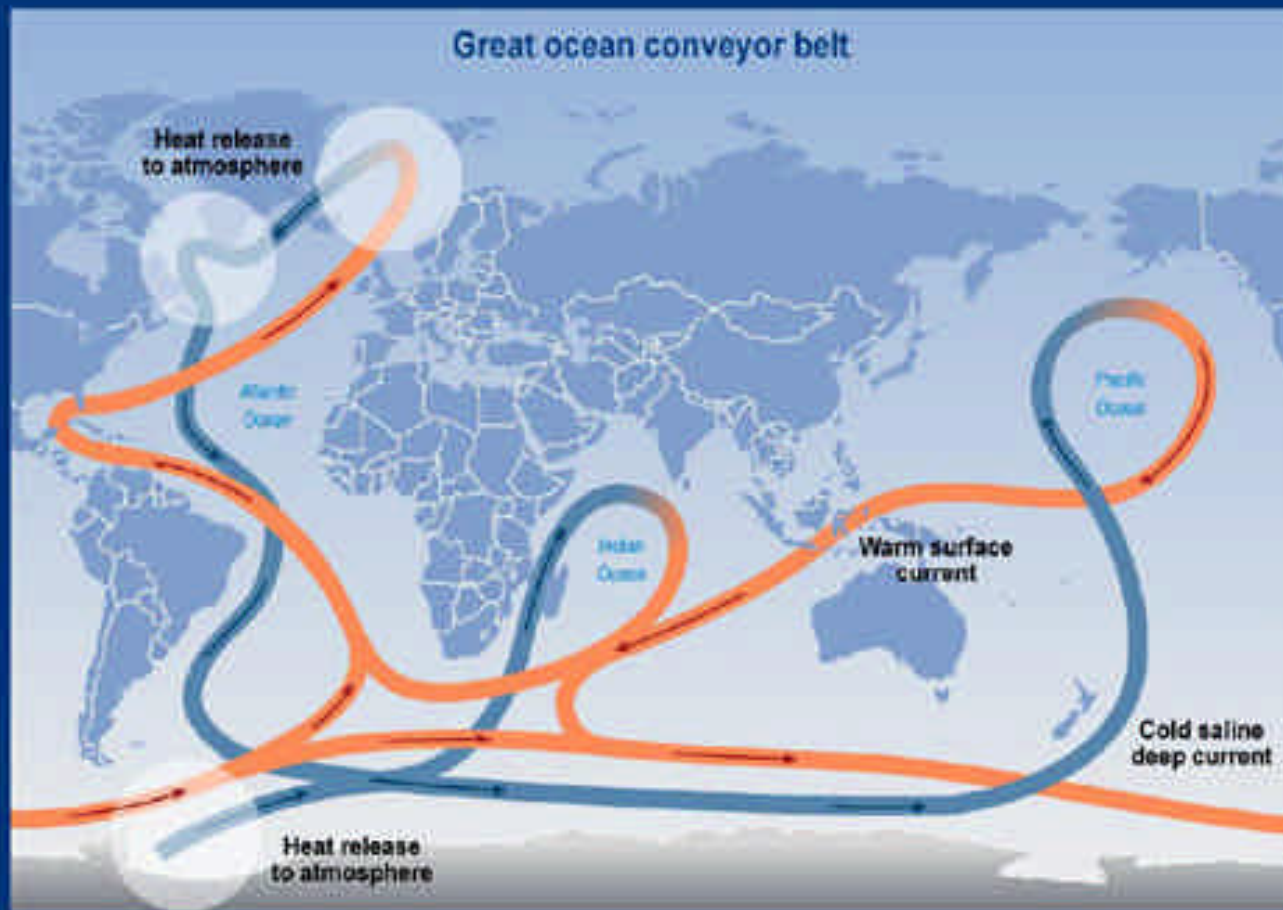
$$t \approx 2 \text{ years}$$

Golf stream

$$dE \approx 2 \cdot 10^{10} \text{ J / m}^2$$

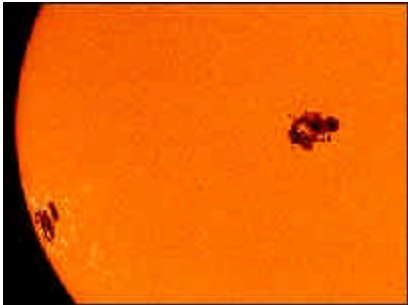
**Q:** Where does the 100 000 year period comes from?

