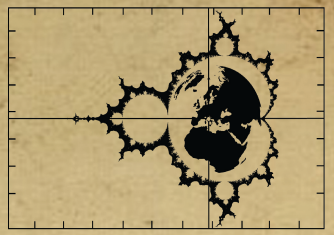
Dipartimento di Scienze della Terra - Università degli Studi di Perugia



6th International Conference on

Fractals and Dynamic Systems in Geoscience

Sala del Dottorato
(Museo Capitolare di San Lorenzo, Piazza IV Novembre)

Perugia
30 Sept. - 02 Oct., 2013

www.fractgeosci2013.unipg.it

Our fractal climate and anthropogenic warming

S. Lovejoy, McGill, Physics

Perugia
29 September, 2013

What is the climate?

A voyage through scales

The climate is not what you expect…

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

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

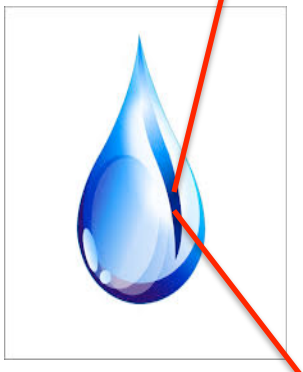
"**Climate in a narrow sense is usually defined as the "average weather"** ... The classical period is 30 years, as defined by the World Meteorological Organization (WMO)… Climate in a wider sense is the state, including a statistical description, of the climate system."

-Intergovernmental Panel on Climate Change, 2007

Scale bound thinking

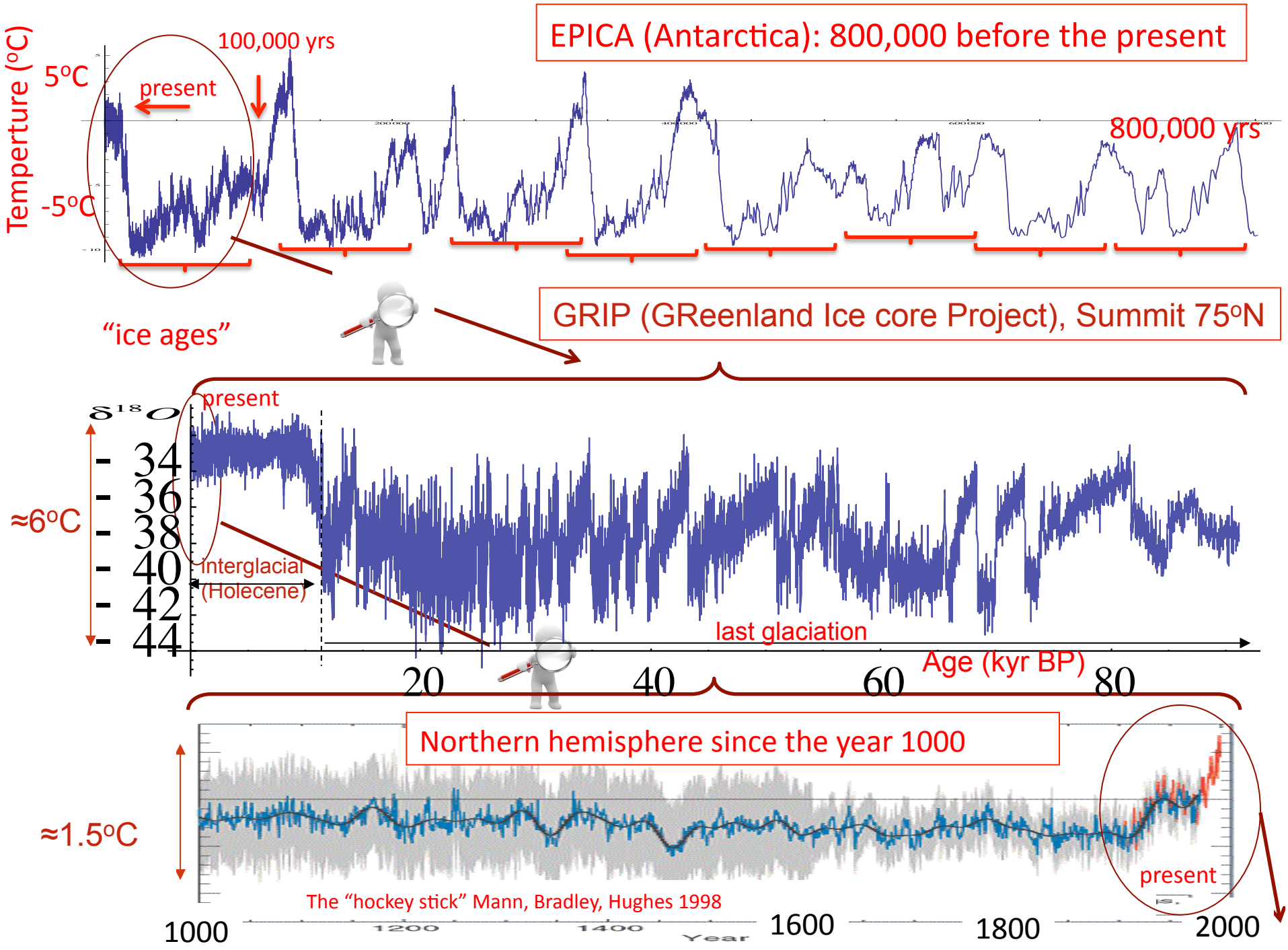
Antonie van Leeuwenhoek (1632–1723)

"A new world" in a drop of water

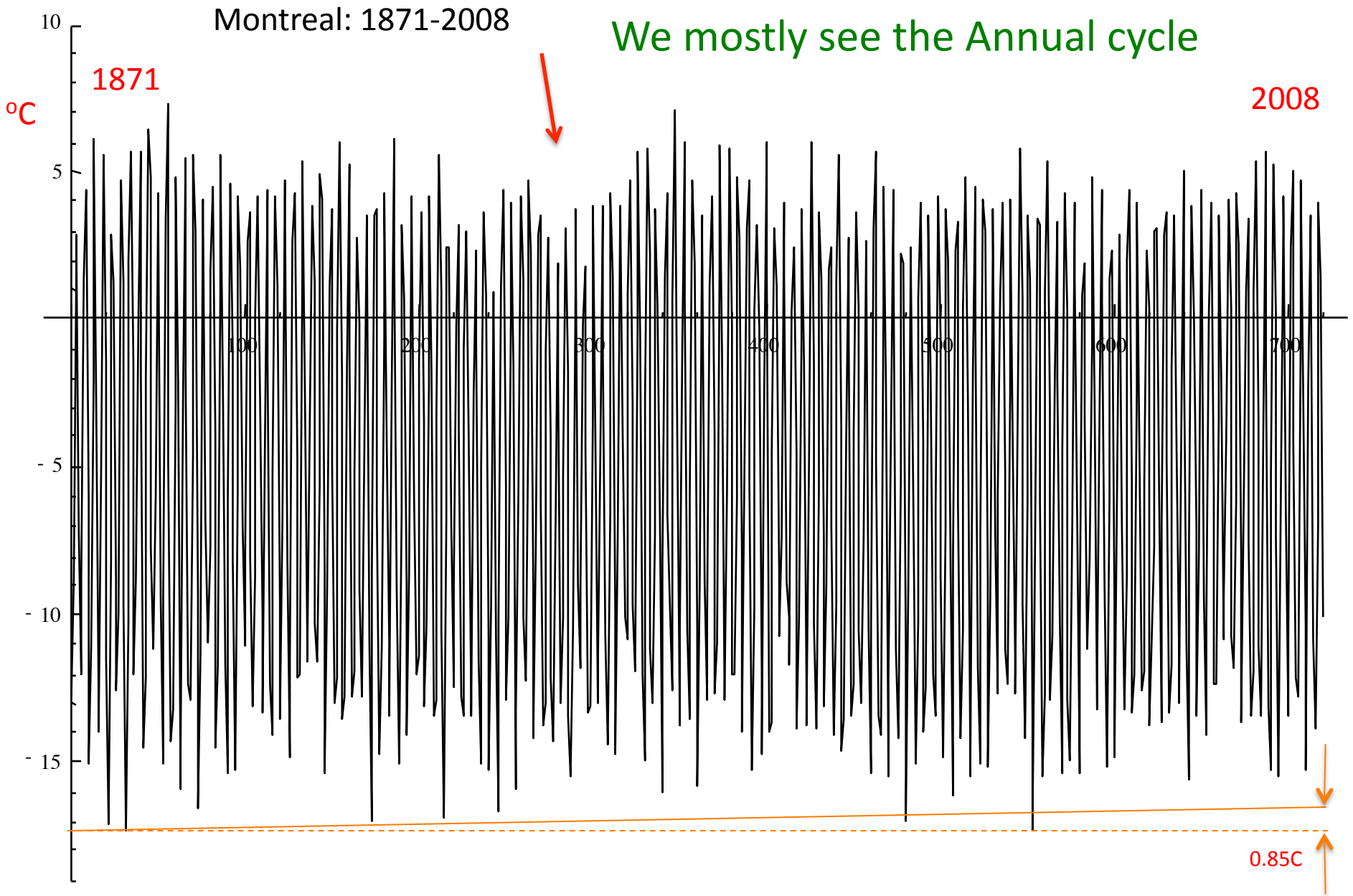


…..the discovery of micro-organisms

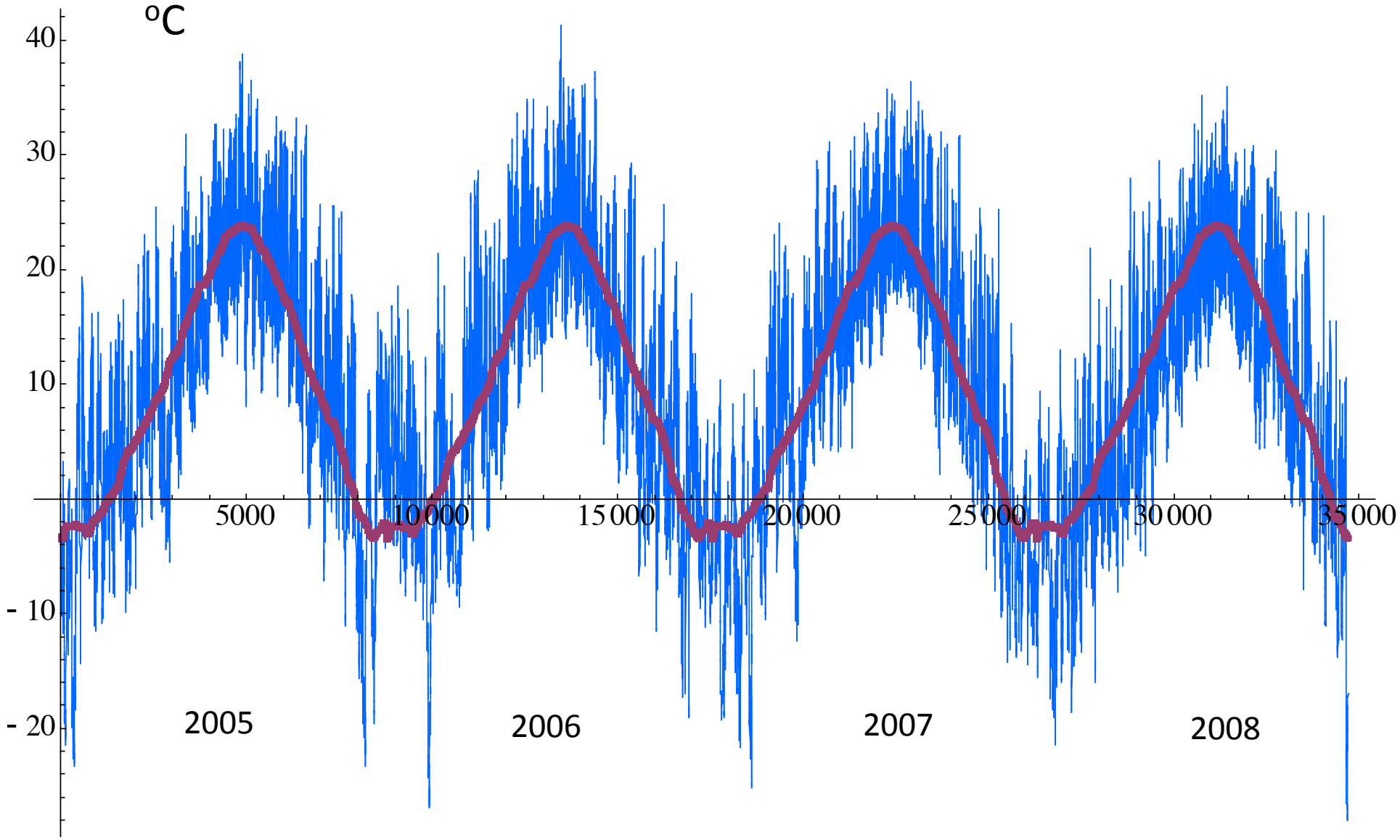
"Animalcules," described in depth by Leeuwenhoek, c1695–1698. By Anton van Leeuwenhoek

