Weather Macroweather Climate

BIG AND SMALL, FAST AND SLOW: OUR RANDOM YET PREDICTABLE ATMOSPHERE

River Institute, Cornwall, May 2, 2018

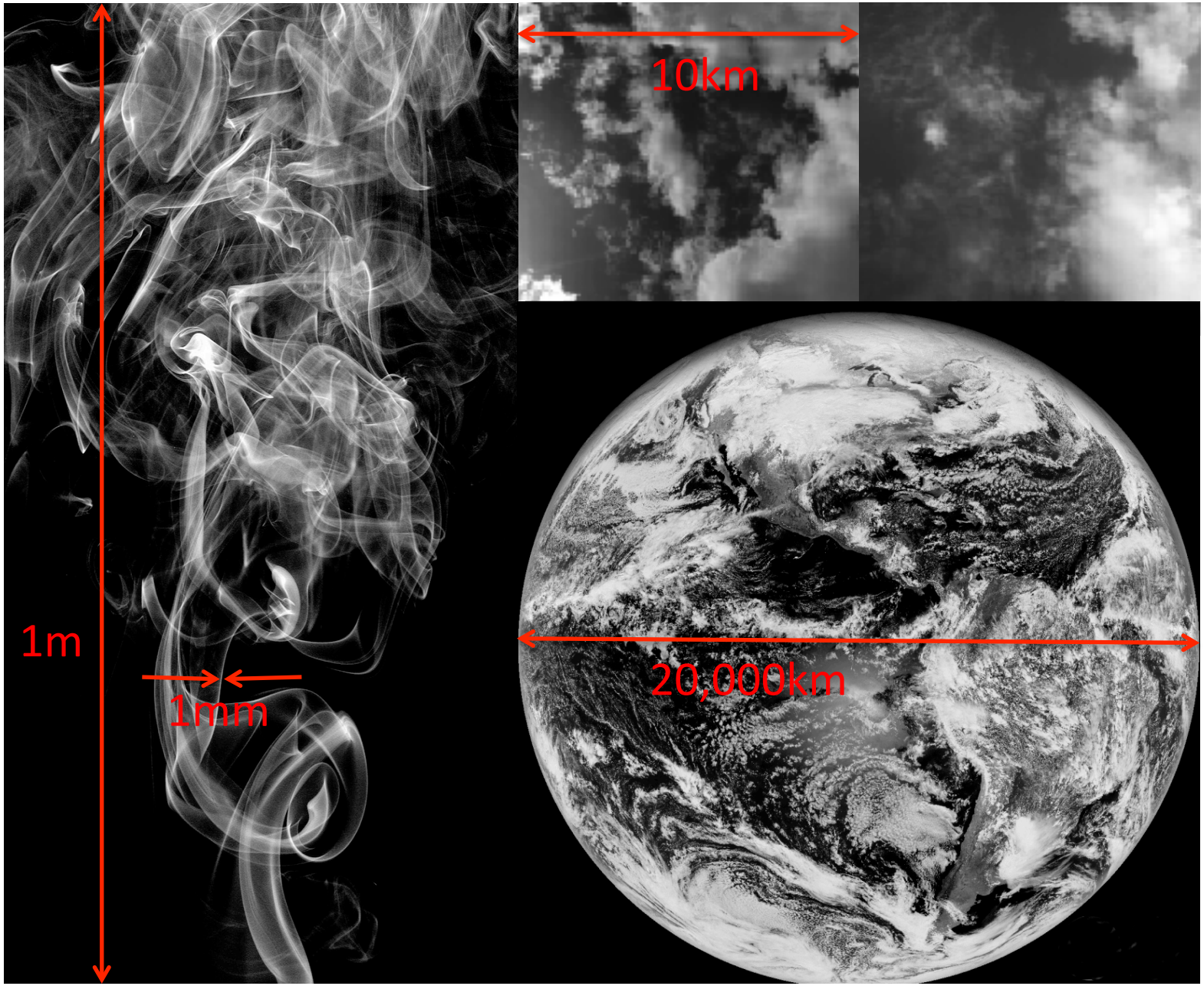
Shaun Lovejoy

A voyage through scales

Zooming through scales by the billion

1mm - 10,000 km

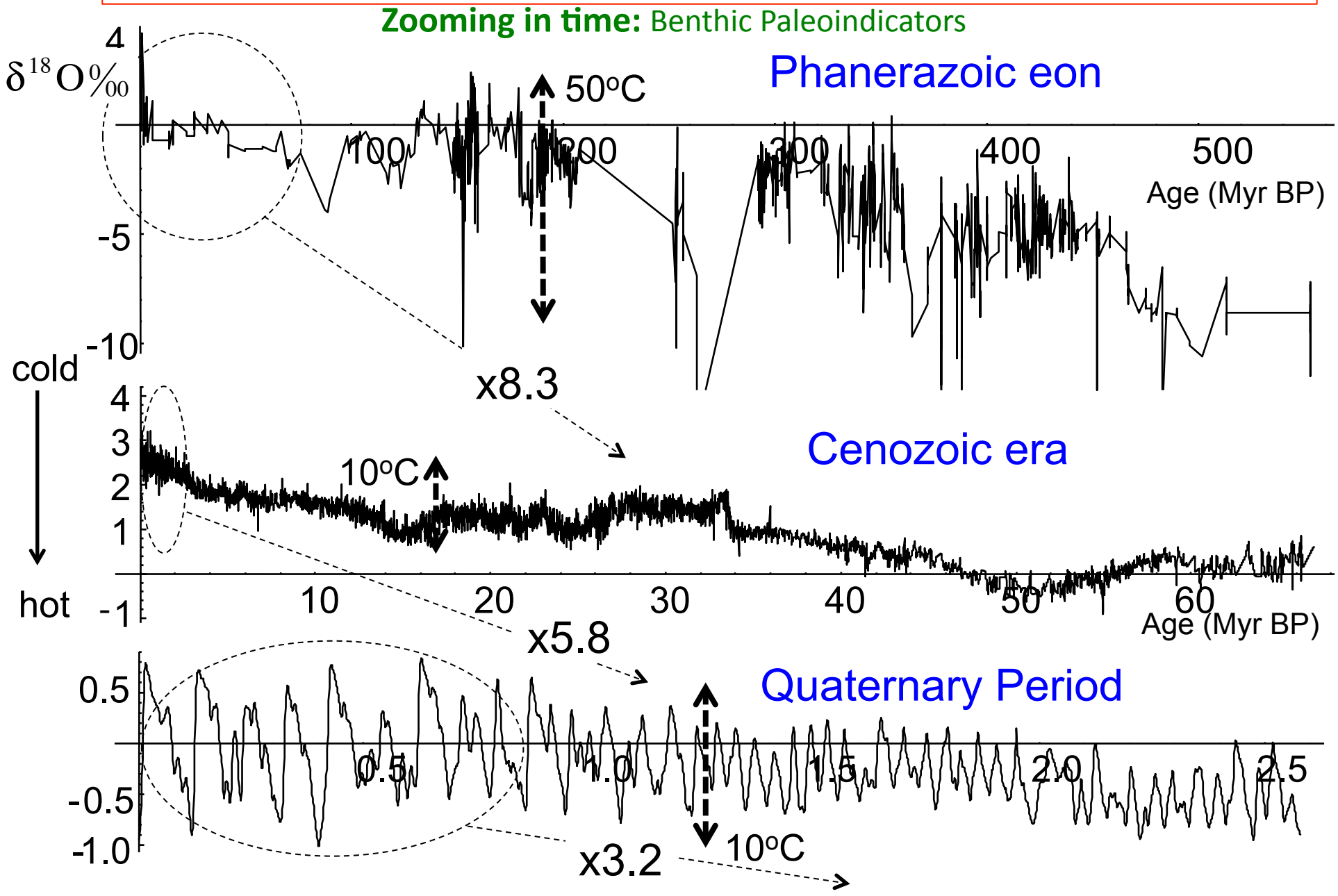
A voyage through scales: Space, 0.1mm – 10,000km

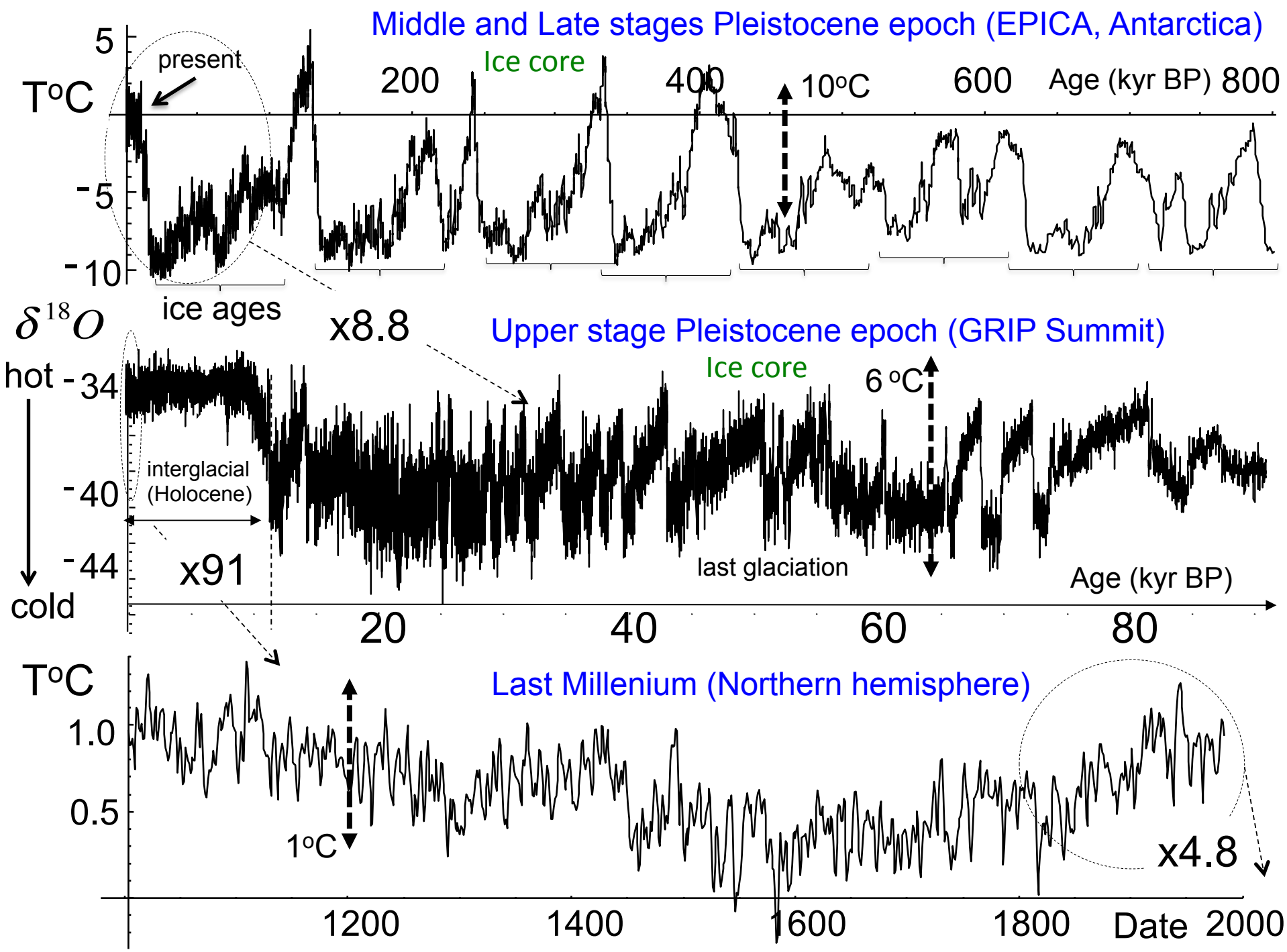


A voyage through scales

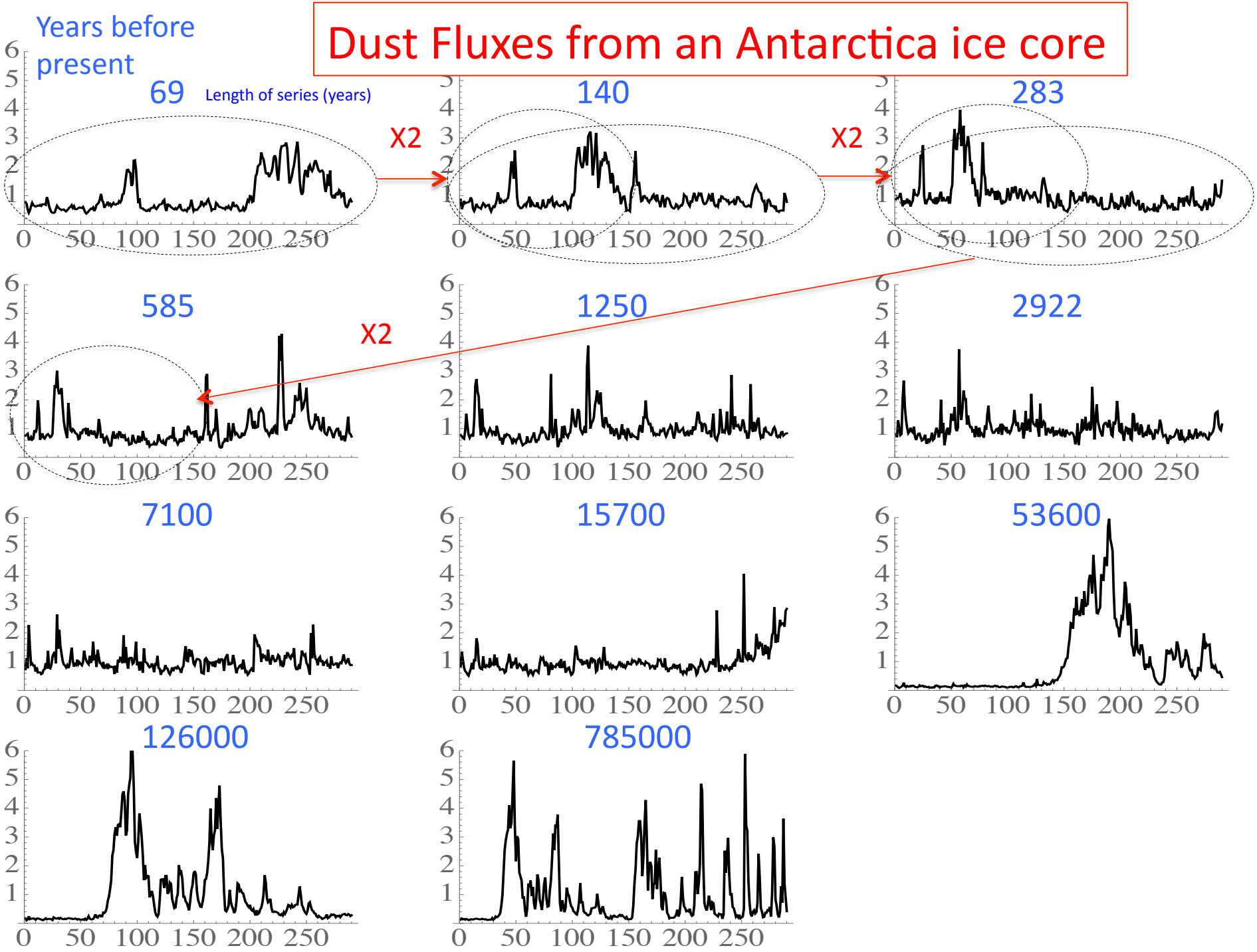
Zooming through scales by the billion billion milliseconds to half a billion years