# The great thermohaline conveyor belt

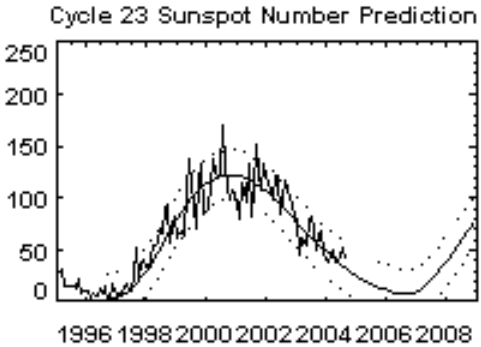


SYR - FIGURE 4.2

# Sunspots, solar wind, cosmic radiation

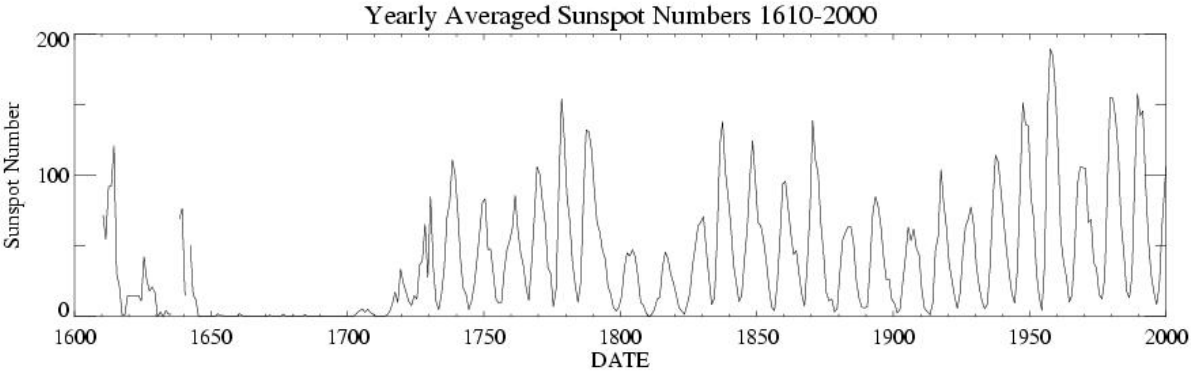


Dynamo model:  
Longer periods?



$$dJ_E / J_E \approx 0.001$$

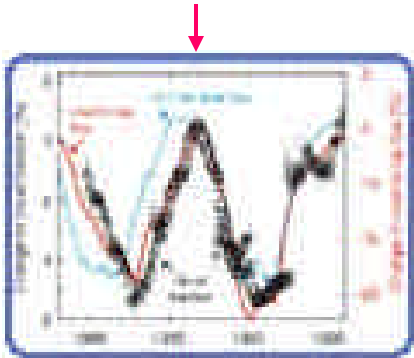
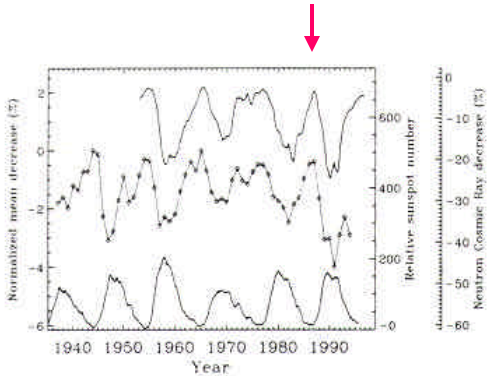
same order of magnitude  
as excentricity



