# Scale invariance of fluctuations, the return time of climate events and anthropogenic warming*

"A mephiticly ectoplasmic emanation from the forces of darkness"
– Viscount Christopher Monckton of Brenchley

"Une émanation éctoplasmique méphitique des forces des ténèbres."
- Lord Christopher Monckton de Brenchley

CNRS, Wimereux 12, May, 2014
Université Paris Sud, Orsay, 13, May, 2014
Institut Pierre Simon Laplace, ENS, 15, May, 2014

**S. Lovejoy, McGill, Montreal**

*** Transparencies in English presentation given in French**

# L'invariance d'échelle des fluctuations, le temps de retour des évènements climatiques et le réchauffement anthropique

"A mephiticly ectoplasmic emanation from the forces of darkness"
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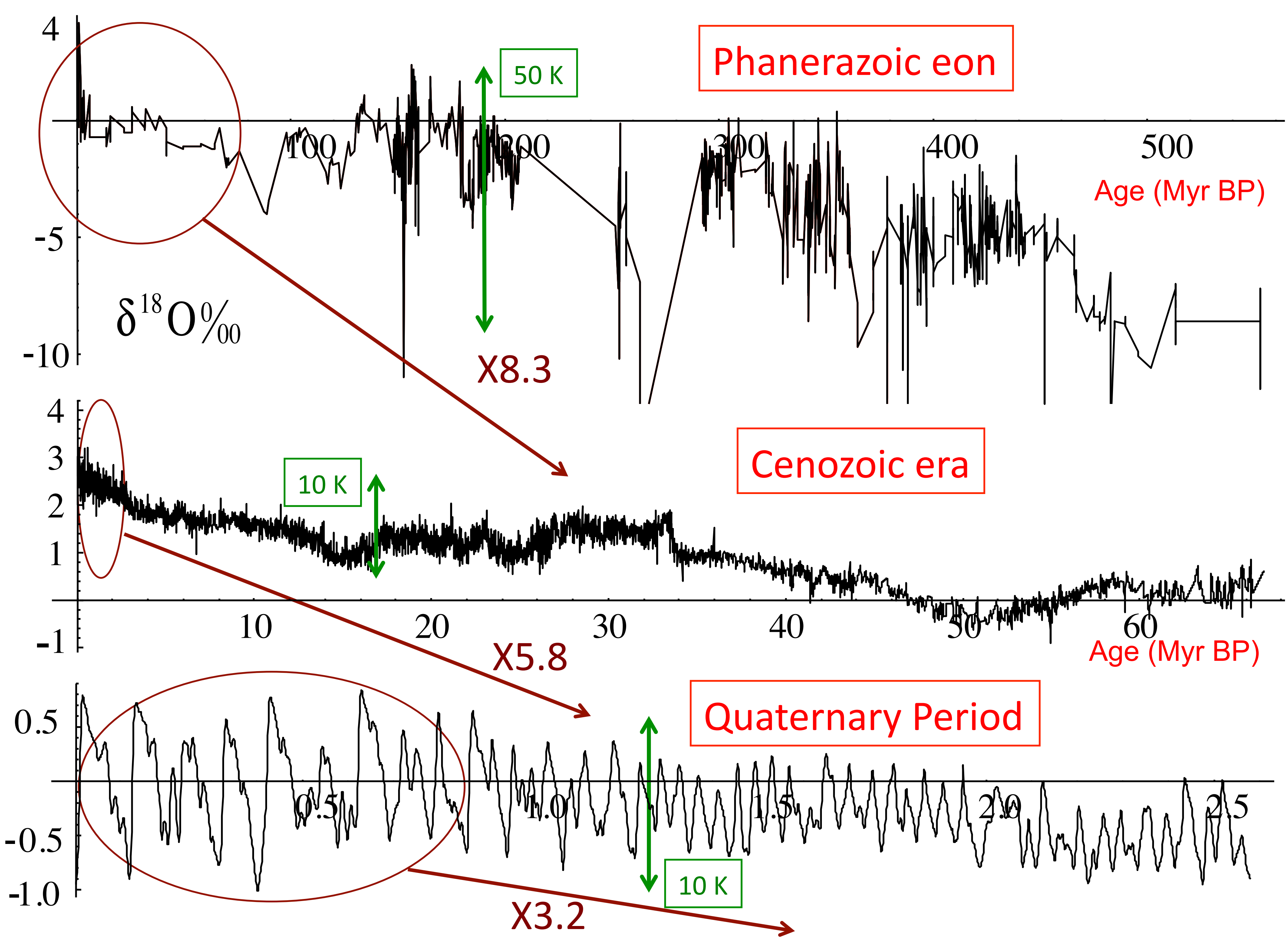
IPSL 15, Mai, 2014

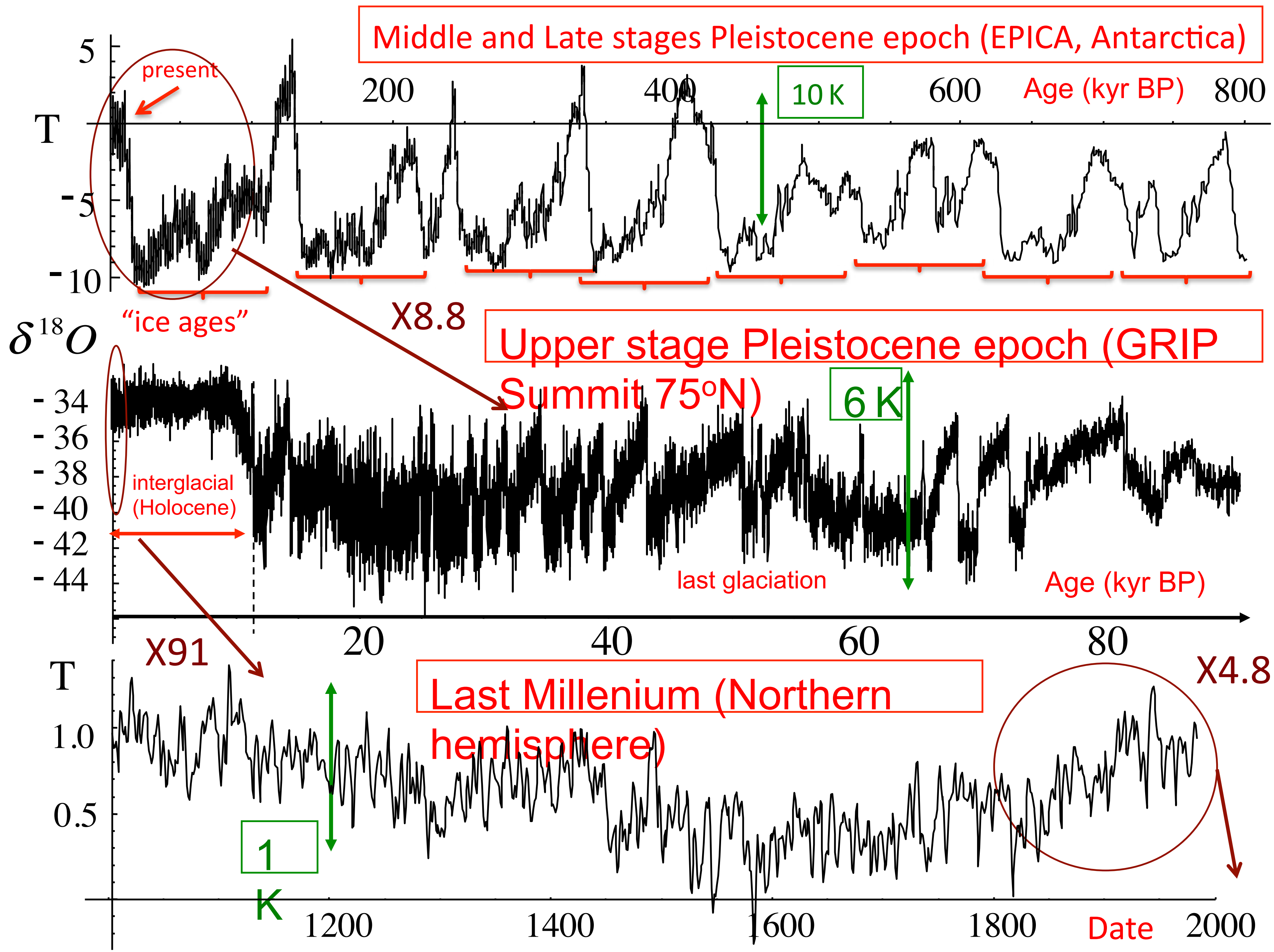
From the age of the earth to the viscous dissipation scale: $4.5\times10^9$ years - 1 ms:

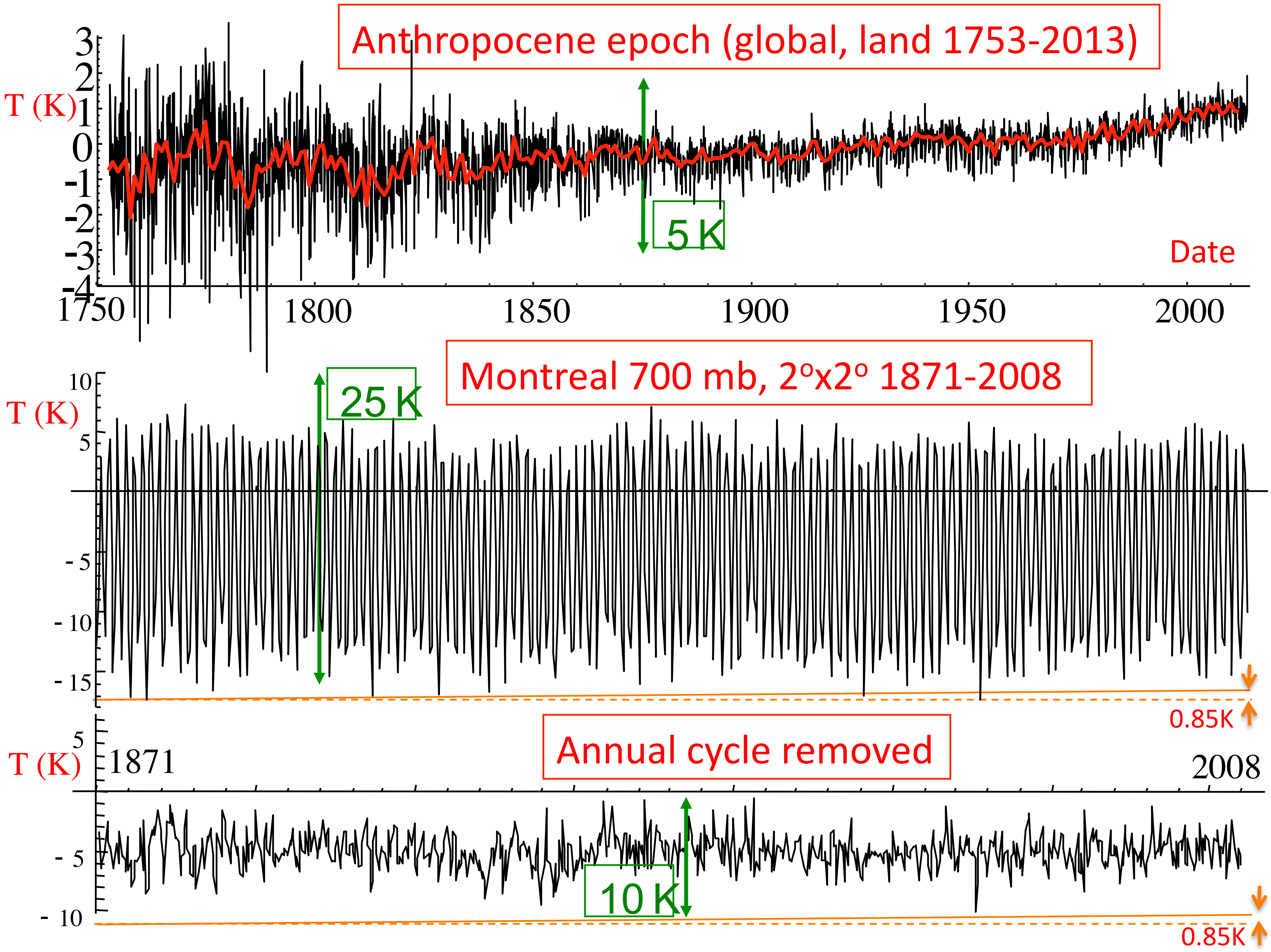
20 orders of magnitude in time

A voyage through scale…

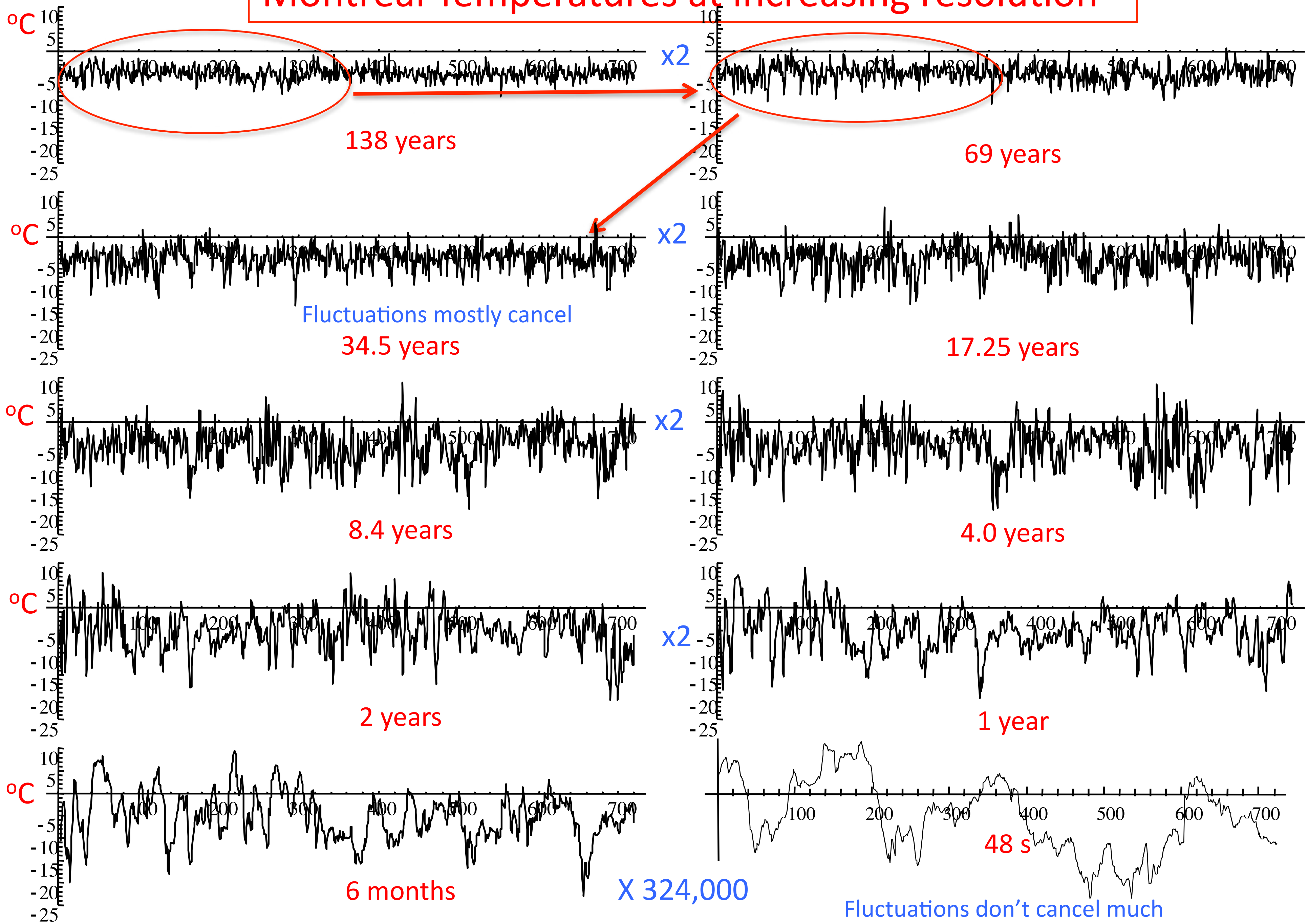


Phanerazoic eon
50 K
4
-5
-10
$\delta^{18}O‰$
100
200
300
400
500
Age (Myr BP)
X8.3
Cenozoic era
10 K
4
3
2
1
-1
10
20
30
40
50
60
Age (Myr BP)
X5.8
Quaternary Period
0.5
-0.5
-1.0
0.5
1.0
1.5
2.0
2.5
10 K
X3.2


Middle and Late stages Pleistocene epoch (EPICA, Antarctica)
T
5
-5
-10
present
200
400
600
Age (kyr BP)
800
10 K
"ice ages"
X8.8
$\delta^{18}O$
Upper stage Pleistocene epoch (GRIP Summit 75ºN)
6 K
- 34
- 36
- 38
- 40
- 42
- 44
interglacial
(Holocene)
last glaciation
Age (kyr BP)
20
40
60
80
X91
X4.8
T
1.0
0.5
Last Millenium (Northern hemisphere)
1 K
1200
1400
1600
1800
Date
2000


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



How to understand the variability?