A voyage through scales: Time, 0.001s − 4.5 billion years

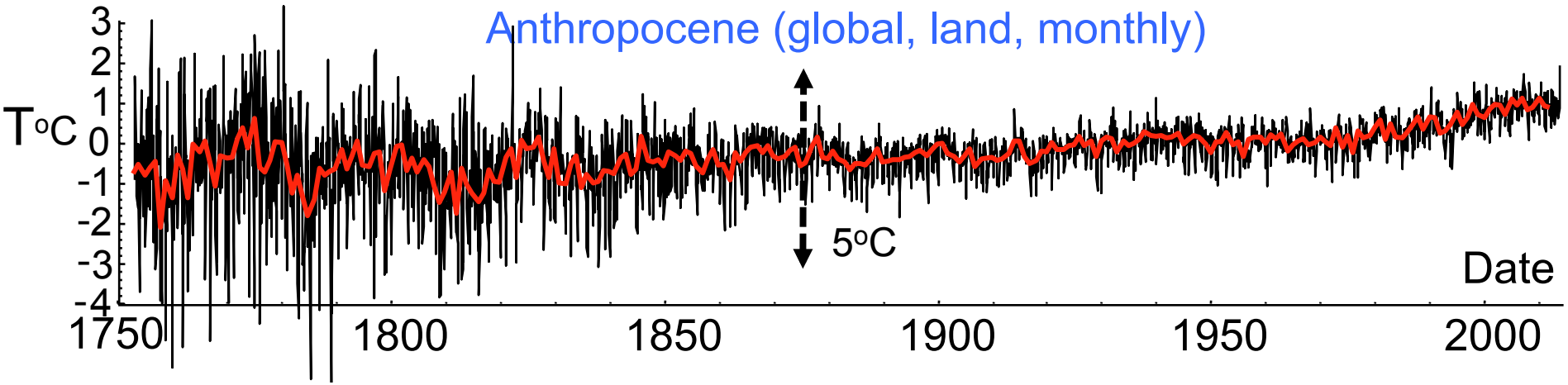


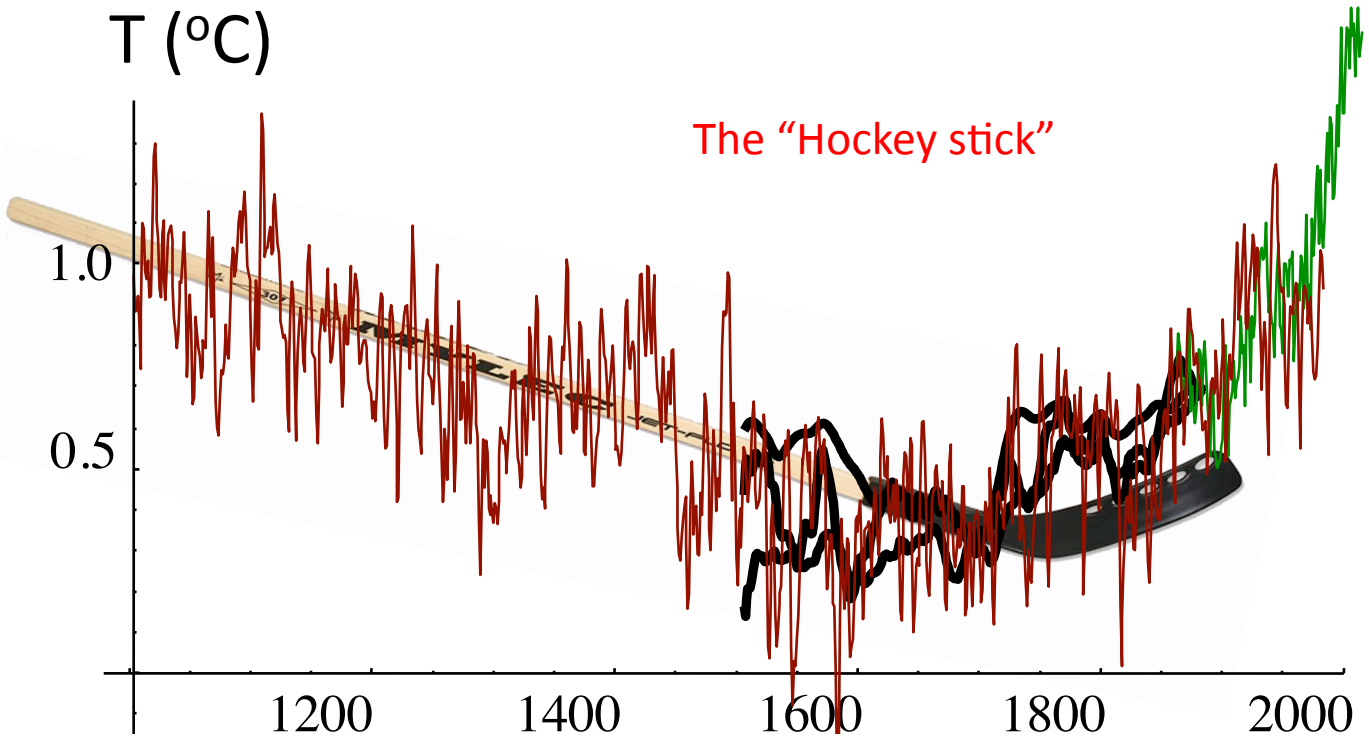

Middle and Late stages Pleistocene epoch (EPICA, Antarctica)
Ice core
present
TºC
5
-5
-10
200
400
600
800
Age (kyr BP)
10ºC
ice ages
x8.8
δ18O
hot
cold
-34
-40
-44
Upper stage Pleistocene epoch (GRIP Summit)
Ice core
6 ºC
interglacial
(Holocene)
x91
last glaciation
Age (kyr BP)
20
40
60
80
TºC
1.0
0.5
Last Millenium (Northern hemisphere)
1ºC
x4.8
1200
1400
1600
1800
Date
2000

Dust Fluxes from an Antarctica ice core

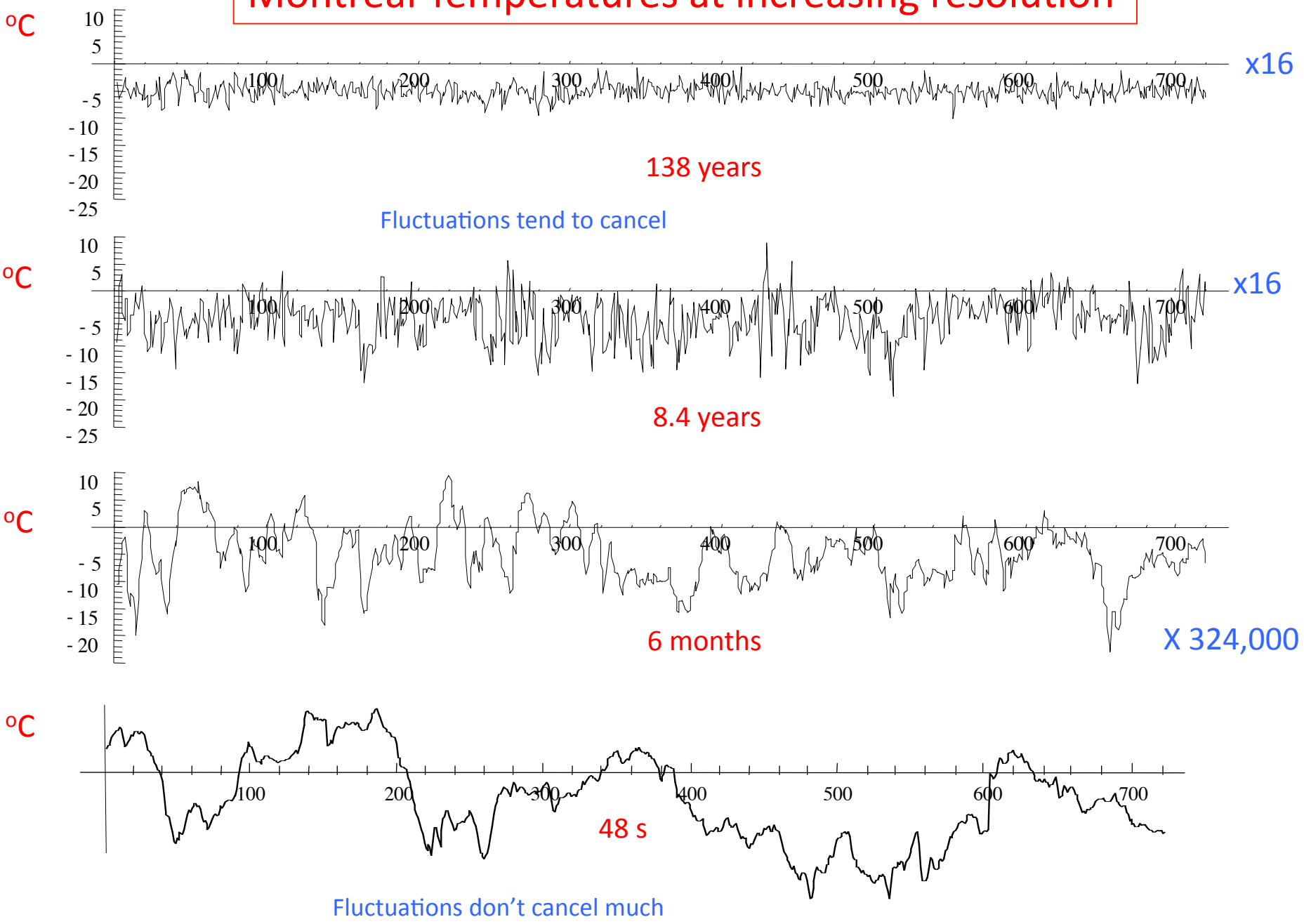


Instrumental temperatures





Montreal Temperatures at increasing resolution

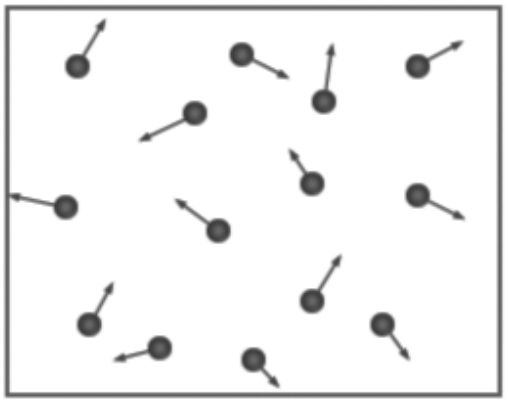


How to understand this mind-boggling variability?

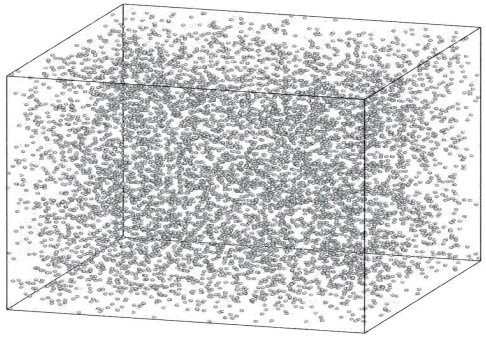
(1): High level or low level laws?

Emergent laws: Which level?

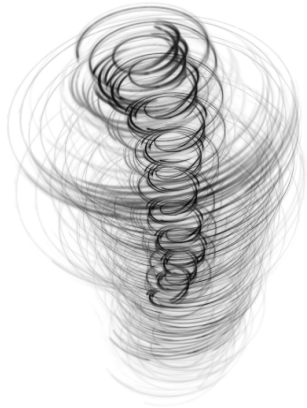
Mechanics of a few particles



Statistical Mechanics: many particles

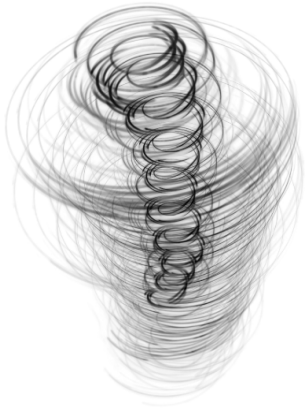


Collective behaviour of Thermodynamics, continuum mechanics, GCMs



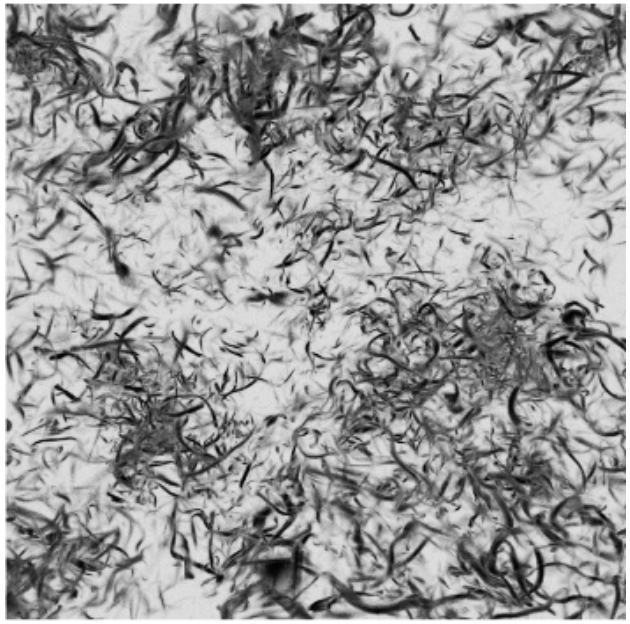
Irrelevance of most of the details, collective behaviour of many, many components

The hierarchy continues



Continuum mechanics of a single vortex

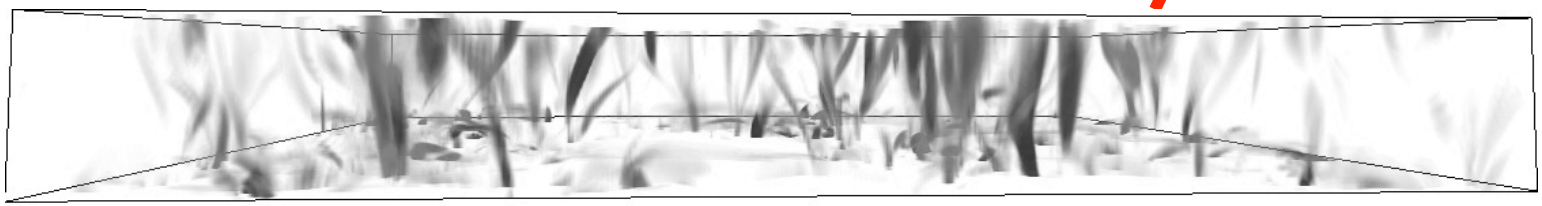
Collective behaviour of many vortices: Turbulent laws



