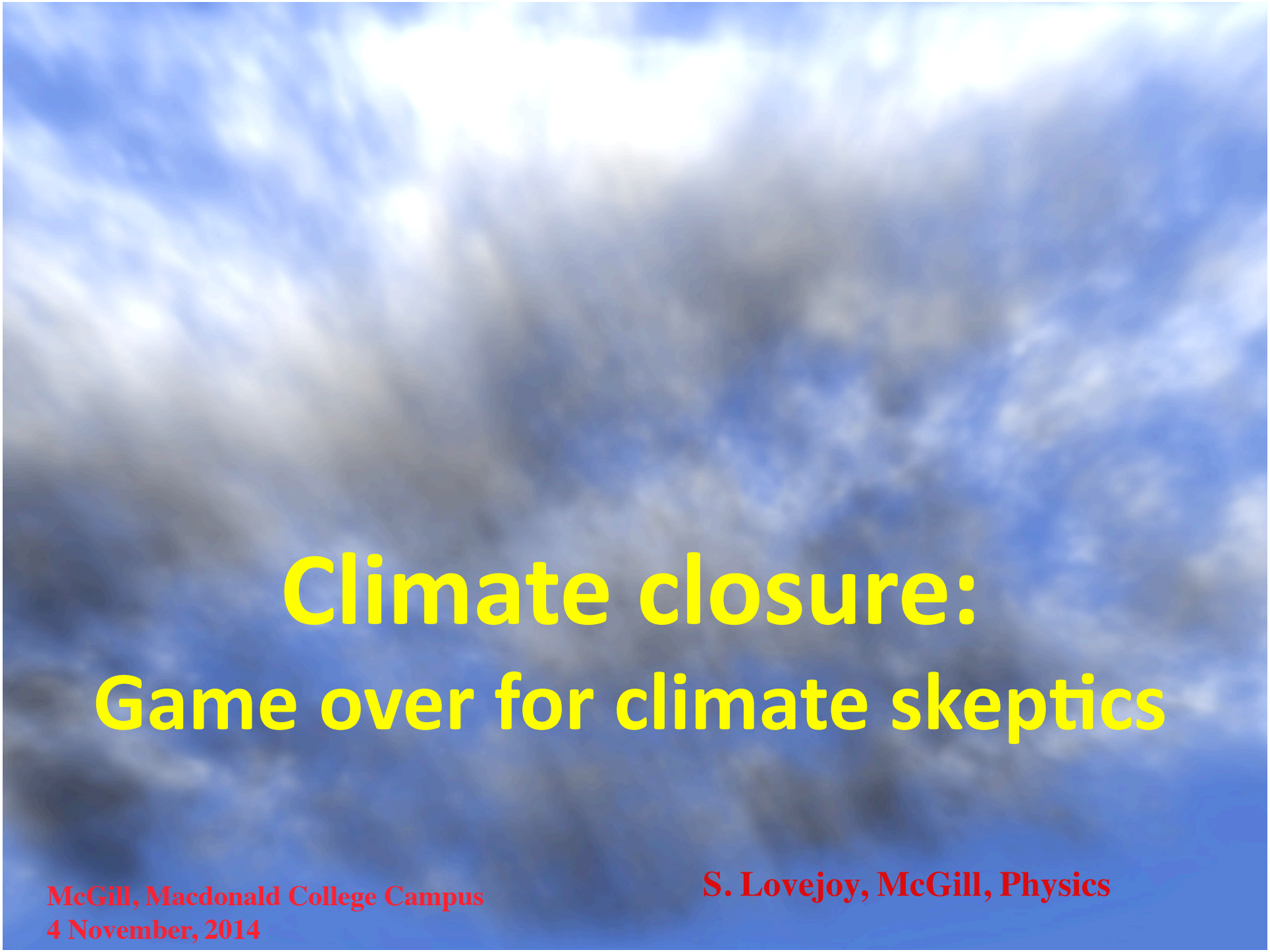


Climate closure:
Game over for climate skeptics

S. Lovejoy, McGill, Physics

McGill, Macdonald College Campus
4 November, 2014

What is the climate?

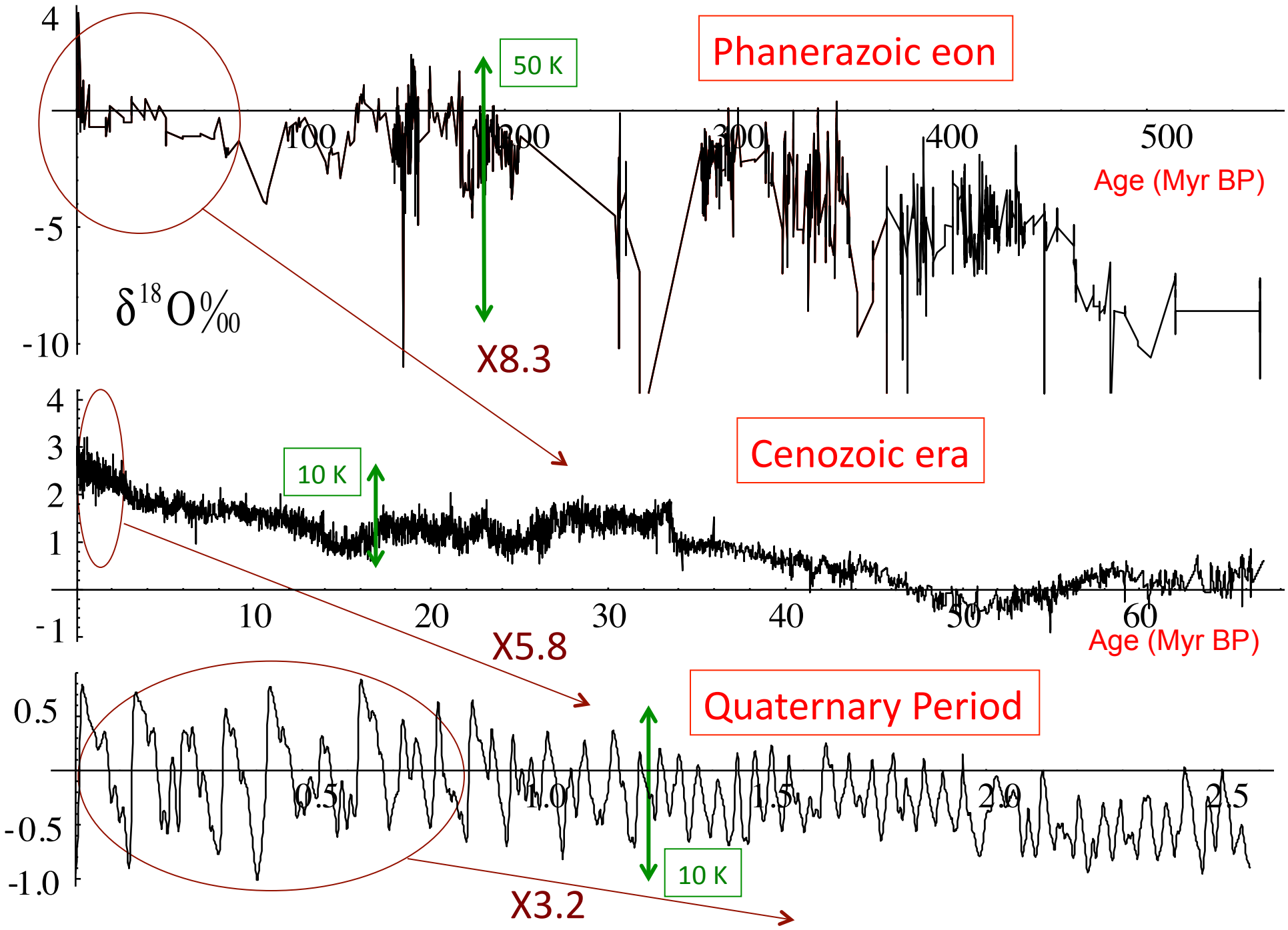
A voyage through scales

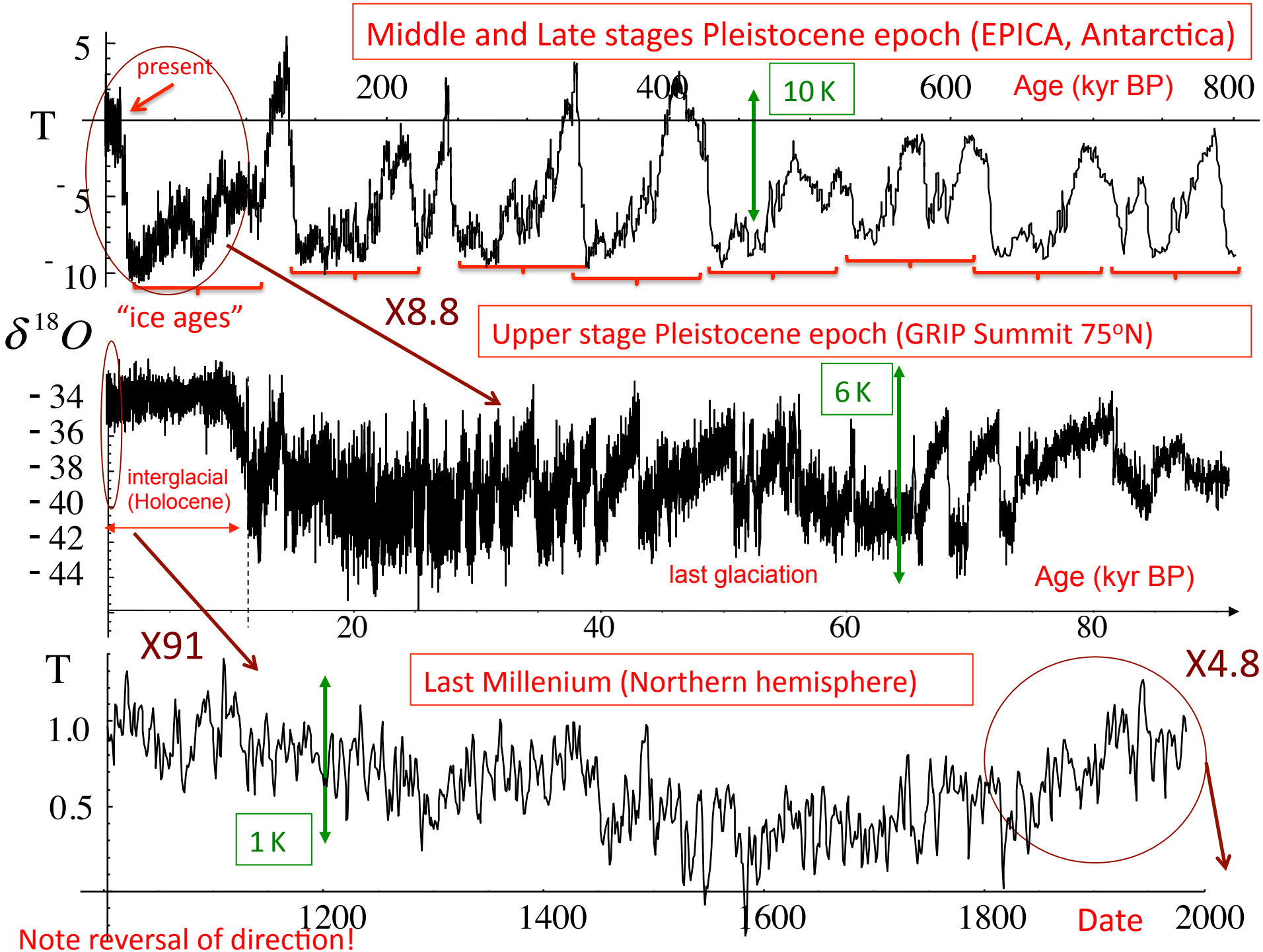
From the age of the earth to the viscous dissipation scale: 4.5×10^9 years - 1 ms:

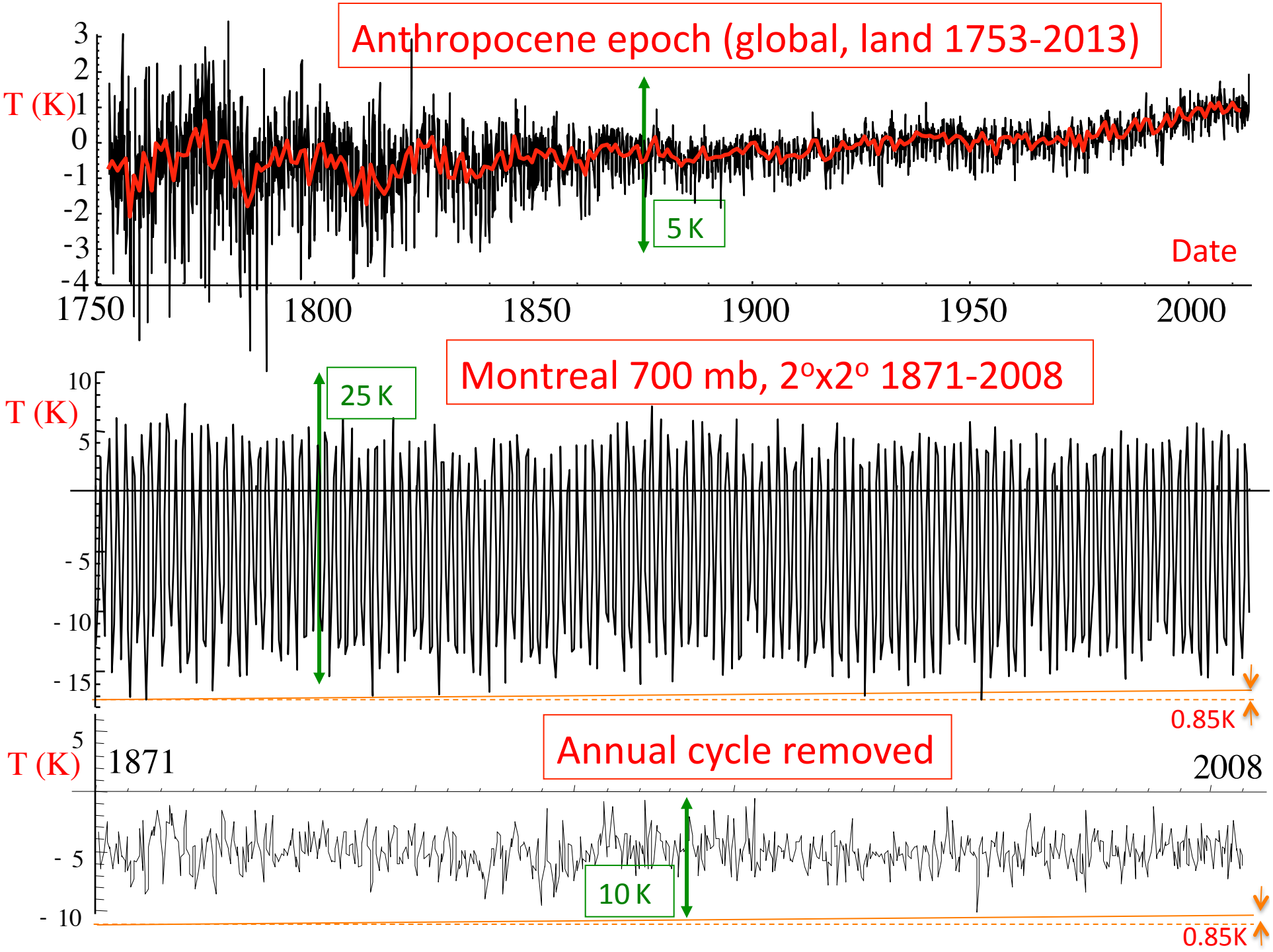
20 orders of magnitude in time

In space: the size of the planet to viscous dissipation scales:

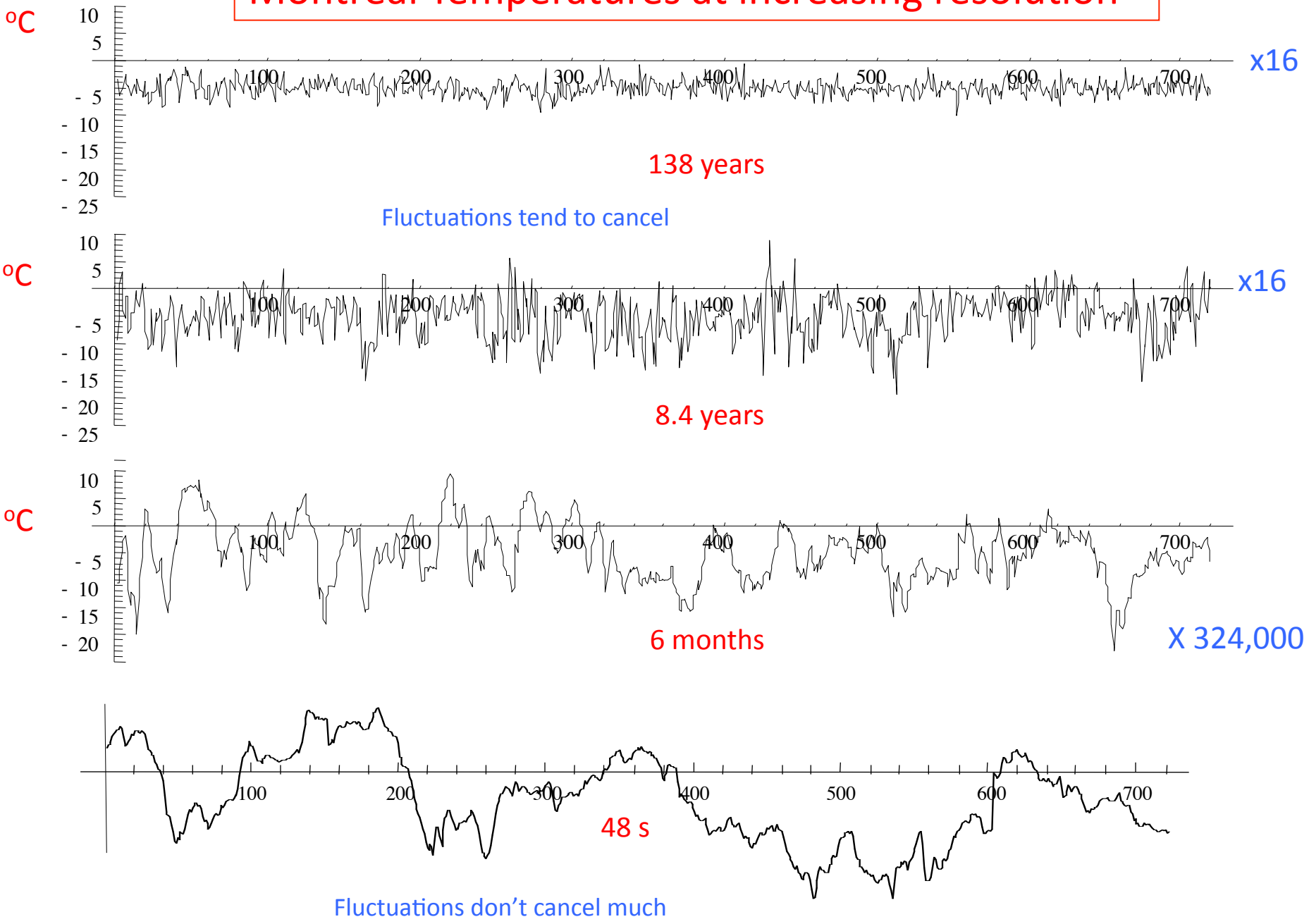
10 orders of magnitude


Phanerazoic eon
50 K
X8.3
δ18O‰
Age (Myr BP)
Cenozoic era
10 K
X5.8
Age (Myr BP)
Quaternary Period
10 K
X3.2


Middle and Late stages Pleistocene epoch (EPICA, Antarctica)
T
5
-5
-10
present
200
400
600
800
Age (kyr BP)
10 K
"ice ages"
X8.8
δ18O
Upper stage Pleistocene epoch (GRIP Summit 75°N)
-34
-36
-38
-40
-42
-44
6 K
interglacial
(Holocene)
last glaciation
20
40
60
80
Age (kyr BP)
X91
T
1.0
0.5
Last Millenium (Northern hemisphere)
X4.8
1 K
1200
1400
1600
1800
Date
2000
Note reversal of direction!


Anthropocene epoch (global, land 1753-2013)
T (K)
3
2
1
0
-1
-2
-3
-4
5 K
Date
1750
1800
1850
1900
1950
2000
Montreal 700 mb, 2°x2° 1871-2008
T (K)
10
5
- 5
- 10
- 15
25 K
0.85K
Annual cycle removed
T (K)
5
1871
2008
- 5
- 10
10 K
0.85K

Montreal Temperatures at increasing resolution



The climate is not what you expect…

"Climate is what you expect, weather is what you get."

***-Lazarus Long*, character in R. Heinlein 1973**

"**Climate in a narrow sense is usually defined as the "average weather"** ... The classical period is 30 years, as defined by the World Meteorological Organization (WMO)… Climate in a wider sense is the state, including a statistical description, of the climate system."

