Why the climate sensitivity is low

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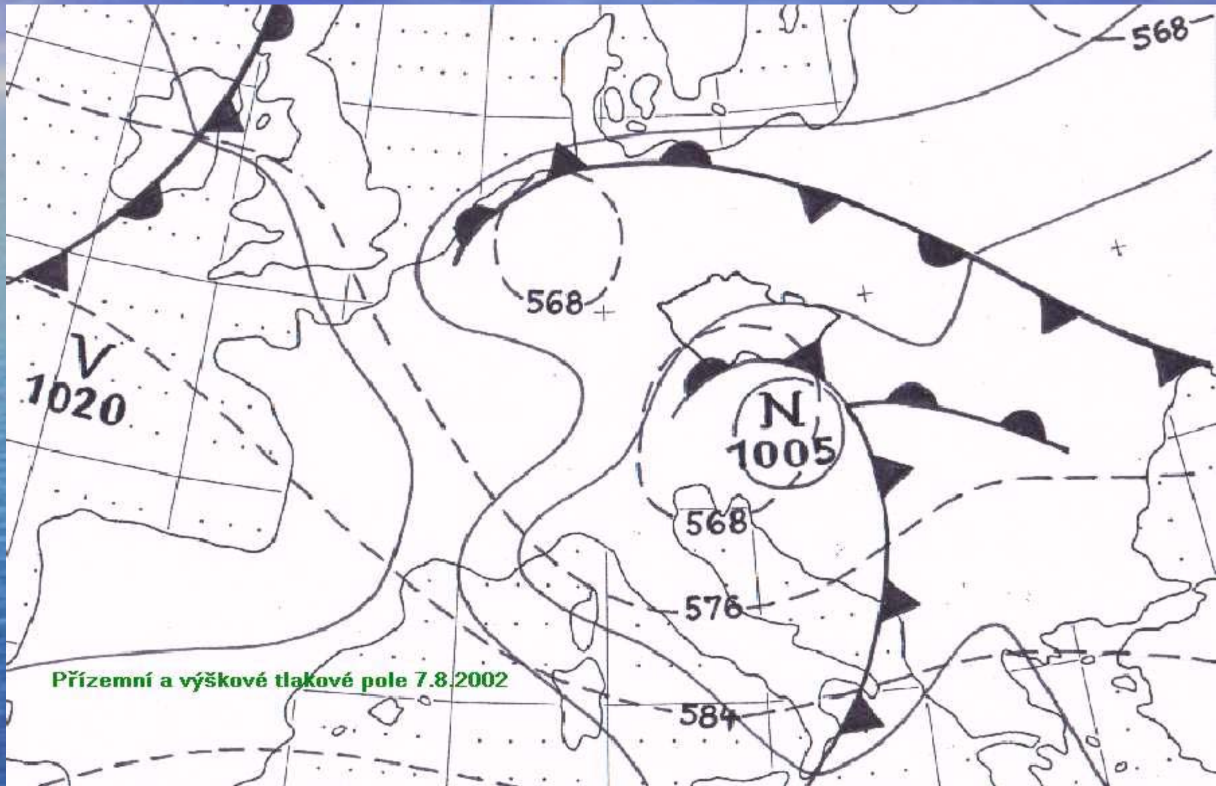
This file will be posted at:
http://lubos.motl.googlepages.com/berlin.ppt

Plan of my talk

- Weather, climate, basic concepts
- Some climate phenomena affecting us since the geological eons
- Ice ages & CO2
- Greenhouse effect: basics and energy budget
- Sublinear (logarithmic) dependence of the effect
- Bare climate sensitivity
- Climate sensitivity from geological eons
- Climate sensitivity from 20th century measurements
- Schwartz's argument
- Dependence of warming on latitude
- Ocean, cosmic rays, other effects
- Impact on sea level and local ecosystems

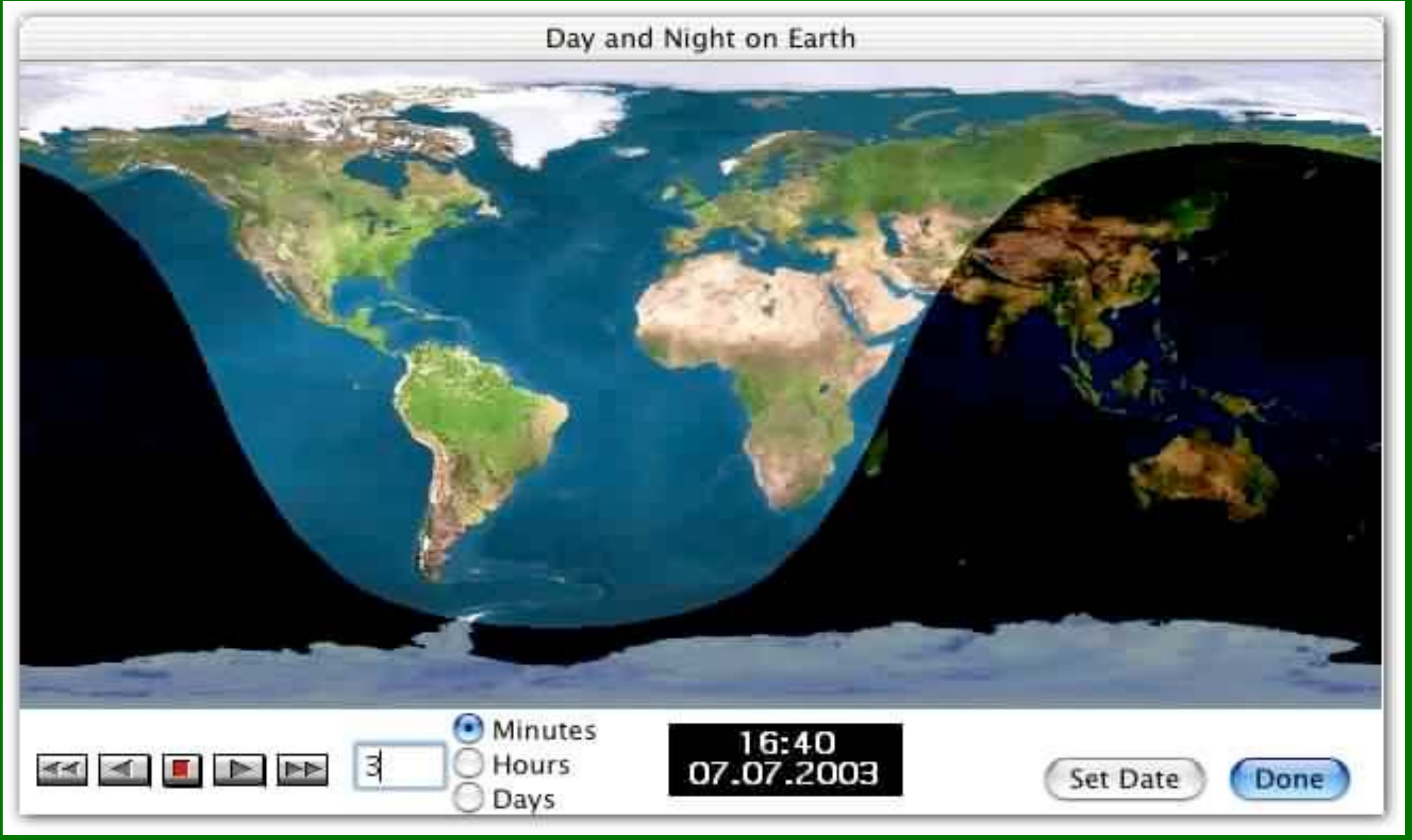
Weather studied by meteorology: temperature, pressure, humidity now and here...



Climate: the character of weather statistically observed over 30 years or longer (convention!) - studied by climatology

Day and night

- 24-hour periodicity, the Earth is spinning ;-), the most important fast oscillations of the temperature



Seasons

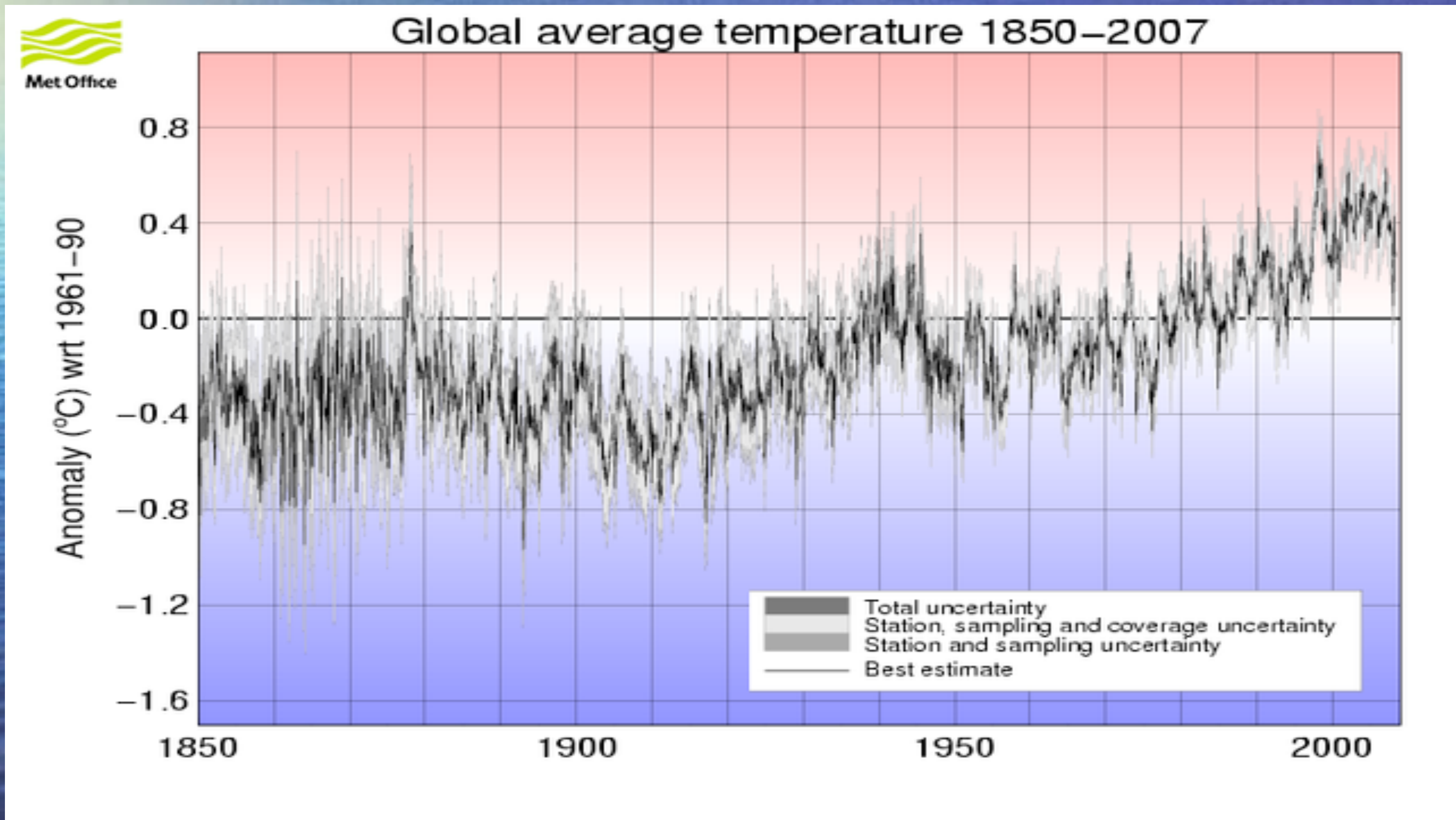
- Earth revolves around the Sun, a one-year cycle

- Virtually all other cycles and effects on the temperature are much less regular and much less understood

