



# Why the warming can't be natural: harnessing butterflies for climate closure

University of Algarve, 11 November 2015

S. Lovejoy, McGill, Montreal

November  
2014

# “Friends of Science” Versus Science

Montreal



Friends of Science

Montreal

Ce que la science dit VRAIMENT:  
Le climat change. À cause de nous.

ACS Association des  
communicateurs scientifiques  
du Québec acs.qc.ca

Association des Communicateurs Scientifiques

Toronto



Ottawa



# Climate Closure

Published Oct. 20, 2015  
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CLIMATE CHANGE Opinion

Climate Closure

In the battle of public opinion over climate change, we can play to science's strengths by shifting tactics: Instead of struggling to prove humans are to blame, let's prove denialist fantasies wrong.



A straightforward line of reasoning demonstrates that the only viable explanation of postindustrial warming is an anthropogenic source. This explanation is compatible with the "pause" in the warming since 1998, and it demonstrates that, in a statistical sense, such a pause is extremely likely. Credit: Shaun Lovejoy

By S. Lovejoy © 20 October 2015

Global warming science has concentrated on proving the theory that the postindustrial warming is largely caused by human activities. Yet no scientific theory can be proved beyond all doubt, and our attempts to convince people of the science are entering a period of diminishing returns.

For example, the [Fifth Assessment Report](#) (AR5, 2013) of the International Panel on Climate Change (IPCC) reiterated its 2007 statement "that human influence has been the dominant cause of the observed warming since the mid-20th century," only upgrading it from "likely" to "extremely likely." Meanwhile, those who reject this anthropogenic hypothesis have continued to push their theory that the warming is a giant fluctuation of solar, nonlinear dynamics that are internal to the atmosphere or other natural origin. For brevity we will call this group the "denialists," following the suggestion of [Gillis](#) [2015].

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# What is the climate?

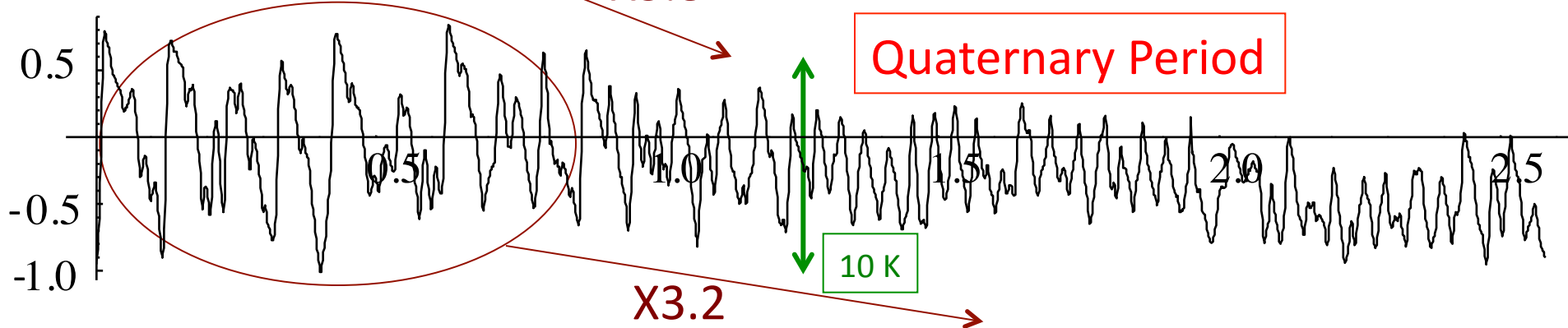
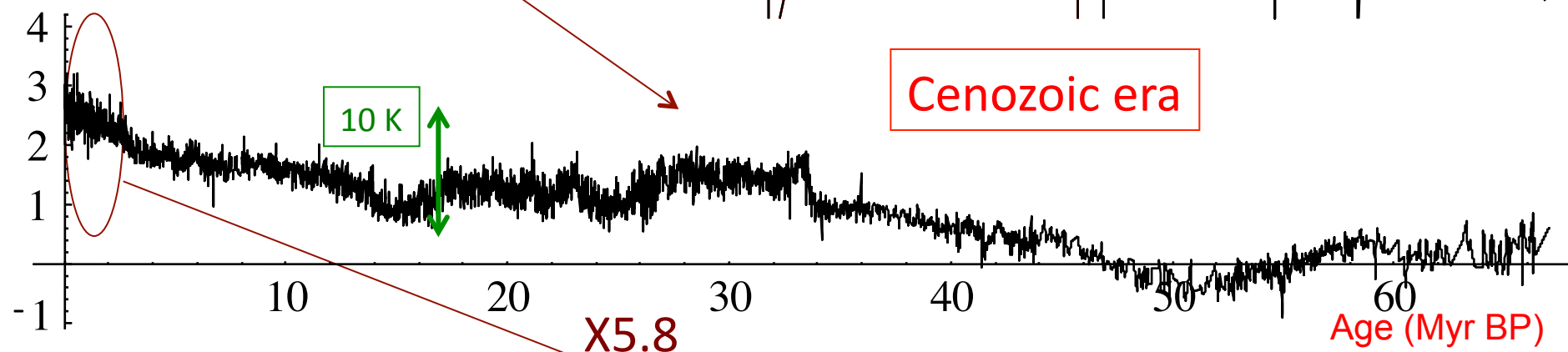
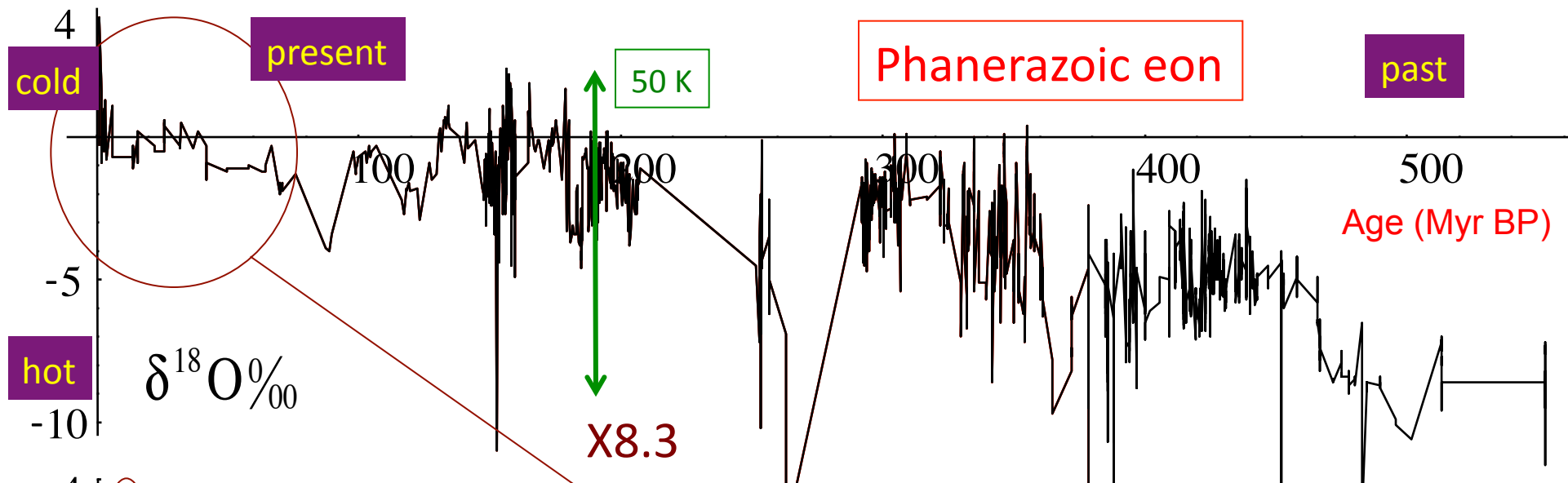
A voyage through scales

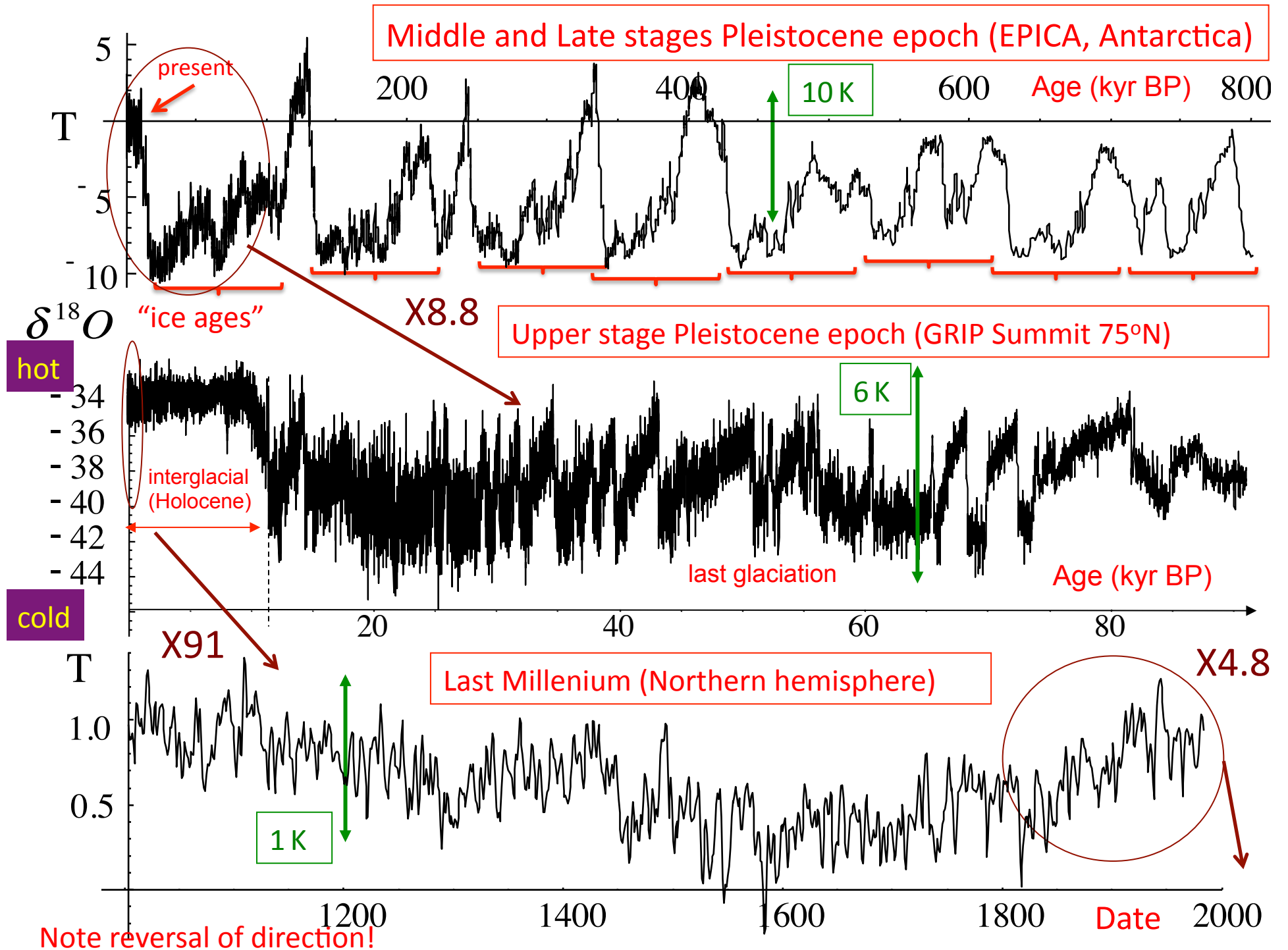
From the age of the earth to  
0.001 seconds:

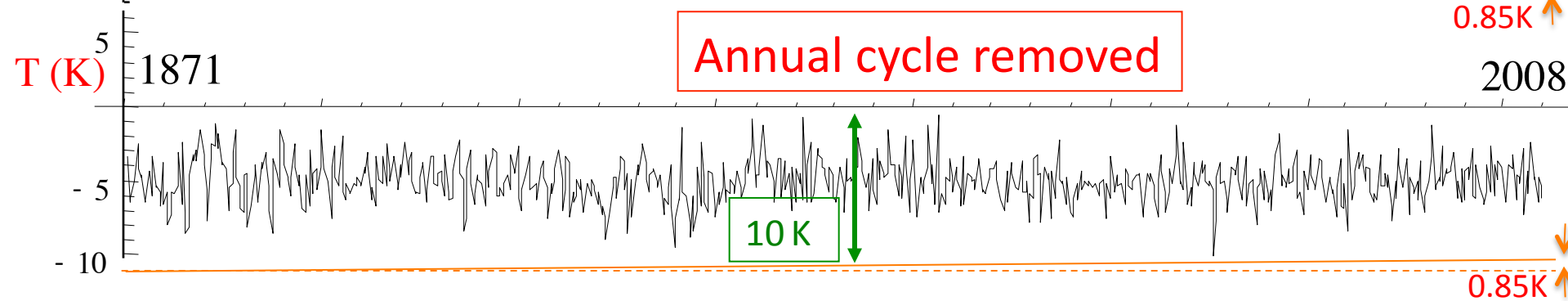
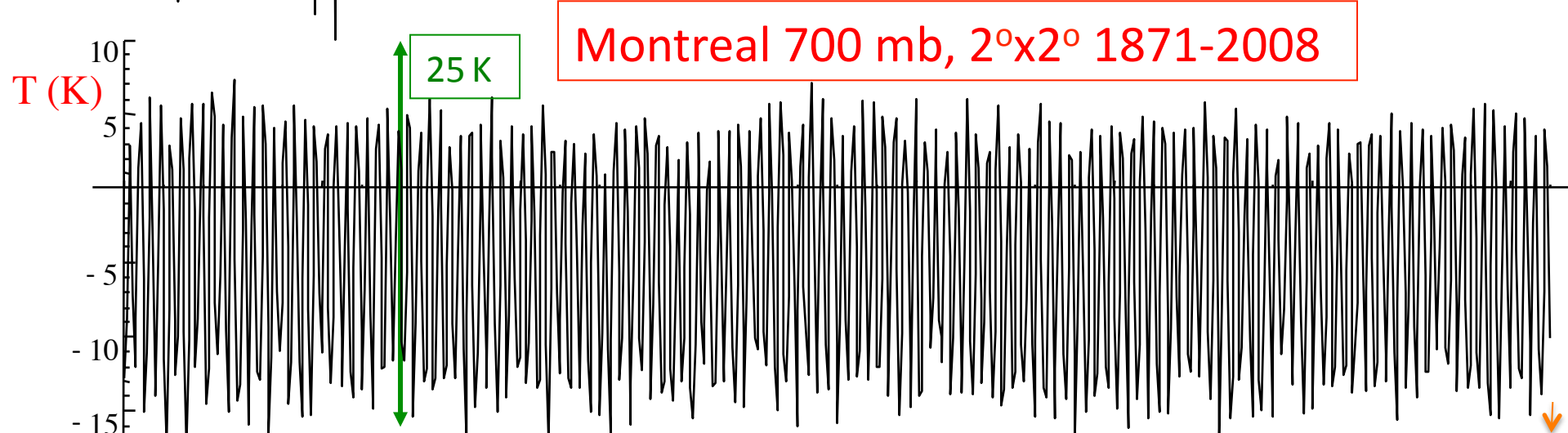
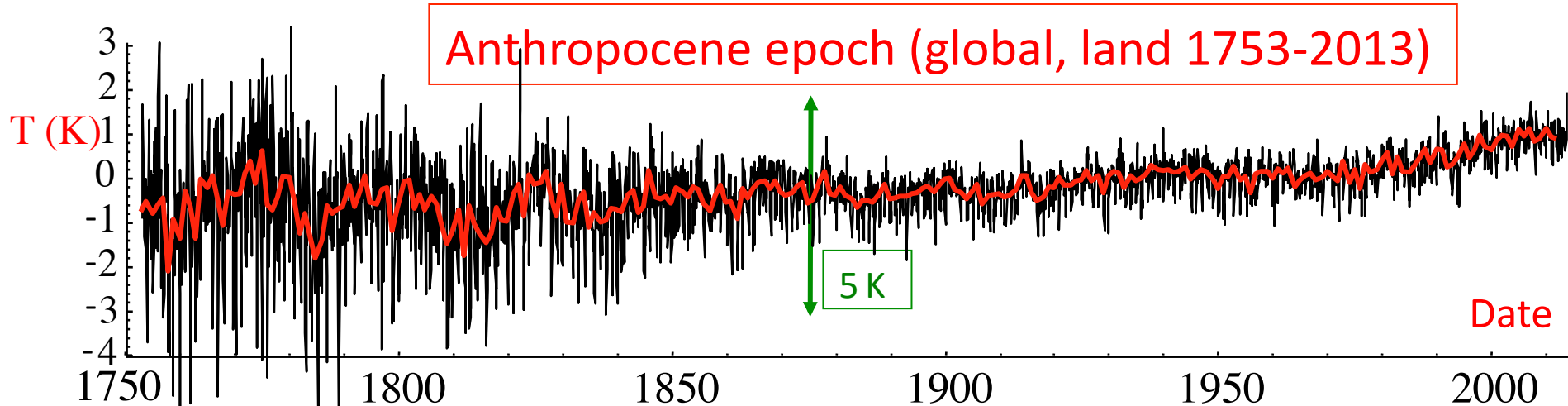
20 orders of magnitude in time

In space: the size of the planet to  
millimetres:

10 orders of magnitude

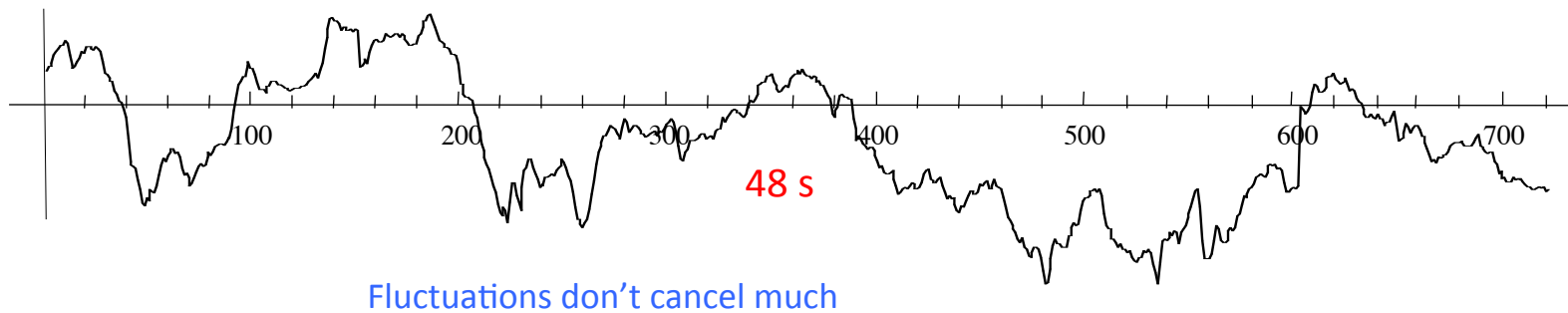
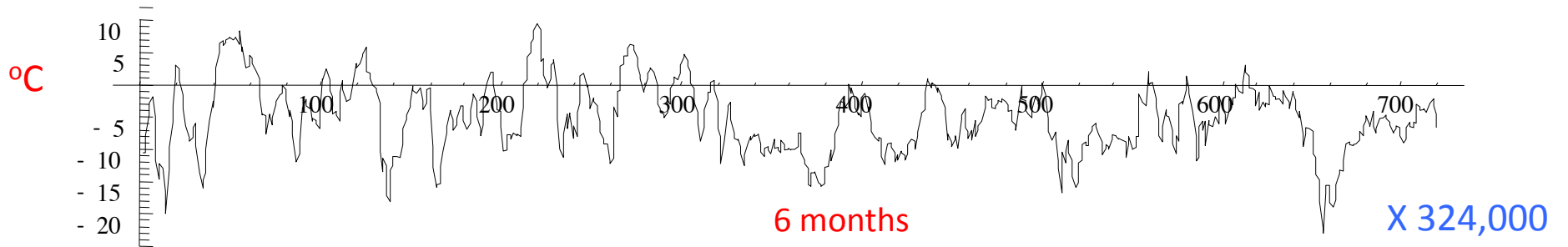
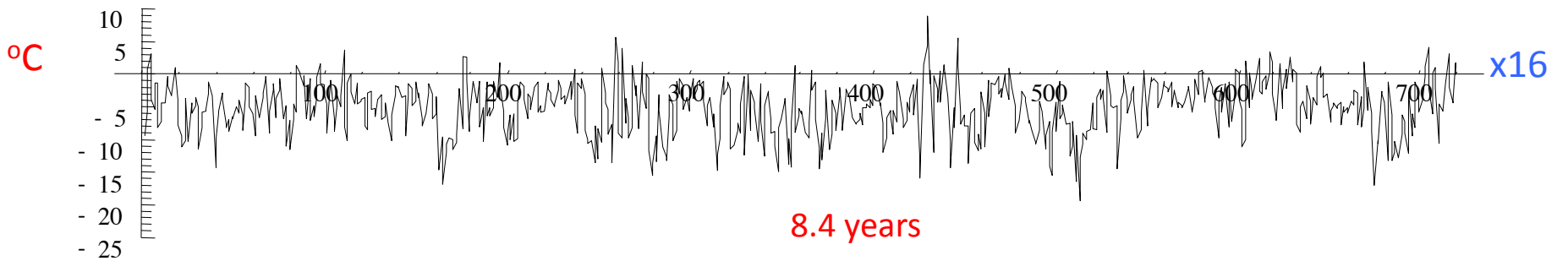
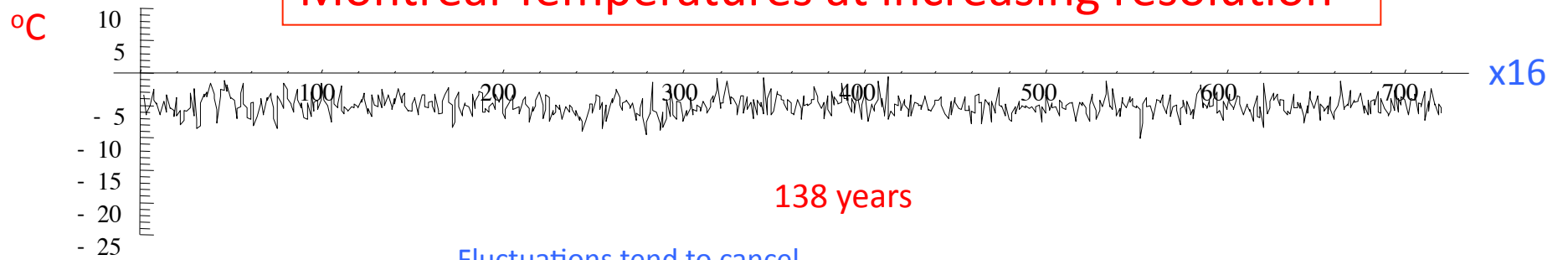








# Montreal Temperatures at increasing resolution



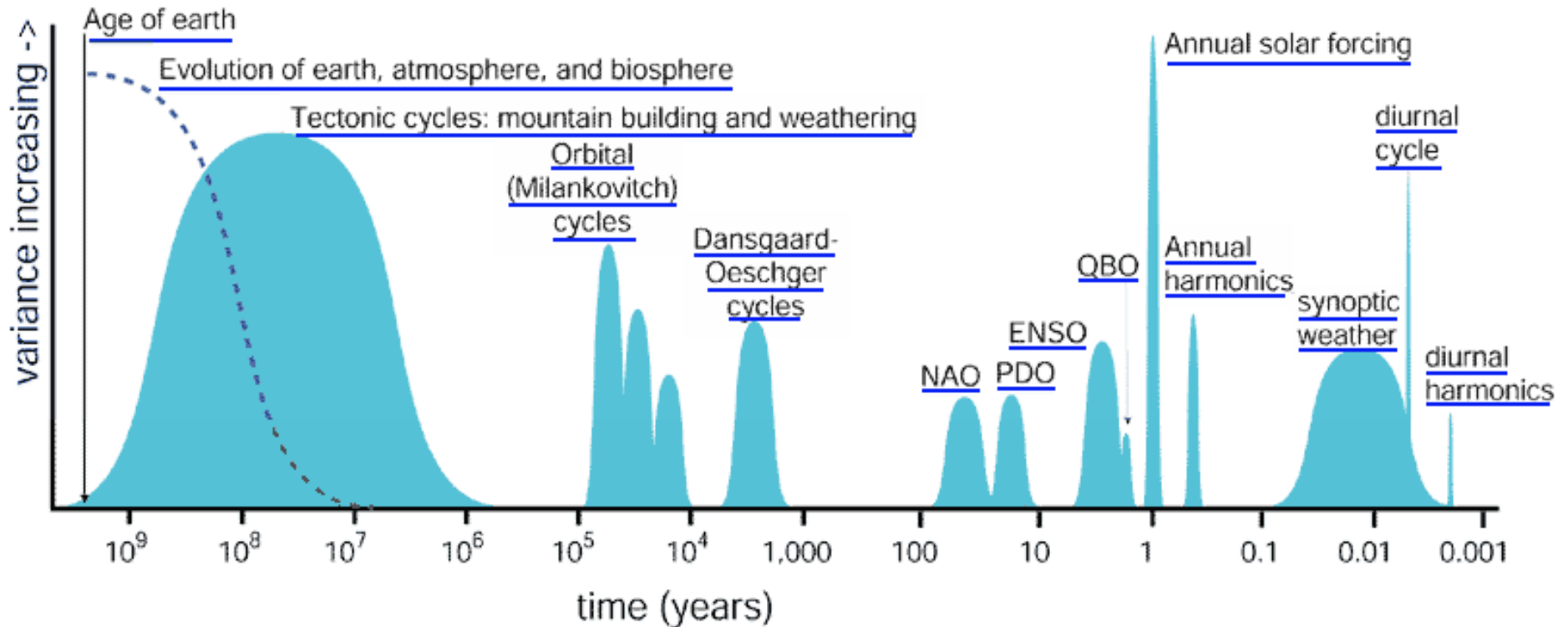
How to understand the variability?