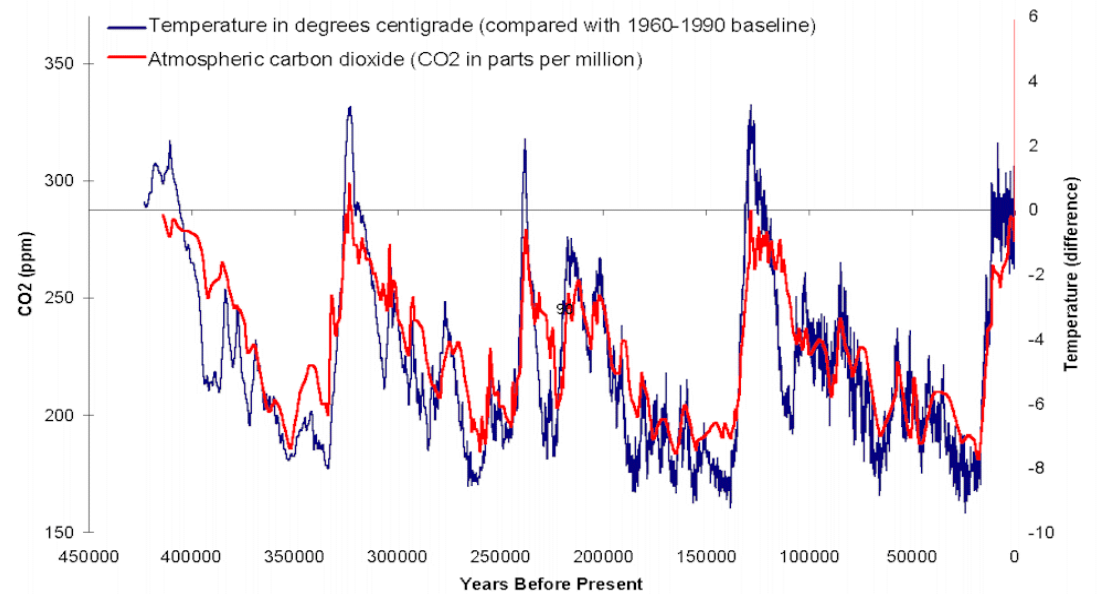
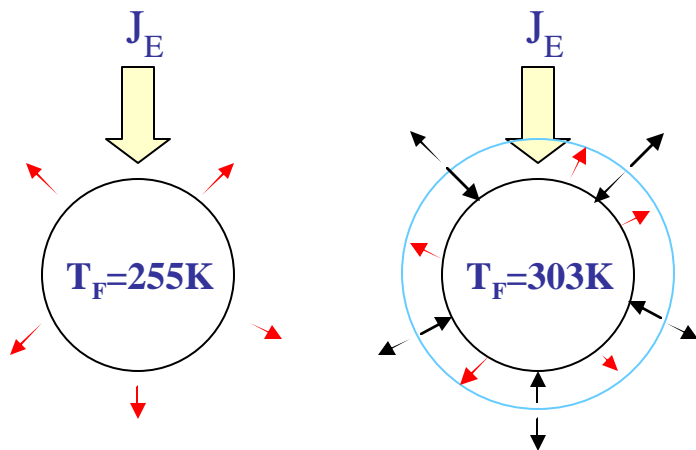
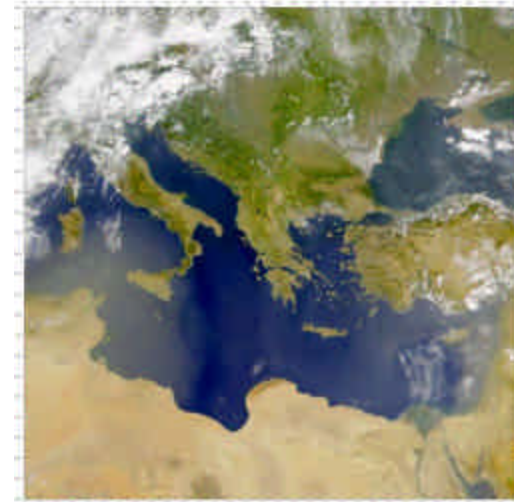
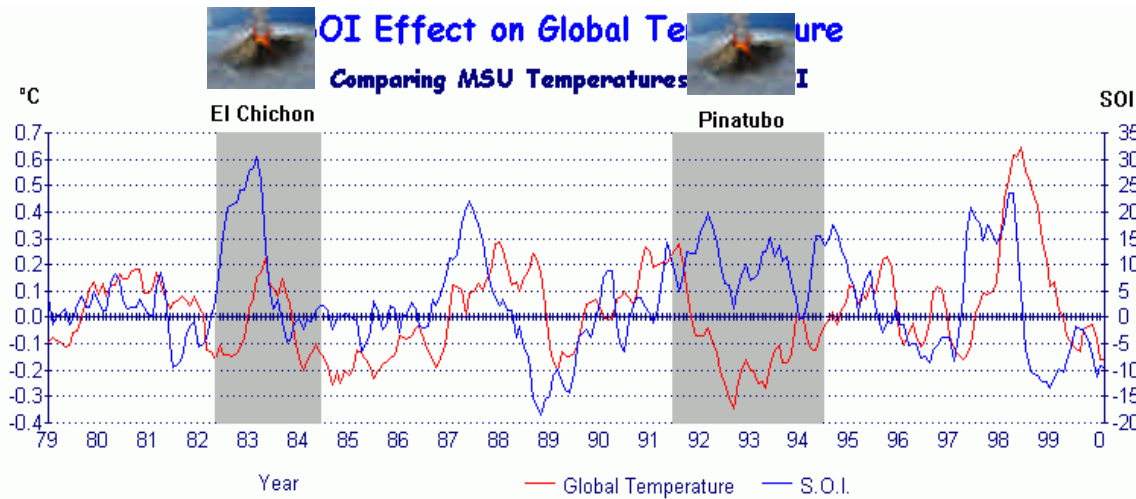
Sunspot activity increasing  
(~ 400 years)