Answer #1:

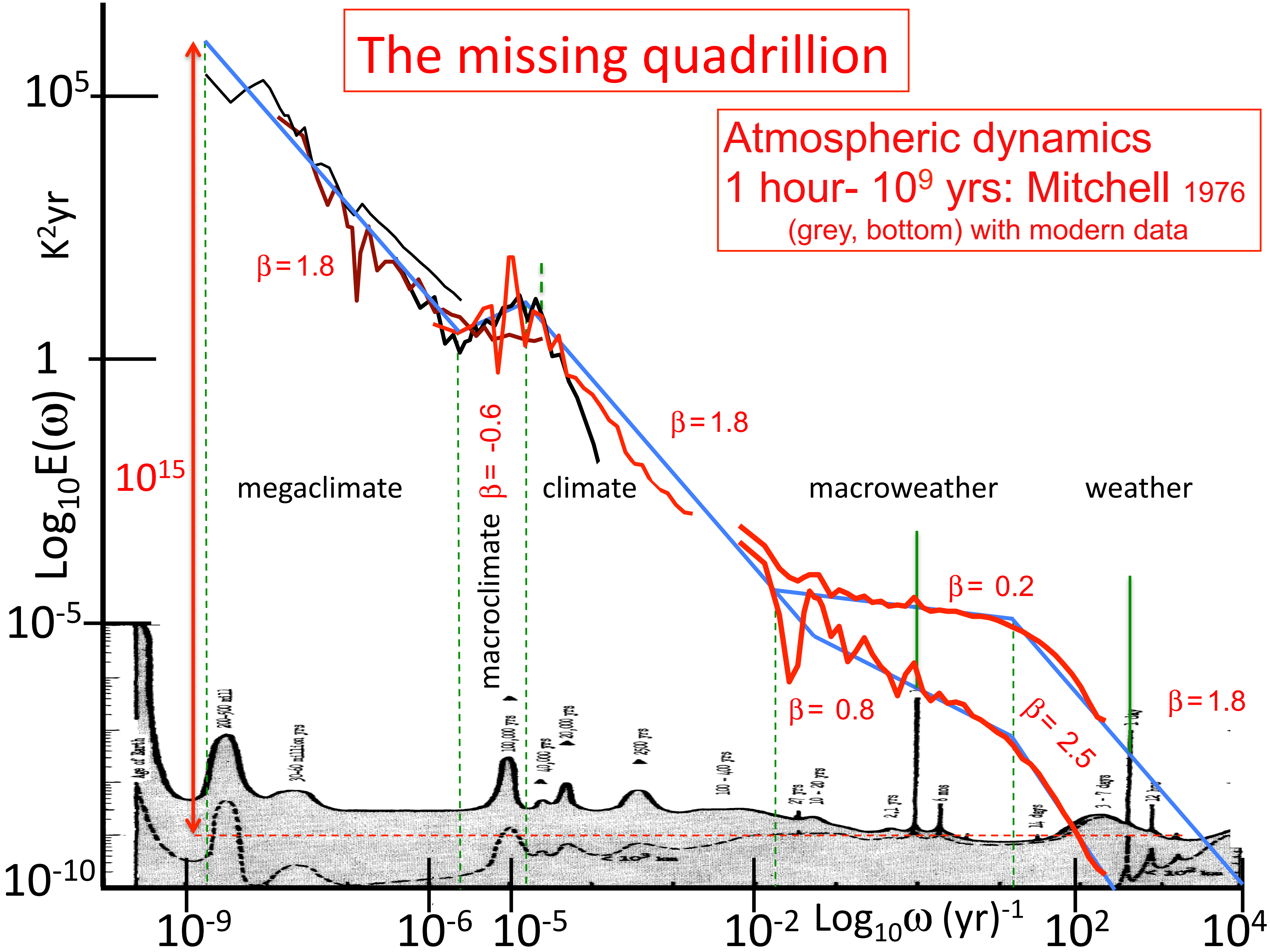
# Scale bound thinking

# Antonie van Leeuwenhoek (1632–1723)

## "A new world" in a drop of water

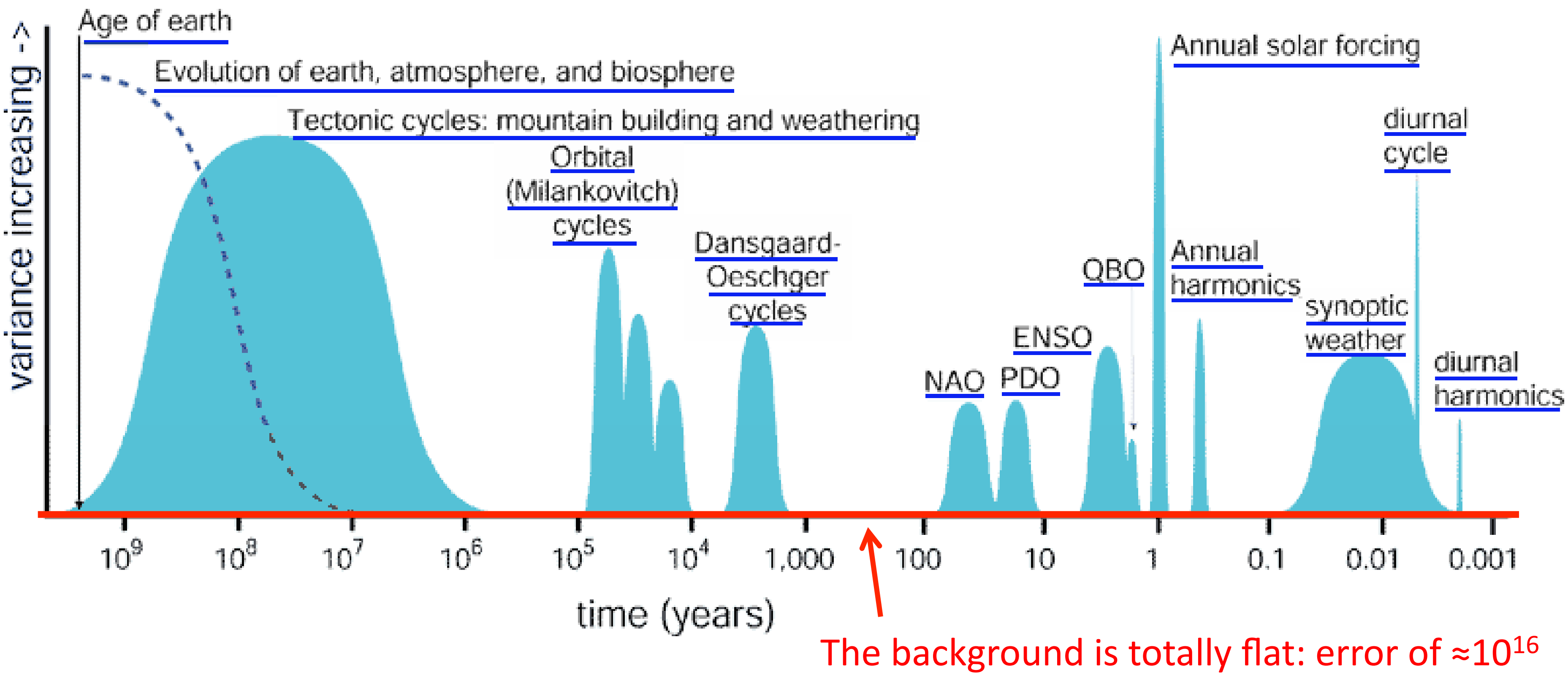

.....the discovery of  micro-organisms

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



The missing quadrillion
Atmospheric dynamics
1 hour- 10^9 yrs: Mitchell 1976
(grey, bottom) with modern data
Log10E(ω) K²yr
10^5
1
10^-5
10^-10
10^15
β=1.8
β = -0.6
β=1.8
β= 0.2
β= 0.8
β= 2.5
β=1.8
megaclimate
macroclimate
climate
macroweather
weather
10^-9
10^-6
10^-5
10^-2
Log10ω (yr)^-1
10^2
10^4

# The NOAA NCDC Paleoclimate data site graph (inspired by Mitchell)




The explanation of the figure:
"… figure is intended as a mental model to provide a general "powers of ten" overview of climate variability, and to convey the basic complexities of climate dynamics for a general science savvy audience."
The site assures us that just "because a particular phenomenon is called an oscillation, it does not necessarily mean there is a particular oscillator causing the pattern. Some prefer to refer to such processes as variability."

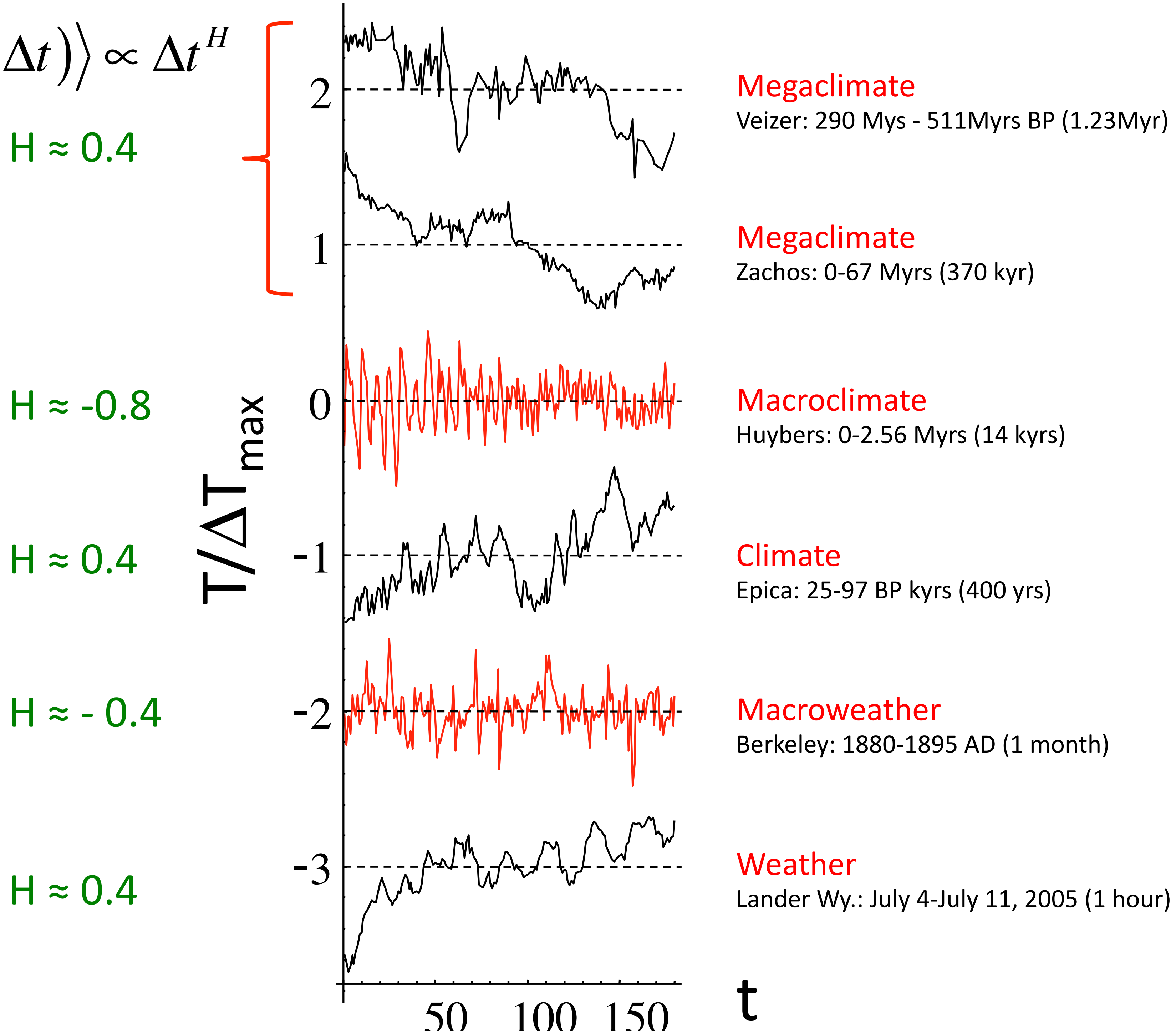
# How to understand the variability?

## Answer #2

- Scaling, scale invariance:

$$\left\langle \Delta T\left(\Delta t\right)\right\rangle = \left\langle \varphi \right\rangle \Delta t^{H}$$

$$\langle \Delta T(\Delta t) \rangle \propto \Delta t^H$$



# Difference, Anomaly, Haar fluctuations

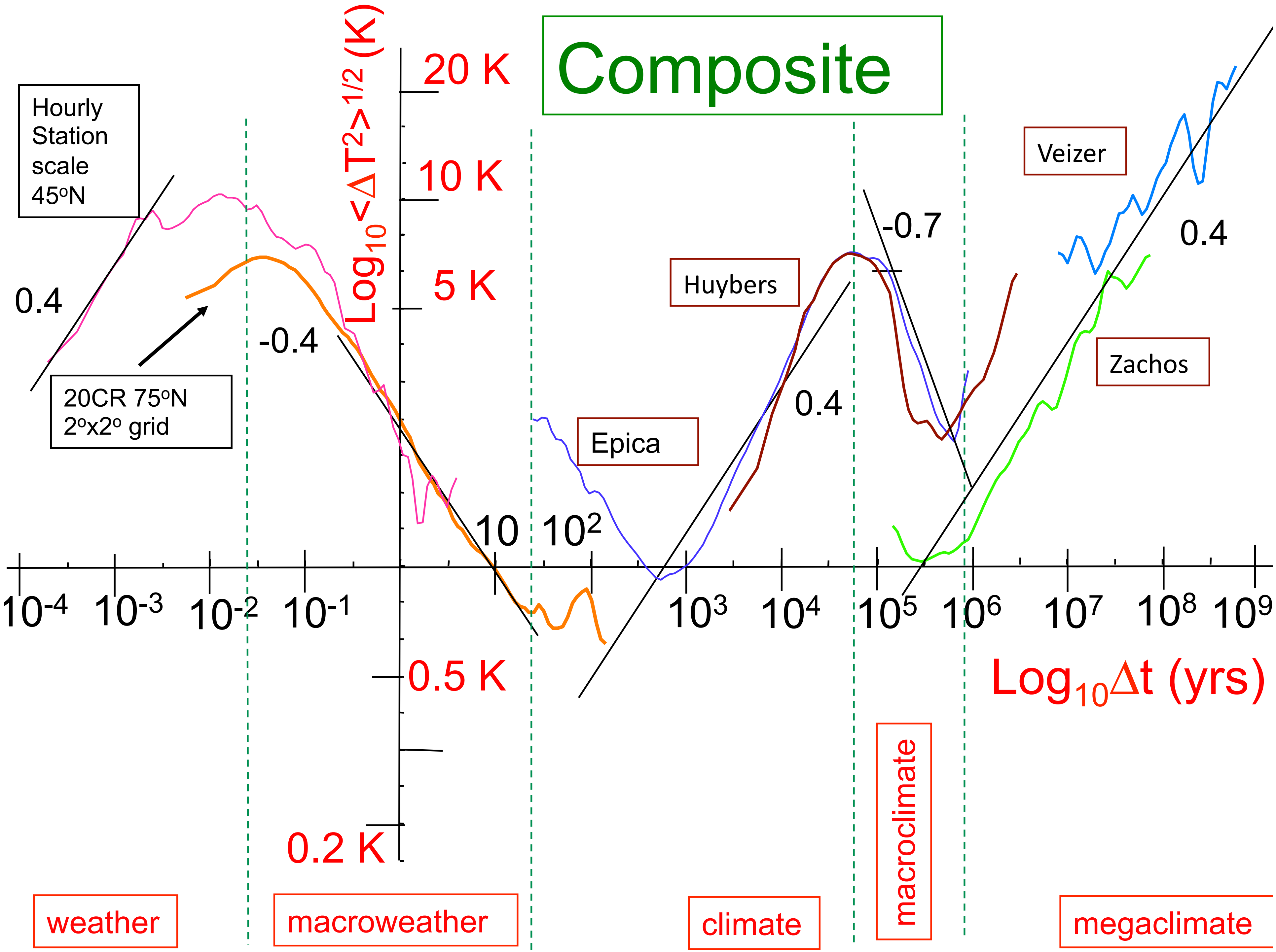
**Differences:** The difference in temperature between t and $t+\Delta t$