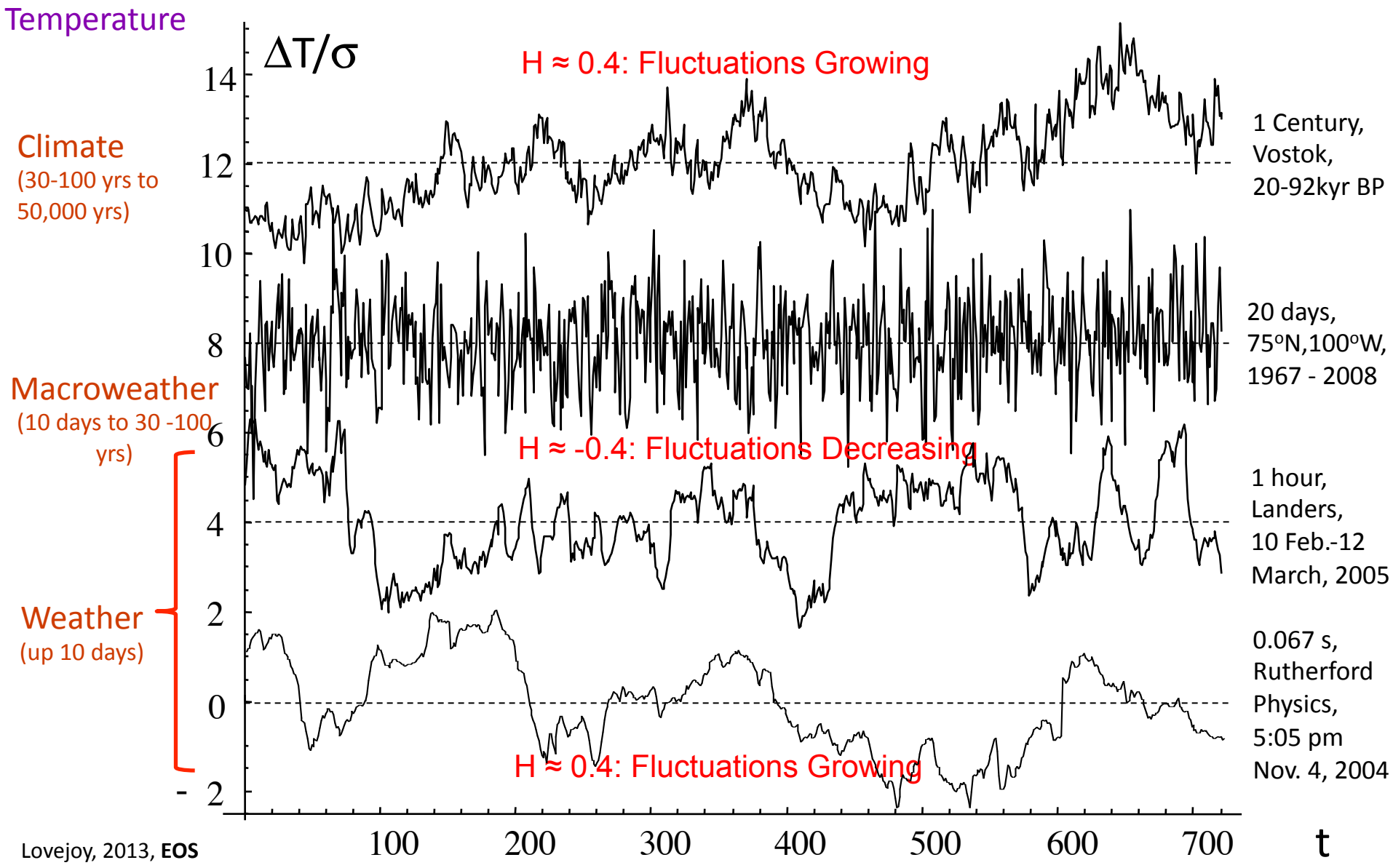
-Intergovernmental Panel on Climate Change, 2007

Trichotomy:
Weather – macroweather - climate

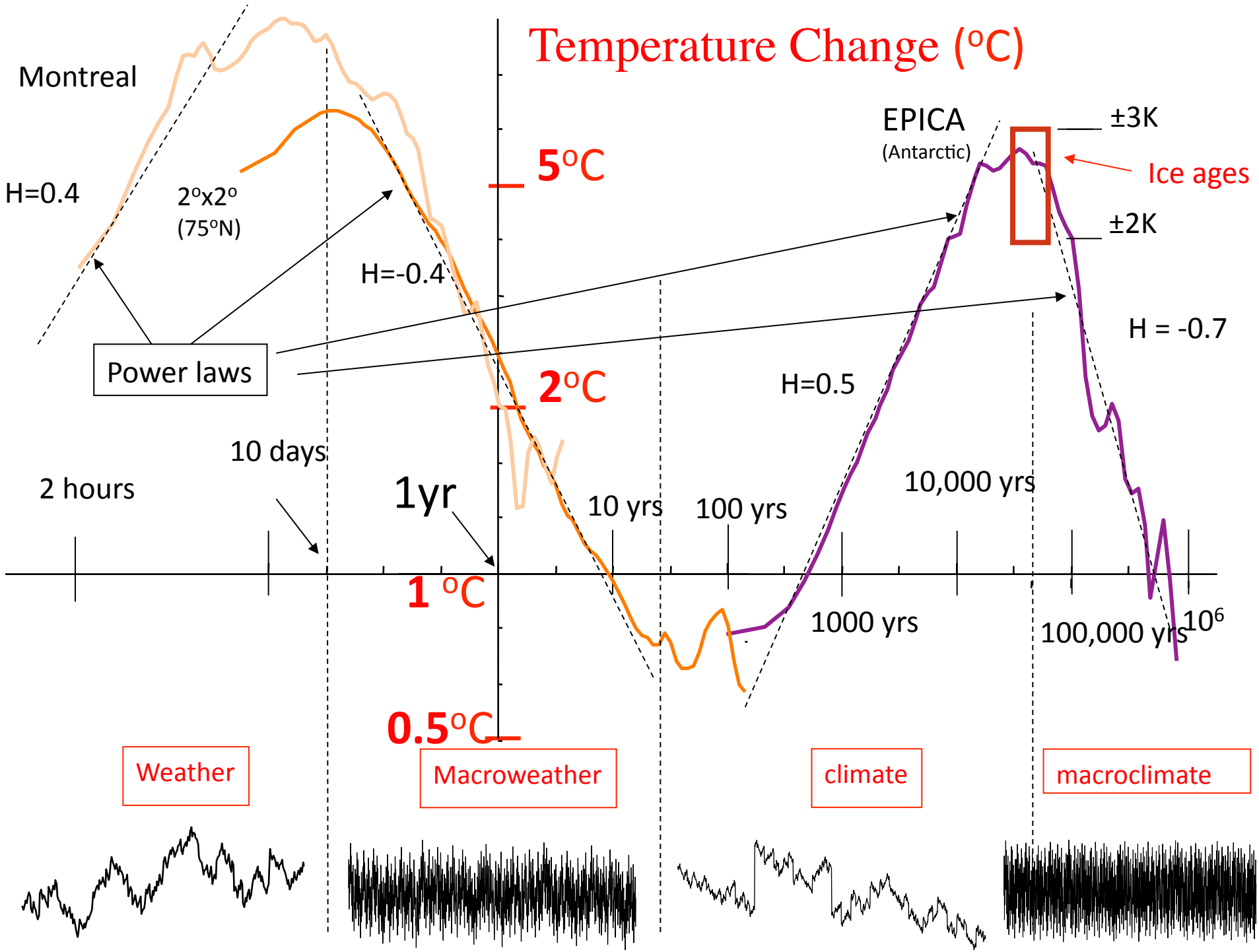
$$\langle \Delta I \rangle = \langle \varphi \rangle \Delta t^{H}$$

Fluctuation

= constant



Lovejoy, 2013, **EOS**


Temperature Change (°C)
Montreal
H=0.4
2°x2°
(75°N)
H=-0.4
Power laws
5°C
2°C
1 °C
0.5°C
EPICA
(Antarctic)
±3K
Ice ages
±2K
H = -0.7
H=0.5
10 days
2 hours
1yr
10 yrs
100 yrs
10,000 yrs
1000 yrs
100,000 yrs
10^6
Weather
Macroweather
climate
macroclimate

Conclusion:

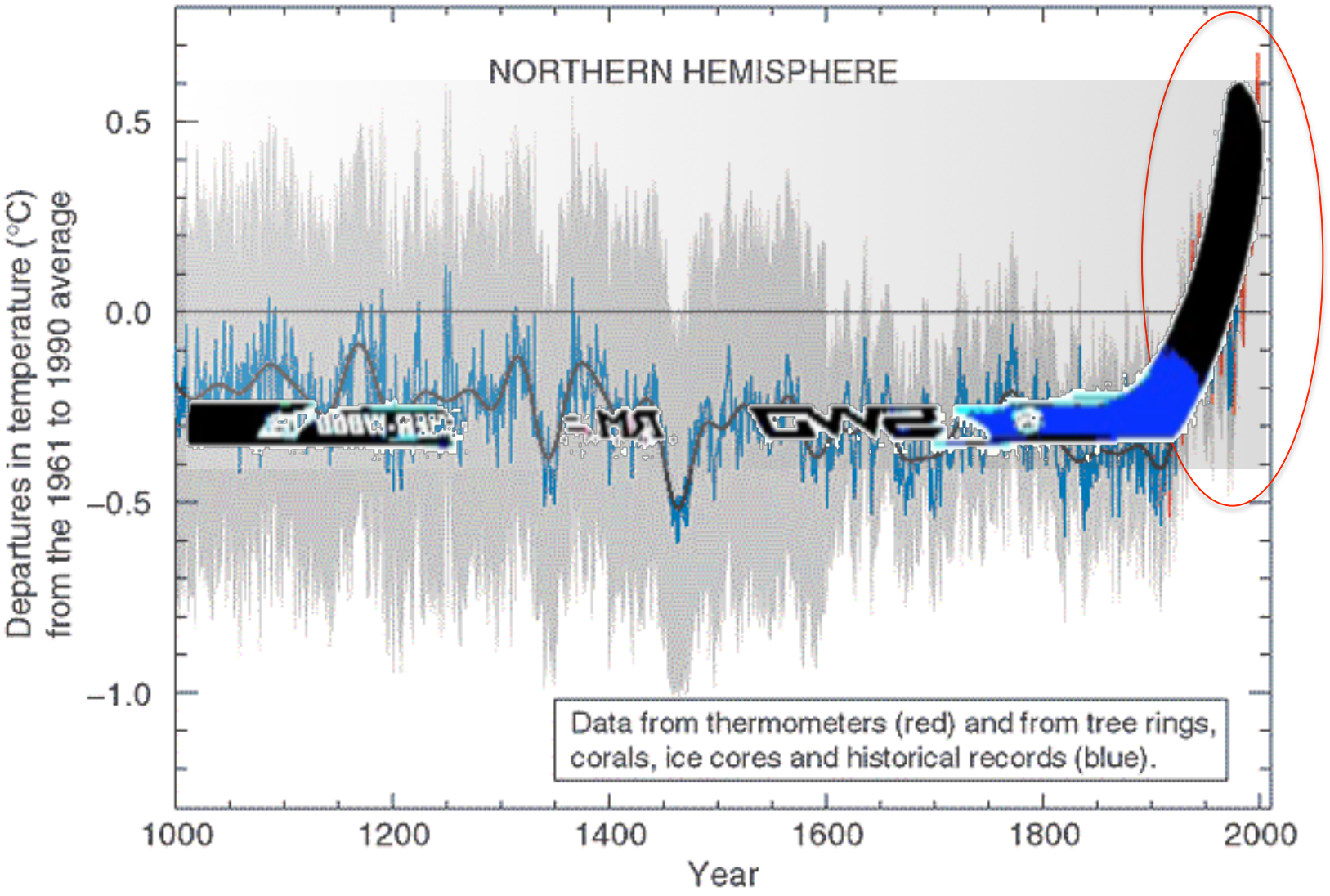
"Macroweather is what you expect
The climate is what you get!"

Weather, macroweather and the climate are distinguished by the way the change under a zoom!

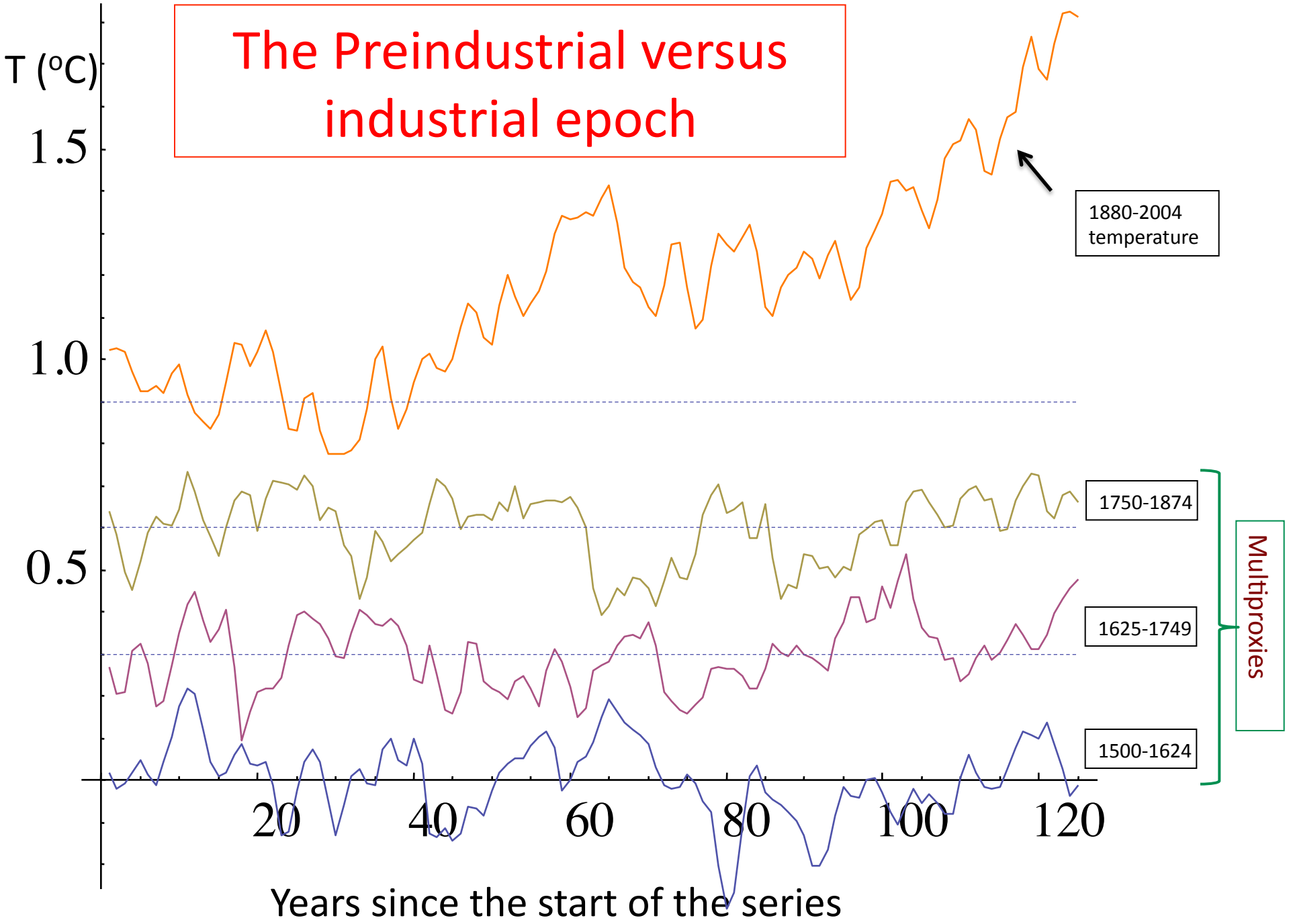
Evidence for warming

The “hockey stick”

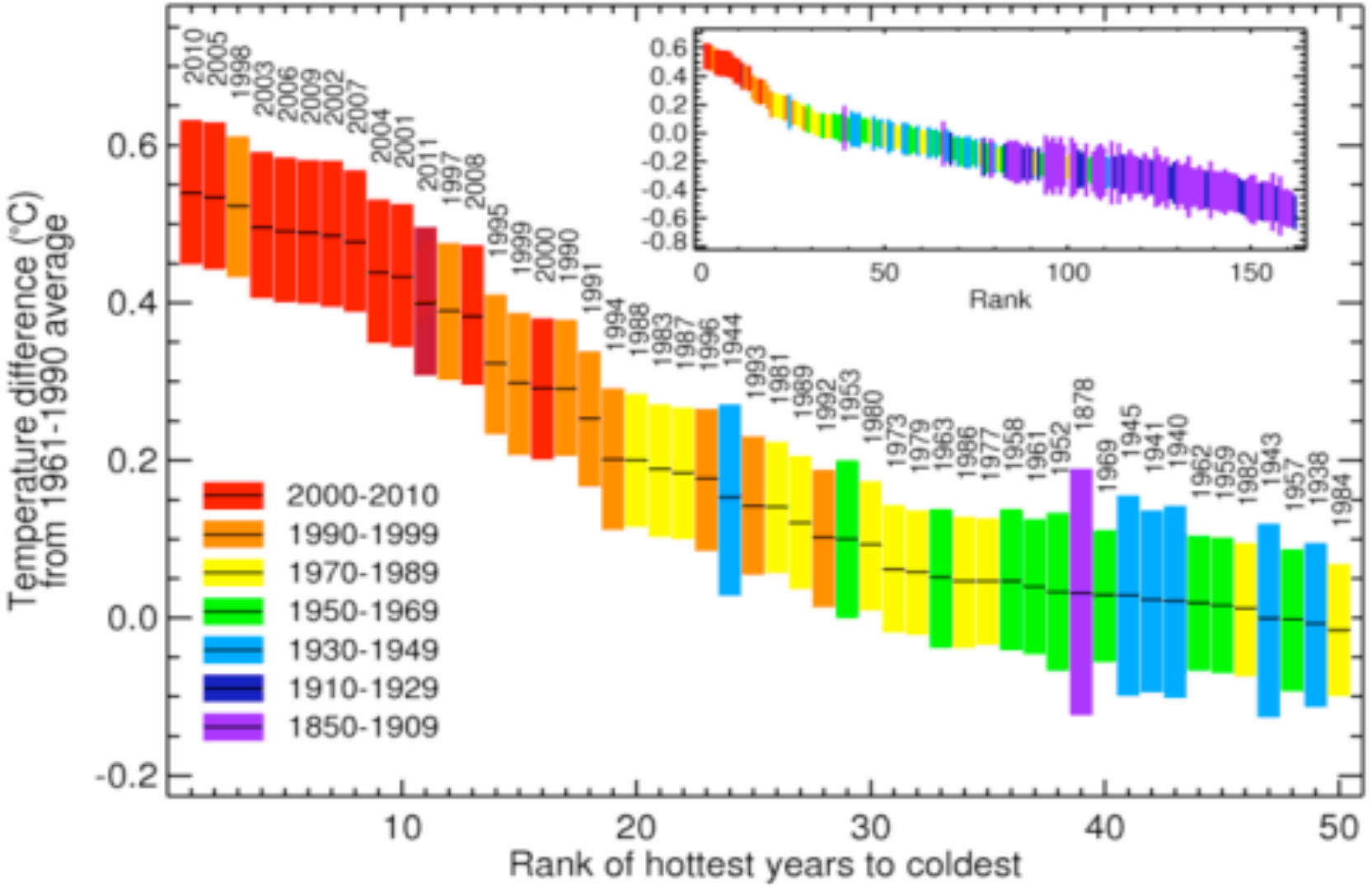
Mann, Bradley, Hughes 1998



Industrial epoch warming

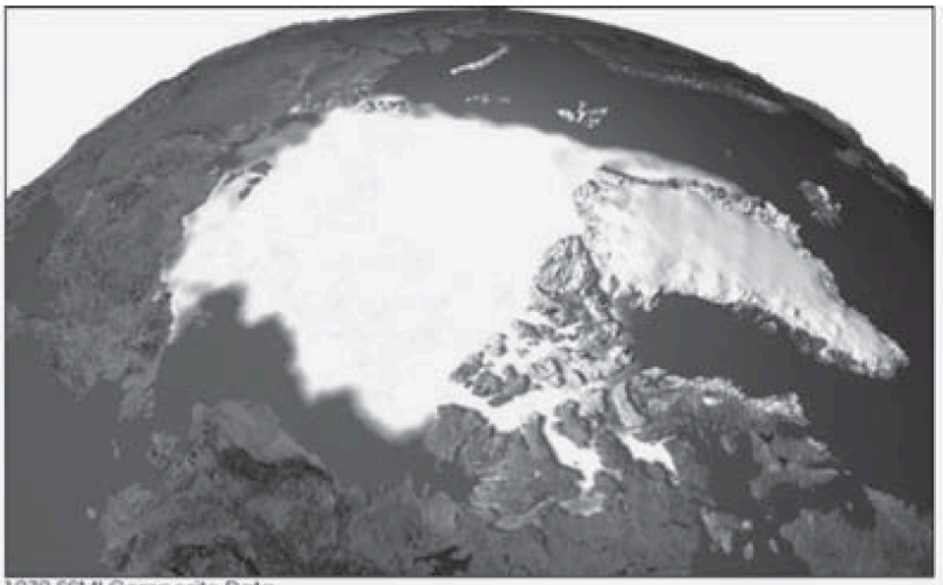

The Preindustrial versus industrial epoch
T (°C)
1.5
1.0
0.5
1880-2004 temperature
1750-1874
1625-1749
1500-1624
Multiproxies
20
40
60
80
100
120
Years since the start of the series

Ranking of temperatures from hottest to coldest



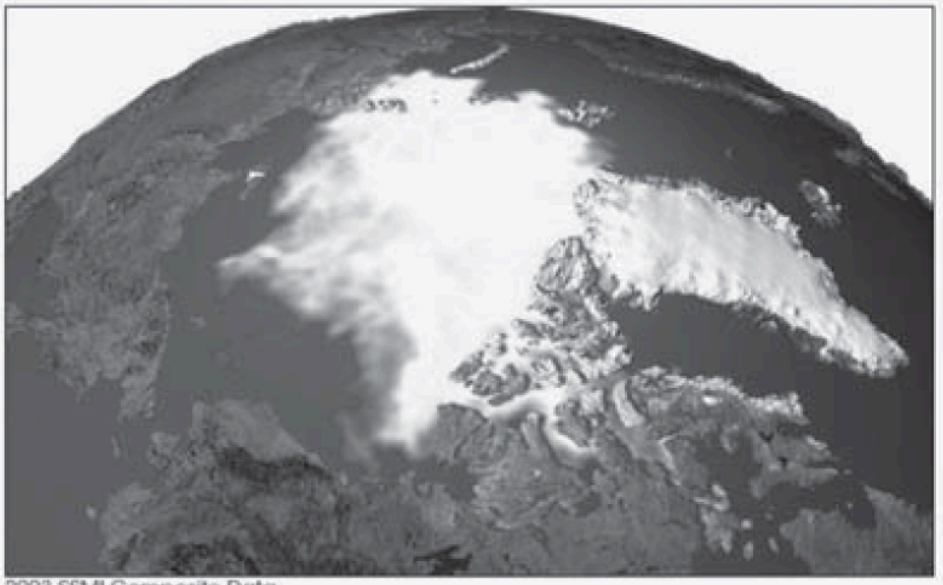
The Arctic

(melting of sea ice)