- They appear at all conceivable timescales

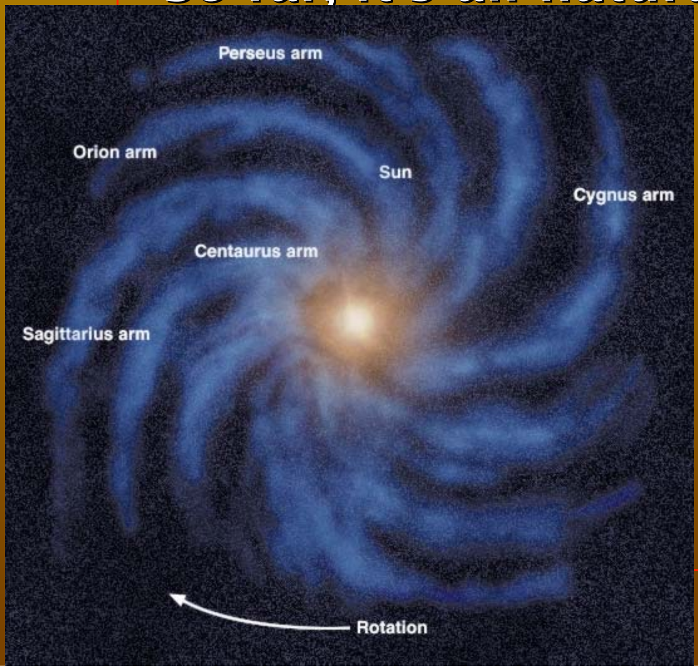
Some people are worried about the 20th century warming

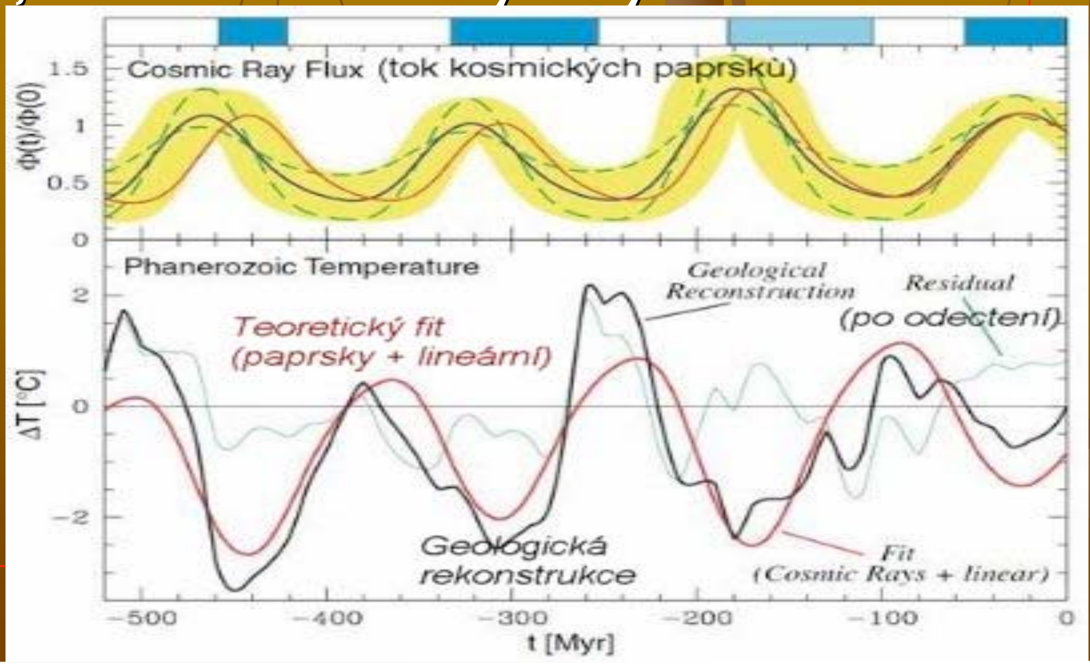
U.K. Met Office: global temps since 1850



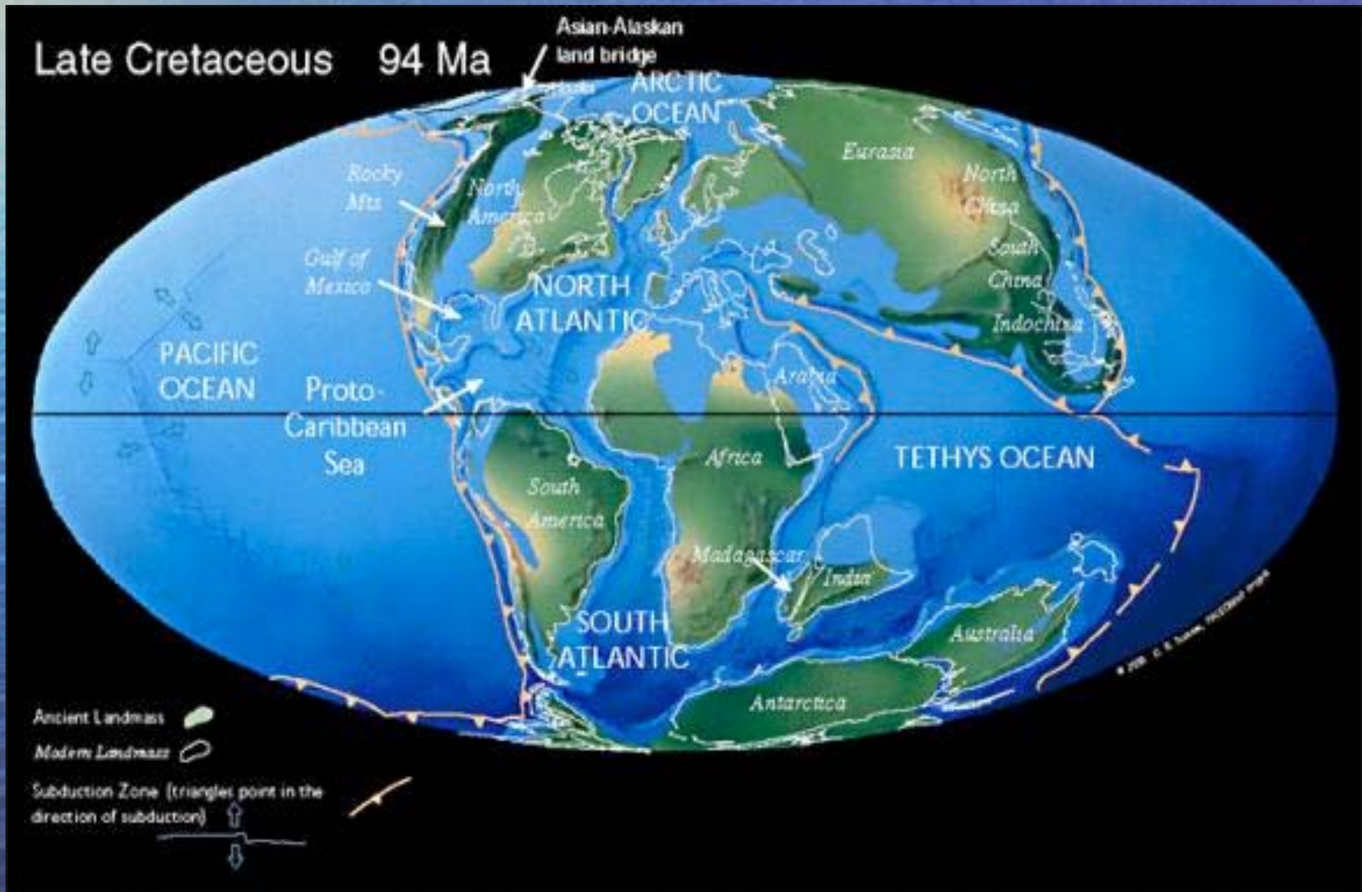
Climate has been changing since the birth of the Earth 4.7 billion years ago

- Each time scale or frequency brings its own phenomena that influence the temperature
- **Let's start with the slowest ones:**
- The Solar System has been bubbling through the spiral arms of the Milky Way which affected the temperature roughly with the 140 million year periodicity, plus minue 2.5 °C
- **So far, it's all natural, and it will mostly stay so**



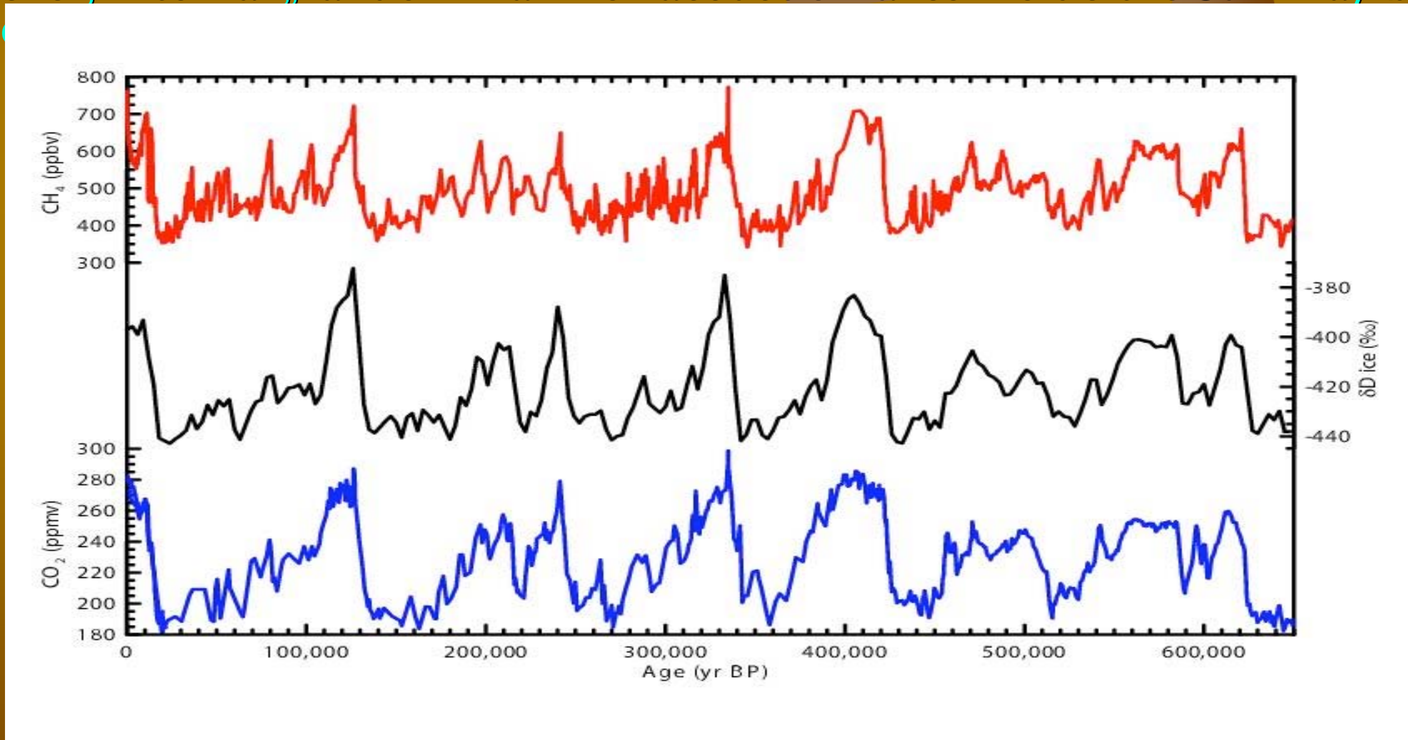


Continental drift takes hundred of millions of years but profoundly changes continental climates