**Anomaly:** The average of the temperature (with overall mean removed) between t and $t+\Delta t$

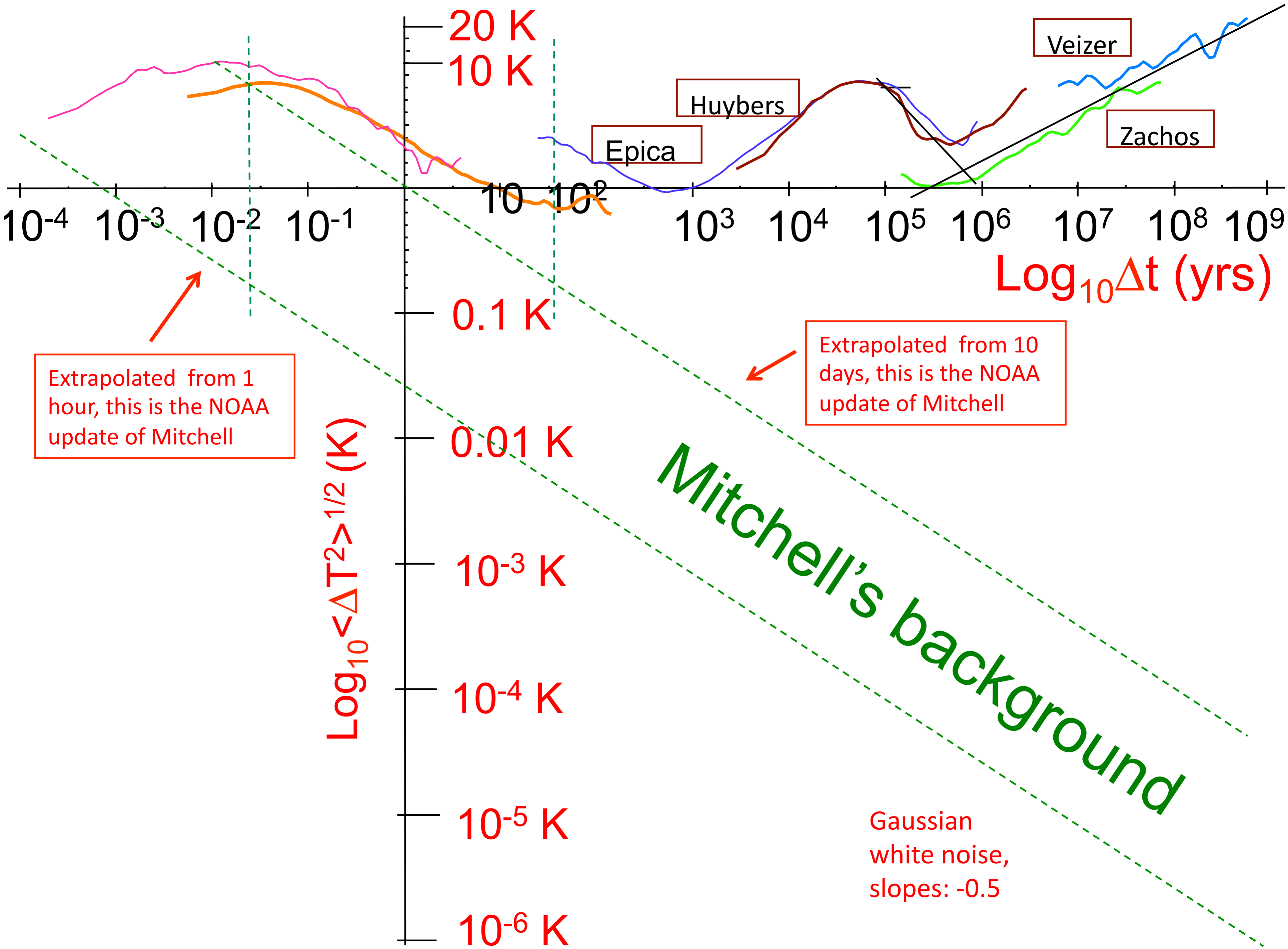
**Haar:** The difference between the average of the temperature from t and $t+\Delta t/2$ and from $t+\Delta t/2$ and $t+\Delta t$

**Relations:**

When $1 > H > 0$: Haar ≈ difference
When $0 > H > -1$: Haar ≈ tendency



Composite
Hourly Station scale 45ºN
20CR 75ºN 2ºx2º grid
Epica
Huybers
Veizer
Zachos
0.4
-0.4
-0.7
0.4
0.4
20 K
10 K
5 K
0.5 K
0.2 K
Log10<ΔT2>1/2 (K)
Log10Δt (yrs)
10-4 10-3 10-2 10-1 10 102 103 104 105 106 107 108 109
weather
macroweather
climate
macroclimate
megaclimate


20 K
10 K
0.1 K
0.01 K
10-3 K
10-4 K
10-5 K
10-6 K
10-4 10-3 10-2 10-1 10 102 103 104 105 106 107 108 109
Log10Δt (yrs)
Log10<ΔT2>1/2 (K)
Epica
Huybers
Veizer
Zachos
Extrapolated from 1 hour, this is the NOAA update of Mitchell
Extrapolated from 10 days, this is the NOAA update of Mitchell
Mitchell's background
Gaussian white noise, slopes: -0.5

# The macroweather regime

Low frequency cascades

Time scales ≈>10 days ($\tau > \tau_w$ )

# "First principles" predictions Atmosphere:

The large scale winds and weather-climate transition scale

Horizontal wind: $\Delta v = \varepsilon^{1/3}\Delta x^{1/3}$

$\varepsilon$ = Energy flux (Fourier space) also "energy rate density"

**Power / area:**

Solar heating, top of the atmosphere: $\approx 10^3$ W/m$^2$

Absorbed $\approx 2X10^2$ W/m$^2$

$\approx$4% Converted to K.E.$\approx$ 8 W/m$^2$

**Mass / area =** $\Delta p/g \approx 8x10^3$ Kg/m$^2$ ← Troposphere only

**Energy flux:**

$\varepsilon \approx 8/(8x10^3) = 10^{-3}$ W/Kg

Prediction using horizontal relation: $\Delta v = \varepsilon^{1/3}\Delta x^{1/3}$

**Scales:**

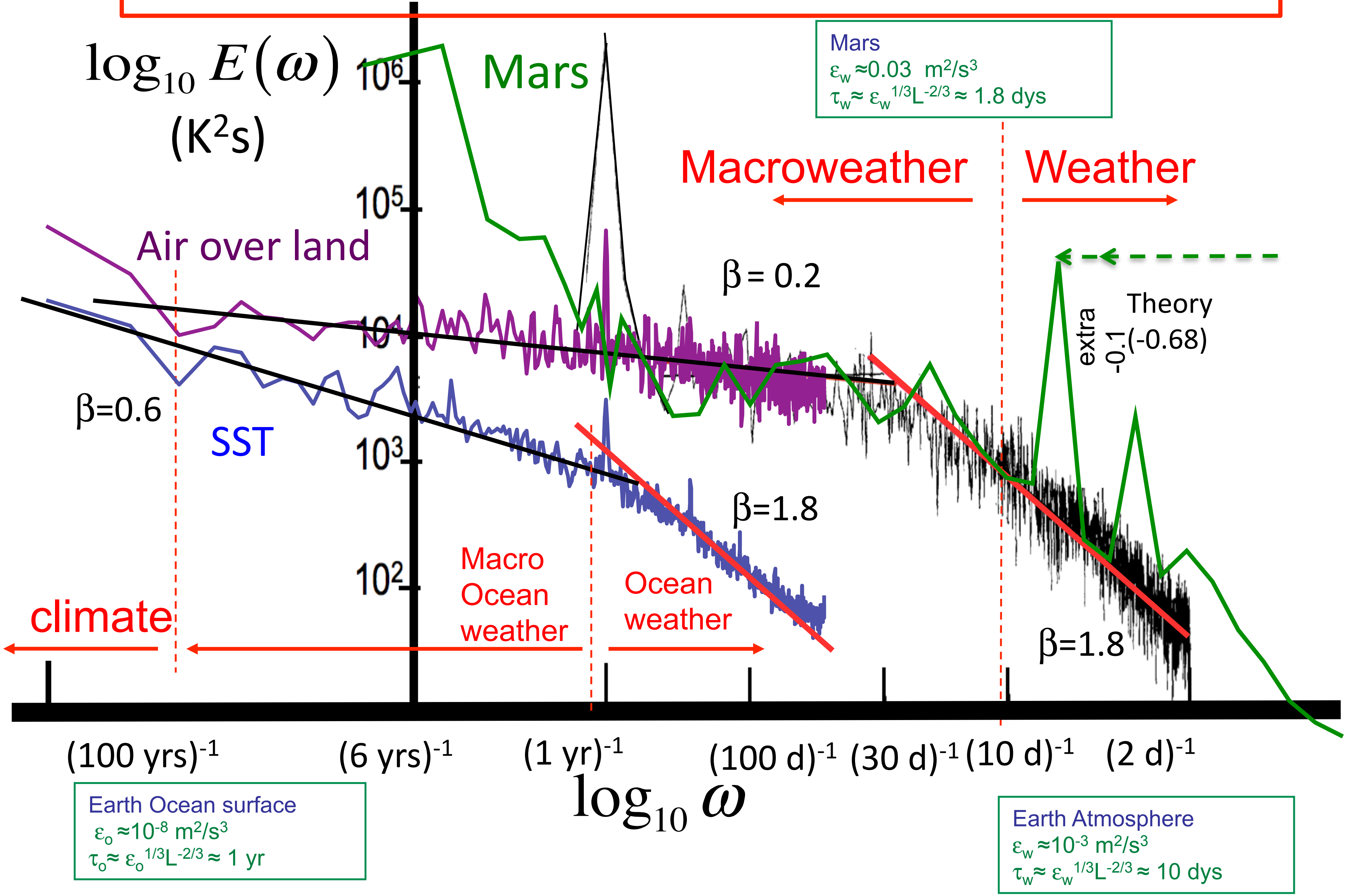
Length: $L \approx 2x10^7$ m

Velocity: $V \approx \varepsilon^{1/3} L^{1/3} \approx 21$ m/s

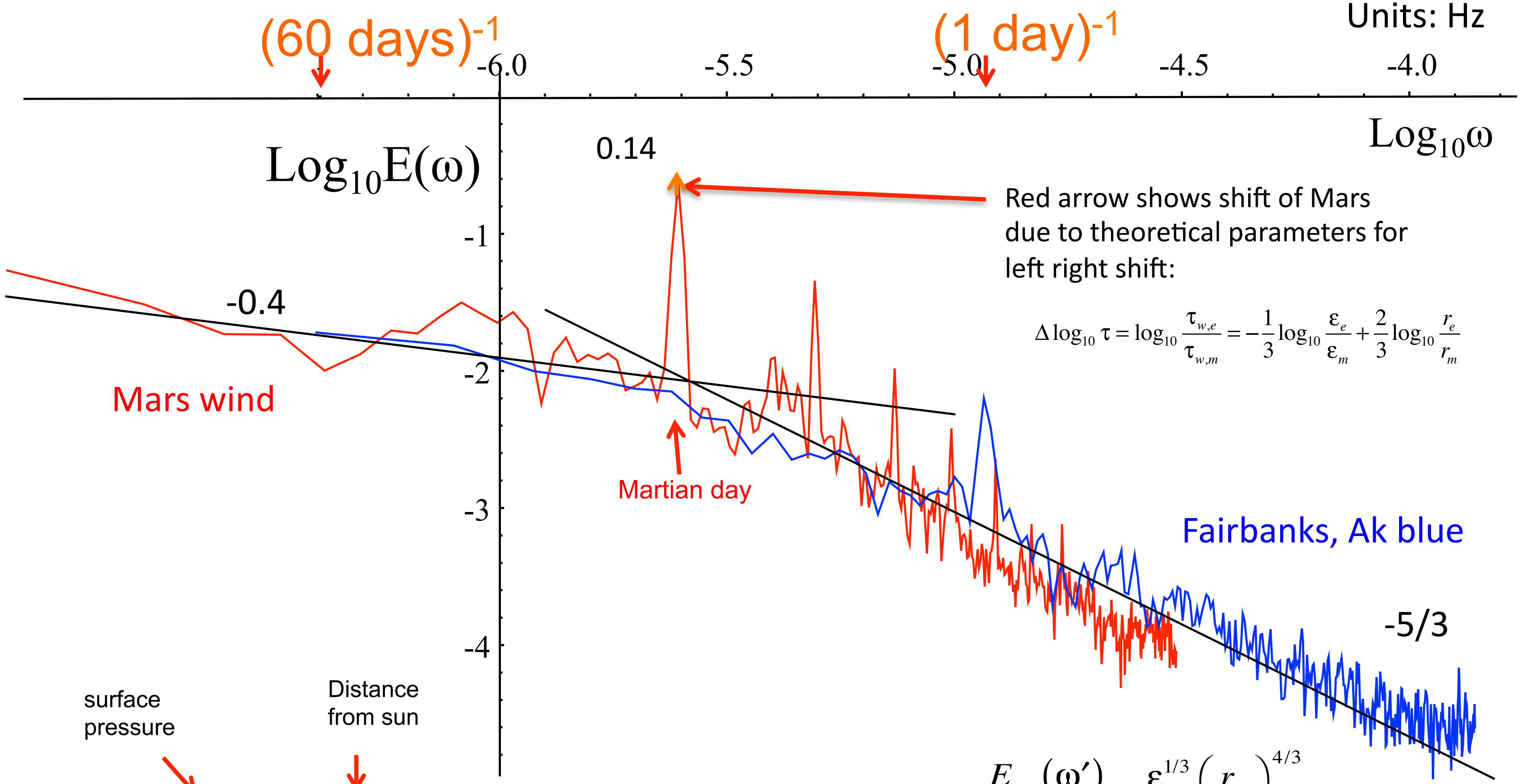
Time: $T = L/V \approx 10^6$ s = 11 days

c.f. empirical antipodes velocity difference 17.4±5.7 m/s

# Macroweather, Macro “ocean weather”, Martian macro weather



# Wind: Mars-Earth comparison
## (No adjustable parameters)




$$\Delta \log_{10}\tau = \log_{10}\frac{\tau_{w,e}}{\tau_{w,m}} = -\frac{1}{3}\log_{10}\frac{\varepsilon_e}{\varepsilon_m} + \frac{2}{3}\log_{10}\frac{r_e}{r_m}$$