1979 SSMI Composite Data

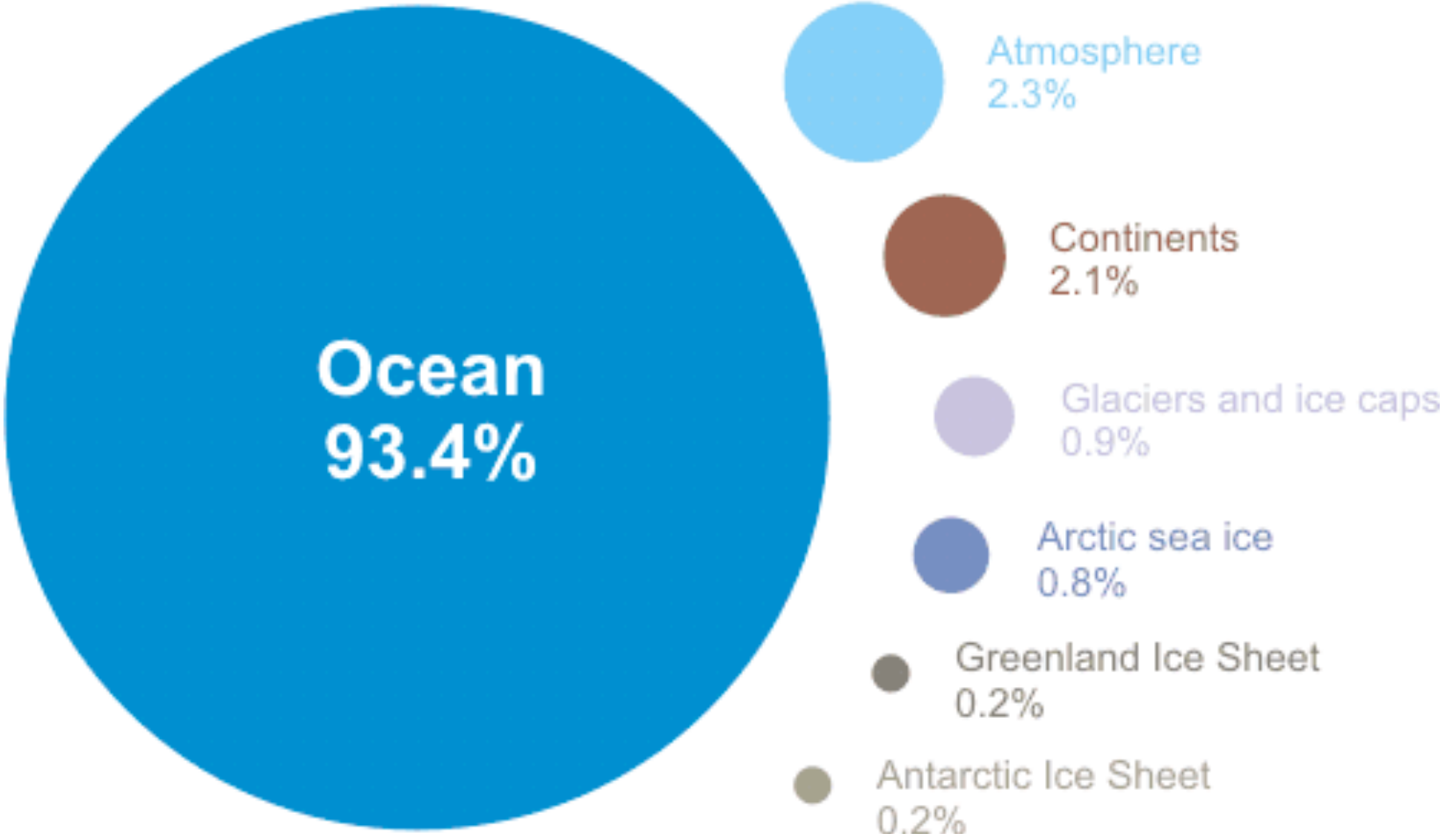
1979



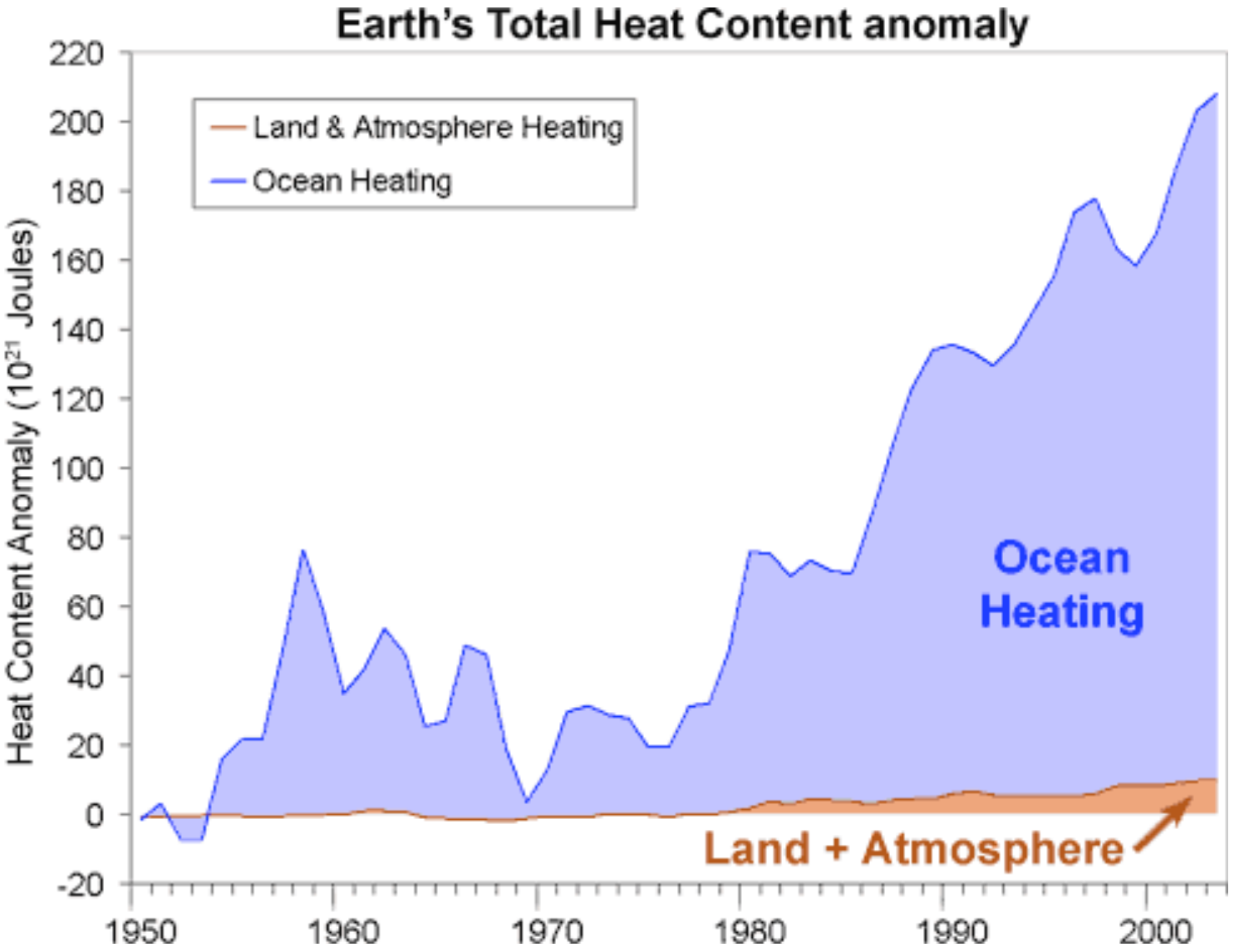
2003 SSMI Composite Data

2005

Where is global warming going?



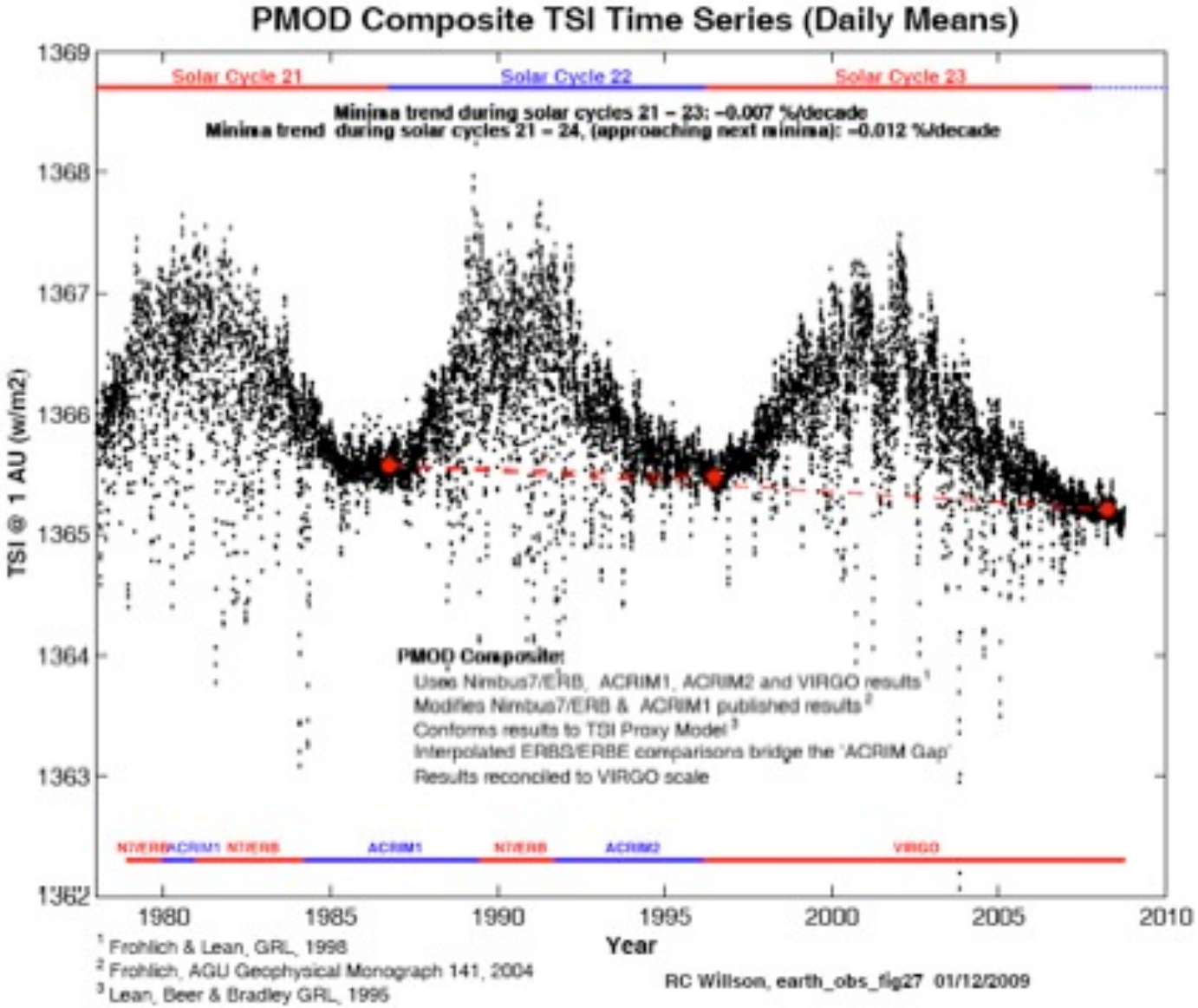
Where is the warming going?



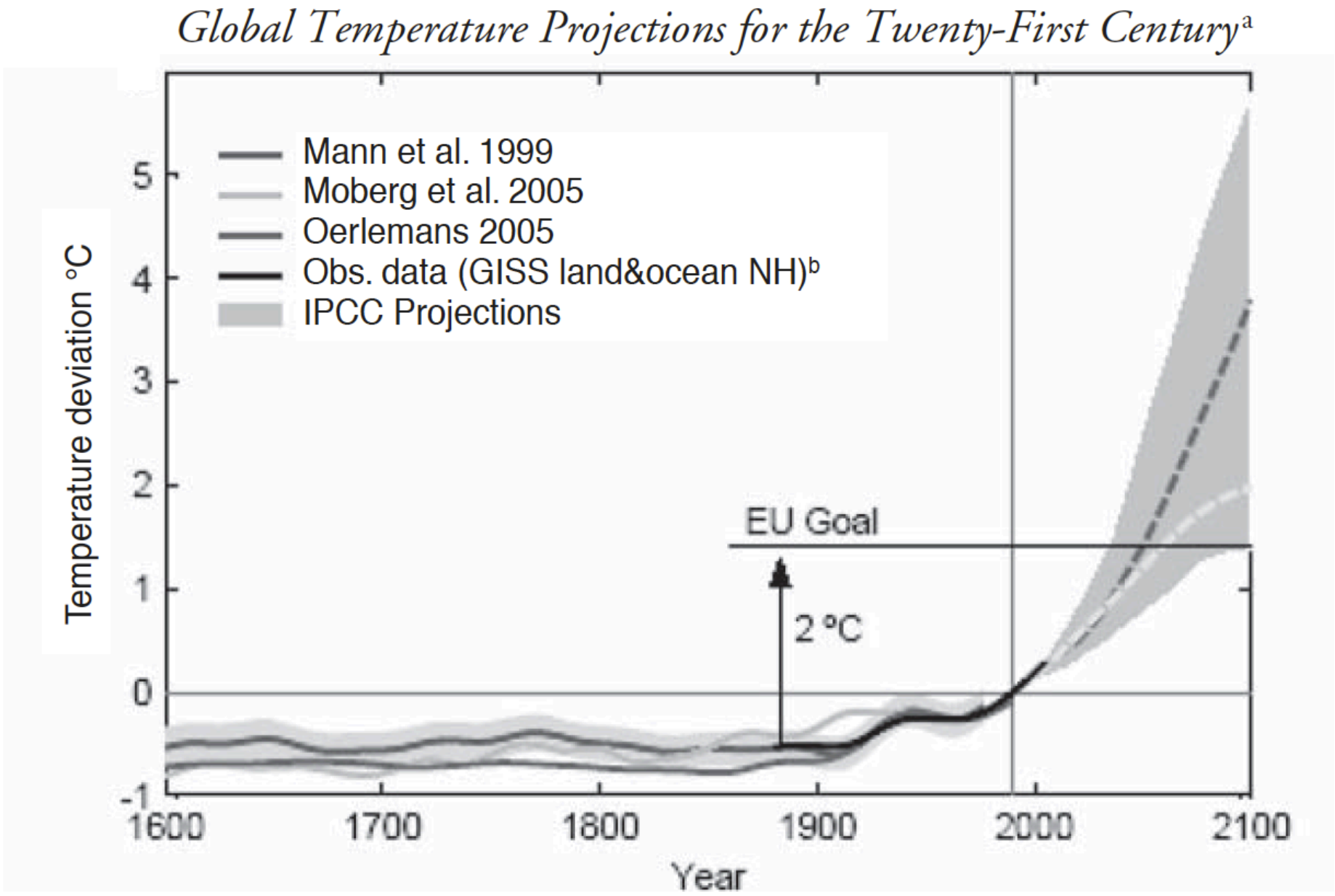
It's not the sun:

Total Solar Insolation

(satellite)

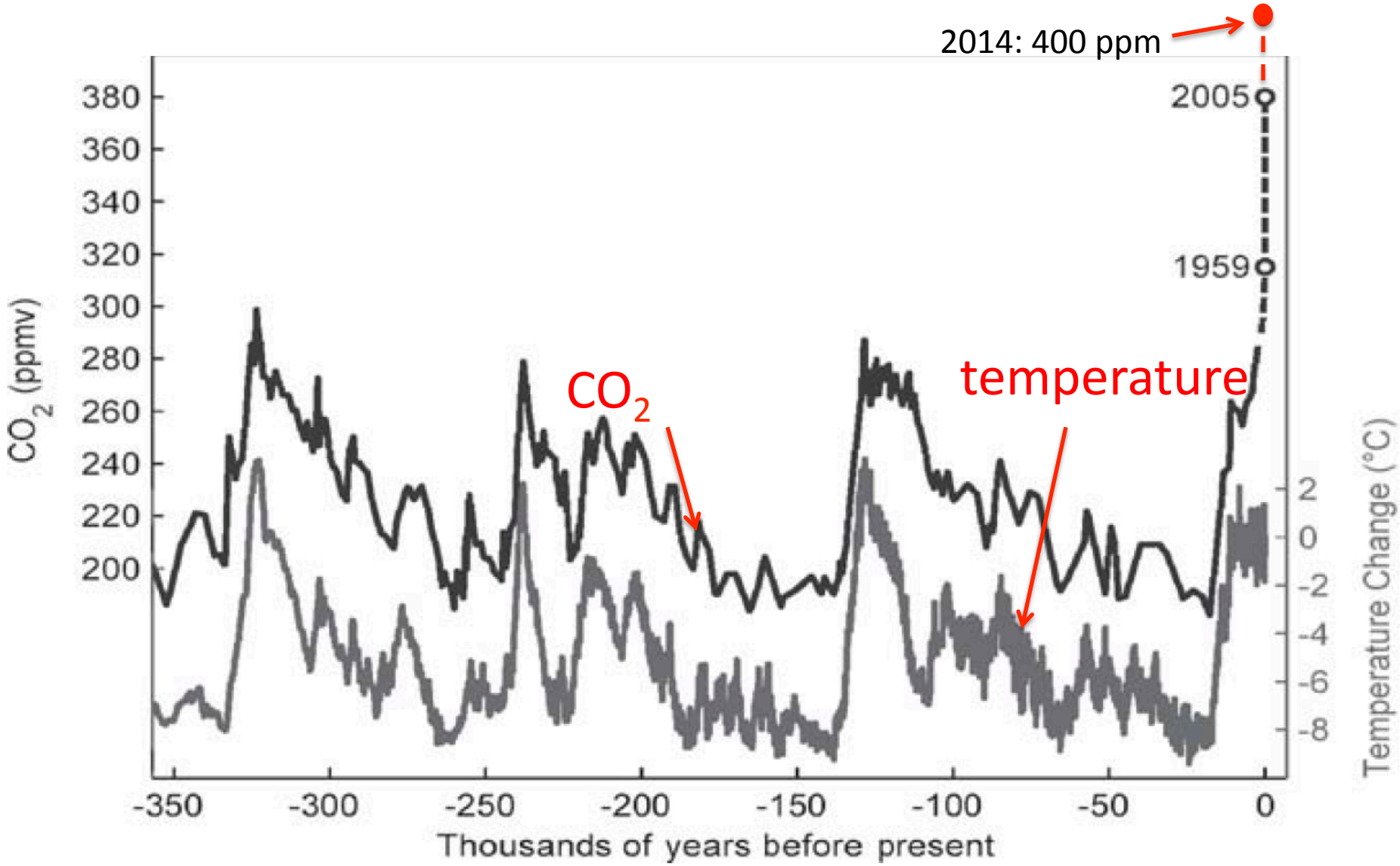


21st century



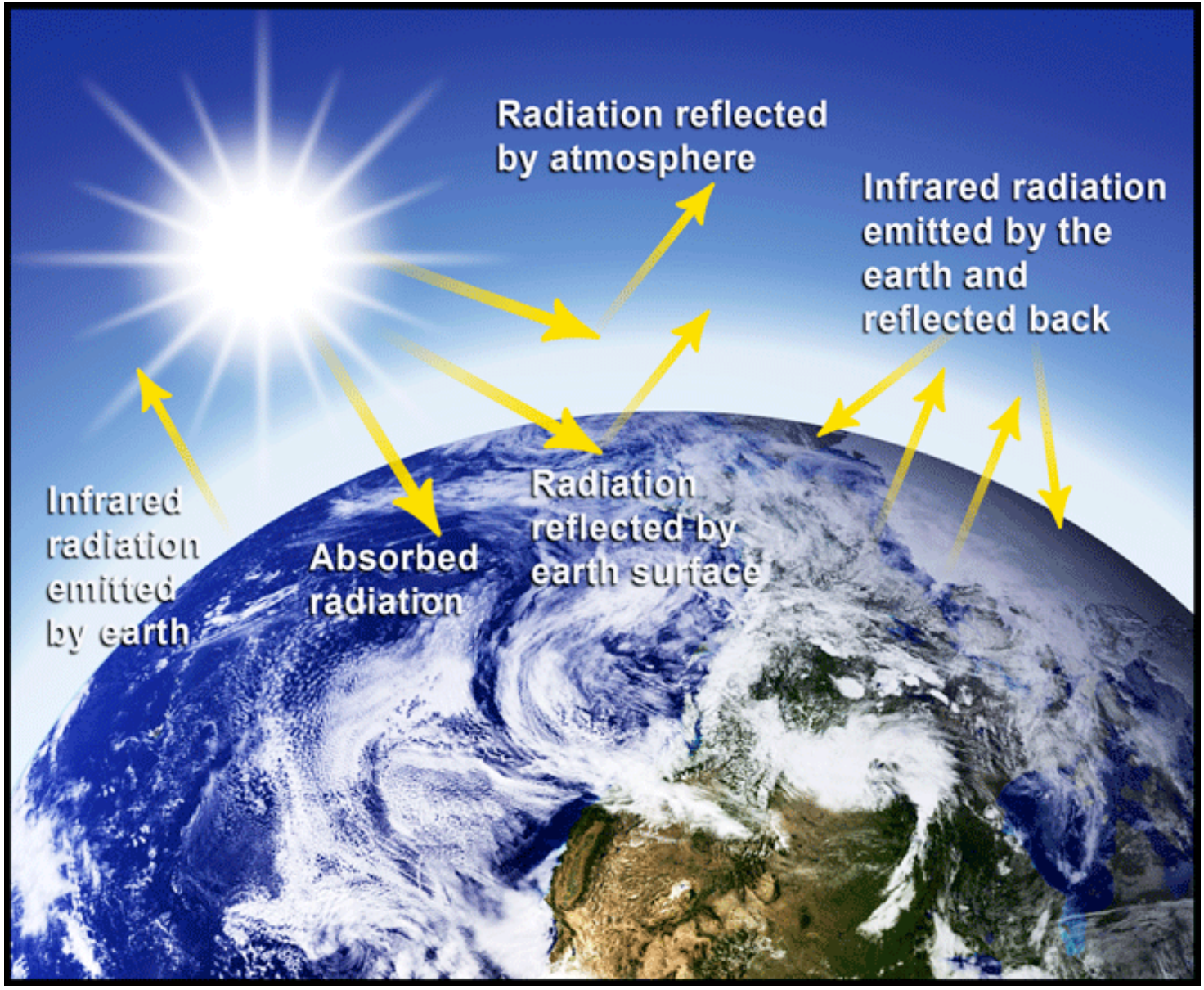
Why is it warming?