Solar wind and sunspot activity  
shows an 11 year periodicity  
cloud formation  $\Rightarrow$

H. Svensmark, PRL81, 5027 (1998)



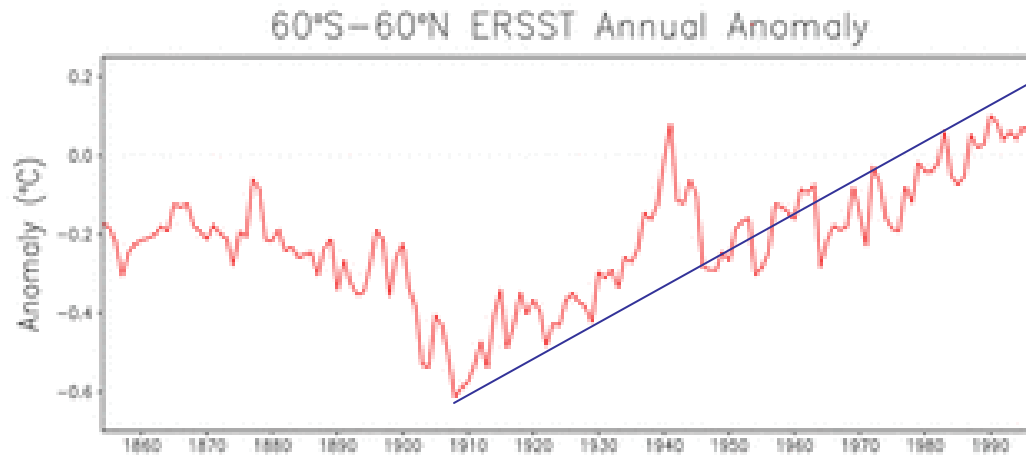
# Greenhouse effect: Dust, volcanos, aerosols, CO<sub>2</sub>, ...