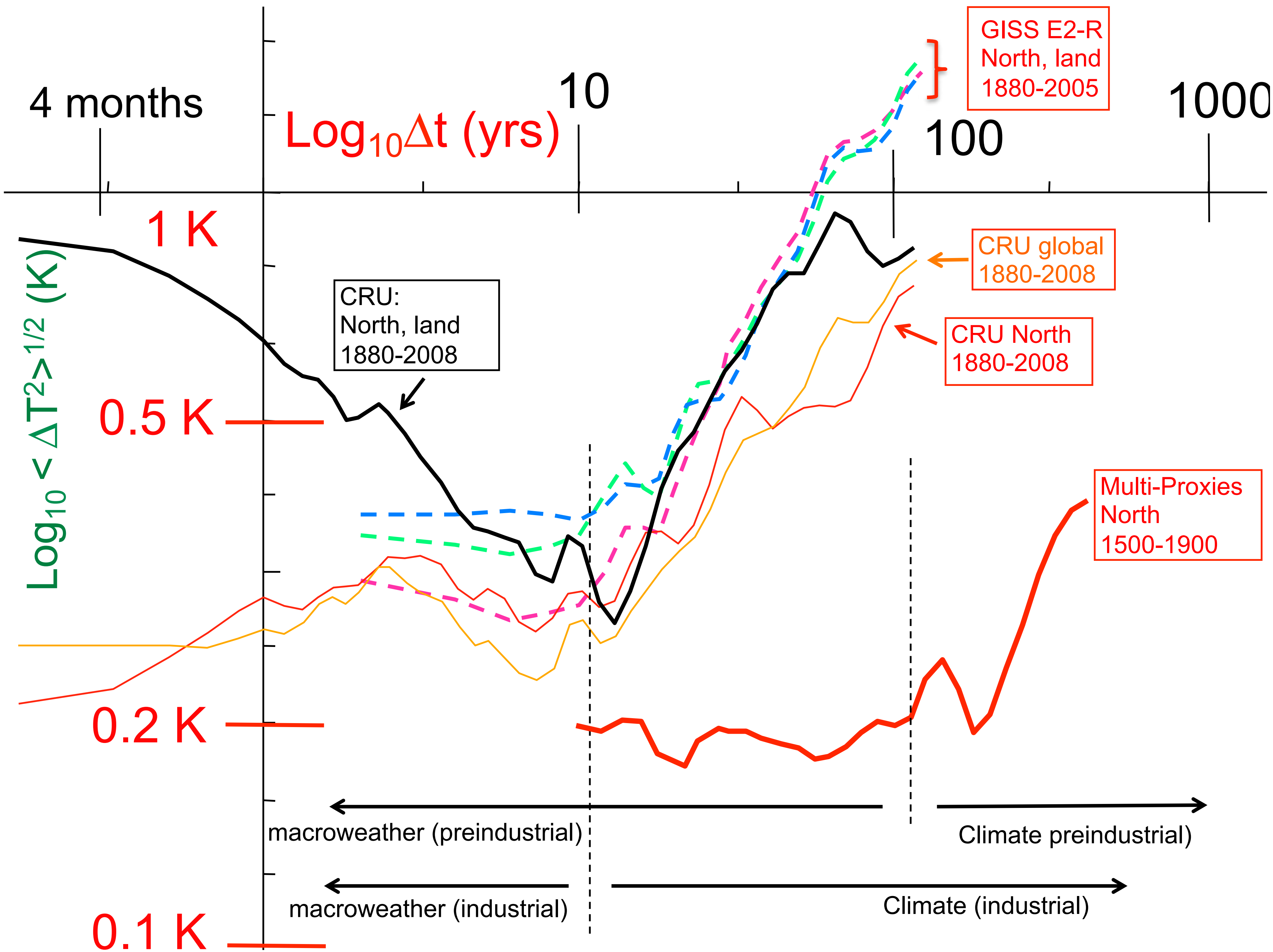
$$\frac{\varepsilon_m}{\varepsilon_e} = \left(\frac{\Delta p_e}{\Delta p_m}\right)\left(\frac{r_e}{r_m}\right)^2\left(\frac{R_e}{R_m}\right)^2\left(\frac{m_m}{m_e}\right)\left(\frac{1-\alpha_m}{1-\alpha_e}\right)$$

surface pressure; Distance from sun; Energy flux; Planet radius; Planet mass; Planet albedo

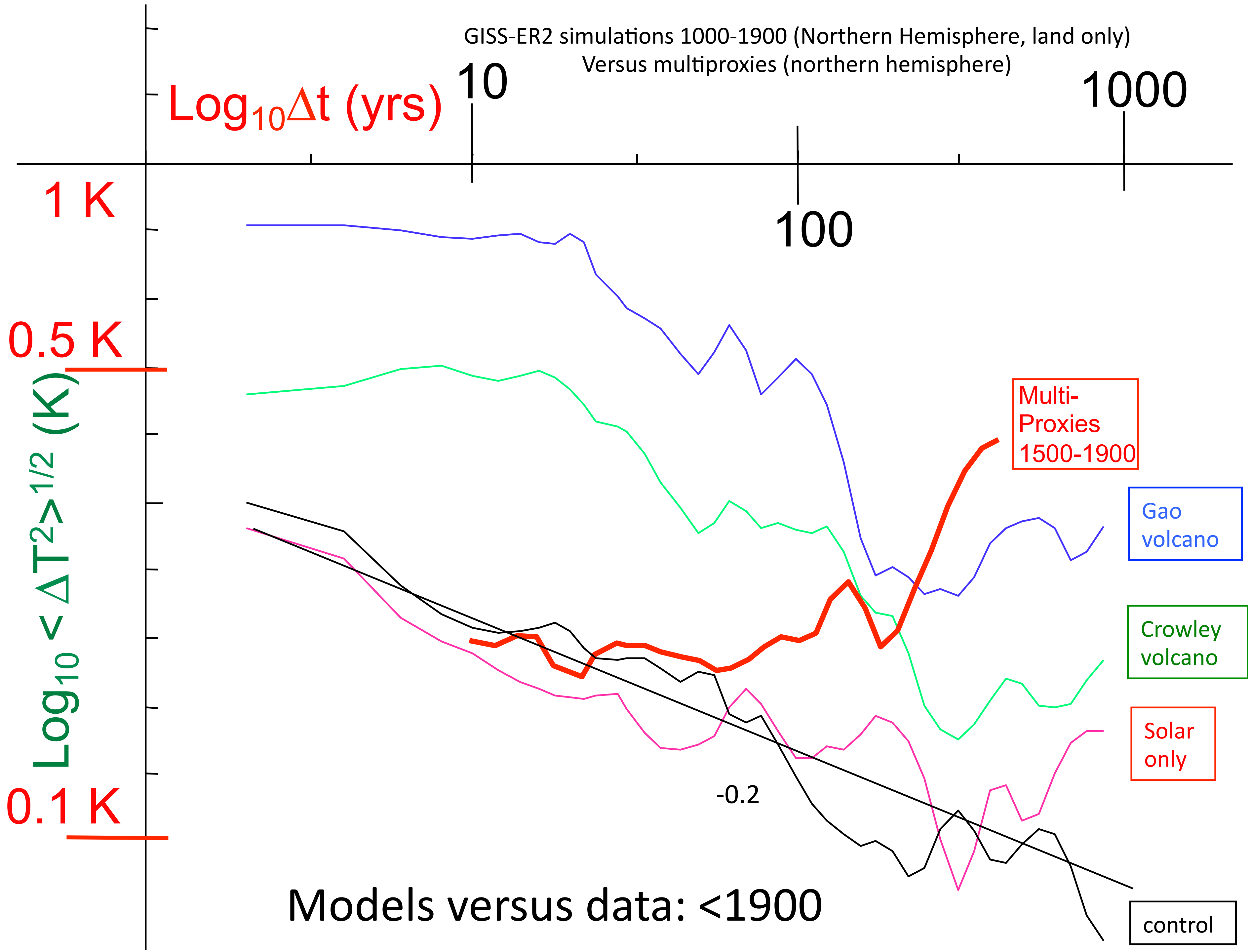
$$\frac{E_{v,e}(\omega')}{E_{v,m}(\omega')} \approx \frac{\varepsilon_e^{1/3}}{\varepsilon_m^{1/3}}\left(\frac{r_e}{r_m}\right)^{4/3}$$

Nondimensional frequency

# Do GCM's predict the climate…. Or Macroweather?



4 months
Log10Δt (yrs)
10
100
1000
GISS E2-R
North, land
1880-2005
1 K
0.5 K
0.2 K
0.1 K
Log10 <ΔT2>1/2 (K)
CRU:
North, land
1880-2008
CRU global
1880-2008
CRU North
1880-2008
Multi-Proxies
North
1500-1900
macroweather (preindustrial)
Climate preindustrial)
macroweather (industrial)
Climate (industrial)

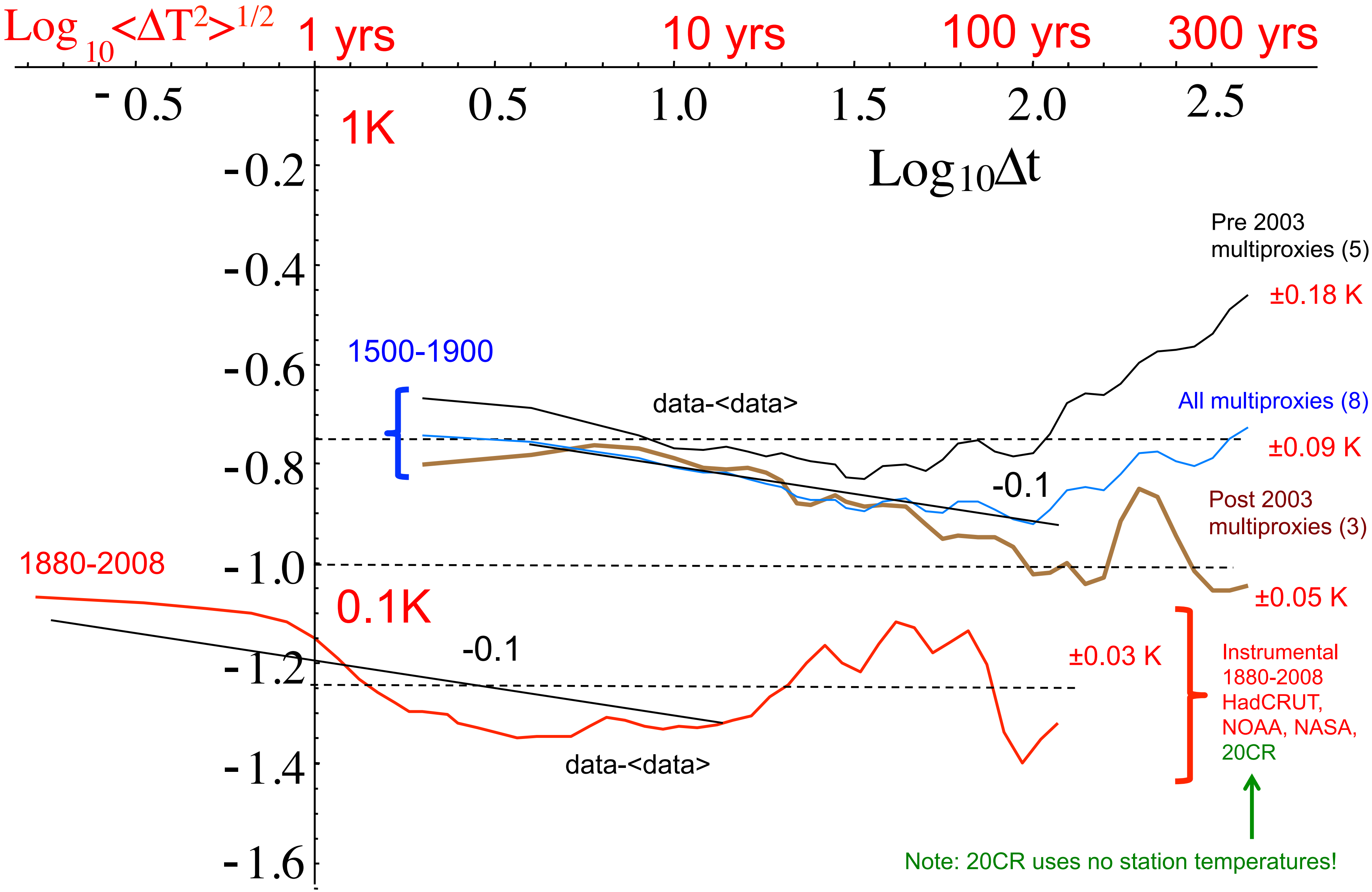



Models versus data: <1900

# How well can we measure the global temperature?

What is $\varepsilon(t)$?

# Instruments versus multiproxies (global scale)



# Proving the truth of Anthropogenic Global Warming

## Diminishing returns

- In its AR5 report last September, the IPCC upgraded the AR4's (2007) qualification "*likely*" to conclude that it is "*extremely likely* that human influence has been the dominant cause of the observed warming since the mid-20th century".

"*extremely likely*" = 95-100% confidence

- Climate sensitivity: 1.5 – 4.5 $^{o}$C

Unchanged since 1979

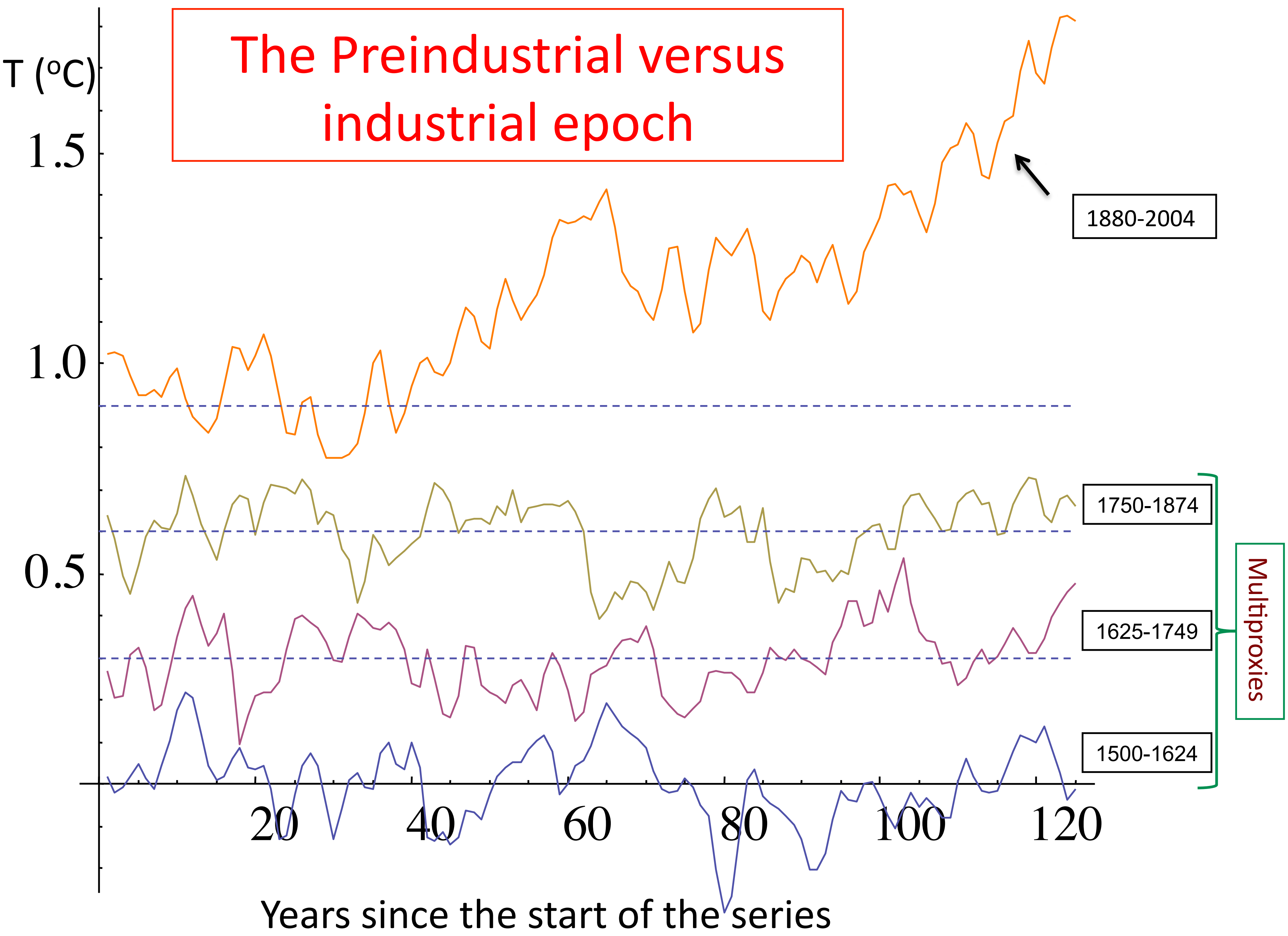
# - Disproving natural global warming

## Relatively easy due to an asymmetry

-No theory can ever be proven beyond "reasonable doubt" but a single decisive experiment can effectively *disprove* one.