CO_2: The last 350,000 yrs



Source: J. R. Petit and others, "Climate and Atmospheric History of the Past 420,000 Years from the Vostok Ice Core, Antarctica," *Nature* 399 (June 1999): 429–36.

The theory of anthropogenic warming: the “Greenhouse effect”



History of the theory of anthropogenic warming (1)

1896

Nobel prize winner Svante Arrhenius: CO_2 doubling: 5 – 6°C of warming, "climate sensitivity" (c.f. IPCC 2013: 1.5 - 4.5° C).

Svante Arrhenius
(1859 –1927)

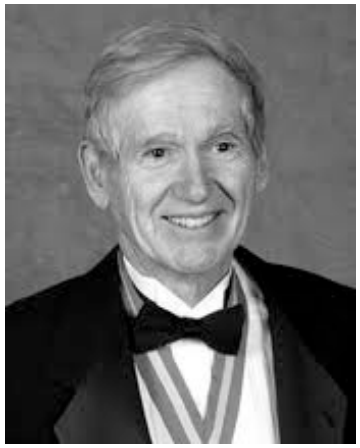
1938

Callender estimated the warming as 2° C

Guy Stewart Callendar
1898 - 1964

1957

Keeling started his celebrated CO_2 measurements at Mauna Loa and at the south Pole



Charles David Keeling
1928 –2005

1960

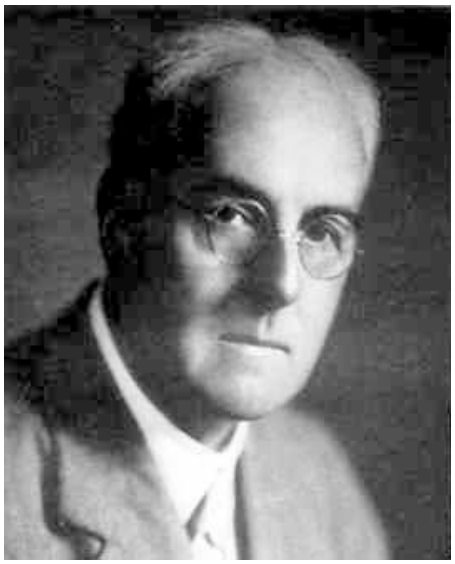
Skepticism:

a) The idea that a single factor was responsible was "simplistic".

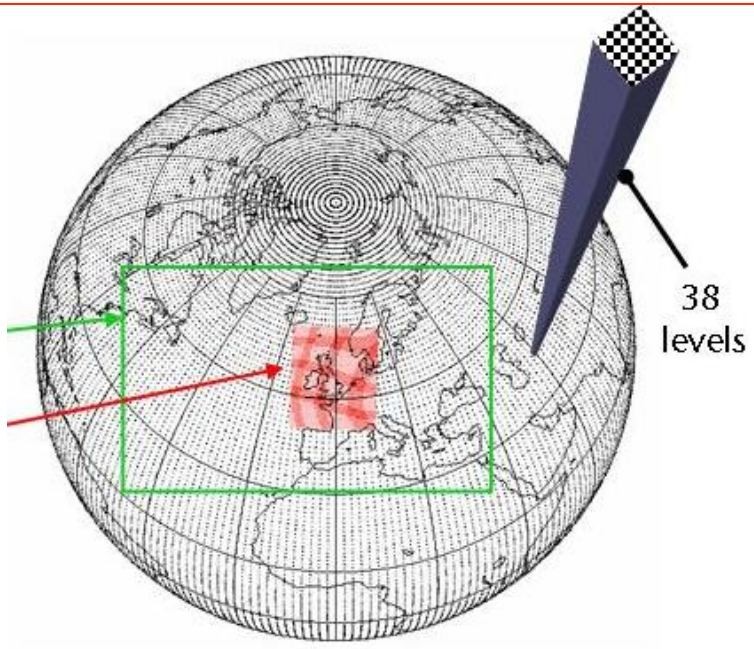
b) The idea that human action could have such vast consequences was repugnant.

c) In error, the meteorological authorities opposed the theory.

History (2): Global Climate Models (GCM)



Richardson:
1881-1953
Father of numerical models of the atmosphere: 10^{-2} Flops (?)



MilkyWay-2: World's fastest supercomputer (June 2013)

National University of Defense Technology, Changsha, China

3,120,000 cores: 3×10^{16} Flops

GCM's: for CO_2 doubling

IPPC3 (2002): 1.5- 4.5°C
IPPC4 (2007): 2- 4.5°C
IPPC5 (2013) : 1.5- 4.5°C
(*"high confidence"*)

History (3)

1975

The first numerical climate models: GCM's ("Global Circulation Model")

Why the models?

Without feedbacks, doubling CO_2 would increase heating by 3.7 W/m^2 which would give rise to a warming of 1°C. The debate is about the feedbacks: radiation, clouds, humidity.

1979

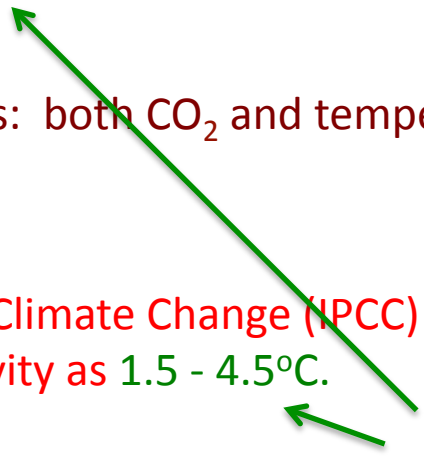
The US Academy of Sciences: CO_2 doubling would increase global mean temperatures by 1.5 - 4.5°C.

1990

Vostok (Antarctica) ice cores: both CO_2 and temperatures, sensitivity = 3–4°C for CO_2 doubling.

2013

The International Panel on Climate Change (IPCC) 5th Assessment Report (AR5, 2013) estimates the sensitivity as 1.5 - 4.5°C.



Diminishing returns… same as 1979!

Skeptics and Deniers

Some legitimate Grounds for climate skepticism

- 1. The models are unreliable they have not been tested, they aren't valid.

  They have been tested but are only valid to a point: no model is perfect, predictions of warming doesn't depend on the models

- 2. The historical observations of warming are not reliable.
- 3. Other data contradict the warming.

(legitimate until at latest 2005)

- 4. Even if the Earth is warming it is due to natural causes.
- 5. The "pause": earth has stopped warming since 1998 hence the warming can't be anthropogenic.

Disproved in 2014… see the following!

Illegitimate Climate skepticism The deniers (1)

A few examples:

In 1998, the Marshall Institute for Science and Environmental Policy and ExxonMobil launched a $20 million campaign to:

-Find reputable scientists to spread doubt about anthropogenic warming.

-Fund an advertising campaign proting the idea that the warming is neither real nor worrying.

-To lobby the US congress.

In 2007, the American Enterprise Institute: $10,000 plus expenses to scientists willing to denigrate the IPCC 4th Assessment Report.

In 2012, the Heartland Institute:

- Funded denier literature:
  - paid several persons to spread climate denier views on the internet
  - paid scientists to write reports to decision makers or the public promoting skeptical views.

- Funded a campaign to encourage schools to teach climate denier material.

In 2014, in the US:

Tthere are currently *91* different organizations with combined funding of over $900 million (think tanks, advocacy groups, and trade associations) that collectively comprise a "climate change counter-movement. [*Brulle*, 2014],

Illegitimate skepticism: The deniers (2)

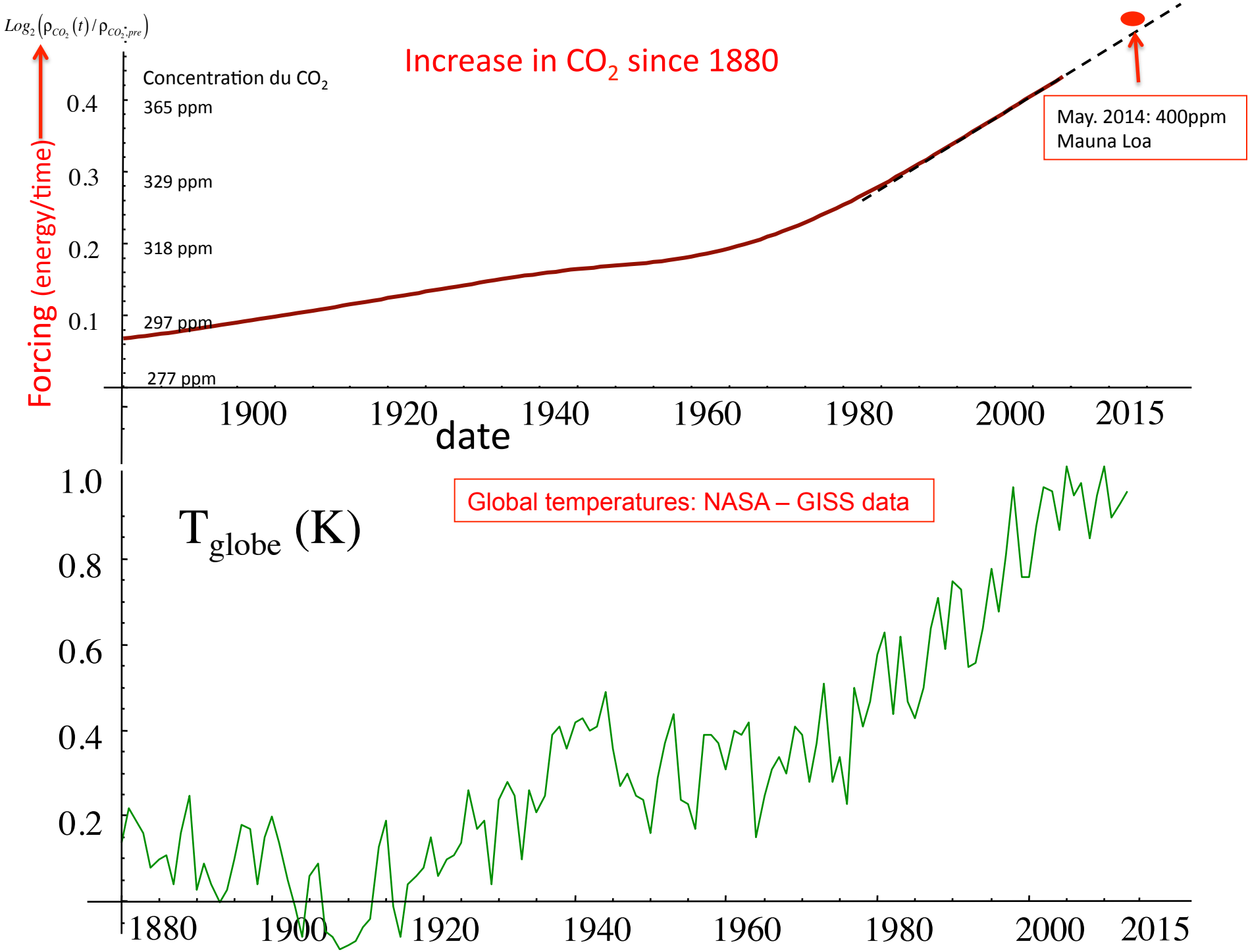
Tactics shared with the industry, creationists and holocaust deniers

-Quotation mining: citing short quotes from reputable scientists out of context.
-Juxtaposing cites from different sources to amplify minor disagreements between scientists in order to ridicule them.
-Drawing attention to minor scientific errors in order to bring into question the entire scientific enterprise.

Other indices of illegitimate criticism:

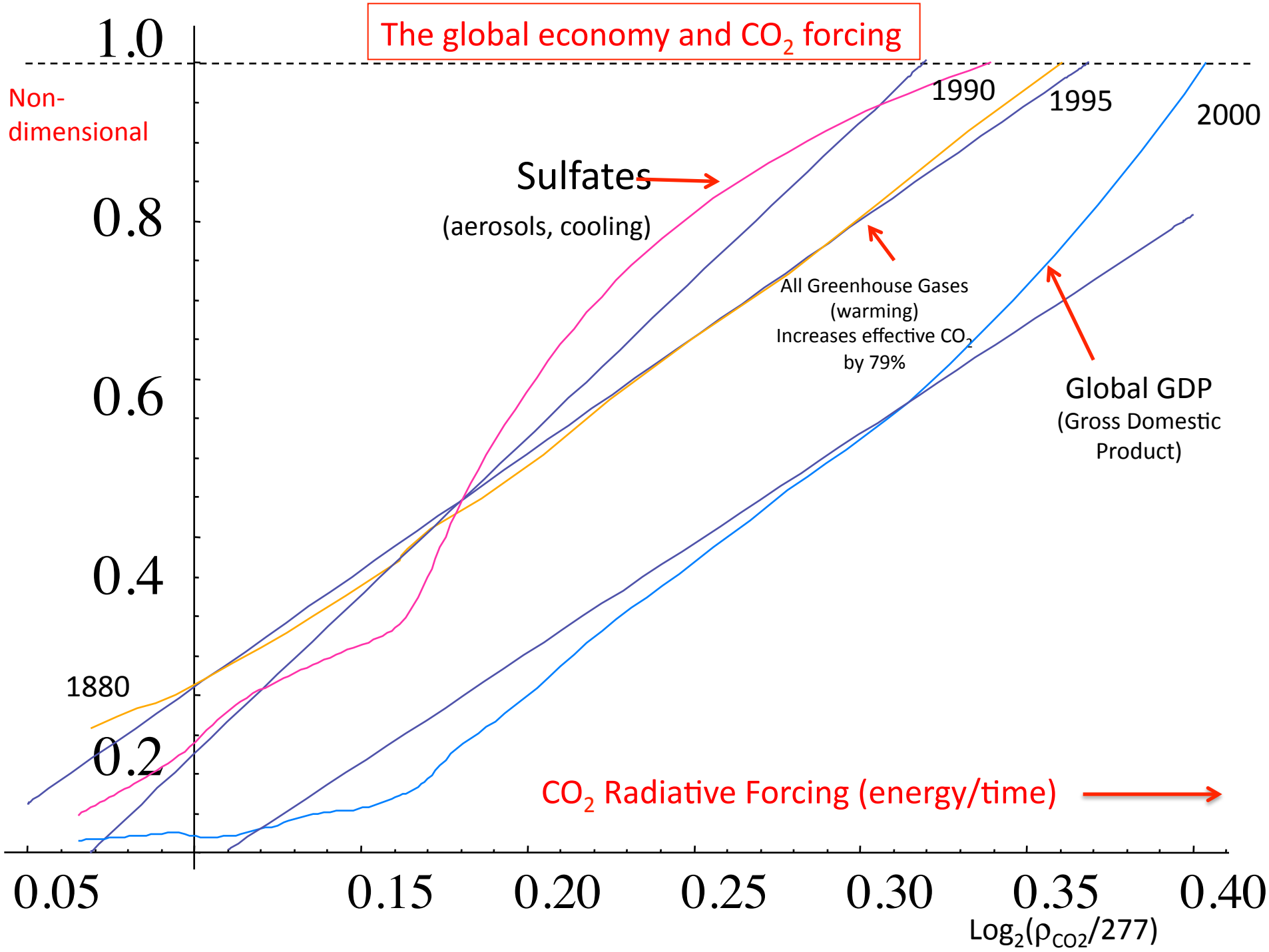
-The members of creationist and climate skeptic groups have a lot of overlap.
-Their antiscientific views are covered in the same media in the US:
Fox News, Glenn Beck, Rush Limbaugh. Creationism and Climate denial are increasingly the same people, organizations, outlets.

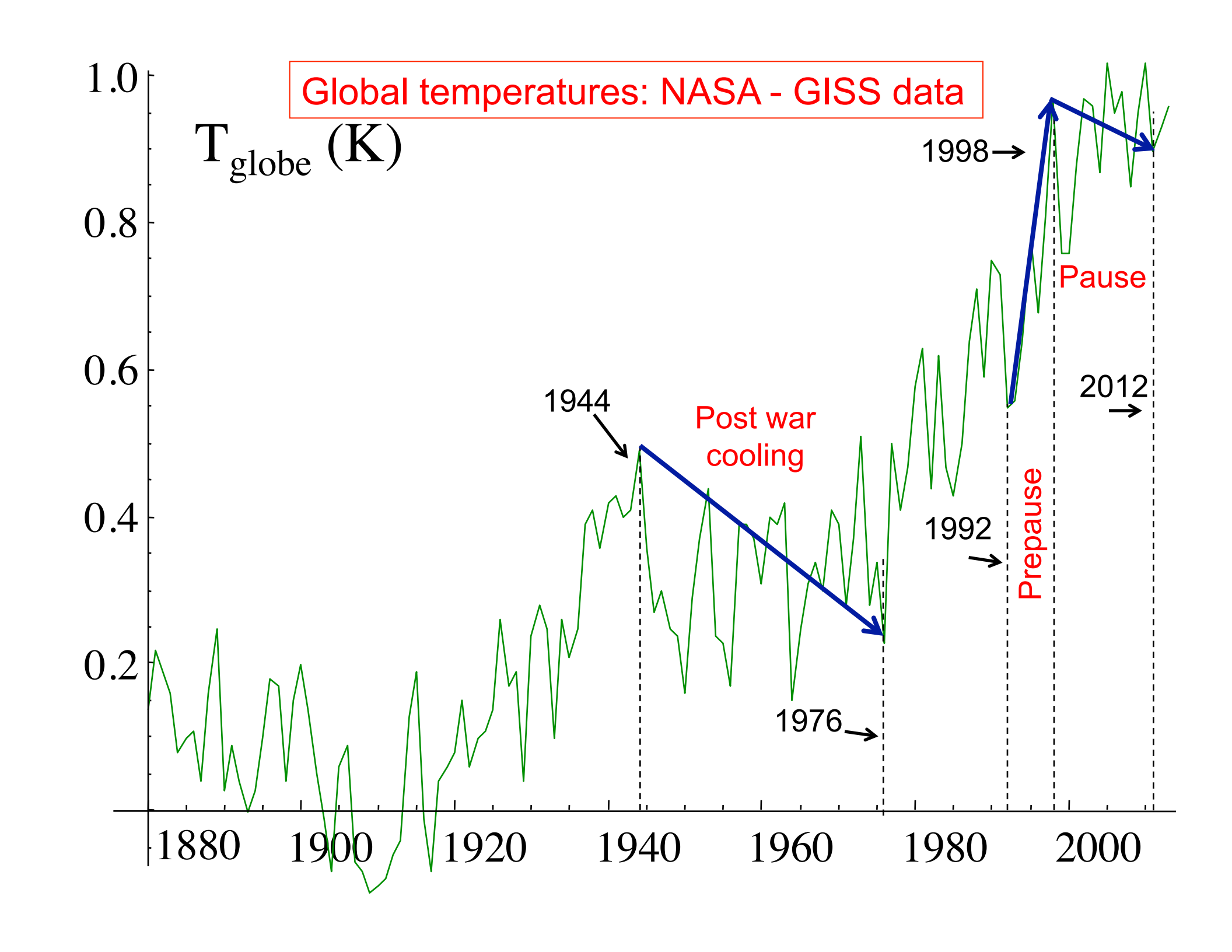
Disproving Natural warming without GCM's