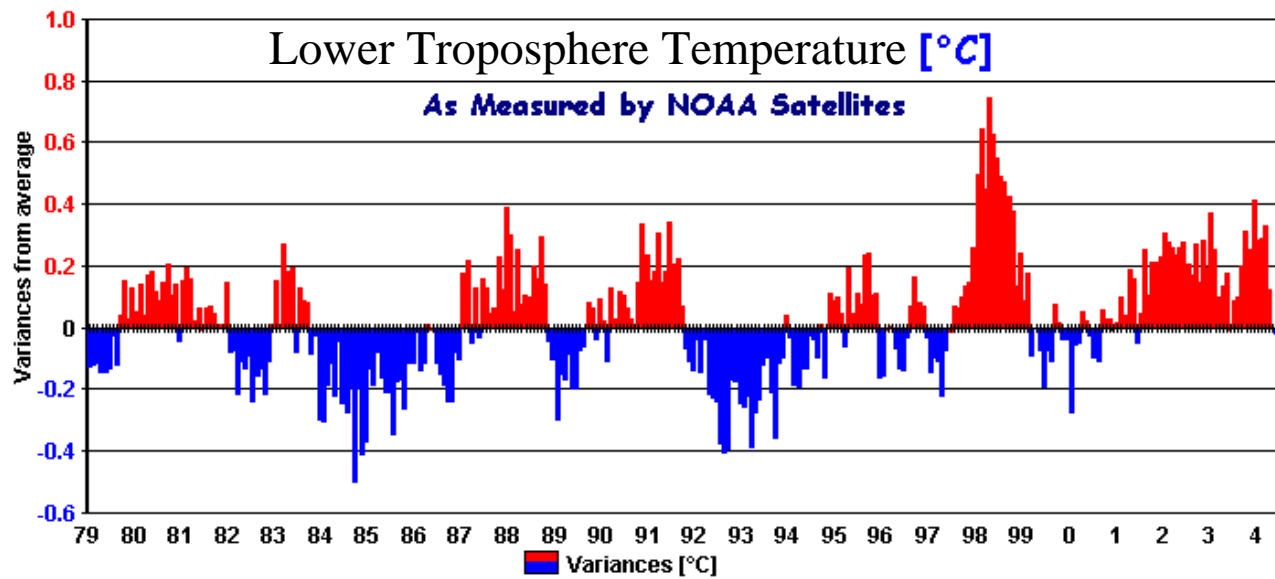


# Global warming

Surface temperature of oceans



$$\frac{dT}{dt} \leq 0.8 \frac{C^\circ}{100y}$$