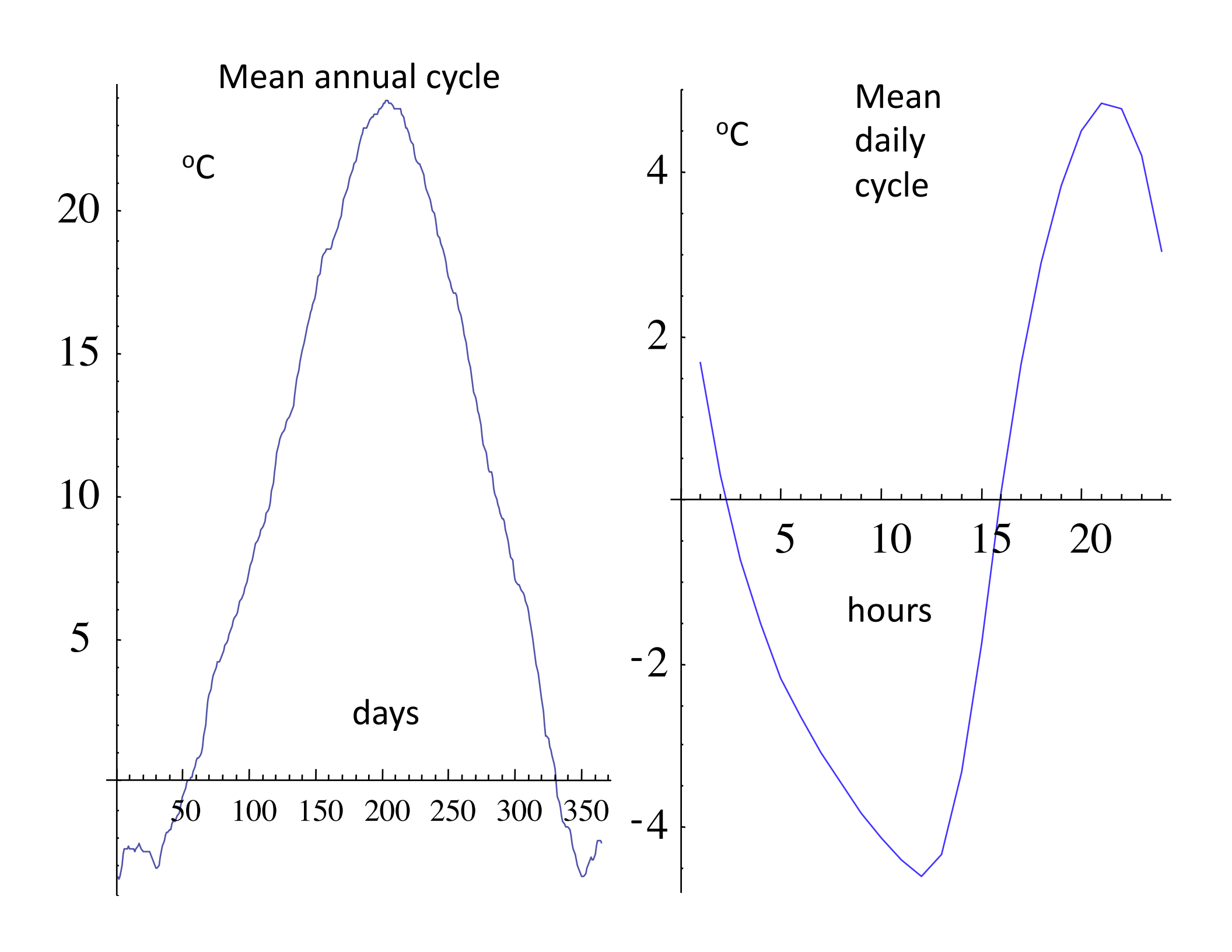

EPICA (Antarctica): 800,000 before the present
Temperture (°C)
5°C
-5°C
100,000 yrs
present
800,000 yrs
"ice ages"
GRIP (GReenland Ice core Project), Summit 75°N
≈6°C
δ18O
34
36
38
40
42
44
present
interglacial
(Holecene)
last glaciation
20
40
60
80
Age (kyr BP)
Northern hemisphere since the year 1000
≈1.5°C
present
The "hockey stick" Mann, Bradley, Hughes 1998
1000
1200
1400
Year
1600
1800
2000

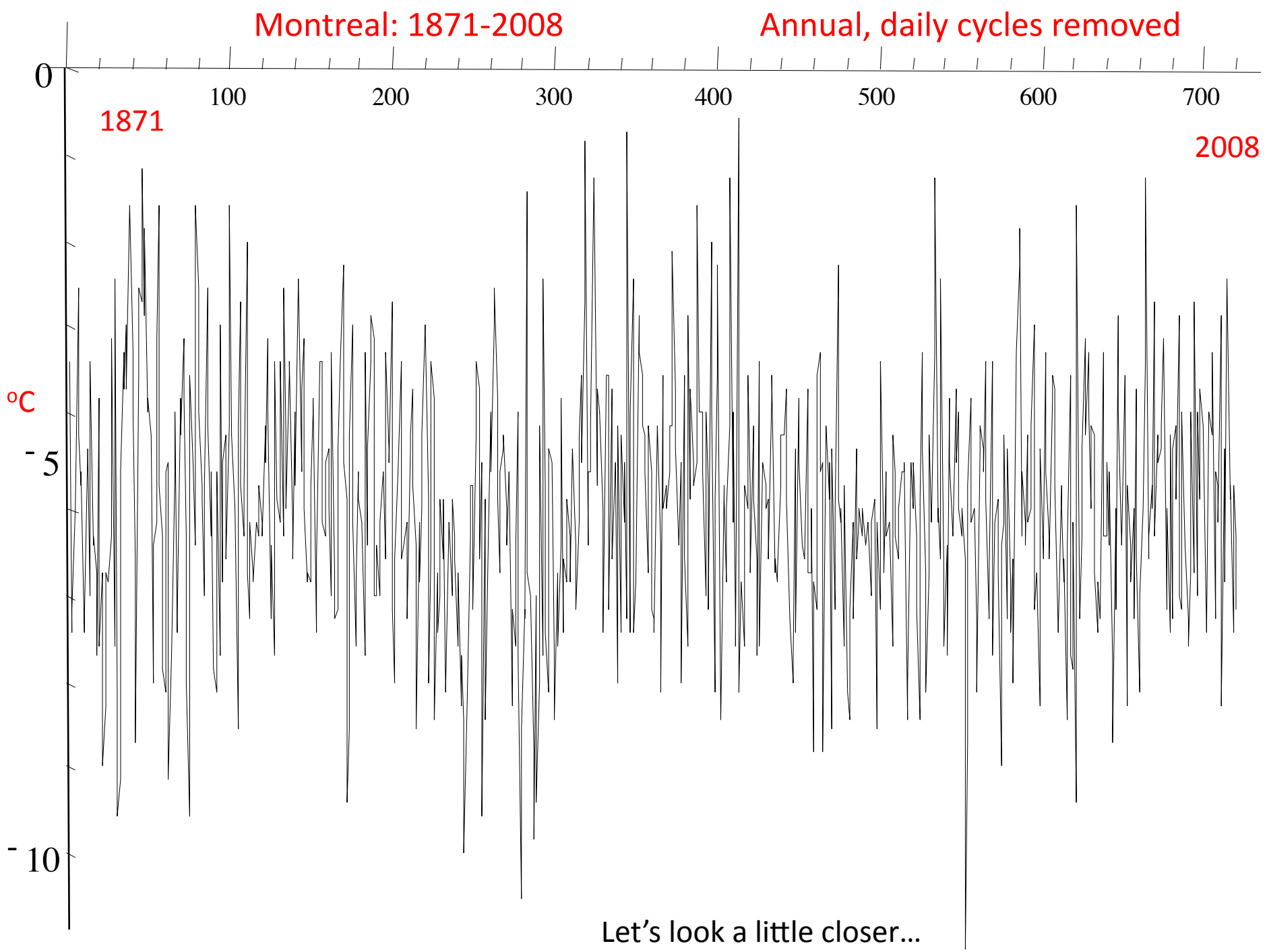
A voyage through scales with Instrumental Data



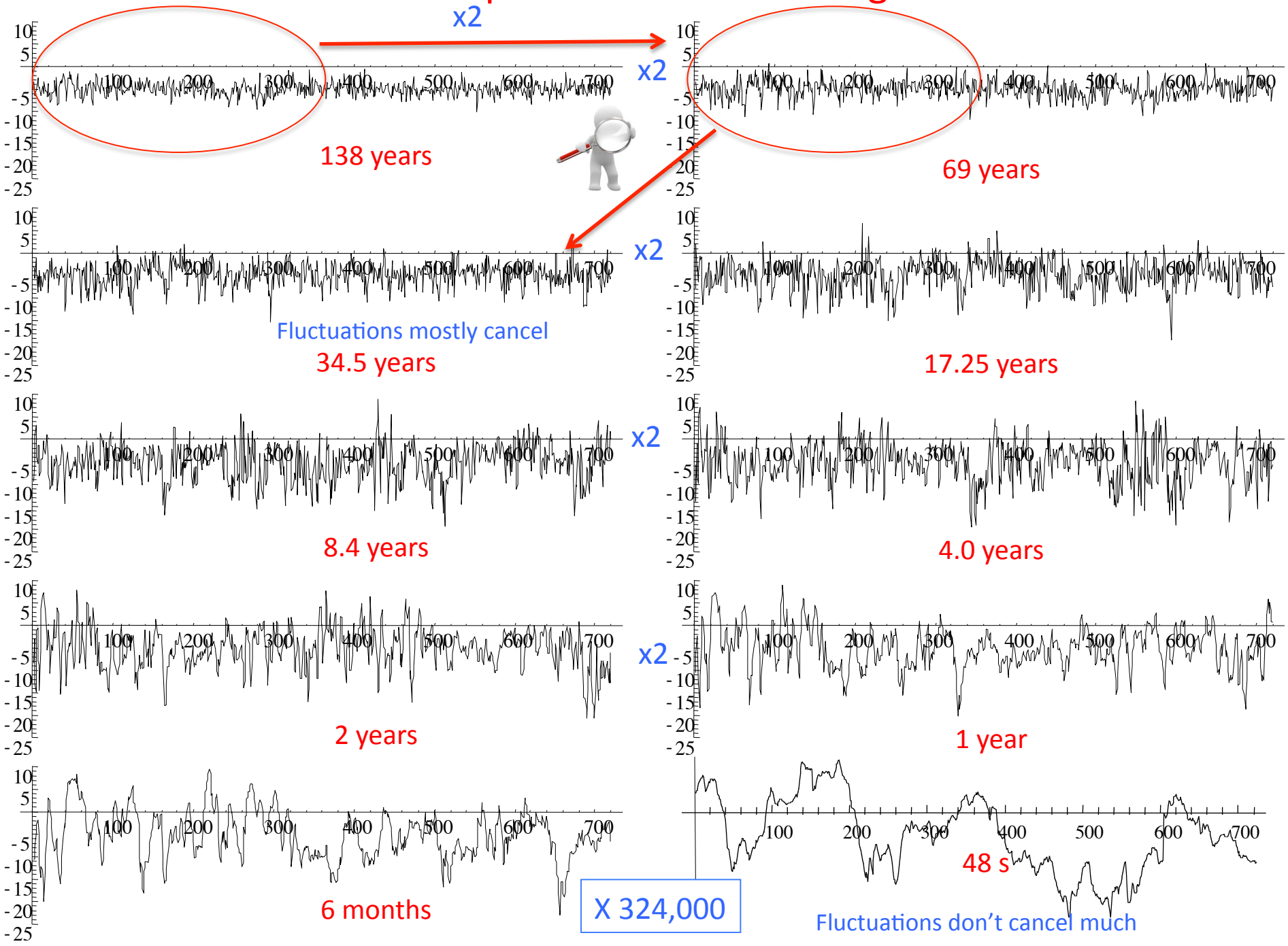
2005-2008 at hourly resolution: the annual cycle




Mean annual cycle
°C
20
15
10
5
days
50
100
150
200
250
300
350
Mean
daily
cycle
°C
4
2
-2
-4
5
10
15
20
hours


Montreal: 1871-2008
Annual, daily cycles removed
0
100
200
300
400
500
600
700
1871
2008
°C
-5
-10
Let's look a little closer…

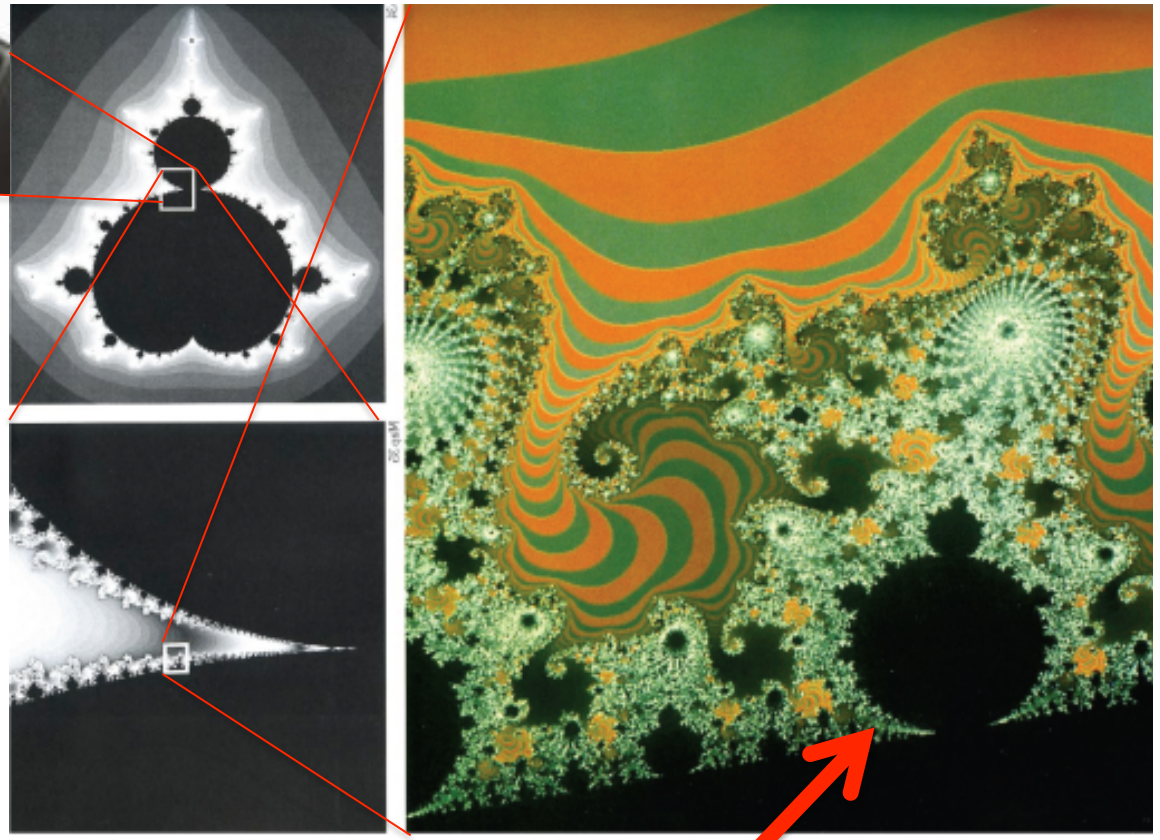
Montreal Temperatures at increasing resolution

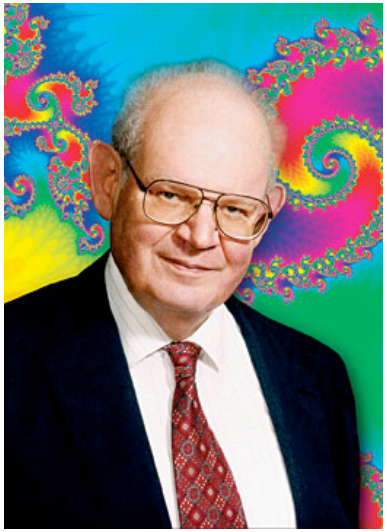


How to understand such variability?

What if….