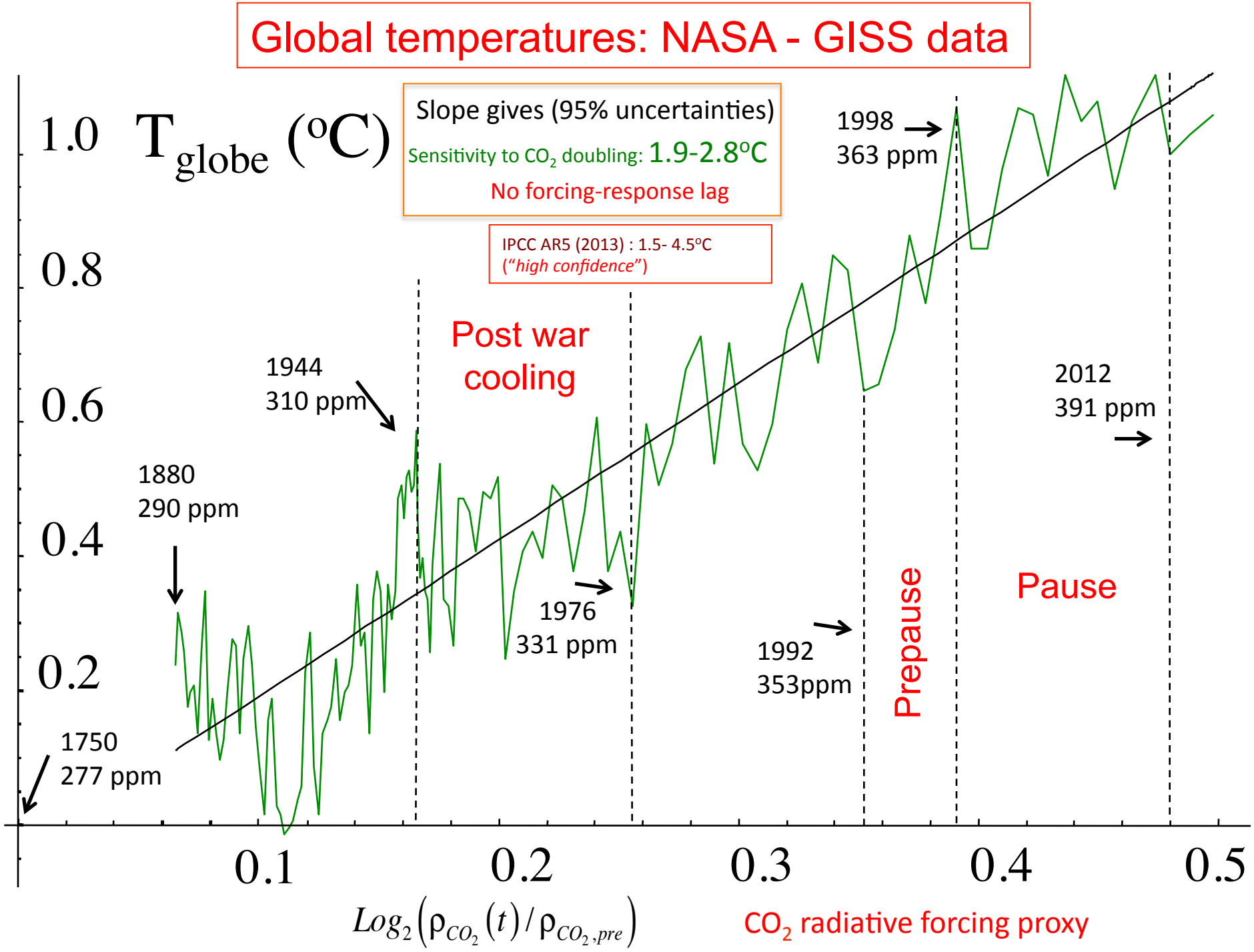

$Log_2\left(\rho_{CO_2}(t)/\rho_{CO_2;pre}\right)$
Forcing (energy/time)
Concentration du CO_2
365 ppm
329 ppm
318 ppm
297 ppm
277 ppm
0.4
0.3
0.2
0.1
1900
1920
1940
1960
1980
2000
2015
date
Increase in CO_2 since 1880
May. 2014: 400ppm
Mauna Loa
T_{globe} (K)
Global temperatures: NASA – GISS data
1.0
0.8
0.6
0.4
0.2
1880
1900
1920
1940
1960
1980
2000
2015

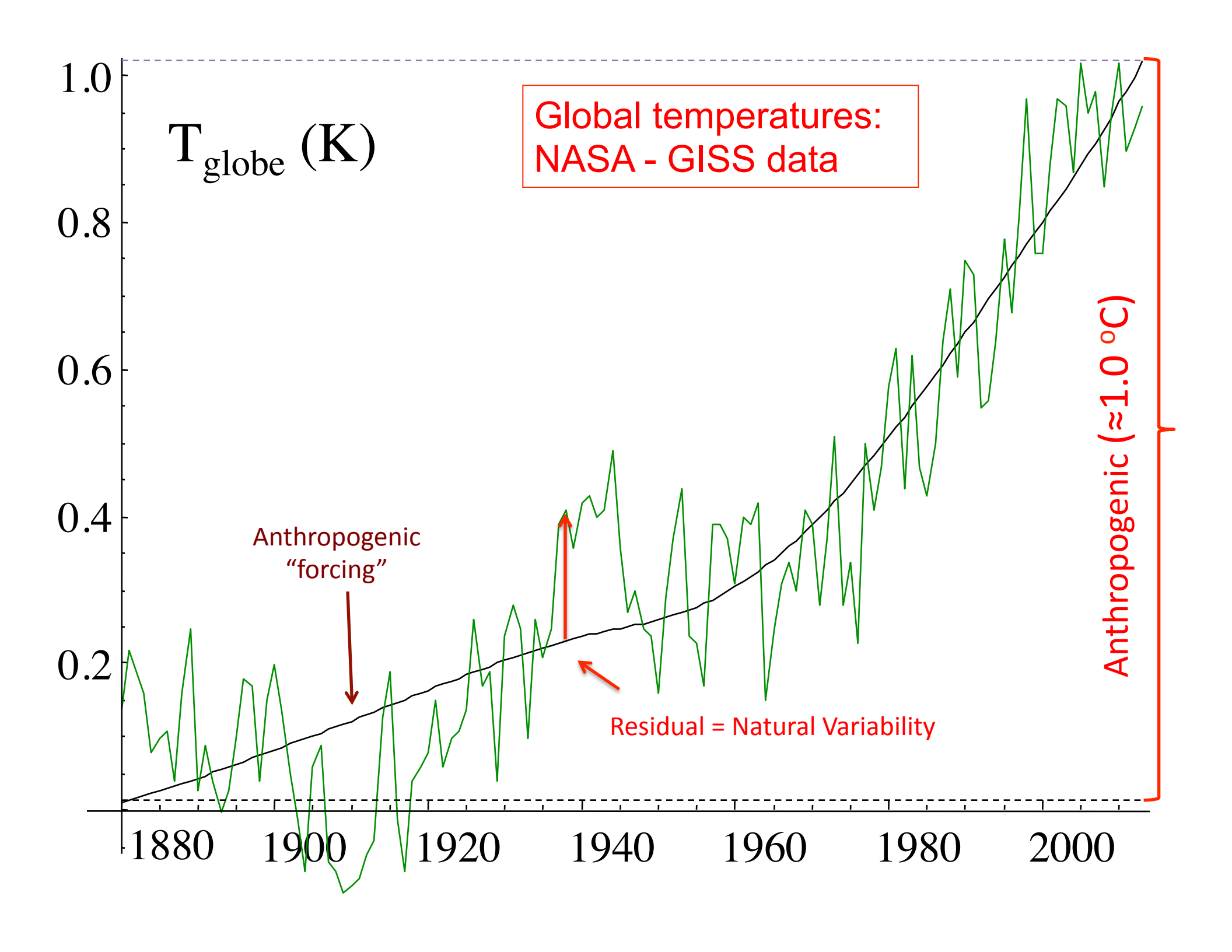
CO_2 forcing as surrogate for all anthropogenic effects

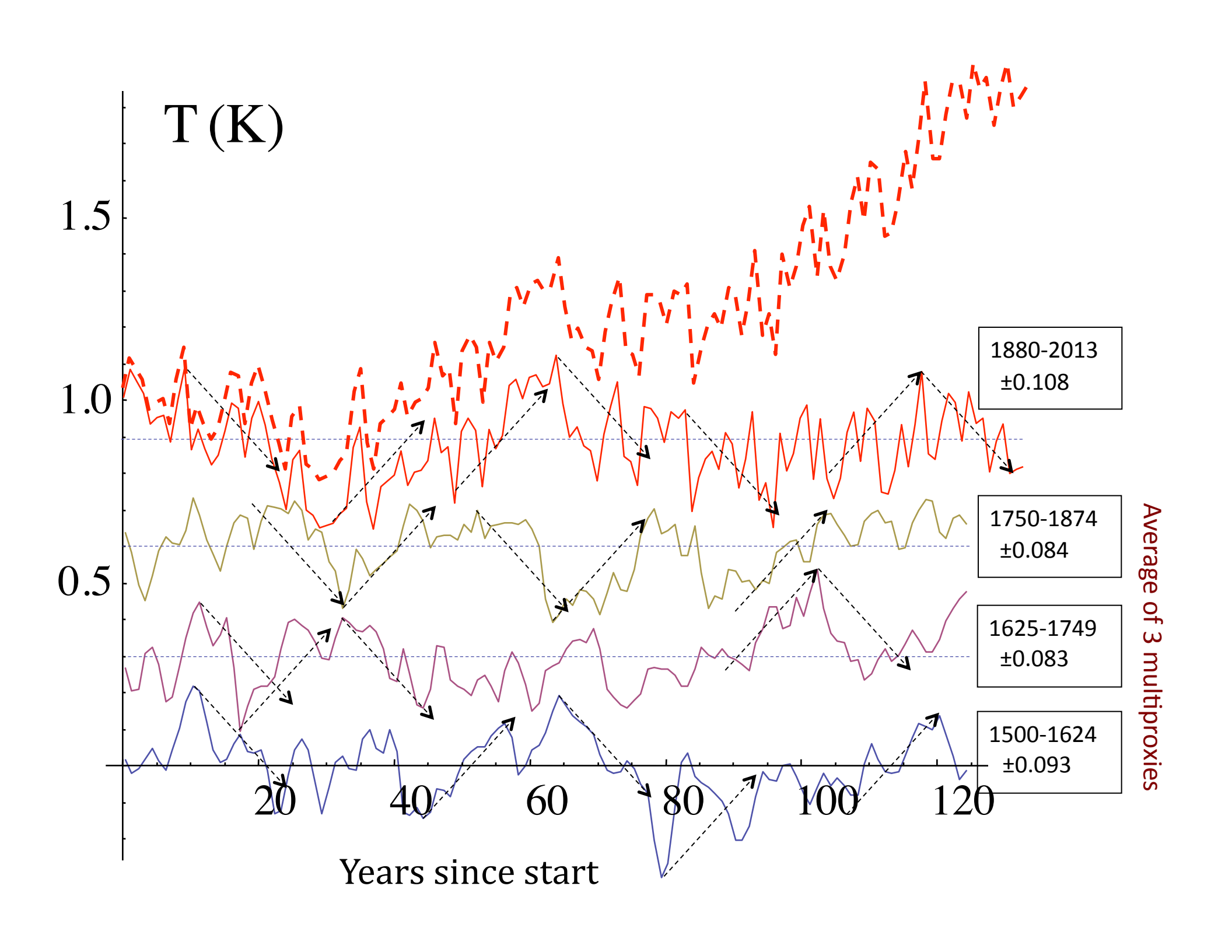
Roughly: you double the global economy, you double the emissions, land use and other changes, you double the effects

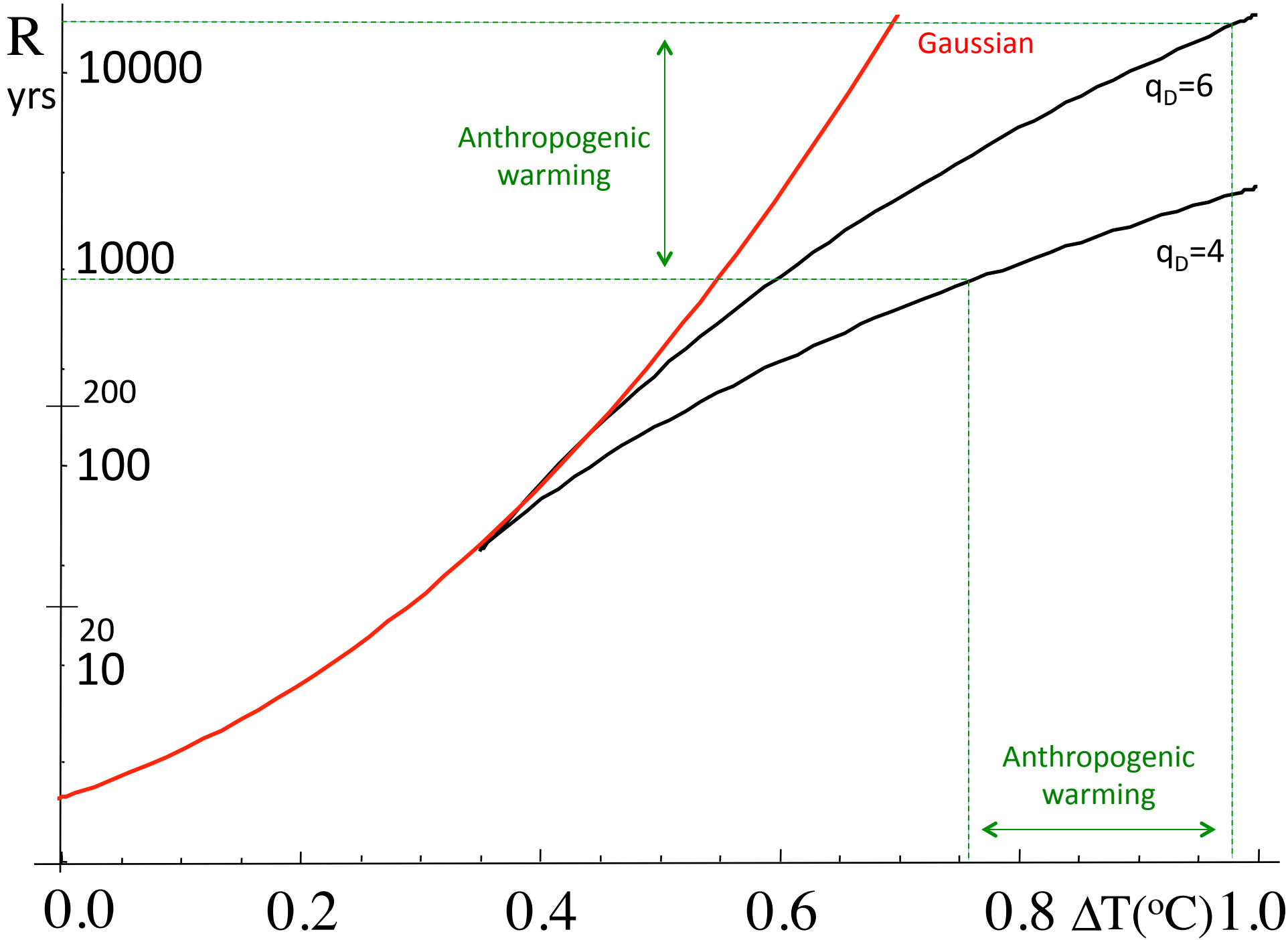

The global economy and CO_2 forcing
1.0
Non-dimensional
0.8
0.6
0.4
0.2
1880
1990
1995
2000
Sulfates
(aerosols, cooling)
All Greenhouse Gases
(warming)
Increases effective CO_2
by 79%
Global GDP
(Gross Domestic Product)
CO_2 Radiative Forcing (energy/time)
0.05
0.15
0.20
0.25
0.30
0.35
0.40
$Log_2(\rho_{CO2}/277)$


Global temperatures: NASA - GISS data
T_{globe} (K)
1.0
0.8
0.6
0.4
0.2
1880
1900
1920
1940
1960
1980
2000
1944
Post war
cooling
1976
1998
Pause
2012
1992
Prepause


Global temperatures: NASA - GISS data
T_{globe} (°C)
Slope gives (95% uncertainties)
Sensitivity to CO_2 doubling: 1.9-2.8°C
No forcing-response lag
IPCC AR5 (2013) : 1.5- 4.5°C
("high confidence")
1998
363 ppm
2012
391 ppm
1944
310 ppm
1880
290 ppm
1976
331 ppm
1992
353ppm
1750
277 ppm
Post war cooling
Prepause
Pause
1.0
0.8
0.6
0.4
0.2
0.1
0.2
0.3
0.4
0.5
$Log_2\left(\rho_{CO_2}(t)/\rho_{CO_2,pre}\right)$
CO_2 radiative forcing proxy

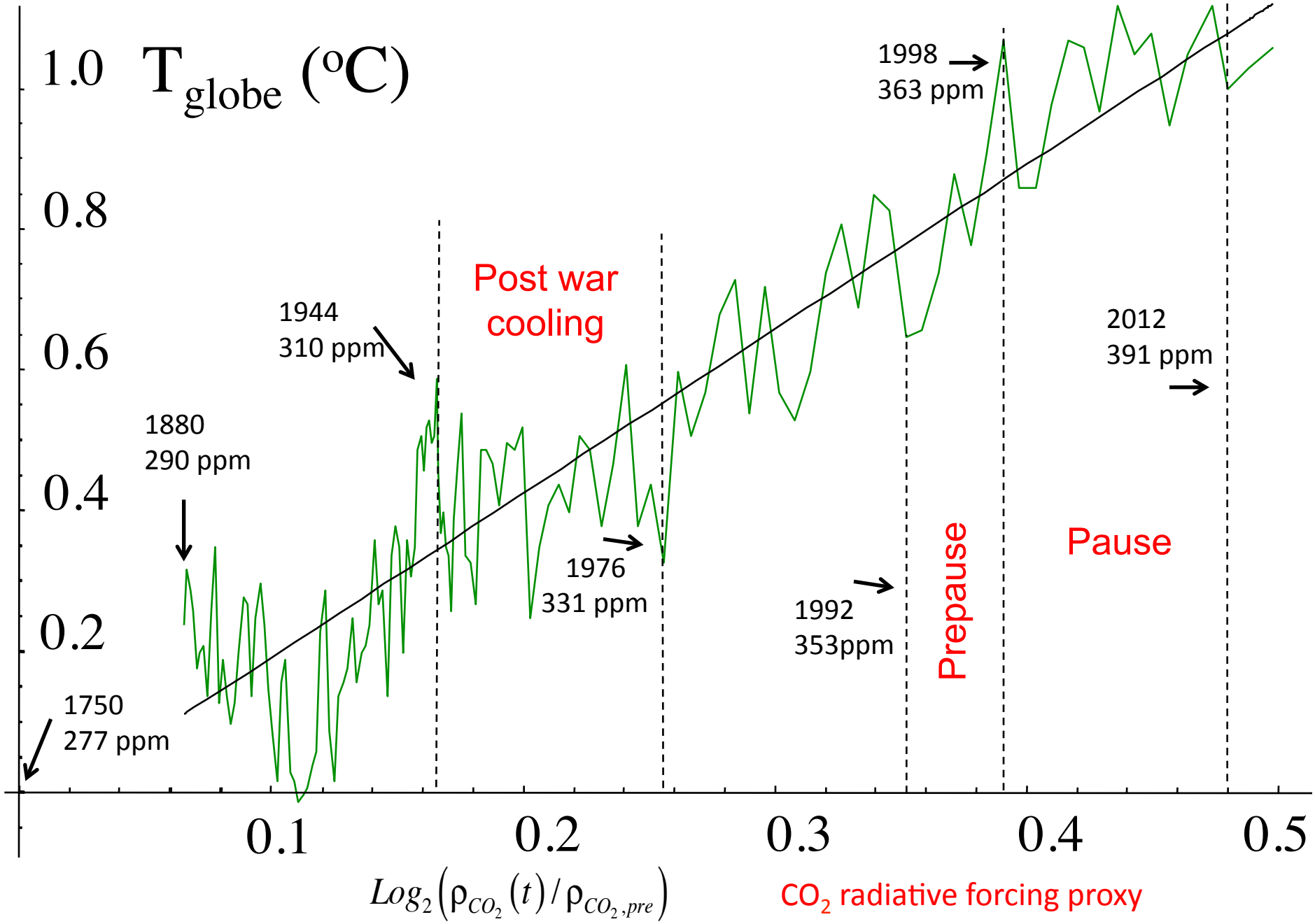

1.0
0.8
0.6
0.4
0.2
T_{globe} (K)
Global temperatures:
NASA - GISS data
Anthropogenic
"forcing"
Residual = Natural Variability
Anthropogenic (≈1.0 °C)
1880
1900
1920
1940
1960
1980
2000


T (K)
1.5
1.0
0.5
20
40
60
80
100
120
Years since start
1880-2013
±0.108
1750-1874
±0.084
1625-1749
±0.083
1500-1624
±0.093
Average of 3 multiproxies

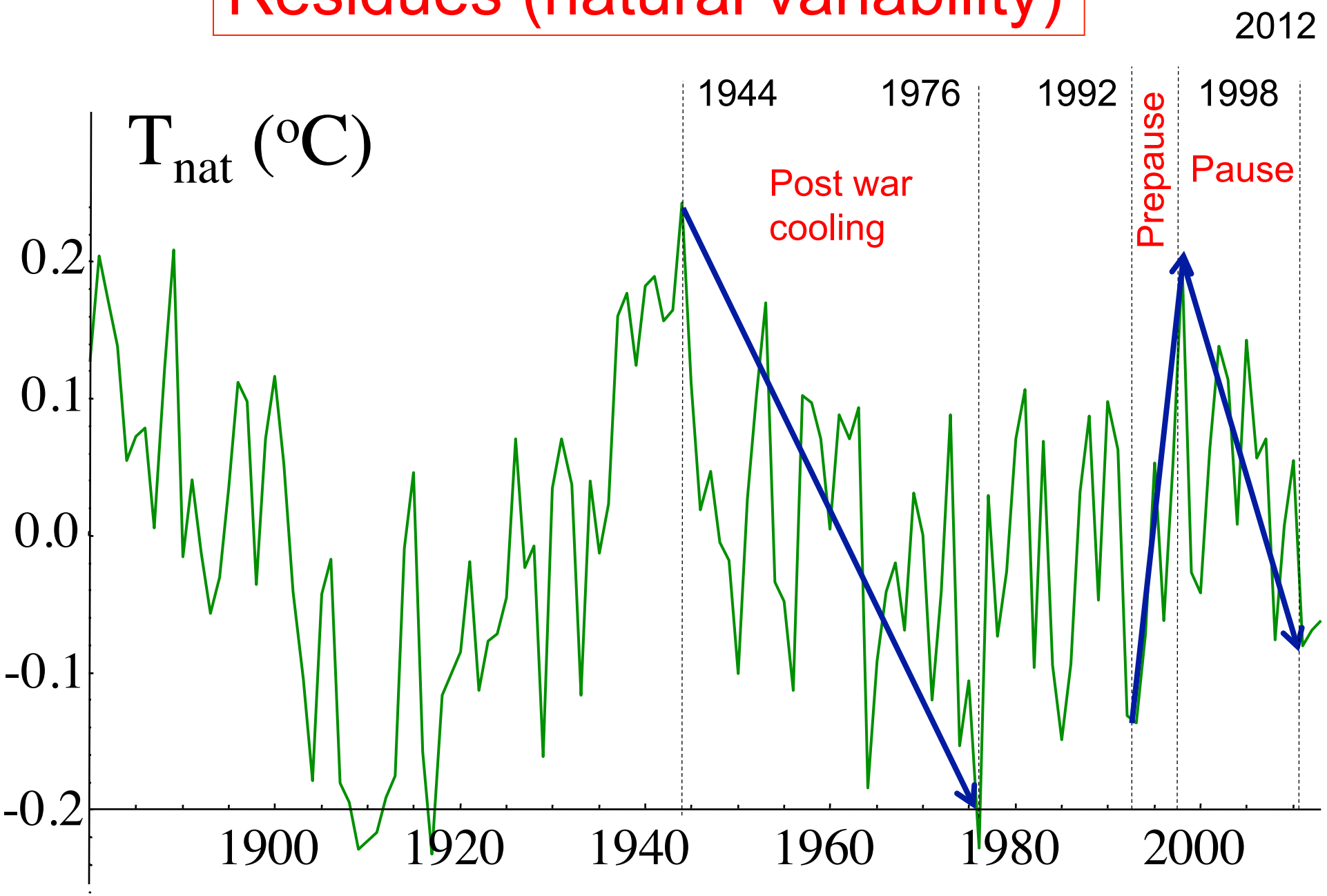

R
yrs
10000
1000
200
100
20
10
Gaussian
q_D=6
q_D=4
Anthropogenic warming
Anthropogenic warming
0.0
0.2
0.4
0.6
0.8
ΔT(°C)
1.0