Requires no numerical models, needs Nonlinear Geophysics

# Primary evidence for anthropogenic warming


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

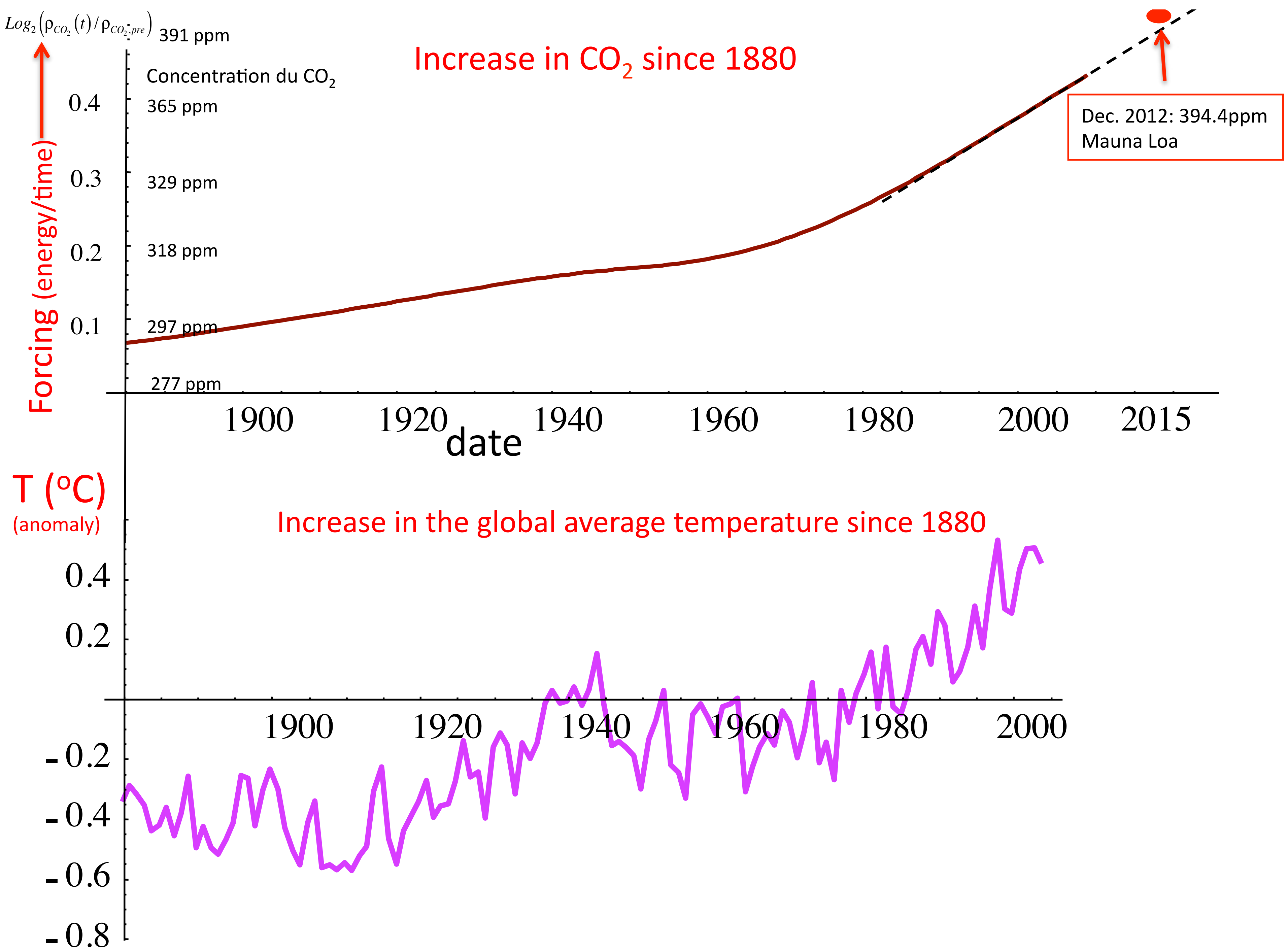
# GCM-free quantification of

## Anthropogenic effects

(including extremes)*

Premise: if anthropogenic warming is as strong as claimed, then why do we need huge numerical models to demonstrate it?

*Thanks to the Quebec Skeptical Society!


$Log_2(\rho_{CO_2}(t)/\rho_{CO_2;pre})$
391 ppm
Increase in CO2 since 1880
Concentration du CO2
365 ppm
329 ppm
318 ppm
297 ppm
277 ppm
0.4
0.3
0.2
0.1
Forcing (energy/time)
Dec. 2012: 394.4ppm
Mauna Loa
1900
1920
1940
1960
1980
2000
2015
date
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

# Natural variability as a perturbation to anthropogenic change

Effective climate sensitivity (K/(W/m²))

Measurement error: ≈±0.03K

$$T_{globe}(t) = \lambda_{2xCO2,eff} \log_2\left(\rho_{CO_2}(t)/\rho_{CO_2,pre}\right) + T_{natural}(t) + \varepsilon(t)$$

Proportional to $CO_2$ radiative forcing (W/m²)
Linear **Surrogate** for all anthropogenic forcings (determinstic)

Small fluctuations due to natural variability (stochastic).
Includes responses to solar, volcanic and other natural forcings.

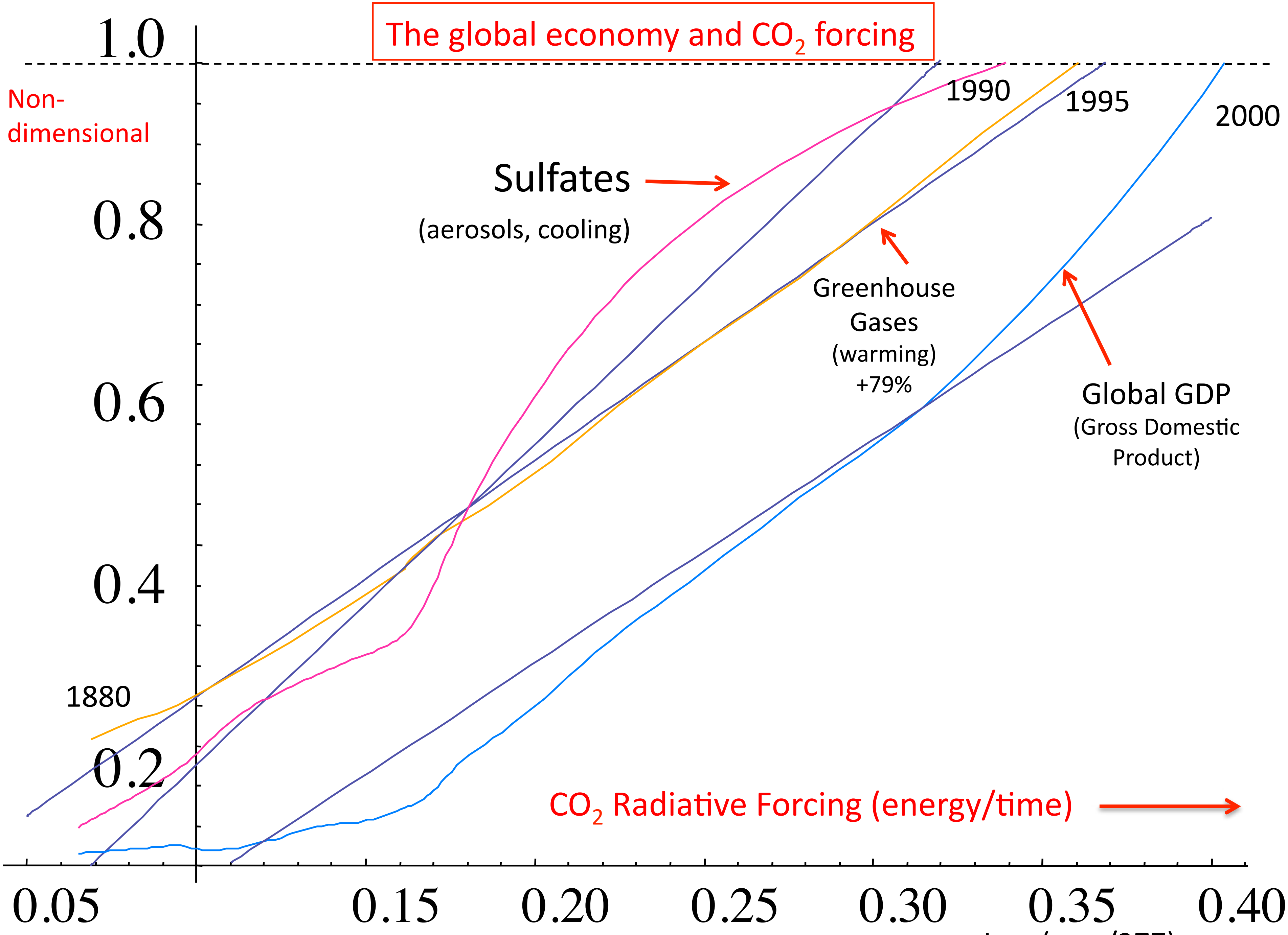
Justified if:

a) the anthropogenic effects do not effect the *type* of internal dynamic (variability),
b) nor their responses to (natural) external forcing

# $CO_2$ forcing as surrogate for all anthropogenic effects

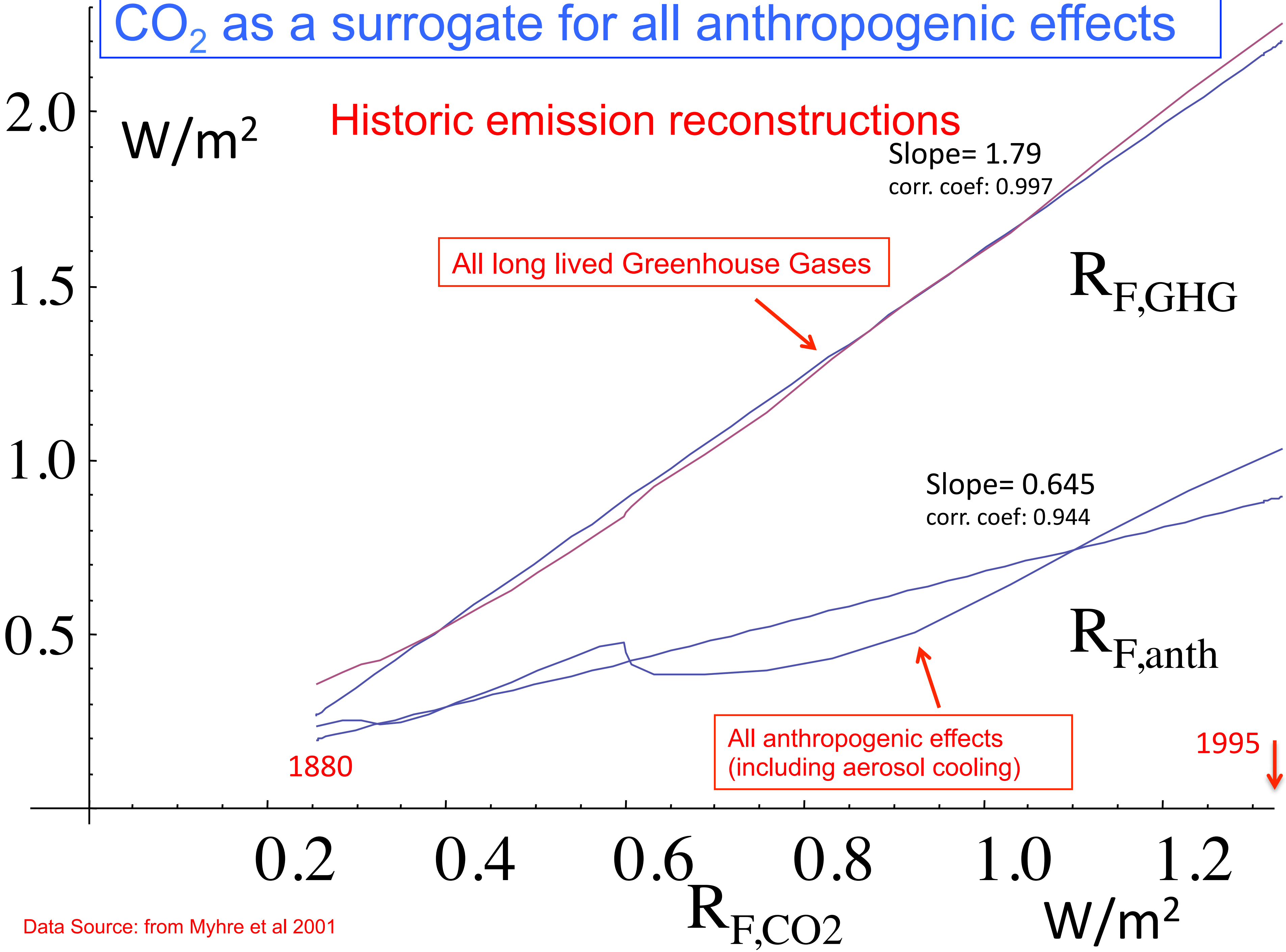
Roughly: you double the global economy, you double the emissions, land use and other changes, you double the effects