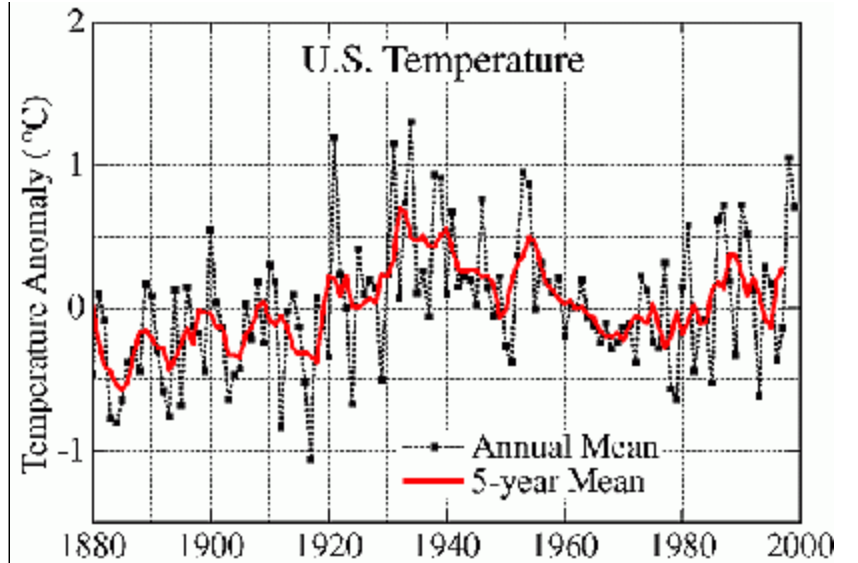
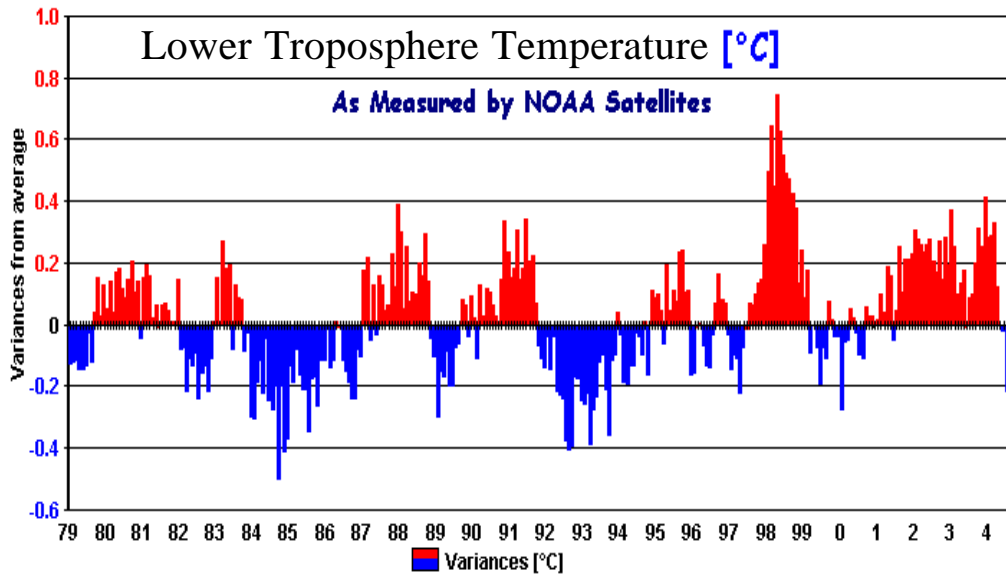
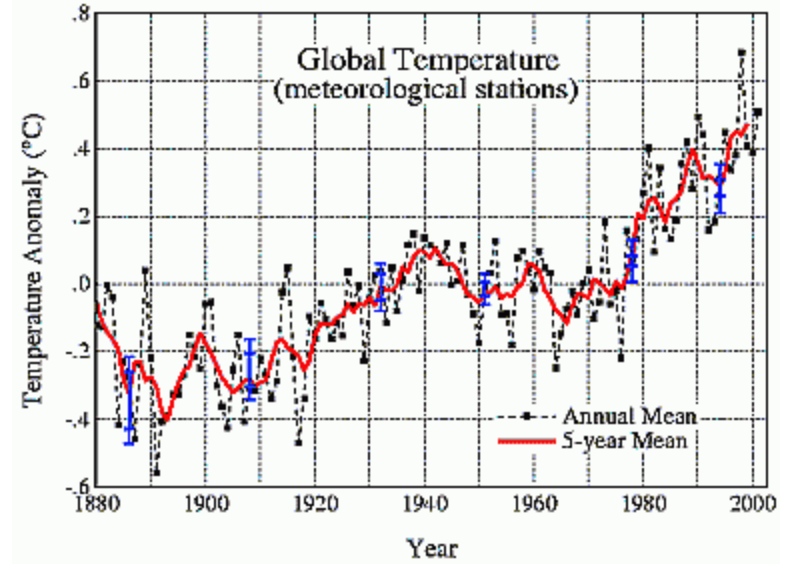
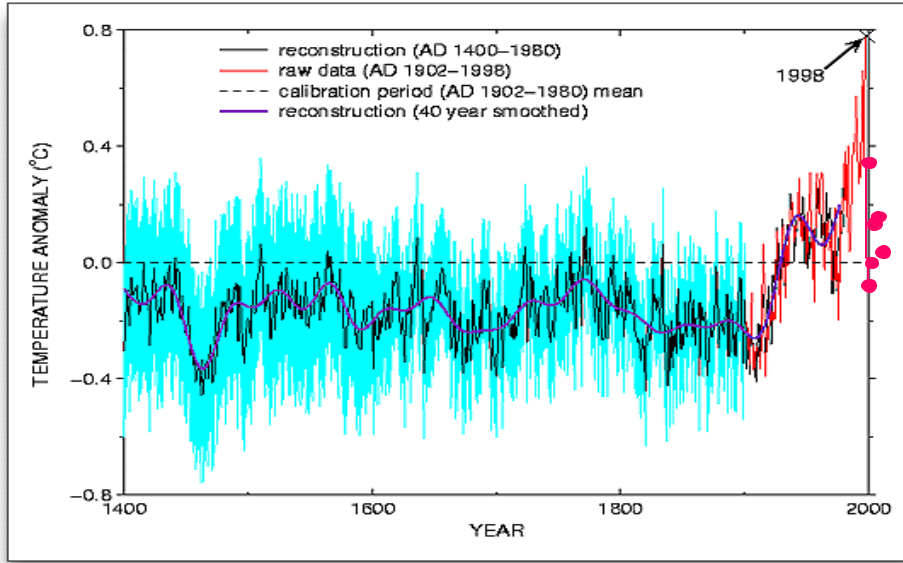