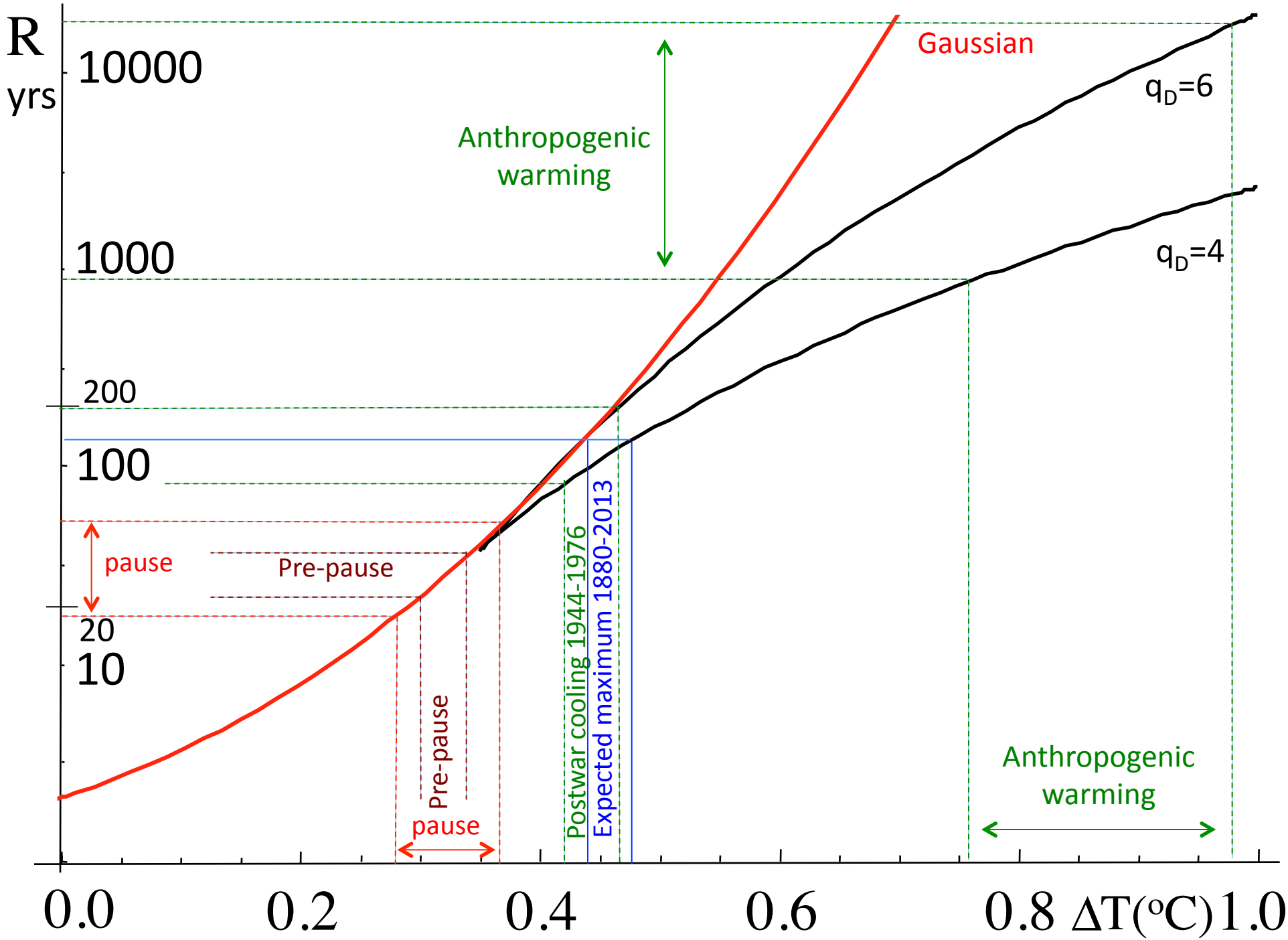
The Pause

Global temperatures: NASA - GISS data

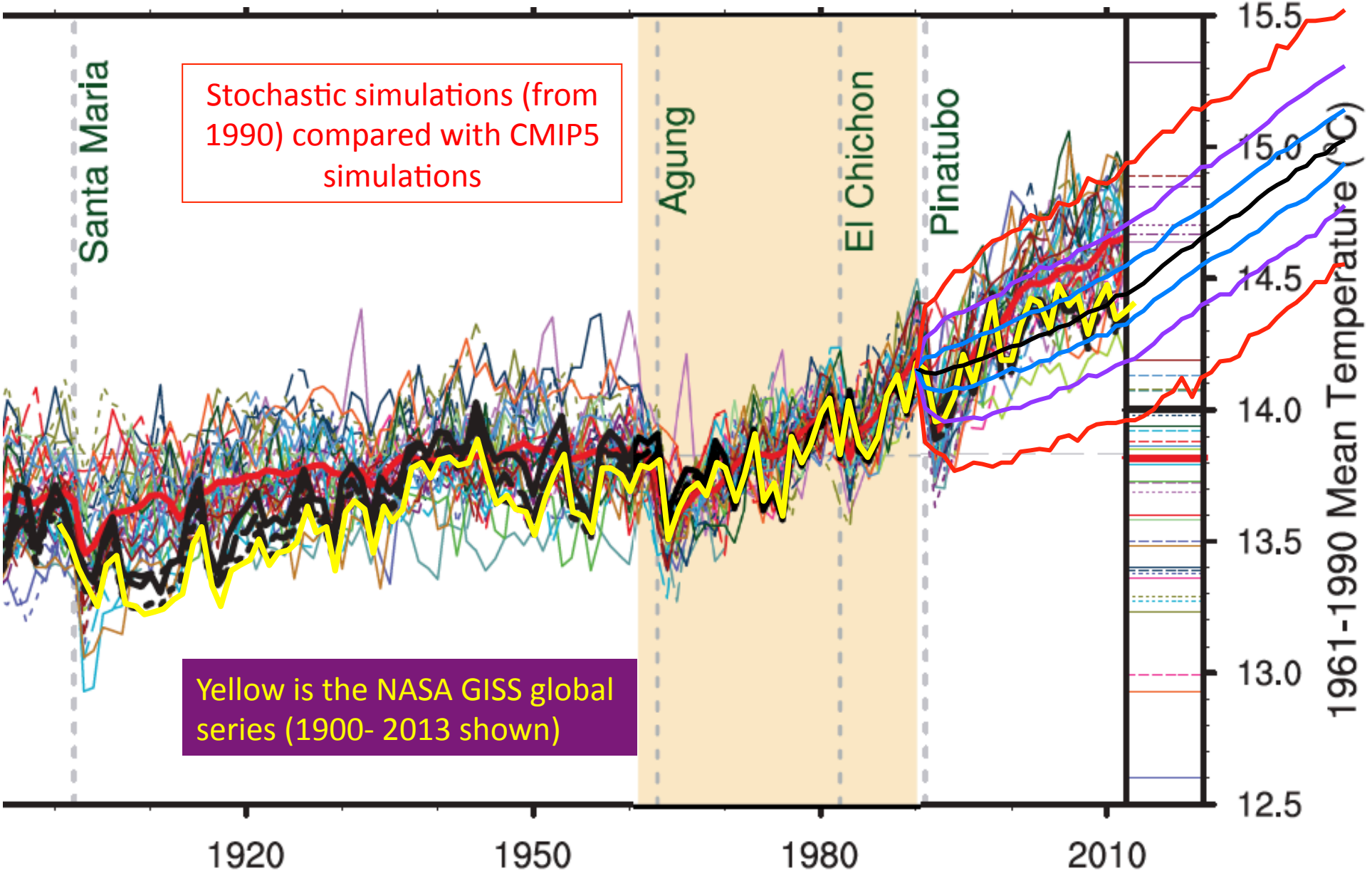


Residues (natural variability)




R
yrs
10000
1000
200
100
20
10
Gaussian
q_D=6
q_D=4
Anthropogenic warming
pause
Pre-pause
Pre-pause
pause
Postwar cooling 1944-1976
Expected maximum 1880-2013
Anthropogenic warming
0.0
0.2
0.4
0.6
0.8
ΔT(°C)
1.0

Observed and CMIP5 mean surface temperature

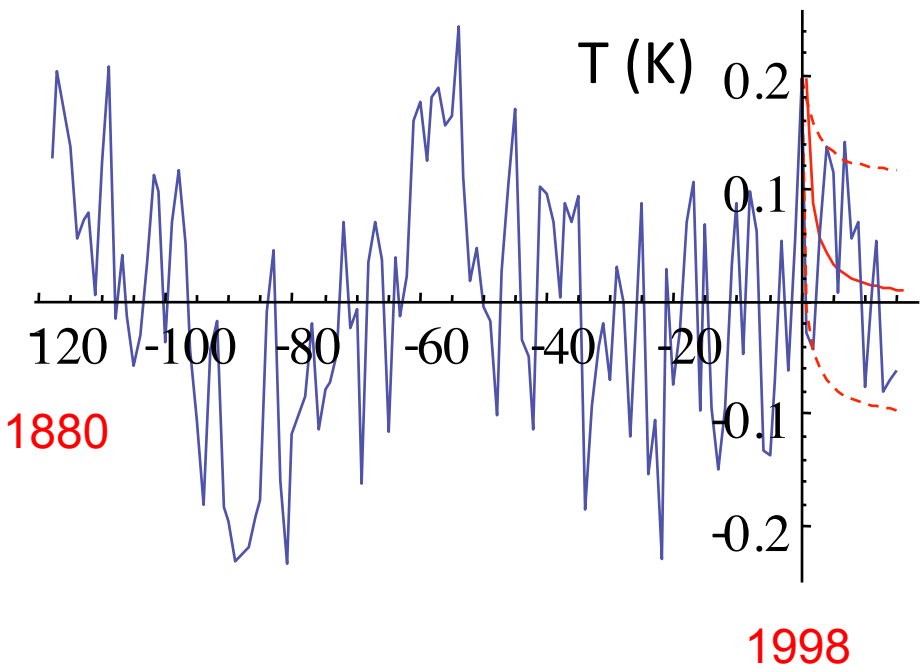


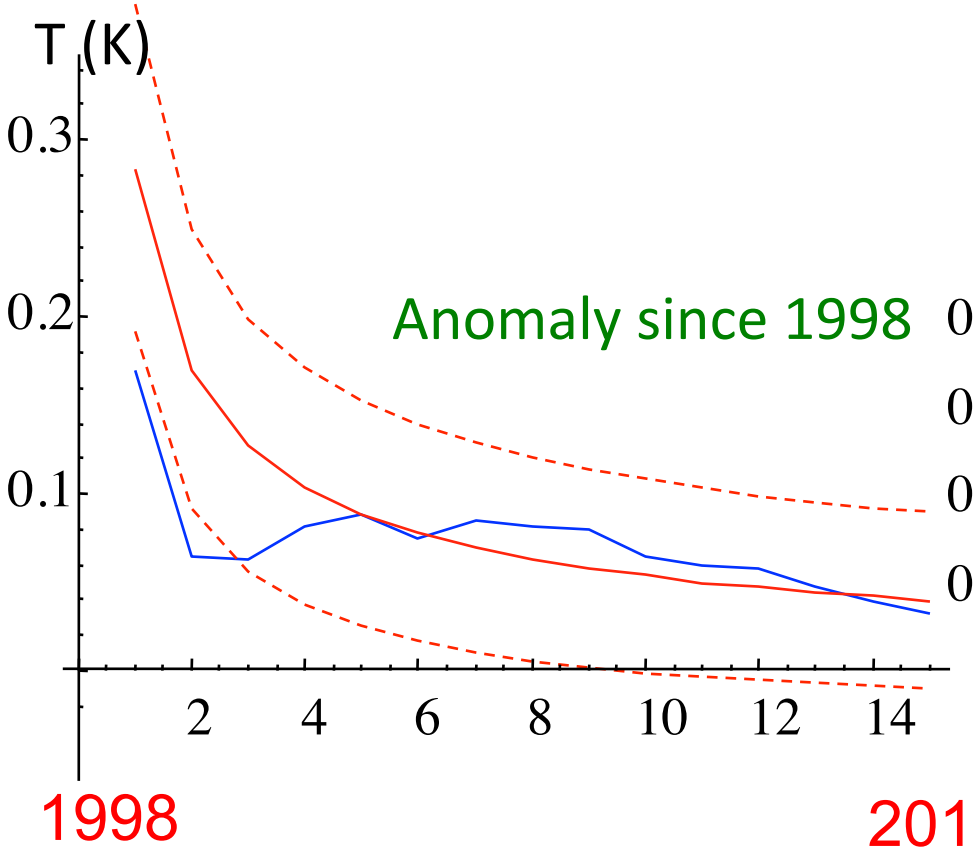
Hindcasting the Pause

(Global mean annual T since 1998, natural variability only)