"spaghetti" picture

Irrelevance of most of the details, collective behaviour of many, many components

Continuum mechanics Of several vortices

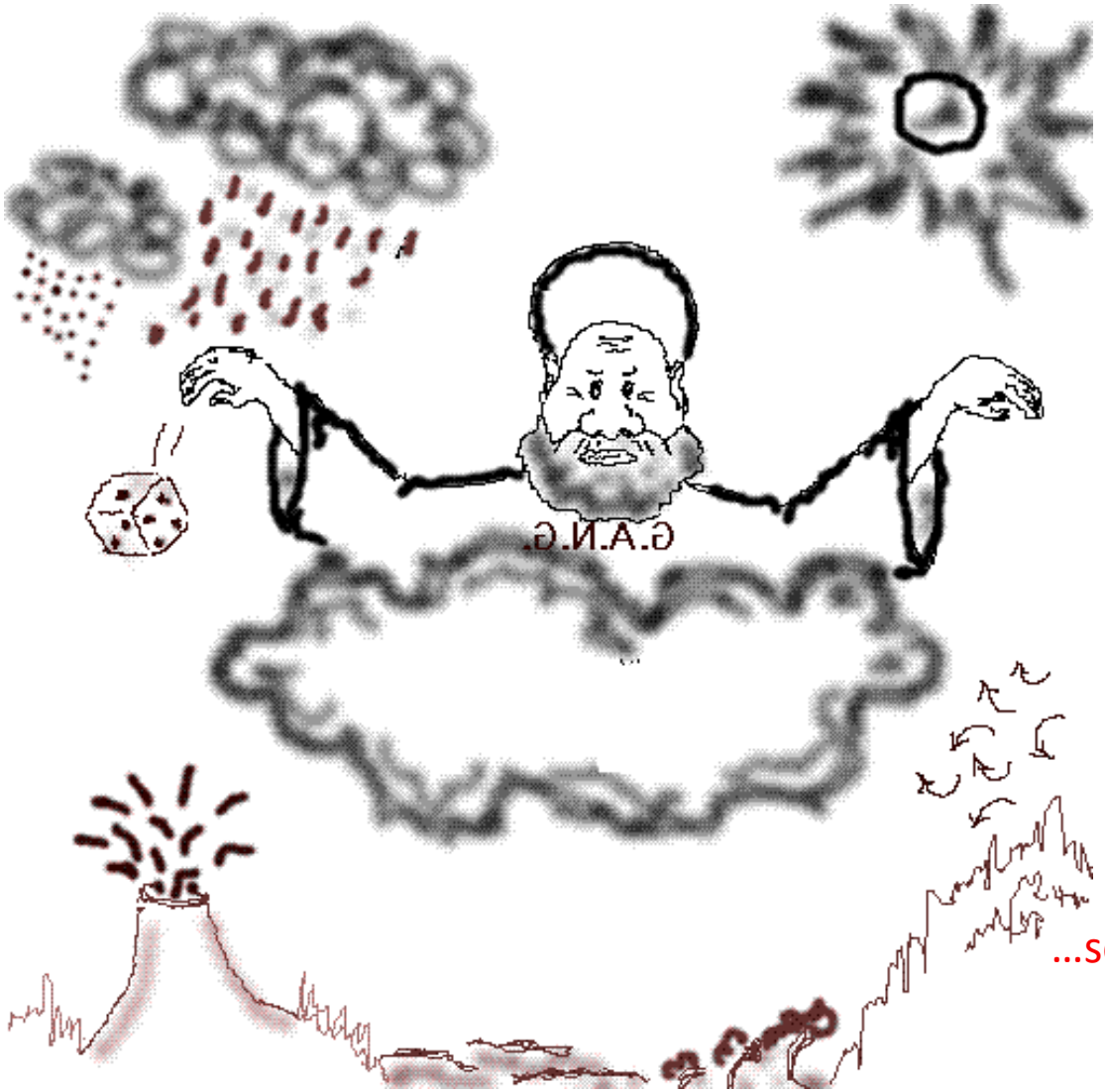


How to understand this mind-boggling variability?

(2): Deterministic or random?

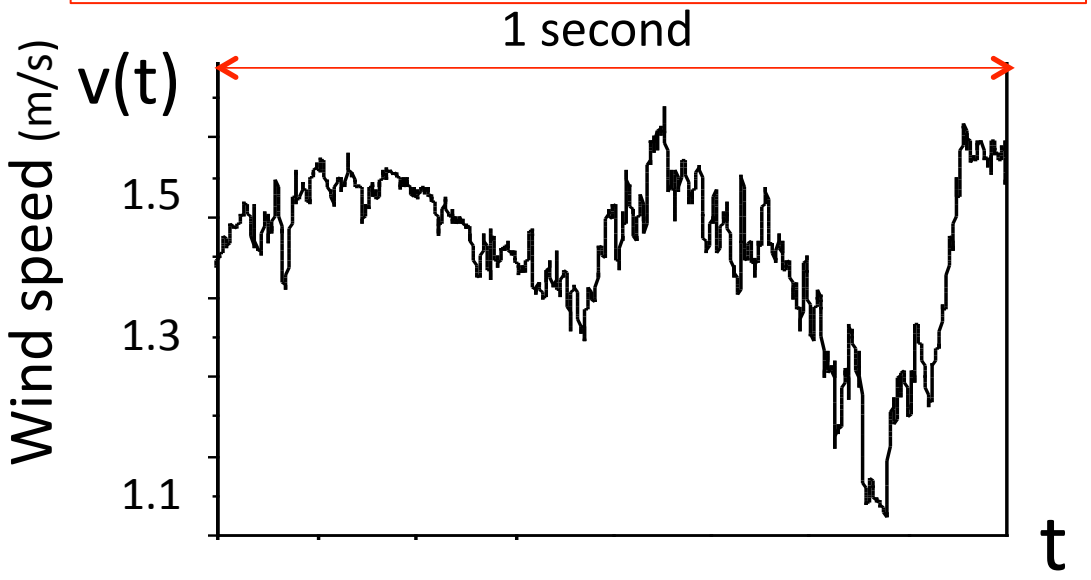
Which Chaos?

How does God play dice??

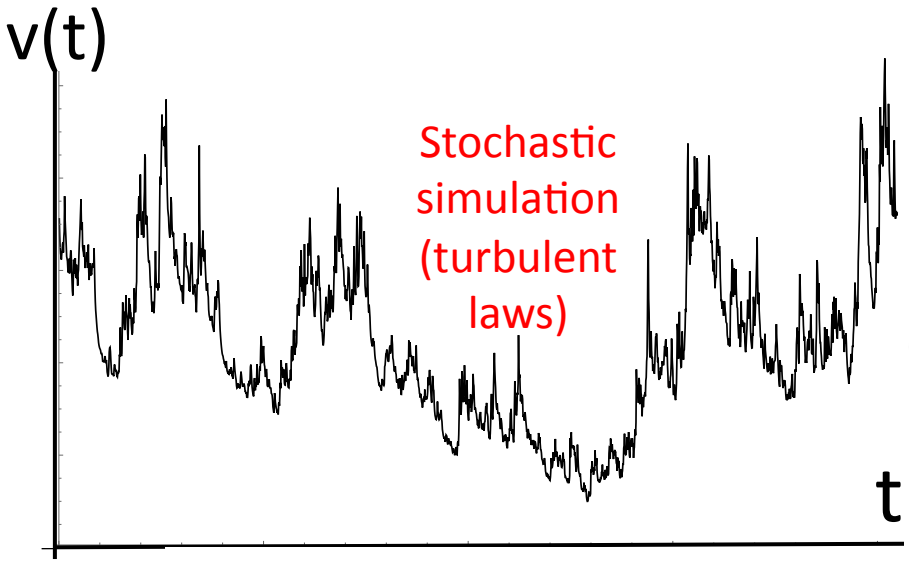


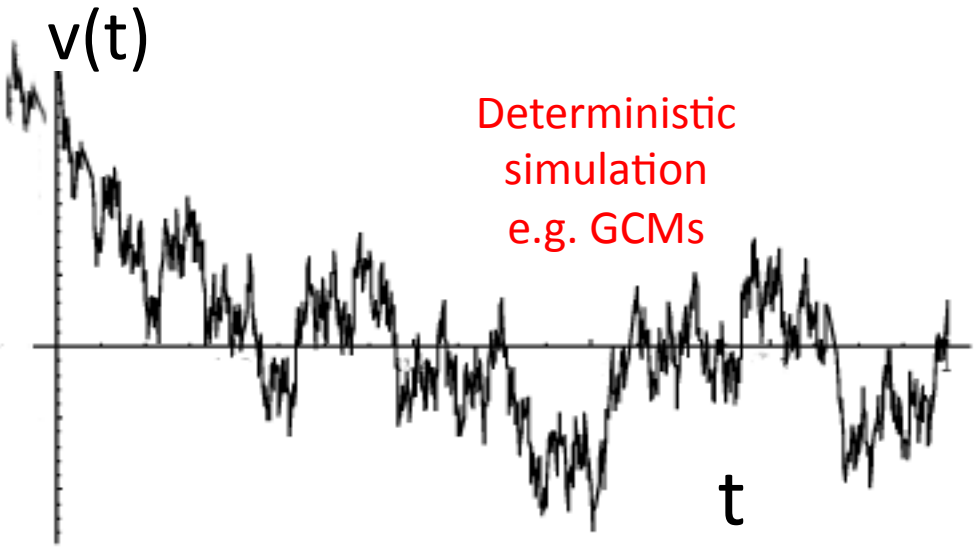
…sorry Einstein!

Which Chaos?
Stochastic or Deterministic?



Data,
roof of
physics
building





Cosmos versus chaos through the ages

Chaos-Cosmos (ancient Greeks)

Scientific ideas about determinism and randomness

Determinism: God supplies the initial conditions (e.g. planets in orbits, Newton, 1670's)

"…if a sufficiently vast intelligence exists…" Laplace (1749-1827)

Chance: Ignorance, subjective

"Chance is nothing" Voltaire: (1694-1778).

Chance: Irrelevance of the details

Statistical Mechanics e.g. the bell curve distribution of molecular velocities in a gas (Maxwell, Gibbs, Boltzman, 1870-1900)

Chance: Objective

Quantum Mechanics: Born interpretation of the wave function (1926)

Mathematics: Kolmogorov axiomatized probability theory (1930)

The Nonlinear Revolution
1970 - 1990 - present

The Deterministic Chaos Revolution: The Butterfly Effect

-Tiny perturbations could be amplified

-Random looking phenomena might not be random after all…

-Backlash: an attempt to resurrect Newtonian determinism

The Stochastic Chaos alternative: scale symmetries, fractals, multifractals

-Objective randomness…

How to understand this mind-boggling variability?

(3): New worlds or scaling?

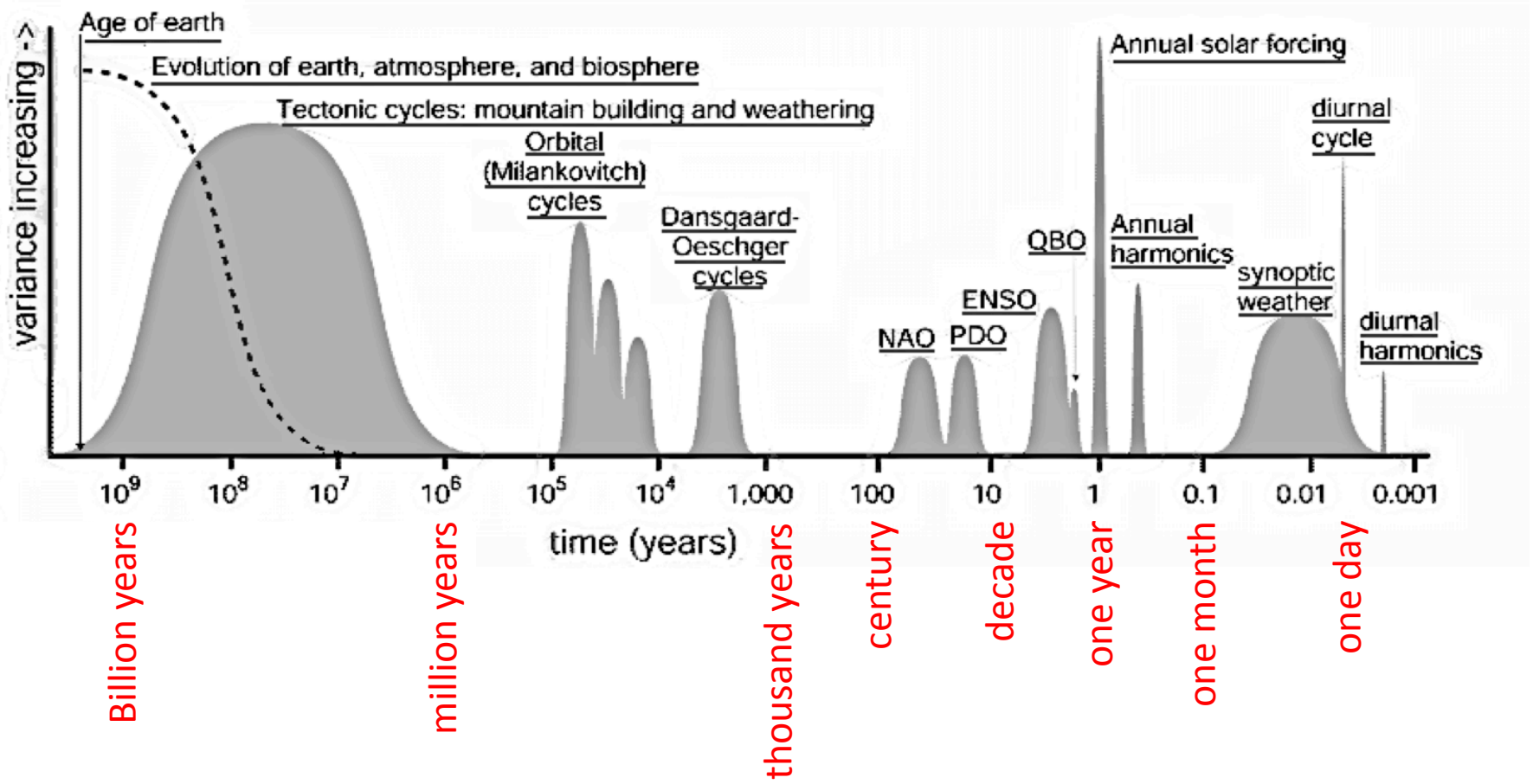
From Van Leeuwenhoek to Mandelbrot

Scalebound thinking and the missing quadrillion

The Scalebound view

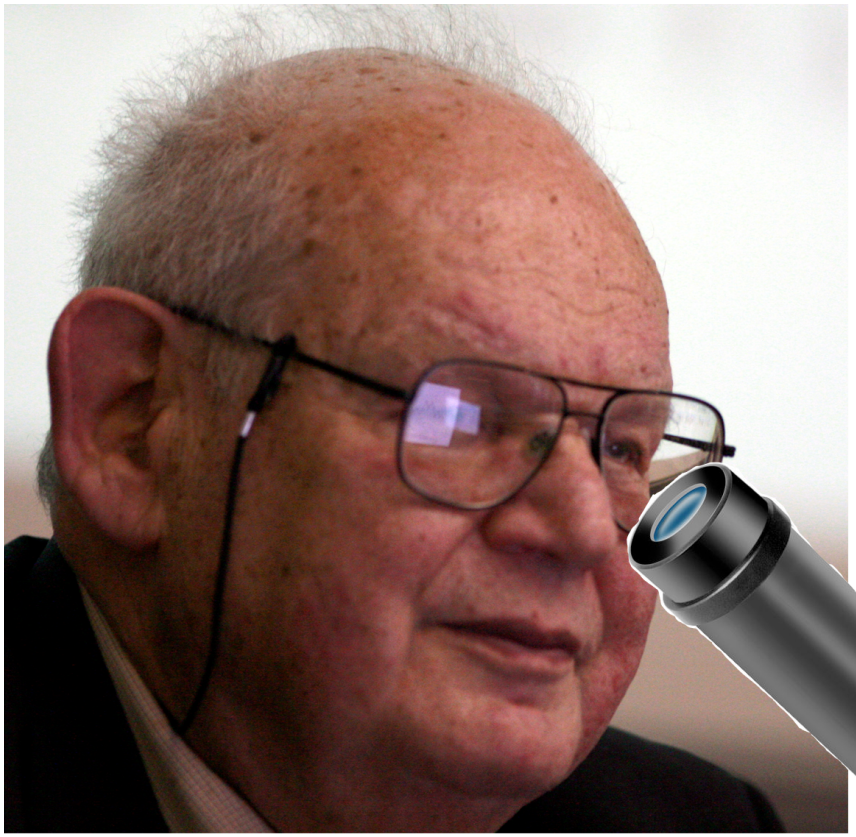
Van Leeuwenhoek discovering a “new world” in a drop of water (circa 1690)