Peitgen et al



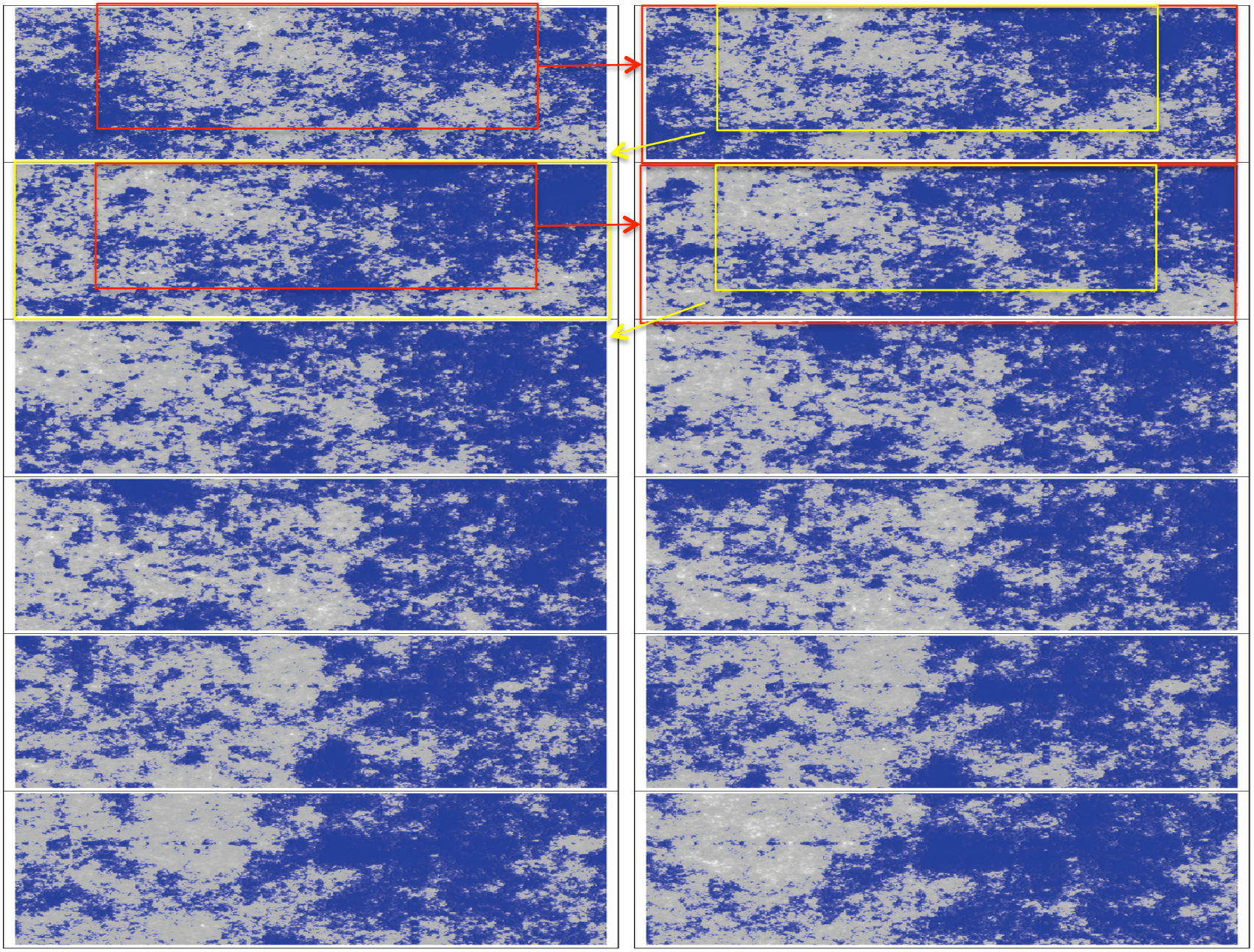


Mandelbrot 1924-2010

We found the same!!!
"Scaling"

(the Mandelbrot set)

Clouds….. Zooming in by factors of 1.7

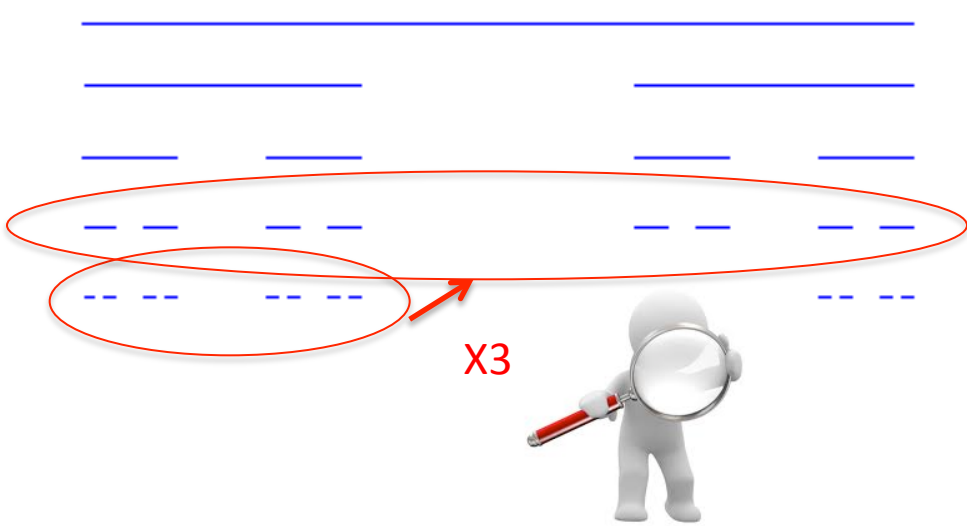


The simplest fractal, the Cantor set

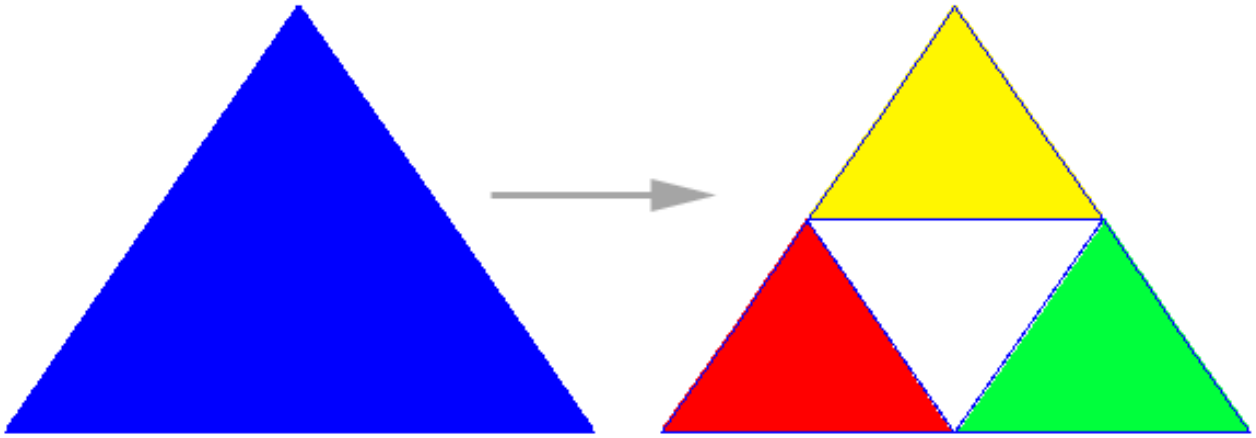
(1871)

- Start with:

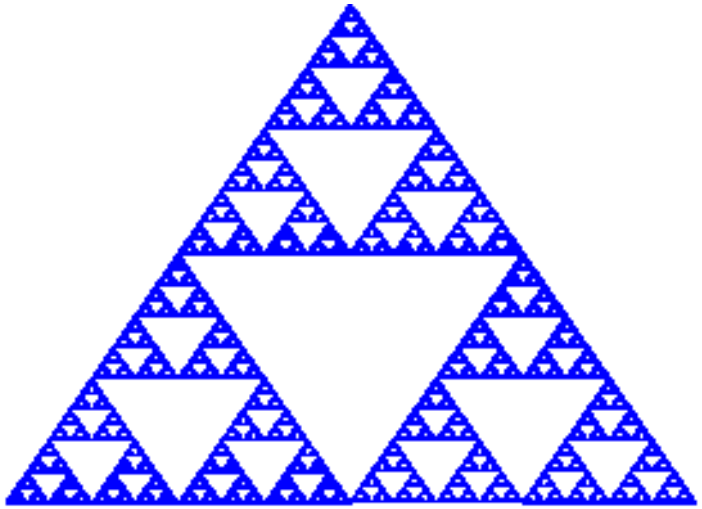
iterate:



Sierpinski Triangle



1 2



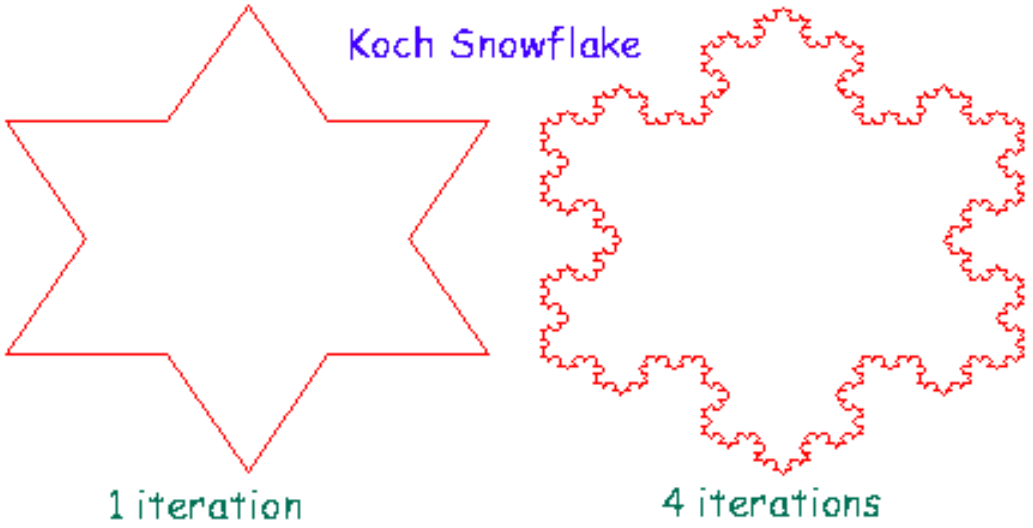
10 iterations

The Koch snowflake

- Start with:

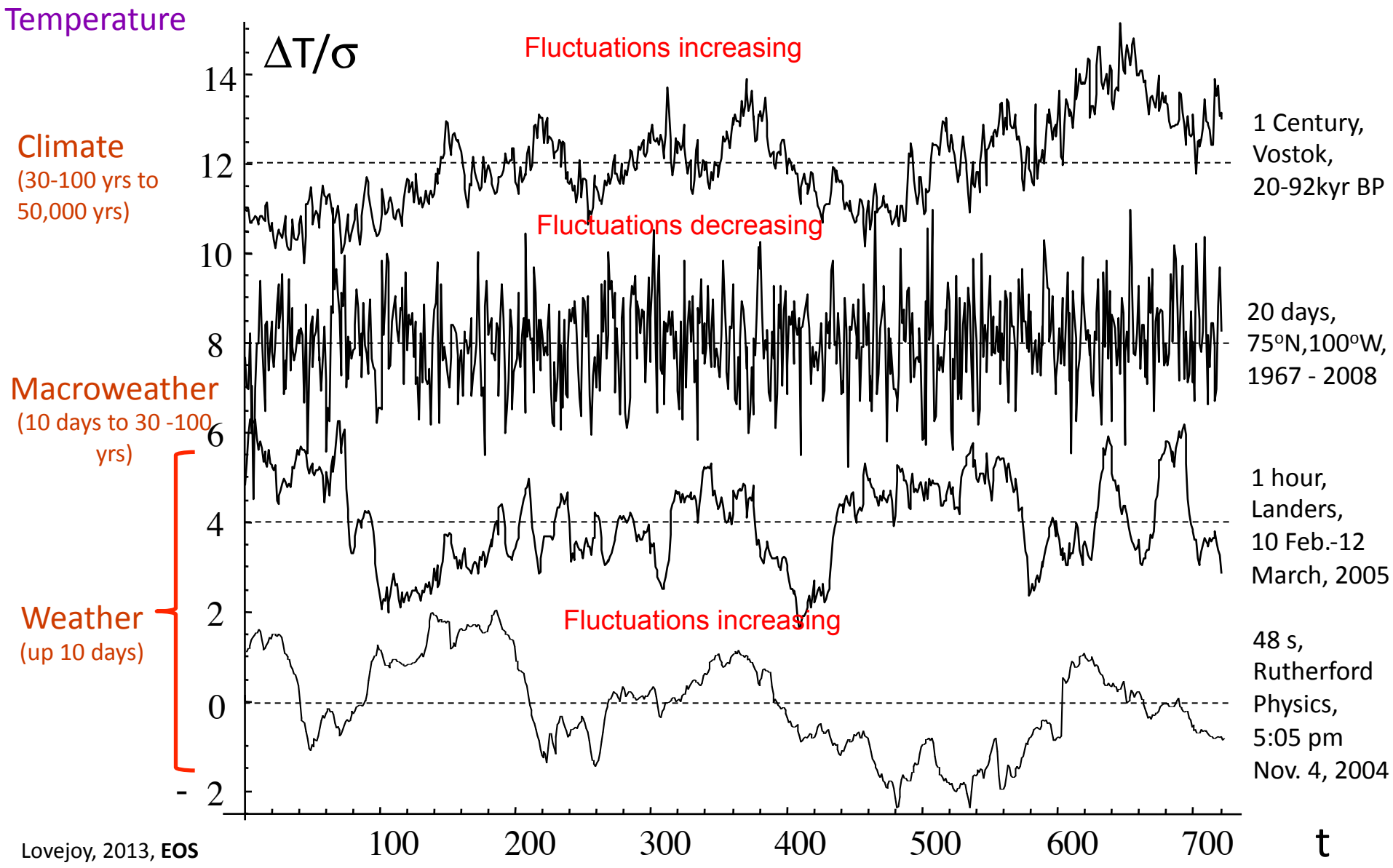
substitute  by 

iterate:

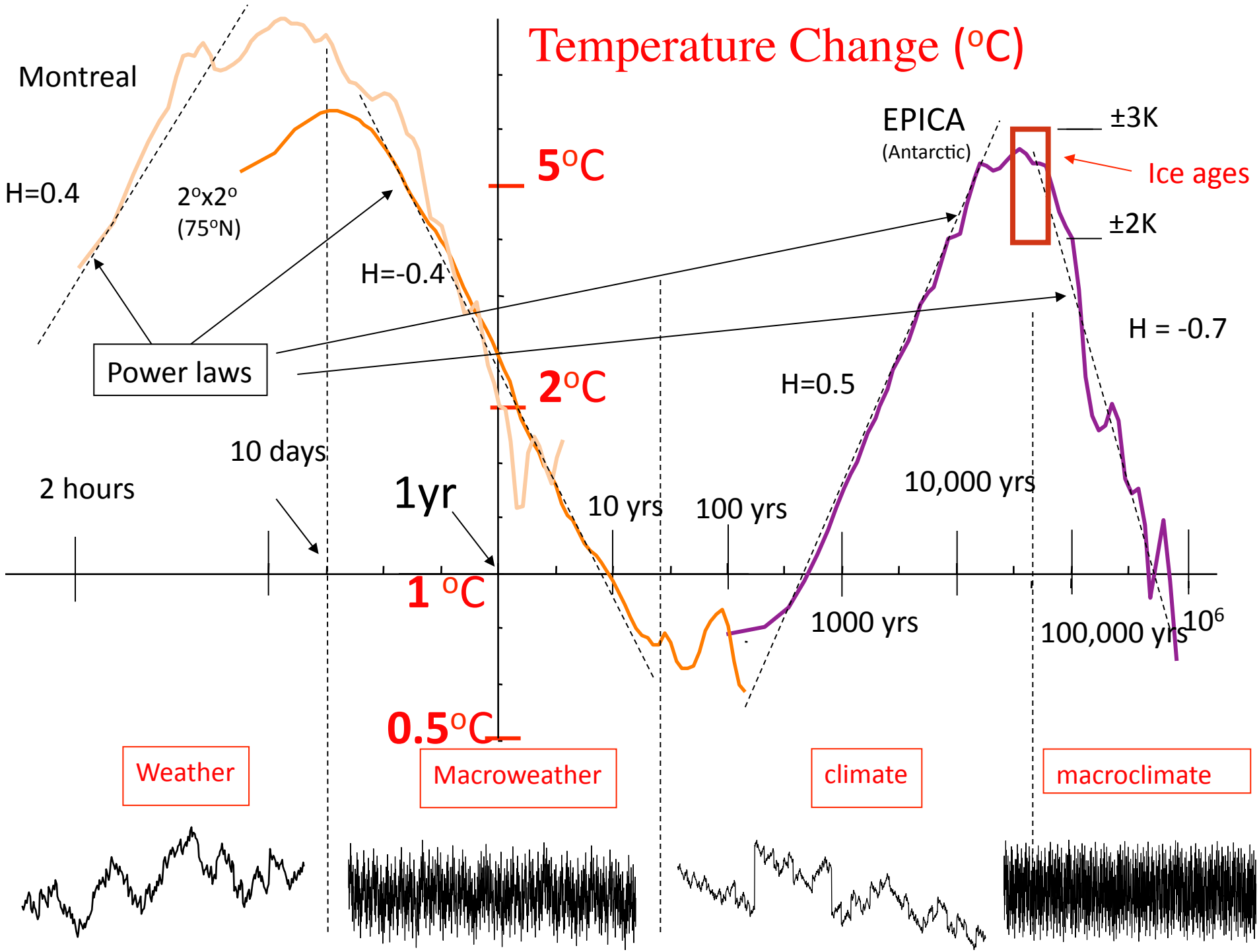


Trichotomy:

Weather – macroweather - climate



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
2 hours
10 days
1yr
10 yrs
100 yrs
1000 yrs
10,000 yrs
100,000 yrs
10^6
Weather
Macroweather
climate
macroclimate

Conclusion:

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

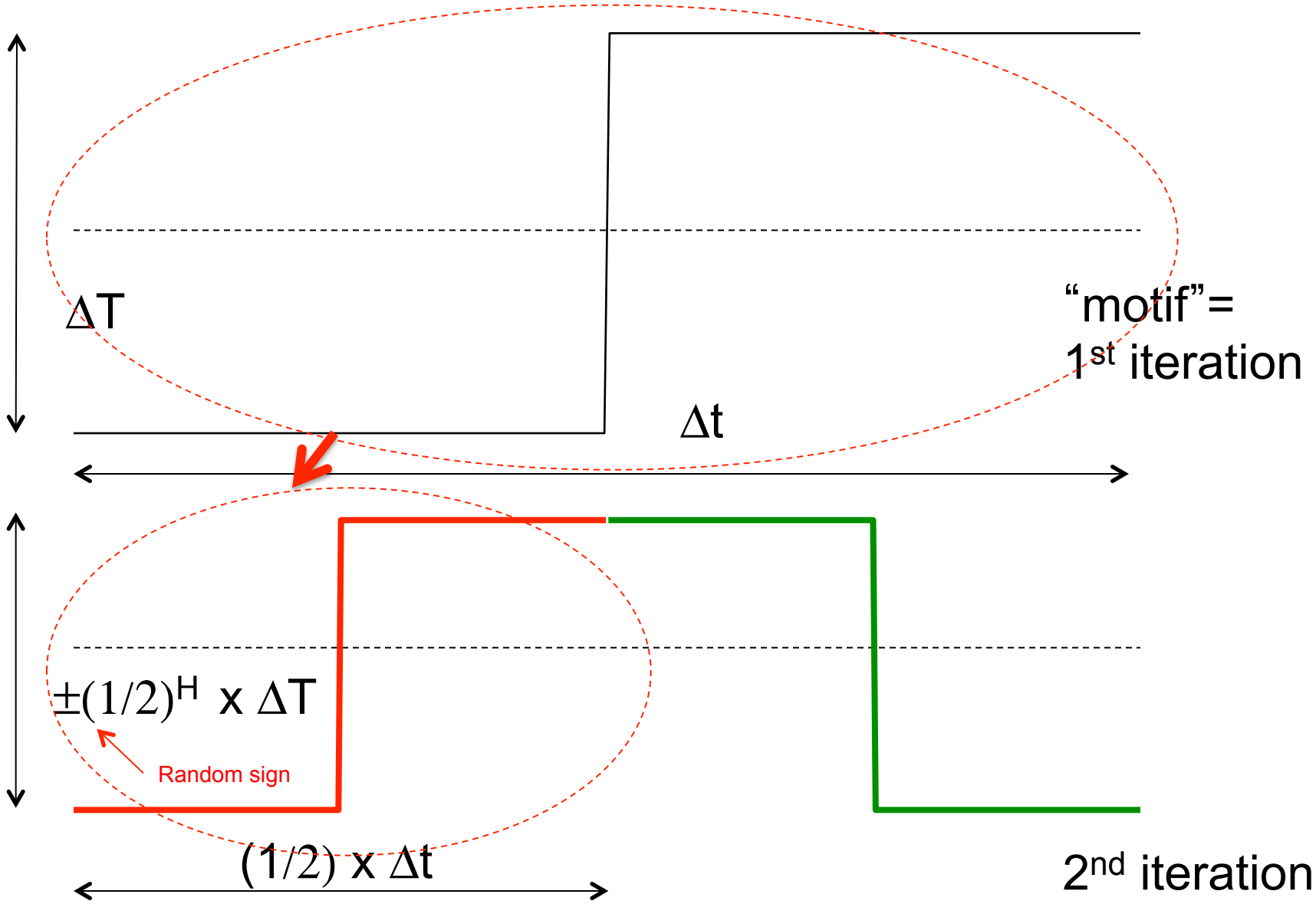
Weather, macroweather and the climate are distinguished by the way the change under a zoom!

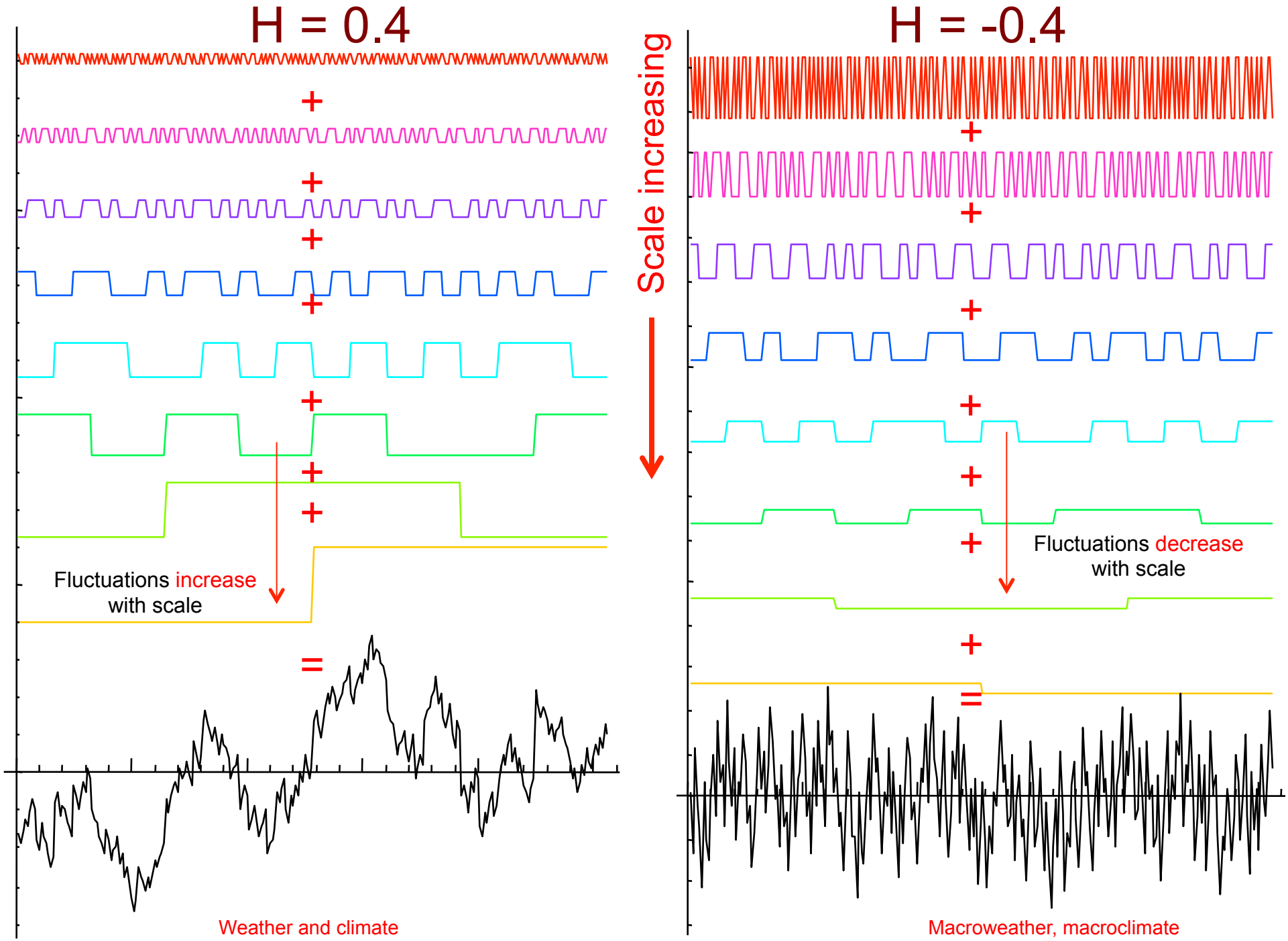
To understand the different regimes

The fractal H model

(Lovejoy 2013)

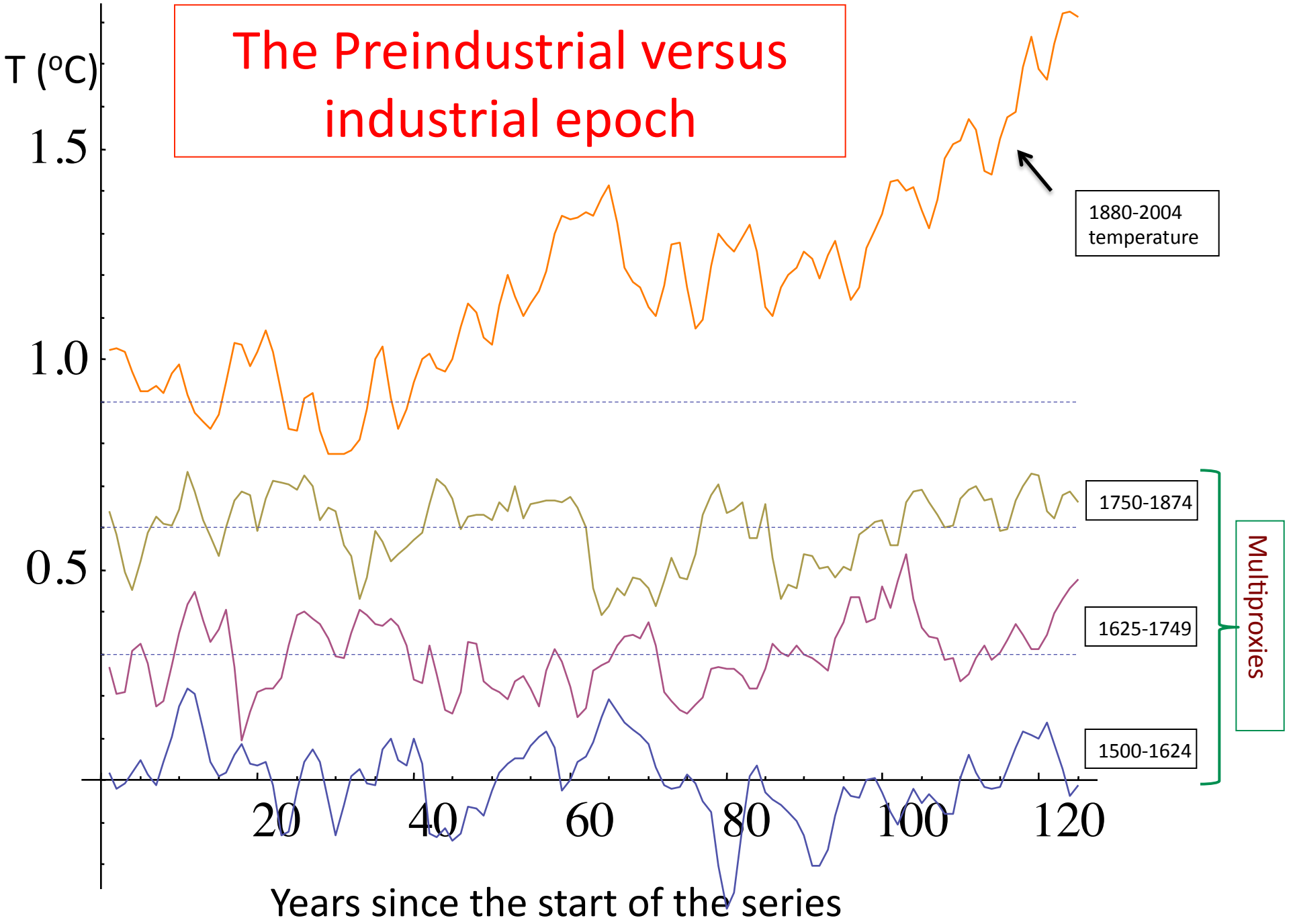
(fractal dimenension= 2-H)