Ice ages and interglacials

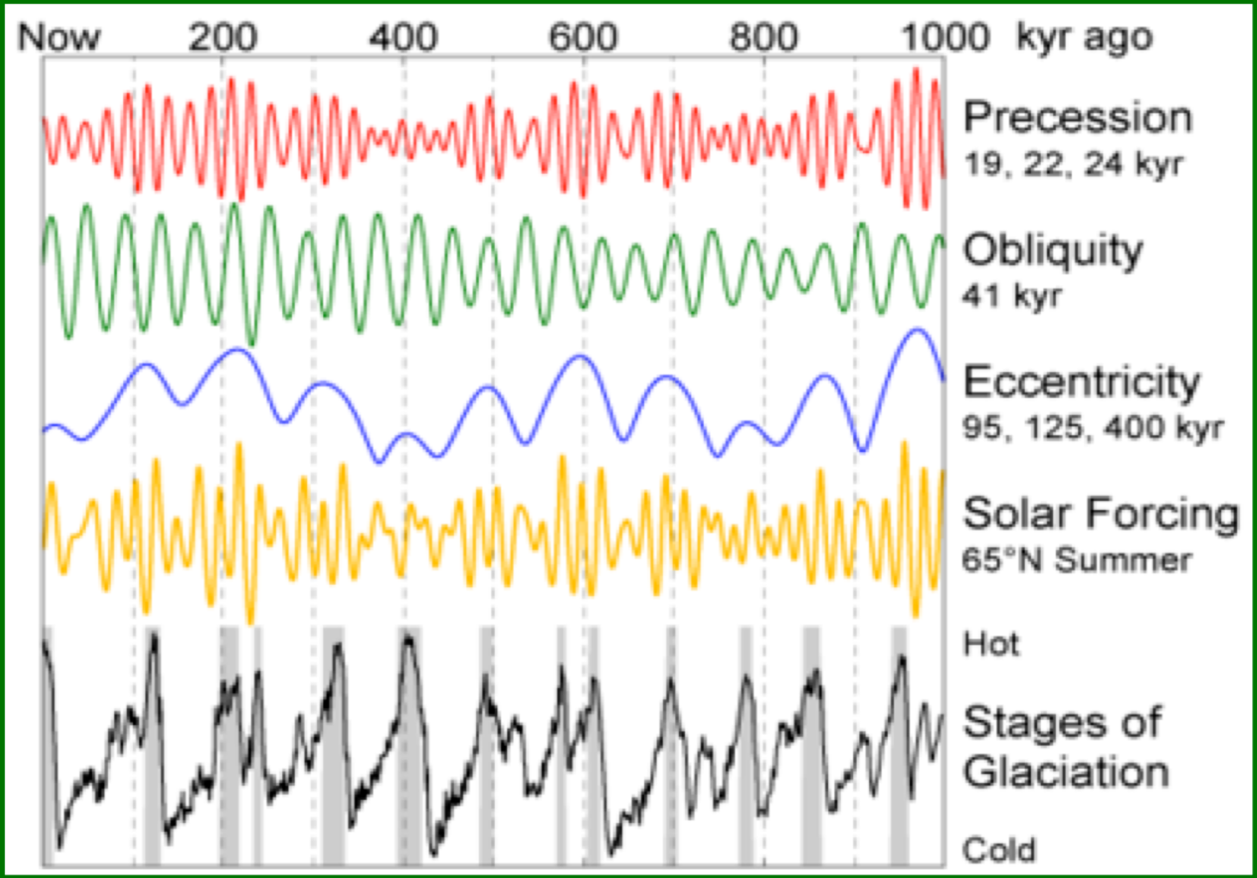
- Let's move from tens or hundreds of millions of years to tens or hundres of thousands of years
- **The Milankovitch theory explains the variation as orbital fluctuations of the Earth revolving around the Sun**
- However, internal „random walk“ or acoustic waves inside the Sun may be the caus



- Recent 650,000 years show an almost perfect correlation between temperature, methane, CO2
- **The causal relationship has to be looked at carefully**

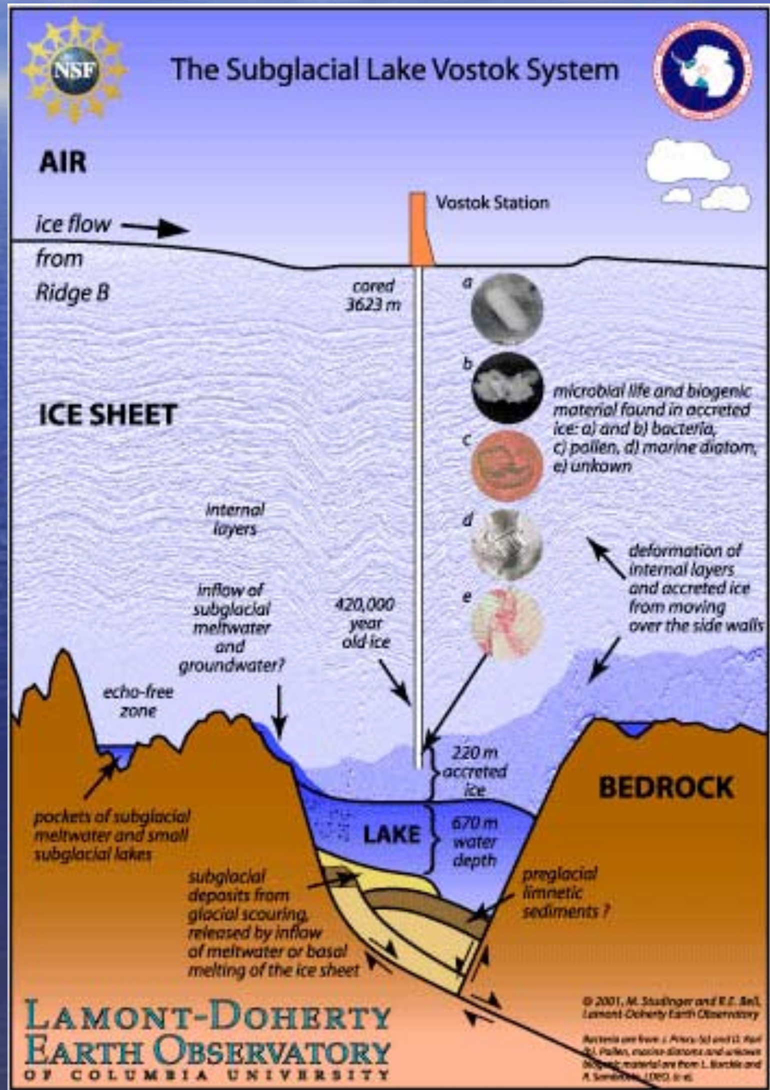
Milankovitch cycles

- Orbital irregularities contribute to the glaciation cycles, but other effects including random-walk variations may matter, too – no working complete description is known



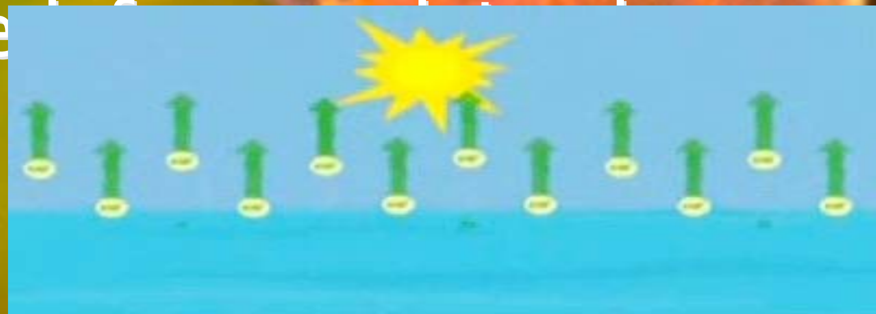
The charts were measured from the concentrations of CO2 and oxygen isotopes in the Antarctic Vostok ice core's bubbles

Depth in ice = time into the past



Temperature has been the cause, changes of the gases are its effect

- **Why? First, CO2 is well correlated not only with T but also with CH4, methane**
  - If CO2 were the cause, the CO2-CH4 correlation would be

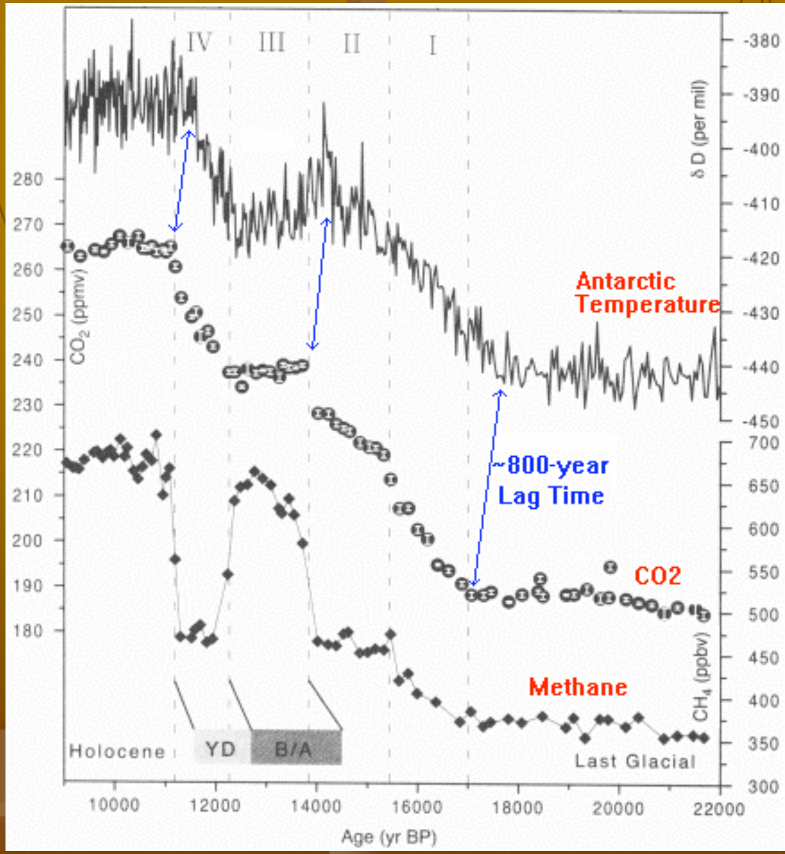


  - & outgassing:
- **Second, we know the mechanism**
  - A warmer ocean can't keep too much gas – compare with a Coke can on a hot day – so

The temperature-CO2 lag

- **CO2 and gases change 800+-600 years after the changes in temperature**
- Chart on the right:
  - time goes to the left
  - temperature heats/cools the oceans
  - after centuries, CO2 absorbed/released
- The last ice age:
  - more accurate data exist

Graph: Monin et al., vol. 291, Science 2001



Is there also the opposite relationship?

- **There can be but it's been much less important than outgassing because:**
  - the lag would otherwise go in the **opposite direction**
  - the direction we learned **can't be flipped or unlearned or forgotten**
  - a reinforcing mechanism would be a positive feedback; feedbacks greater than „1“ would create instabilities but exponential runaway behavior hasn't occurred for 4.7bn years
  - the only thing we learn from both considerations for sure is that the greenhouse effect is weaker than the temperature/CO2 rate extracted from outgassing, i.e. less than 8 °C of warming per 100 ppm of added CO2 – pretty obvious, not too useful

- **But how strong the greenhouse effect is?**

ABC of greenhouse effect: history

- No news: discovered by Joseph Fourier in 1824 =>

- Svante Arrhenius proposed (incorrectly) the effect as an explanation of ice ages in 1896