Scalebound "Powers of ten" view

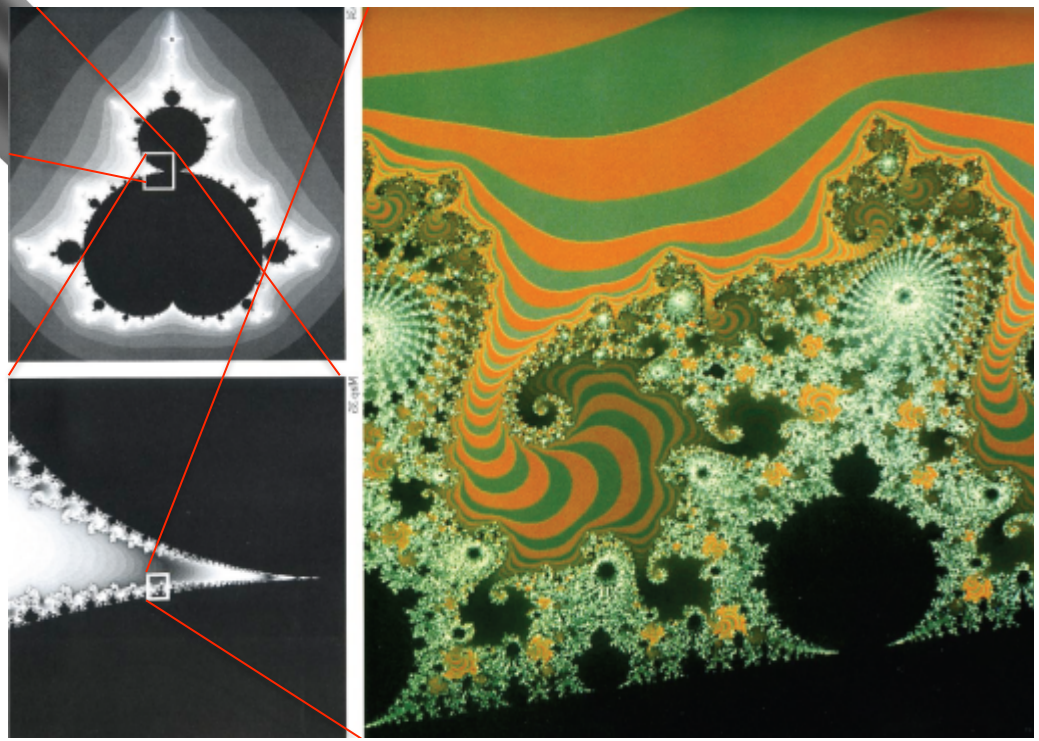


Official National Oceanographic and Atmospheric Administration (NOAA) website

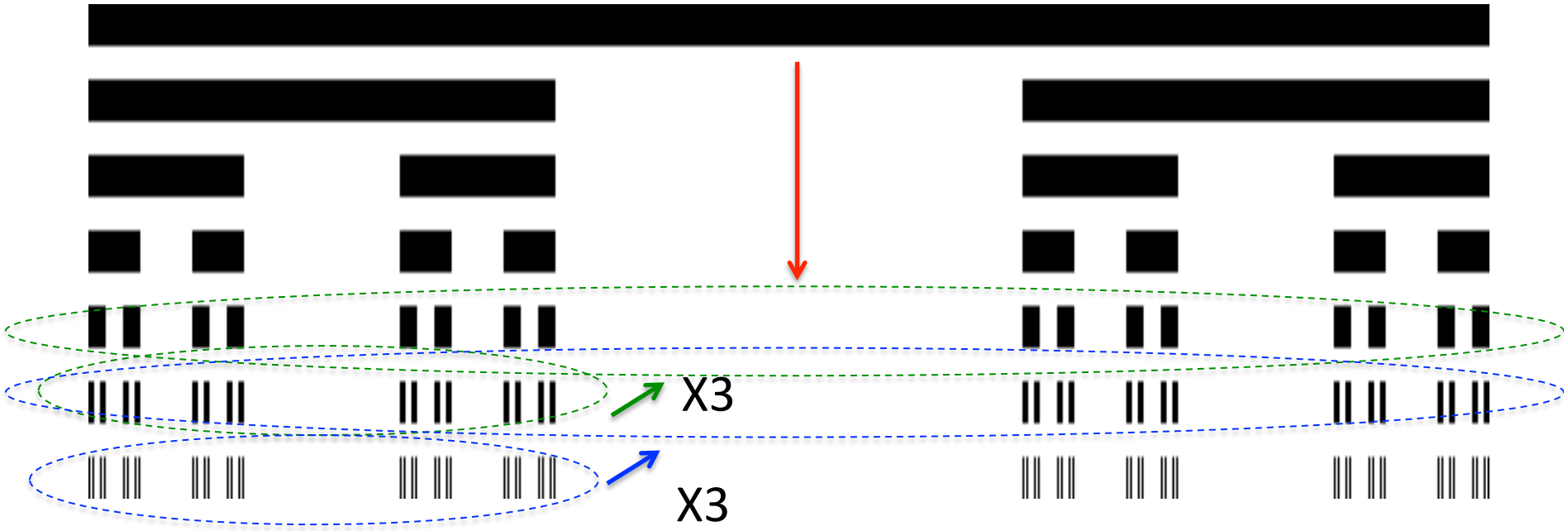
The Scaling view



Mandelbrot (1924-2010)
zooming into the
Mandelbrot set



Fractals sets
Cantor's "Perfect" set (1870)



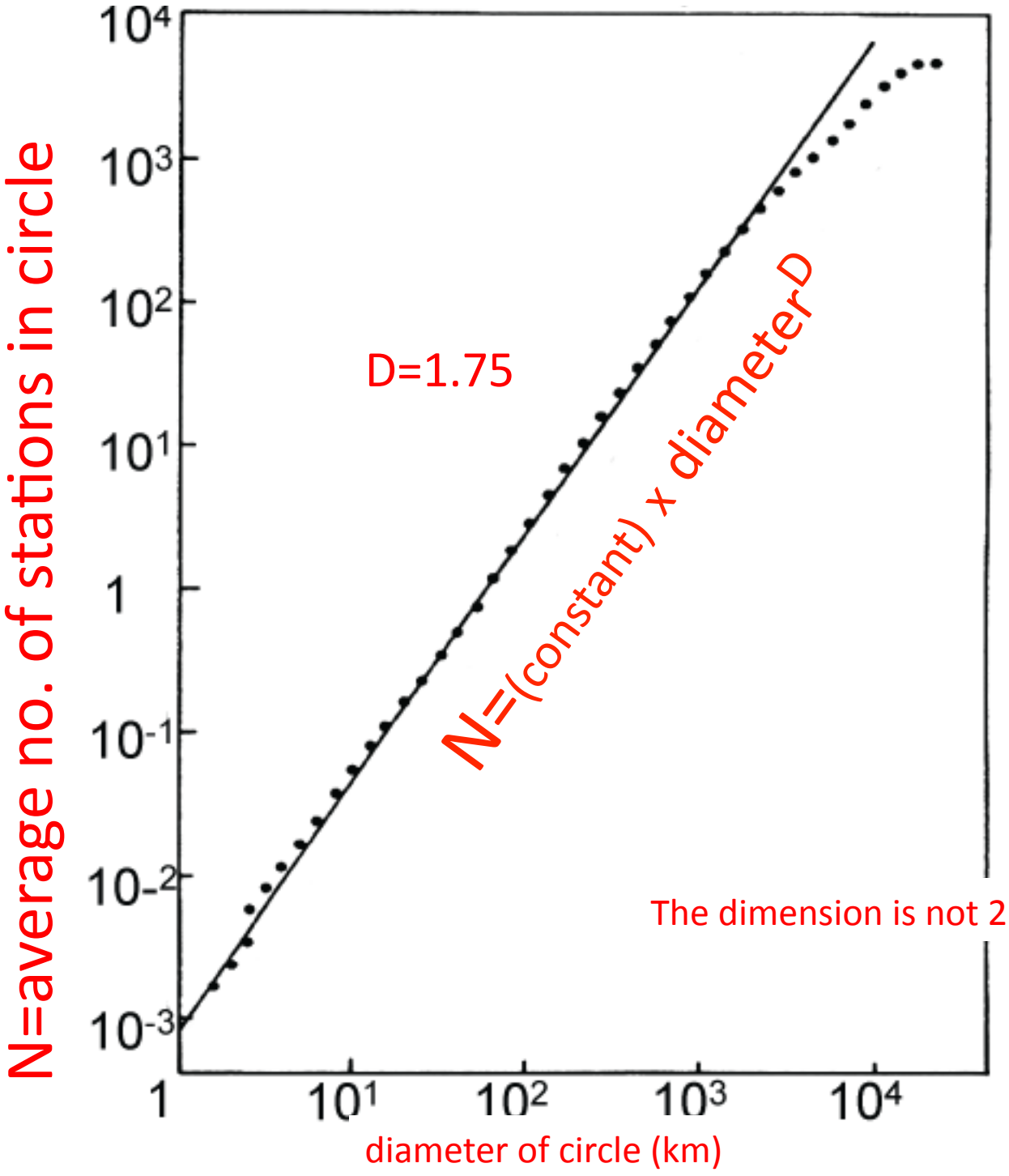
Self-similarity: a part resembles the whole

Zooming gives the same set!

9962 Meteorological measuring stations

"Holes" at all scales: Zooming gives on average the same sparseness of points

Lovejoy and Scherzter 1986



The dimension is not 2 but 1.75…

Scale invariance

$$\text{Number of stations} = (\text{scale})^{D}$$

(fractal) dimension of the set of stations

Average number number of stations in a circle

diameter of the circle

The relationship is the same at all scales: **scale invariant**

Ex:

$$\text{Number of stations in a small circle} = (\text{small diameter})^{D}$$

$$\text{Number of stations in a big circle} = (\text{big diameter})^{D}$$

Classifying atmospheric variability using Scale invariance

- What is the weather?

Macroweather?

- What is the Climate?