Answer #1:

Scale bound thinking

2015

The NOAA NCDC Paleoclimate data site graph (inspired by Mitchell 1976)



The explanation of the figure:

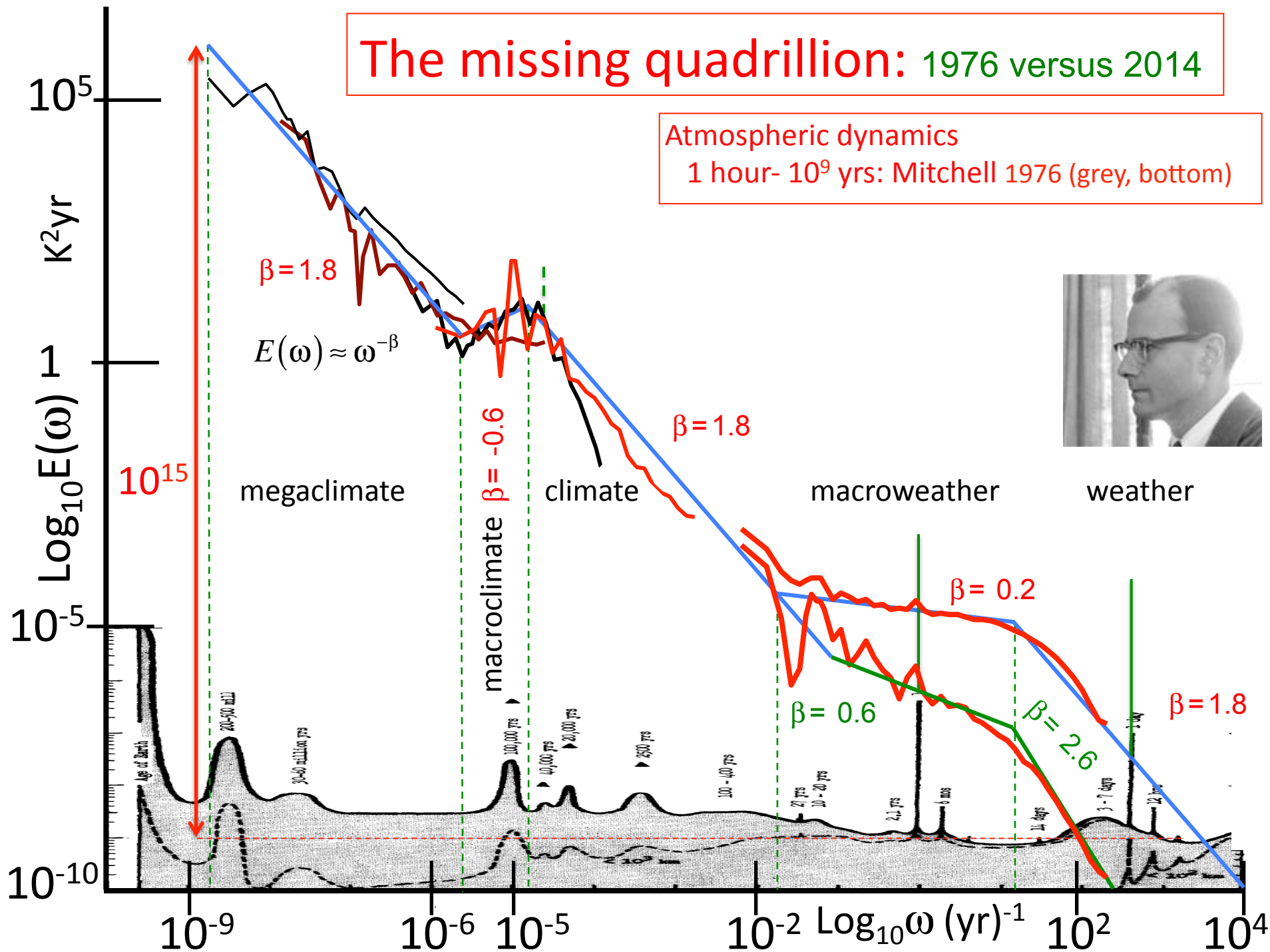
“... figure is intended as a mental model to provide a general "powers of ten" overview of climate variability, and to convey the basic complexities of climate dynamics for a general science savvy audience.”

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.”

# The missing quadrillion: 1976 versus 2014

Atmospheric dynamics

1 hour- 10<sup>9</sup> yrs: Mitchell 1976 (grey, bottom)



How to understand the variability?

## Answer #2

- Scaling, scale invariance:

$$\langle \Delta T (\Delta t) \rangle = \langle \varphi \rangle \Delta t^H$$

Corresponding spectrum:  $E(\omega) \approx \omega^{-\beta}$

Intermittency  
corrections (often  
small)



$$\beta = 1 + 2H - K(2)$$

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

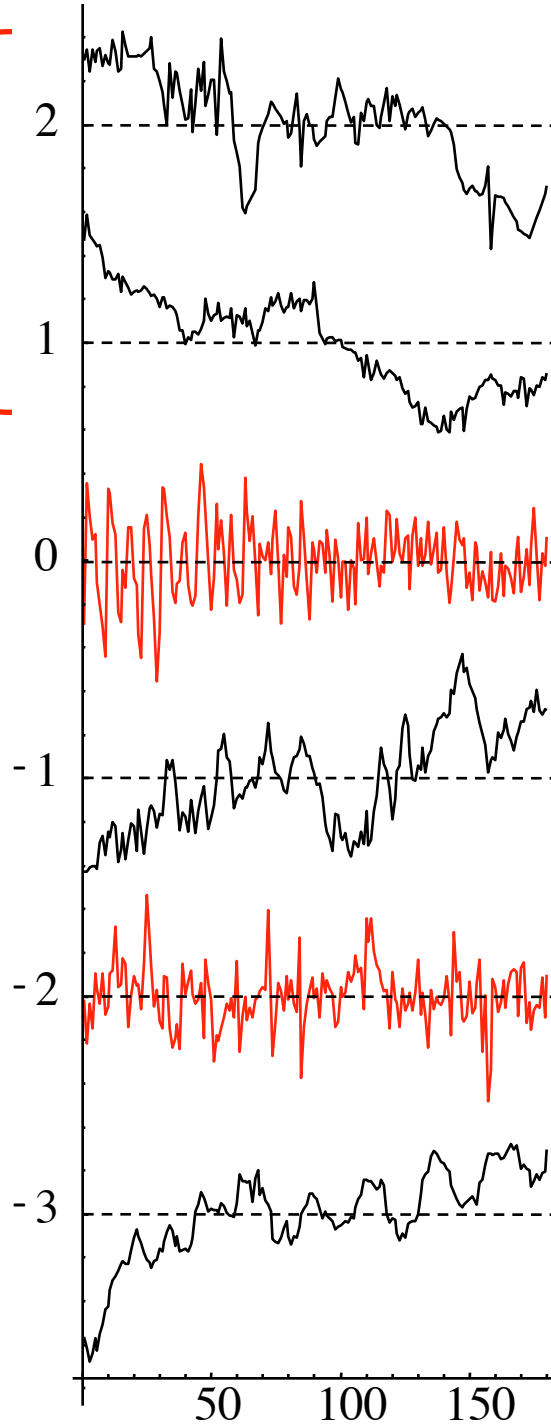
$$H \approx 0.4$$

$$H \approx -0.8$$

$$H \approx 0.4$$

$$H \approx -0.4$$

$$H \approx 0.4$$

$$T/\Delta T_{\max}$$


**Megaclimate**

Veizer: 290 Mys - 511Myrs BP (1.23Myr)

**Megaclimate**

Zachos: 0-67 Myrs (370 kyr)

**Macroclimate**

Huybers: 0-2.56 Myrs (14 kyrs)

**Climate**

Epica: 25-97 BP kyrs (400 yrs)

**Macroweather**

Berkeley: 1880-1895 AD (1 month)

**Weather**

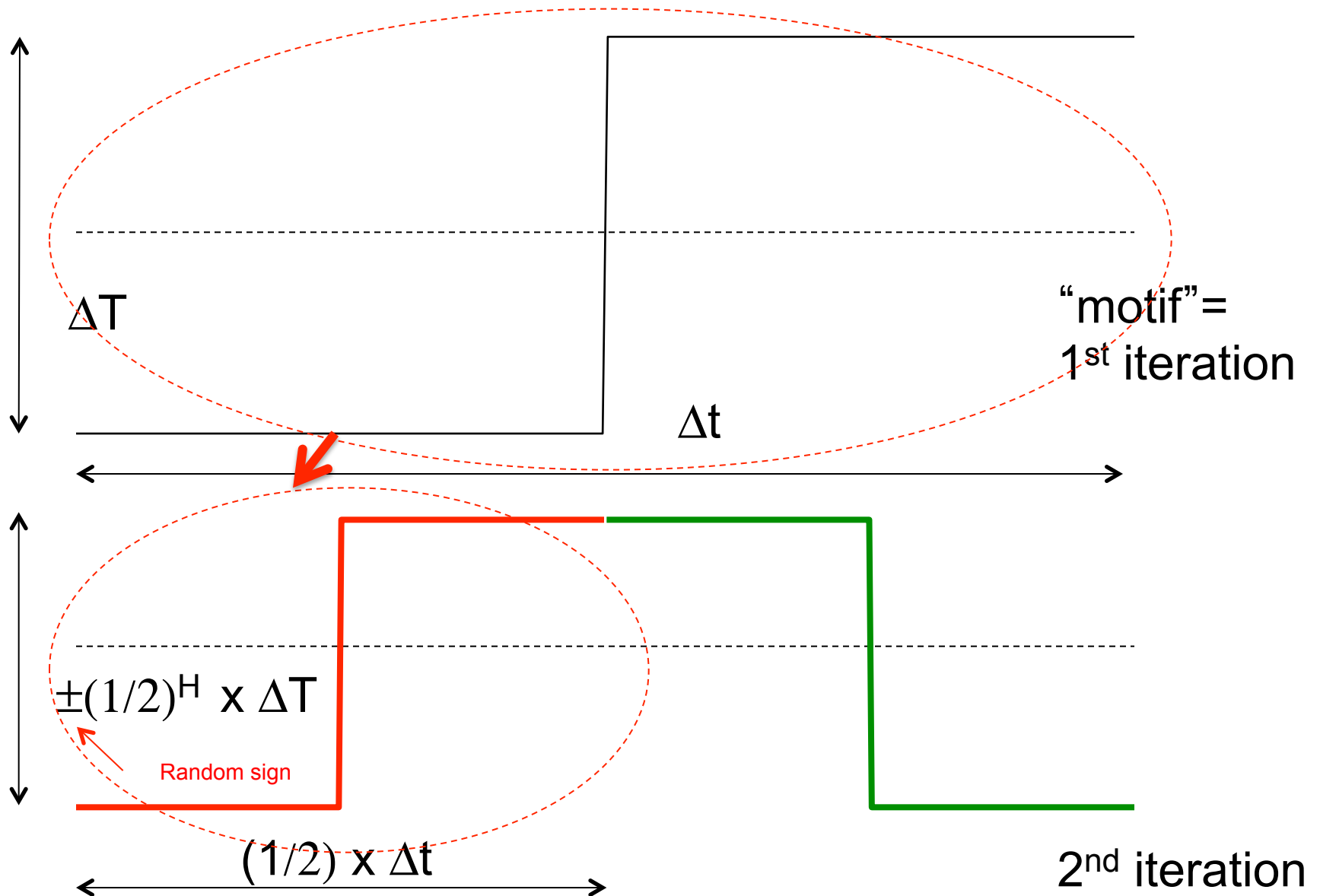
Lander Wy.: July 4-July 11, 2005 (1 hour)

**t**

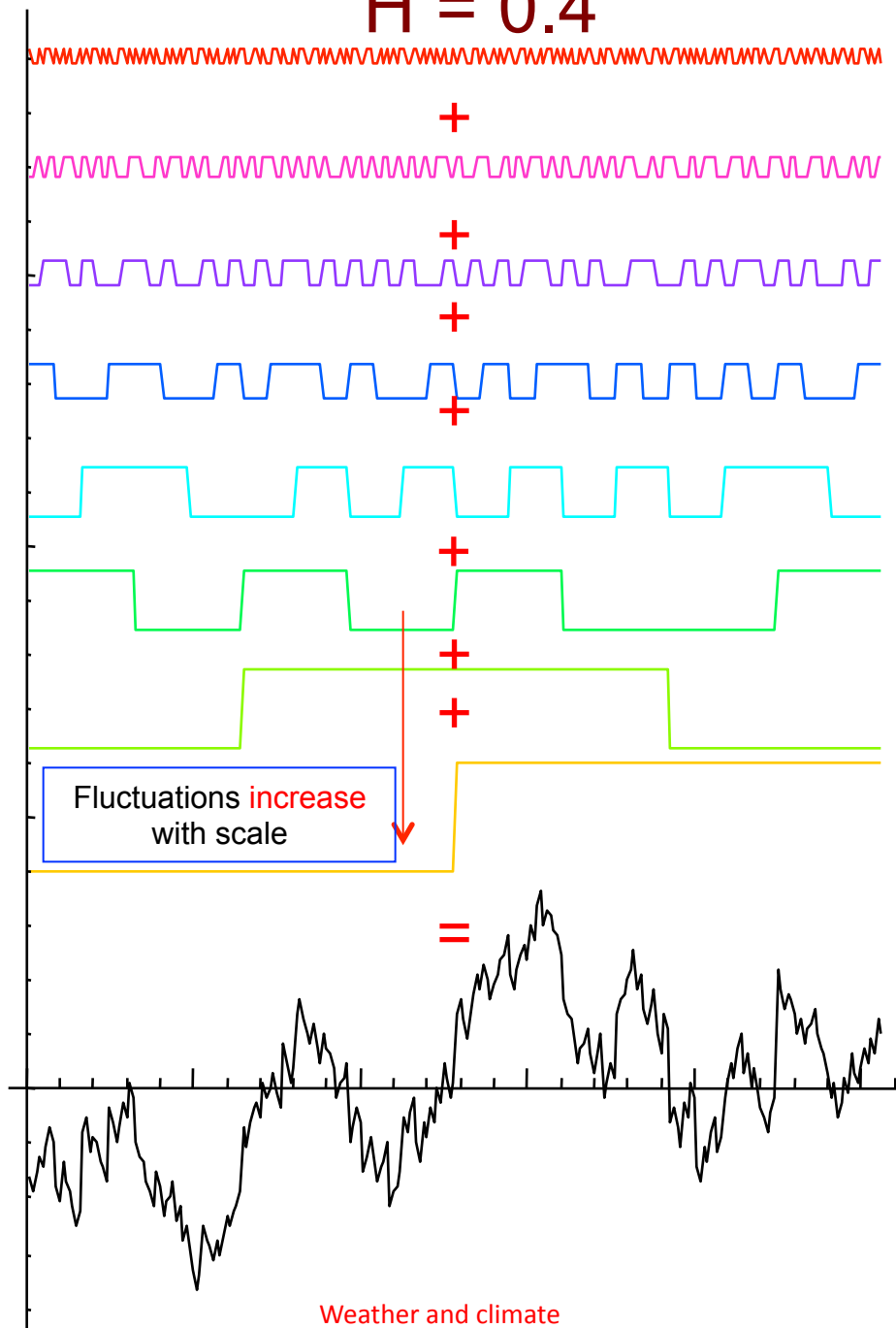
Understanding the fluctuation exponent  $\langle \Delta T (\Delta t) \rangle = \langle \varphi \rangle \Delta t^H$

## The "H model"

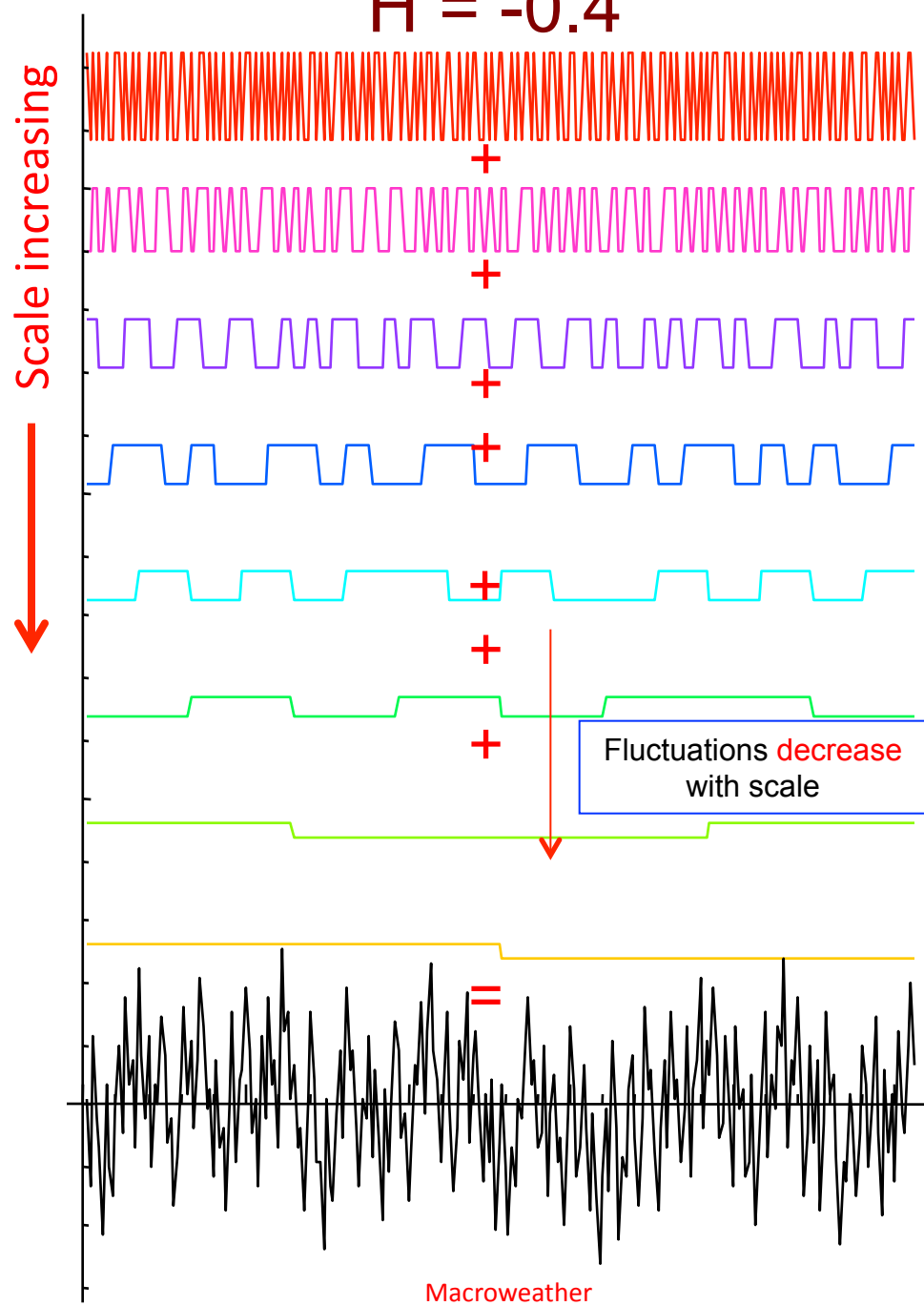
(Lovejoy 2013)



