Growth Constant Fingerprints of Economically Driven Climate Change:
From 1780 origin to post-WWII great acceleration

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Systemic Growth Constants of Climate Change

Abstract

The direct connection between world economic growth and climate change is greatly clarified. Recently discovered long-term growth constants in atmospheric CO2 show coupling between economic events and long-term maximization of economic growth. Curve fitting based on the near-linear relation between atmospheric CO2 PPM and the greenhouse warming effect allows linear scaling of the PPM growth curve to predict future warming, assuming that the COVID recession is temporary. We found that the growing greenhouse effect began abruptly in about 1780, concurring with the perfection of the steam engine. It then grew at a near-constant average exponential rate of 1.48 %/yr for 160 years, only to be interrupted by WWII. The reorganization of the modern world economy then pushed up the CO2 PPM growth constant to 2.0 %/yr. These growth constants are human fingerprints of human self-organization for maximizing the rate of economic growth. At the pre-COVID rates the 1.5 °C threshold would be reached by 2031, nine years earlier than the IPCC's 2018 prediction of 2040, and in 35 years would increase atmospheric CO2 by as much as in the prior 240 years. A brief discussion follows on the general ways that growth systems can change their patterns of development to mature and become sustainable.

Electronic supplementary material (ESM):

Figures Slide set:
http://synapse9.com/_pub/FingerprintsOfEconDrivenClimate-figs.pdf (Pending)

Preliminary Studies, Economic coupling, and Methods:
http://synapse9.com/_pub/FingerprintsOfEconDrivenClimate-Supl.pdf (Draft)

Keywords:

natural systems physics, climate, human fingerprints, economic drivers, self-organization, growth constant states, coupling CO2 & warming

This work originated with field studies of self-organization in natural convection patterns in homes, observed to shift from one stable state to another as the positions of the sun moved during the day. The same kind of shift from one state to another was recently discovered in the indicators of climate change, shifting from one systemic growth constant before WWII to a faster one after. We see clear human fingerprints in these shifts between organizational states telling a poignant story that will give anyone a far more clear understanding of the nature of the climate change phenomenon.

This work uses a natural systems approach, focused on recognizing self-organization patterns in history curves. It starts much like traditional scientific methods by collecting carefully authenticated data. Instead of converting that data to equations to study, though, it takes a direct diagnostic approach, associating recognizable behaviors of the data with natural events in history, to shed light on the systems involved. One of the key physics principles is that systemic organization needs to develop for systems to use energy, generally understood by the study of their systemic growth.

For example, the onset of climate change has been studied by Abram et al. (2016), finding it likely to have begun by ~1835. The IPCC (2014) sets the beginning at the 1850-1900 average temperature, also roughly agreeing with the tree ring study by Mann et al. (1998), as a dramatic rise in earth temperatures breaking away from prior trends about 1900. Hansen (2018) nicely summarizes the climate science behind that view. None of these studies, however, marks the beginning of climate change at the beginning of the greenhouse effect, which is visible in the 1780 beginning of regular exponential growth in atmospheric CO2 PPM (Fig 1). How to tie that beginning to the temperature data, which shows little evidence of it till recently, requires following natural systems diagnostic practices developed in the years following the original micro-climate studies (Henshaw 1978, 1979, 1985, 1999, 2008, 2010, 2011, 2015, 2018).

Most relied on is the association of growth patterns as evidence of emerging growth systems, seen in context, starting with plotting the history of atmospheric CO2 back to 1500 (Fig 1). It's the dramatic and abrupt shift at about 1780 from lazy variation to regular compound growth, which marks the abrupt start of industrial fossil fuel use changing the global atmosphere (Fig 1). Two different methods were used to analytically identify systemic growth constants of CO2 PPM, marking systemic phases of the greenhouse effect. One method was to visually fit a constant growth curve to the data by manually adjusting the 'baseline,' 'rate,' and 'exponent' variables (Equn 1). The other is plotting the locally averaged dy/Y growth rates of the data to recognize linear trends (Fig 2).

What gets interesting is then to connect the granular observations and the broad patterns, to see whether departures of the data from the trends fit discoverable histories of events, or bring into question the initial findings.

In the process, we also confront various data quality problems: 1) the poor quality of the ice core CO2 data relative to the high-quality recent atmospheric measures of mountain top CO2, and 2) the evidence of highly incomplete data on global CO2 emissions making any climate correlation with recorded emissions seem unreliable. We explore these further in the Supplementary Materials (Preliminary Studies and Methods: A to I). Luckily where the study most needed accurate climate forcing data, for the period from the end of WWII to the present, it was available.

1. Results

1.1. The Origin of Global Warming

Based on the historical data on atmospheric CO2, Fig 1, climate change seems to have begun abruptly in about 1780, when the prior wavy variation in CO2 PPM shifts abruptly to constant growth at a rate of 1.48 %/yr (dotted line). That constant growth curve was made by adjusting the variables of Eqn 1, baseline, scale, and exponent until the curve best fit the data. That the fit to the data is quite close helps confirm the assumption that the waviness of the data was superficial. That the 160-year pre-WWII growth constant has a clear beginning and end helps verify that it represents a period of stable self-organization in the world economic system generating the CO2, one of the human fingerprints on display. Other human fingerprints include the about 15-year pause in CO2 accumulation during and after WWII, and then the restabilization of constant growth at a higher rate of 2.0 %/yr after 1960, discussed further for Fig 2.