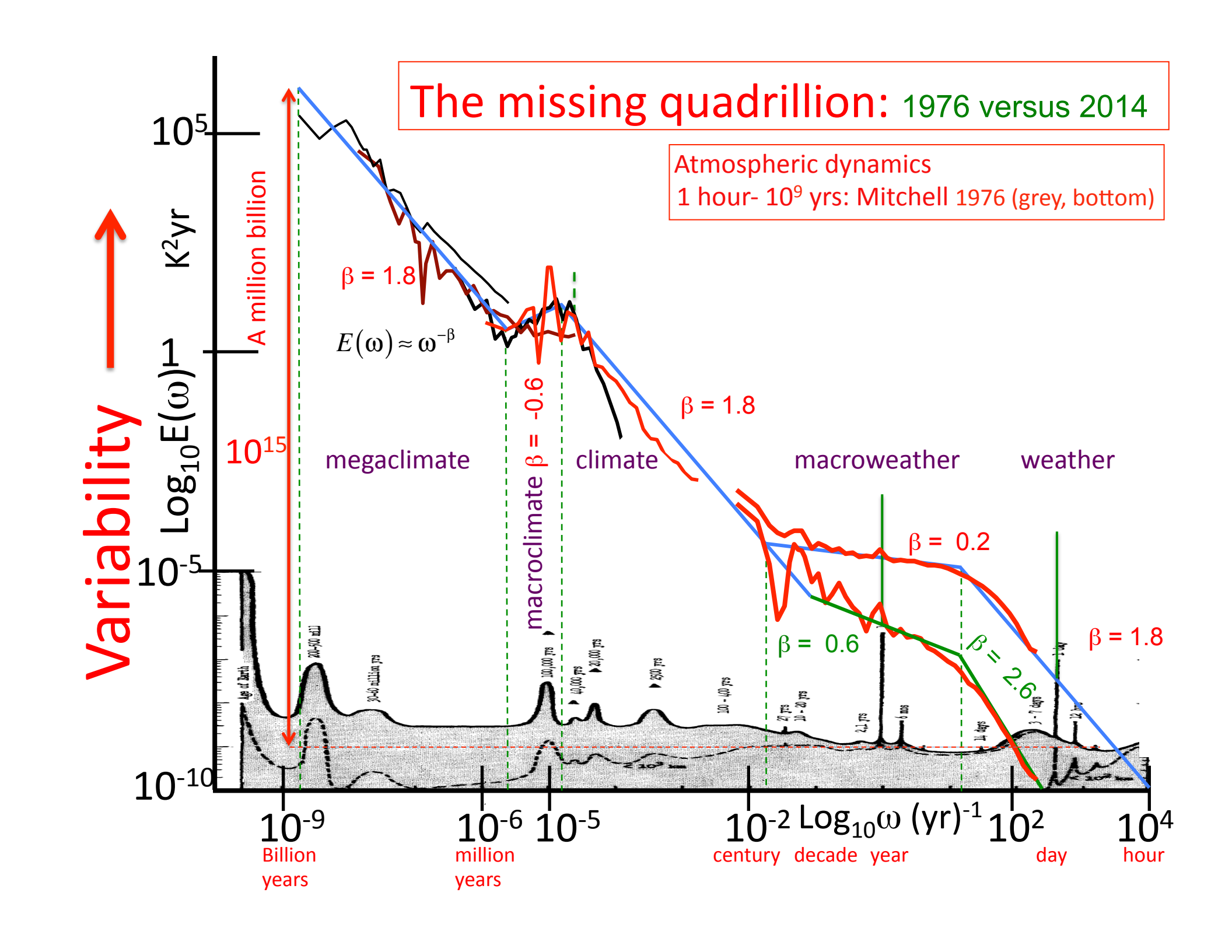
The climate is not what you expect…

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

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

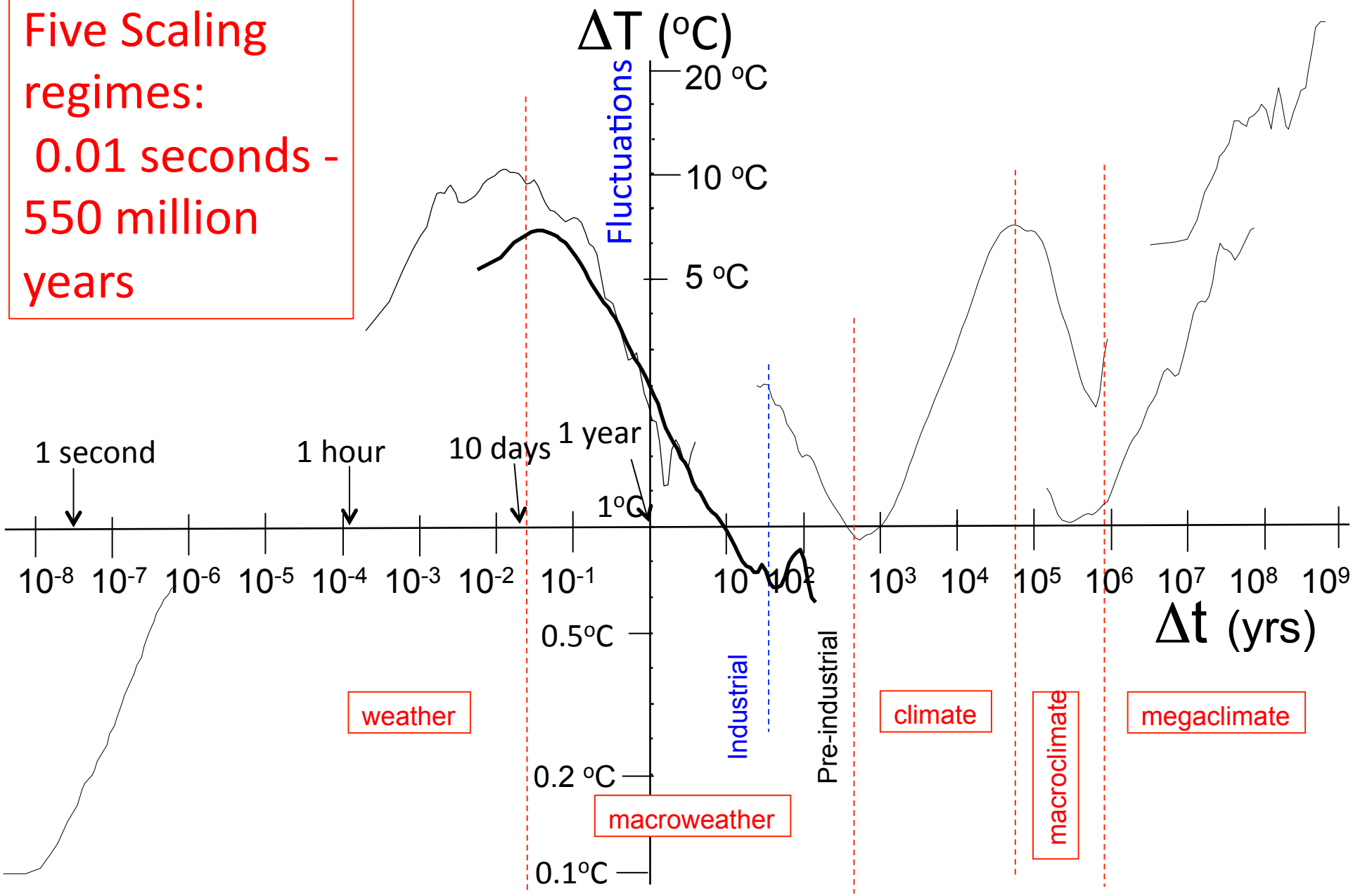
"Climate in a narrow sense is usually defined as the "average weather" ...

- Intergovernmental Panel on Climate Change, 2007


The missing quadrillion: 1976 versus 2014
Atmospheric dynamics
1 hour- 10^9 yrs: Mitchell 1976 (grey, bottom)
Variability
Log10E(ω)
K²yr
10^5
1
10^-5
10^-10
A million billion
10^15
β = 1.8
E(ω) ≈ ω^-β
β = 1.8
megaclimate
macroclimate β = -0.6
climate
macroweather
weather
β = 0.2
β = 0.6
β = 2.6
β = 1.8
10^-9
Billion years
10^-6
million years
10^-5
10^-2
century
decade
year
Log10ω (yr)^-1
10^2
day
10^4
hour

New simple technique discovered in 2012: Fluctuation analysis

Five Scaling regimes:
0.01 seconds - 550 million years



How does scaling help?

Scaling, scale invariance:

Typical Fluctuation ≈ (scale)^H

H>0: Fluctuations grow with scale, unstable

H<0: Fluctuations decrease with scale, stable

~~"The climate is what you expect, the weather is what you get"~~

Expect Macroweather!

Weather: H>0, macroweather, H<0, climate, H>0

Is civilization due to freak macroweather?

"The long, stable Holocene is a unique feature of climate during the past 420,000 years, with possibly profound implications for evolution and the development of civilizations."

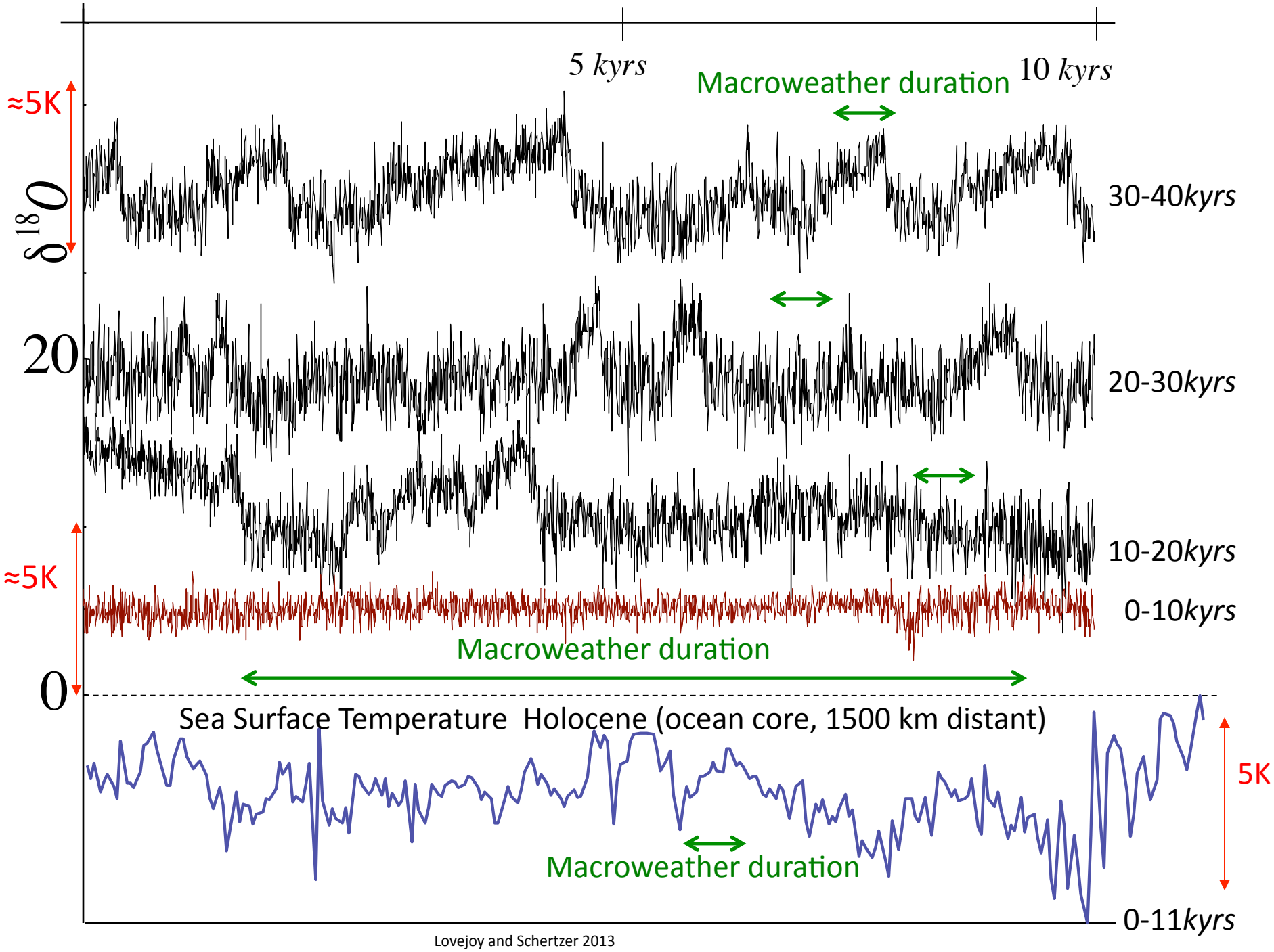
Petit et al , Nature, 1999, Based on the analysis of Vostok Antarctica cores

The Holocene is "highly unstable".

Berner et al 2008, based on paleo Sea Surface Temperatures from ocean cores near Greenland.

"Have our species been spoiled by a long and blissful macroweather hiatus, or – on the contrary - did harshly varying climate adversity force us to invent new ways of coping?"

Lovejoy 2017 ("Weather, Macroweather and climate: big and small, fast and slow, our random yet predictible atmosphere", Oxford U. press, in press)