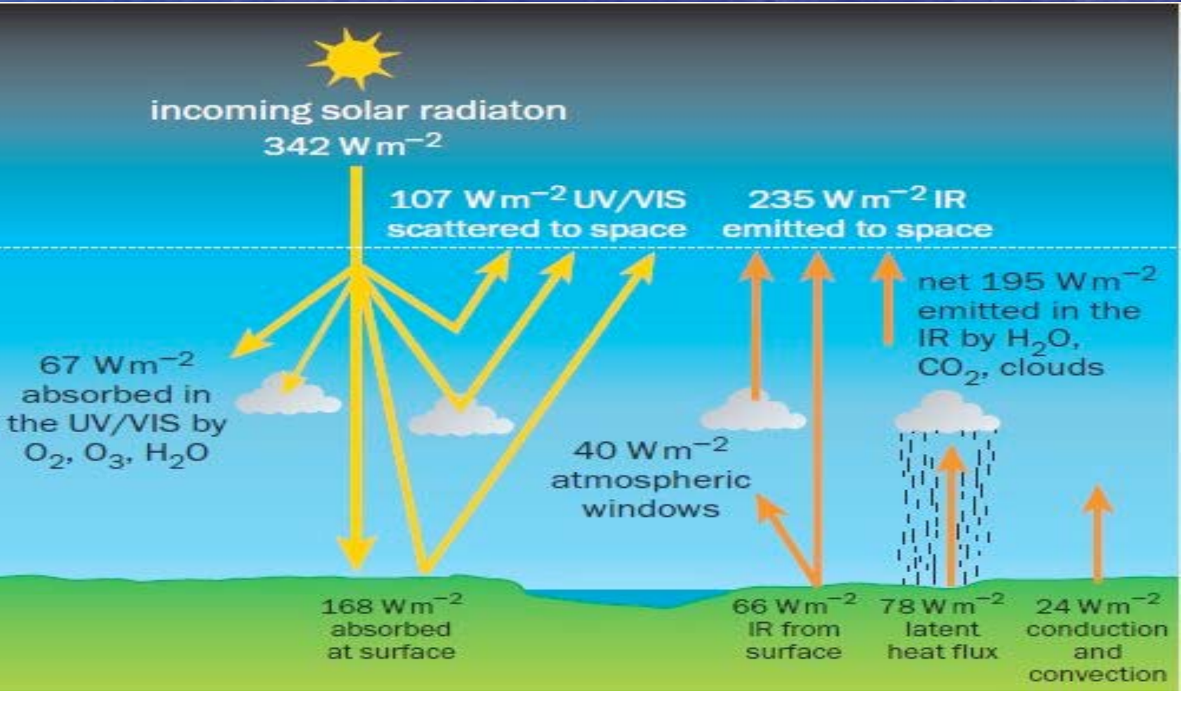
=>

- The only news is that this small effect is important for mankind

Radiation and energy budget

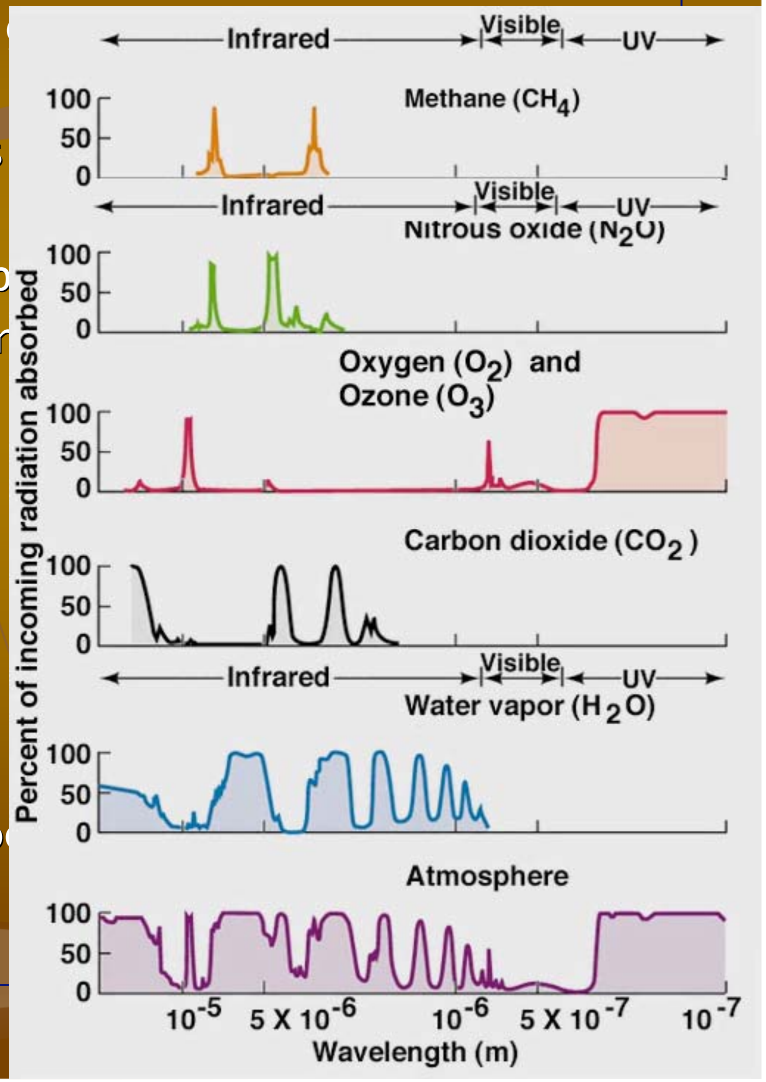
- The Earth is getting at most 1366 Watts per squared meter (solar constant) divided by four which is around 342 W/m^2 in average over time and location
- A part is reflected instantly. The absorbed part is balanced by the Earth's infrared thermal radiation
- Greenhouse gases absorb a part of the IR photons in the troposphere and modify the numbers
- The surface is heated by about 30 °C by the greenhouse effect. Around 90% of this extra warming is water vapor, 7% is natural CO2, 2% is our added CO2, less than a degree

- At the top, I divided by 4 because the total radiation 1366 W/m^2 doesn't arrive normally to the whole surface, 4.pi.R^2, but is shared by the cross section, pi.R^2, of the Earth



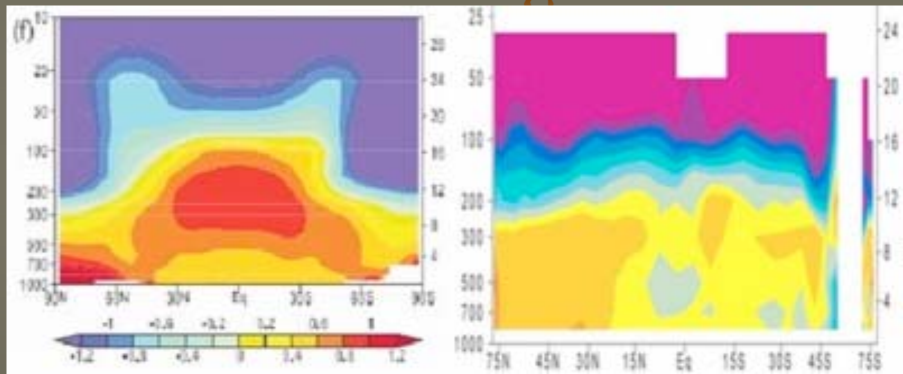
List of greenhouse gases & spectrum

- **Only complex enough molecules may absorb relatively low-energy radiation – and increase the relative motion of the molecules' nuclei**
- Monoatomic gases (e.g. Argon) can't be greenhouse
- **Water wins among the GH gases – see the images**
- However, it seems that H2O wapor concentration rap adjust according to other, more stable external param
- **CH4, N2O, O3 may still survive for decades or centuries**
- CO2 is the main controversy
- **Methane (agriculture), N2O, SF6, hydrofluoro-carbons, perfluorocarbons are Kyoto-regulated, to**



A general problem of the greenhouse models: their wrong fingerprint

- Dependence of temperature trend (in °C per decade0 on latitude (x) and altitude (y)



- Left graph (PCM model U.N., IPCC 2007 page 687 or appendix 9c) is predicted by greenhouse-led models, right graph is observed (radiosondes, CCSP 2007, p. 116)
- **The colors are self-explanatory and the graphs disagree**

Climate sensitivity: a definition

- The most popular quantity measuring how important CO_2 is for the temperature

- Start with 280 ppm, as in 1800, and quickly increase CO_2 to 560 ppm – expected around 2090 with the current consumption

- By sensitivity, I will mean the warming (or, less likely, cooling) caused by this change of CO_2

Intermezzo: CO_2 concentrations

- Usually expressed in ppm (parts per million), which is 0,0001 percent of the volume (i.e. of the number of molecules – recall that $pV = NkT$ and p, T, k are shared by all gases)
- **180 ppm – ice ages (e.g. 16,000 BC)**
- 280 ppm – interglacials (e.g. in the year 1800)
- **388 ppm – today; we're adding 3.9 ppm a year but 2.1 ppm a year (of excess CO_2) is absorbed by oceans & forests: 1.8 ppm growth remains**
- 560 ppm – "doubled" CO_2, around the year 2090
- **700 ppm – average in your office**
- 4,500–6,000 ppm – half a billion years ago (leaves...)
- **10,000 ppm – one percent: a small part of people start to feel dizzy**
- 50,000 ppm – toxic effects of CO_2 itself begin

Sensitivity is comparable to 1 °C

- That would mean that because we have already seen 0.7 °C of warming that could be attributed to our activity (the natural contribution could have been positive or negative, in this era), **0.3 °C or so remains to be added until 2090** (560 ppm)

- Why around 1 °C? Neglecting clouds and other complexities, the **bare absorption** by CO2 is a doable, „clean“ physics exercise and the calculable result is 1.2 °C per CO2 doubling. Feedbacks may change the figure in both ways – and different for different locations (especially latitudes)

- Since 1800, our added CO2 was such that approximately **50 percent of the effectu** expected from the doubling has already occurred (see the other transparencies, linked to the logarithmic dependence); so we could expect about the same warming by 2090

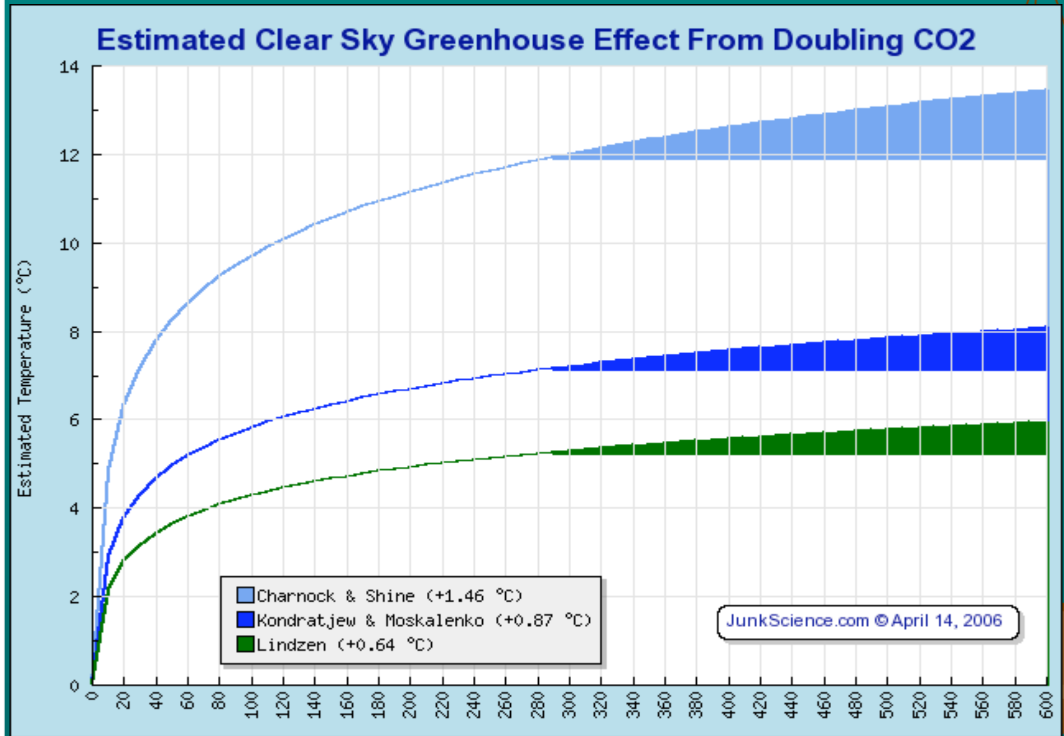
- Other arguments, calculations, papers, e.g. **Stephen Schwartz** (2007), lead to 1.1 °C or similar figures; I will discuss additional arguments

- **IPCC needs to inflate the sensitivity to 2-5 °C or more.** Untrustworthy, but even with those figures, the real „danger“ would be questionable

Nonlinearity: The influence of each new CO_2 molecule is weaker than that of the previous one

When you're painting your office for the 10th time, it doesn't make the same difference

The Arrhenius law dictates the same for the greenhouse effect. At most 100% of a spectral line can be absorbed: the effect is slowing down. In reality, approximately,   Delta T = Sensitivity * log_2 (conc/280ppm)



Different gases also fight for „overlapping“ spectral lines which weakens the effect further

It follows that around 50% of the greenhouse effect from doubling has already been added

In other words, the 2009-2090 greenhouse warming is likely to be close to the 1850-2009 warming, whatever it was

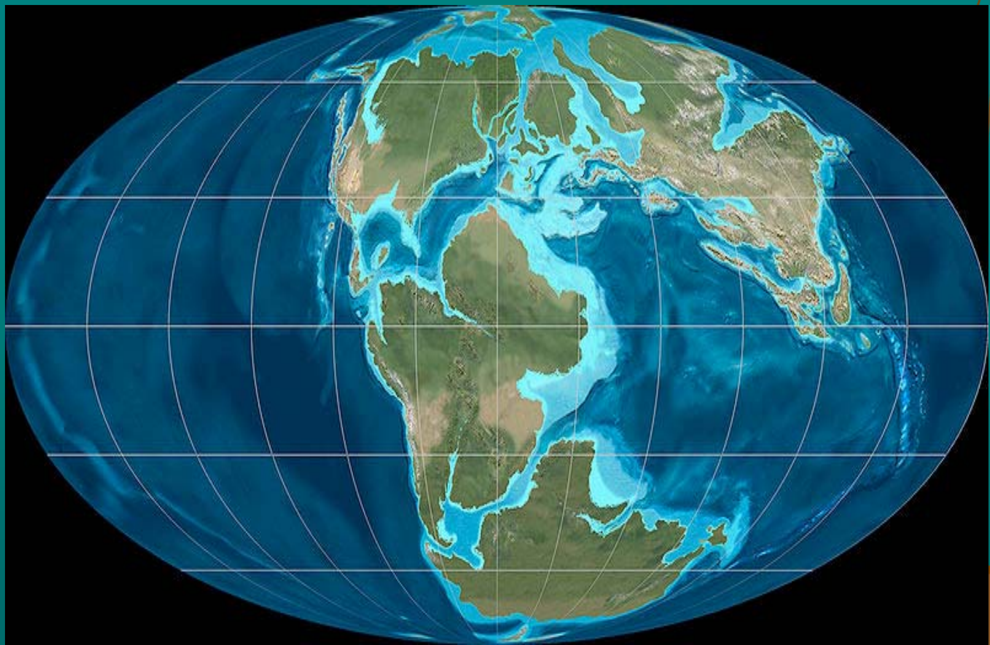
Feedback: positive or negative?

