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in Geoscience

Sala del Dottorato
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Perugia
30 Sept. - 02 Oct., 2013

www.fractgeosci2013.unipg.it
Our fractal climate and anthropogenic warming

Perugia
29 September, 2013

S. Lovejoy, McGill, Physics
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
Temperature ($^\circ$C) vs. Age (kyr BP)

- **EPICA (Antarctica):** 800,000 before the present

- **GRIP (GRGreenland Ice core Project), Summit 75°N:**
  - "ice ages"
  - Last glaciation
  - Interglacial (Holocene)

- **Northern hemisphere since the year 1000:***
  - The "hockey stick" Mann, Bradley, Hughes 1998
  - Present

### Temperature and Age

- **Current:** $0^\circ$C
- **Approximately 6°C:** (during interglacial periods)
- **Approximately 1.5°C:** (recent warming)
- **-5°C to 5°C:** Temperature range over the past 800,000 years
Montreal: 1871-2008

A voyage through scales with Instrumental Data

Montreal: 1871-2008

We mostly see the Annual cycle

1871

2008

-15

0.85°C
2005-2008 at hourly resolution: the annual cycle
Mean annual cycle

Mean daily cycle

°C

days

hours
Montreal: 1871-2008

Annual, daily cycles removed

Let’s look a little closer...
Montreal Temperatures at increasing resolution

- 138 years
- 69 years
- 34.5 years
- 17.25 years
- 8.4 years
- 4.0 years
- 2 years
- 1 year
- 6 months

Fluctuations mostly cancel
Fluctuations don’t cancel much

X 2

X 324,000
How to understand such variability?
What if....

We found the same!!!

"Scaling"

(the Mandelbrot set)

Peitgen et al

Mandelbrot 1924-2010
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:

Koch Snowflake

1 iteration

4 iterations
Trichotomy:
Weather – macroweather - climate

Temperature

Climate (30-100 yrs to 50,000 yrs)

Macroweather (10 days to 30-100 yrs)

Weather (up 10 days)

ΔT/σ

- Fluctuations increasing
- Fluctuations decreasing

Lovejoy, 2013, EOS
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

\[ \Delta t \]

\[ \Delta T \]

\[ \pm (1/2)^H \times \Delta T \]

Random sign

(1/2) \times \Delta t

2^{nd} iteration

"motif" = 1\textsuperscript{st} iteration

(fractal dimension = 2-H)

(Lovejoy 2013)
Fluctuations decrease with scale

\( H = 0.4 \)

Fluctuations increase with scale

\( H = -0.4 \)

Weather and climate

Macroweather, macroclimate

Fluctuations decrease with scale
How can we distinguish anthropogenic and natural variability?

... by their different fractality!
The Preindustrial versus industrial epoch

Years since the start of the series

Temperature T (°C)

- 1880-2004 temperature
- 1500-1624
- 1625-1749
- 1750-1874

Multiproxy
At times > 10 yrs, the human impact is dominant.

Northern hemisphere 1880-2008

Northern hemisphere 1500-1900
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°C
Global Climate Models (GCM)

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

GCM’s: for \(\text{CO}_2\) doubling
- IPPC3 (2002): 1.5- 4.5°C
- IPPC4 (2007): 2- 4.5°C
- IPPC5 (2013): 1.5- 4.5°C
(“high confidence”)

MilkyWay-2: World’s fastest supercomputer (June 2013)
National University of Defense Technology, Changsha, China

3,120,000 cores: \(3 \times 10^{16}\) Flops
A (new) simple argument without GCM’s
CO$_2$: The last 350,000 yrs

$\text{CO}_2$: The last 1000 yrs

2012: 394 ppm
\[ \log_2 \left( \frac{\rho_{CO_2}(t)}{\rho_{CO_2,pre}} \right) \]

**Increase in CO₂ since 1880**

Concentration CO₂

- 391 ppm
- 365 ppm
- 329 ppm
- 318 ppm
- 297 ppm
- 277 ppm

**Date**
- 1900
- 1920
- 1940
- 1960
- 1980
- 2000
- 2015

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...
Increase in the global average temperature since 1880

Increase in CO₂ since 1880

Concentration du CO₂:
- 277 ppm
- 297 ppm
- 318 ppm
- 329 ppm
- 365 ppm
- 391 ppm

Mauna Loa:
- Dec. 2012: 394.4ppm
The global economy and CO₂ forcing

Non-dimensional

Log₂(ρ_{CO₂}/277)

0.2

0.4

0.6

0.8

1.0

Sulfates
(aerosols, cooling)

All Greenhouse Gases
(warming)
Increase by 79%

Global GDP
(Gross Domestic Product)

1880

1990

1995

2000

CO₂ Radiative Forcing (energy/time)
The Temperature is nearly linear with the CO$_2$ forcing

Forcing (energy/time) ->

This direct method (no GCM’s):
Temperature increase with doubled CO$_2$

$\lambda = 1.94 - 4.24$ °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”

L \log_{2} \left( \frac{\rho_{CO_2}(t)}{\rho_{CO_2,pre}} \right)

Update 2004-2012

Forcing (energy/time) ->

Slope: 2.33 °C/CO₂ doubling

373 ppm (2004)

330 ppm (1975)

316 ppm (1960)

290 ppm (1880)

1999
The CO₂ “forcing”

Global Temperature

Residual = Natural Variability

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

Years since the beginning

1500-1624
1625-1749
1750-1874
1880-2004

(residues)

1880-2004 temperature

1500-1624
1625-1749
1750-1874

Multiproxy
Anthropogenic Warming 1880-2004 (°C)

- 97.5% of the 125 yr fluctuations are less than 0.4°C
- 90% confidence with which we can reject the hypothesis of natural variability
- 99.9% confidence with which we can reject the hypothesis of natural variability

No extremes

Strong extremes $q_D=4$

Weak extremes $q_D=5$

Empirical method

Gaussian $\left(q_D = \infty\right)$

Lovejoy 2013
SRES (Special Report on Emissions Scenarios, IPCC)

Increase from 2010 (already 0.8-0.9 K above pre-industrial)

Blue is with, $\lambda=3.82^\circ$C/CO$_2$ doubling (extreme high)

Red with $\lambda=2.33^\circ$C/CO$_2$ doubling (extreme low)

$3^\circ$C increase

$2^\circ$C increase from pre-industrial

3%/yr growth (GDP x10 in 2100)

2%/yr growth (GDP x5 in 2100)
The role of existent and new technologies

(IPCC scenarios, 2007; Stabilisation at 550ppm)

A2
Grey = inexistant technology

A1F1
3% / yr growth
(GDP x10 in 2100)

B2
2% / yr growth
(GDP x5 in 2100)

Total CO2 emissions (existing technology)
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 $\approx100,000$ yrs).

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 $0.85^\circ$C, for CO$_2$ doubling, $3.08\pm0.58^\circ$C.

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