Lovejoy and Schertzer 2013

November 2014

"Friends of Science" Versus Science

Montreal

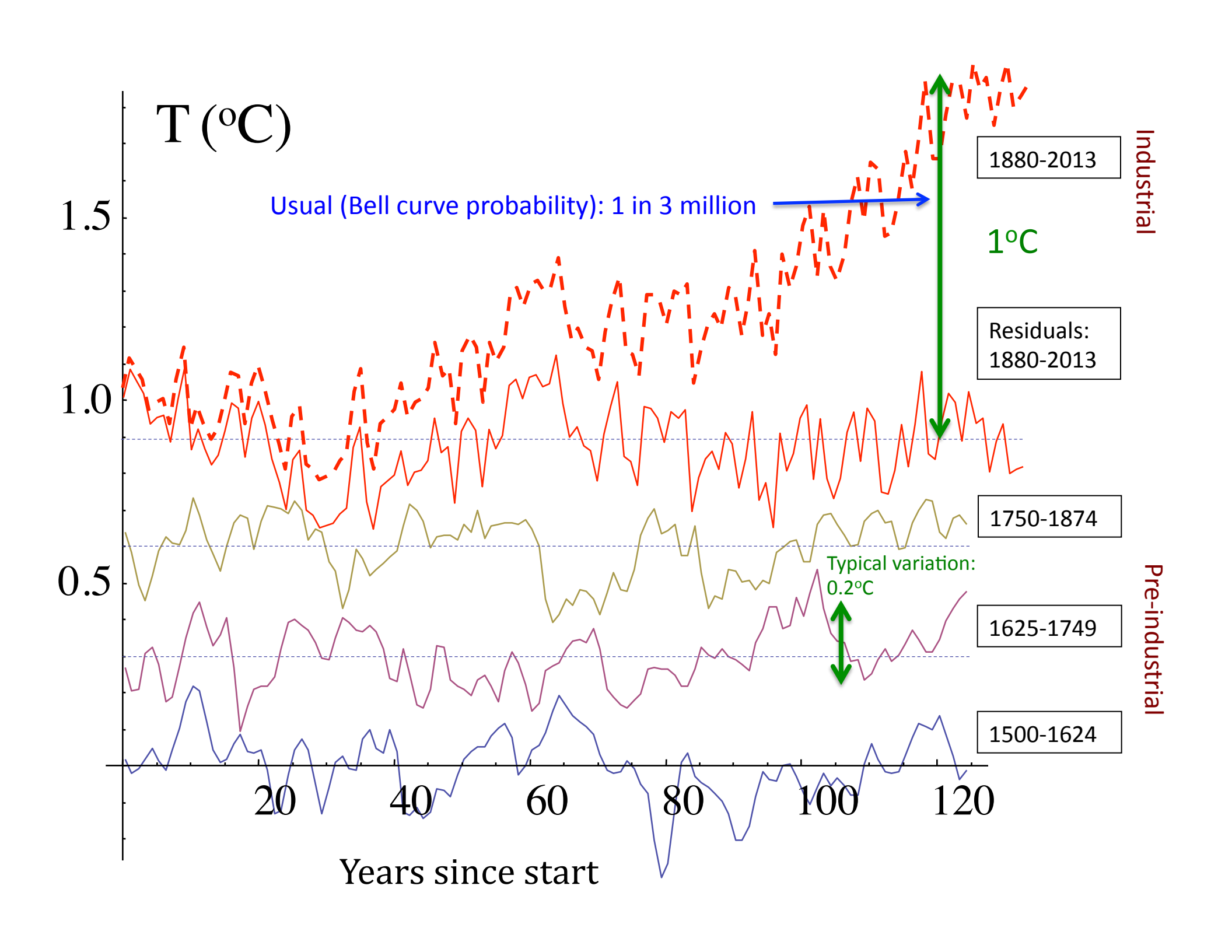
Friends of Science

Montreal

Association des Communicateurs Scientifiques

Toronto

Ottawa

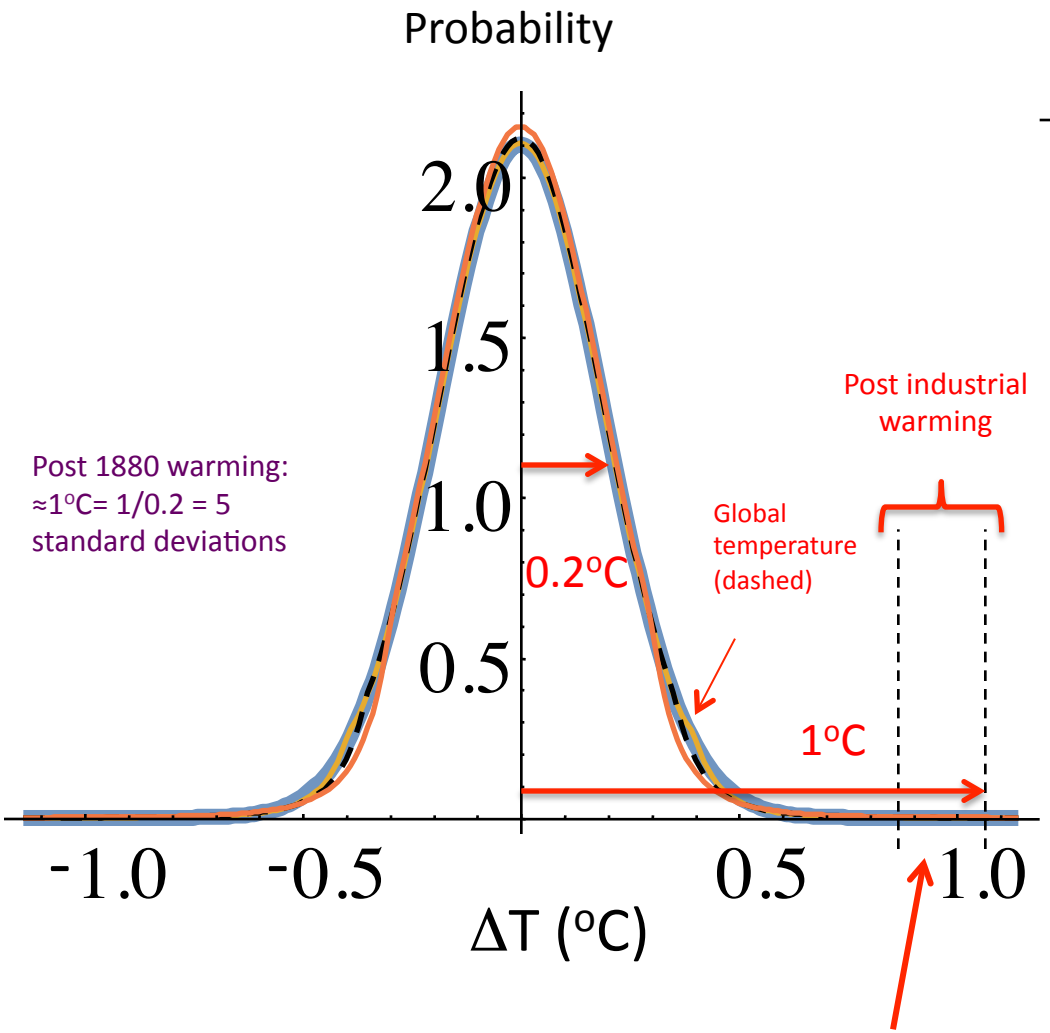

T (°C)
1.5
1.0
0.5
Usual (Bell curve probability): 1 in 3 million
1°C
1880-2013
Residuals:
1880-2013
1750-1874
Typical variation:
0.2°C
1625-1749
1500-1624
Industrial
Pre-industrial
20
40
60
80
100
120
Years since start

The skeptics' Giant Natural Fluctuation Hypothesis

What is the probability
of a ≈1°C global
temperature increase
over ≈ 125 years?

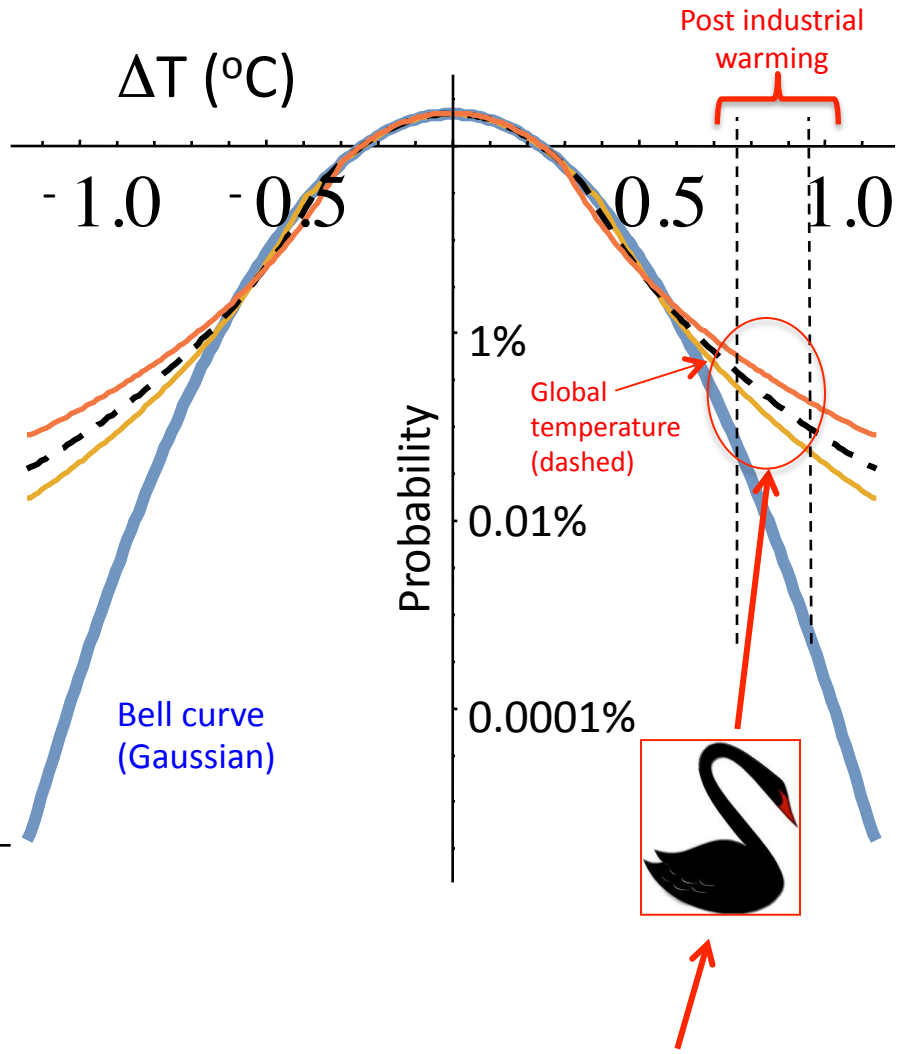
Probabilities of extreme centennial temperature changes: Bell Curve, Black Swans

Usual representation



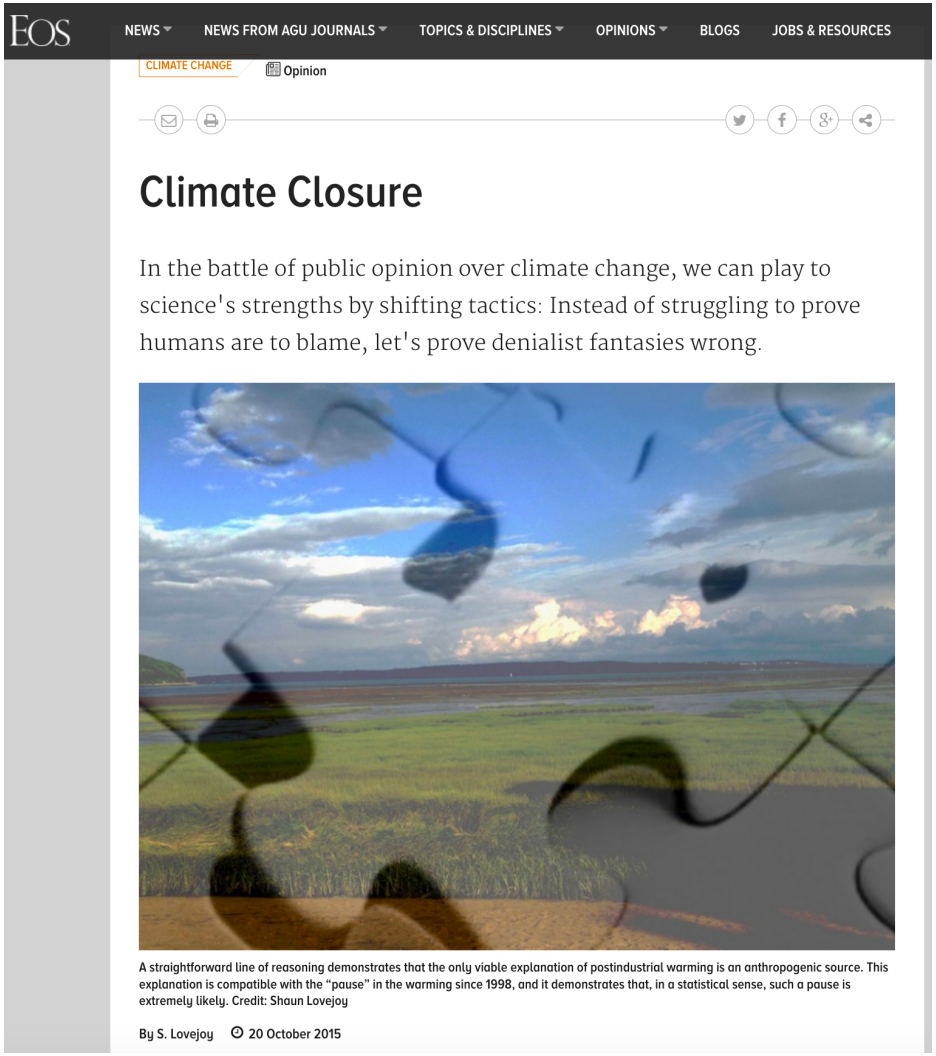
≈ 5 standard deviations: one in 3 million chance

Representation showing extremes



one in 3 thousand chance
Algebraic fall-off of probability

Climate closure



EOS NEWS NEWS FROM AGU JOURNALS TOPICS & DISCIPLINES OPINIONS BLOGS JOBS & RESOURCES

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

The skeptics reaction

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.

Viscount Lord Christopher Monckton of Brenchley:

"A mephitic ectoplasmic emanation of the forces of darkness"

A mephitic ectoplasm

Scaling and (elephantine) memory: forecasts and projections

The basic GCM limitation and macroweather forecasting (≈10 days to decades)

Weather systems (<10 days) generated by GCMs
= random weather noise (statistics)…
but not fully realistic

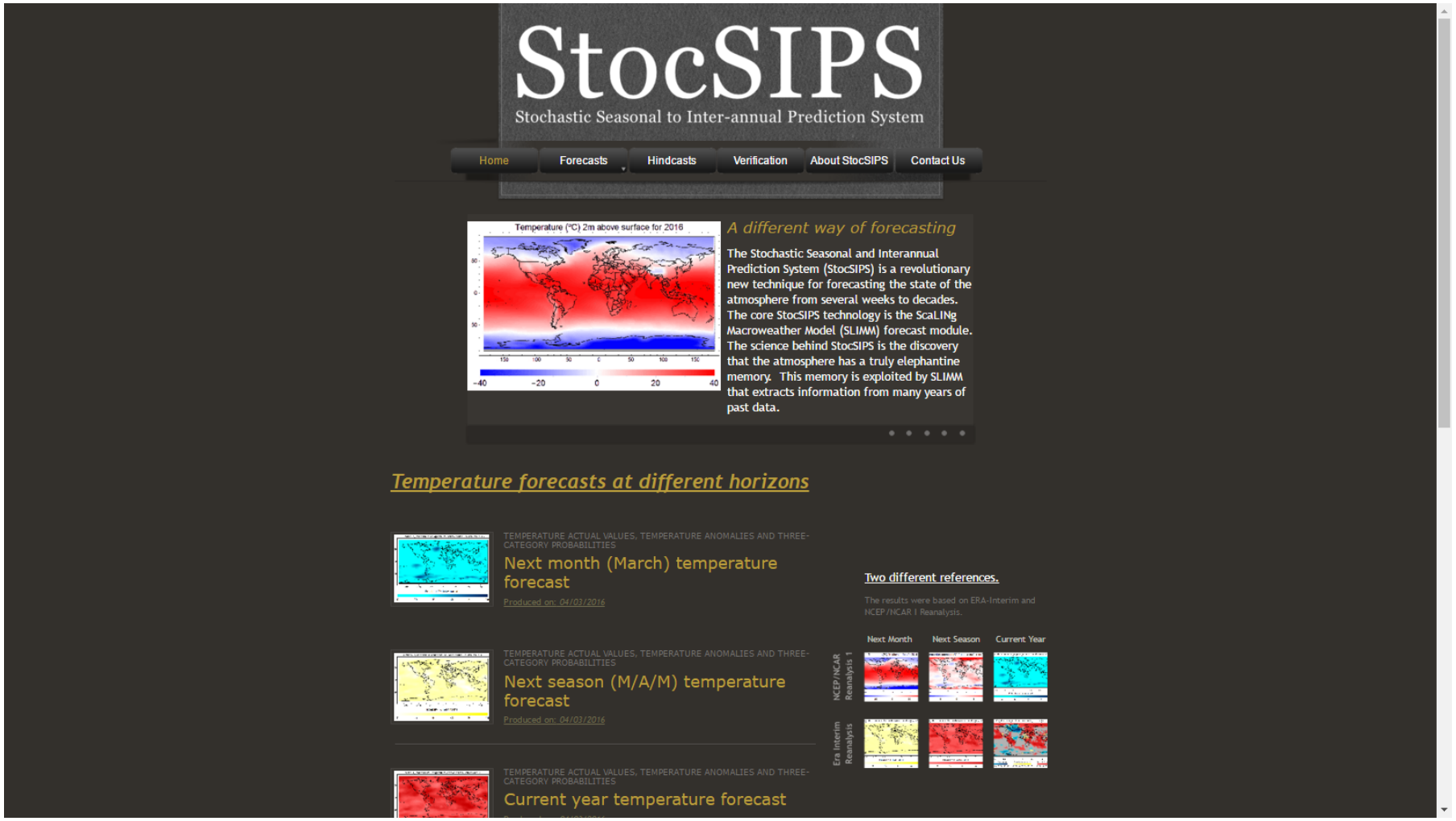
Scaling, stochastic models: use data to force convergence to the real climate.

The “killer app” for atmospheric scaling?