- The „bare“ climate sensitivity, 1.2 °C per doubling, may be increased or decreased by positive or negative feedbacks
- **IPCC „needs“ large positive feedbacks – enhanced water vapor (extra greenhouse gas) may be one of them. But it also needs to humiliate, relativize or overlook the negative ones (the iris effect, effects of clouds) that are likely to (over)compensate the positive ones.**
- Richard Lindzen's iris theory postulates increased precipitation (and thus decreased density of cirrus clouds – that mostly have a warming effect) in areas where air is flowing up (warmer regions): a negative feedback

Geological eons: a rough estimate of the sensitivity

Dozens and hundreds of millions of years:

Continental drift clearly affected the continental climates in particular. But what about the global mean temperature and CO_2 concentrations? Have they been linked during the last 550 million years?

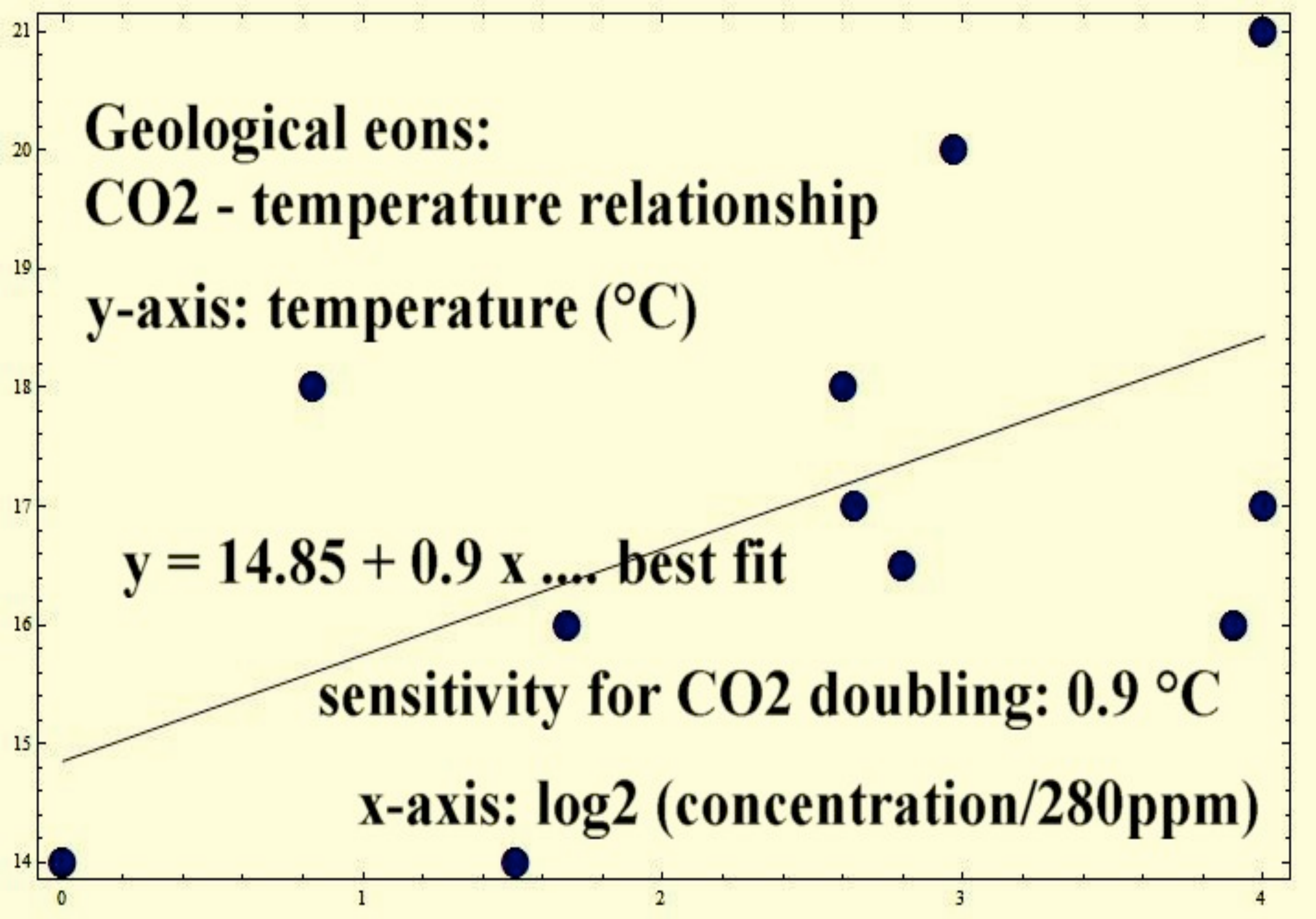


Let's find the best linear model linking the observed temperature in different geological epochs, and the logarithm of the CO_2 concentration...

Geological eons: a rough estimate of the sensitivity

- **542 million years ago**
  Proterozoic era ends, Paleozoic era begins
- The Cambrian: 4500 ppm, 21 °C
  expansion of life, trilobites (anthropods)
- **488 million years ago**
- The Ordovician: 4200 ppm, 16 °C
  marine animals, mollusca
- **444 million years ago**
- The Silurian: 4500 ppm, 17 °C
  corals, mosses
- **416 million years ago**
- The Devonian: 2200 ppm, 20 °C
  seeds, forests, many sharks, fish
- **359 million years ago**
- The Carboniferous: 800 ppm, 14 °C
  sea stars, sponges, corals, fish, equisetales, insect, tetrapods, fungi
- **299 million years ago**
- The Permian: 900 ppm, 16 °C
  invertebrates, reptiles, cockroaches, cynodonts
  Coal in Siberia, East Asia, Australia; Oil in the U.S.
- **251 million years ago** (extinction event)
  Paleozoic era ends, Mezozoic era begins
- The Triassic: 1750 ppm, 17 °C
  no coal, new corals, ammonites, turtles
- **199 million years ago**
- The Jurassic: 1950 ppm, 16.5 °C
  dinosaurs, crocodiles, conifers, coralline algae
  Oil in Middle East, North Sea, Siberia (part)
- **145 million years ago**
- The Cretaceous: 1700 ppm, 18 °C
  figs, magnolias, some mammals, birds, modern sharks
  Oil around Venezuela; Earth by 4 °C warmer than today; see Climate Audit
- **65 million years ago** (extinction event)
  Mesozoic era ends, Cenozoic era begins
- The Paleogene: 500 ppm, 18 °C
  birds and mammals explode
- **23 million years ago**
- The Neogene and The Quaternary Period (last 2 megayears): 280 ppm, 14 °C
  mammals include early humans
- **Today**
- Our world in 2009: 385 ppm, 14 °C

Geological eons: 0.9 °C per doubling



Temperatures at 4500 ppm

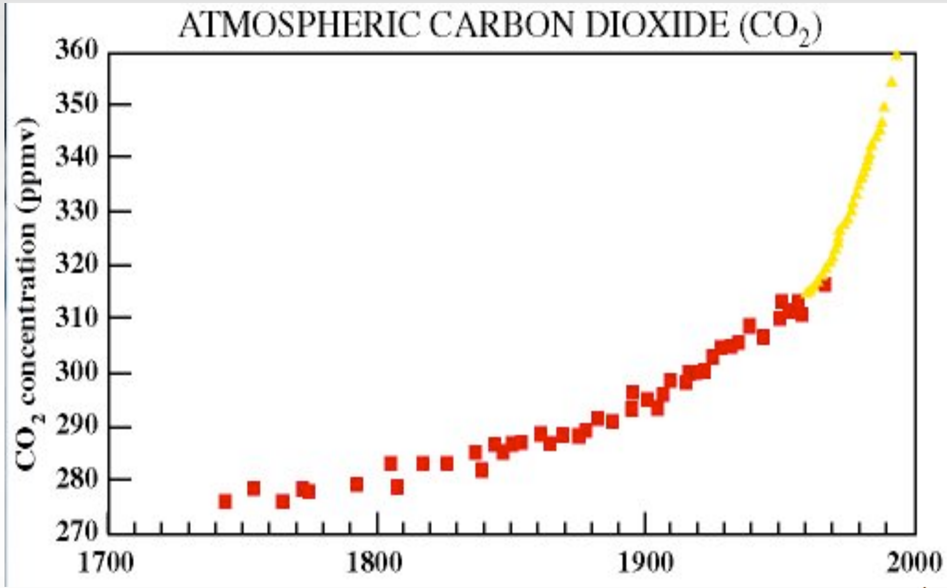
- In particular, in the geological eons when the CO2 temperature was 4500 ppm = 16 x 280 ppm (four doublings above 280 ppm), the temperature was only 2-6 °C higher than in 1800

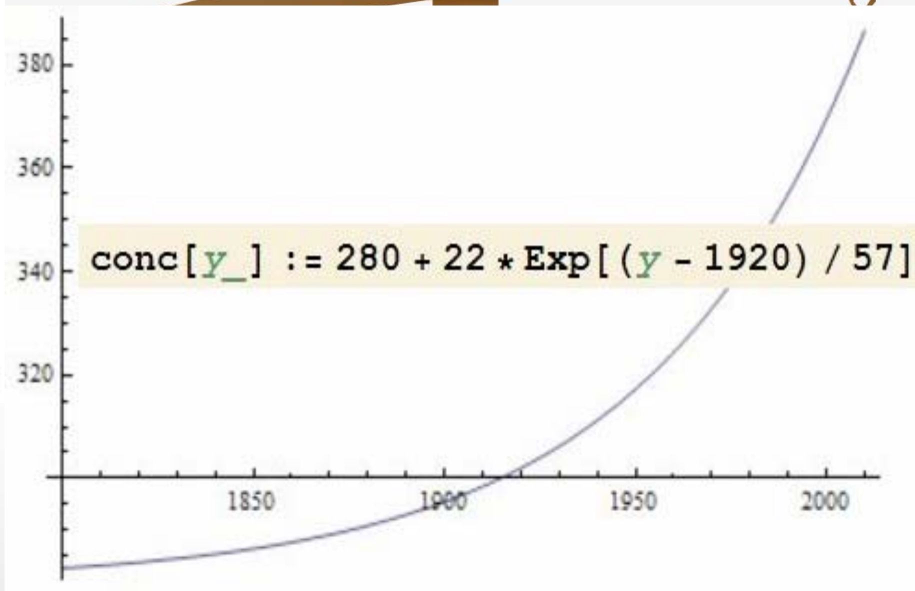
- It follows that the per-doubling warming is 0.5-1.5 °C, while sensitivity above 2 °C is almost

Sensitivity extracted from 20th century readings

- The geological records gave us a sensitivity lower than the bare one, i.e. negative net feedbacks
- Attributing the mostly increasing temperatures in the last 150 years completely to CO_2 gives us significantly higher but not „very large“ figures for the sensitivity, via linear regression. It's very likely to be an overestimate.
- Start with the known CO_2 concentrations since 1800 or so. Let's see the figures

Observed CO2 concentrations and an exponential fit





The best fit multiplies the deviation from 280 ppm (and emissions) by 2.718 every 57 years (=1.7% annual emissions growth).

This emissions growth is probably slowing down these days.

Results for the high, 20th century instrumental sensitivity (CO_2 is the only non-chaotic forcing here)

- Define the logarithmic concentration as

logconc = log(conc/280 ppm) / log(2)

- Find the best linear fit (linear regression) for the prescription

temperature = T0 + sensitivity x logconc

- The doubling sensitivity ends up being

1.7 °C for HadCRUT3 replaced by UAH since 1979, 1850 – 2009 (continuously)

1.9 °C for HadCRUT3, 1850 – 2009 (still predicts just 1.2 °C by 2100)

2.2 °C for UAH MSU, 1979 – 2009

2.7 °C for HadCRUT3, 1979 – 2009

- Our assumptions led to a positive feedback, but still at the low end of the IPCC range: higher for „faster warming“ teams; higher if extracted from a shorter, „uniform warming period“, of course

- If we assume that 50% of warming was unrelated to CO_2, the sensitivity drops to 1/2, of course; adding extra terms (functions) to the fit can change the sensitivity in both directions

Stephen Schwartz (2007)

Journal of Geoph. Res.