$$\frac{dT}{dt} \approx 0.77 \frac{C^\circ}{100y}$$

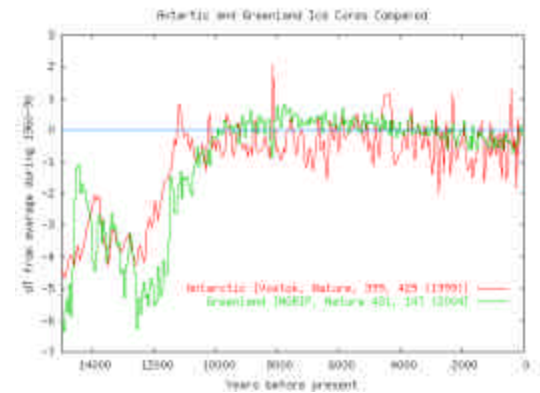
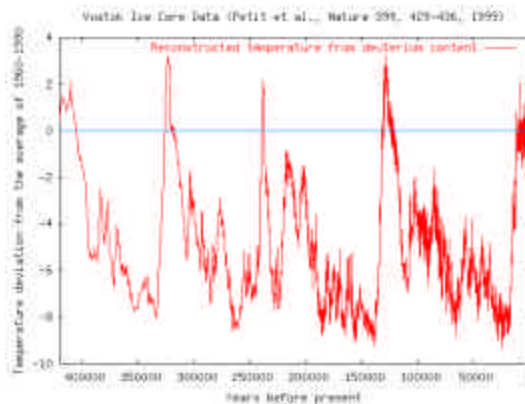
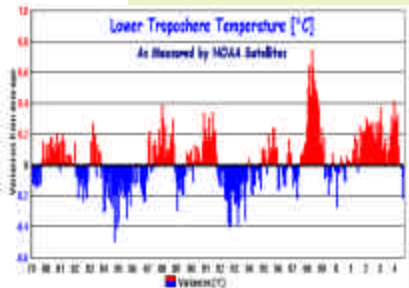
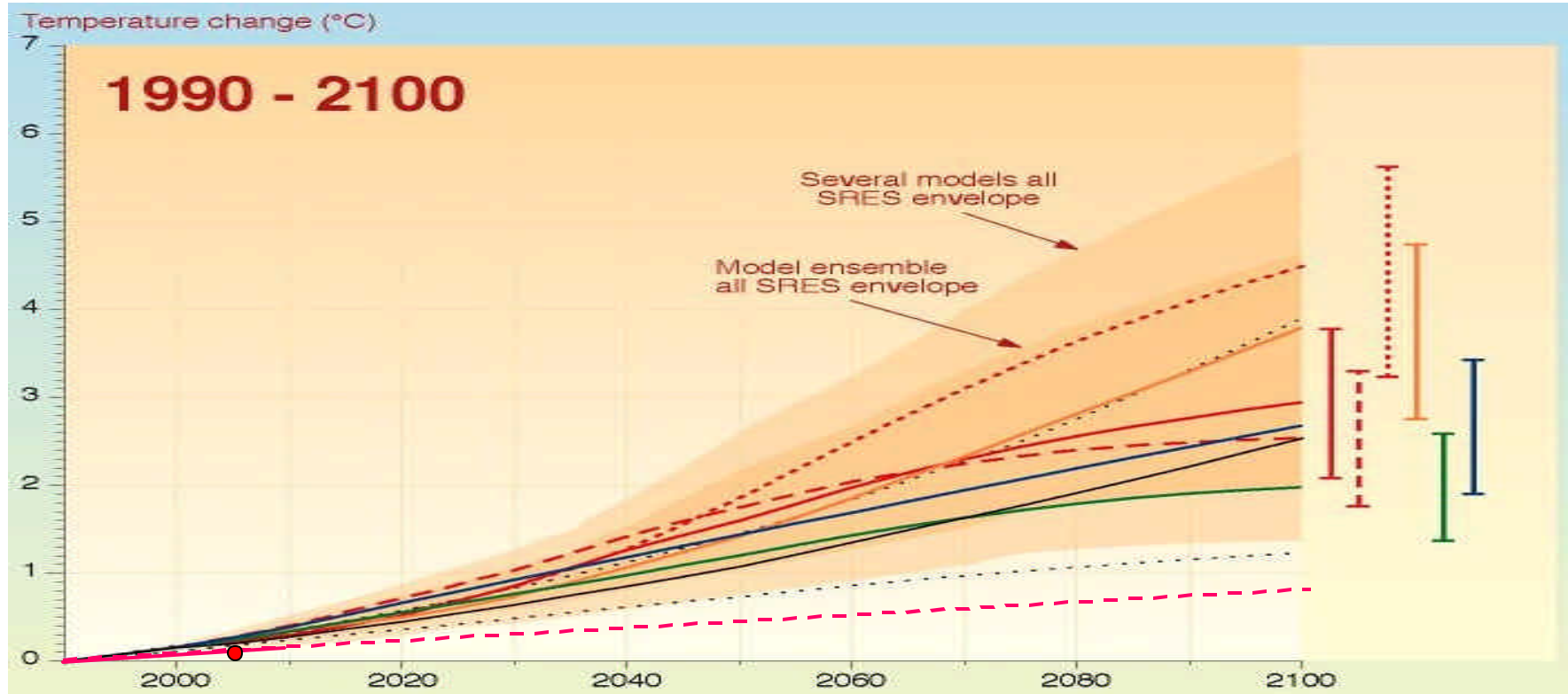
IPCC