$H = 0.4$

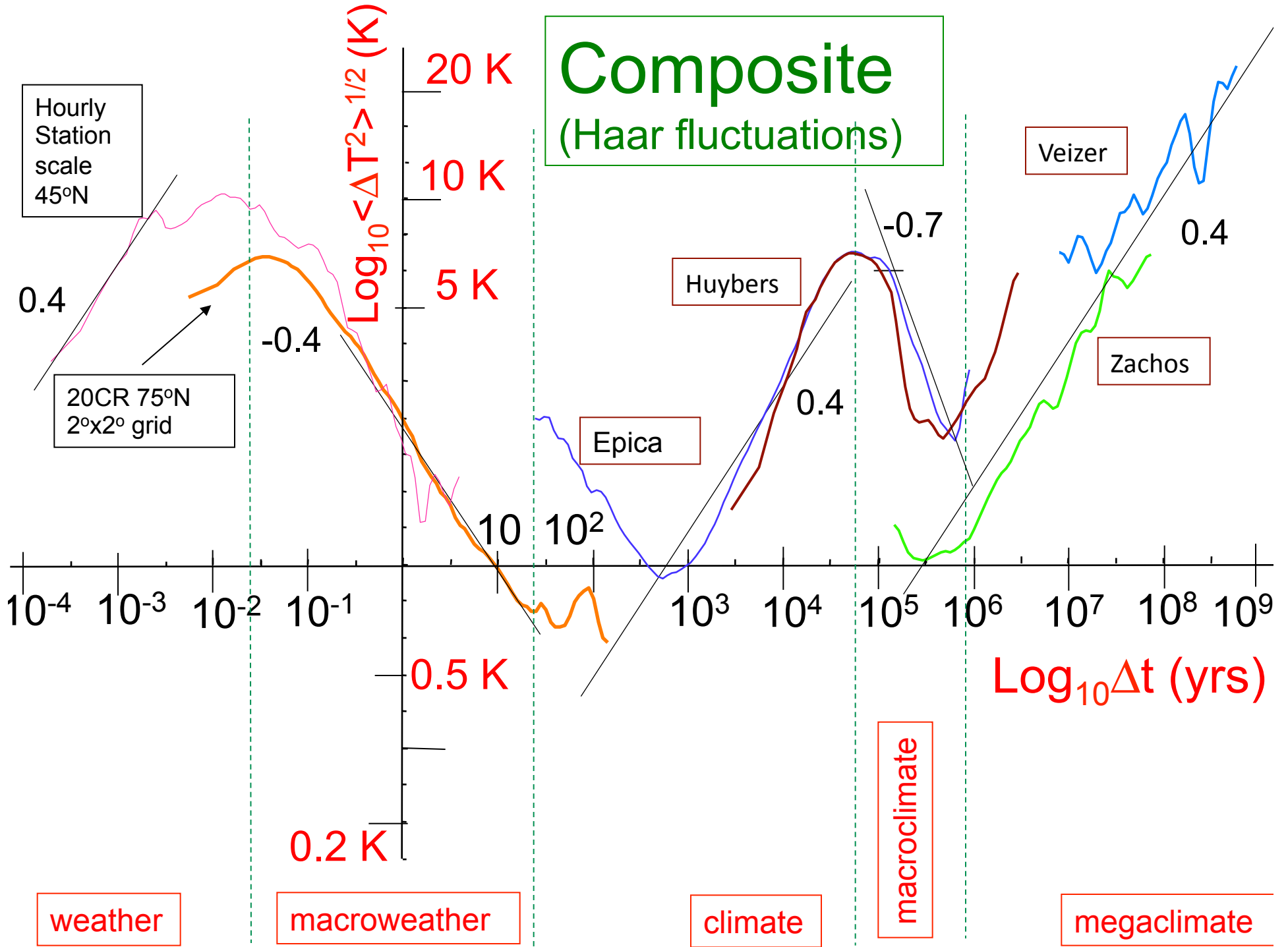


$H = -0.4$





# Composite (Haar fluctuations)



# Trichotomy:

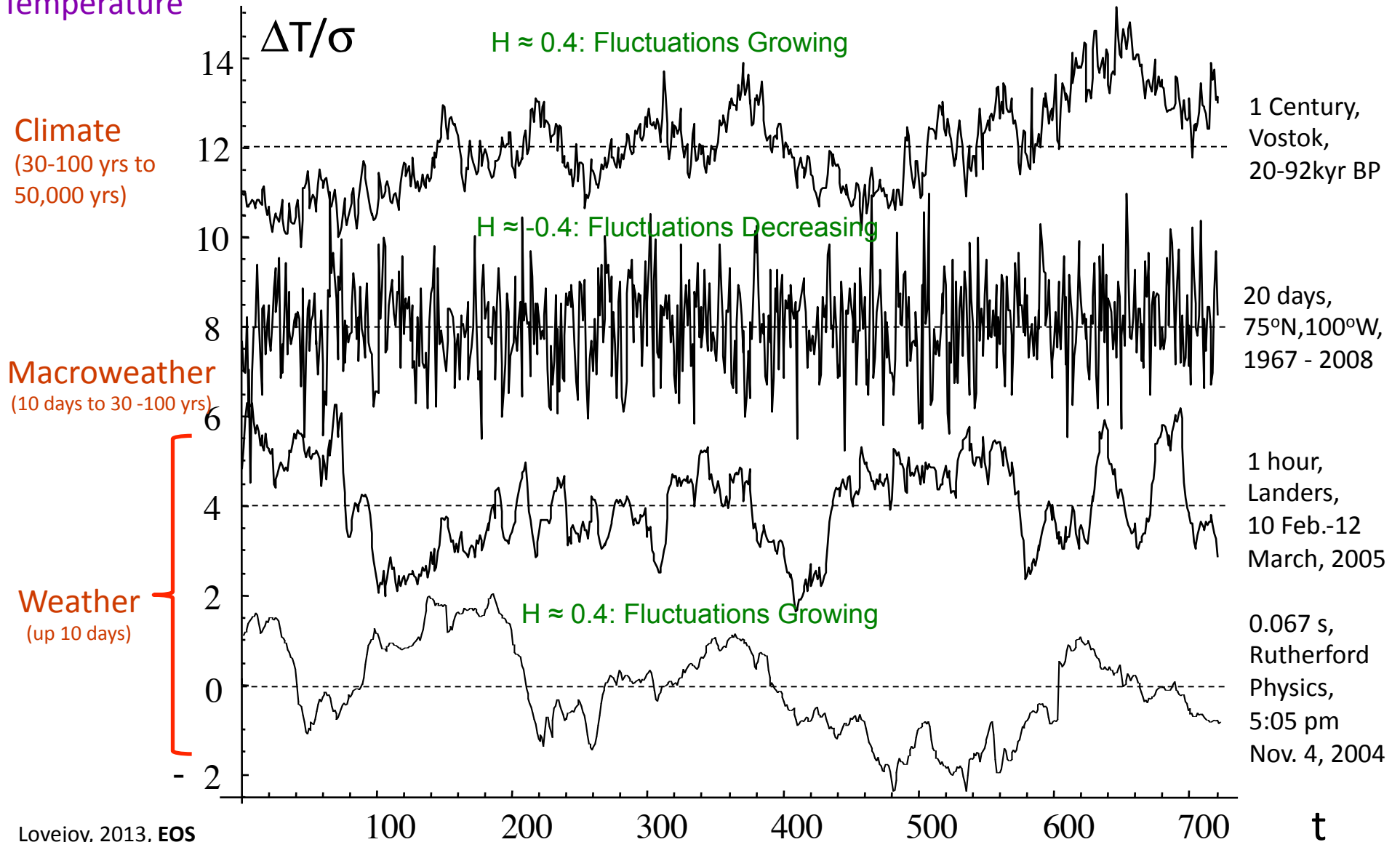
Weather – macroweather - climate

Lovejoy 2013

$$\langle \Delta I \rangle = \langle \phi \rangle \Delta t^H$$

Fluctuation  $\rightarrow$   $\langle \phi \rangle$   $\rightarrow$  constant

Temperature



Lovejoy, 2013, EOS

# The climate is not what you expect...

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

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

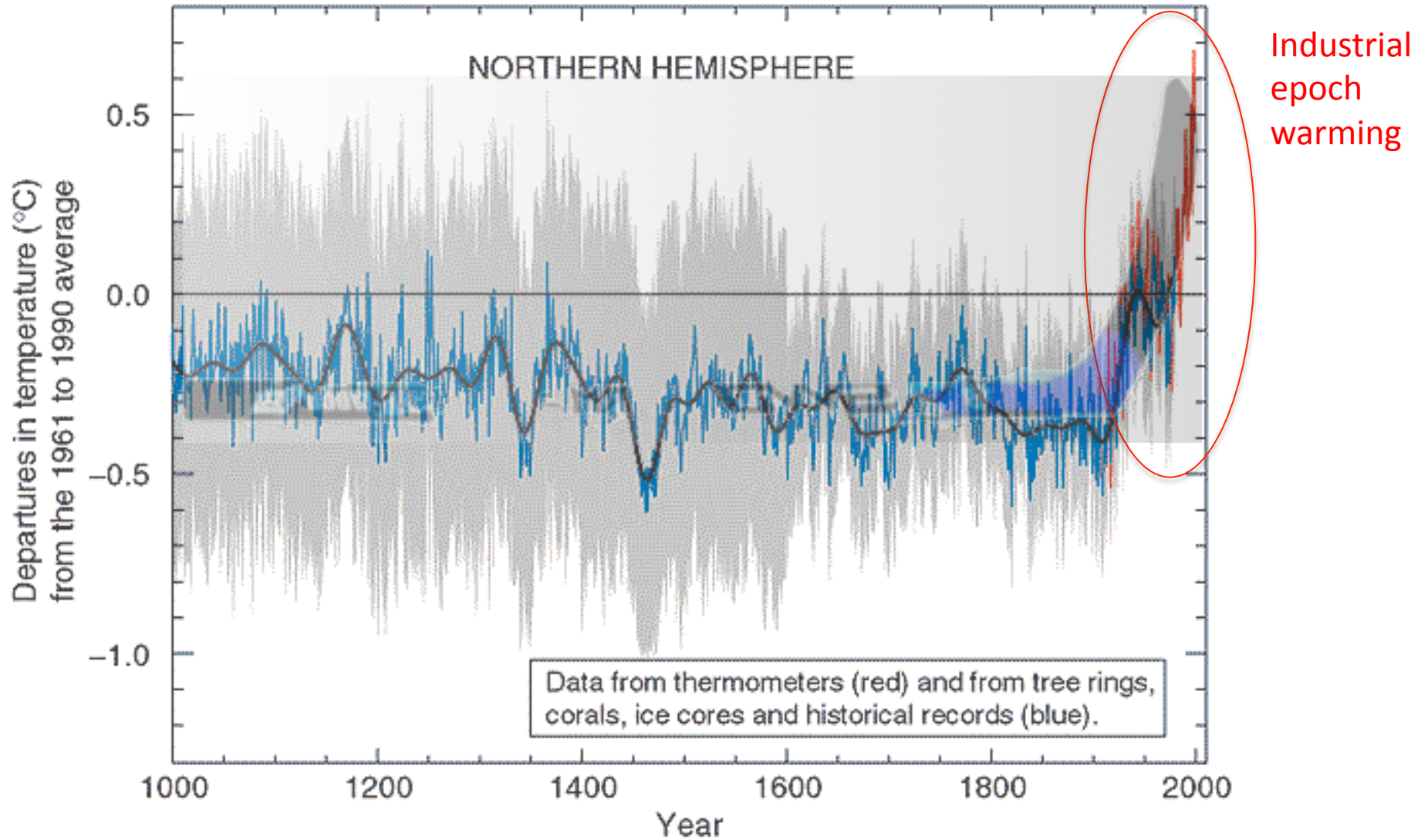
**"Climate in a narrow sense is usually defined as the "average weather" ... The classical period is 30 years, as defined by the World Meteorological Organization (WMO)... Climate in a wider sense is the state, including a statistical description, of the climate system."**

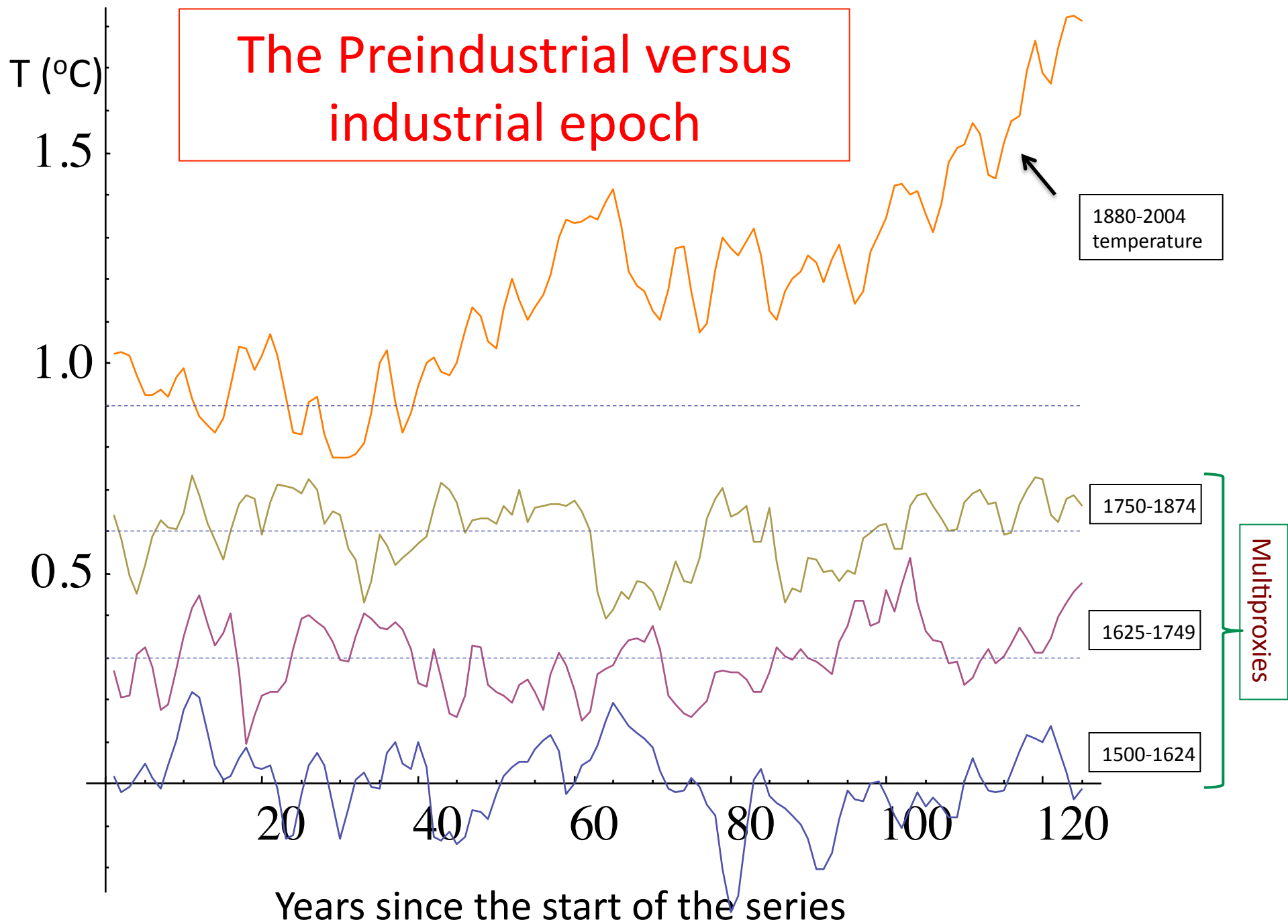
-Intergovernmental Panel on Climate Change, 2007

Evidence for warming

# The “hockey stick”

Mann, Bradley, Hughes 1998

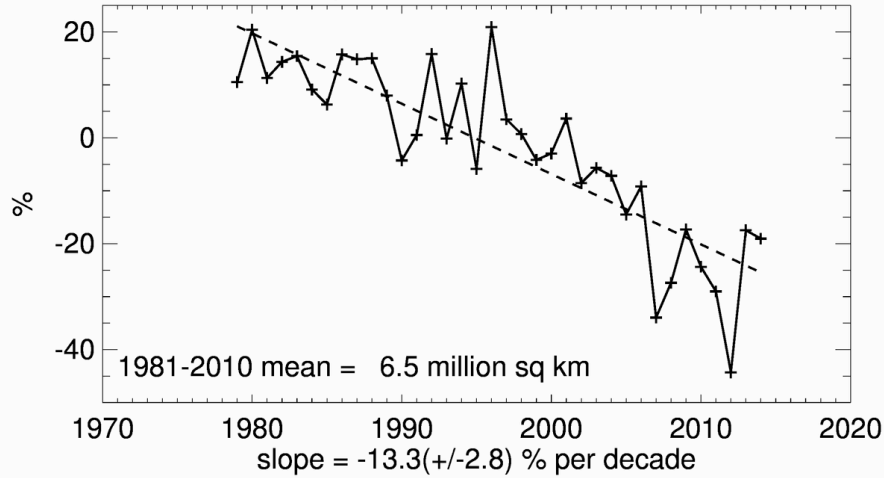




# The Arctic

(melting of sea ice)

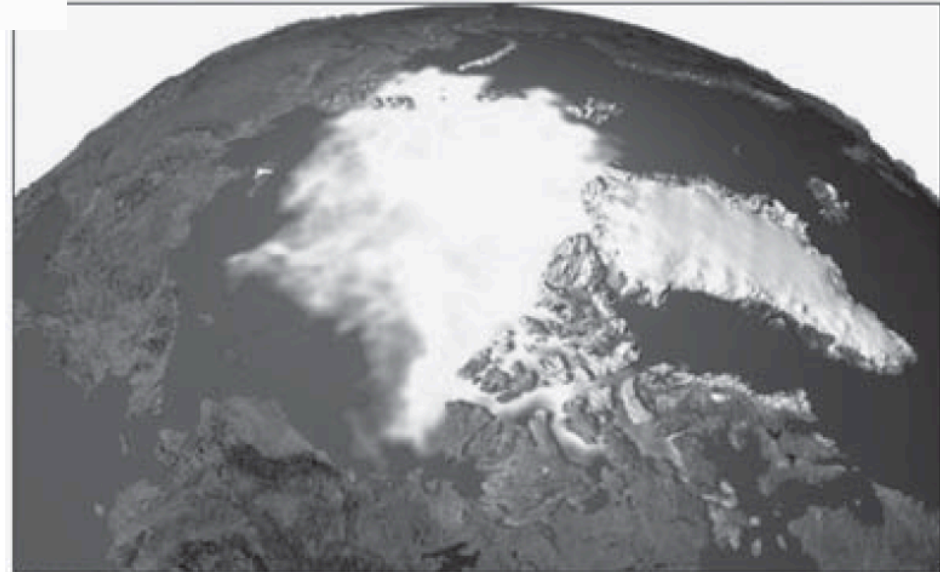
Northern Hemisphere Extent Anomalies Sep 2014



1979

SSM/I Composite Data

Over 2 million square km of sea ice lost over 35 years



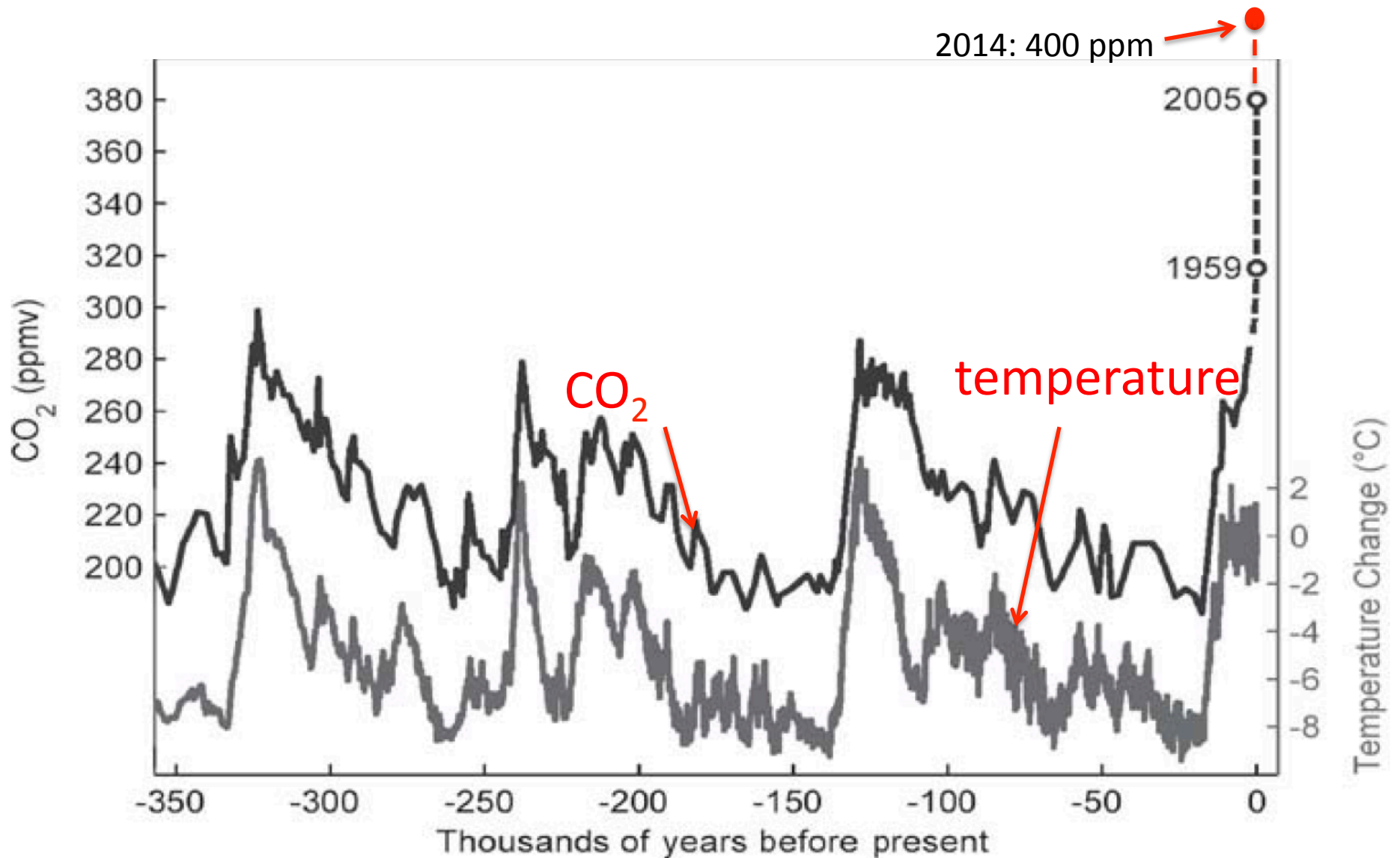
2005

2003 SSM/I Composite Data

# Anthropogenic Theory

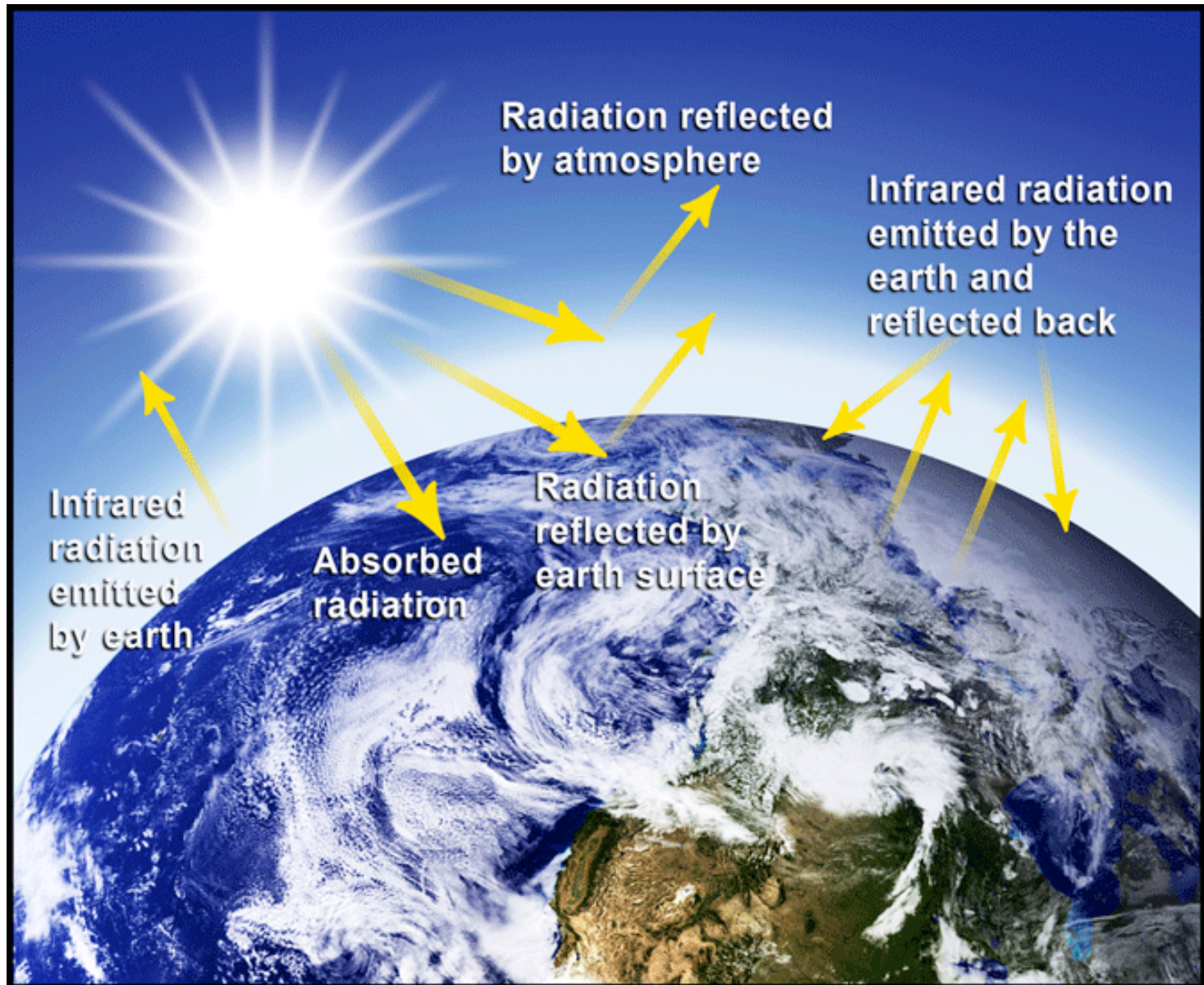


# CO<sub>2</sub>: The last 350,000 yrs



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”



# Anthropogenic warming: Pre-GCM era

1896

Nobel prize winner Svante Arrhenius: CO<sub>2</sub> doubling: 5 – 6°C of warming, “climate sensitivity”



Svante Arrhenius  
(1859 –1927)

1938

Callender estimated the warming as 2° C



Guy Stewart Callendar  
1898 - 1964

1957

Keeling started his celebrated CO<sub>2</sub> measurements at Mauna Loa and at the south Pole



Charles David Keeling  
1928 –2005

GCM = Global Circulation Model

# GCM era (post 1975)

GCM's: for CO<sub>2</sub> doubling:

US National Academy of Science (1979): 1.5- 4.5°C

1998 climate models somewhat over-forecast the warming in the 2000's (the "pause")

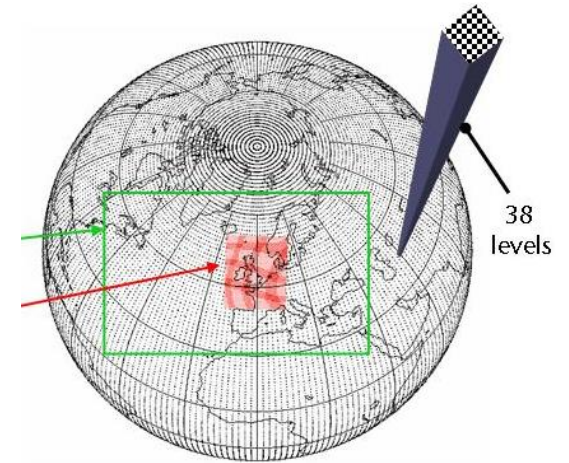
## Proving AW: Diminishing Returns

GCM's: for CO<sub>2</sub> doubling:

IPCC3	(2002):	1.5- 4.5°C
IPCC4	(2007):	2- 4.5°C
IPCC5	(2013):	1.5- 4.5°C

IPCC 5 (2013) extremely

IPCC 4 (2007) "it is likely that human influence has been the dominant cause of the observed warming since the mid-20th century"



MilkyWay-2: World's fastest supercomputer



3,120,000 cores: 3x10<sup>16</sup> Flops (Nov. 2014)