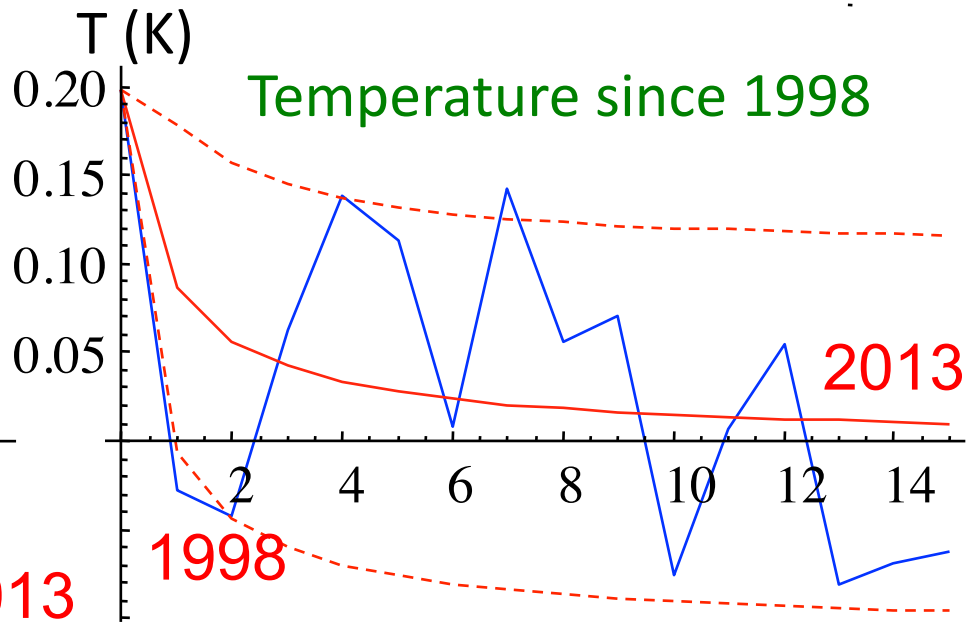
Red= forecast

Blue= observations





Anomaly since 1998

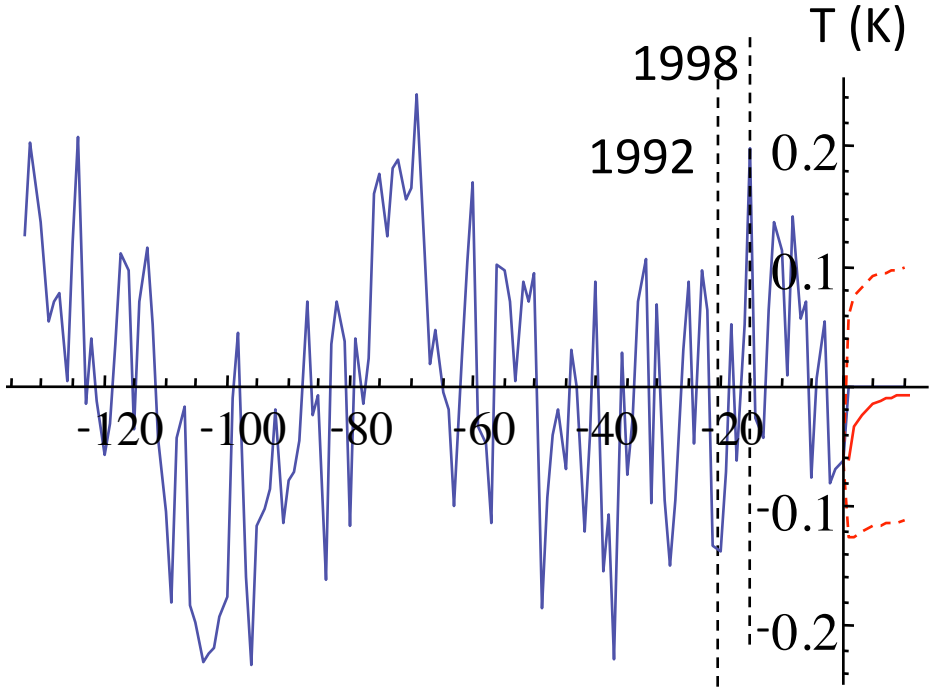


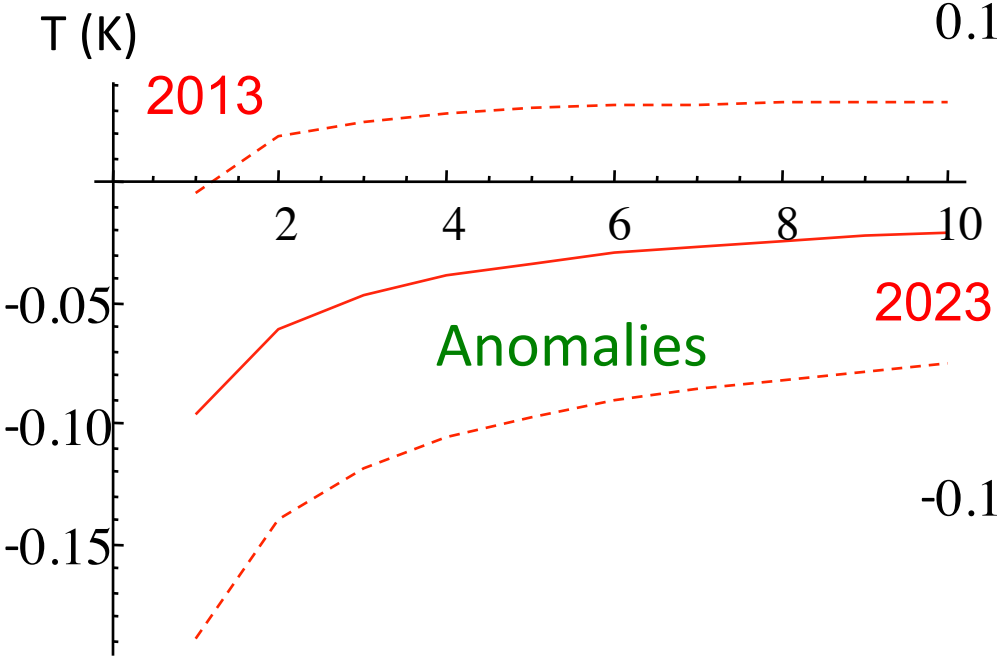
Temperature since 1998

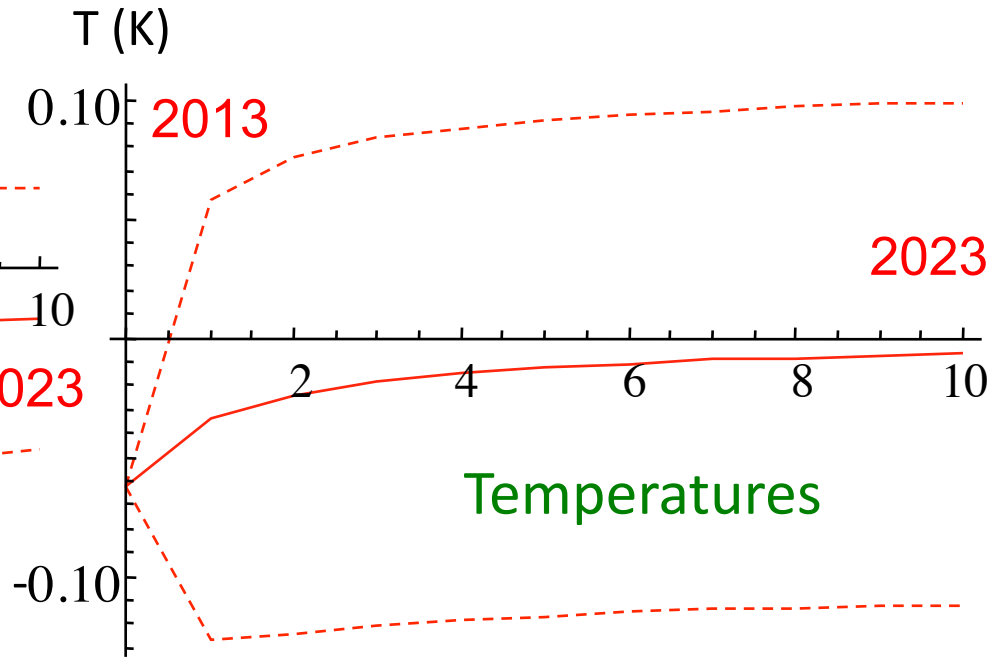
The Future

The next 10 years: Global: 2014-2023

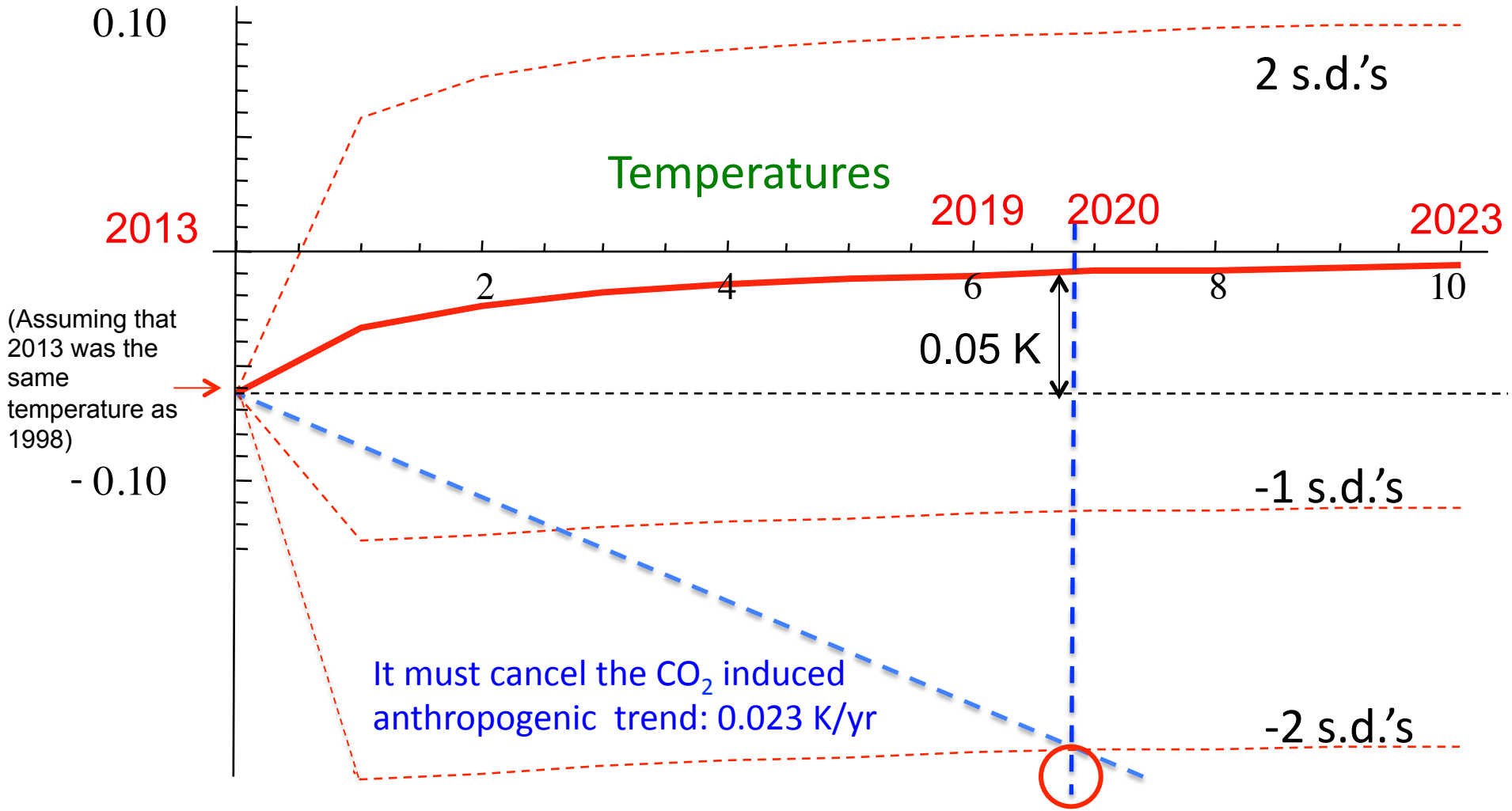
(natural variability only)







Q: “How long must the pause continue before you admit that the warming is over?” – irate climate skeptic
A: About 6 years…



Current Anthropogenic increase: $\frac{d\log_2 CO_2}{dt} \approx 0.010\,/\,yr$ $\frac{dT}{dt} \approx 0.023\,/\,yr$

Forecast for 2023: +0.05±0.10K (natural)+0.23±0.02 K (anthropogenic) = 0.28±0.11 K above 2013

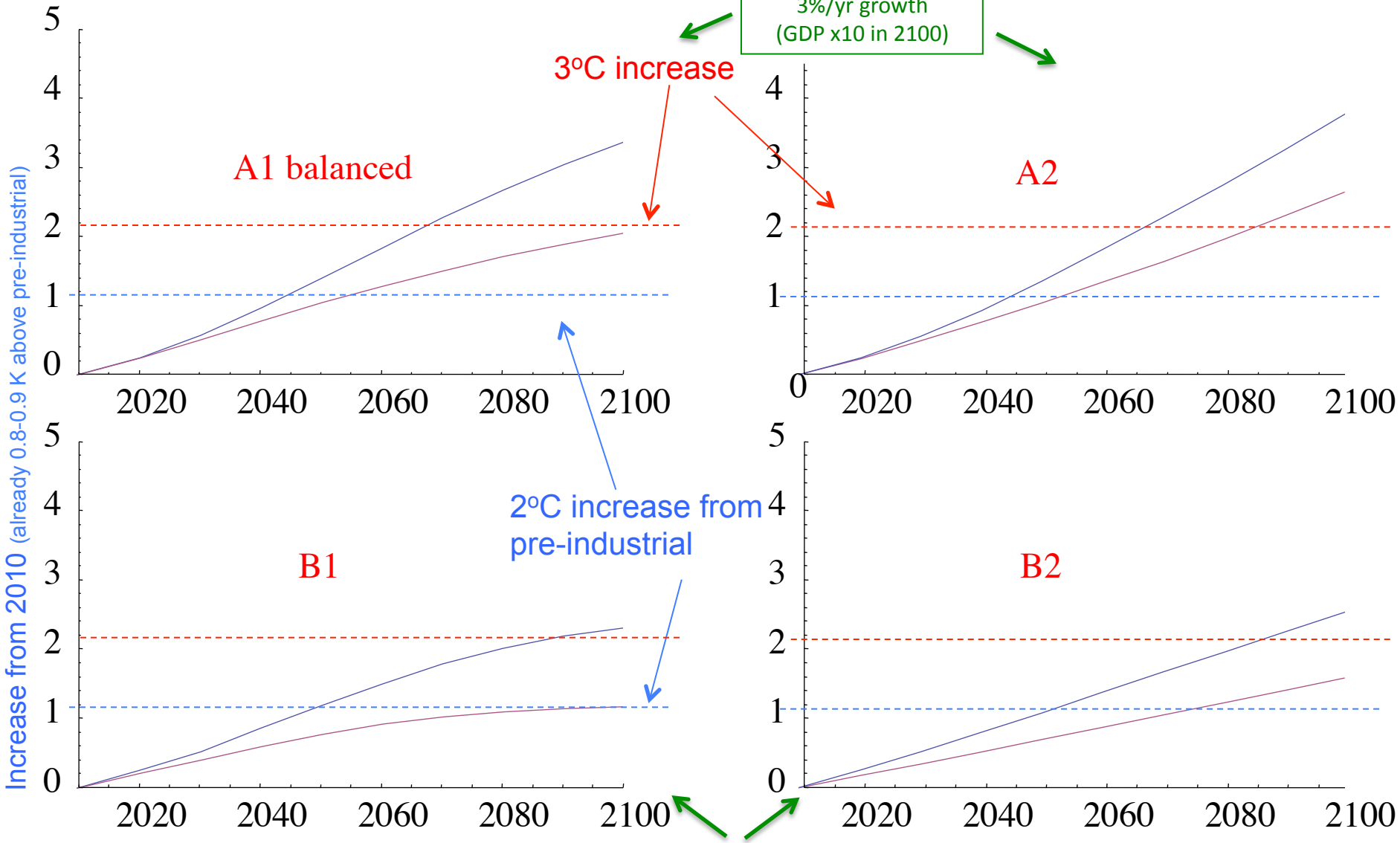
Future Projections

T (°C)

Based on SRES (Special Report on Emissions Scenarios, IPCC, AR2-4)

3%/yr growth (GDP x10 in 2100)

3°C increase



2°C increase from pre-industrial

Blue is with, λ=3.82°C/ CO_2 doubling (extreme high)

Red withλ=2.33°C/ CO_2 doubling (extreme low)

2%/yr growth (GDP x5 in 2100)

The skeptics reaction

"A mephitic ectoplasmic emanation of the forces of darkness"
-Viscount Lord Christopher Monckton of Brehnchley commenting on this work

The "Friends of Science" (Calgary based group) tried to bully the McGill chancellor into removing the press release from its site.

Common reactions.. and misconceptions:

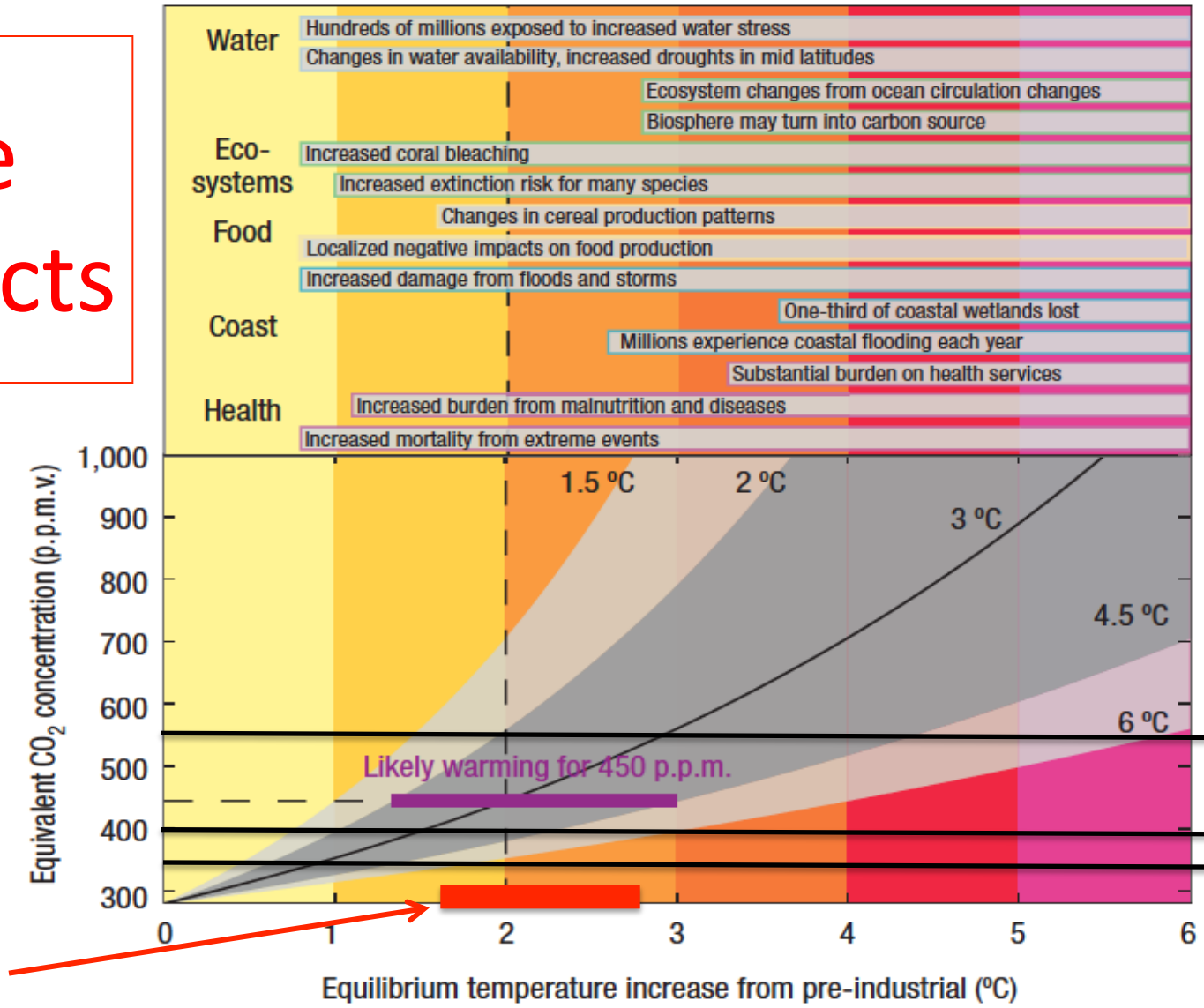
-Use of historical information:
Q: 800 years ago in medieval Europe *global* temperatures might have been warmer than today if so, doesn't this contradict the analysis?
A: It is the probability of a large temperature changes over *125 year periods*, that is small - there is nothing to prevent the same changes occurring much more slowly (i.e. over much longer periods).

-Use of unrepresentative paleo or instrumental sources
Q: (the "Friends"): The temperature change in central England from 1663-1762 was 0.90 ^{o}C, so such changes are not unusual.
A. England is only 0.04% of the earth's surface. The *global scale* temperature change was only 0.21±0.12 ^{o}C.

Impacts

The impacts

Knutti et al 2008



Our simple method: doubling CO_2: 3.08±0.58 °C

For 450 ppm: 2.2±0.4 °C (0.6±0.15 °C more than in 2013)

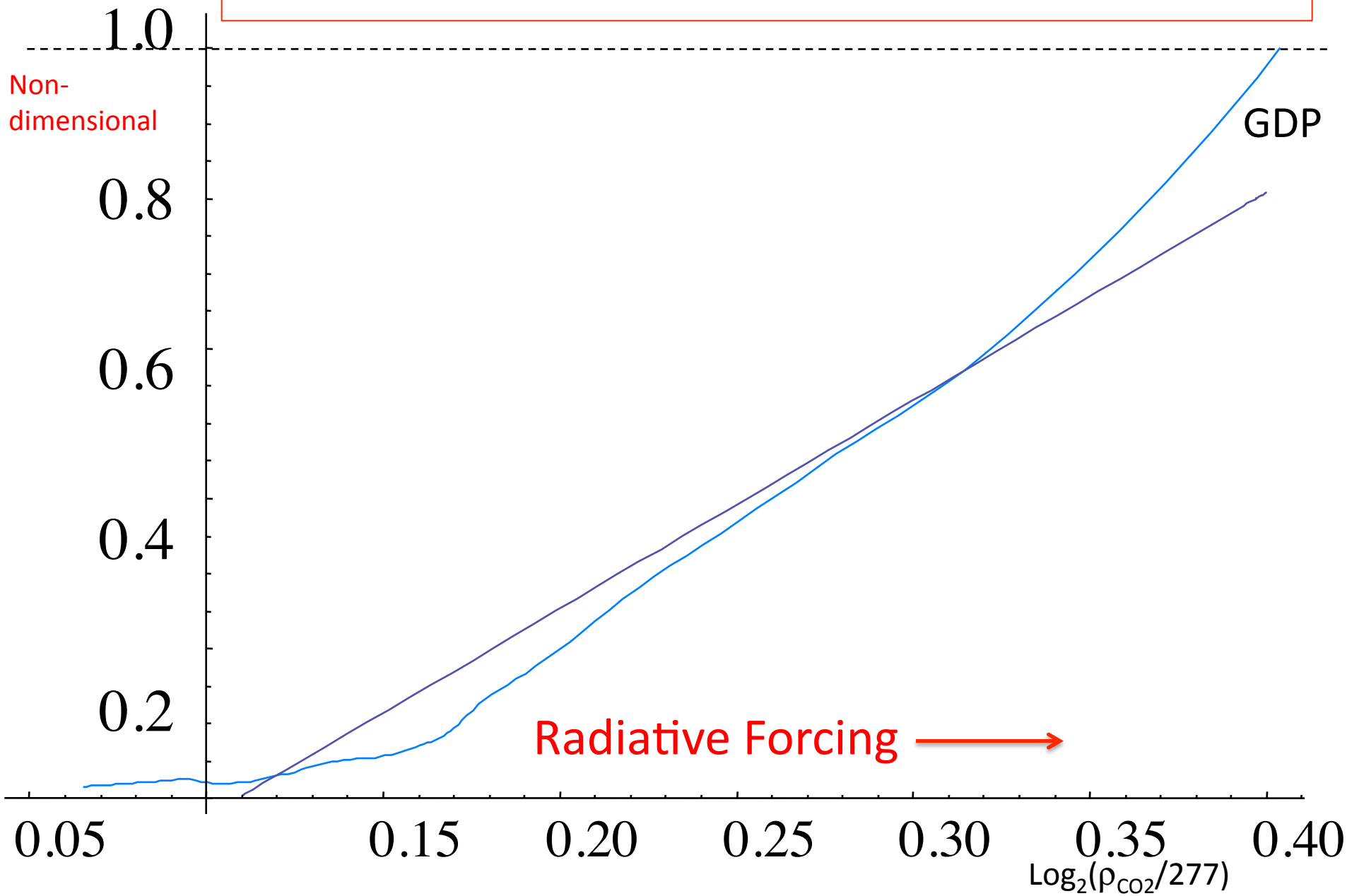
Stern report (economic stability)

Today

"Levels of CO_2 in excess of only 350 ppm are not compatible with the planet on which civilization developed or to which life on earth is adapted": Hansen et al 2008:

What is to be done?

Tight link between CO_2 forcing and GDP



The challenge:

Decarbonize the economy

Can we break the link between economic growth and CO2 emissions?

Mainstream economists:
Climate change is no big deal

"Agriculture, the part of the economy the most sensitive to climate change, accounts for just 3% of national output. That means that there is no way to get a very large effect on the US economy".

-Yale Economist William Nordhaus *Science* (1993)

"Even if the net output of US agriculture fell by 50% by the end of the next century, this is only a 1.5% cut in GNP"

-Oxford economist Wilfred Beckerman in *Small is Stupid* (1995)
(echoed by economics Nobel prize winner Thomas Schelling).

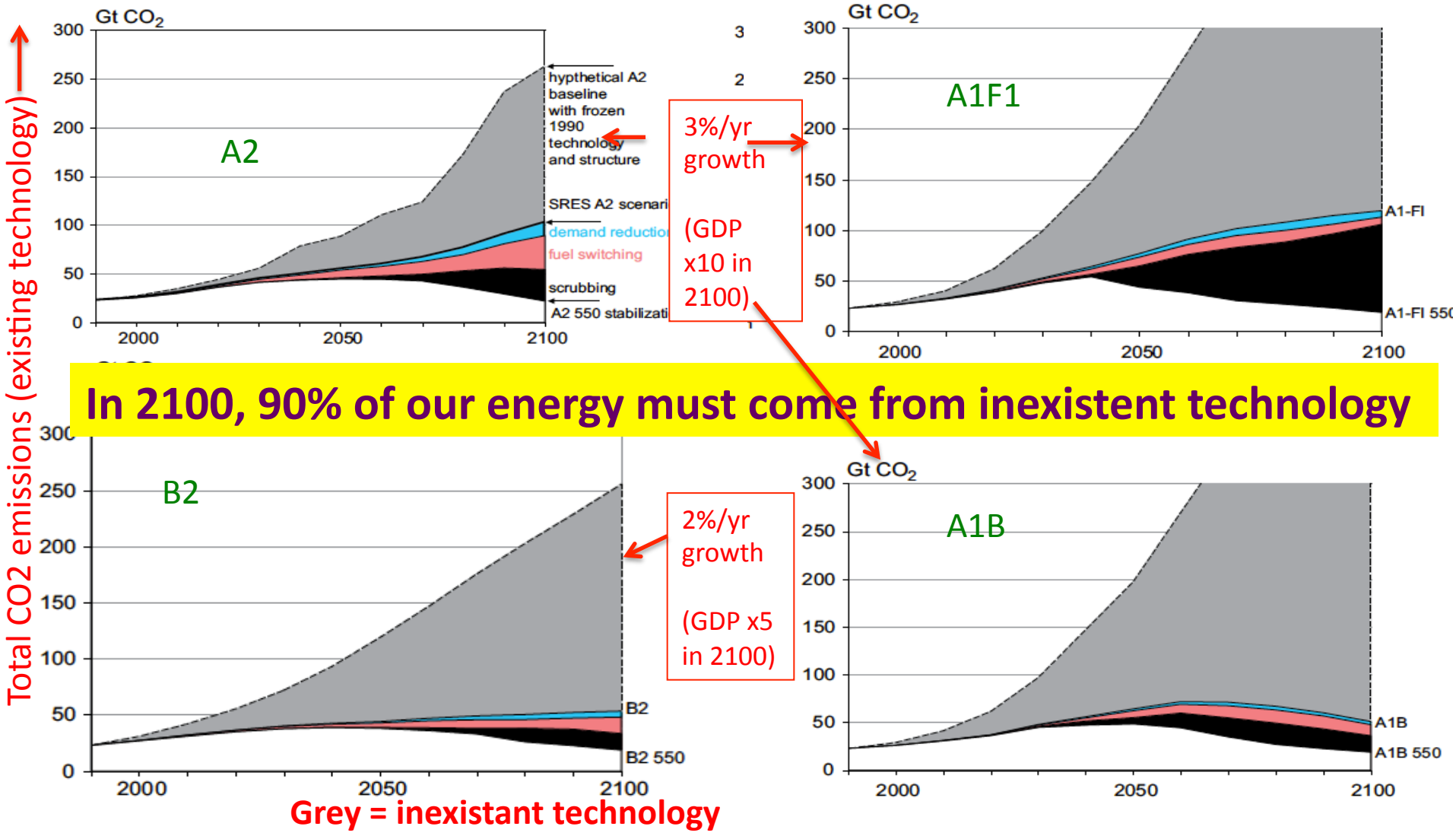
One might be forgiven for concluding that if climate change made all agriculture impossible, that the economy would contract by a mere 3%...

