The Four Horsemen of Modern Multidecadal Climate

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1. Causal Chain

**CO2: Emissions, retained, effect (\% of each at max)**

- **Emitted:** 1850-2017: 202 ppm, 2018-2100: \(\sim\)1000 ppm
- **Retained:** 1850-2017: 116 ppm, 2018-2100: \(\sim\)580 ppm
- **Climate:** 1850-2017: 1.05 °C, 2018-2100: \(\sim\)2.0 °C

202 ppm of CO2 weighs 1.6 trillion tons
1000 ppm of CO2 adds a further 8 trillion tons to that
2. The Two Fastest Horsemen

Recent WMO (30-year) climate and the 21-year band

- 30-year climate (HadCRUT4)
- 21-year bandpass
The 21-year bandpass filter reveals a 21-year oscillation well correlated with the polarity reversals of the heliomagnetic field (HMF).

The 30-year moving average filter defines global climate according to the WMo. It reveals a 65-year fluctuation superimposed on global warming due to CO2.

This accounts for three of the four horsemen. The fourth, a slow component of total solar insolation, is not visible in this plot.
Greenhouse Effect (GHE): Greenhouse gases as thermal insulation.

Main GHGs: Water vapor and CO2.

Climate Warmth CW: Lapse rate + water vapor. Both essentially fixed in time.

Climate Change CC: changing CO2.

Richard Alley 2009: CO2 as the biggest control knob in paleoclimate.

Venus: CW but with CO2 in place of water vapor. No CC.
Horace de Saussure 1780 Identified greenhouse effect but not lapse rate
Joseph Fourier 1810 Supported de Saussure
John Tyndall 1850 Heat trapping by triatomic and larger molecules
Svante Arrhenius 1896, 1906 Invented and estimated climate sensitivity
Guy Callendar 1938-1964 Rising CO2 causing rising temperature
Charles Keating 1958 Built CO2 observatory, on Mauna Loa
(Taken from Peter Lynch, history of NWP, J. Comp. Phys. 2007)

Cleveland Abbe 1901: mathematical basis

Vilhelm Bjerknes 1904: specific equations (theory)

Lewis Richardson 1922: invented NWP as an application of Bjerknes equations, proposed parallel computation: one computer per cell


Jule Charney 1948-1956: Meteorology component of project
7. NUMERICAL WEATHER PREDICTION (NWP)

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Elaboration of NWP:

Manabe & Wetherald 1967: First atmosphere-ocean coupled model, 1974: Application of model to influence of GHE: CS, greater lapse rate and hydrological cycle

Coupled Model Intercomparison Project (CMIP), phases 1-6 ... major role in recent IPCC assessment reports
Alternative to elaboration of NWP

Claim: Far more accurate and easier than NWP because

1. Climate: Sparseness of centennial band: only Sun and CO₂
2. CO₂: Predictable via Hofmann’s law of exponentially growing ACO₂
3. Based on prevailing CS (PCS) instead of ECS or TCR
10. Lovejoy’s really simple method, 2014

![Graph showing global temperatures and CO₂ radiative forcing proxy](image)
Slope gives climate sensitivity as 2.33 C/dbl

Compare this with the more usual approach of fitting unit radiative forcing (URF = log2(CO2)) to climate using linear regression (best fit via least squares).
Tune into the band using a 65-year moving average filter.

Use linear regression to fit URF
13. Residual

But examine residual.

It is suspiciously regular!
14. Residual

Compare with TSI: amazing match

Fit CO2 and TSI to Climate using multiple linear regression

Two parameters: PCS = 1.8 C/dbl, R2 way up.
Difficulty: Confounding of parameters Uncertainty is 1.7-1.9 C/dbl Could be fixed if we had an independent way of estimating the solar parameter.
Lovejoy’s method of estimating climate sensitivity gives CS 2.1 C/dbl when the curve is resampled uniformly. This is because taking the log concentrates the samples on the left. Detrending climate by TSI further reduces it to 1.9 C/dbl.
17. ANALYTICITY OF CO2, big picture

**CO2 1006-2017: observed (Law Dome, Mauna Loa) and modeled (Hofmann)**

- CO2 Observed (Law Dome ice cores, Mauna Loa)
- CO2(y) Modeled: $280 + 120 \times 1.02^{y-2014} \pm 5 \text{ ppm}$

- Year: 1000 to 2000
- CO2: 260 to 420 ppm

- Events:
  - Little Ice Age
  - Industrial Era
  - 1780 Atlantic hurricane (22,000 dead)
  - Warm periods
18. ANALYTICITY OF CO2, close up

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19. HOFMANN’s FORMULA

ACO2 = CO2 - 280

Hofmann: To within 5 ppm, ACO2 is at 120 ppm in 2014 and grows exponentially with a compound annual growth rate (CAGR) of 2%. Extreme straightness implies high confidence in forecasting CO2. (No evidence yet that we can bend this curve downwards.)
Based on two principles: uncertainty principle, and analyticity principle.

Uncertainty principle: if we can predict 65-year climate accurately then we know that half of the 65 years will be hotter than predicted.
21. Analyticity principle

A hidden (unknown) passive (RLC) network responds analytically to an analytic input. Hence if the historical input and output were both analytic, and if the input remains analytic, so will the output, making it predictable.

Application: In this case input is CO2 and output is climate (temperature).

Benefit: Obviates the need to model the coupled ocean-atmosphere.
Heisenberg-like uncertainty principle: give up precision in time for precision in temperature.

Accurate projection for 65-year climate
Half the time colder, half the time hotter.
The hotter half is worse than average
The uncertainty is that we can’t predict which half is hotter.
Not quite right because of upward trend
But we can at least try.
Plot of 65 and 21 year climate:
Problem: can’t predict their phase precisely enough.
65-year cycle may decay, 21-year will not
Low amplitude – colder and hotter parts not that far apart
The two sides of CO2 mitigation

Good because it restores climate to an earlier condition

Bad because how it does so is less predictable than if not done.

The wild card: Annual plant drawdown at 280 ppm is 120 GtC, grew by 3 GtC at 400 ppm.
THANK YOU