# Natural variability Theory: A Giant Natural Fluctuation

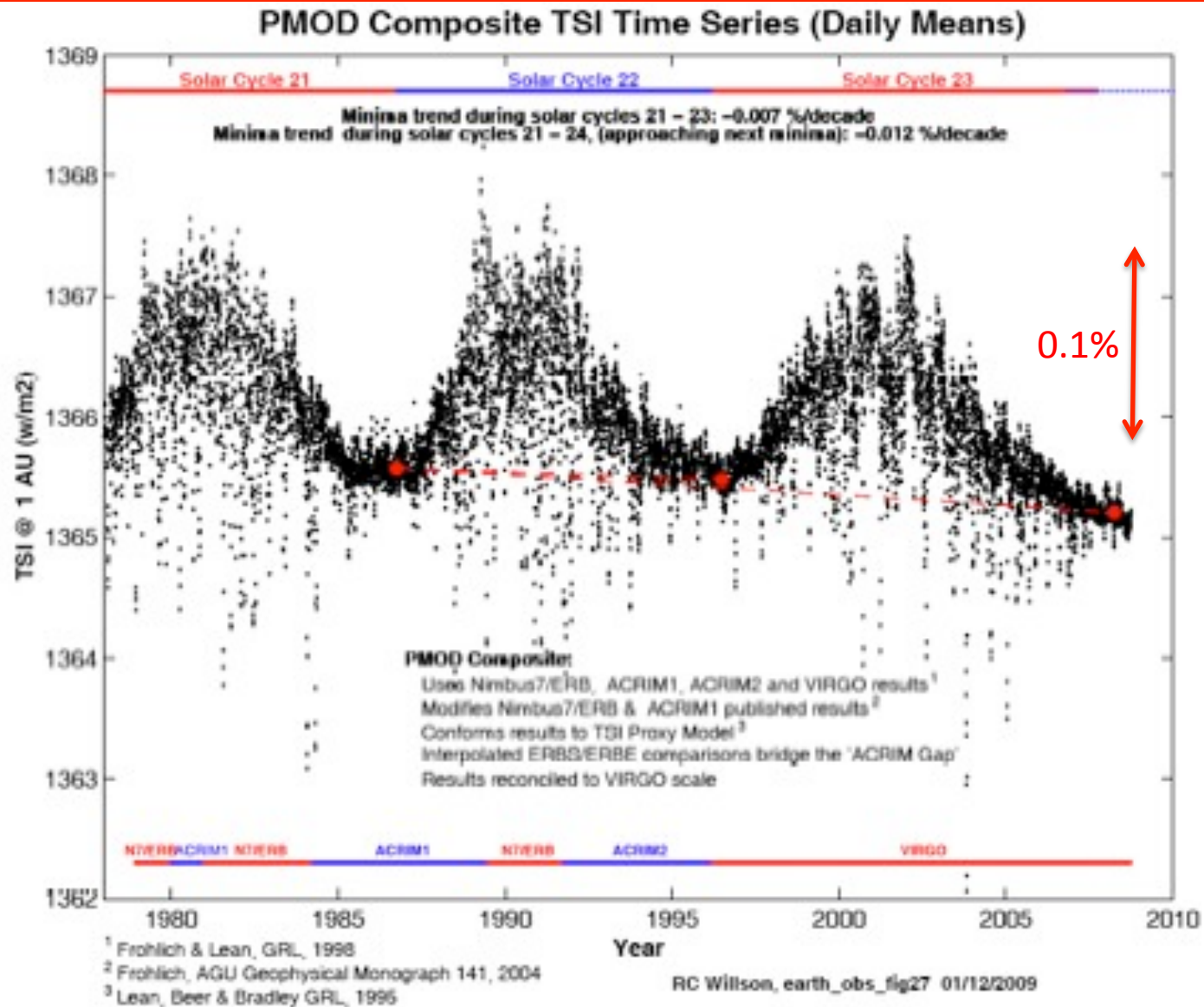


Friends of Science Billboard, Nov. 2014

# The sun ? (1):

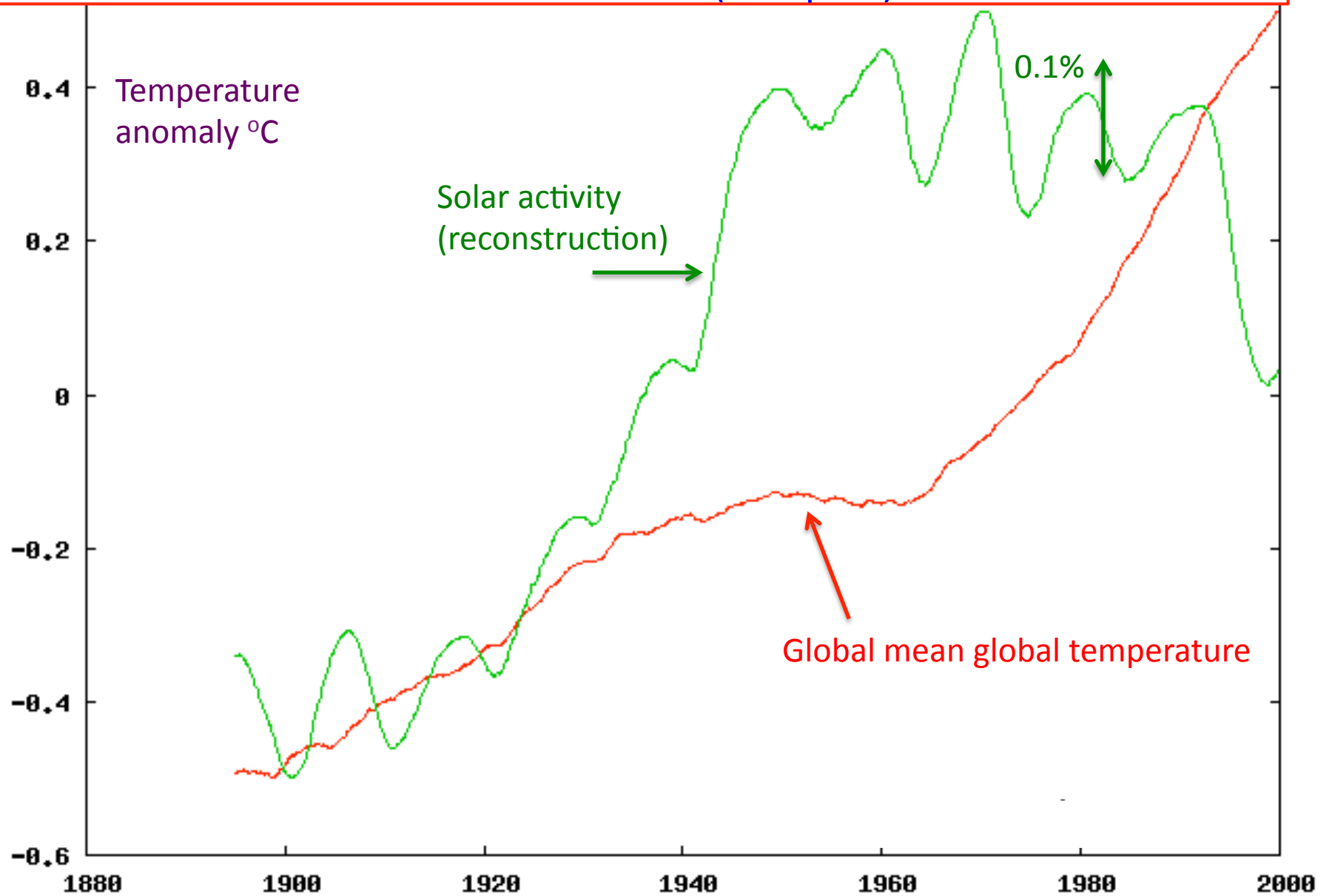
## Total Solar Insolation

(satellite)



# The sun ? (2):

## Solar reconstruction (sunspots)



# “Climate Closure” (1)

## Disproving Natural warming

Clim Dyn (2014) 42:2339–2351  
DOI 10.1007/s00382-014-2128-2

### Scaling fluctuation analysis and statistical hypothesis testing of anthropogenic warming

S. Lovejoy

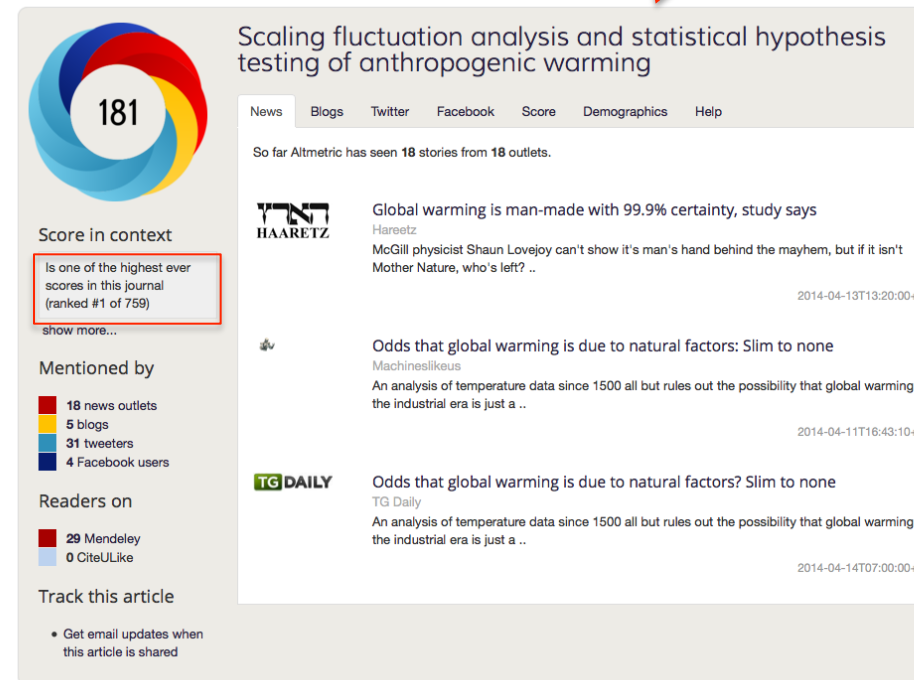
Received: 9 January 2014 / Accepted: 26 March 2014 / Published online: 6 April 2014  
© Springer-Verlag Berlin Heidelberg 2014

**Abstract** Although current global warming may have a large anthropogenic component, its quantification relies primarily on complex General Circulation Models (GCM's) assumptions and codes; it is desirable to complement this with empirically based methodologies. Previous attempts to use the recent climate record have concentrated on “fingerprinting” or otherwise comparing

#### 1 Introduction

Well before the advent of General Circulation Models (GCM's), (Arrhenius 1896), proposed that greenhouse gases could cause global warming and he even made a surprisingly modern quantitative prediction. Today, GCM's are so much the dominant tool for investigating the

Dec. 12, 2014



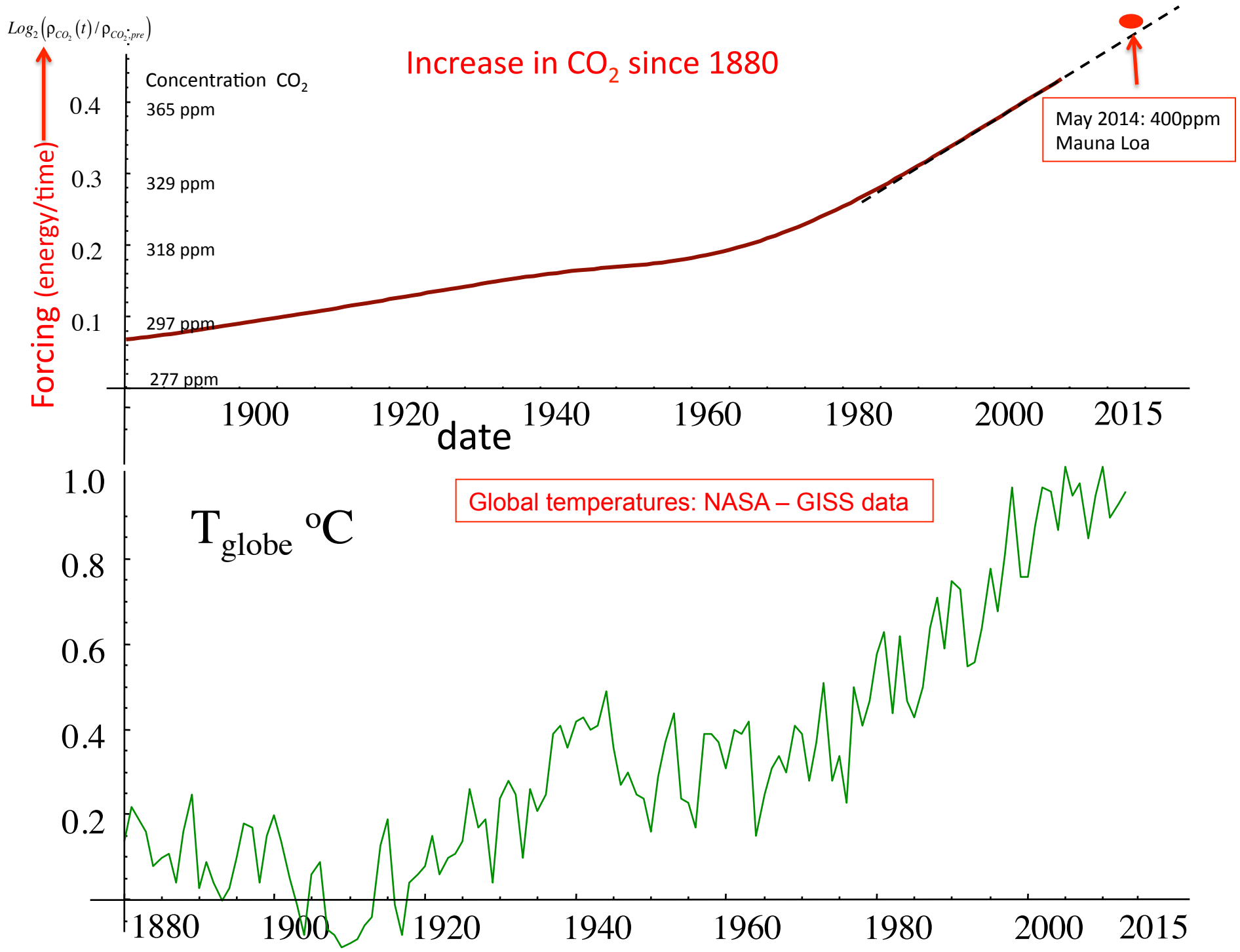
The screenshot shows the Altmetric interface for the article. At the top left is a circular score of 181. Below it, a text box states: "Is one of the highest ever scores in this journal (ranked #1 of 759)". To the right, there are navigation tabs for News, Blogs, Twitter, Facebook, Score, Demographics, and Help. Below these, it says "So far Altmetric has seen 18 stories from 18 outlets." Three news stories are listed:

- HAARETZ**: Global warming is man-made with 99.9% certainty, study says. McGill physicist Shaun Lovejoy can't show it's man's hand behind the mayhem, but if it isn't Mother Nature, who's left? .. (2014-04-13T13:20:00+)
- Machineslikeus**: Odds that global warming is due to natural factors: Slim to none. An analysis of temperature data since 1500 all but rules out the possibility that global warming the industrial era is just a .. (2014-04-11T16:43:10+)
- TG DAILY**: Odds that global warming is due to natural factors? Slim to none. An analysis of temperature data since 1500 all but rules out the possibility that global warming the industrial era is just a .. (2014-04-14T07:00:00+)

At the bottom, there are statistics for "Mentioned by" (18 news outlets, 5 blogs, 31 tweeters, 4 Facebook users) and "Readers on" (29 Mendeley, 0 CiteULike). A "Track this article" section offers to get email updates when the article is shared.

Natural variability hypothesis was neglected by the scientific community





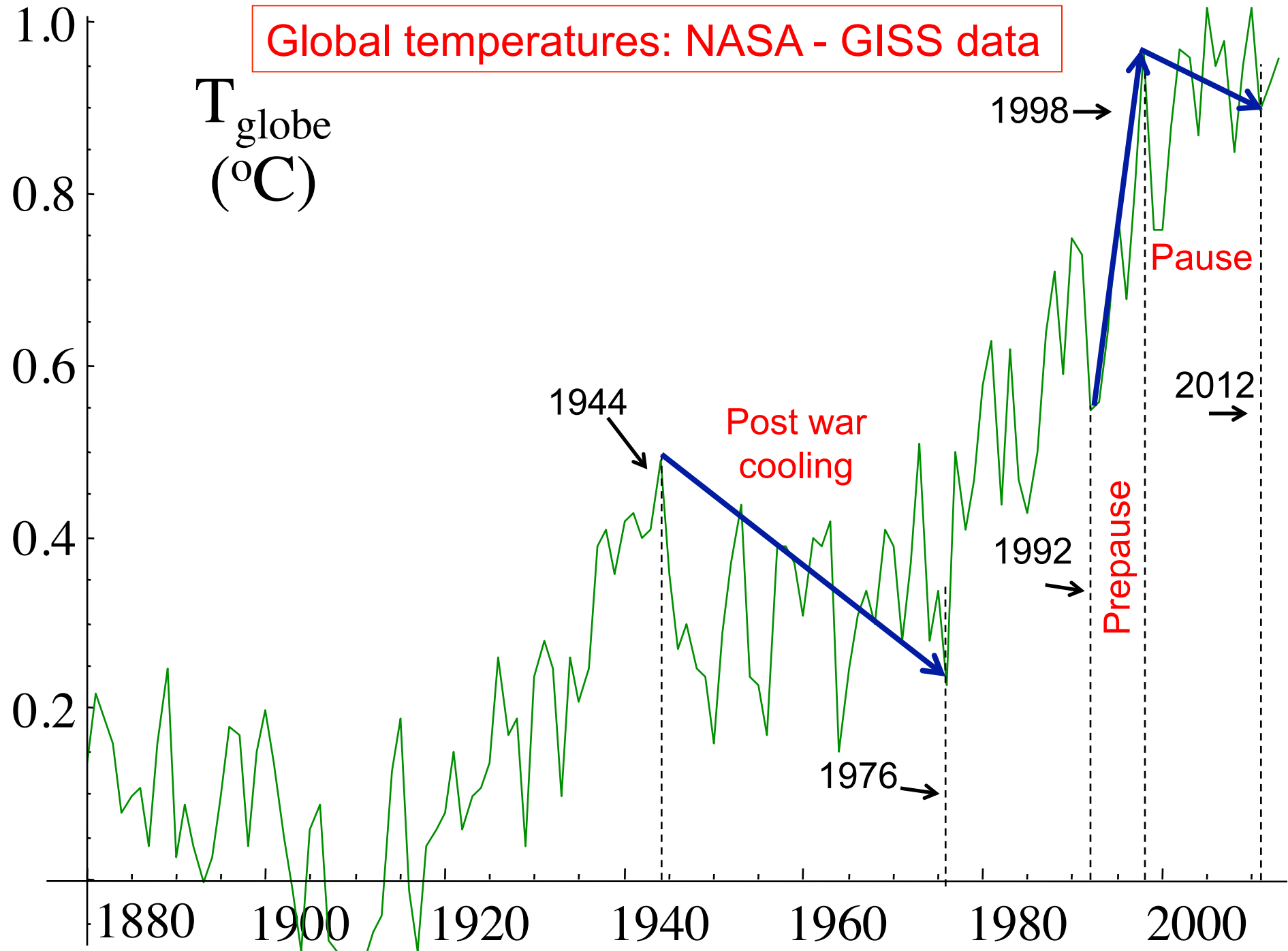
# CO<sub>2</sub> forcing as surrogate for all anthropogenic effects

Roughly:

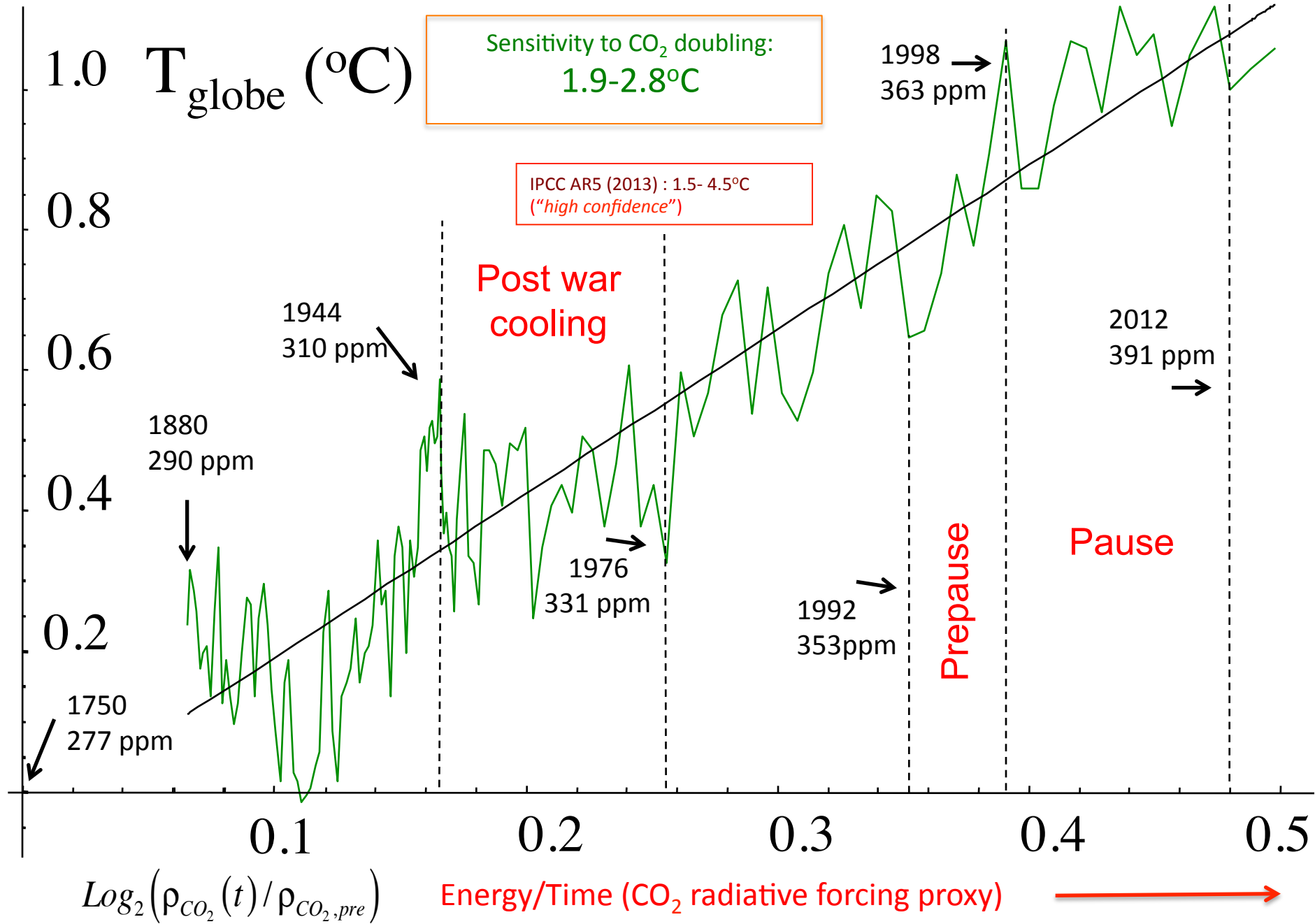
double the global economy, double the emissions, land use and other changes:

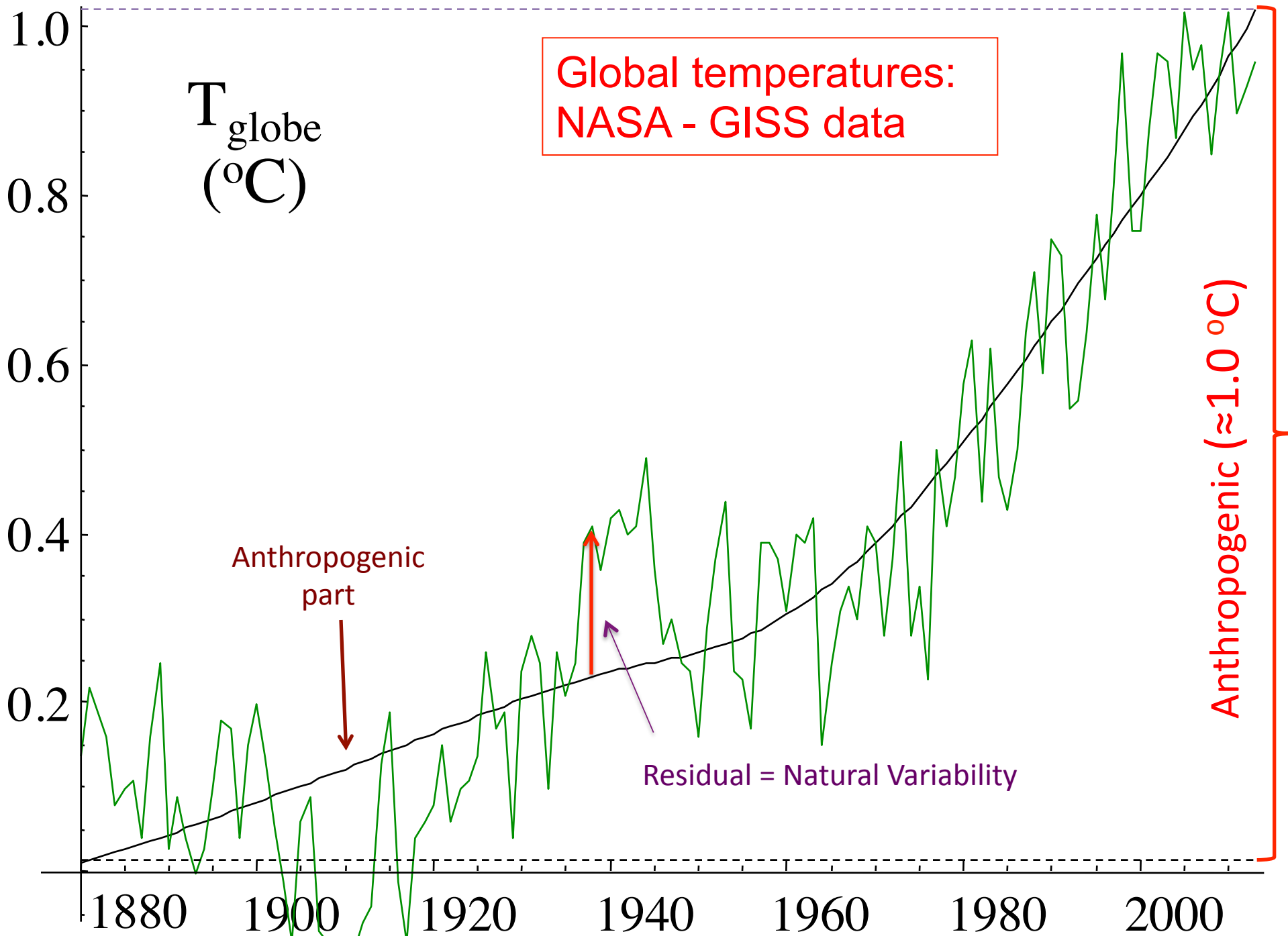
double the effects

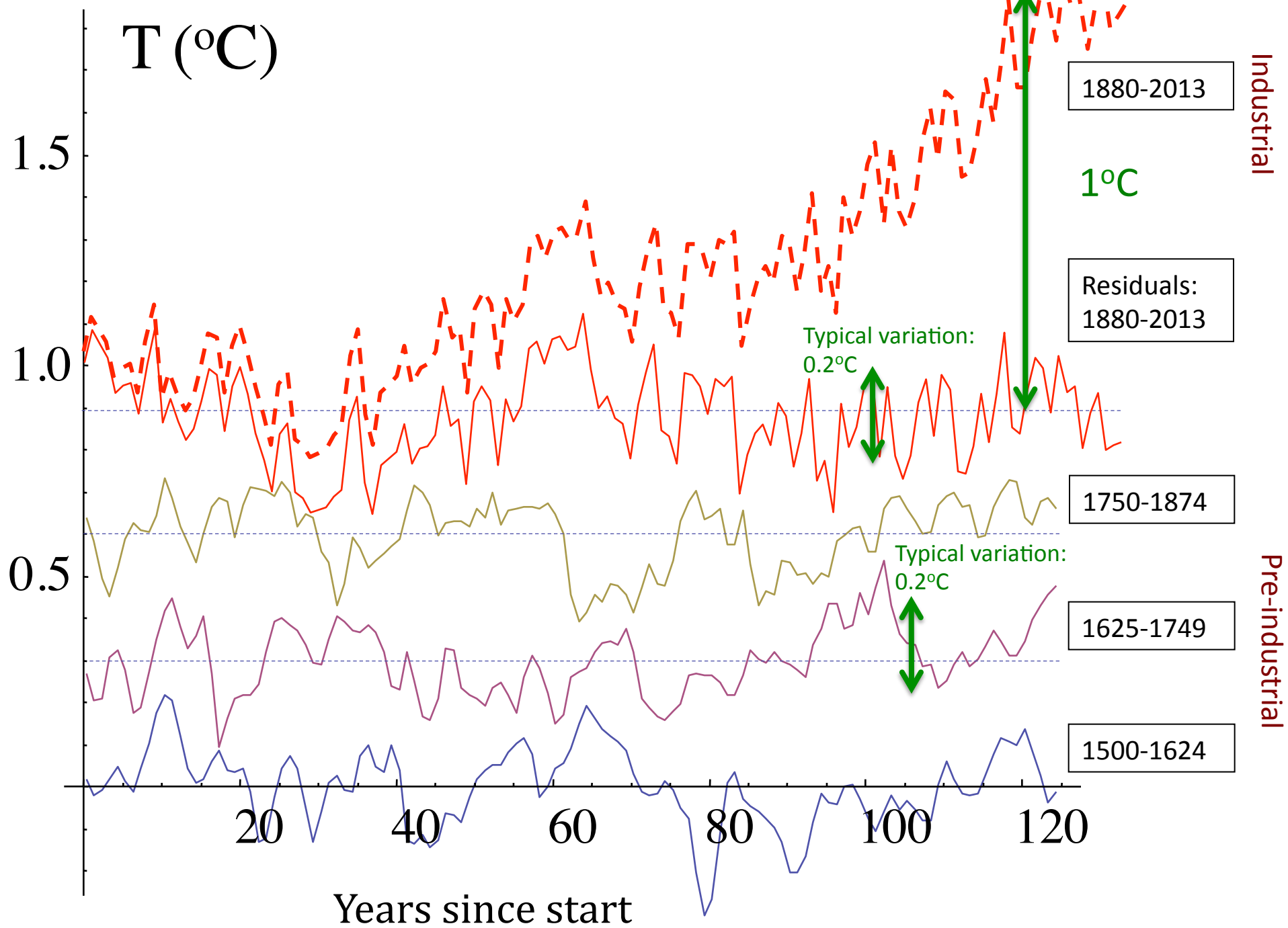
Global temperatures: NASA - GISS data



# Global temperatures: NASA - GISS data

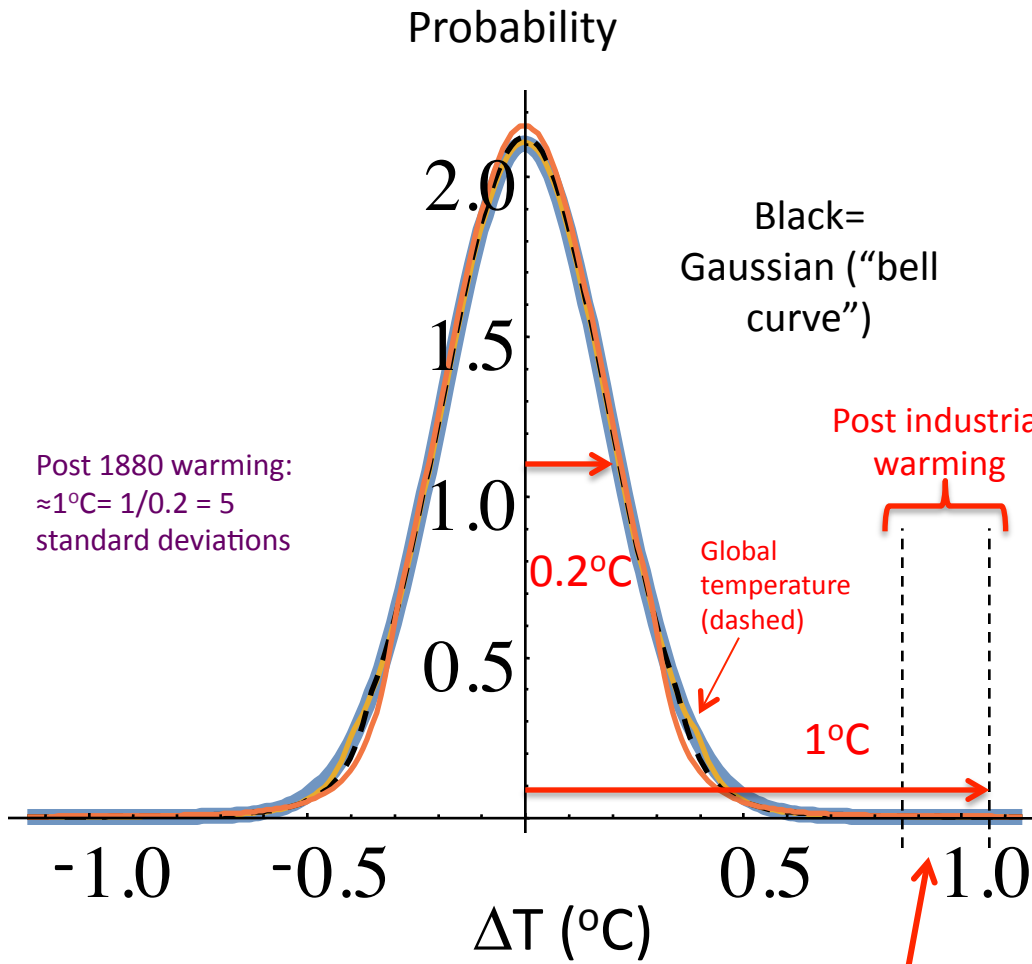




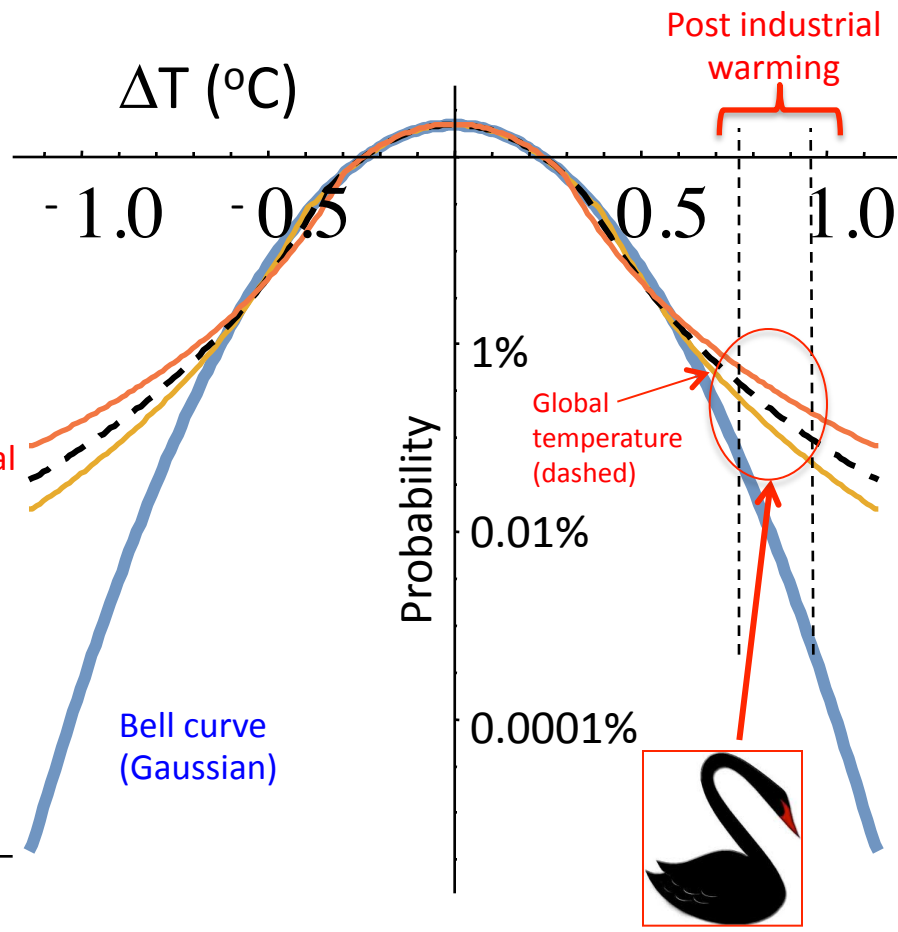


# Probabilities of extremes: Bell Curve, Black Swans (1)

Usual representation



Representation showing extremes



$\approx 5$  standard deviations: one in 3 million chance

one in 4 thousand chance  
Probability  $\approx \Delta t^{-5}$

# Extremes and Black Swans (2)



## Bell curve ('normal distribution') probabilities

Probability of exceeding

1 s.d: 16%  $\approx$  1/6

2 s.d: 2.3%  $\approx$  1/50

3 s.d: 0.13%  $\approx$  1/1,000

4 s.d: 0.0032%  $\approx$  1/32,000

5 s.d: 0.000029%  $\approx$  1/3,000,000

Bell curve probability of a  
1°C warming since 1880

## Black Swan probabilities

Extreme probabilities fall off slowly:

$$\text{Probability} \approx \Delta t^{-5}$$

With black swans: probability of a 5 s.d. event:

$$2.3\% / (5/2)^5 = 0.02\% = 1/4000$$

The probability of a 1°C warming since 1880 is roughly 1000 times larger than expected!

But we can still reject it with 99.97% confidence!

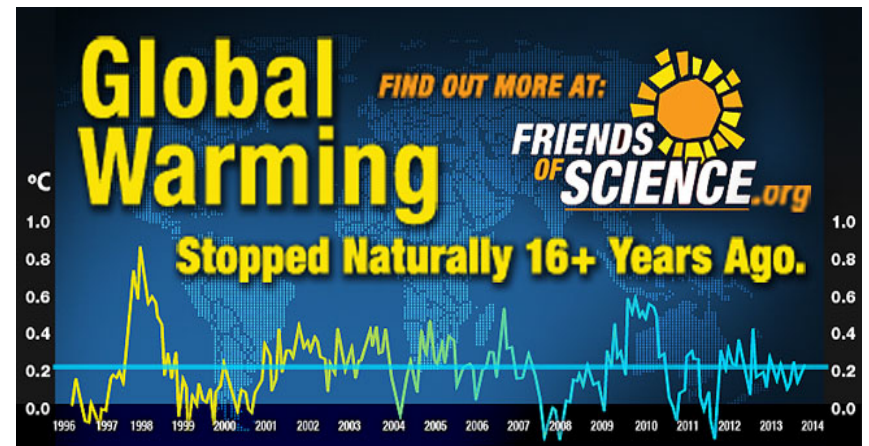


## “Climate Closure” (2)

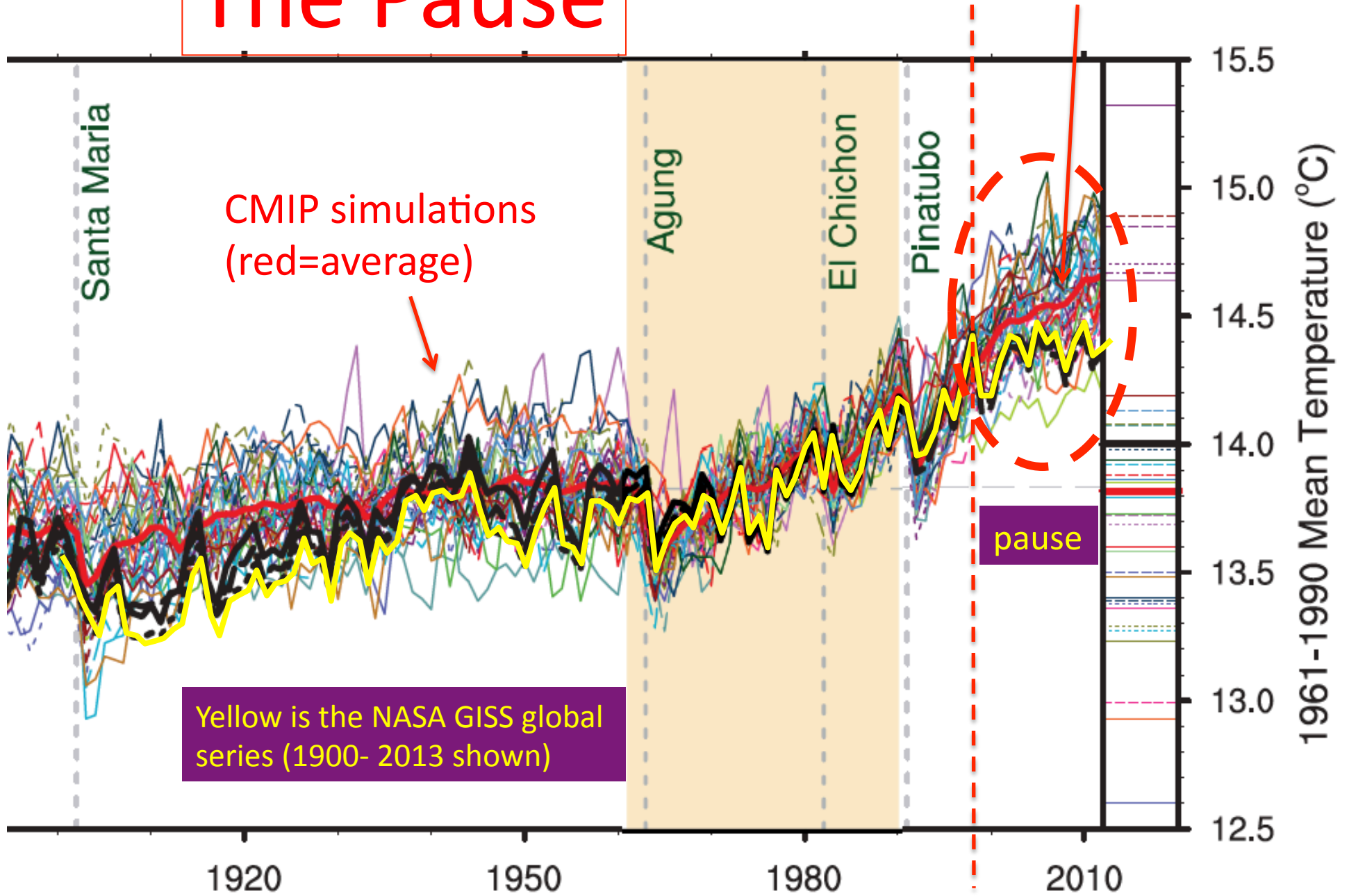
Explaining the “pause”

“Global warming stopped naturally 16 + years ago....”

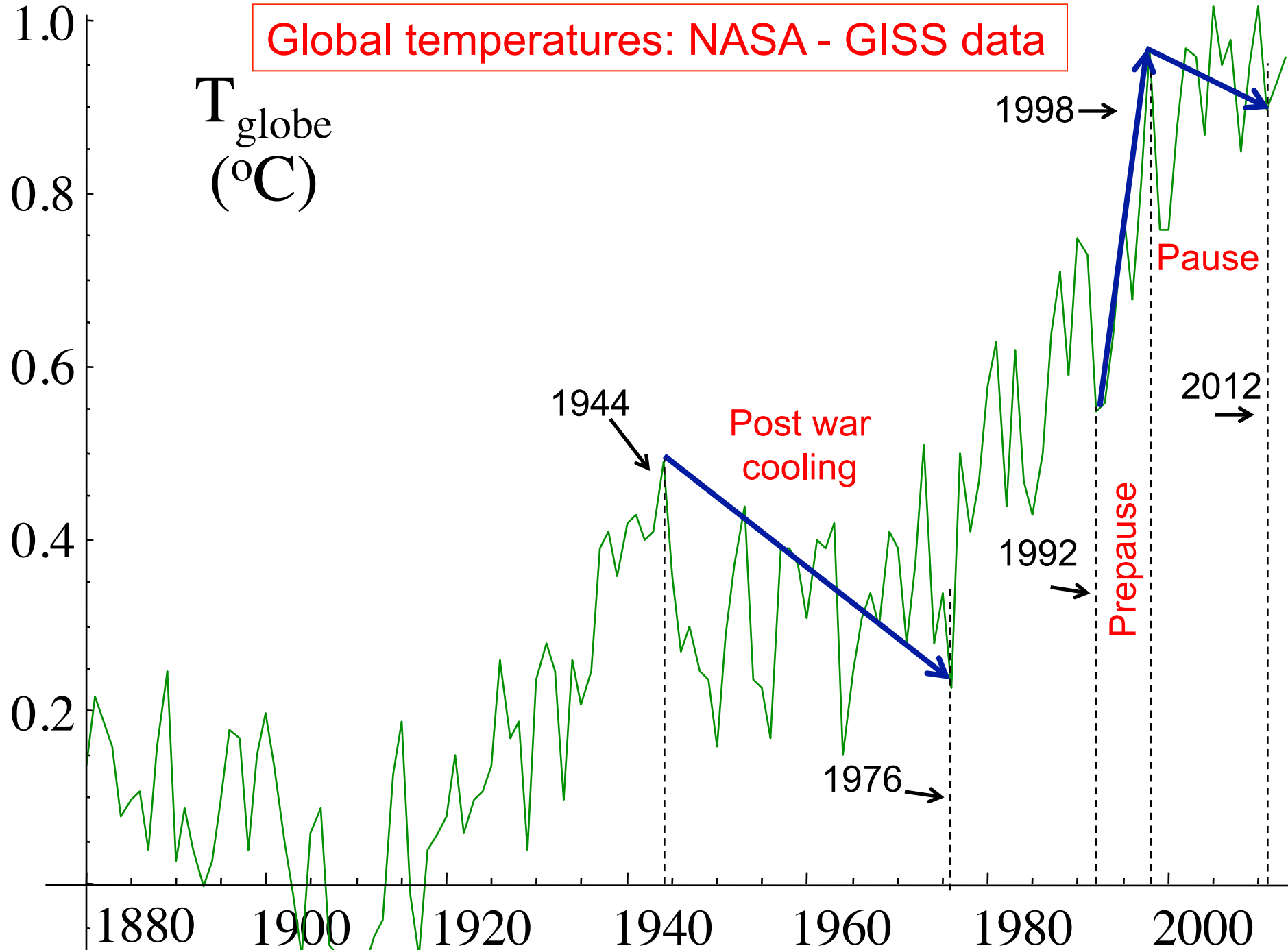
(Friends of Science Billboard, Nov. 2014)



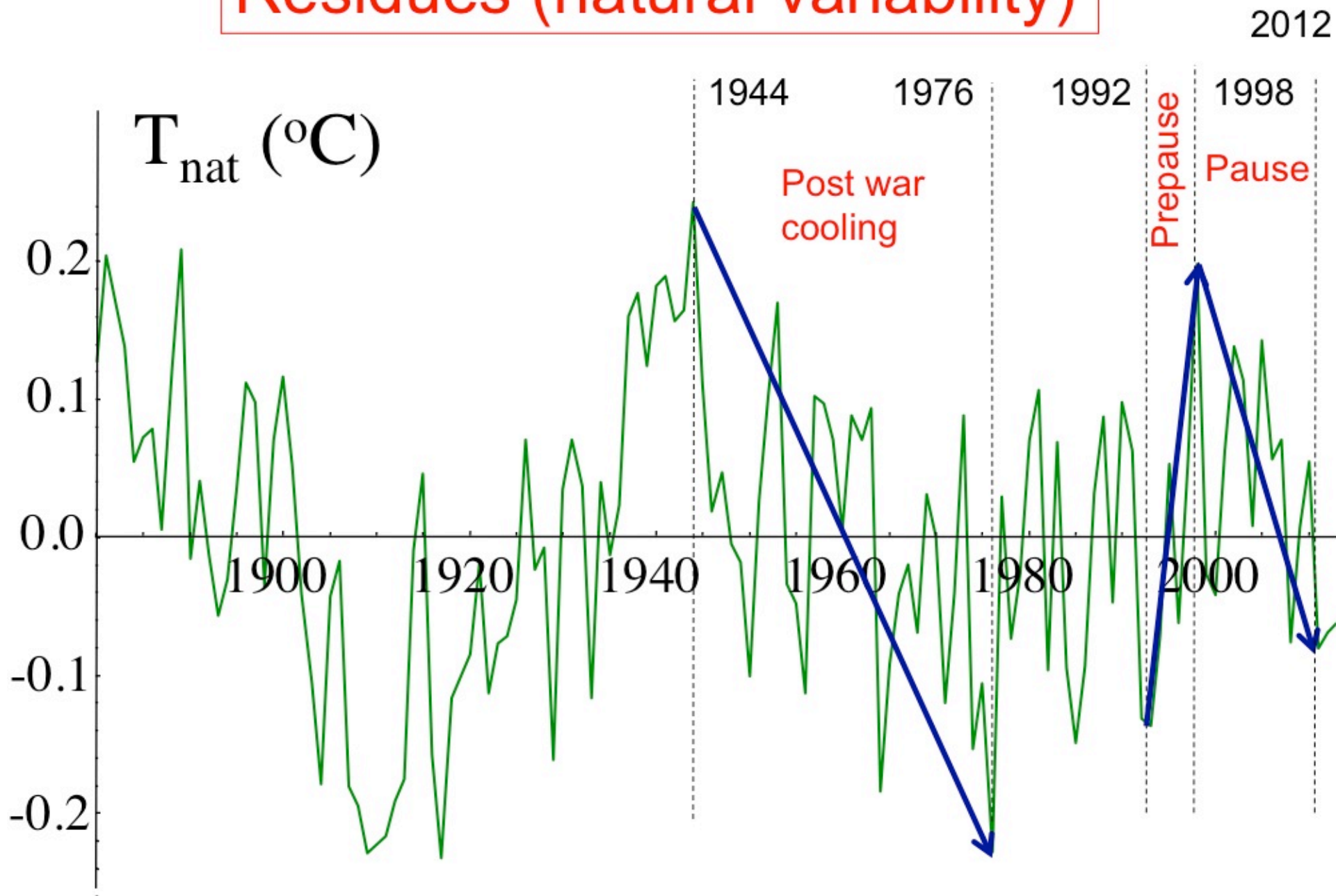
# The Pause

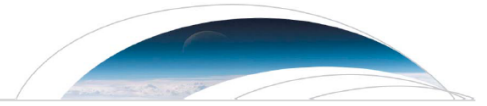


Global temperatures: NASA - GISS data



# Residues (natural variability)





Geophysical Research Letters

RESEARCH LETTER

10.1002/2014GL060478

Key Points:

- The “pause” has a return period of 20–50 years (not unusual)
- Pre-pause (92–98) warming cancels the pause cooling
- The largest expected cooling event = 0.47 K; almost exactly the postwar cooling

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S. Lovejoy,  
lovejoy@physics.mcgill.ca

Citation:

Lovejoy, S. (2014), Return periods of global climate fluctuations and the pause, *Geophys. Res. Lett.*, 41, doi:10.1002/2014GL060478.

Return periods of global climate fluctuations and the pause

S. Lovejoy<sup>1</sup>

<sup>1</sup>Physics, McGill, Montreal, Canada

**Abstract** An approach complementary to General Circulation Models (GCMs), using the anthropogenic CO<sub>2</sub> radiative forcing as a linear surrogate for all anthropogenic forcings [Lovejoy, 2014], was recently developed for quantifying human impacts. Using preindustrial multiproxy series and scaling arguments, the probabilities of natural fluctuations at time lags up to 125 years were determined. The hypothesis that the industrial epoch warming was a giant natural fluctuation was rejected with 99.9% confidence. In this paper, this method is extended to the determination of event return times. Over the period 1880–2013, the largest 32 year event is expected to be 0.47 K, effectively explaining the postwar cooling (amplitude 0.42–0.47 K). Similarly, the “pause” since 1998 (0.28–0.37 K) has a return period of 20–50 years (not so unusual). It is nearly cancelled by the pre-pause warming event (1992–1998, return period 30–40 years); the pause is no more than natural variability.

# The Pause

## CLIMATE CHANGE

# Global warming slowdown just a ‘pause’

### NATURAL COOLING FLUCTUATION

It can't be used to prove that temperature changes not man-made, McGill prof says

KAREN SEIDMAN  
GAZETTE UNIVERSITIES REPORTER

McGill University physics professor Shaun Lovejoy, already a global warming denier's worst enemy, has done it again with his latest statistical analysis showing that a recent slowdown in global warming is merely a “pause” — and not any kind of proof that man-made global warming has waned.

Lovejoy already regularly gets hate mail from global

Lord Christopher Monckton of Brenchley, who referred to Lovejoy's work as an emanation “of the forces of darkness.”

That was Lovejoy's study which proved conclusively, he says, that there is such a tiny probability that what we are experiencing is natural warming — probably less than 0.1 per cent — that it can be dismissed.

He has followed it up with a statistical analysis of average global temperatures be-



ALLEN MANNING/THE GAZETTE

man-made.

His most recent study addresses the argument raised by skeptics that, since greenhouse gases have continued to rise in the last 15 years while there has been a deceleration in rising temperatures, it must dispute the theory that global warming has been caused largely by man-made emissions.