- Heat capacity of the upper ocean is
17 year / Kelvin x Watt / m^2, plus minus 50 percent
- Time constant 4-6 years obtained from autocorrelations

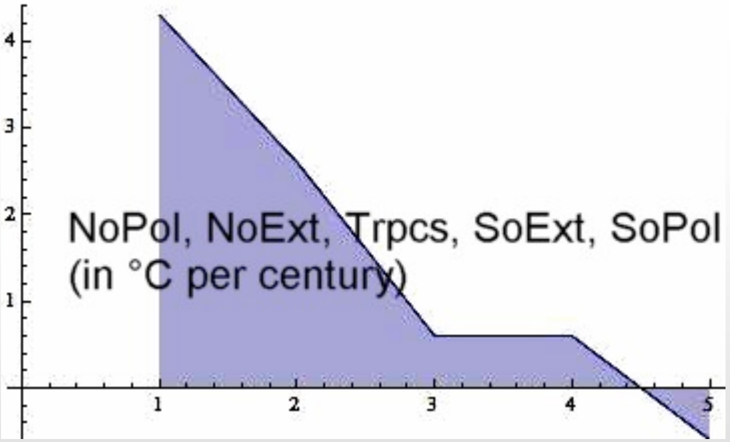
- Their ratio is 0.30 °C per W/m^2, which translates to 1.1 °C per CO2 doubling, plus minus 50 percent

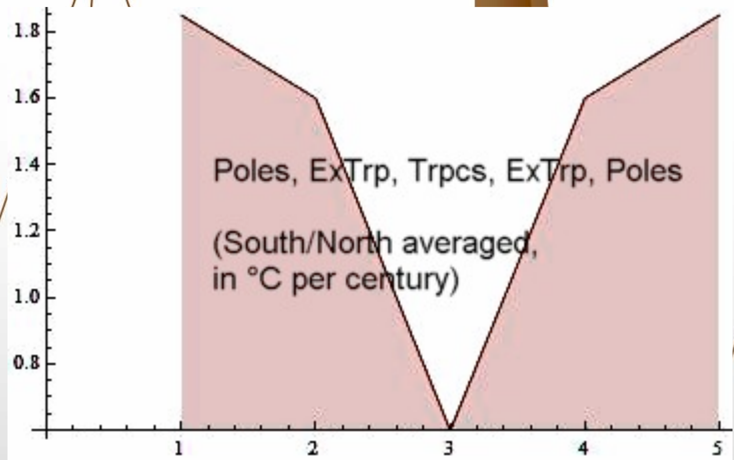
- The mean value is below the bare one (negative feedback)

Dependence of the sensitivity on the latitude 1

The bare greenhouse effect is completely uniform in space (latitude, North/South), and time (day/night, seasons)

However, the full sensitivity including the feedbacks is bound to depend on the location. Below, the centennial warming trend as measured by UAH from 1979 is graphed:

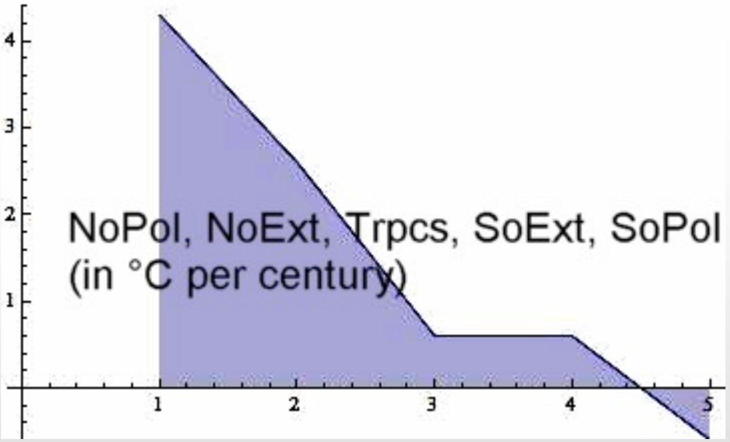


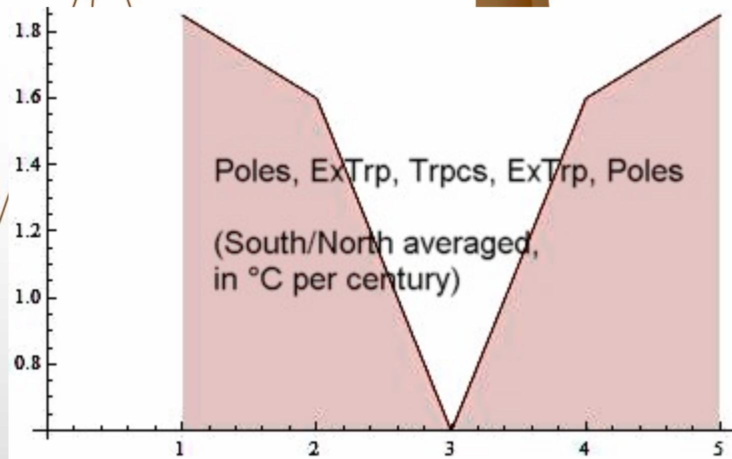


Dependence of the sensitivity on the latitude 2

You see that the left picture is not constant – the warming is not really global (Antarctica was cooling) – a wrong fingerprint

After we „hide the decline“ by averaging North-South, we see that the even empirically, the warming is much smaller in the tropics (smaller, and maybe negative, feedbacks over there)





Tropics (already warm) is exactly where extra warming could be harmful, and they won't get much. The other regions will enjoy some warming, and they may get a little bit of it. Different behavior for different latitudes is essential to clarify the paradoxes raised by Lindzen-Choi etc.

Volcano eruptions

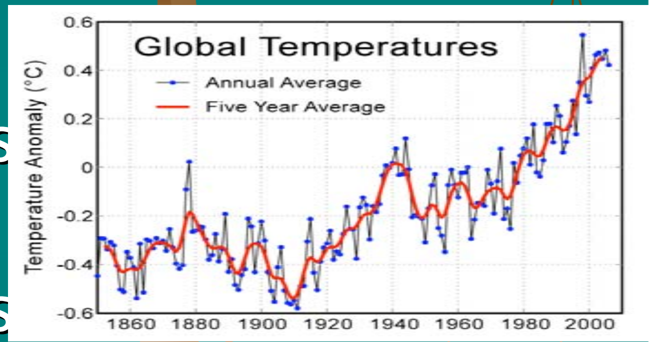
- E.g. Mt Pinatubo in 1991 cooled the global mean temperature by 0.5 °C for at least 5 years or so. The frequency of similar eruptions influences the temperature in the long run, too.

Oceans' impact

- Oceans are important because of their high heat capacity; turbulent flows, and so on. The deep ocean circulation takes up to 2,000 years.
- **Quasi-periodic modes appear in the oceans, too. These alternating „regimes“ bring characteristic weather patterns to various regions on Earth.**
- Pacific Decadal Oscillation (PDO) and El Nino/ La Nina are the most well-known examples.

Pacific Decadal Oscillation (PDO)

- The Pacific Ocean, near 25 °N, 25 °S, often stays warm/cool for decades: regimes
- Cool and warm regimes of PDO:
  - 1750 – frequent oscillations
  - 1905 – warm PDO regime begins
  - 1946 – cool PDO regime begins
  - 1977 – warm PDO regime begins
  - 1998 – a few cool years followed by fluctuations



- This behavior is quite certainly natural, caused by turbulence in the ocean
- Look at the years: the cool PDO regime seems to exactly overlap with periods of global cooling, and vice versa

PDO: temperature map, chart

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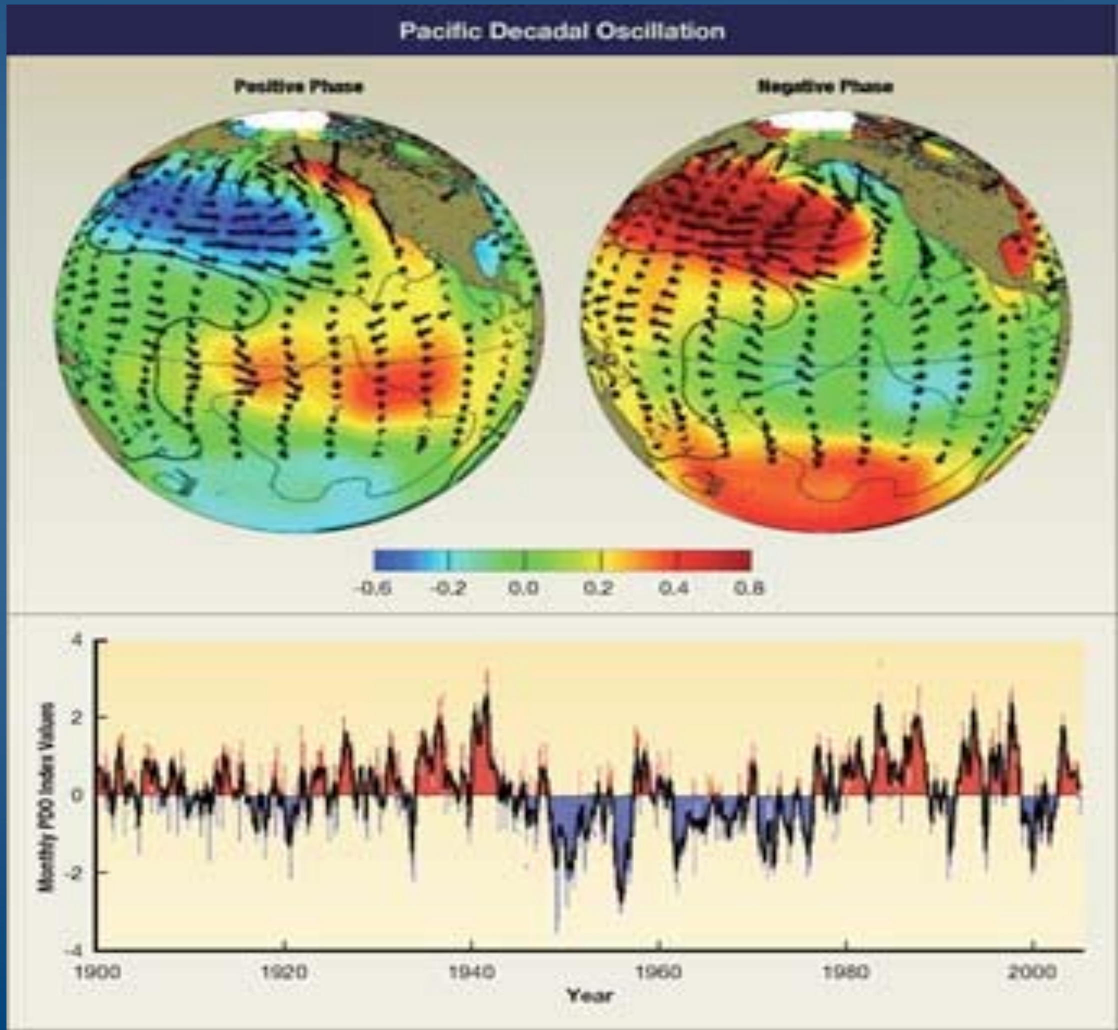
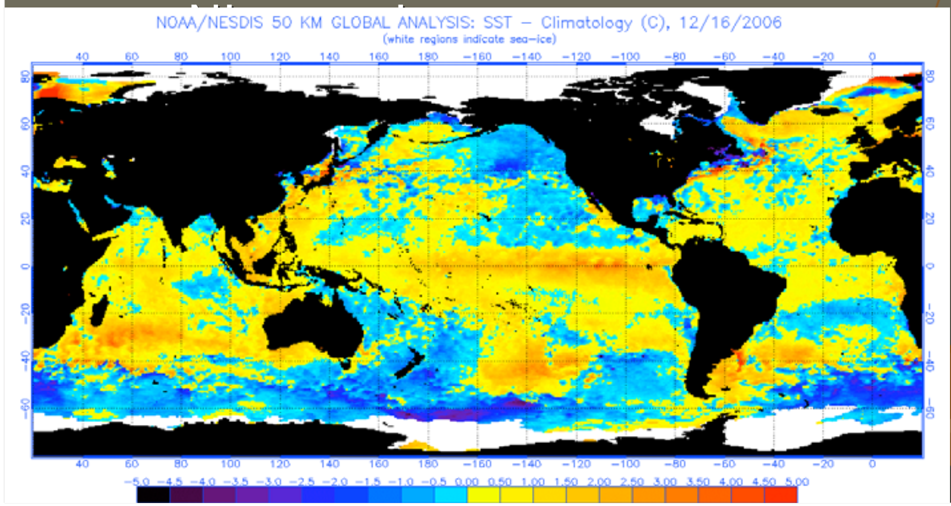
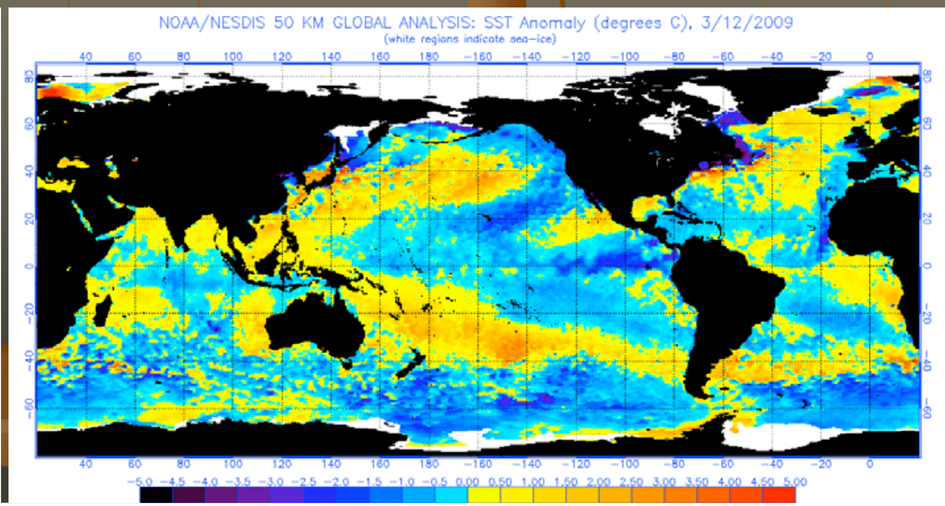