Nordhaus now estimates the reduction of global economic output in the year 2100 due to climate change as 3% of GDP.
This is in line with the IPCC working group 3 on mitigation and the IPCC Synthesis report that appeared on Sunday, Nov. 2.

Magical thinking: if the price is right then technology can be conjured up to solve any problem…

The role of existent and new technologies

(IPCC scenarios, 2007; Stabilisation at 550ppm)



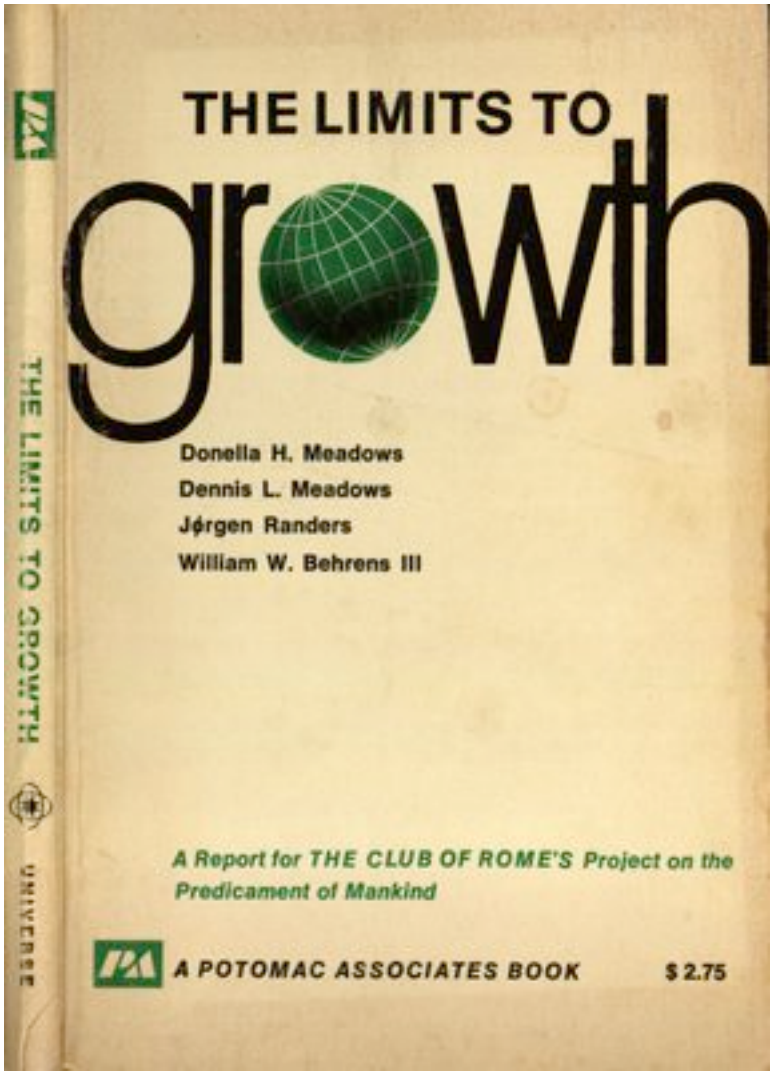
IPCC 2014:

In addition to carbon free energy:

A major role for Carbon Capture and Storage technology that doesn't exist…

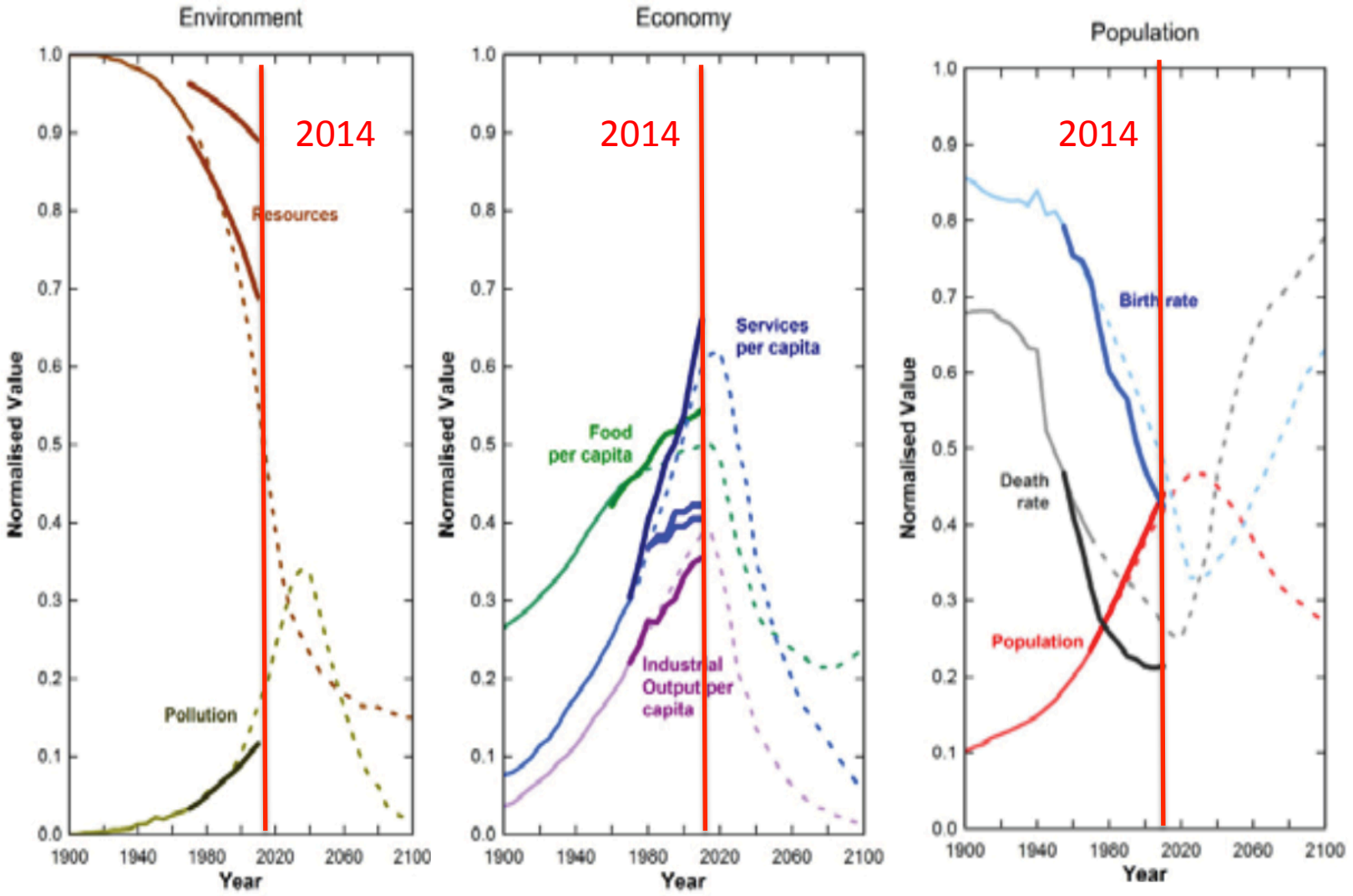
Is continued quantitative economic growth *possible?*

Limits to Growth: Overshoot and collapse



1972

Note: The nonlinear model is completely based on physical (not financial inputs and outputs).



Limits to Growth numerical model (1972):

Business as usual scenario (dashed), historical data, (solid) (G. Turner, 2014).

Reason for collapse: capital increasingly diverted from production to resource extraction

Is continued quantitative growth *desirable*?

-Classical economics:
Formulated in an epoch where climate change and resource depletion were either undreamt of or were so remote as to be of only academic relevance.
Since the 19th century the desirability and need of quantitative economic growth has been taken for granted in order to better the human condition.

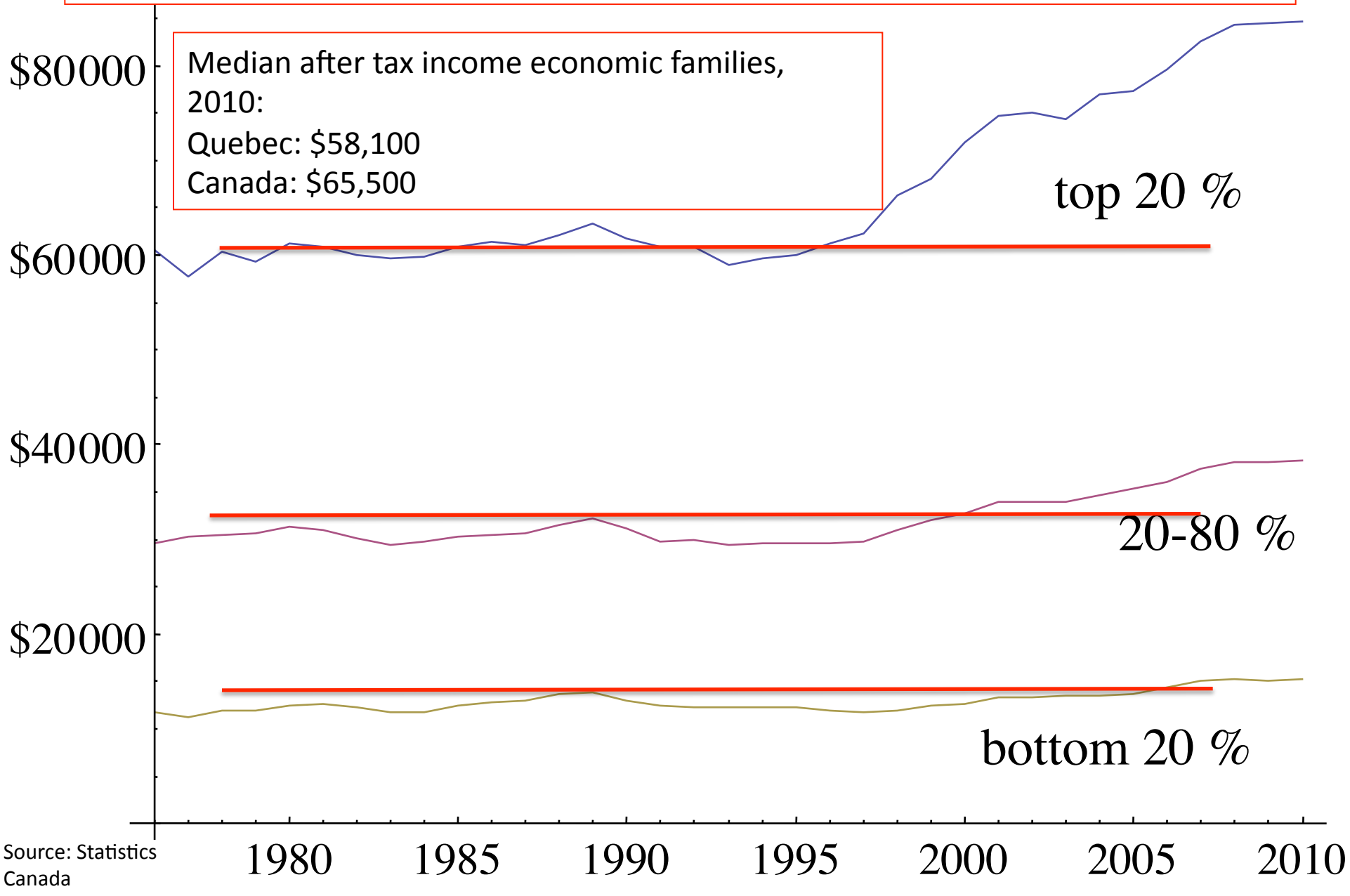
-The world's poor countries:
(Justifiably) want to grow in order to bring themselves out of their relative misery.

-The developed world: Canada:

Since the 1980, the per capita Gross Domestic Product (GDP) has roughly doubled, yet median family income has stagnated, virtually all the increase in economic activity has gone into the pockets of the top 20%, mostly to the top 1% (Statistics Canada).

After - tax income, by family unit, Canada, 1976 – 2010

(2010 constant dollars, economic families)



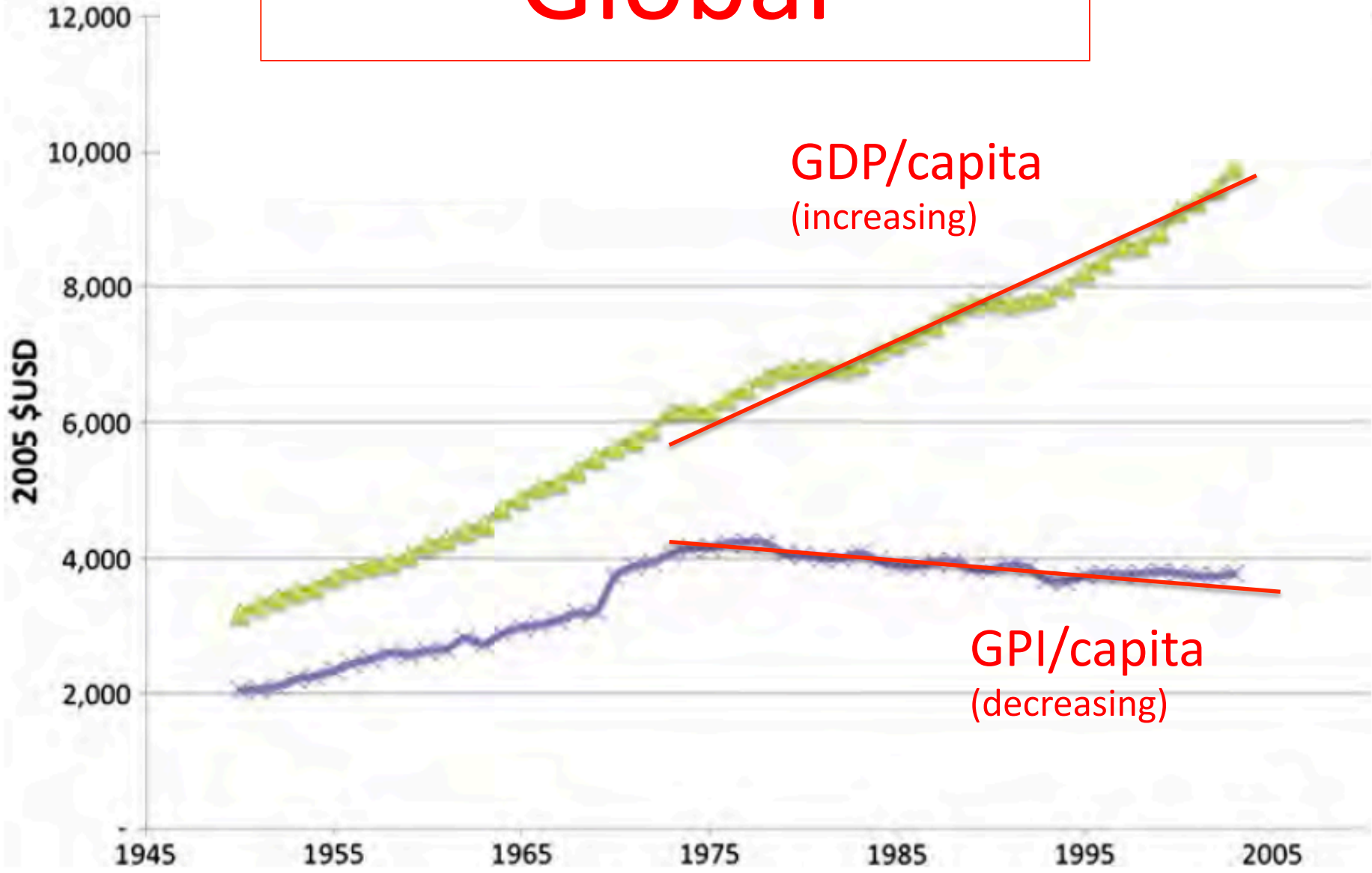
Source: Statistics Canada

GDP is a very poor indicator of economic well being

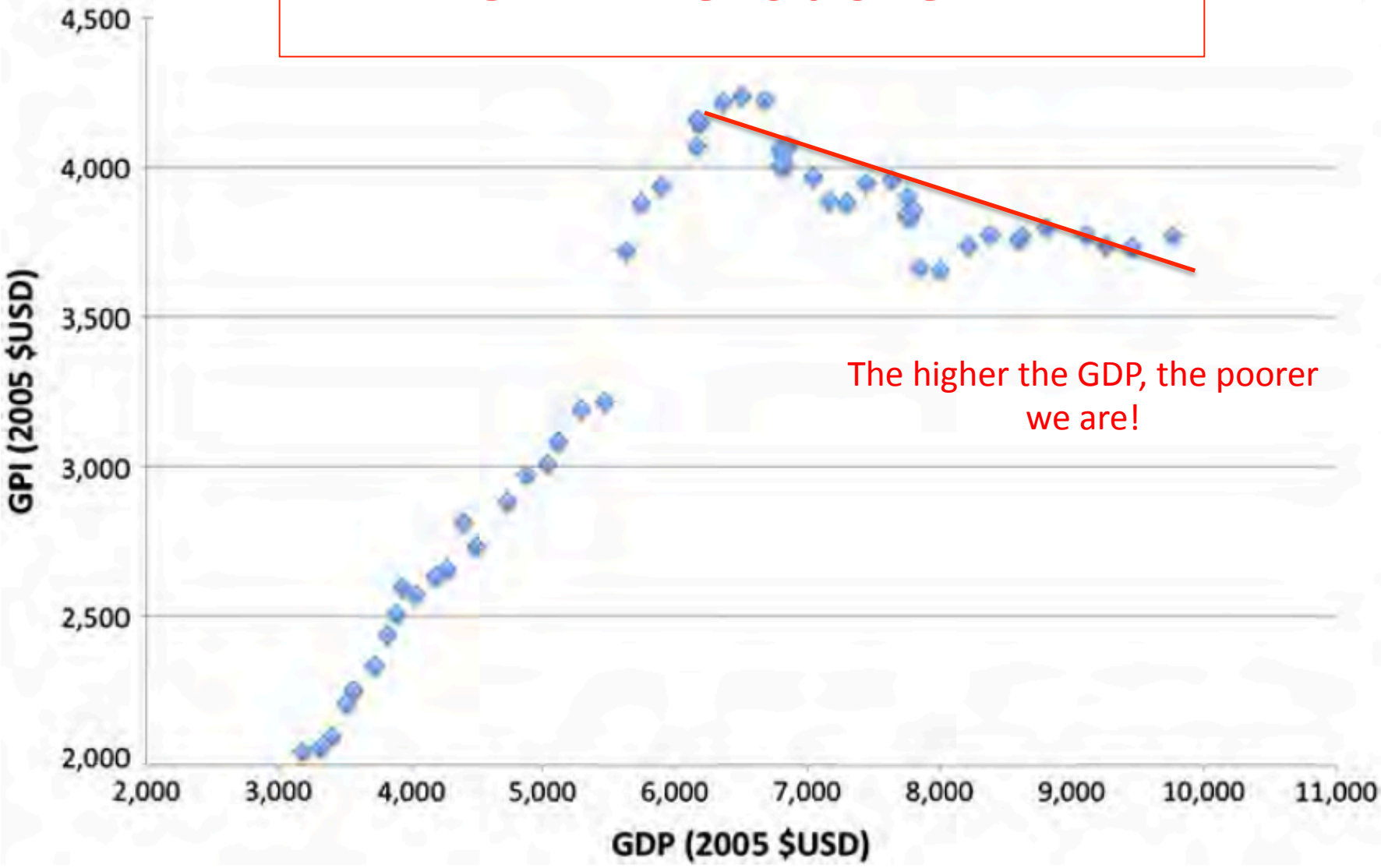
Genuine Progress Indicator (GPI)

- The GPI is the GDP (value of all goods and services produced) minus the environmental and social costs.
- Accordingly, the GPI will be zero if the financial costs of poverty and pollution equal the financial gains in production of goods and services, all other factors being constant.

Global


12,000
10,000
8,000
6,000
4,000
2,000
-
2005 $USD
1945
1955
1965
1975
1985
1995
2005
GDP/capita
(increasing)
GPI/capita
(decreasing)

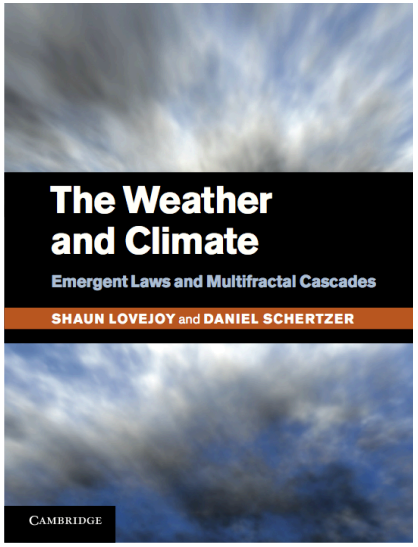
GDP versus GPI



Implications of GDP growth

- Radiative forcing, hence warming is a strong function of GDP
- Since at least the mid 1970's GDP in Canada has not increased income for %80 of the population.
- Since 1978, the global Ecological Footprint/capita exceeded global Biocapacity/capita: as of 2014, humans were using 150% of the resources that can be sustainably generated in one year
- Since 1976, globally, the GDP is negatively related to GPI so that we become poorer as the GDP rises.

Conclusions



1. The climate is not what you expect.

2. Legitimate versus illegitimate climate skepticism. It is much easier to disprove a theory (natural warming) that to prove one (anthropogenic warming).

3. The total anthropogenic warming since 1880 is about 1°C, for CO_2 doubling, 3.08±0.58°C.

4. The probability of the warming being natural is less than 1%.

5. The pause is a natural cooling event.

6. Impacts rise rapidly after 2°C.

7. Decarbonizing unlikely with continued global economic growth ("magical thinking").

8. For many of us, continued economic growth is undesirable (lower GPI).