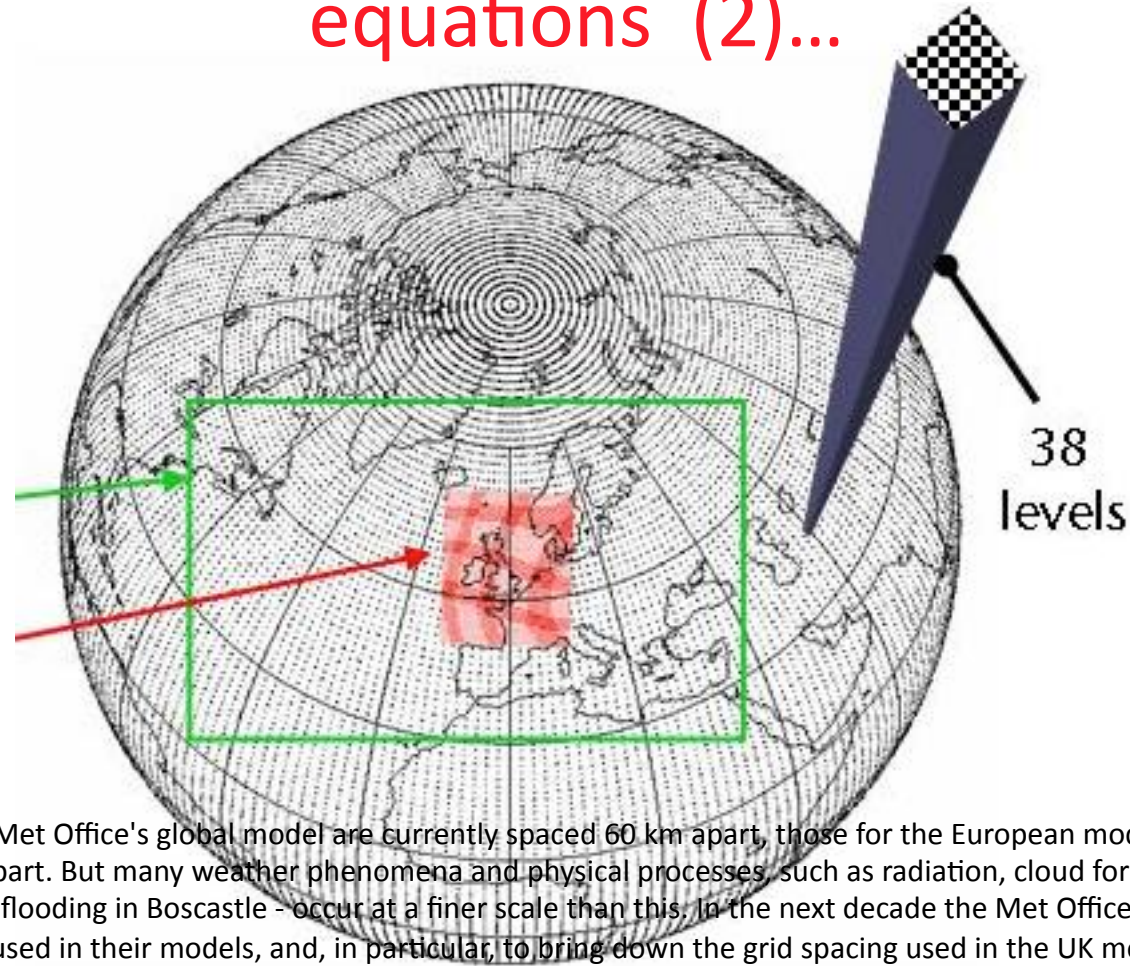
But Lovejoy says his study concludes there has been a natural cooling fluctuation of about 0.28 to 0.37 C since 1998.

“Being based on climate records, this approach avoids any biases that might affect the sophisticated computer models that are commonly used for understanding global warming,” he said.

And while his new finding

The conventional Global  
Circulation Model (GCM)  
approach to climate forecasting  
(Brute force)

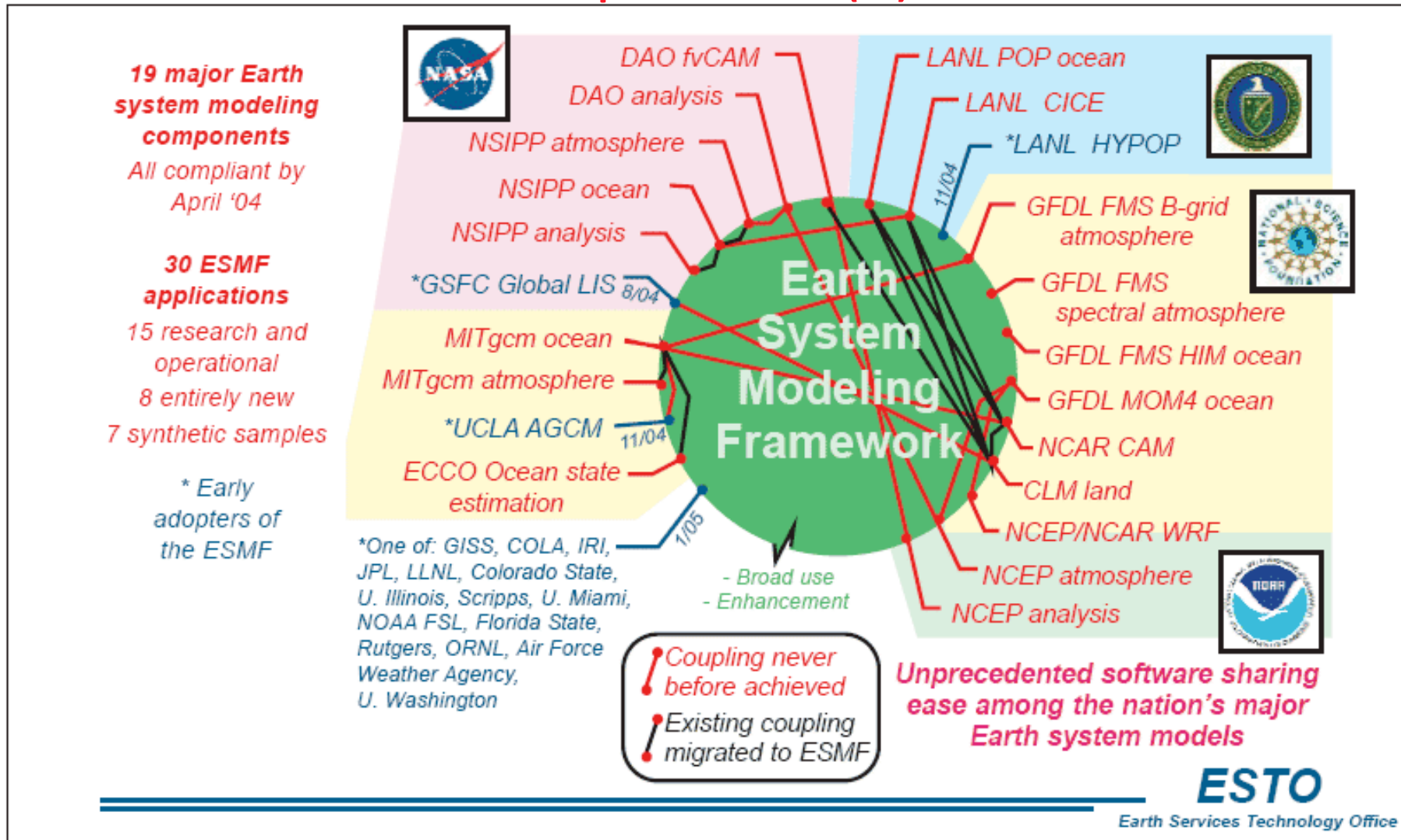
# Brute force numerical solution of the equations (2)...



The grid points for the Met Office's global model are currently spaced 60 km apart, those for the European model, 20km apart and those for the UK model, 12 km apart. But many weather phenomena and physical processes, such as radiation, cloud formation and rainfall - and the storms that caused the flooding in Boscastle - occur at a finer scale than this. In the next decade the Met Office hope to improve the resolution of the grids used in their models, and, in particular, to bring down the grid spacing used in the UK model to 4 km in 2005, and to just 1 km by the end of the decade. Preliminary research tests with these 4km and 1km models have had promising results in capturing localised flooding events such as Boscastle.

## Discretization of the equations

# Brute force numerical solution of the equations (3)...

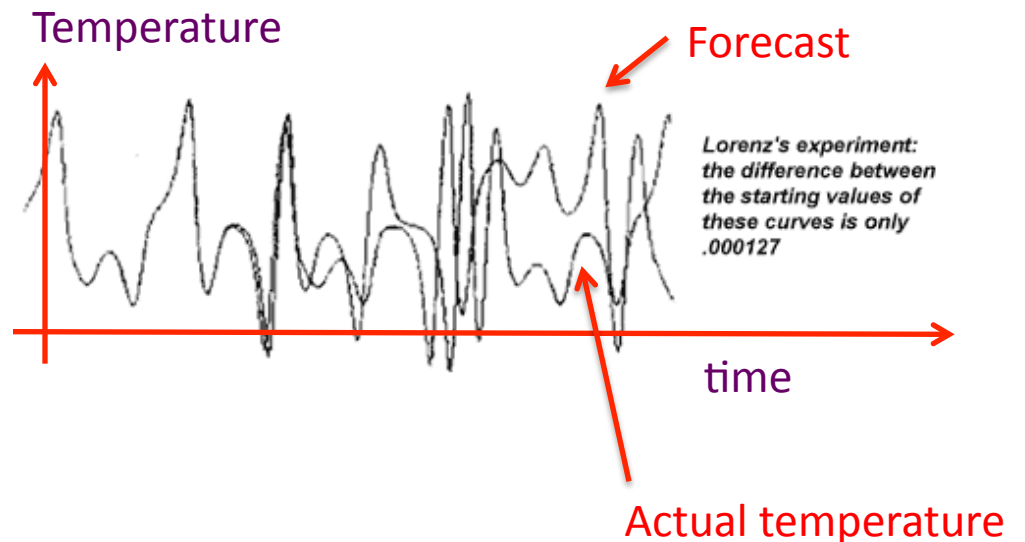


# Earth system modelling



# Limitations of General Circulation Models and stochastic alternatives

Loss of *deterministic* predictability after 10 days  
= “butterfly effect”

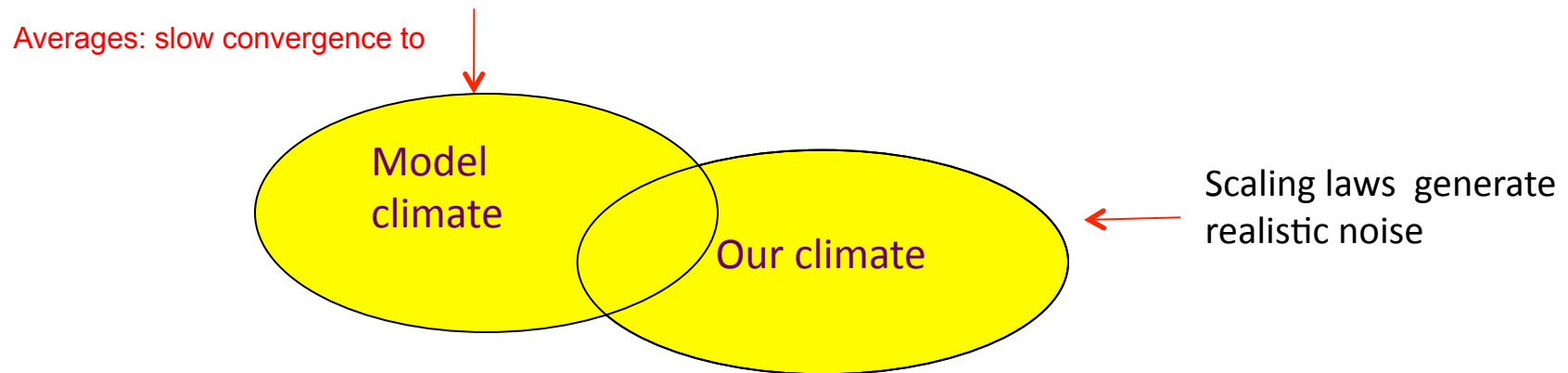


But by harnessing the butterfly effect we obtain  
some stochastic predictability....

# GCMs for forecasts longer than $\approx 10$ days

“Brute force”

Weather systems generated by GCMs = random weather noise... but not fully realistic



**Potential advantages of stochastic forecasting:**

- More realistic weather “noise”
- Ability to use empirical data to force convergence to the real climate

# Scaling Linear Macroweather model (SLIMM)

1. Macroweather  $\approx$  30 years industrial, 100 years pre-industrial

$$\langle \Delta T \rangle \approx \Delta t^H \quad -1/2 < H < 0$$

2. Simple model: fractional Gaussian noise:

$$T(t) = \sigma \int_{-\infty}^t (t-t')^{-(1/2-H)} \gamma(t') dt' \quad \longleftrightarrow \quad \frac{d^{H+1/2}}{dt^{H+1/2}} T(t) = \gamma(t)$$

Gaussian  
white noise

Corresponds to fractional  
integral of order  $H+1/2$  of white  
noise

3. Vast memory due to power laws.

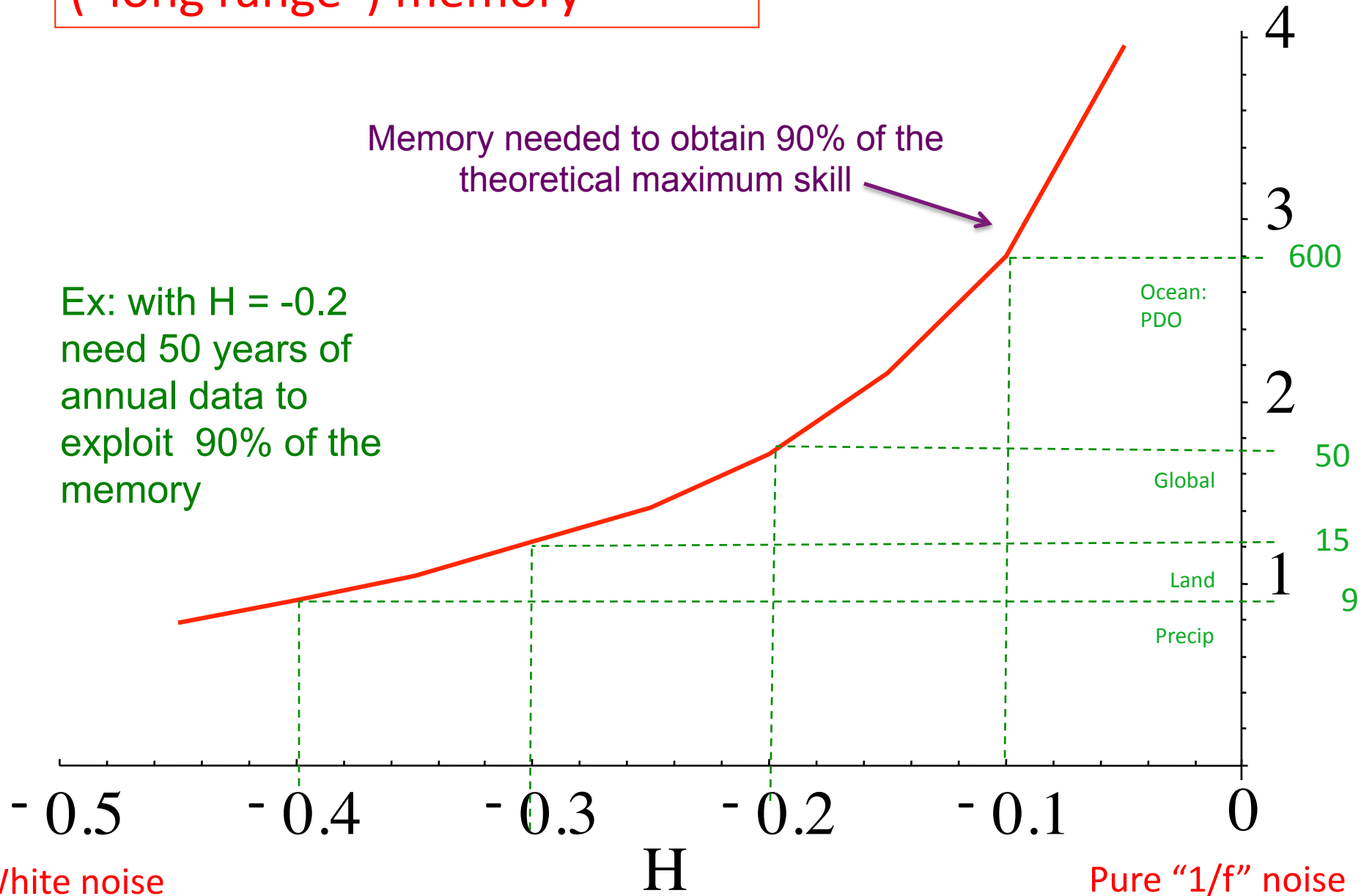
4. Memory can be used for forecasting, the latter is a solved problem mathematically

The unsuspected Elephantine (“long range”) memory

$\text{Log}_{10} \lambda_{\text{mem}}$

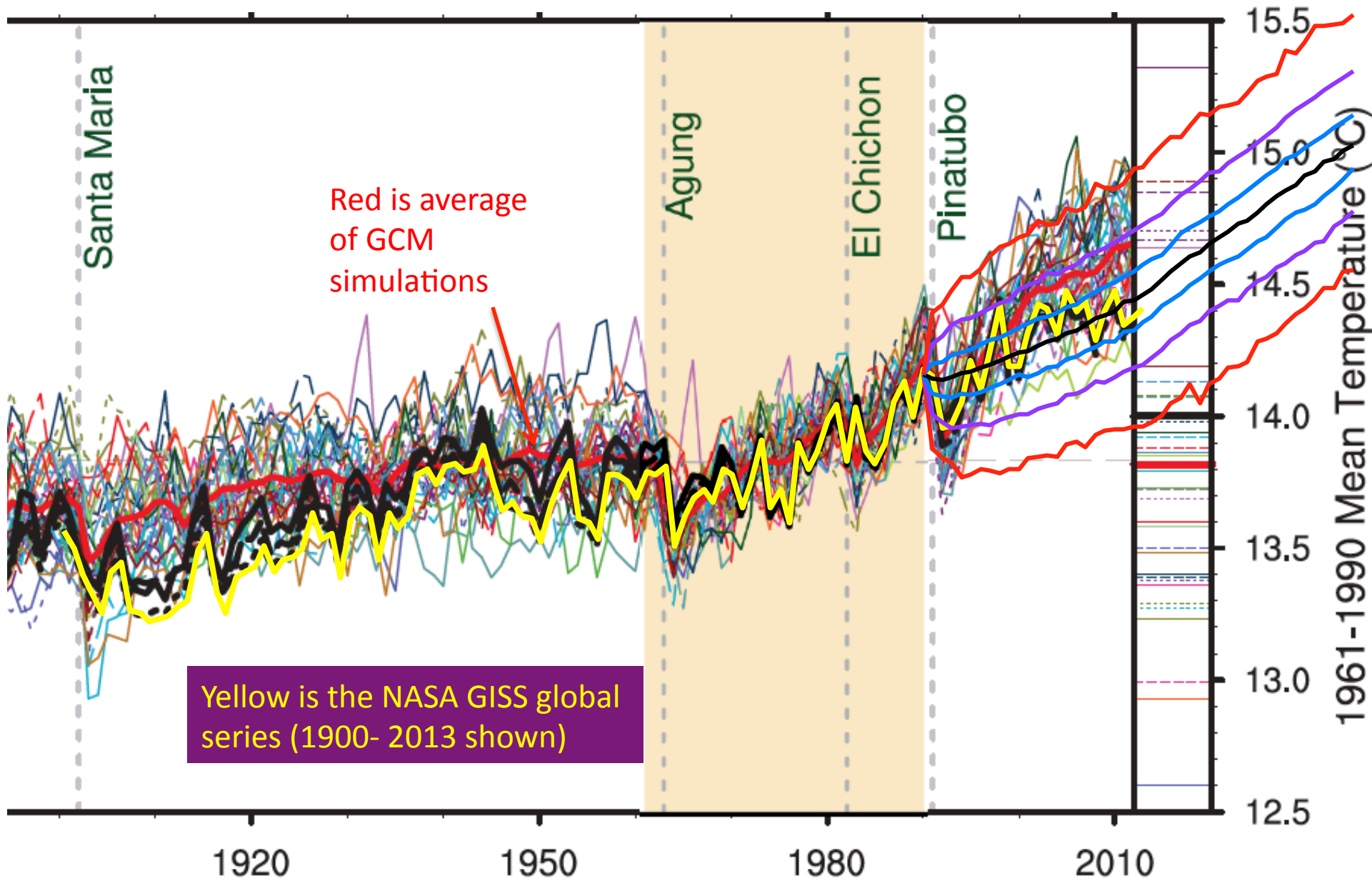
Memory needed to obtain 90% of the theoretical maximum skill

Ex: with  $H = -0.2$   
need 50 years of  
annual data to  
exploit 90% of the  
memory



# SLIMM and the Pause

# The pause with SLIMM forecasts

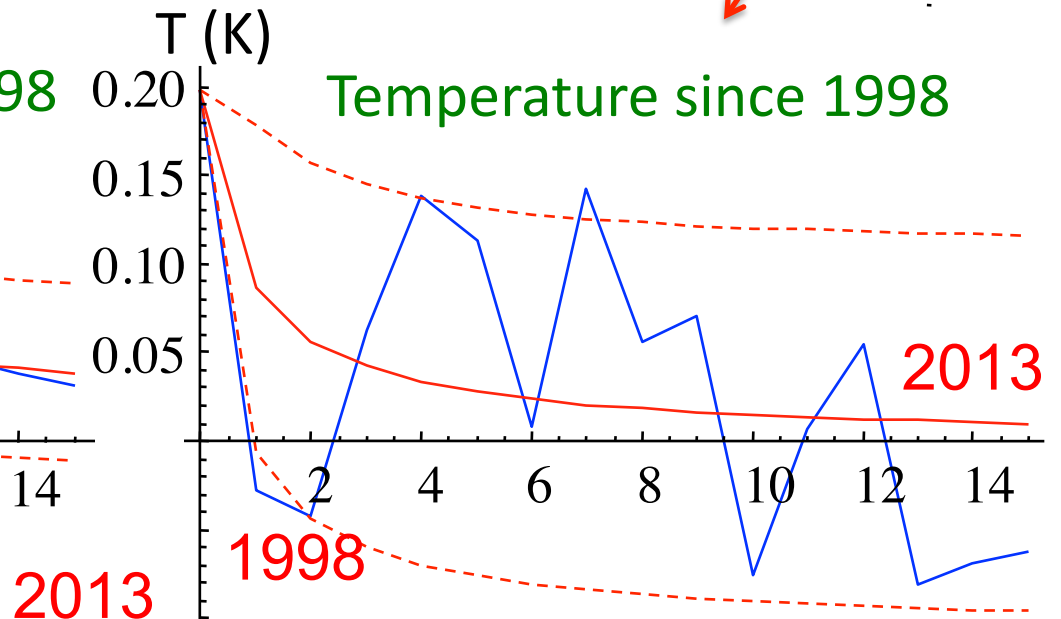
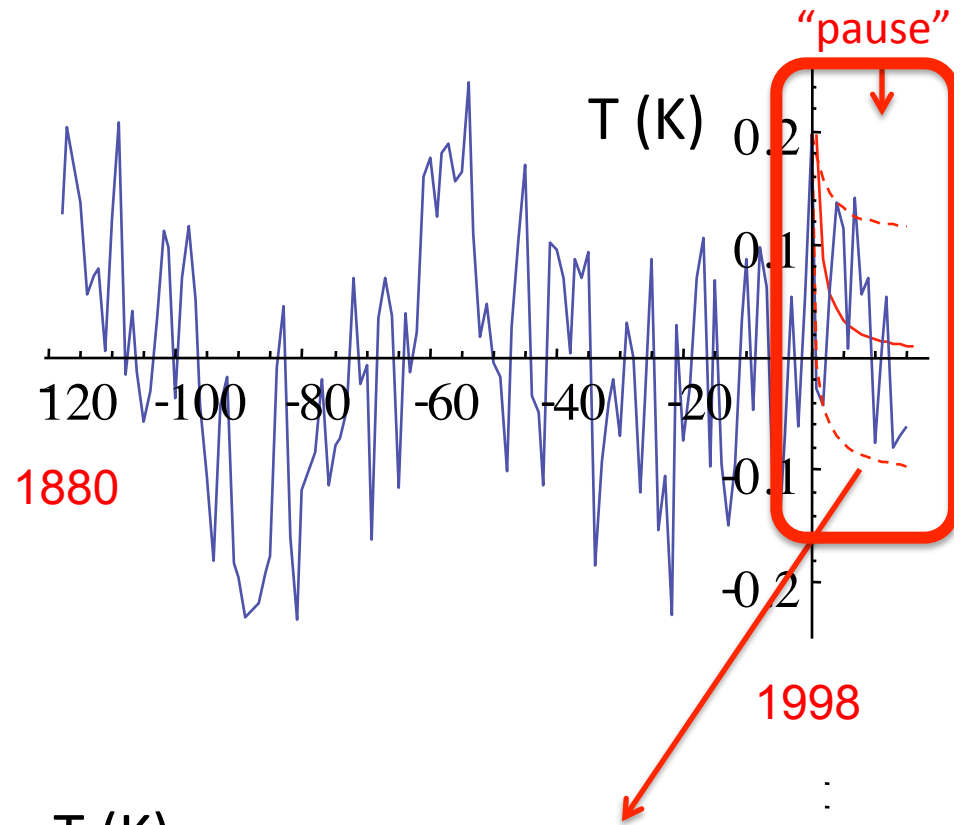
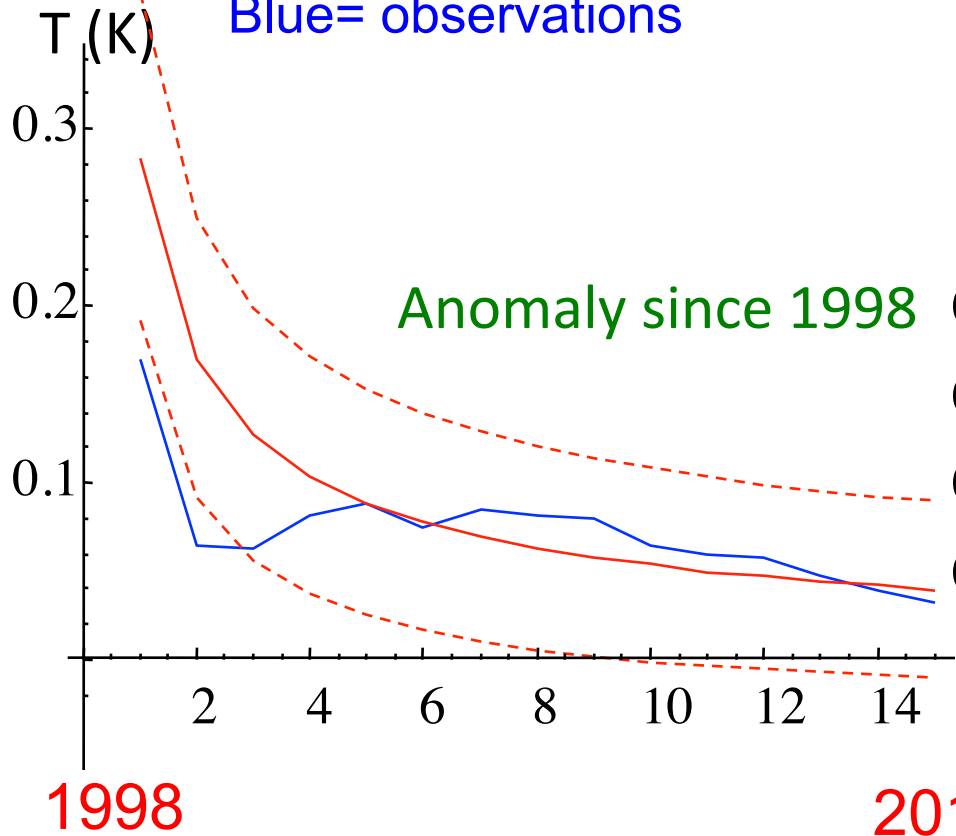


# The "memory": Forecasting the Pause

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

Red= forecast

Blue= observations



# Anthropogenic warming: summary

- The pause is forecast to better than  $\pm 0.11^{\circ}\text{C}$ ,  
3-4 year anomalies to  $\pm 0.03^{\circ}\text{C}$
- If there hadn't been a pause, the warming would have been too strong and it would have contradicted the anthropogenic warming hypothesis.
- Climate closure



# The skeptics reaction (1)



CALGARY, April 17, 2014 /Canadian News Wire/

## **Friends of Science** (Calgary based group)

...Friends of Science are also calling up the Chancellor of McGill University to retract the McGill press release and issue an apology for the use of Lovejoy's quote  
"This study will be a blow to any remaining climate-change deniers..."