# Global warming -- tricks

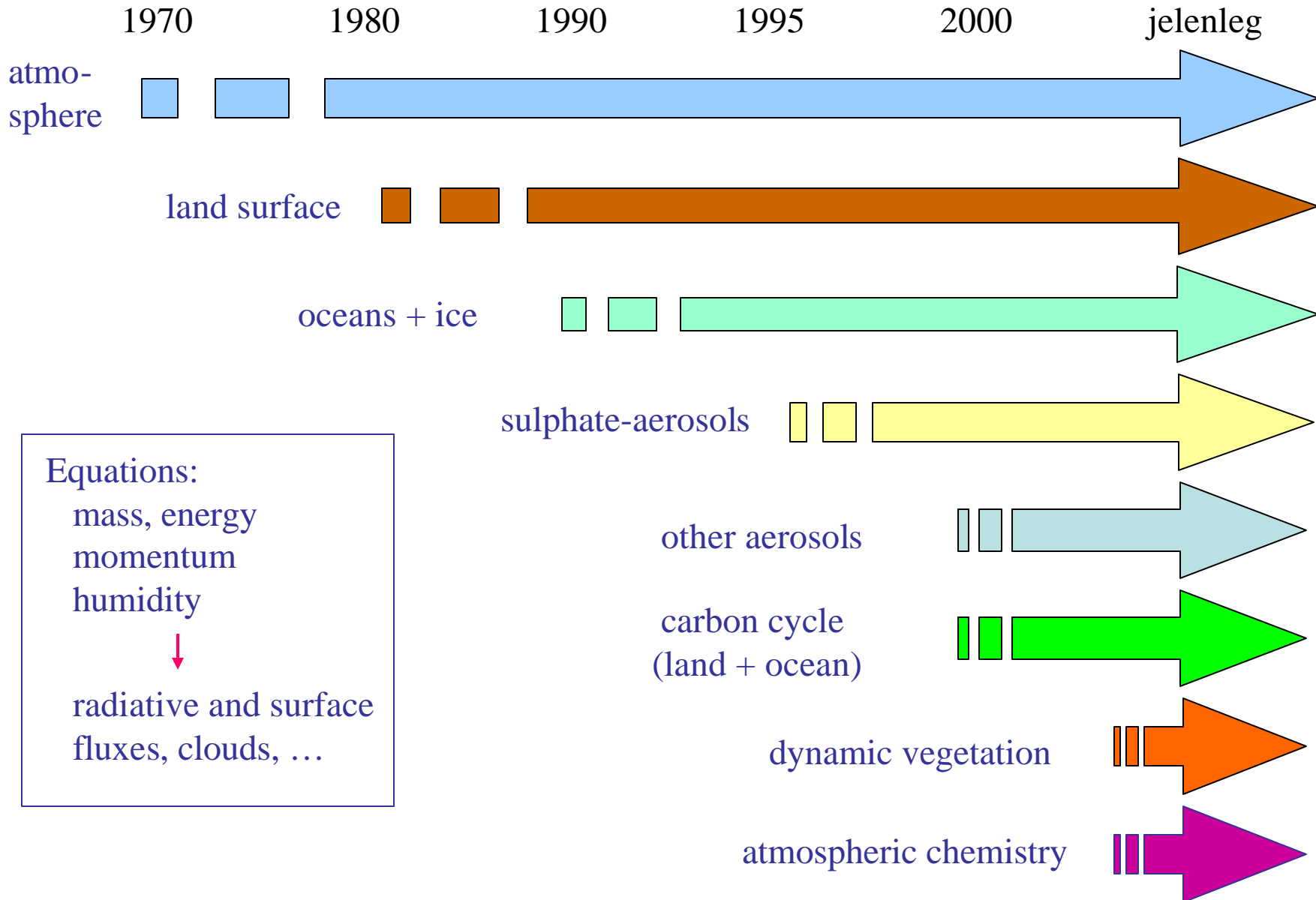
NASA (Goddard)



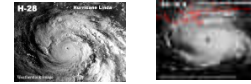
# Global warming: models



# What do the models contain?



# Do witches exist if there are two large hurricanes in a century?



$b$ : hurricanes are caused by witches  
(idea)

$h$ : more than 2 hurricanes occurs in a century (phenomena)

Outset: we do not know

If  $b$ , then the probability of  $h$  is big:

$$P(b) \approx P(\bar{b}) \approx 0.5$$

$$P(h|b) \approx 0.5$$

If  $\bar{b}$ , then the probability of  $h$  is small:

$$P(h|\bar{b}) \approx 0.1$$

$$P(h, b) = P(h|b) P(b) = P(b|h) P(h)$$

Probability of  $h$  and  $b$

Probability of  $b$  if  $h$  happens

$$P(h|b) P(b) + P(h|\bar{b}) P(\bar{b})$$

$$P(b|h) = \frac{P(h|b) P(b)}{P(h|b) P(b) + P(h|\bar{b}) P(\bar{b})} \approx \frac{0.5}{0.5 + 0.1} \approx \underline{\underline{0.83}}$$

# Appendix: CO<sub>2</sub>