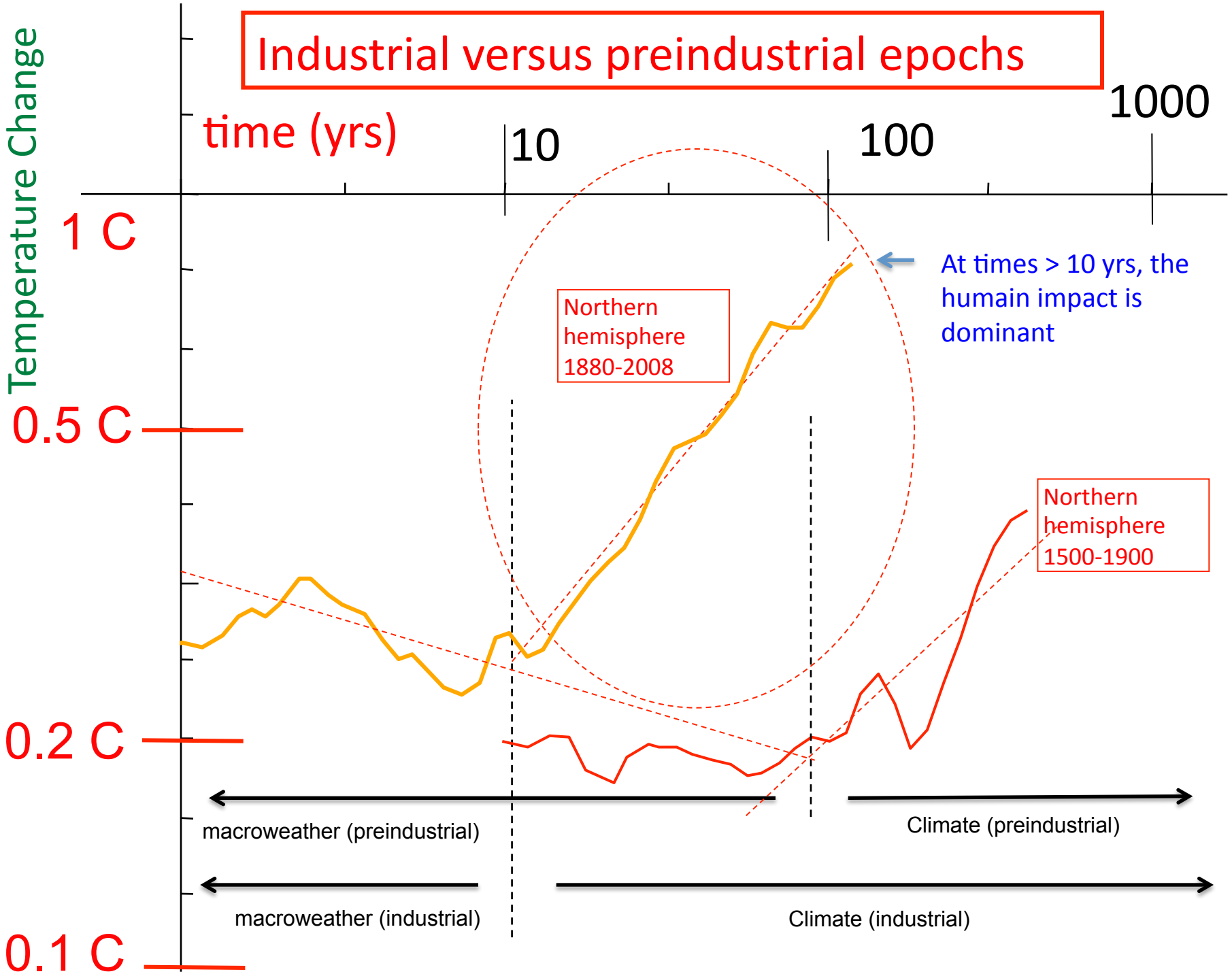



H = 0.4
H = -0.4
Scale increasing
Fluctuations increase with scale
Fluctuations decrease with scale
Weather and climate
Macroweather, macroclimate

How can we distinguish anthropogenic and natural variability?

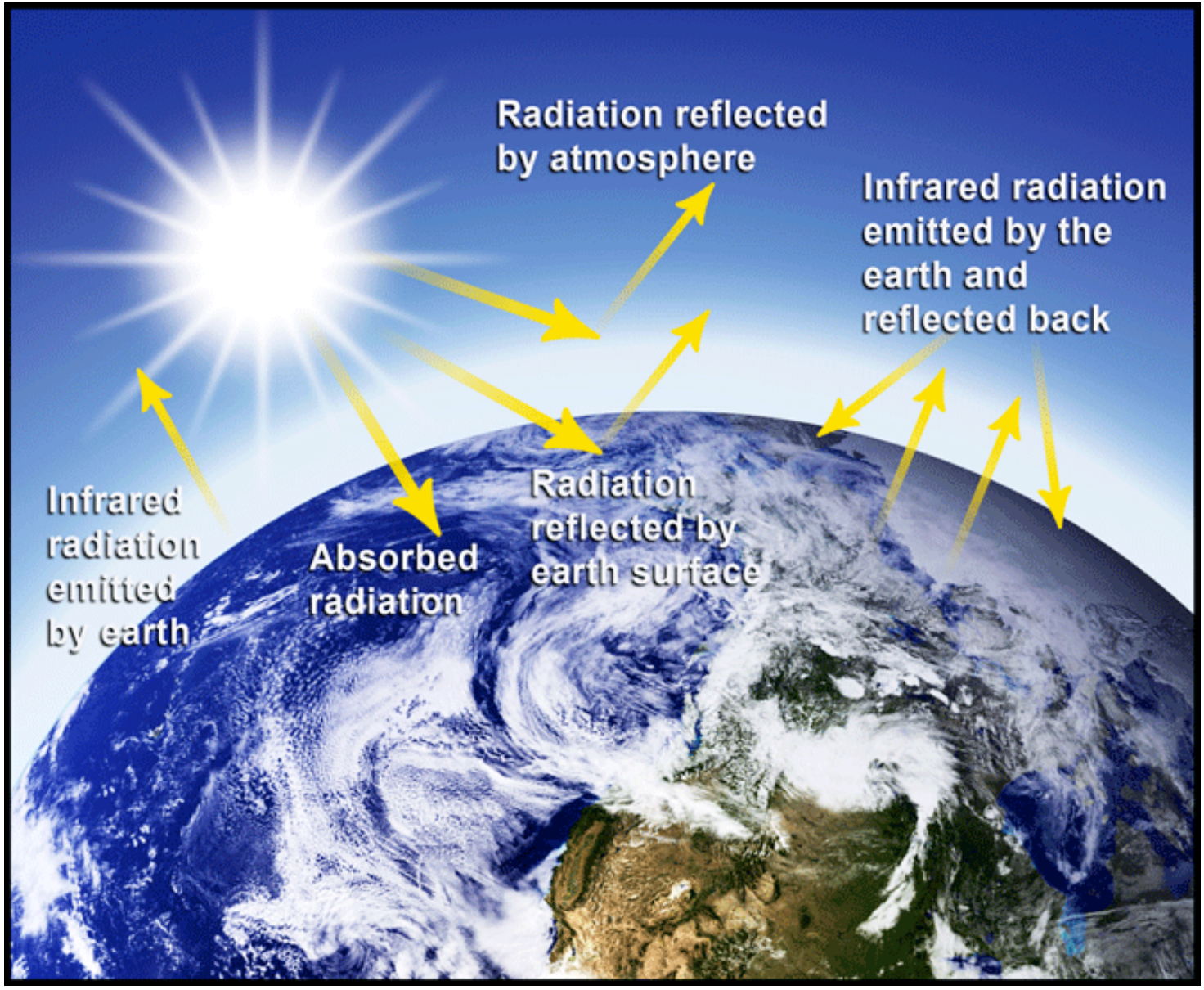
… by their different fractality!


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


Industrial versus preindustrial epochs
time (yrs)
10
100
1000
Temperature Change
1 C
0.5 C
0.2 C
0.1 C
Northern hemisphere 1880-2008
At times > 10 yrs, the humain impact is dominant
Northern hemisphere 1500-1900
macroweather (preindustrial)
Climate (preindustrial)
macroweather (industrial)
Climate (industrial)

Why is it warming?

The theory of anthropogenic warming

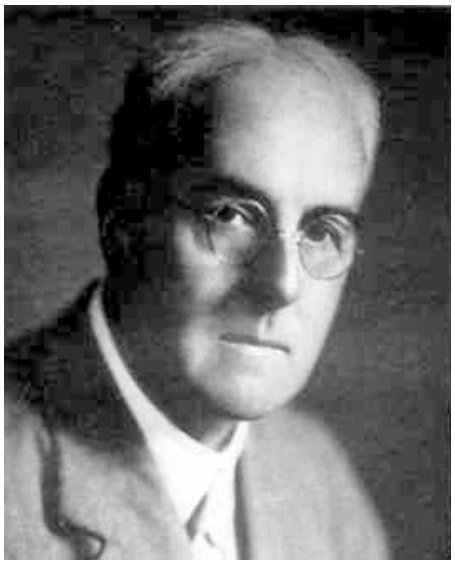


Svante Arrhenius

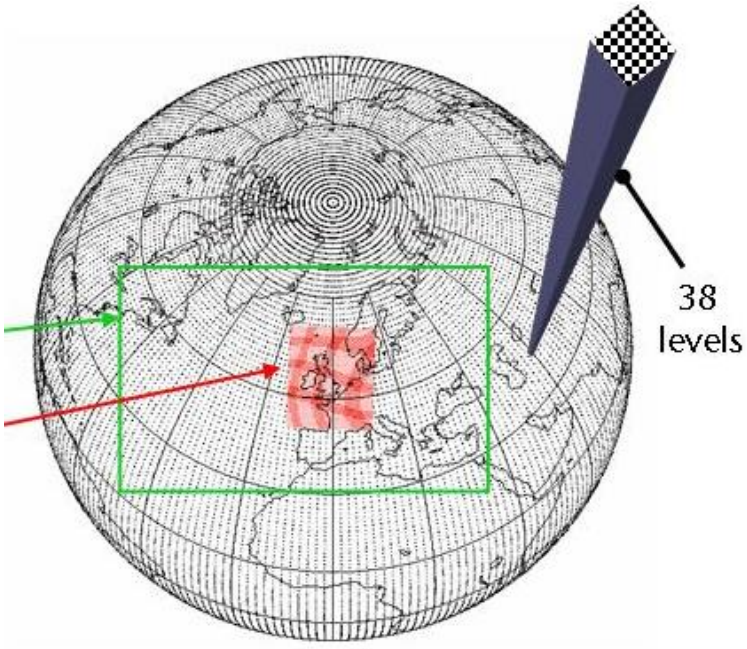
(1859 –1927)

In 1896 predicted CO_2 doubling would increase the earth's temperature by 5-6^{o}C

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

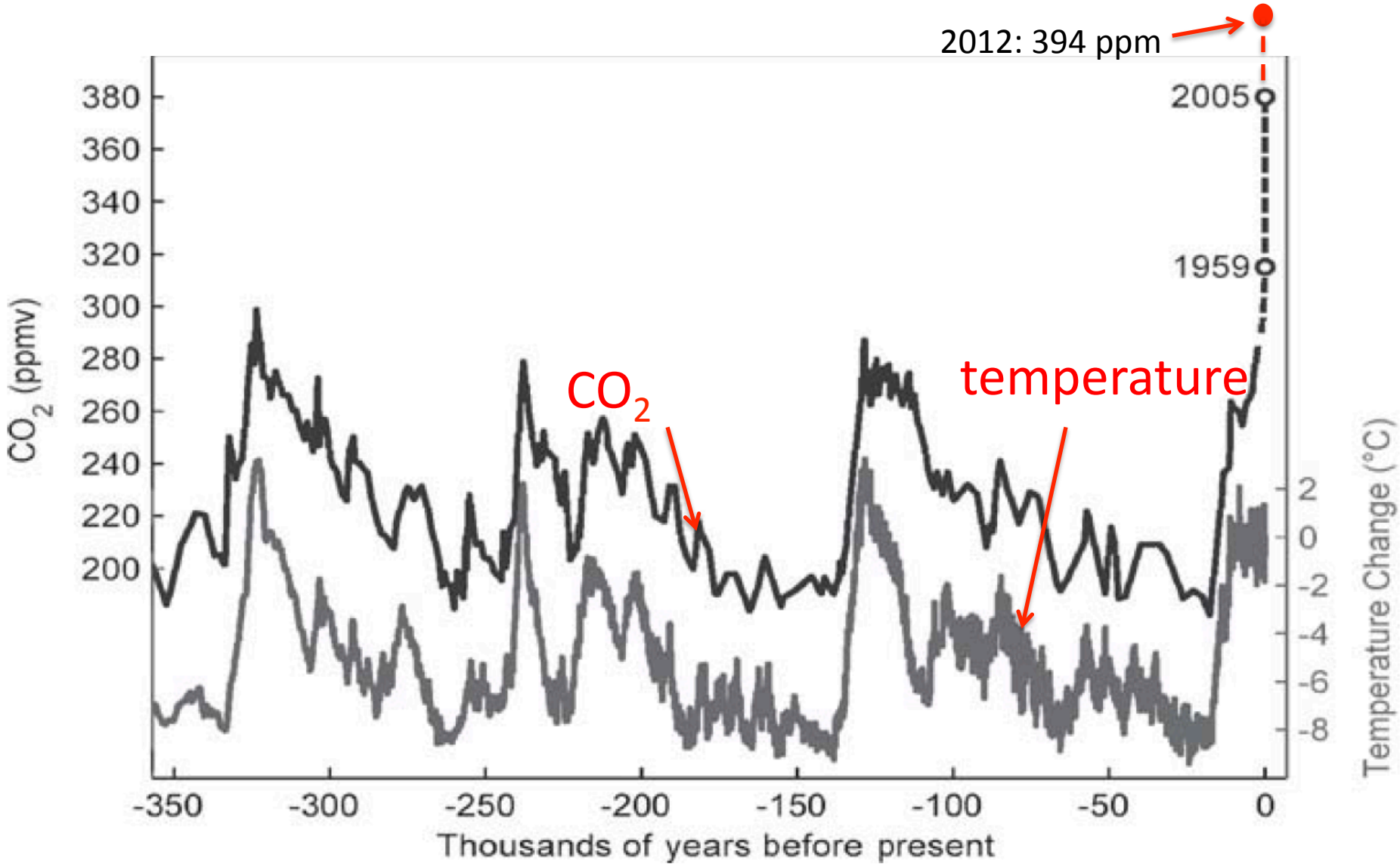
3,120,000 cores: 3×10^{16} Flops

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*")