"This is not the language of science or good taste that one expects from a Nobel Laureate university," says Gregory.

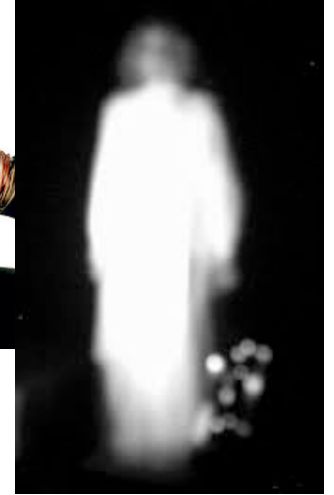
# The skeptics reaction (2)

“A mephitic ectoplasmic emanation of the forces of darkness”

-Viscount Lord Christopher Monckton of Brenchley evaluating this work



A mephitic  
ectoplasm



## 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:** Our conclusions are for **125 year periods** - there is nothing to prevent the same changes occurring much more slowly (i.e. over much longer periods).

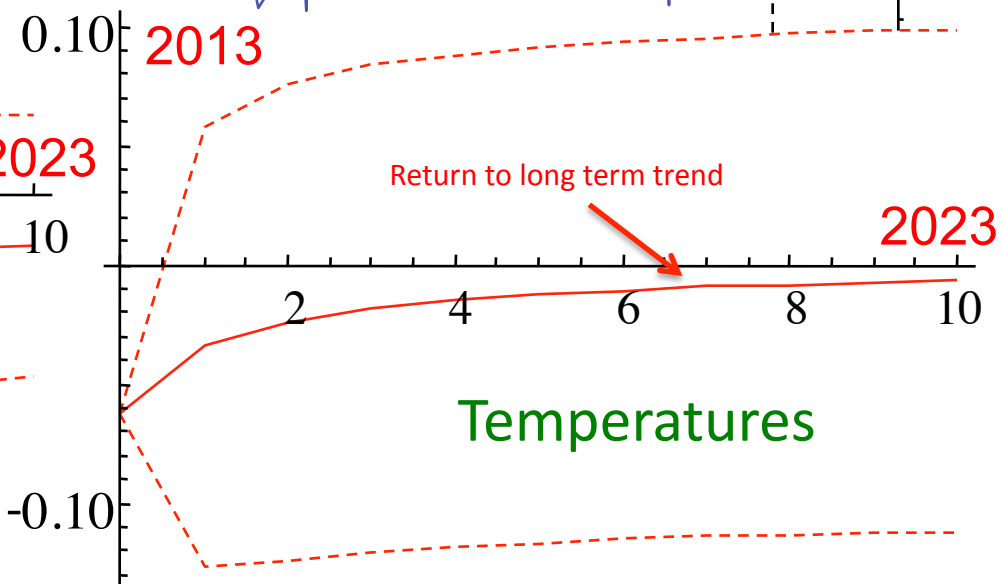
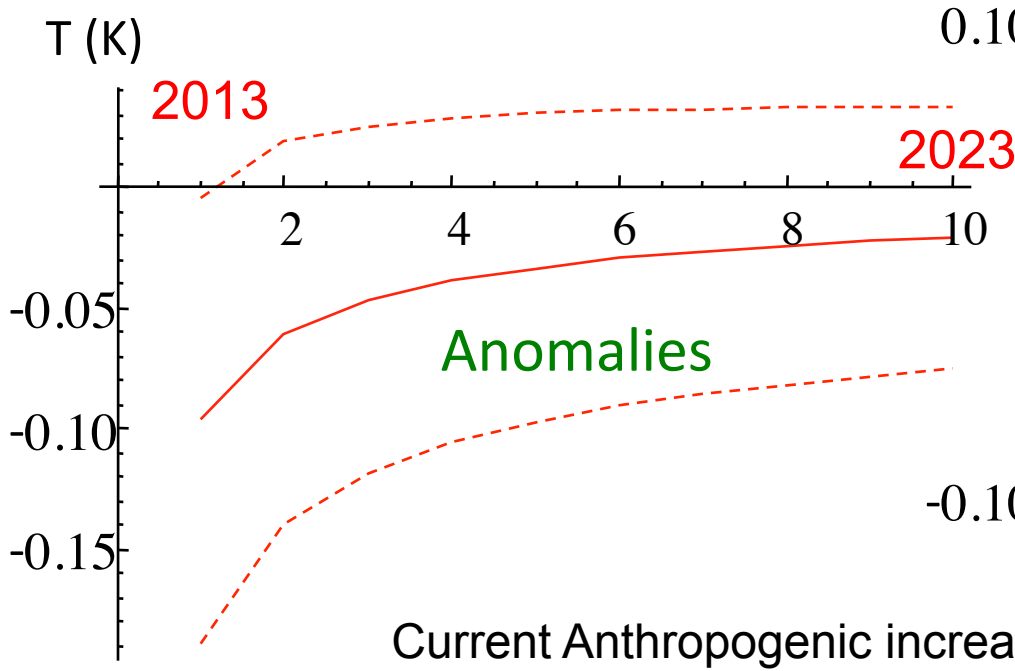
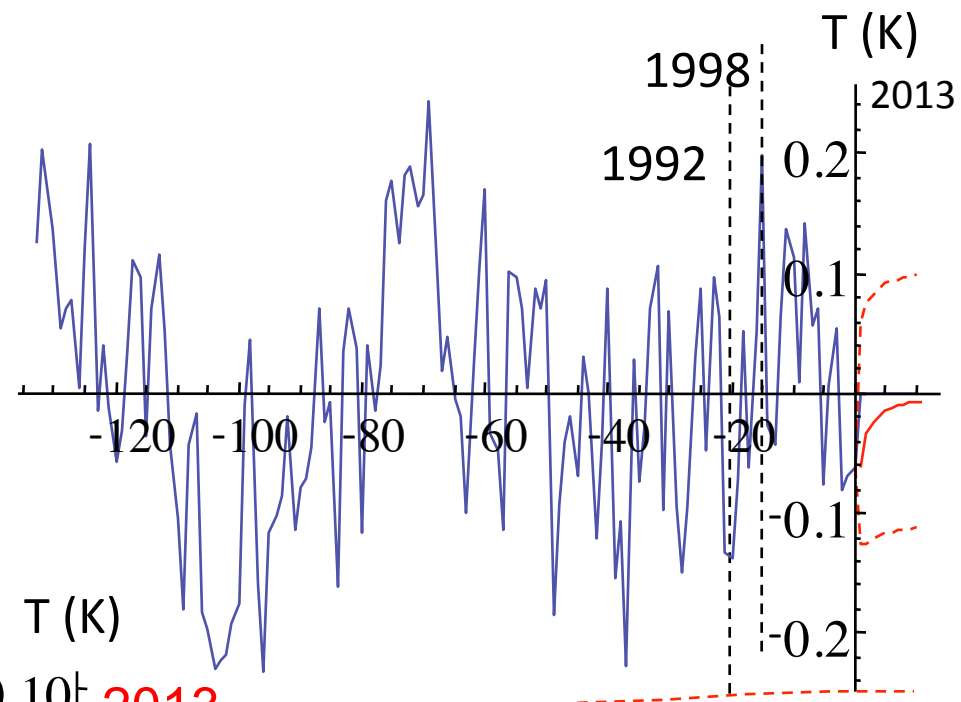
### -Use of unrepresentative paleo or instrumental sources, (the “Friends”):

**Q:** The temperature change in central England from 1663-1762 was 0.90 °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 °C.

The Future

**The next 10 years, Global:  
2014-2023**  
(natural variability only)

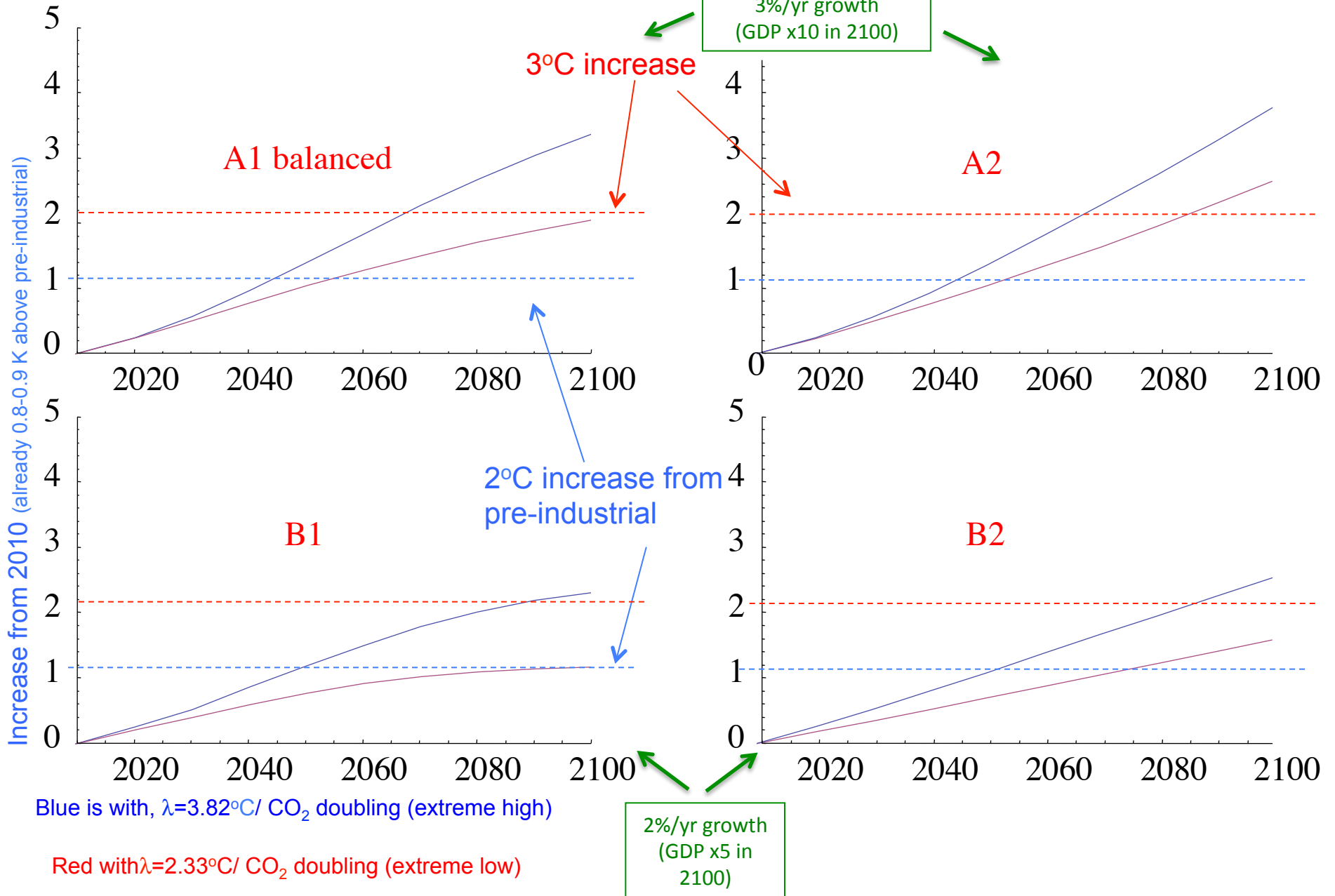


Current Anthropogenic increase:  $\frac{d \log_2 CO_2}{dt} \approx 0.010 / yr$        $\frac{dT}{dt} \approx 0.023 / yr$

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

# Future Projections

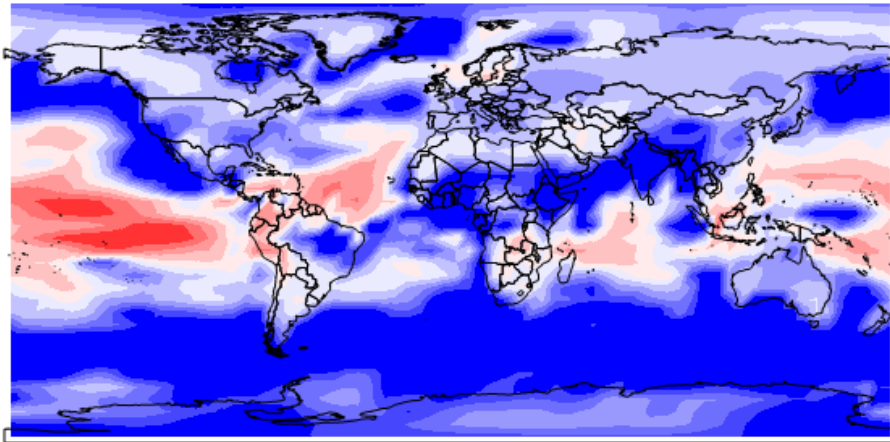
Based on SRES (Special Report on Emissions Scenarios, IPCC, AR2-4)



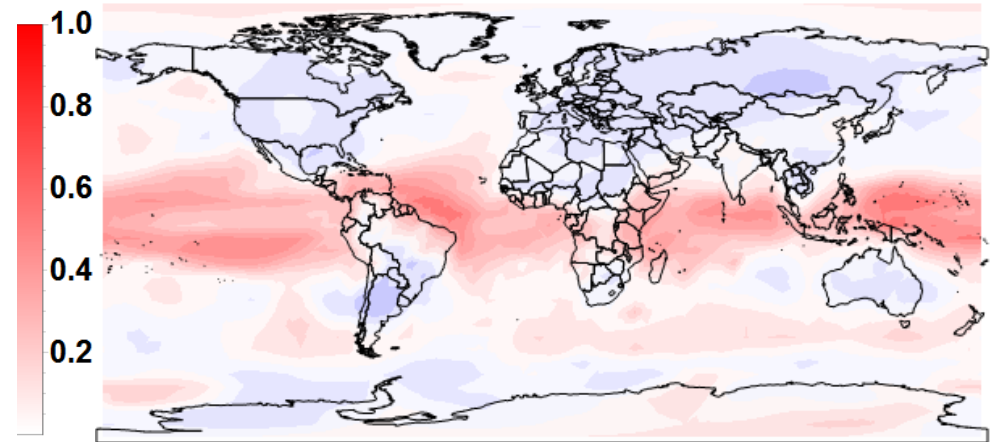
Regional monthly  
and seasonal  
forecasting using  
SLIMM

# Comparing seasonal (3 month) SLIMM and CanSIPS (GCM)

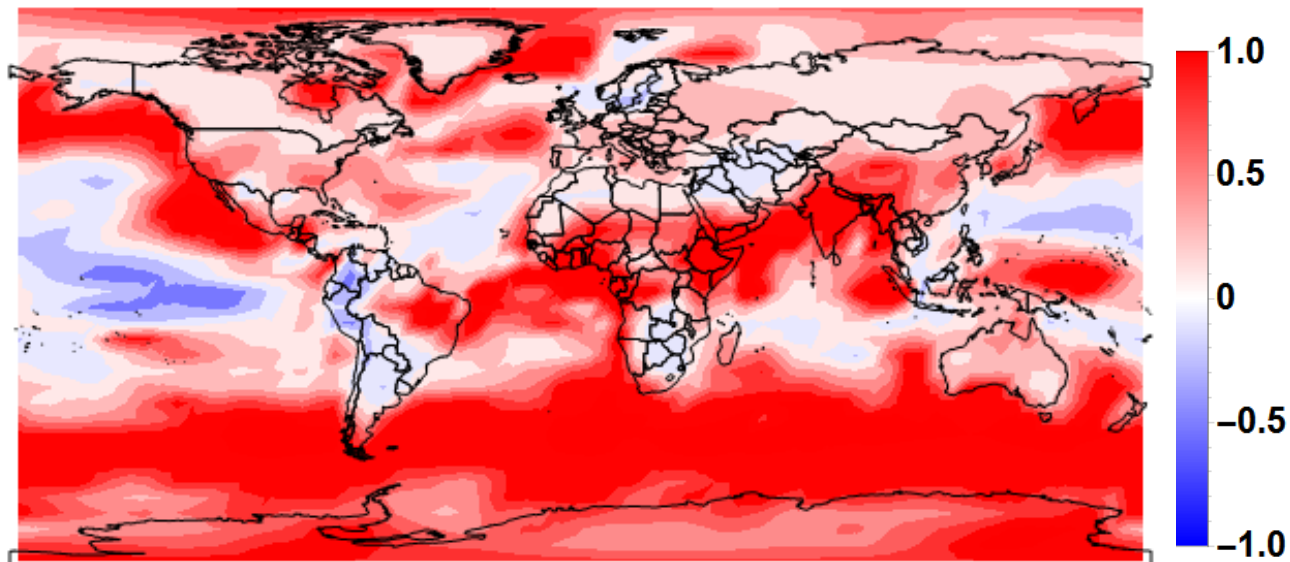
Skill for CanSIPS, 3 months horizon



Skill for SLIMM, 3 months horizon



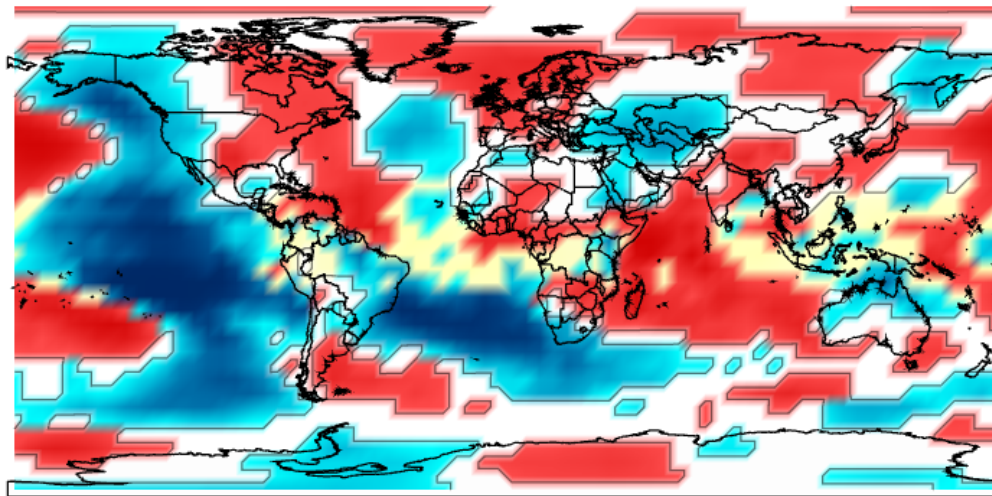
Difference of Skill SLIMM - CanSIPS



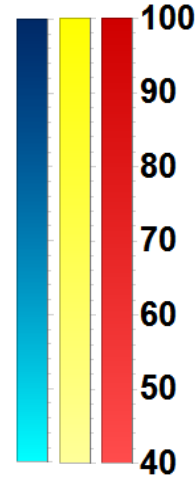
SLIMM better  
than CanSIPS  
over 90% of  
globe

# Probability forecasts using SLIMM

## 3 Category Temperature Probability Forecast, 1 month horizon

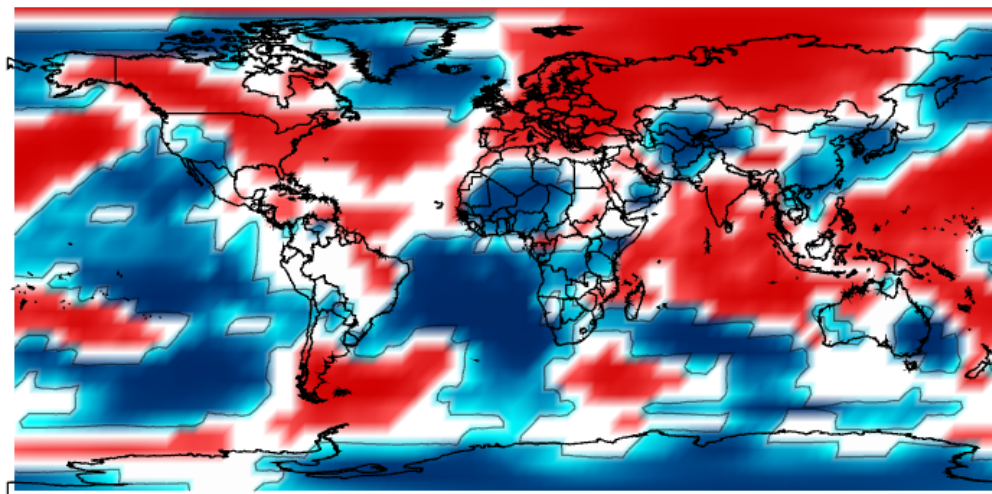


Bellow, Near and Above Normal, scales respectively (%)

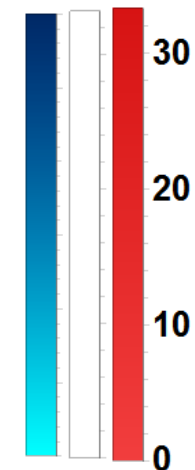


If the probability is below 40% in any of the three categories, we color this region white. The probabilities for each pixel were computed by calculating the respective areas in the histogram below.