# The global economy and $CO_2$ forcing

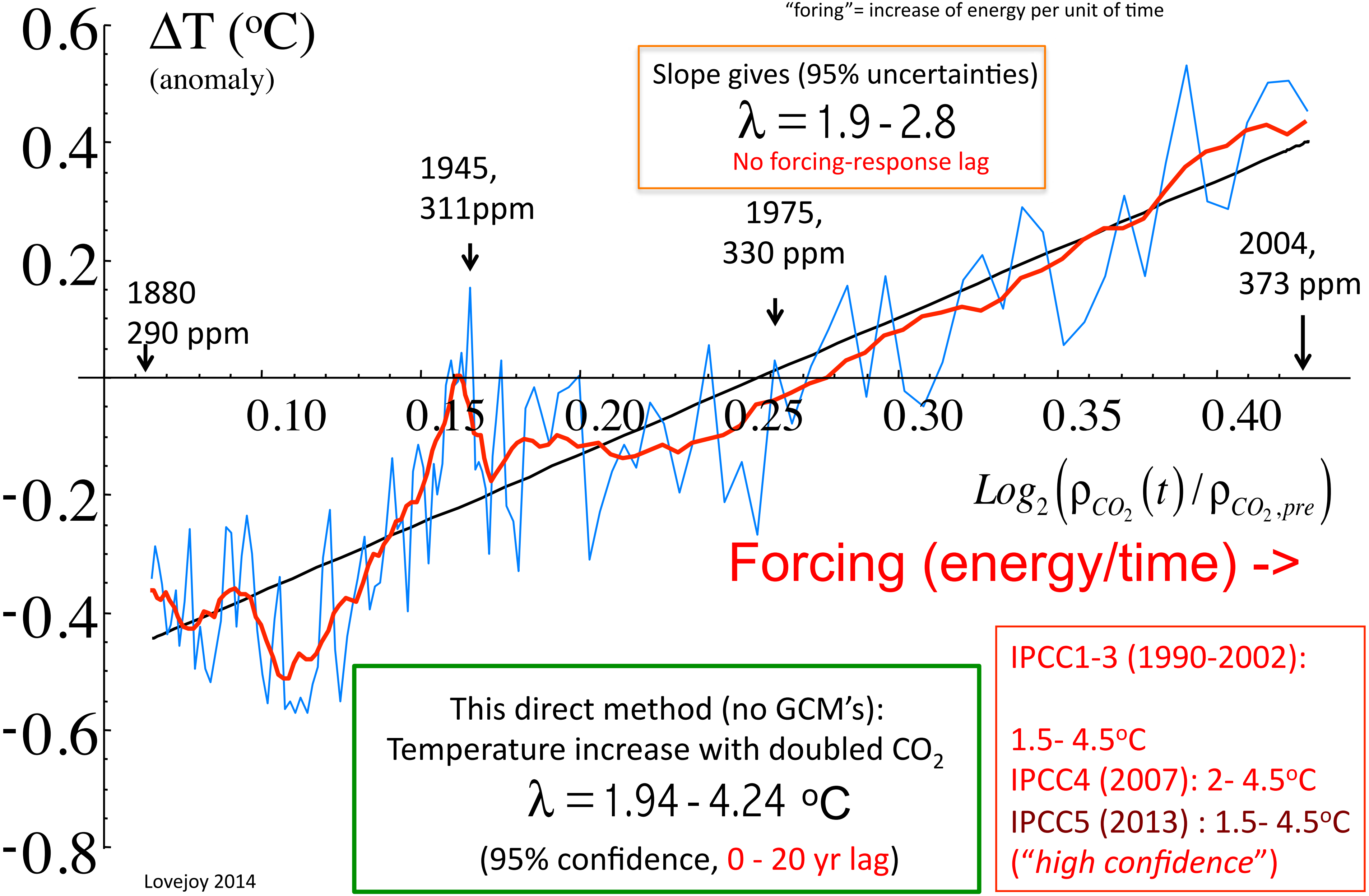


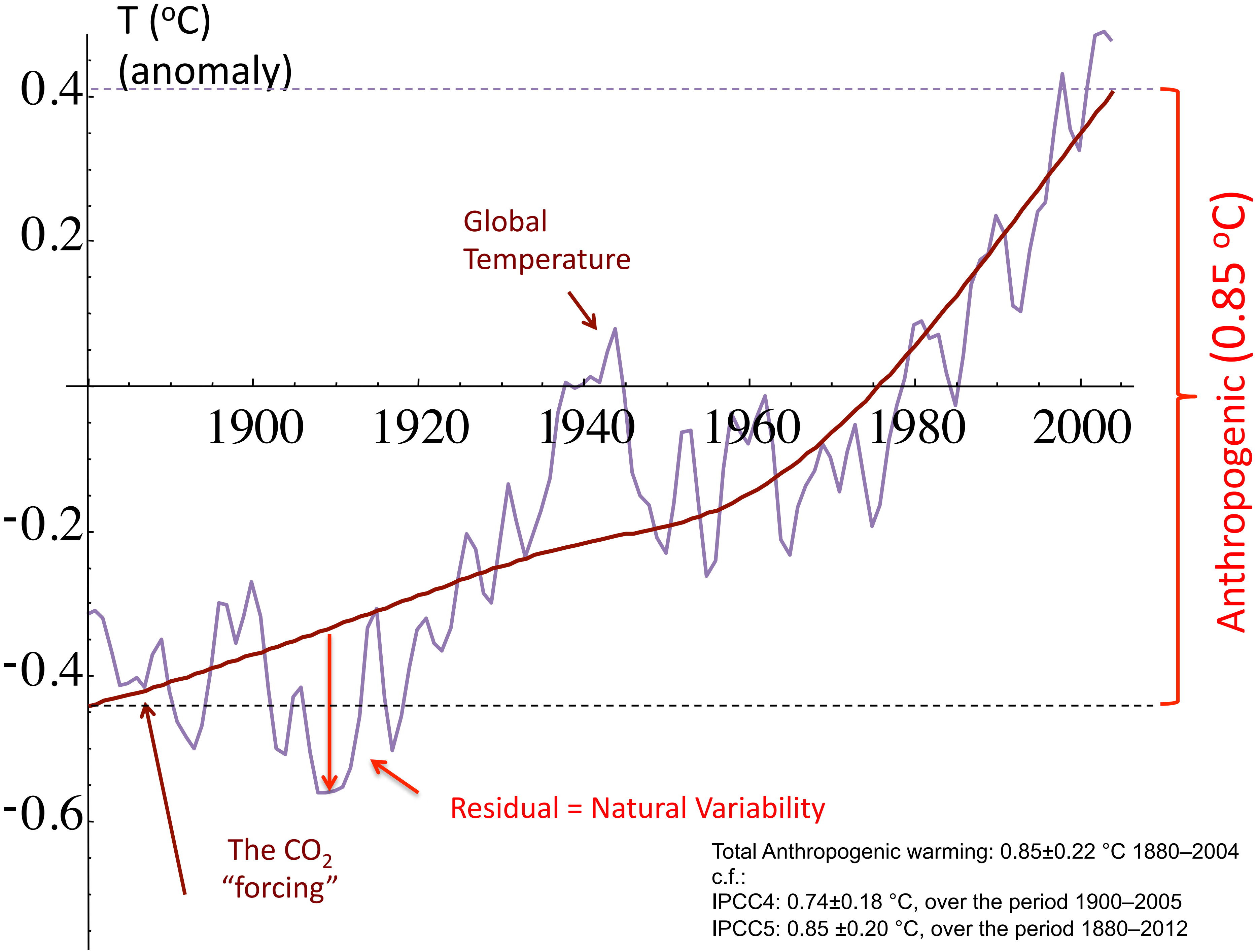

Correlation coefficients: 0.983 (sulfate production), 0.997 (total GHG forcing), 0.963 (GDP).

# $CO_2$ as a surrogate for all anthropogenic effects



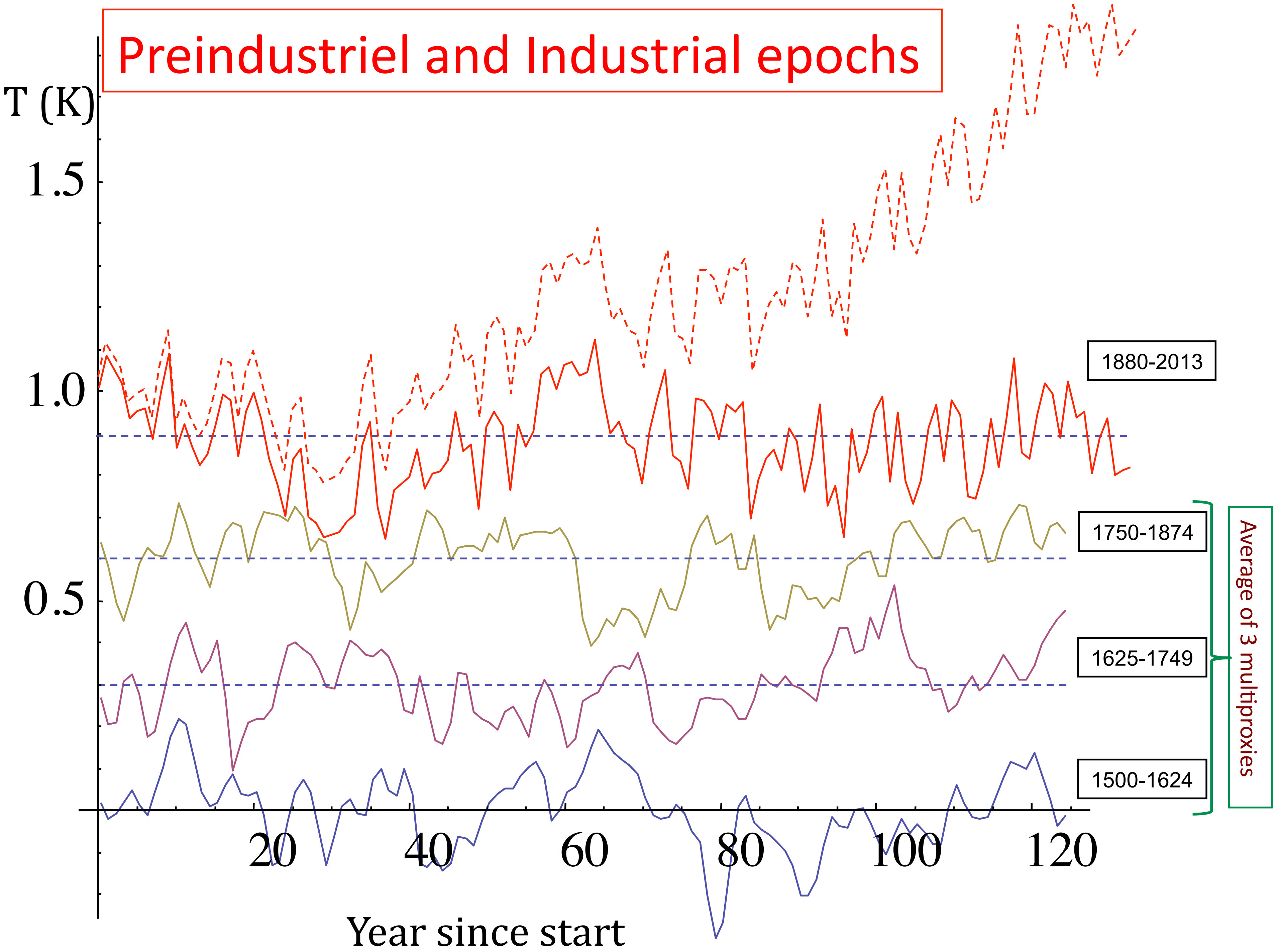
# The Temperature is nearly linear with the $CO_2$ forcing

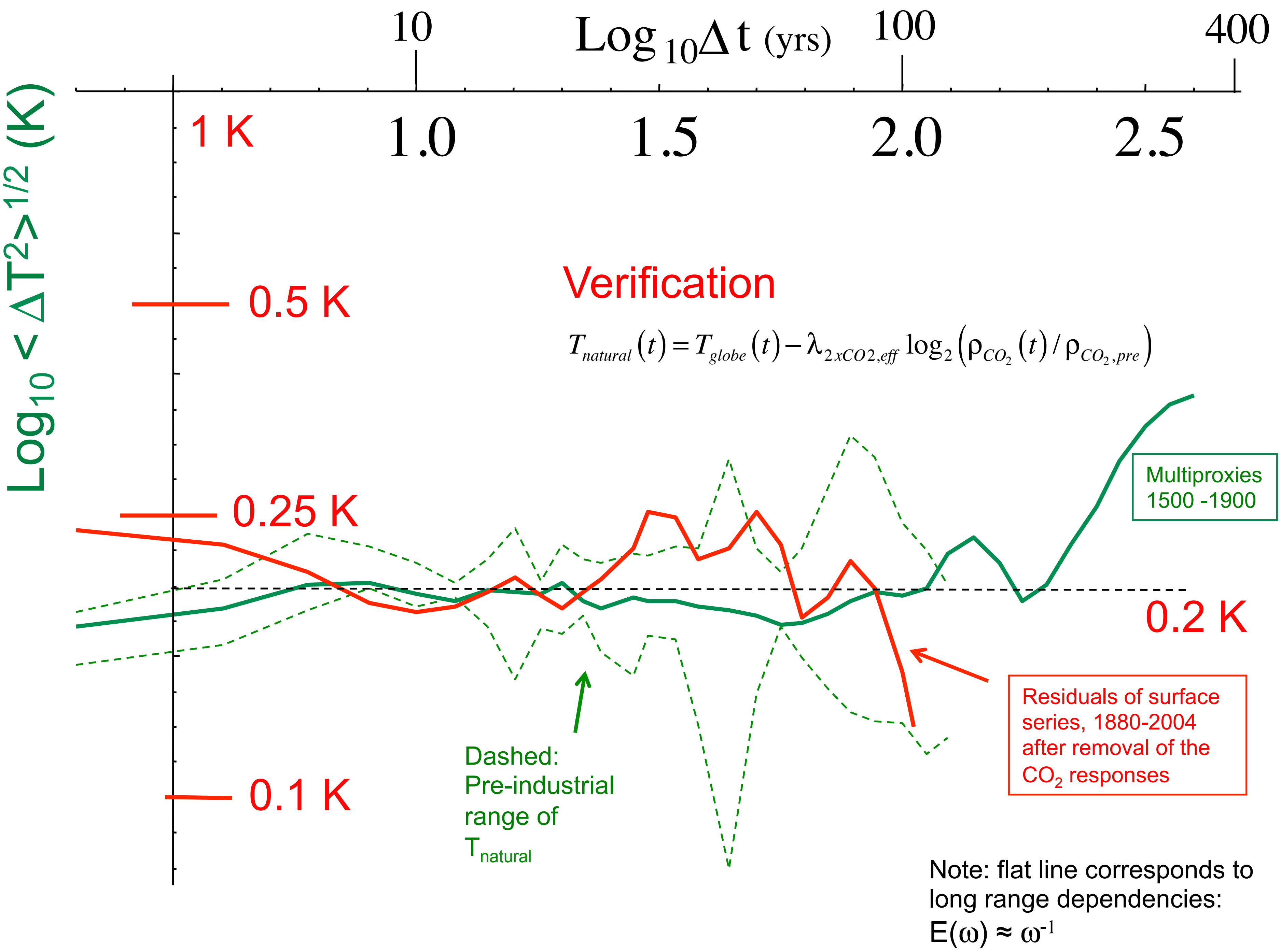




T (°C)
(anomaly)
0.4
0.2
-0.2
-0.4
-0.6
1900
1920
1940
1960
1980
2000
Global
Temperature
Anthropogenic (0.85 °C)
Residual = Natural Variability
The CO2
"forcing"
Total Anthropogenic warming: 0.85±0.22 °C 1880–2004
c.f.:
IPCC4: 0.74±0.18 °C, over the period 1900–2005
IPCC5: 0.85 ±0.20 °C, over the period 1880–2012