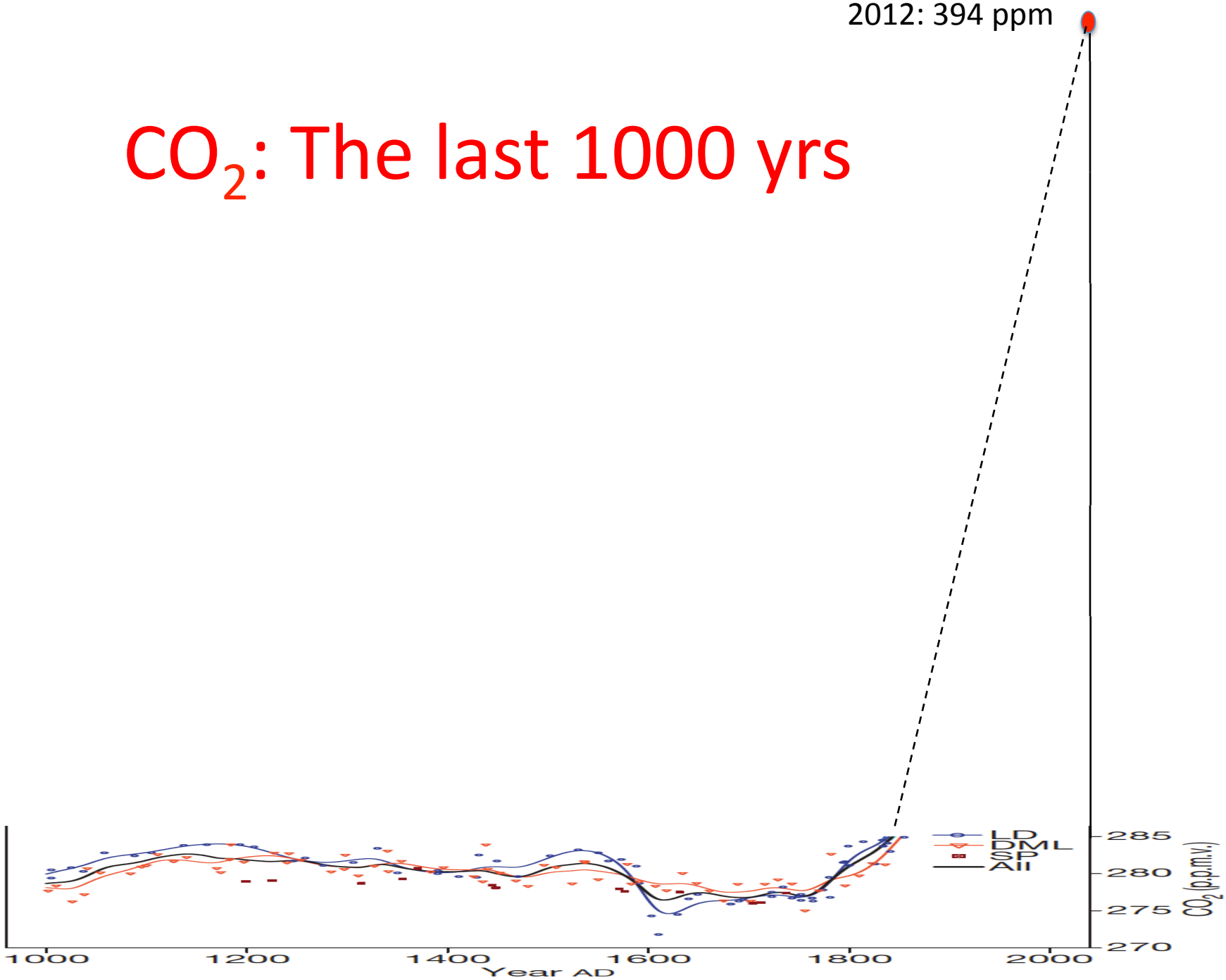
A (new) simple argument without GCM's

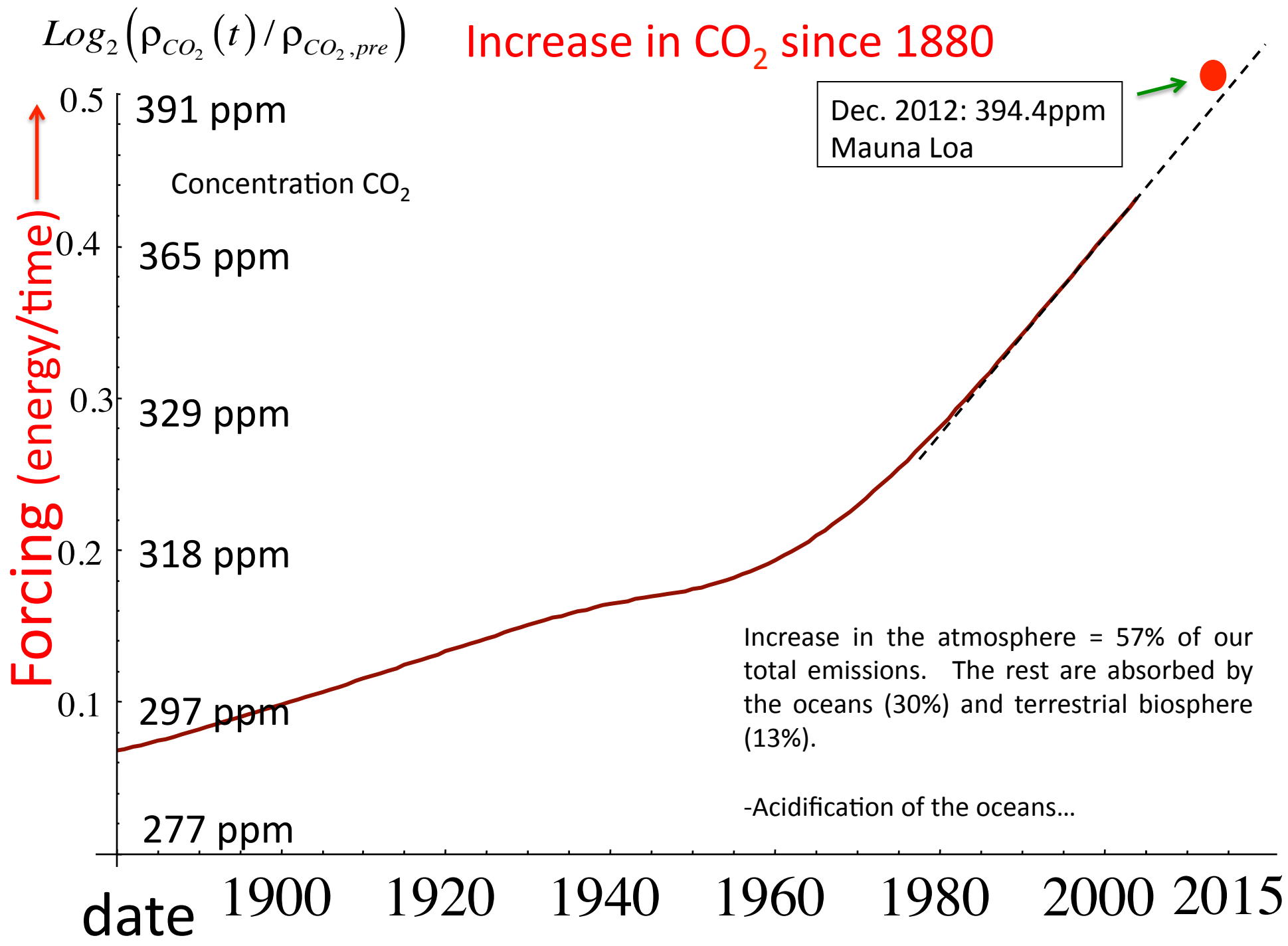
CO_2: The last 350,000 yrs

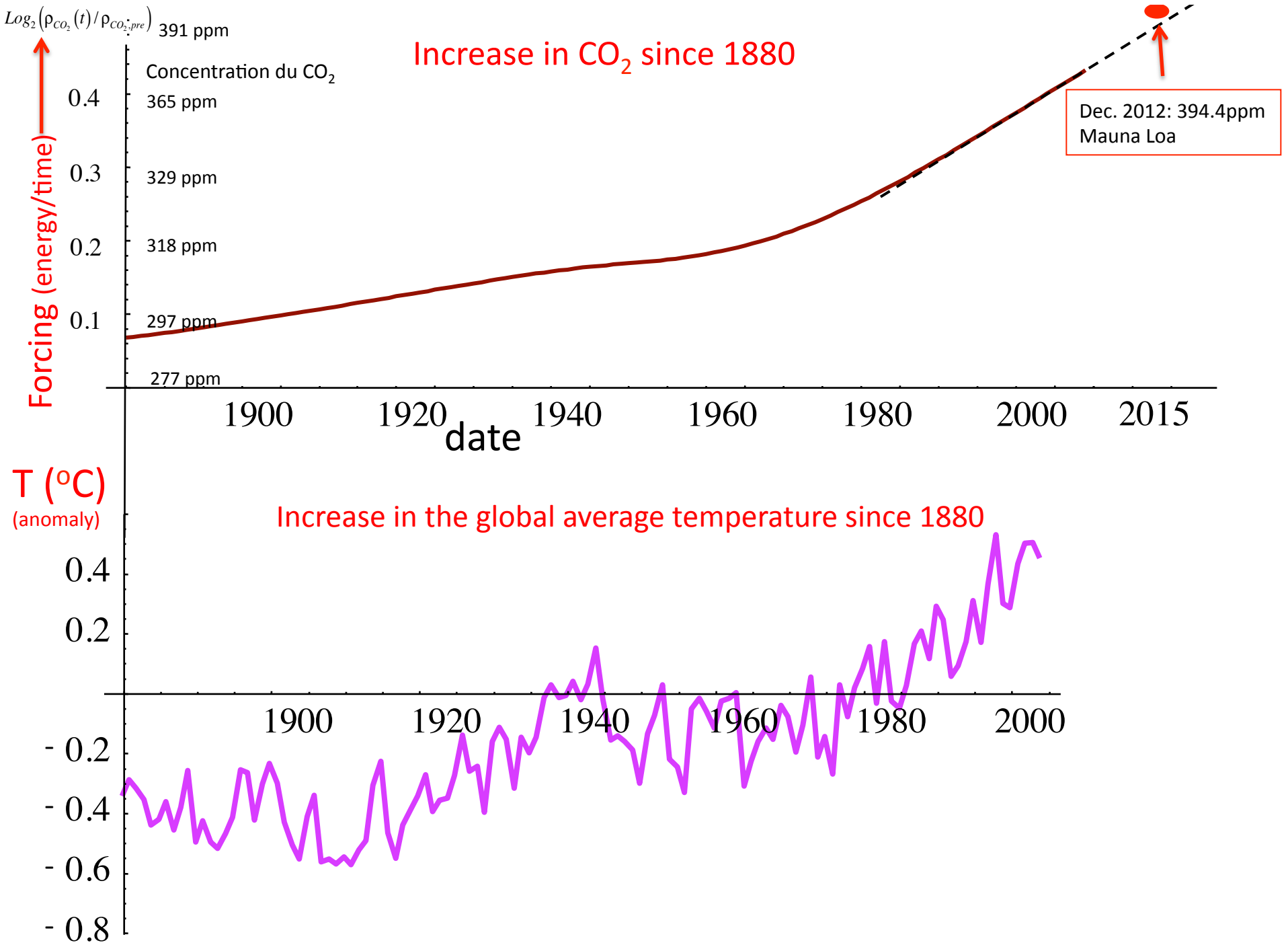


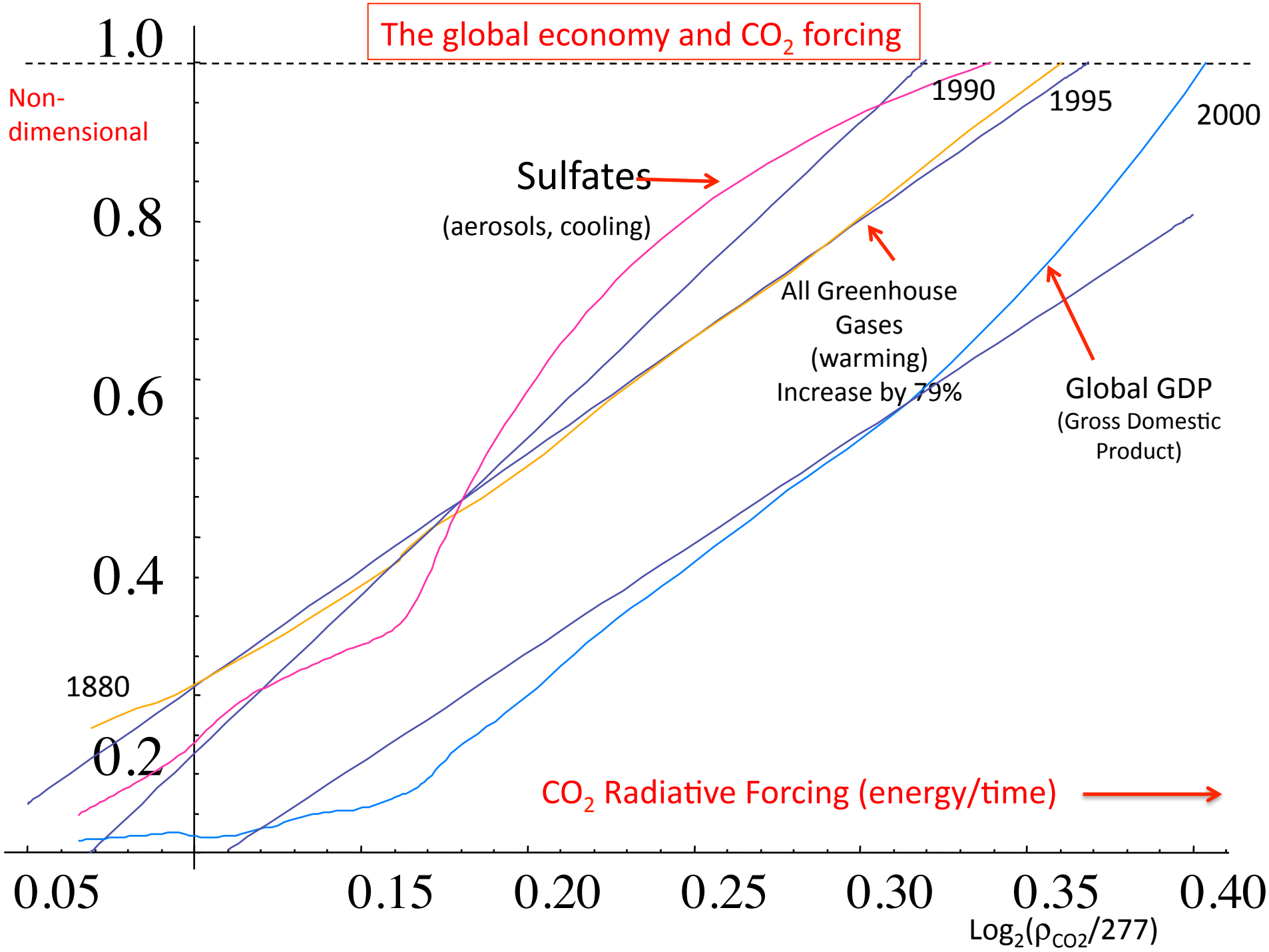
Source: J. R. Petit and others, "Climate and Atmospheric History of the Past 420,000 Years from the Vostok Ice Core, Antarctica," *Nature* 399 (June 1999): 429–36.