StocSIPS

Stochastic Seasonal and Interannual Prediction System

Visit our site

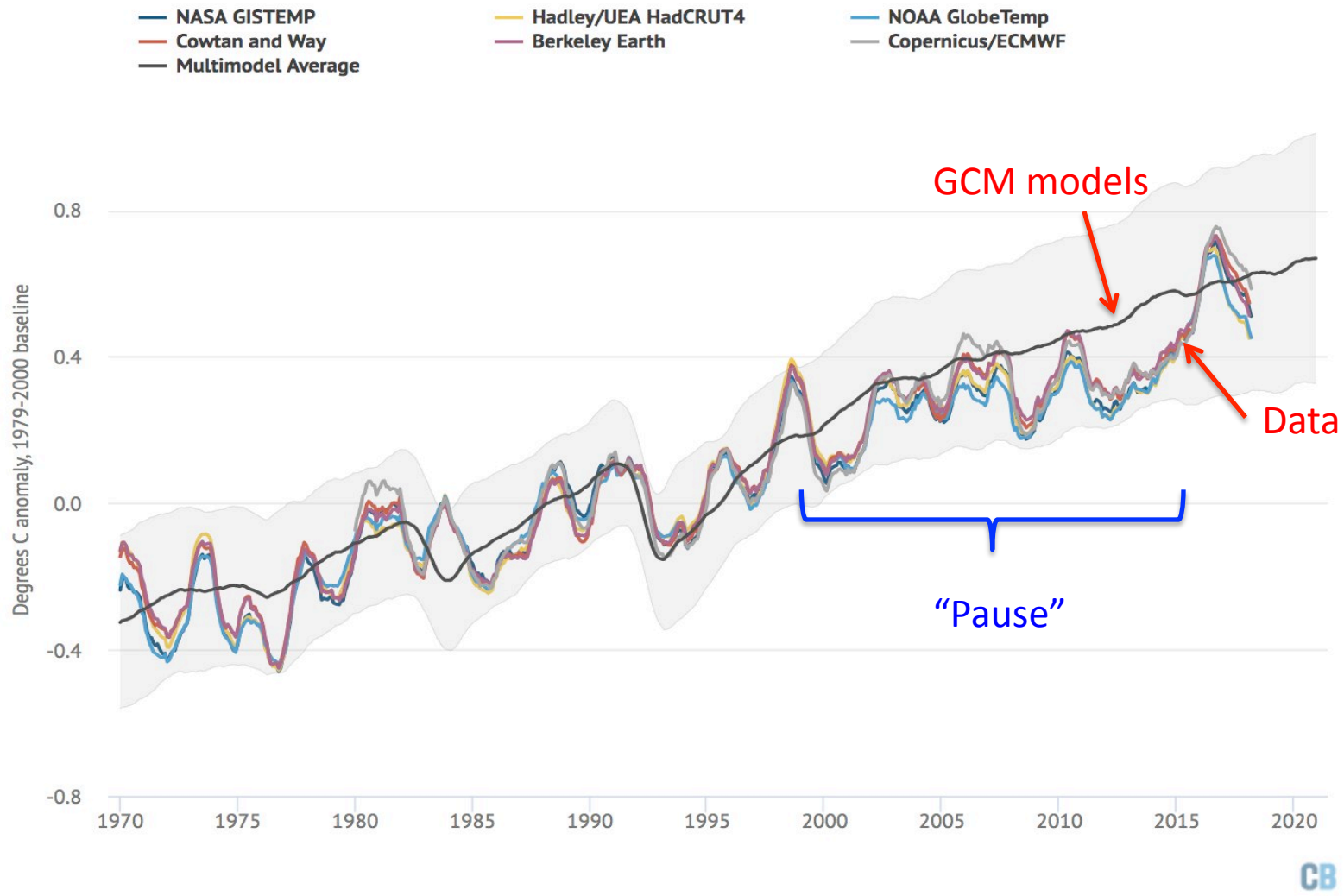


http://www.physics.mcgill.ca/StocSIPS

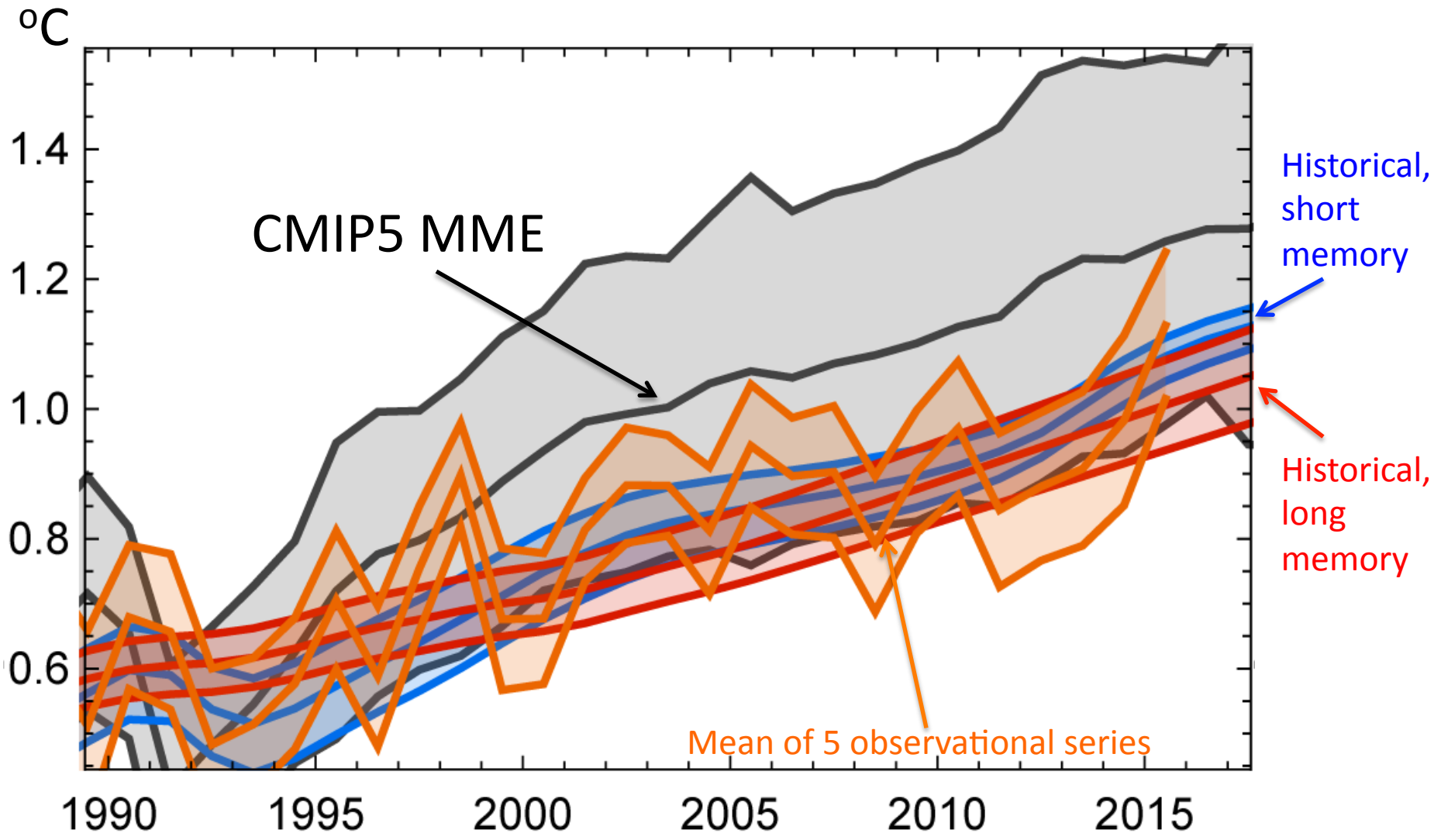
The “Pause”


Global Warming
FIND OUT MORE AT:
FRIENDS OF SCIENCE.org
Stopped Naturally 16+ Years Ago.
°C
1.0
0.8
0.6
0.4
0.2
0.0
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014

Zeke Hausfather
Tweeted yesterday

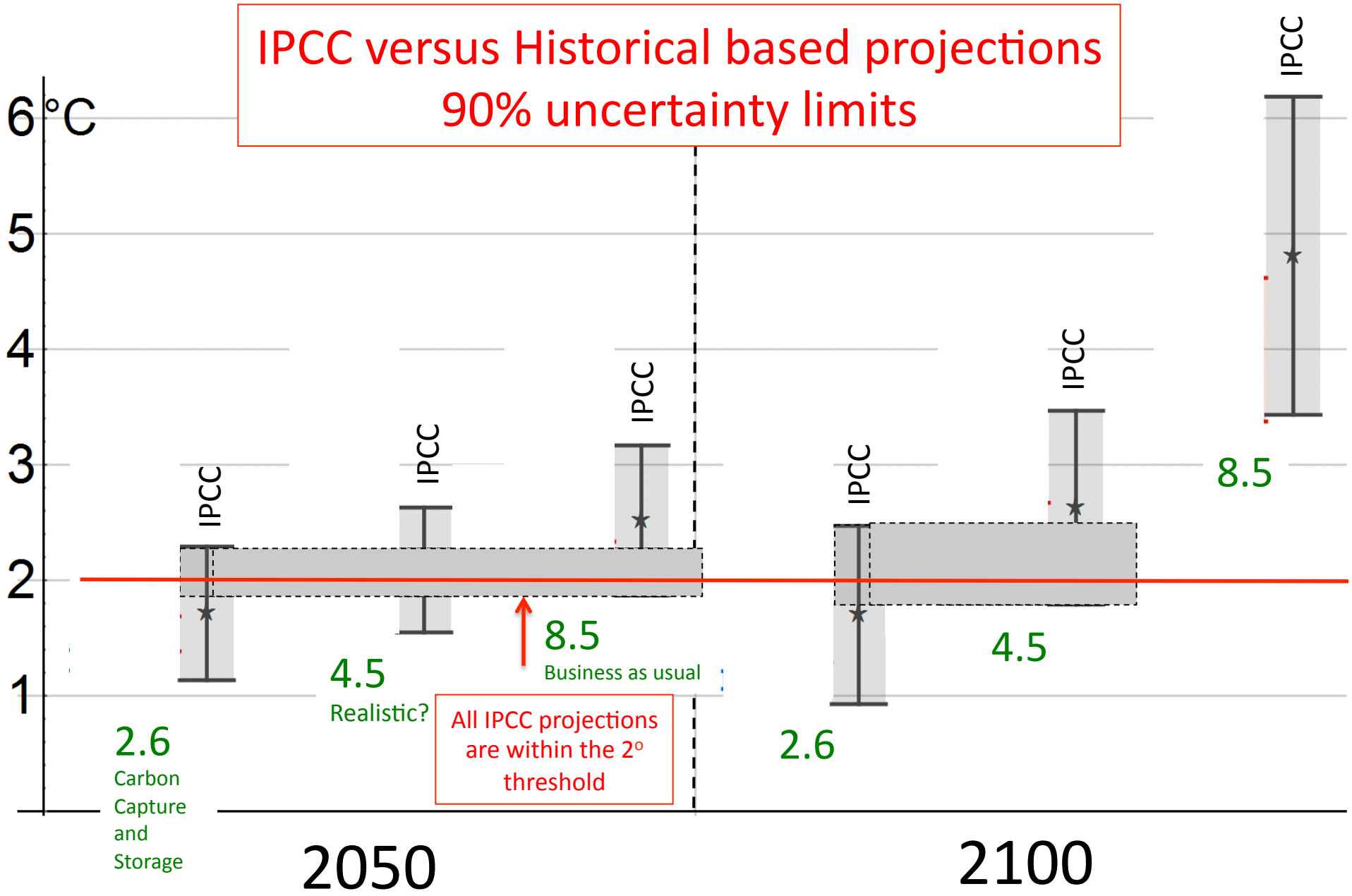


Running 12-month average global average surface temperatures from CMIP5 models and observations between 1970 and 2020. Models use RCP4.5 forcings after 2005. They include sea surface temperatures over oceans and surface air temperatures over land to match what is measured by observations. Anomalies plotted with respect to a 1970-2000 baseline. Chart by Carbon Brief using Highcharts.



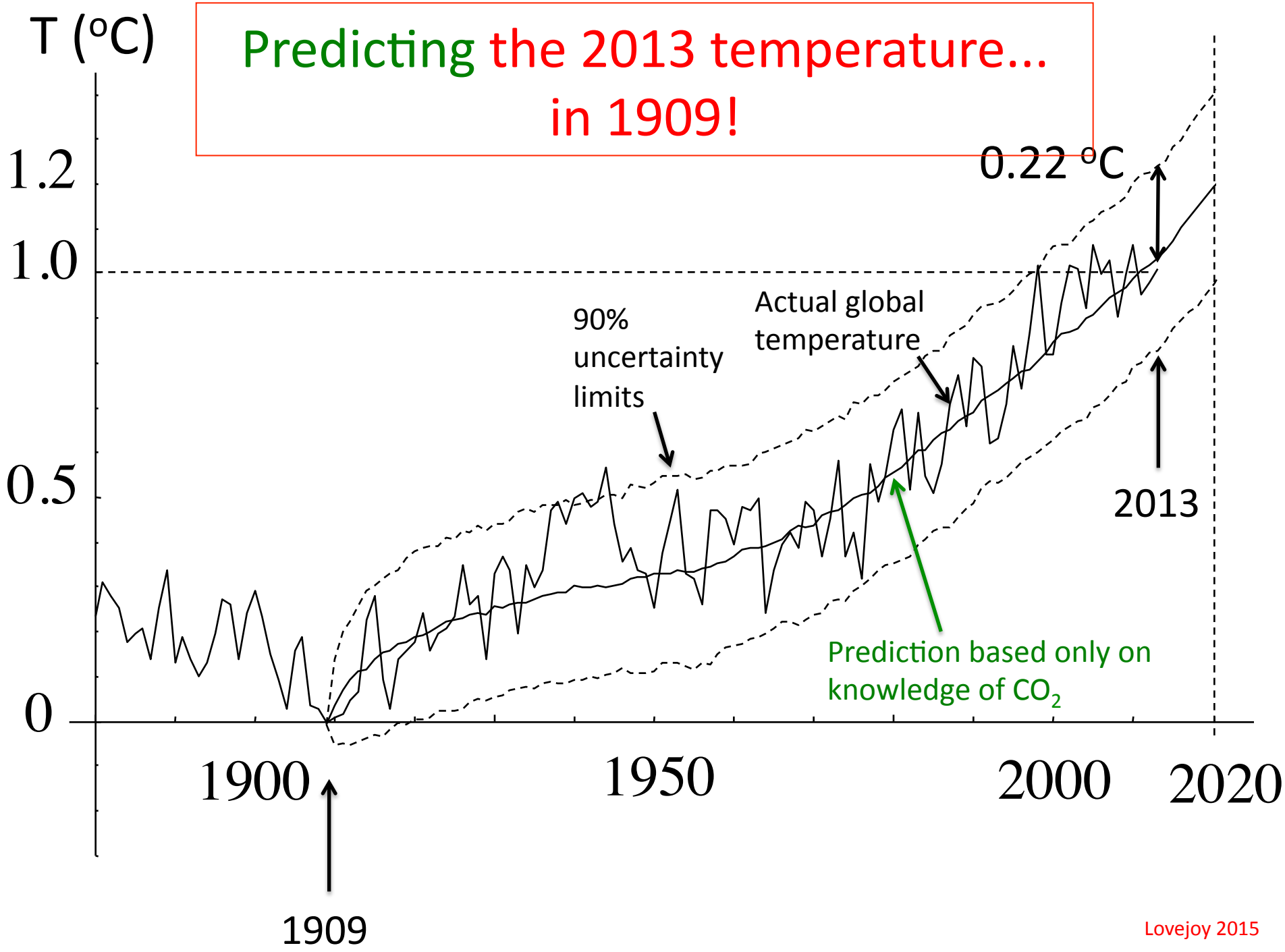
The MME versus historical projection methods. Shaded areas are the 90% confidence limits.