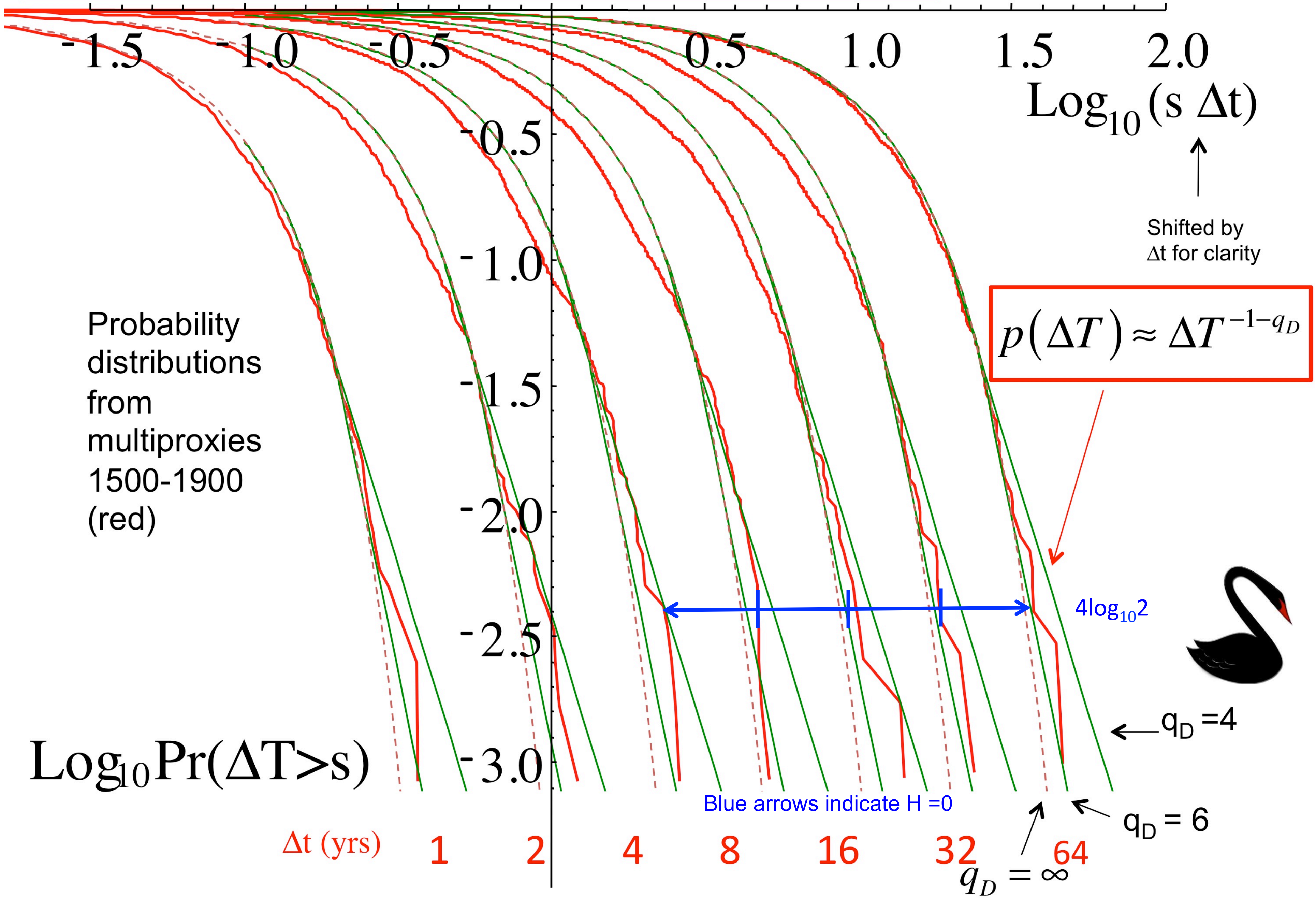
# Preindustriel and Industrial epochs

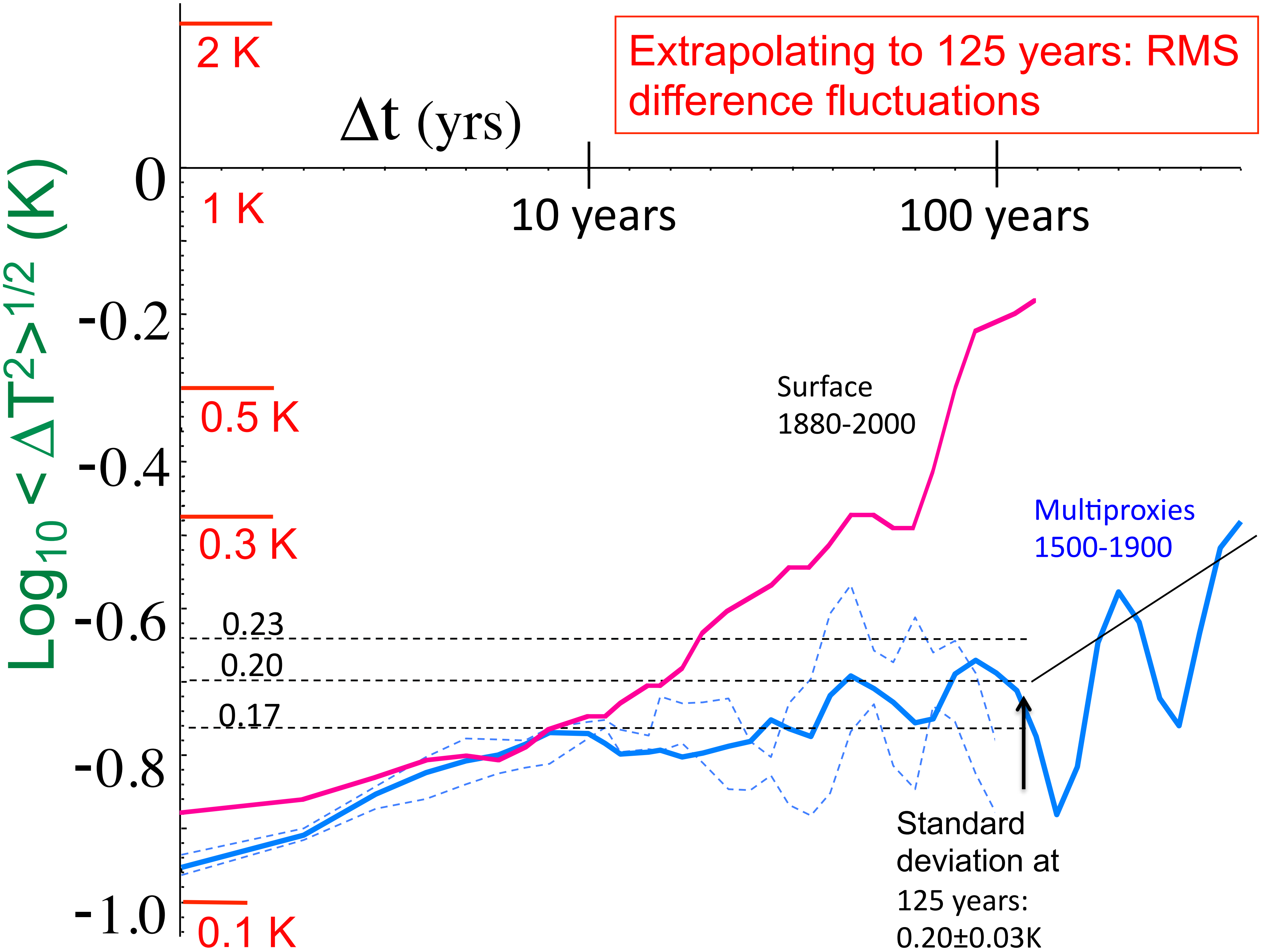


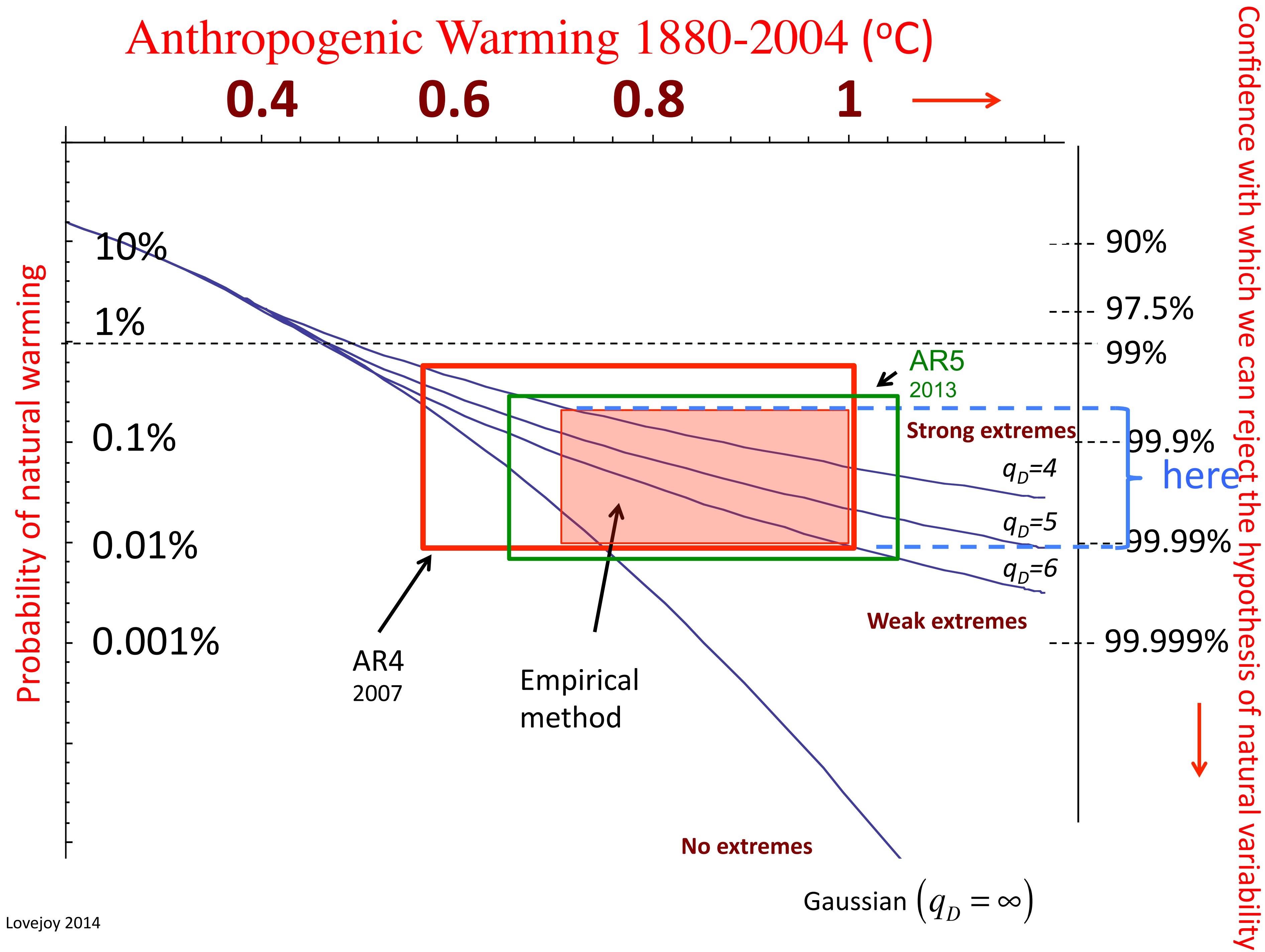

Verification
$T_{natural}(t) = T_{globe}(t) - \lambda_{2xCO2,eff} \log_2\left(\rho_{CO_2}(t)/\rho_{CO_2,pre}\right)$
Log₁₀Δt (yrs)
10
100
400
1.0
1.5
2.0
2.5
$\mathrm{Log}_{10} < \Delta T^2 >^{1/2}$ (K)
1 K
0.5 K
0.25 K
0.2 K
0.1 K
Multiproxies 1500 -1900
Residuals of surface series, 1880-2004 after removal of the $CO_2$ responses
Dashed: Pre-industrial range of $T_{natural}$
Note: flat line corresponds to long range dependencies: $E(\omega) \approx \omega^{-1}$

# Bracketing the temperature extremes with power laws

$s^{-4} > \Pr(\Delta T > s) > s^{-6}$

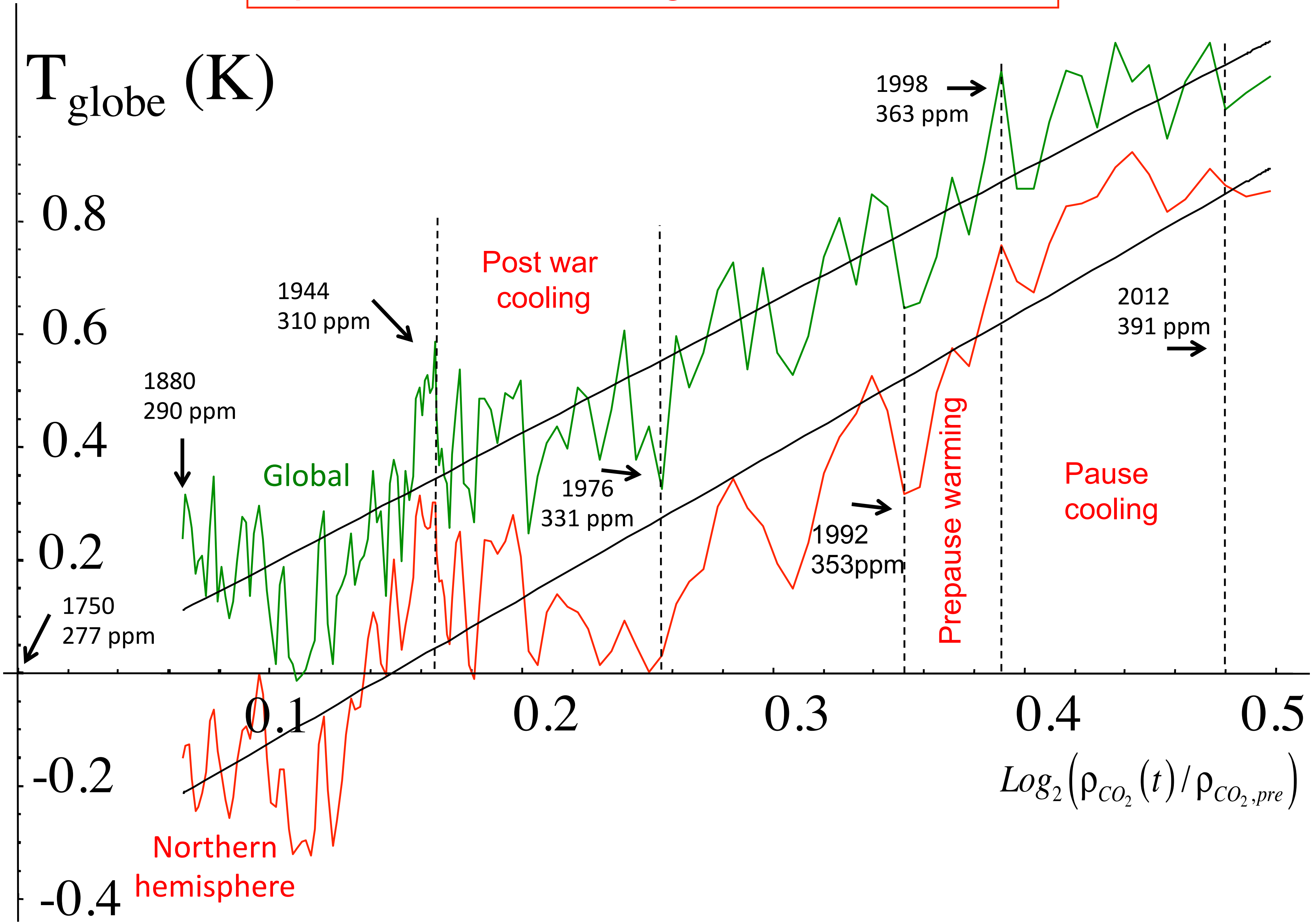



Extrapolating to 125 years: RMS difference fluctuations
2 K
Δt (yrs)
0
1 K
10 years
100 years
-0.2
0.5 K
-0.4
0.3 K
-0.6
-0.8
-1.0
0.1 K
Log10 < ΔT2>1/2 (K)
Surface 1880-2000
Multiproxies 1500-1900
0.23
0.20
0.17
Standard deviation at 125 years: 0.20±0.03K