CO_2: The last 1000 yrs

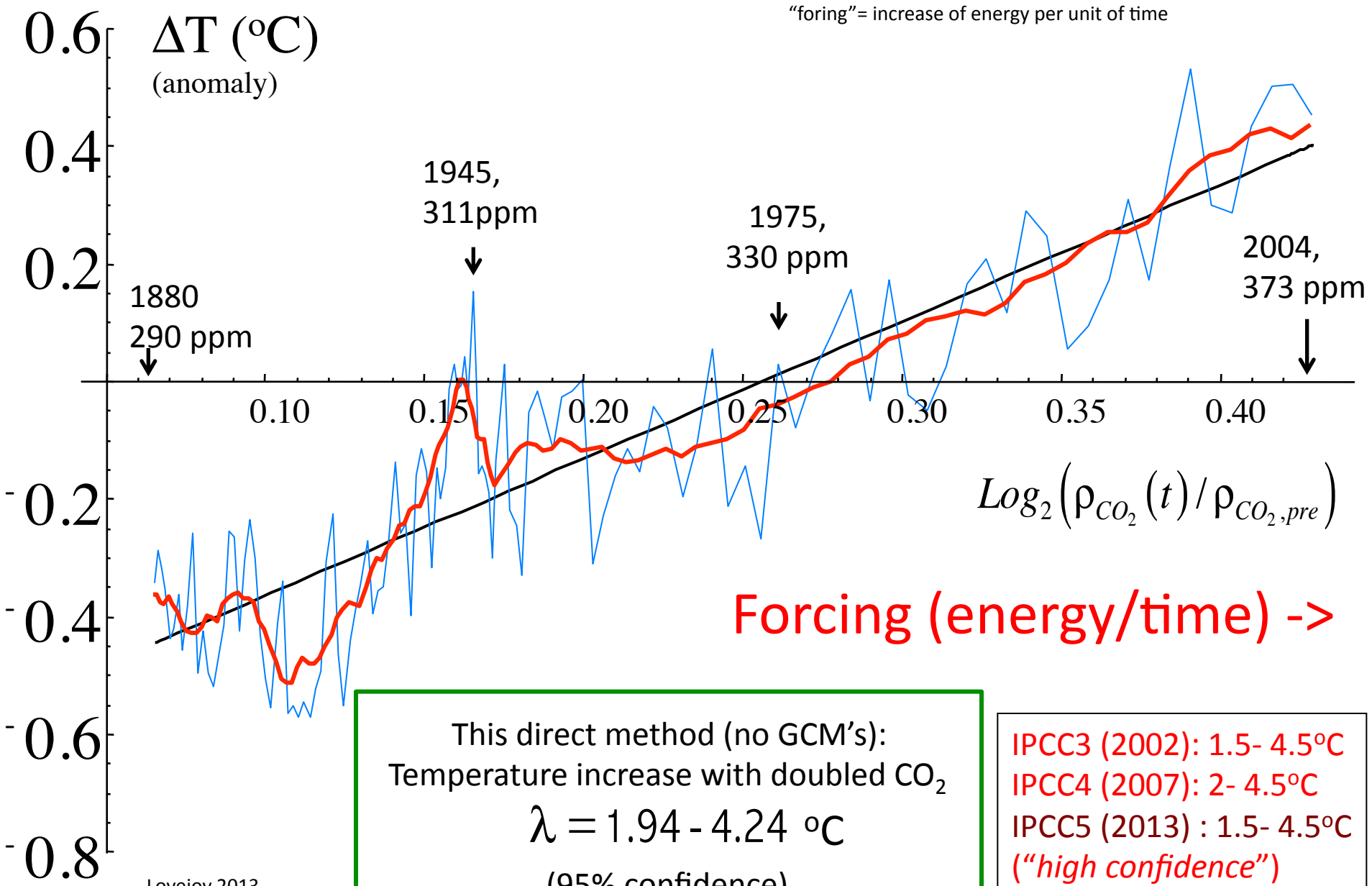



$Log_2\left(\rho_{CO_2}(t)/\rho_{CO_2,pre}\right)$
Increase in CO_2 since 1880
Forcing (energy/time)
0.5
0.4
0.3
0.2
0.1
391 ppm
Concentration CO_2
365 ppm
329 ppm
318 ppm
297 ppm
277 ppm
Dec. 2012: 394.4ppm
Mauna Loa
Increase in the atmosphere = 57% of our total emissions. The rest are absorbed by the oceans (30%) and terrestrial biosphere (13%).
-Acidification of the oceans…
date
1900
1920
1940
1960
1980
2000
2015


$Log_2\left(\rho_{CO_2}(t)/\rho_{CO_2:pre}\right)$
Forcing (energy/time)
391 ppm
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
Dec. 2012: 394.4ppm
Mauna Loa
T (°C)
(anomaly)
Increase in the global average temperature since 1880
0.4
0.2
- 0.2
- 0.4
- 0.6
- 0.8
1900
1920
1940
1960
1980
2000


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) Increase 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
$Log_2(\rho_{CO2}/277)$

The Temperature is nearly linear with the CO_2 forcing

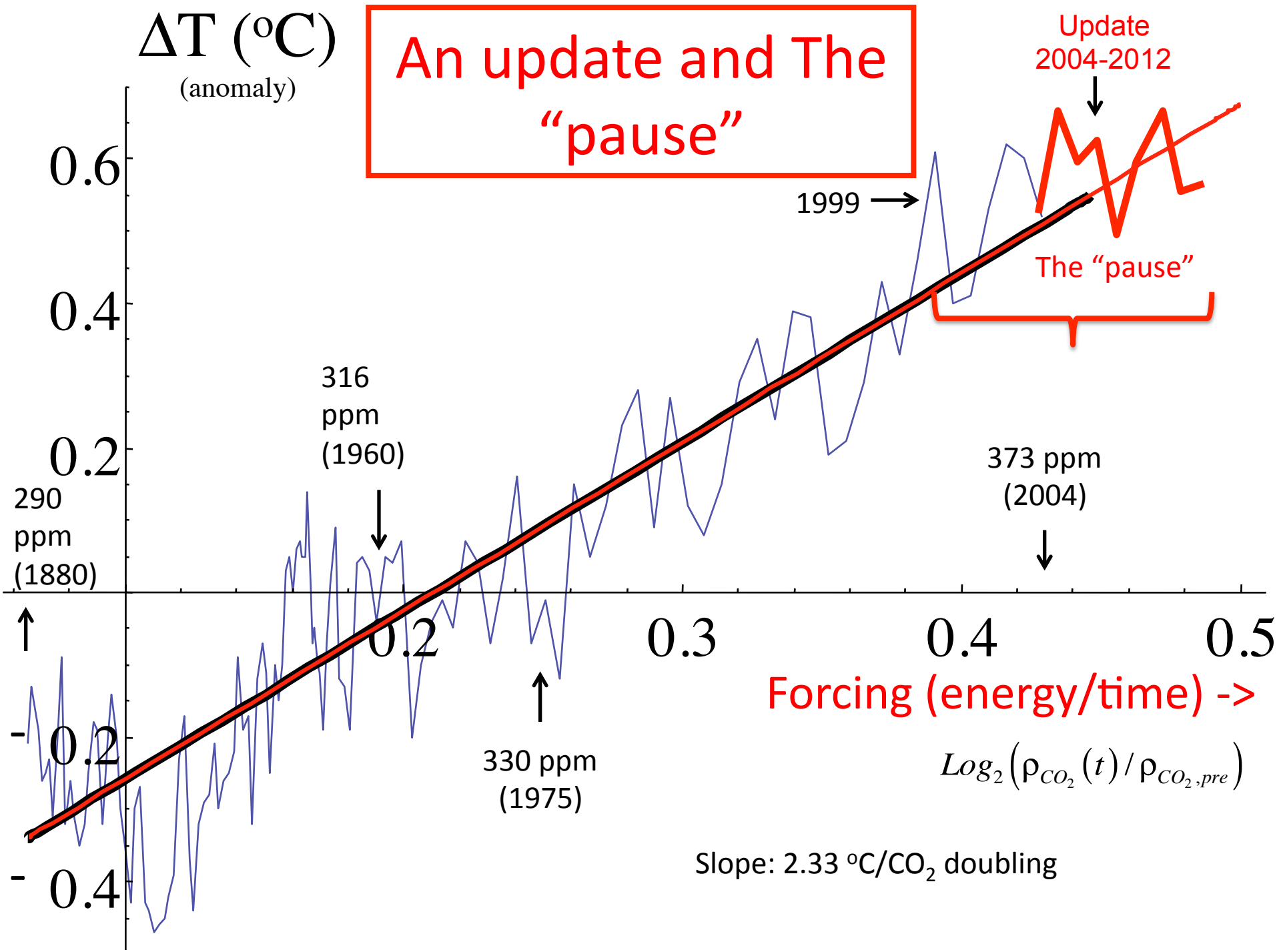


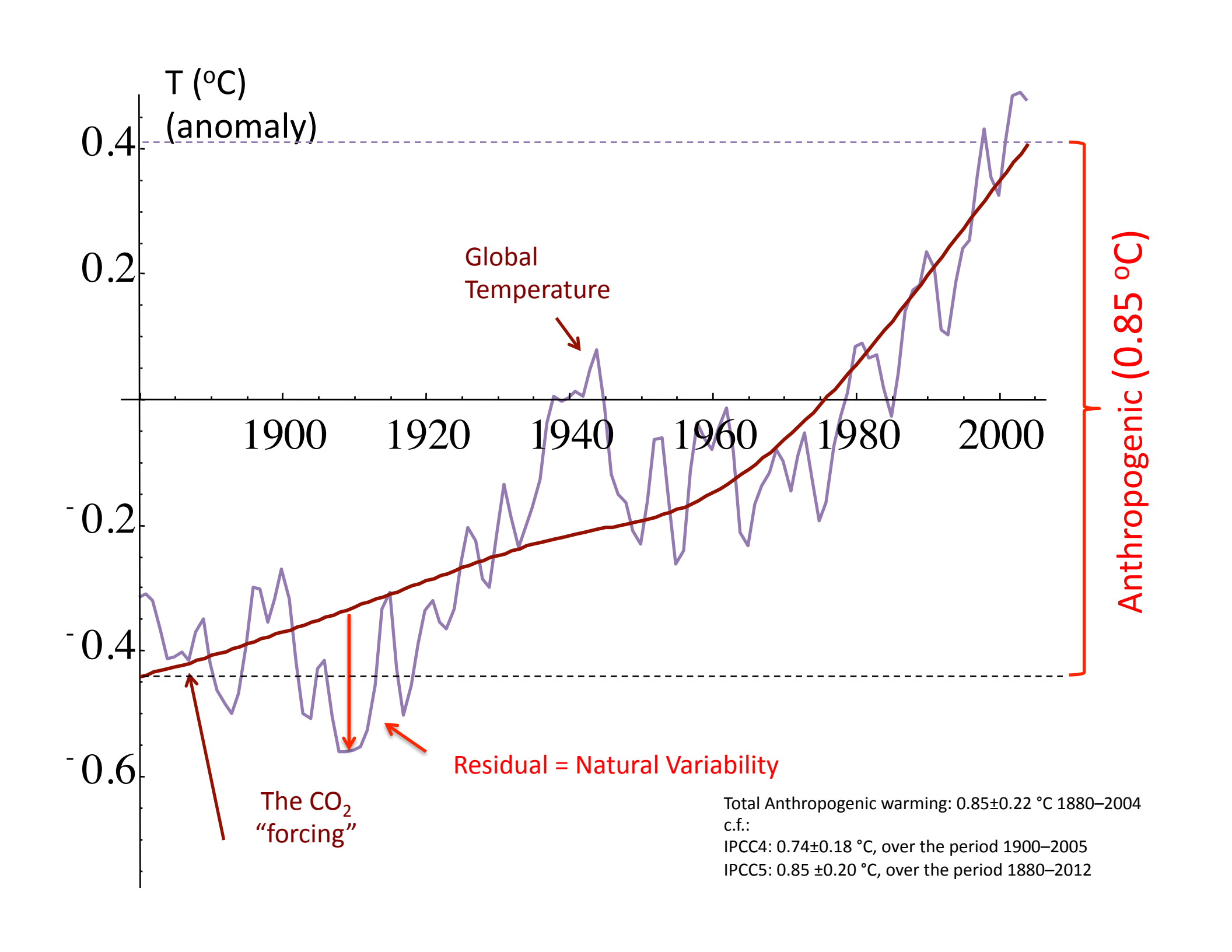
This direct method (no GCM's):
Temperature increase with doubled CO_2