Our future: climate projections



"Simple": without memory, "SCRF": Scaling Climate Response Function, with memory

Lovejoy, Hebert, 2018


Predicting the 2013 temperature...
in 1909!
T (°C)
1.2
1.0
0.5
0
0.22 °C
90%
uncertainty
limits
Actual global
temperature
2013
Prediction based only on
knowledge of CO_2
1900
1950
2000
2020
1909
Lovejoy 2015

Projections: 2080-2100

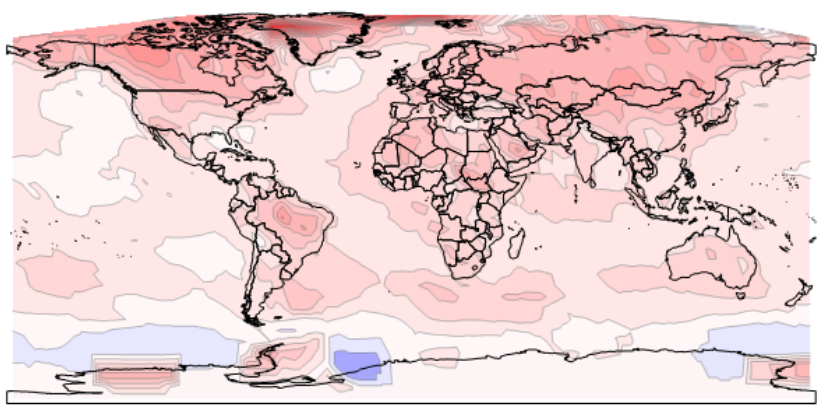
Historical

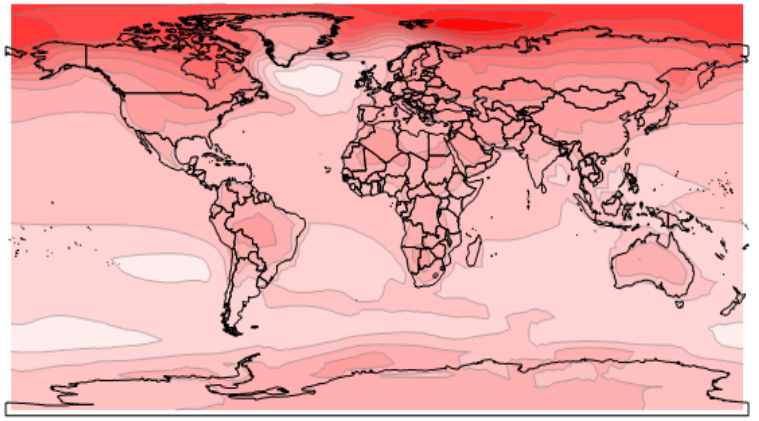
IPCC

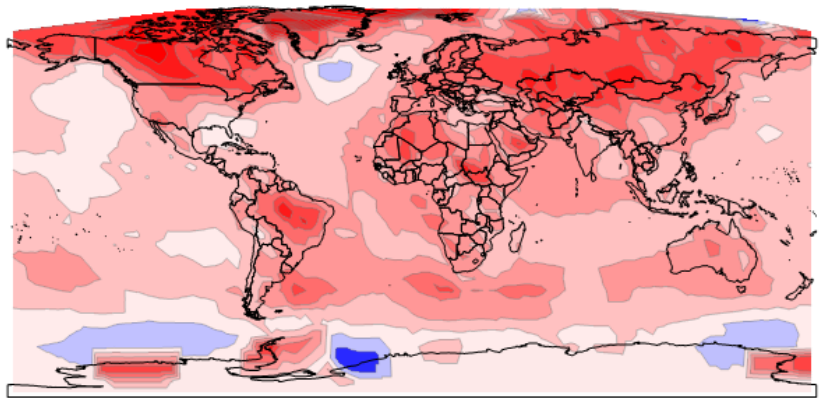
Scenarios

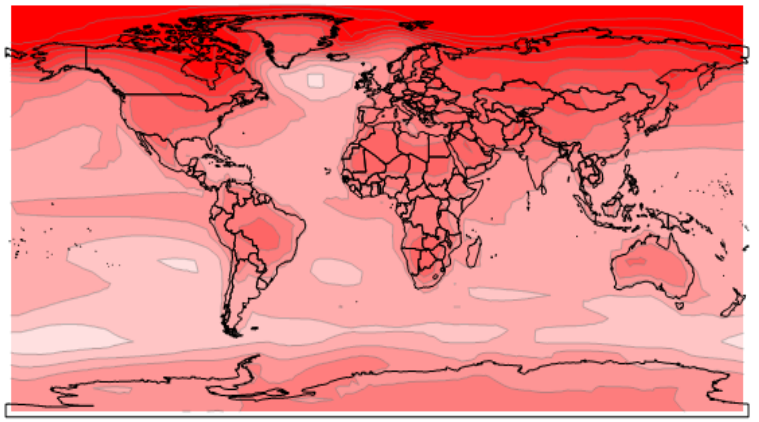
Low emissions (RCP 2.6)

Moderate emissions (RCP 6.0)









°C

6

4

2

0

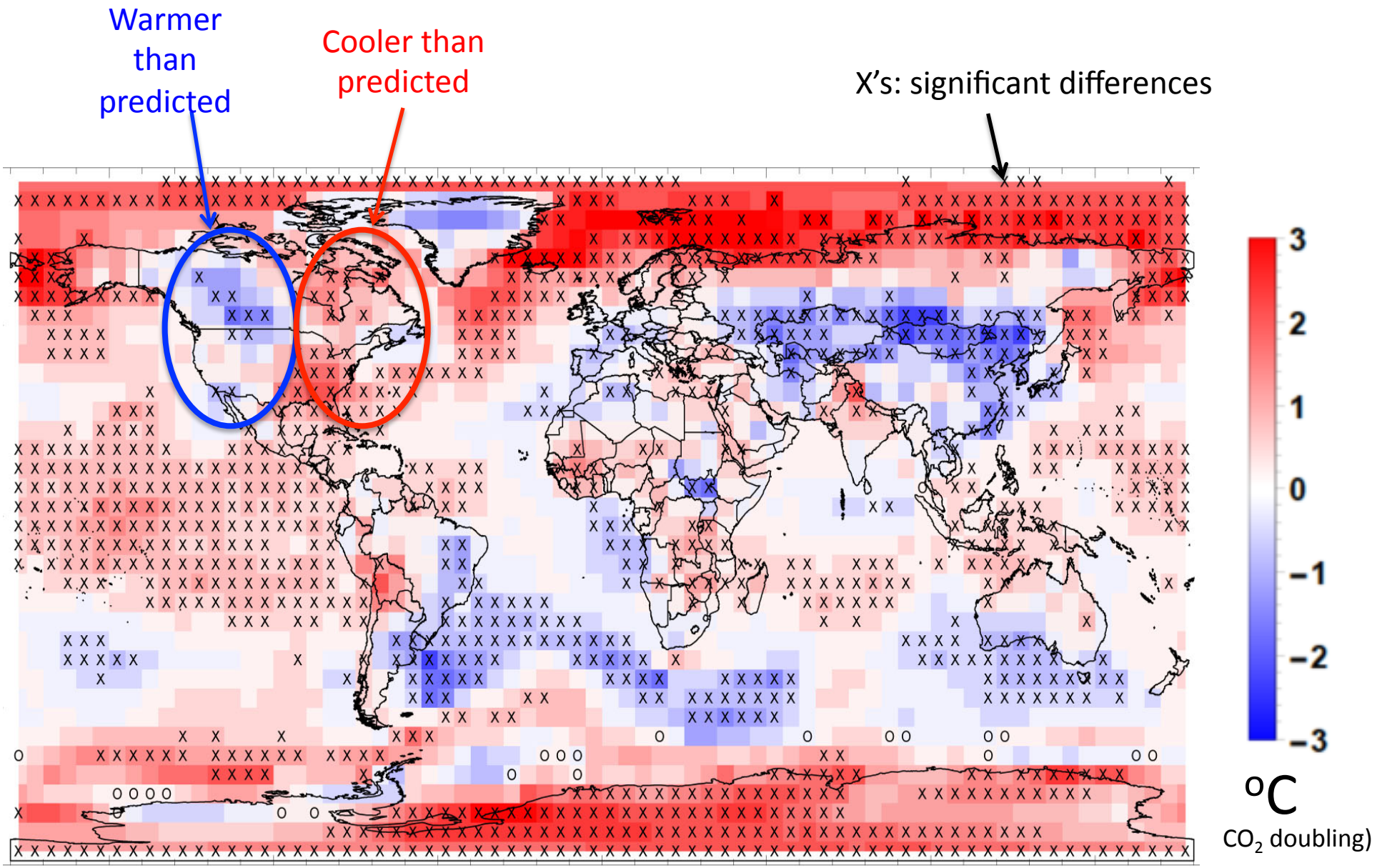
-2

RCP= Representative Carbon Pathways

RCP 2.6: Massive Carbon Capture and storage, strong mitigation, 2.6 W/m^2 of extra warming in 2100

RCP 6.0: moderate mitigation, 6.0W/m^2 of extra warming in 2100

Difference: GCM's- Historical Method



Conclusions

Huge range of scales: time and in space

Emergence: high level versus low level laws
-Turbulence Laws: collective behaviour

Which Chaos: Stochastic or deterministic?

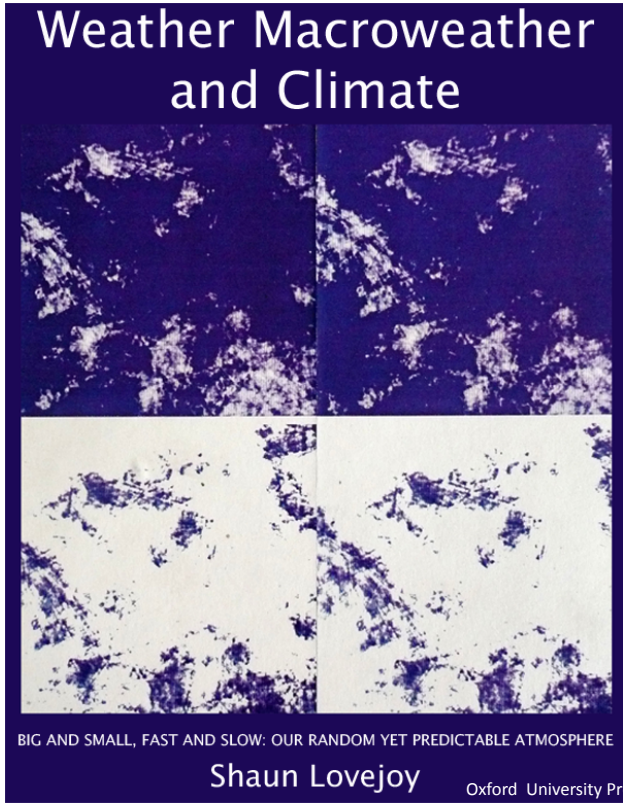
Scalebound or scaling?

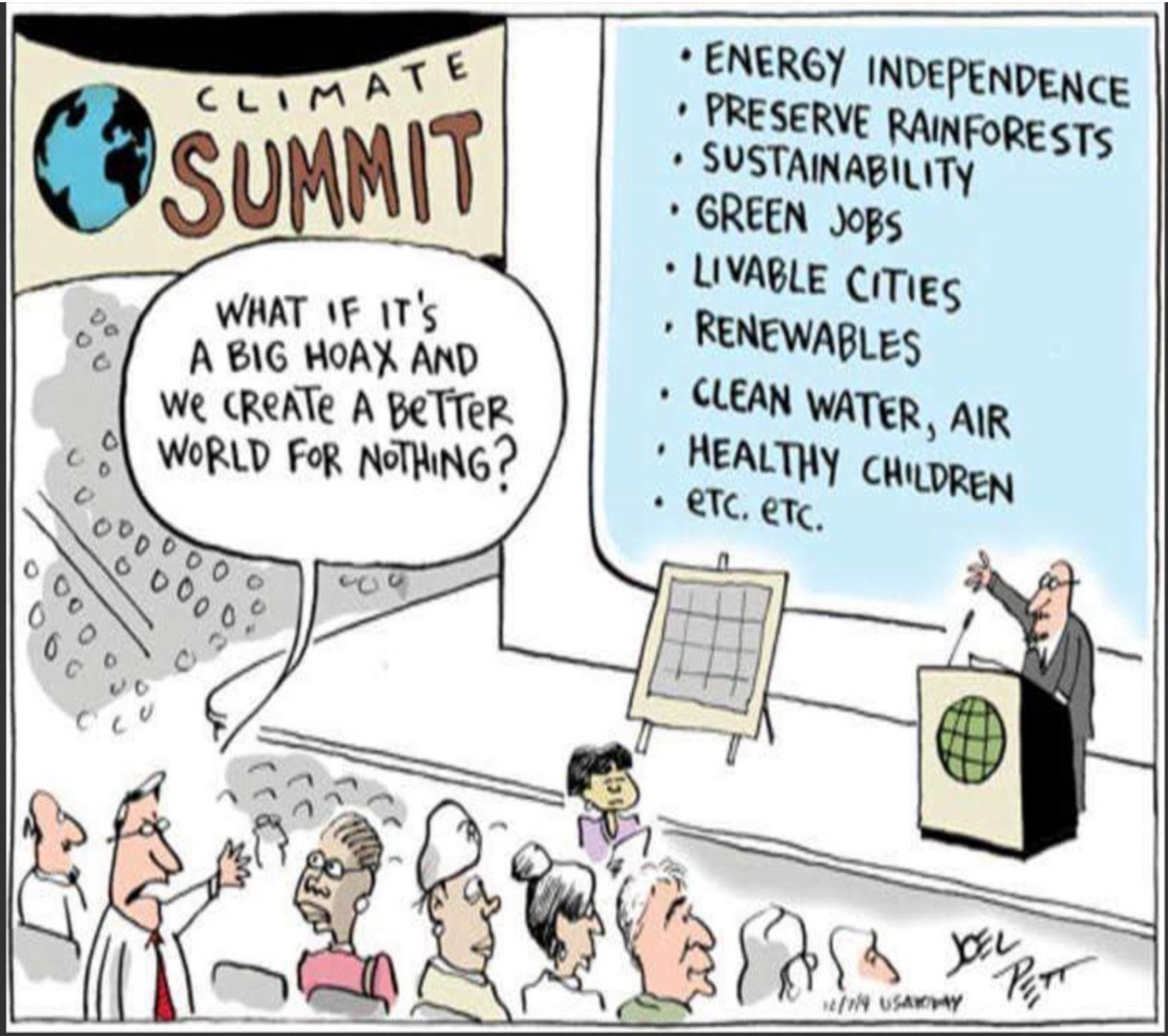
Classifying: Weather, climate… and
macroweather!

Climate Closure

Mars: sister planet, statistical twin

Scaling and memory: forecasts, projections




CLIMATE
SUMMIT
WHAT IF IT'S A BIG HOAX AND WE CREATE A BETTER WORLD FOR NOTHING?
• ENERGY INDEPENDENCE
• PRESERVE RAINFORESTS
• SUSTAINABILITY
• GREEN JOBS
• LIVABLE CITIES
• RENEWABLES
• CLEAN WATER, AIR
• HEALTHY CHILDREN
• ETC. ETC.
JOEL PETT