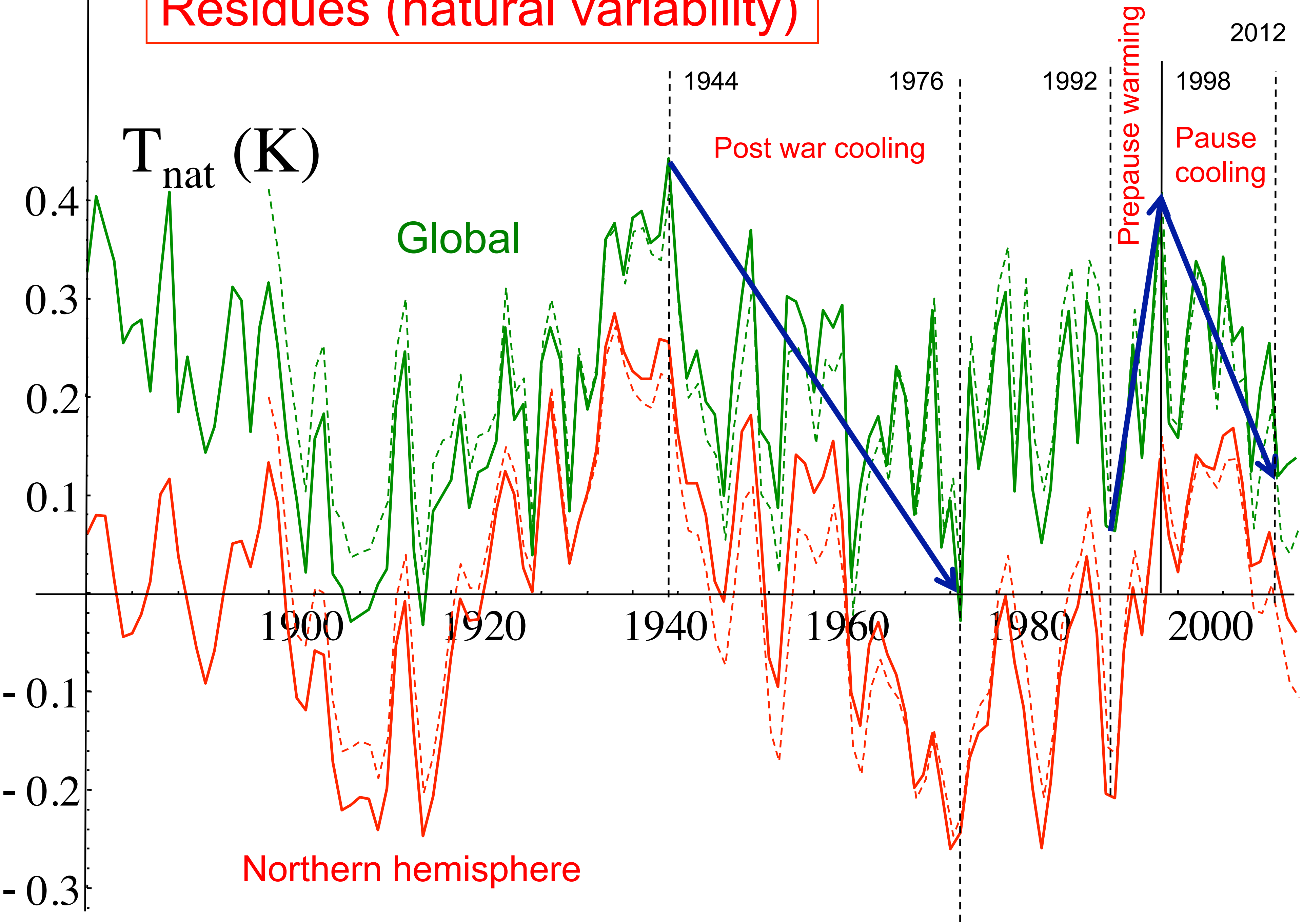

Anthropogenic Warming 1880-2004 (°C)
0.4
0.6
0.8
1
Probability of natural warming
10%
1%
0.1%
0.01%
0.001%
Confidence with which we can reject the hypothesis of natural variability
90%
97.5%
99%
99.9%
99.99%
99.999%
here
AR5
2013
Strong extremes
$q_D$=4
$q_D$=5
$q_D$=6
Weak extremes
AR4
2007
Empirical
method
No extremes
Gaussian $(q_D = \infty)$
Lovejoy 2014

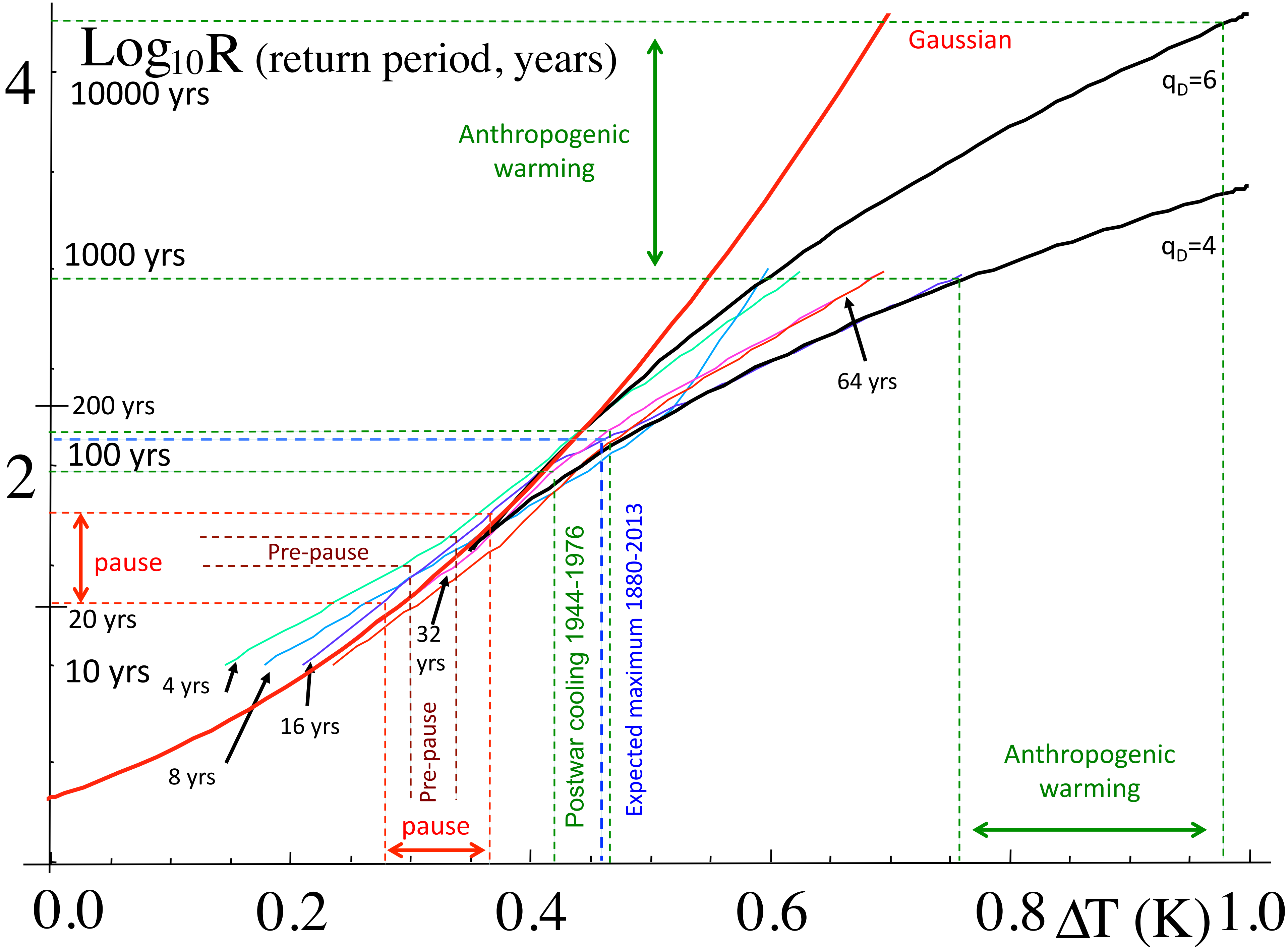
# The “pause” in the warming, return periods

# Update to 2013 using NASA GISS data



# Residues (natural variability)





Log10R (return period, years)
4
10000 yrs
1000 yrs
200 yrs
100 yrs
2
20 yrs
10 yrs
Gaussian
$q_D$=6
$q_D$=4
Anthropogenic warming
pause
Pre-pause
4 yrs
8 yrs
16 yrs
32 yrs
64 yrs
Postwar cooling 1944-1976
Expected maximum 1880-2013
Anthropogenic warming
0.0
0.2
0.4
0.6
0.8
1.0
ΔT (K)

# Predictability and stochastic forecasting

# Forecasting the climate

$$\Delta T(\Delta t) \approx \Delta t^{H_T}$$

Macroweather up to ≈ 100 years $H_T$ ≈-0.1

$$T(t) = I^{\Delta H}\gamma = \int_{-\infty}^{t} (t-t')^{-(1-\Delta H)} \gamma(t')\,dt'$$

Ignore intermittency, take quasi-Gaussian model: $H_\gamma = -1/2$

"Hyper Gaussian"

Fractional integration order ΔH

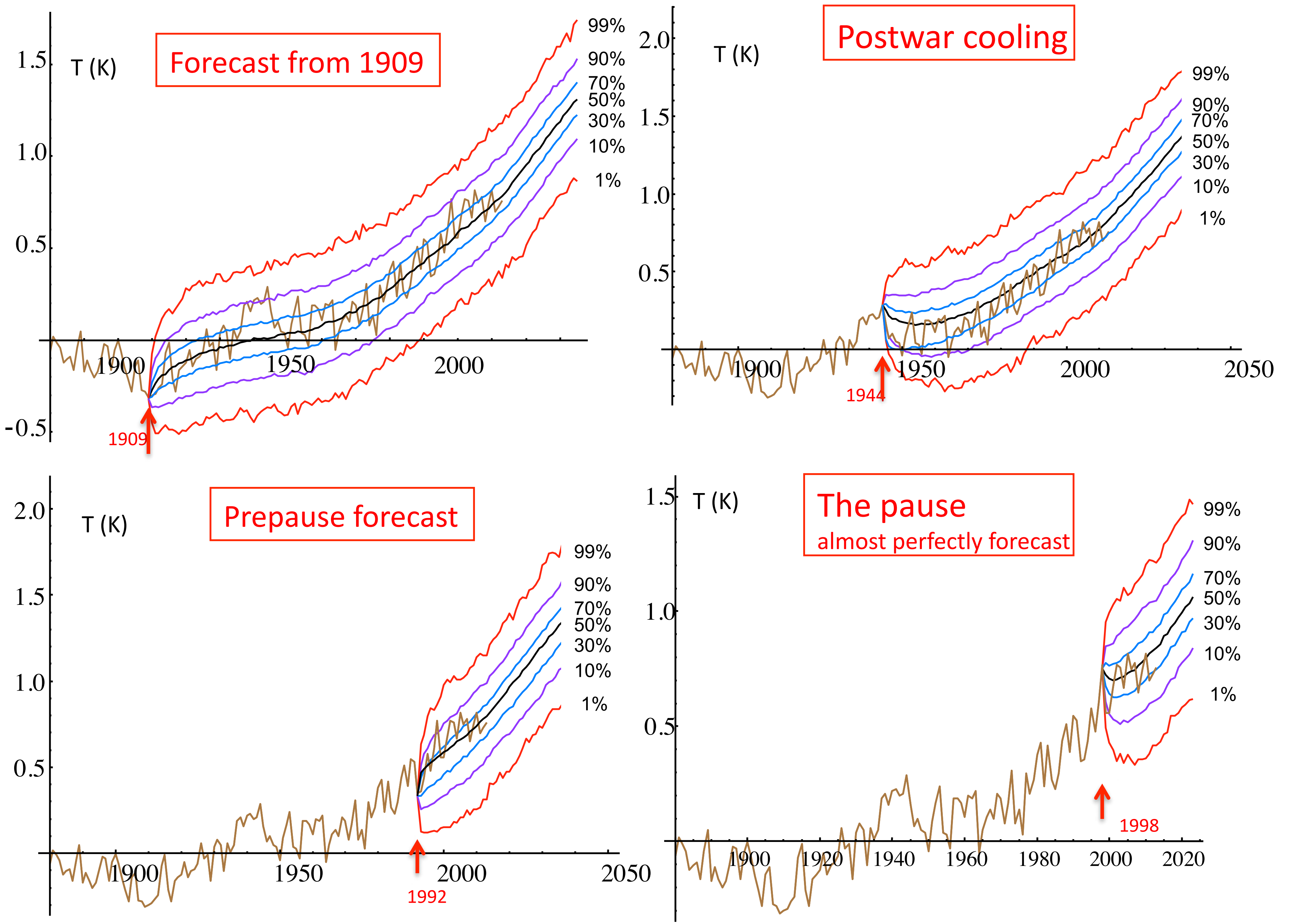
$$\Delta H = H_T - H_\gamma \approx 0.4$$

To obtain independent noises:

$$\gamma(t) = I^{-\Delta H} T(t); \quad t \le 0$$

Estimate past noise generator up to t=0

To predict to time $t_p$, simply add independent noises from $t = 0$ to $t = t_p$ then fractionally integrate to obtain $T(t)$ for $t \le t_p$


Forecast from 1909
T (K)
1.5
1.0
0.5
-0.5
1900
1950
2000
99%
90%
70%
50%
30%
10%
1%
1909
Postwar cooling
T (K)
2.0
1.5
1.0
0.5
1900
1950
2000
2050
99%
90%
70%
50%
30%
10%
1%
1944
Prepause forecast
T (K)
2.0
1.5
1.0
0.5
1900
1950
2000
2050
99%
90%
70%
50%
30%
10%
1%
1992
The pause
almost perfectly forecast
T (K)
1.5
1.0
0.5
1900
1920
1940
1960
1980
2000
2020
99%
90%
70%
50%
30%
10%
1%
1998

# Game over!

Rather than trying to prove anthropogenic warming is true, we disprove natural warming. Note asymmetry: no theory can be proven beyond reasonable doubt, but a theory can be disproved by a decisive experiment.

a) The main source of uncertainty is the lag: 0-> 20 years.

With GCM's, it is cloud, radiation feedbacks.

a) Only changes in global temperature over 125 year periods are important. Taking differences filters out the low frequencies so that historic temperatures such as the medieval warming event may be warmer than today if the changes were slow enough.

The peons can roast!

c) The multiproxies agree with each other up to about 200 year scales so that the probability distributions of 64 year changes are reliable. Using the observed scaling we scale them to 125 years.

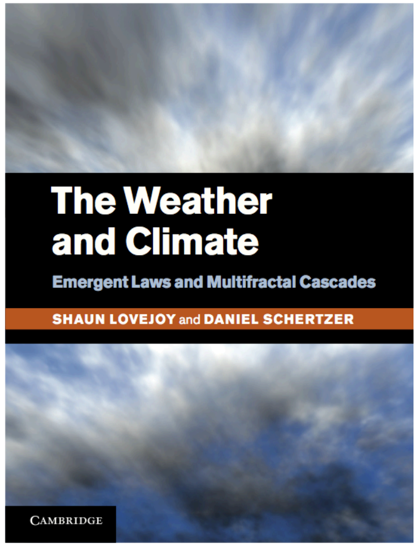
For 125 years periods all the "hockey sticks" are reliable.

d) If we are prepared to accept the natural variability hypothesis at as low a level as 10% (reject it with only 90% confidence), then the change since 1880 must be less than 0.26 $^{o}$C i.e. 3 to 4 times lower than the observations.

Impossible to save natural variability even with fat tails/"black swan events".

e) The "pause" (cooling) was expected: it followed a large prepause warming.

# Conclusions




1. Using scaling fluctuation analysis to characterizing the climate by its type of variability: expect macroweather not climate

2. The need for GCM-free approaches:
a) their climate not ours,
b) disarming climate skeptics
c) Using statistical hypothesis testing to rule out natural variability

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

4. The total anthropogenic warming is about 0.85°C, for $CO_2$ doubling, 3.08±0.58°C, GCM's: 1.5-4.5°C (1979-2013).

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

6. The "pause" has a return period of 20-50 years, the post war cooling ≈ 125 years: not surprising.