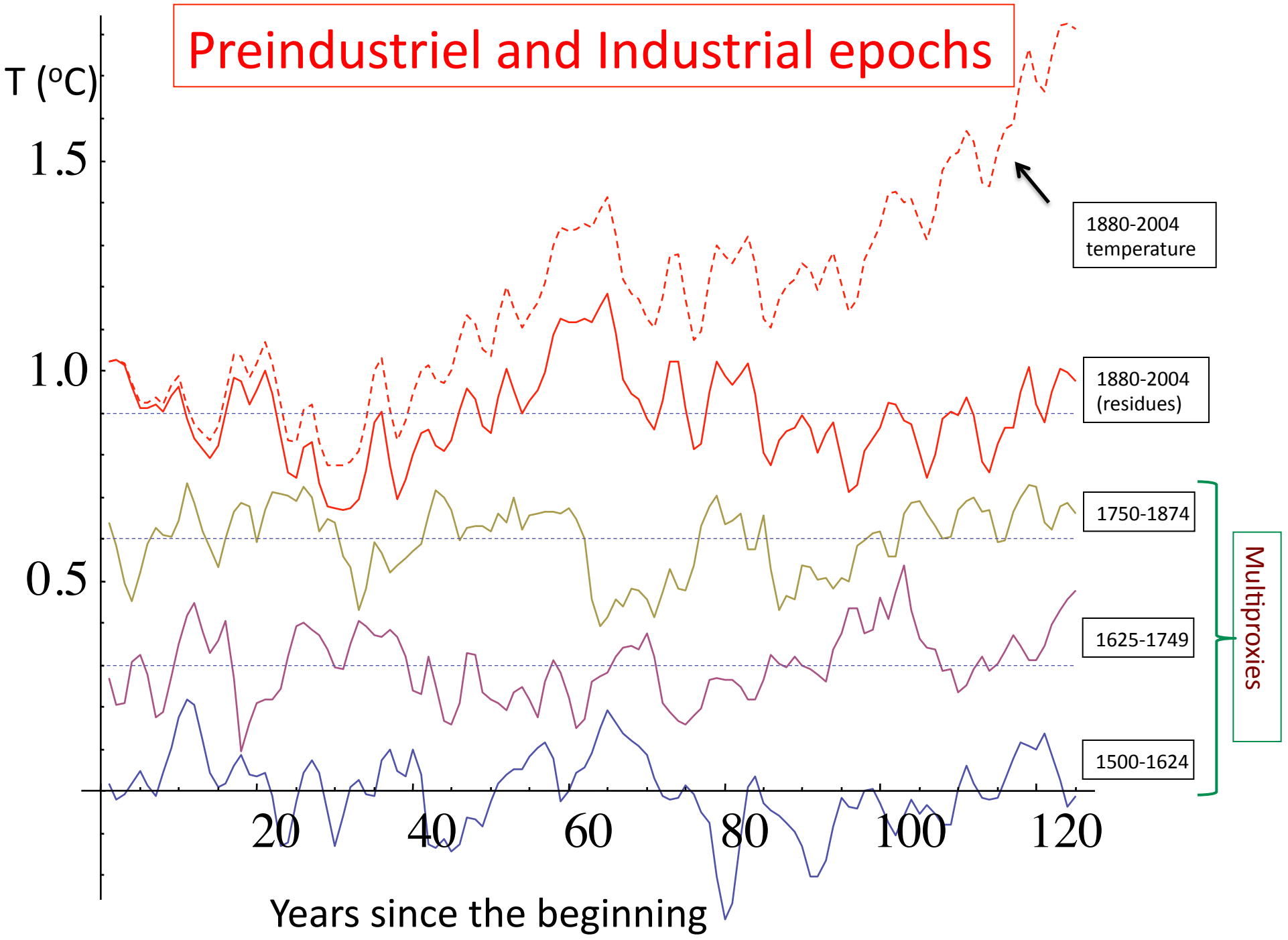
$$\lambda = 1.94 - 4.24\ ^{o}C$$

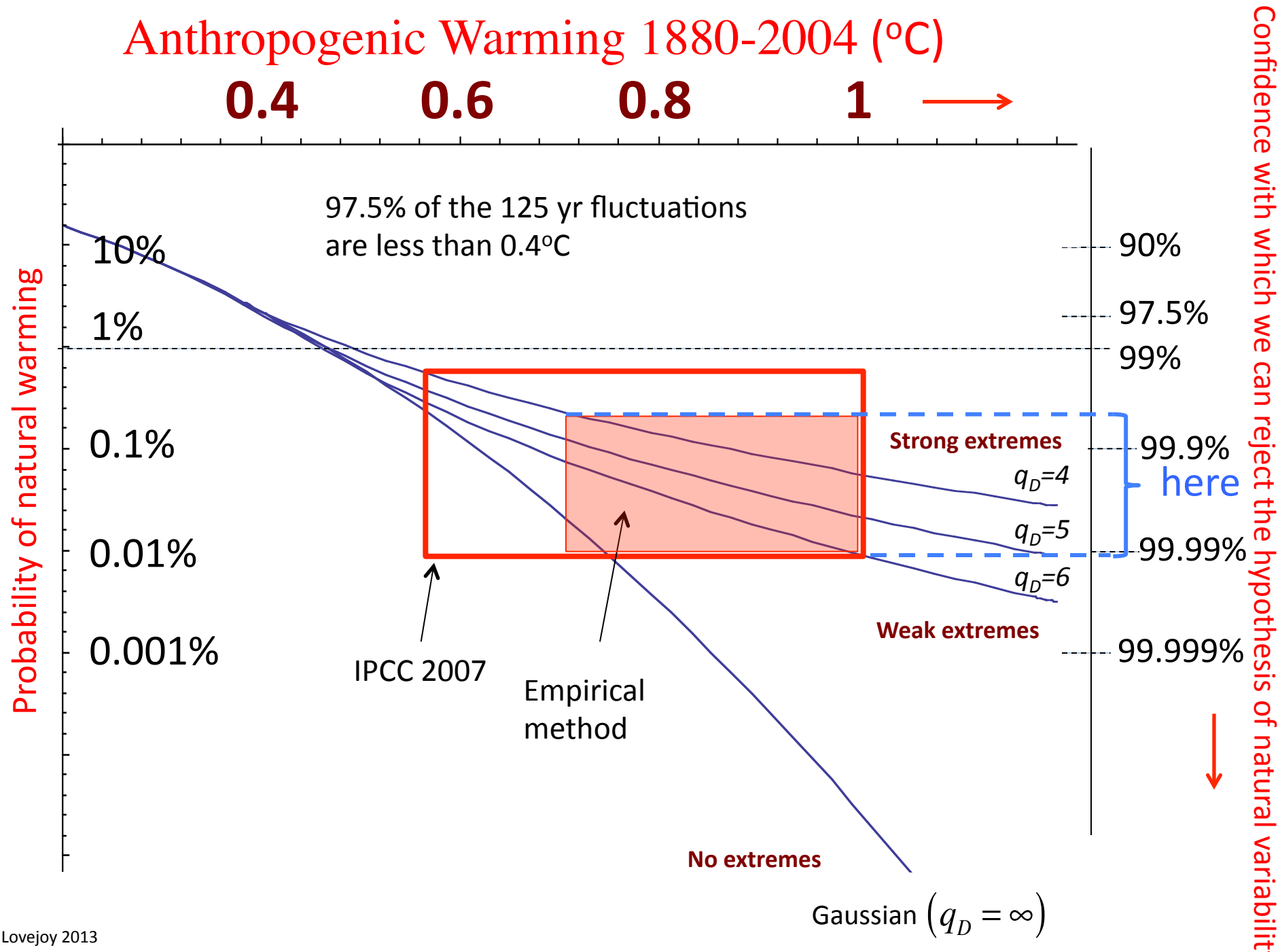
(95% confidence)

IPCC3 (2002): 1.5- 4.5°C
IPCC4 (2007): 2- 4.5°C
IPCC5 (2013) : 1.5- 4.5°C
(*"high confidence"*)

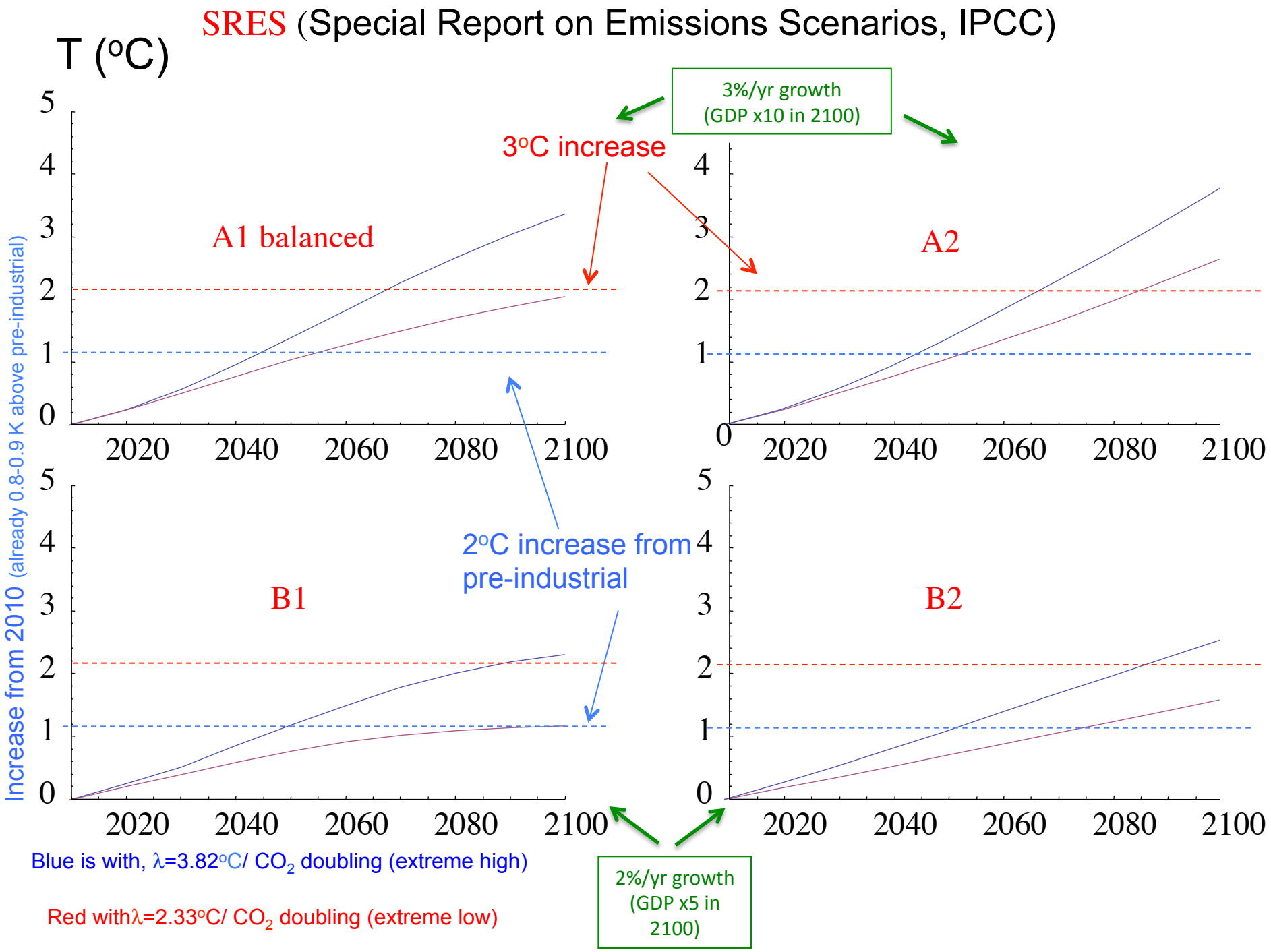

ΔT (°C)
(anomaly)
An update and The "pause"
Update 2004-2012
1999
The "pause"
316 ppm (1960)
290 ppm (1880)
373 ppm (2004)
330 ppm (1975)
0.6
0.4
0.2
-0.2
-0.4
0.2
0.3
0.4
0.5
Forcing (energy/time) ->
$Log_2\left(\rho_{CO_2}(t)/\rho_{CO_2,pre}\right)$
Slope: 2.33 °C/CO2 doubling


T (°C)
(anomaly)
0.4
0.2
-0.2
-0.4
-0.6
1900
1920
1940
1960
1980
2000
Global
Temperature
Anthropogenic (0.85 °C)
Residual = Natural Variability
The CO_2
"forcing"
Total Anthropogenic warming: 0.85±0.22 °C 1880–2004
c.f.:
IPCC4: 0.74±0.18 °C, over the period 1900–2005
IPCC5: 0.85 ±0.20 °C, over the period 1880–2012


Preindustriel and Industrial epochs
T (°C)
1.5
1.0
0.5
1880-2004 temperature
1880-2004 (residues)
1750-1874
1625-1749
1500-1624
Multiproxies
20
40
60
80
100
120
Years since the beginning

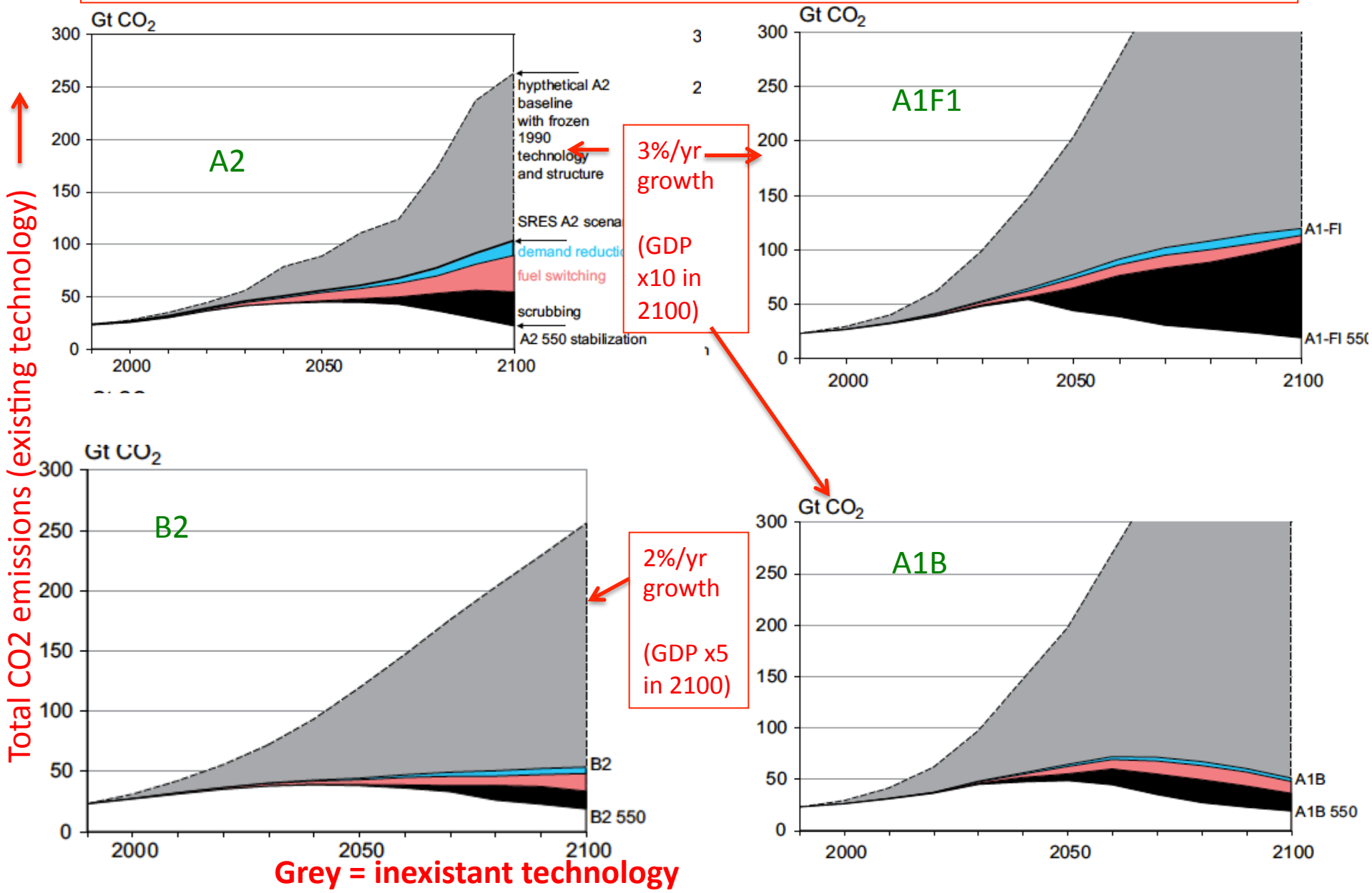


Lovejoy 2013

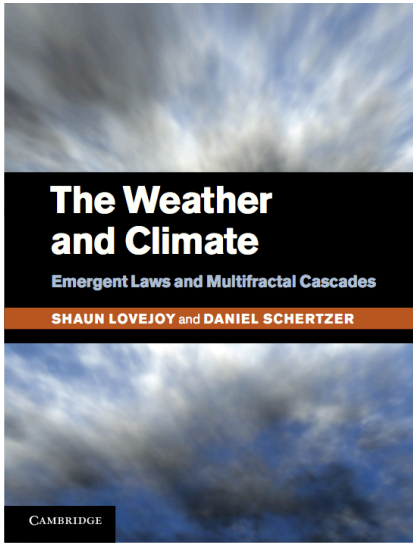

SRES (Special Report on Emissions Scenarios, IPCC)
T (°C)
Increase from 2010 (already 0.8-0.9 K above pre-industrial)
3%/yr growth
(GDP x10 in 2100)
3°C increase
A1 balanced
A2
B1
B2
2°C increase from
pre-industrial
2%/yr growth
(GDP x5 in
2100)
Blue is with, λ=3.82°C/ CO2 doubling (extreme high)
Red withλ=2.33°C/ CO2 doubling (extreme low)
0
1
2
3
4
5
2020
2040
2060
2080
2100

The role of existent and new technologies

(IPCC scenarios, 2007; Stabilisation at 550ppm)



Conclusions



1. The variability of the atmosphere over the last 100,000 yrs has three different regimes not two:

-weather (less than about 10 days),

-macroweather (10 days to about 10 years (industrial), 100 years (preindustrial),

-climate (up to ≈100,000yrs).

2. The regimes are defined by the way they change under zooms: their fractality.

3. Fluctuations increase with scale in the weather and climate regime but decrease with scale in the macroweather regime: "macroweather is what you expect".

4. Anthropogenic warming dominates macroweather at about 10 years rather than about 100 years (preindustrial).

5. The total anthropogenic warming is about 0.85°C, for CO_2 doubling, 3.08±0.58°C.

6. The probability that the warming since 1880 is natural is <1% (most likely <0.1%).