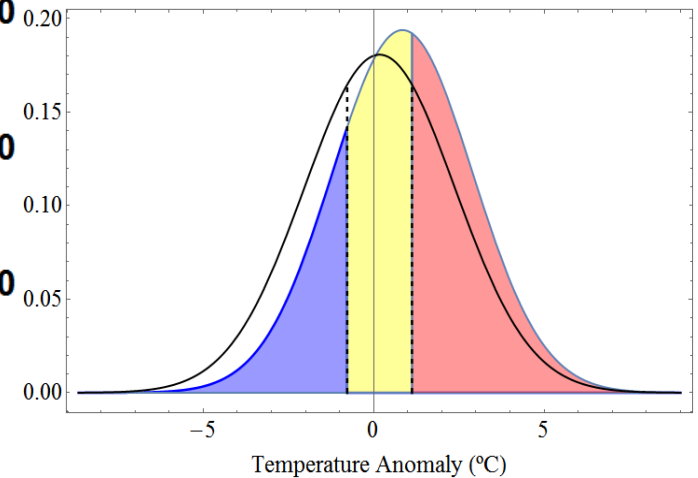
## Actual values of the anomalies given in percentiles of the climate distributions for the same time



Bellow, Near and Above Normal, scales respectively (%)



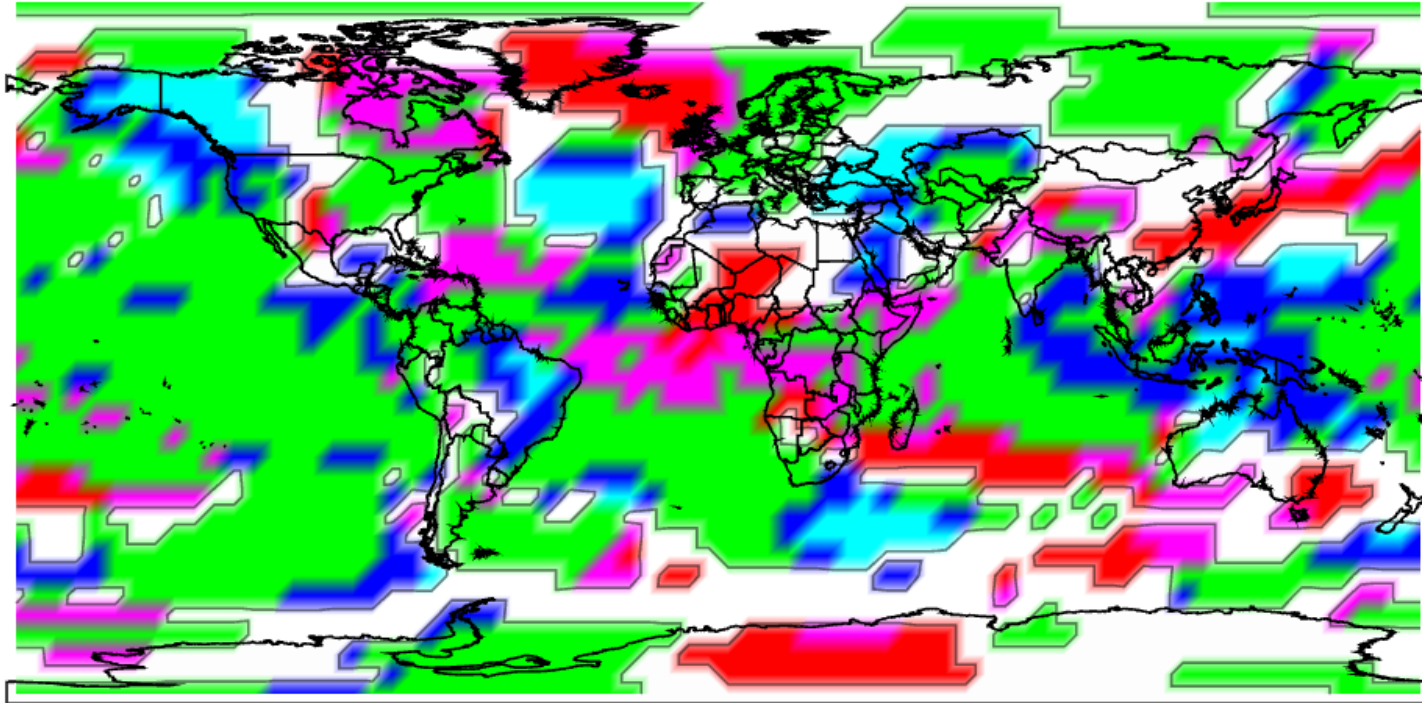
Distribution for actual climate (black line) and for probability forecast at a given grid point in the planet



December 2011- February 2012



# Verification of Probability Forecast. Comparison between the two previous maps



Too Low Estimation    ■  
Low Estimation        ■  
Good Estimation       ■  
High Estimation       ■  
Too High Estimation   ■  
Equiprobable          □

Here, “too low estimation” means that we were wrong for two categories below the actual value observed. For example, we predicted a decrease in the temperature when an increase was actually observed. “Low estimation” means that we were wrong by only one category. The same applies for the high estimations.

What is to be done?

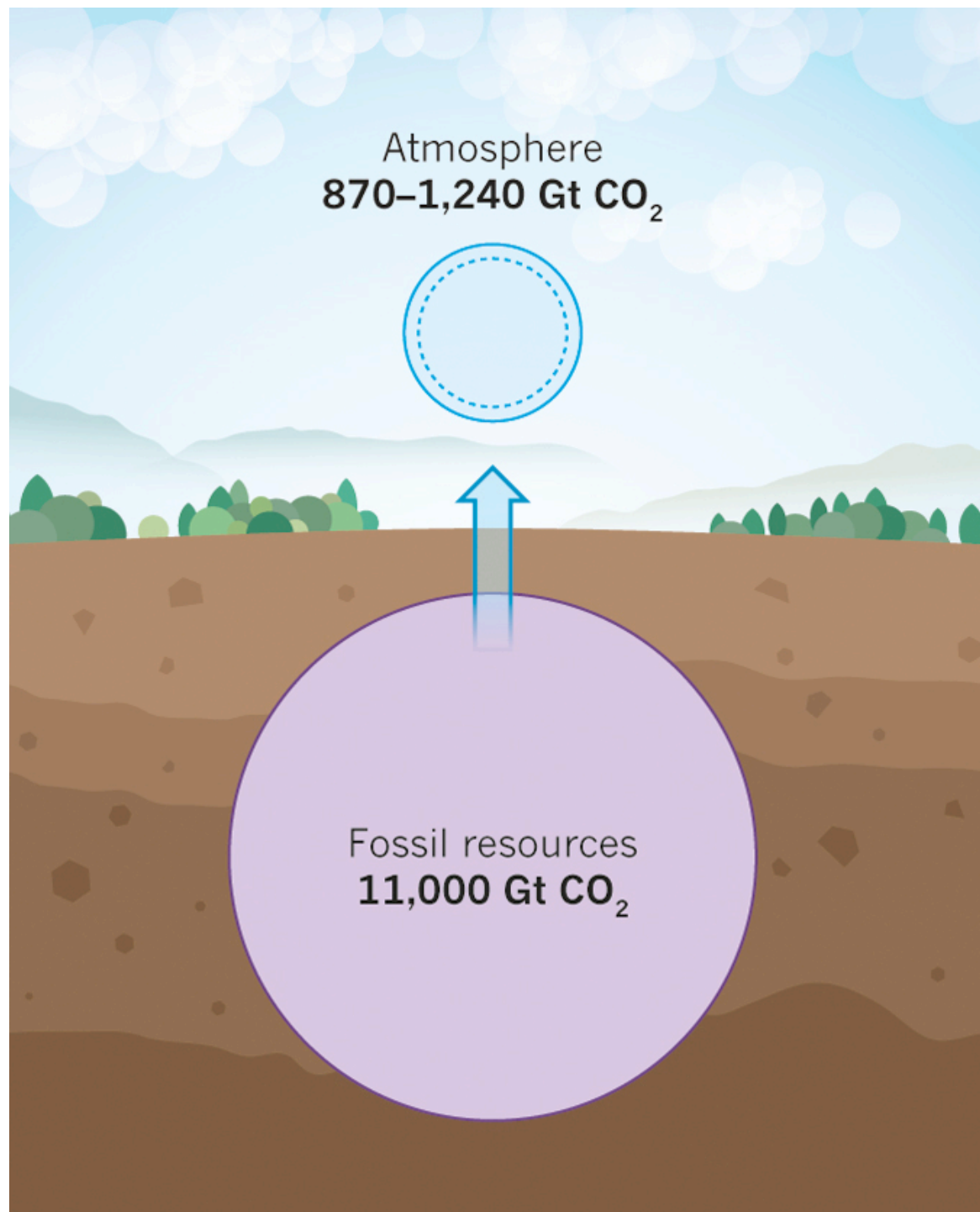
Fossil-free week

# How much can we burn without roasting?

The basis of the  
campaign to Divest  
from fossil fuels

Proven reserves of fossil fuels  
are over 3 times the amount  
that can be burned while  
maintaining the temperature  
to within 2° of pre-industrial  
levels

Jakob & Hilaire 2015



# The challenge: Decarbonize the economy

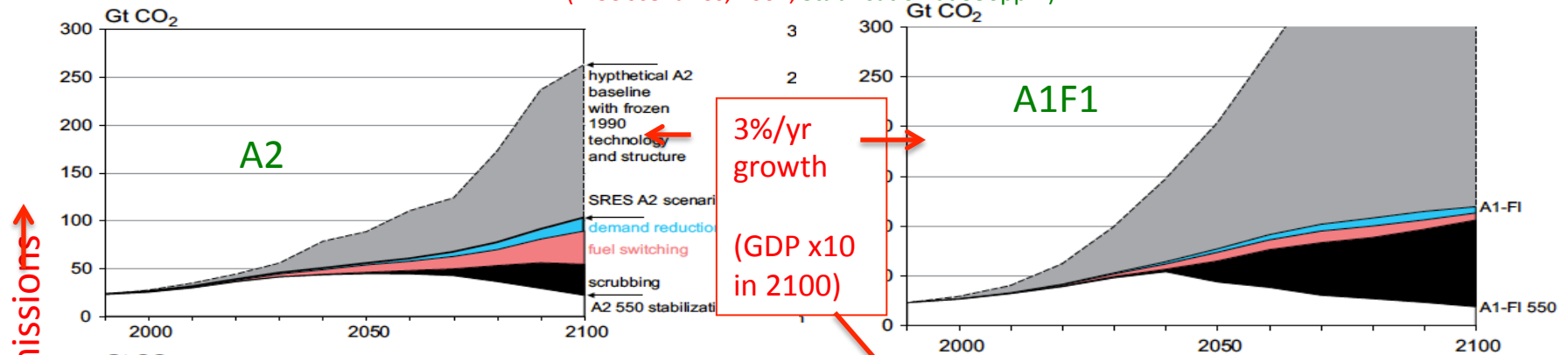
Can we break the link between economic growth  
and CO<sub>2</sub> emissions?

# Economists' magical thinking

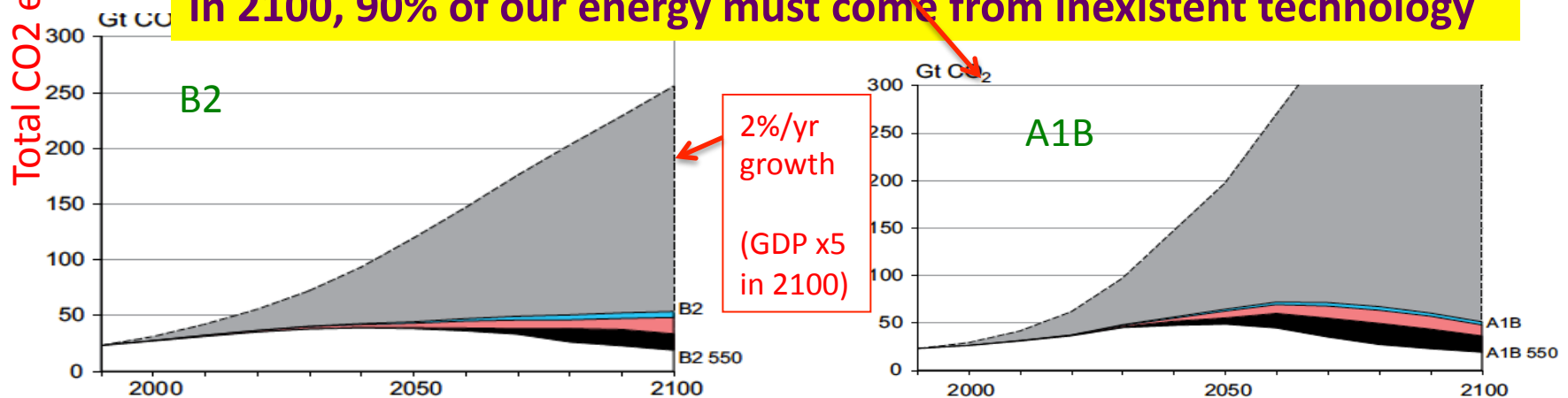
No physical limits: if the price is right then technology can be conjured up to solve any problem...

## The role of existent and new technologies

(IPCC scenarios, 2007; Stabilisation at 550ppm)



In 2100, 90% of our energy must come from inexistent technology



Grey = inexistant technology

NEW!

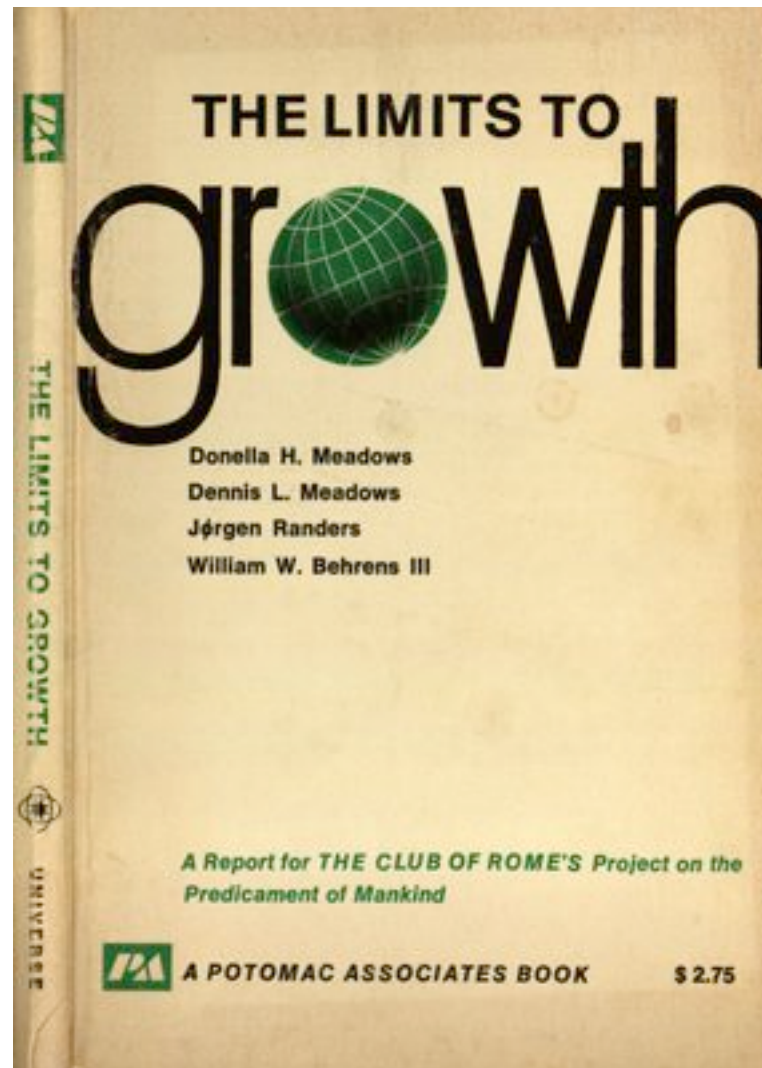
IPCC 2014 (working group 3 on mitigation and adaptation)

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

According to the 1972 “Business as Usual” projection, the last 40 years have tracked well and collapse will start around 2015 (G. Turner, 2014)

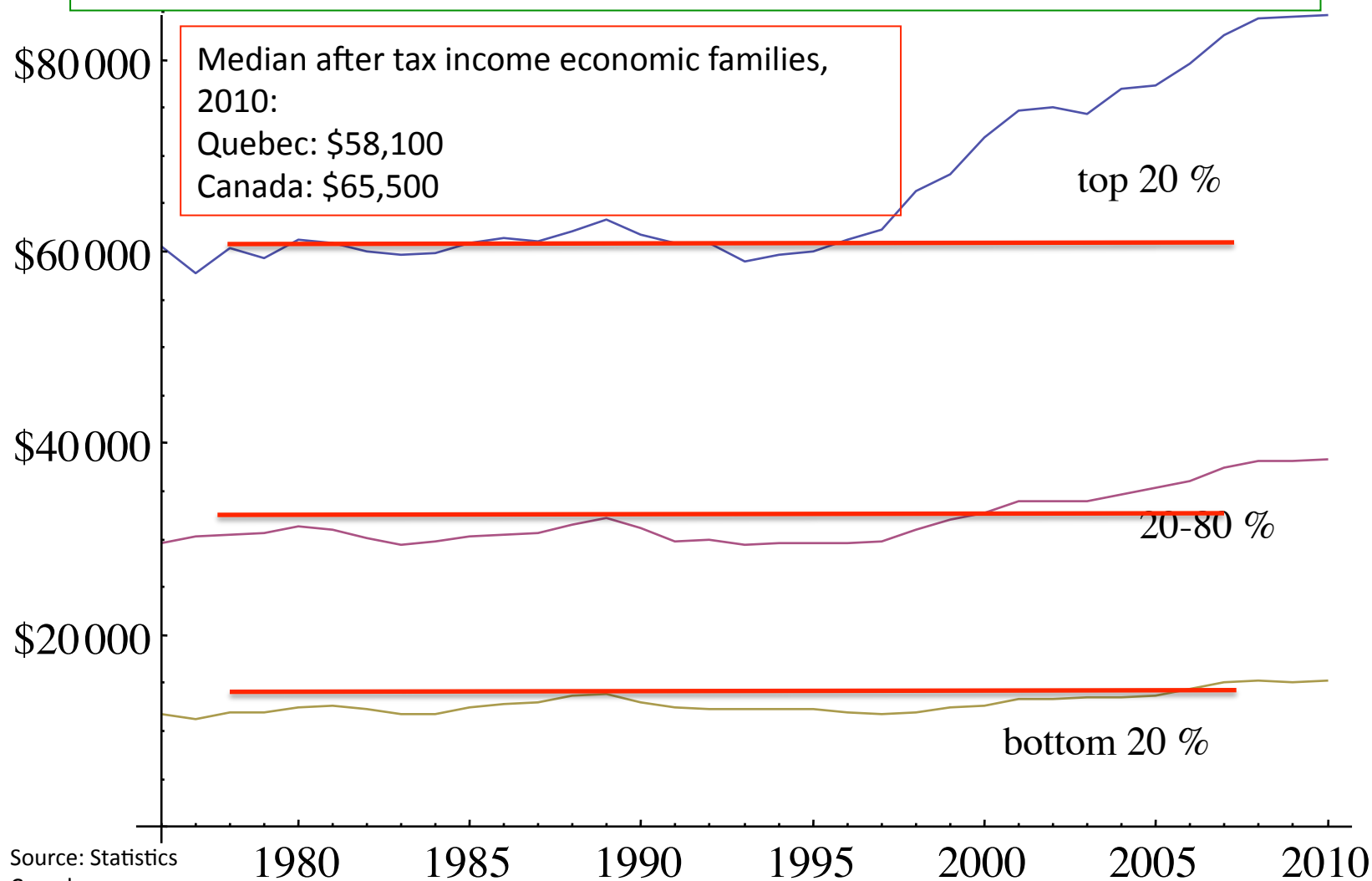


Note: The **nonlinear** model is completely based on physical (not financial inputs and outputs).

1972

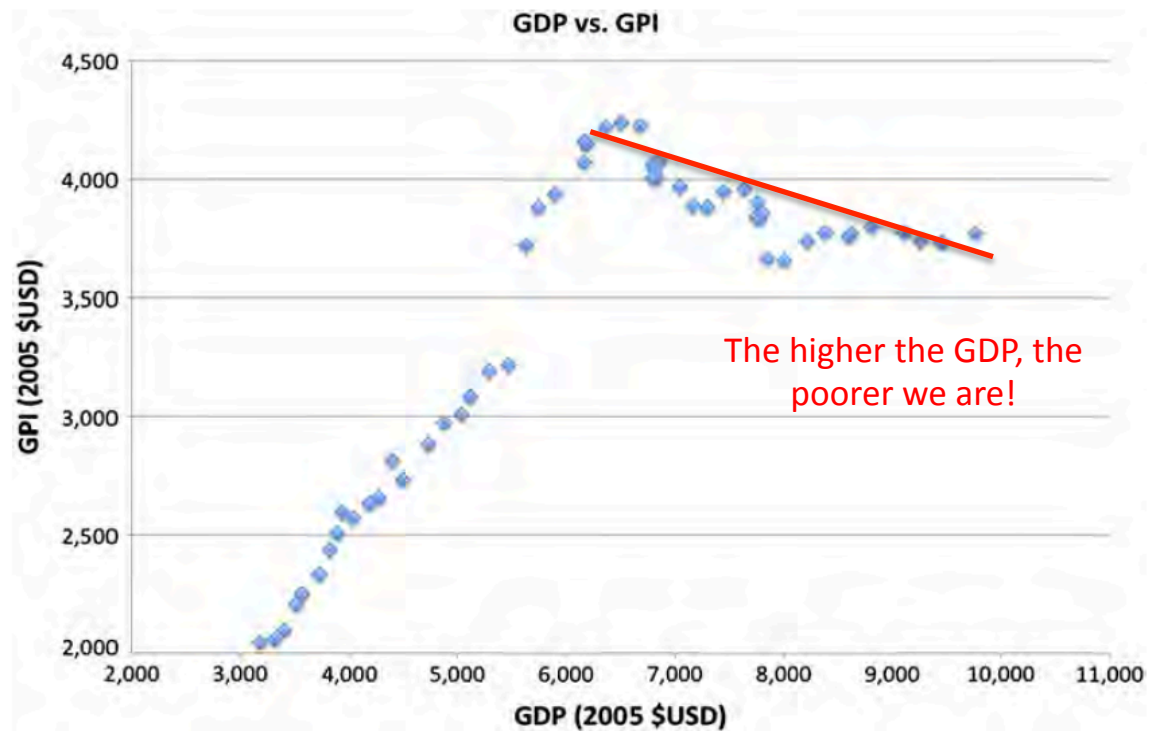
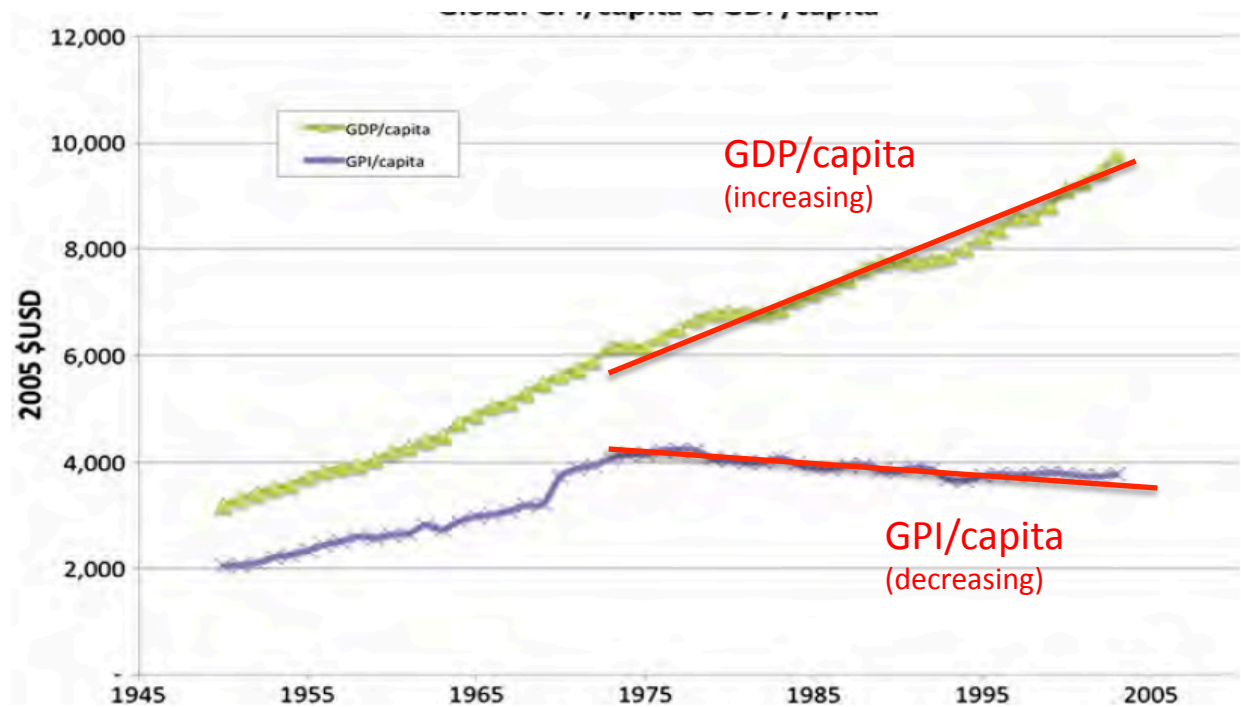
# Is continued quantitative growth *desirable*?

After - tax income, by family unit, Canada, 1976 – 2010  
(2010 constant dollars, economic families)



# GDP versus GPI

GDP=Gross Domestic Product  
GPI=Genuine Progress Indicator





# What is to be done?

- Global Warming is a global problem requiring global scale cooperation.
- Saving the climate is incompatible with the current triumph of the “free” market.

What is to be done?

DIVEST  
McGILL



NAOMI  
KLEIN  
THIS CHANGES  
EVERYTHING  
CAPITALISM vs  
THE CLIMATE

McGill: divest  
from fossil fuels

Montreal:  
countering the  
“Friends of  
Science”

**COULE PAS PAS CHEZ NOUS**

“L'AVENIR N'EST PAS DANS LES PIPELINES!”

**COULE PAS CHEZ NOUS!**  
EST UNE CAMPAGNE DE SENSIBILISATION CITOYENNE QUI DIFFUSE DE L'INFORMATION AFIN DE MIEUX COMPRENDRE L'ENJEU PÉTROLIER ET POURQUOI NOUS DEVONS DIRE NON AU TRANSPORT DE PÉTROLE SUR NOTRE TERRITOIRE

**AGISSONS ENSEMBLE MAINTENANT!!**

★★ DÉFILEZ JUSQU'EN BAS POUR NE RIEN MANQUER! ↓

A circular logo featuring a red and black oil drop falling into a blue puddle.

Quebec: block the tar sands pipelines!

**Ce que la science dit VRAIMENT:**  
Le climat change. À cause de nous.

**ACS** Association des communicateurs scientifiques du Québec [acs.qc.ca](http://acs.qc.ca)

A billboard featuring a silhouette of an oil refinery against a sunset sky. The text is in white and yellow.

# 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) than to prove one (anthropogenic warming).
3. The total anthropogenic warming since 1880 is about 1°C, for CO<sub>2</sub> doubling, 3.08±0.58°C.
4. The probability of the warming being natural is less than 0.1%.
5. The pause is a natural cooling event.
6. Impacts rise rapidly after 2°C of warming.
7. Decarbonizing unlikely with continued global economic growth (“magical thinking”).
8. For most of us, continued economic growth is undesirable (lower GPI).