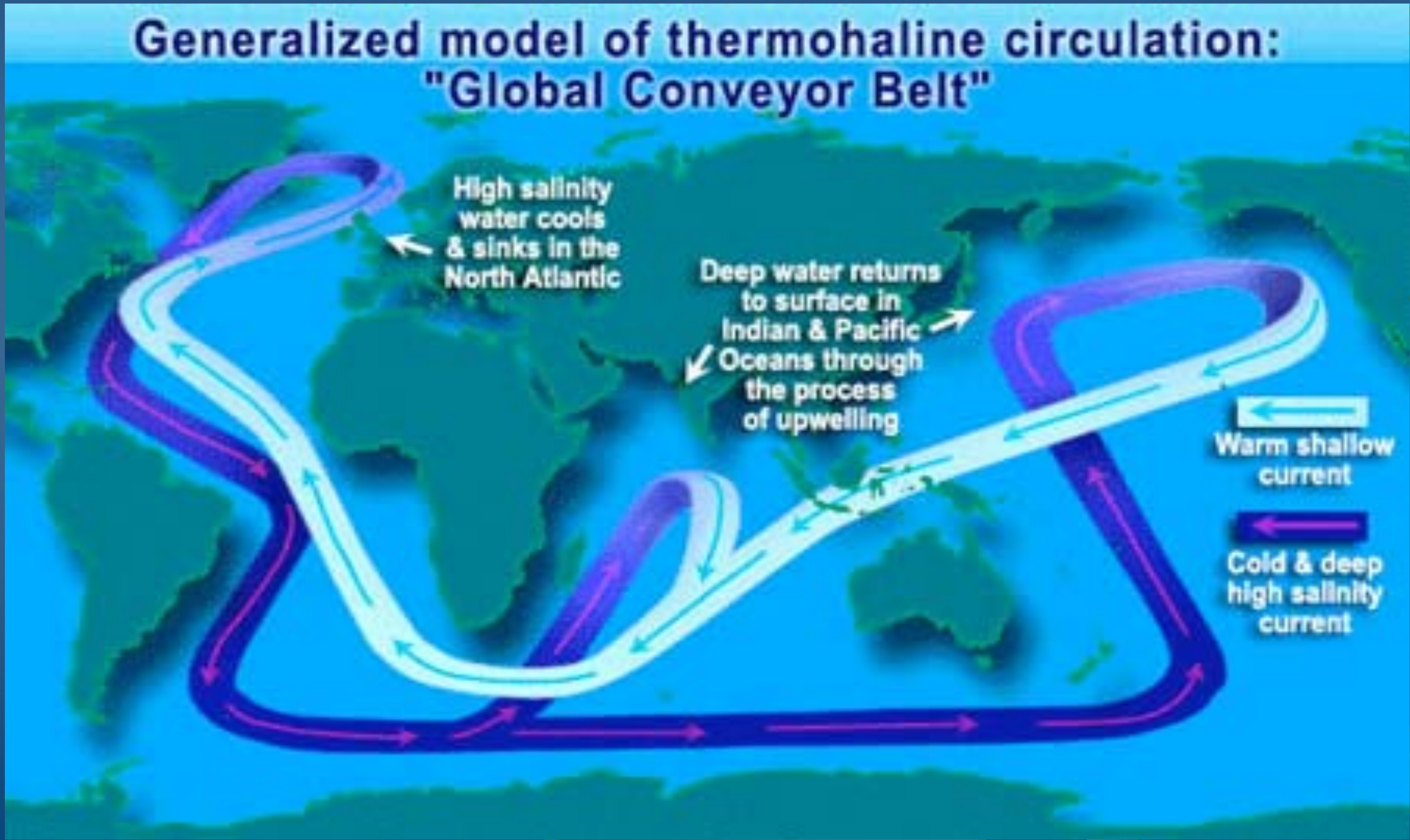
El Nino and La Nina

- El Nino (Spanish: little boy or Baby Jesus) and its opposite La Nina (Spanish: little girl) are ocean regimes with characteristic distributions of temperatures and precipitations in various regions. Natural origin.
- Defined by excess (boy) or deficit (girl) heat in the equatorial Pacific
- La Nina adds Atlantic hurricanes. El Nino increases the global mean temperature on Earth – 1998 El Nino of the century made it the record hot year
- Graphs below: El Nino 2006, La Nina Spring 2009. Now: strong El



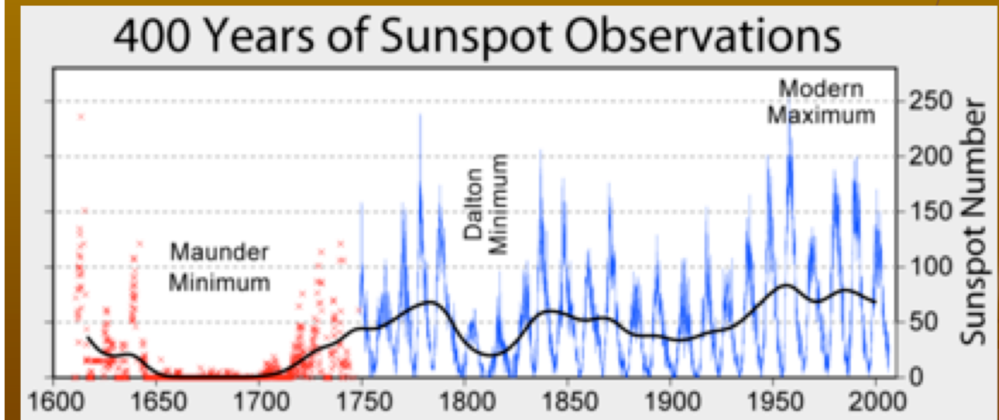


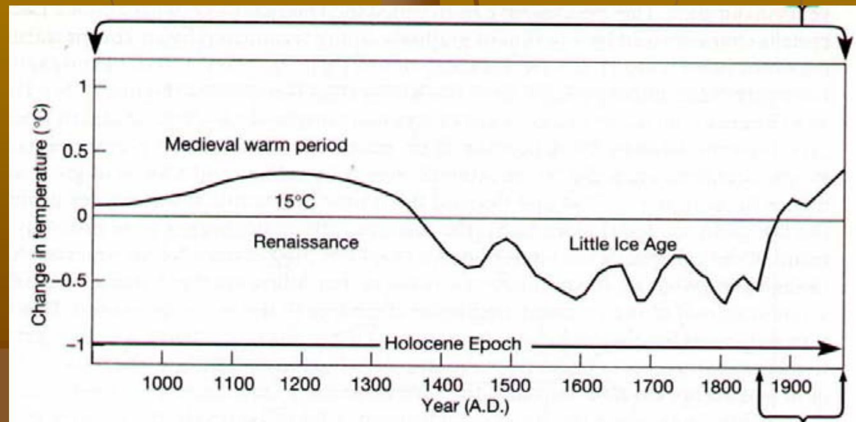
Complex deep-ocean circulation: up to 1,500 years

- 

The impact of cosmic rays and solar activity

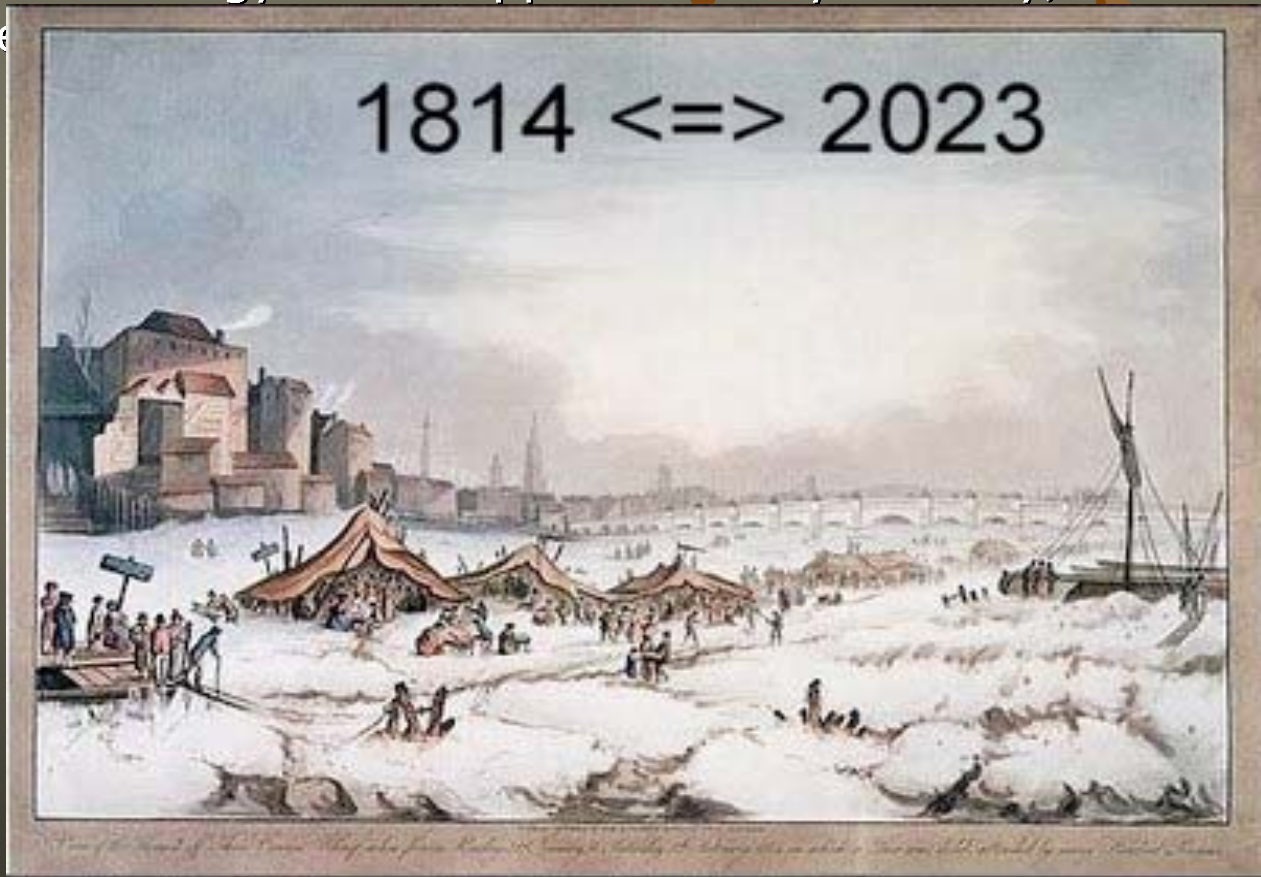
- The sunspot number seems to be strongly correlated with temperature in the last 400 years
- The Maunder minimum (1650–1700) overlaps with the Little Ice Age and the Dalton minimum was cool, too
- The graph of sunspots since 1600, and the IPCC 1990 graph of temperatures in England:





If the solar activity affects the temperature on Earth

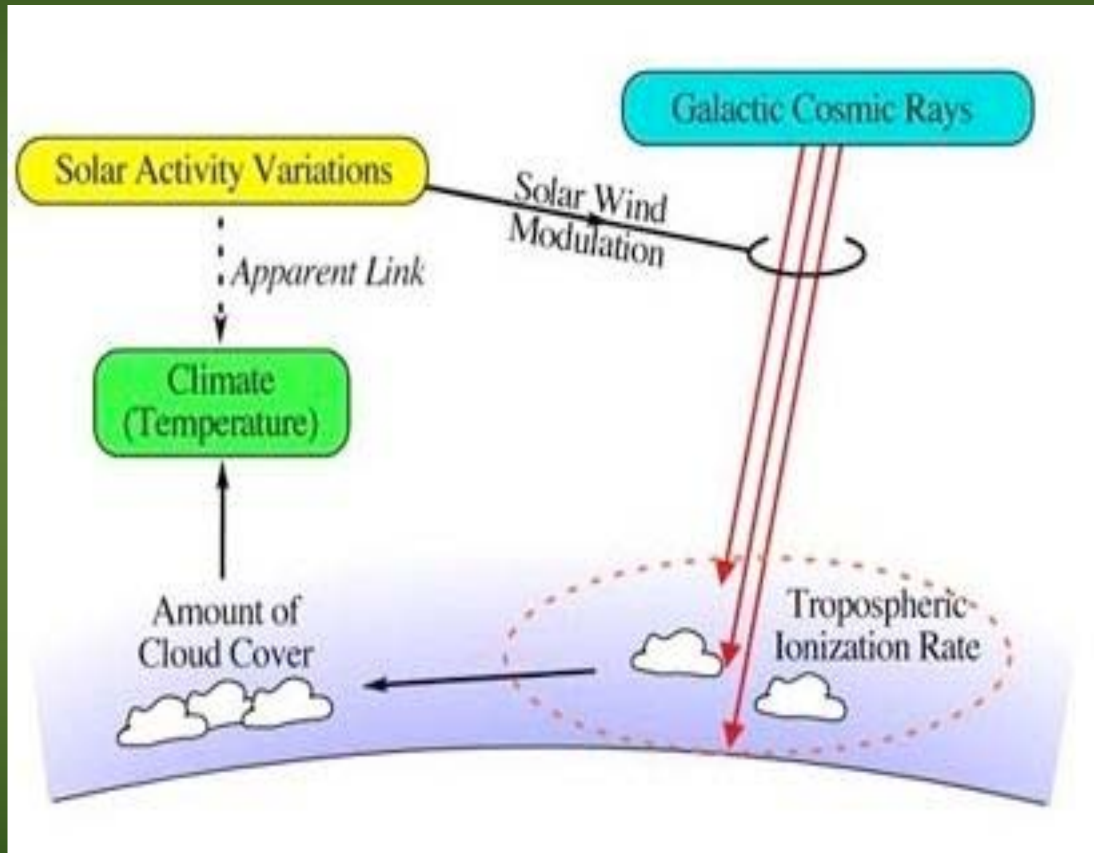
- We've seen a pretty strong solar minimum – almost no sunspots for years
- Similar to Maunder minimum etc.
- With this analogy and an apparent 209-year delay, Thames may freeze



View of the frozen River Thames off Three Cranes Wharf, London, 1814

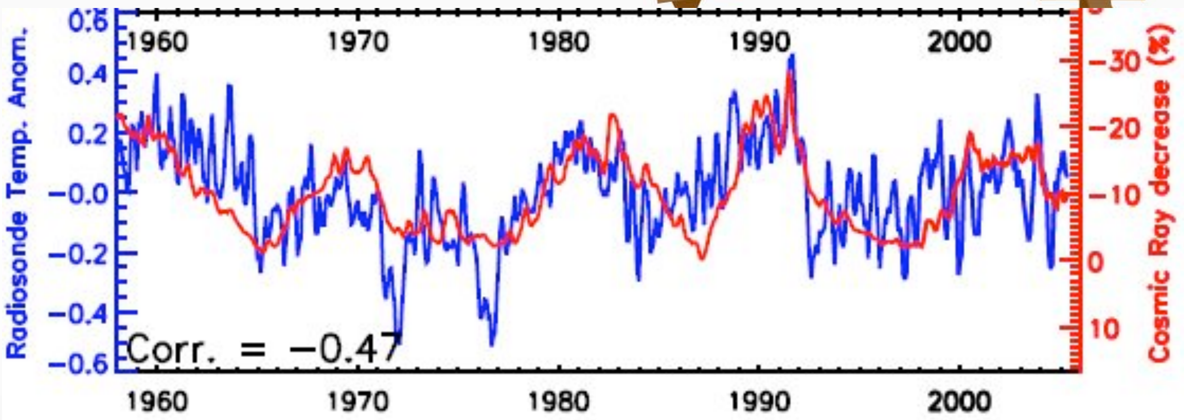
Cosmic rays probably influence temperature

- **Solar activity increases the solar magnetic field and „solar wind“**
- The latter may screen a part of the galactic cosmic rays
- **Cosmic rays produce condensation seeds of clouds: a tested proposition, new tests (CLOUD) at CERN are underway**
- Reduced cosmic rays flux therefore reduces cloudiness i.e. increases temperatures
- **Summary: increased solar activity means warming, and decreased solar activity adds to cooling**



Combined picture

- A convincing reconstruction of temperatures since 1950 was composed by Svensmark & Friis-Christensen (2007).
- The key graph from that paper:

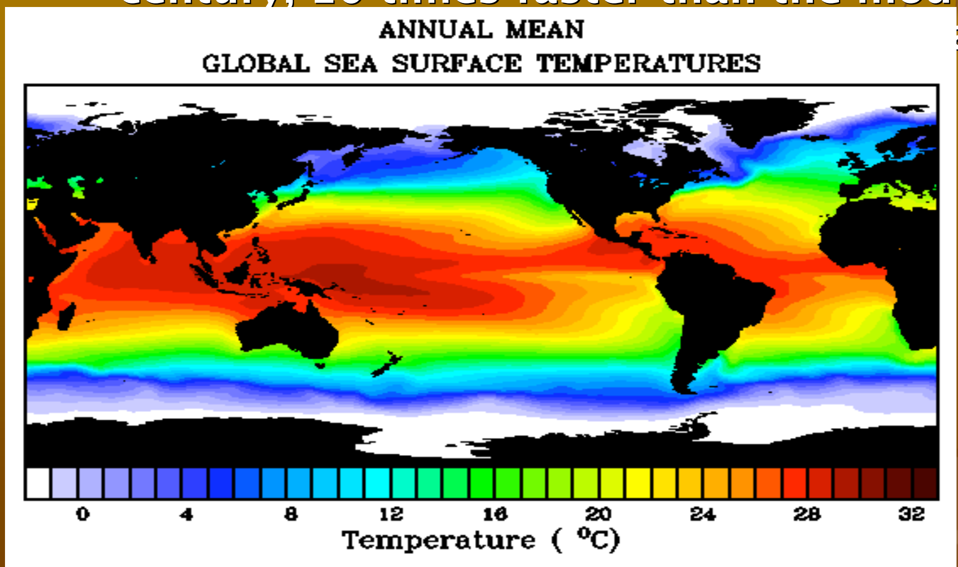


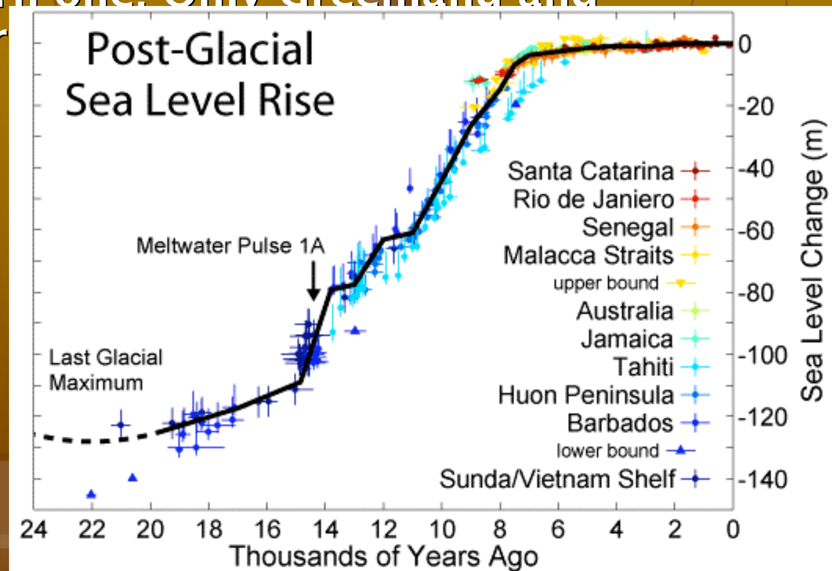
- The graph shows an intriguing correlation between the cosmic ray flux (red, upside down) and the temperature anomaly (blue).

- The anomaly is the temperature measured by radiosondes minus:
  - The expected effect of El Nino and La Nina (natural effects)
  - A standard calculable cooling effect by volcano eruptions (natural effect)
  - A linear function – warming by 0.14 °C per decade. This warming may or may not be anthropogenic in Nature and it may or may not continue in the 21st century.
- Cosmic rays plus these three factors seem to capture the temperatures well...

Influence on ice sheets

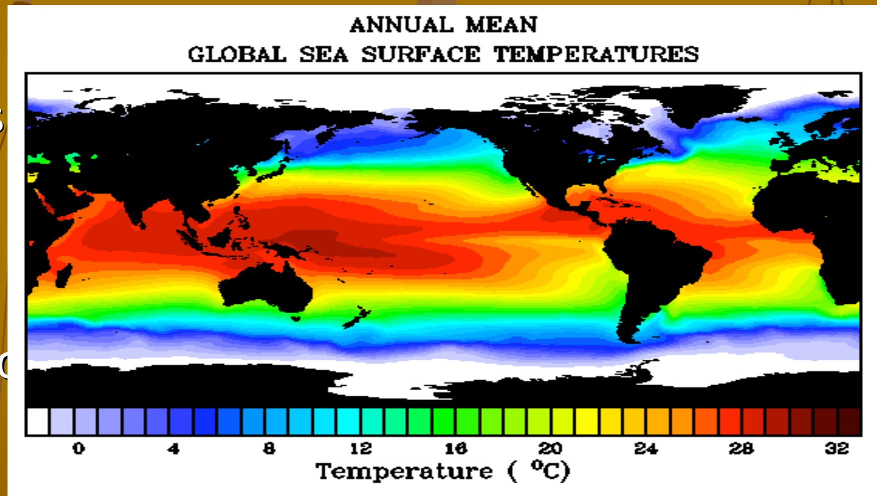
- If the increasing trend we mentioned – or seen since the 1970s – will continue, there will be extra warming by 1–1.5 °C by 2100. According to other estimates we have made, it'll be 0.6 °C or less.
- **Will it lead to a catastrophe? Hardly.**
- Even with the IPCC's 2.0 – 4.5 °C of warming, the sea level will rise by 20–43 cm per century only – which is not worth talking about by anyone except for specialists
- **In the last 15,000 years, the sea level rose by 120 meters – about 1 meter per century – and 10,000 years ago, the rate was up to 2 meters per century, 10 times faster than the modern one! Only Greenland and ... ar**





Impact on ecosystems

- What about local influences? Even if a man, animal, plant, system couldn't stand the mild warming, the 1.5 °C warming can be fully compensated by moving 200-400 miles away from the equator, to higher altitudes, or away from oceans



- Annual mean temperatures go from less
0°C to more than +35 °C; 1 °C is nothing

- Most living forms can't even detect
1-2 °C individually; statistically, most
Them find warming beneficial

- **Let's prefer numbers over words,**
avoid biases, corruption, temptation to look as a messiah, desire to scare others, be unaffected by higher circulation of „scary" newspapers, higher grants. When these biases are removed, we can see there's no reason for alarm

The End …