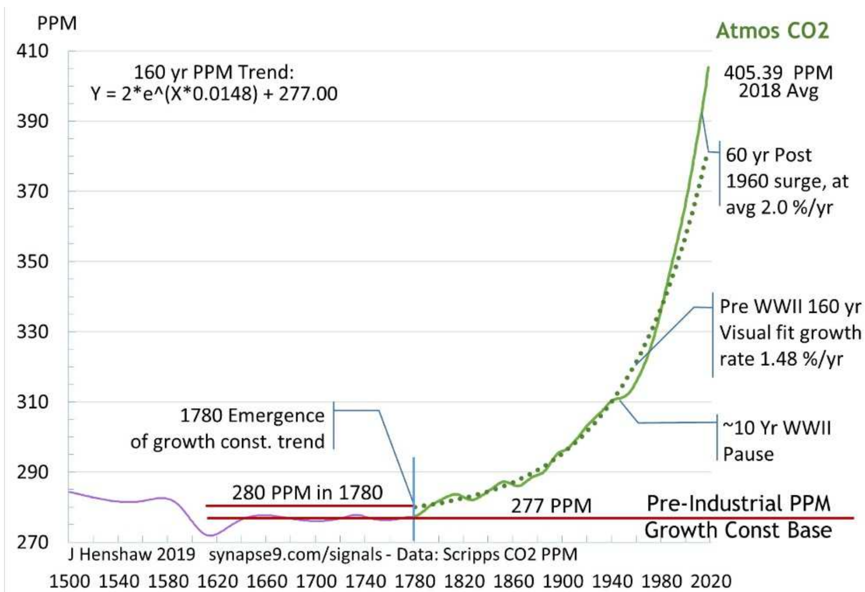

Fig 1. Historical Atmospheric CO2 PPM from 1500 to the present; showing pre and post-WWII systemic growth constants of 1.48 %/yr (Eqn 1) and 1.90 %/yr, respectively.

Eqn: 160 yr Visual fit growth constant: Baseline = 277, Scale = 2, Exponent 0.0148

$$Y = 2 * e^{X*0.0148} + 277 \tag{1}$$

A systemic growth constant reflects a sustained period of homeostatic variation when local departures above and below essentially cancel each other out because the system is self-correcting. It also implies a period in which the system is maximizing its rate of stable growth, correcting lags and surges to expand as fast as possible while remaining stable. Maximizing growth is, of course, a very familiar current global economic policy, a collective effort to steer a steady course between overheating and recession. So finding evidence of two extended periods of stable growth, the second faster than the first, is a remarkable display of the world economy working just as it is supposed to, except for limiting its prohibitively swelling external costs, of course.

A very telling departure from the data left to explain is at the 1780 start. The first growth trend seems to have a jump-start, beginning 3 PPM above the data in 1780. What the curve fitting suggests is that the growth state preceded the

CO2 PPM data. So the sudden jump could represent prior industrial development converting to fossil fuels, showing pent-up demand being relieved in the first wave. That seems to be the actual case, given the period from 1776 to 1781 was when Watt was perfecting the steam engine, and only providing a rotating power shaft option suited to replace water wheels with steam power in 1781, apparently producing a surge of replacing water power all over Europe and America eager to grow[1] This also demonstrates why telling the story from the beginning will help set the stage and identifies the forces that will drive the narrative. The year 1780 was just four years after the ratification of the US constitution, at a time of revolutionary economic and governmental changes, in the US and Europe, and steam power played a big role in fulfilling the great promise of the century-long cultural revolution known as the Enlightenment[2].

One of the ironies the curve exposes is that the period since 1960 includes many of the most dramatic increases in industrial energy efficiency, commonly advocated for reducing energy impacts. The great advances in efficiency have only further increased the growth rate the CO2 pollution, though, the real product of marshaling global scientific, financial, business, governmental, and institutional efforts to accelerate growth and create our modern world. These connections offer more evidence of human fingerprints on the events shown in the data. Since the 1960s efforts to reduce economic impacts by improving efficiency began in earnest, another kind of human fingerprint and sign of the true cause of climate change, that society fell prey to Jevons principle (1885), however it looks, economies use efficiency to accelerate economic growth, resource consumption, and resulting pollution as well, shrinking unit resource costs and multiplying units.

1.2. Detailed CO2 growth rate movements

Fig 2 lets us look much more closely at the composition of the Scripps CO2 PPM data (Data Source #1) (Scripps 1958, Macfarling Meur 2006), that couples highly irregular ice core CO2 data, smoothed with a spline, before 1958 with very regular annual averages of Mauna Loa and Antarctic air sample data after an including 1958 (lower curve rt. axis). The upper curve (lt. axis) shows the annual growth rates of the PPM data (dy/Y), exposing more interesting conditions to explain. The two dashed red lines represent the two systemic growth constants. The lower is 1.48 %/yr and represents the approximate midline of the dramatic fluctuations up to 1940, and the upper is on the midline of the annual growth rates following 1960, showing apparent damped oscillation around 2 %/yr. That would indicate dynamic systemic stabilization in that period.

The post-1960 period roughly coincides with the period of worldwide economic integration we call "globalization," during which the world's scientific, business, financial, and government communities modernized and reorganized the world for maximum growth. Another fingerprint of human influence on the growth rate of climate change. The data curve and the self-organization of the economy connected with it are still different things. CO2 PPM is an atmospheric measure showing the net result of all CO2 sources and with absorption by all sinks. So the current systemization of 2 %/yr growth of CO2 indicated here does not say where it's from, but the damped oscillation does seem to say human activity is responsible.

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[1] Watt steam engine https://en.wikipedia.org/wiki/Watt_steam_engine

[2] Wikipedia https://en.wikipedia.org/wiki/Age_of_Enlightenment

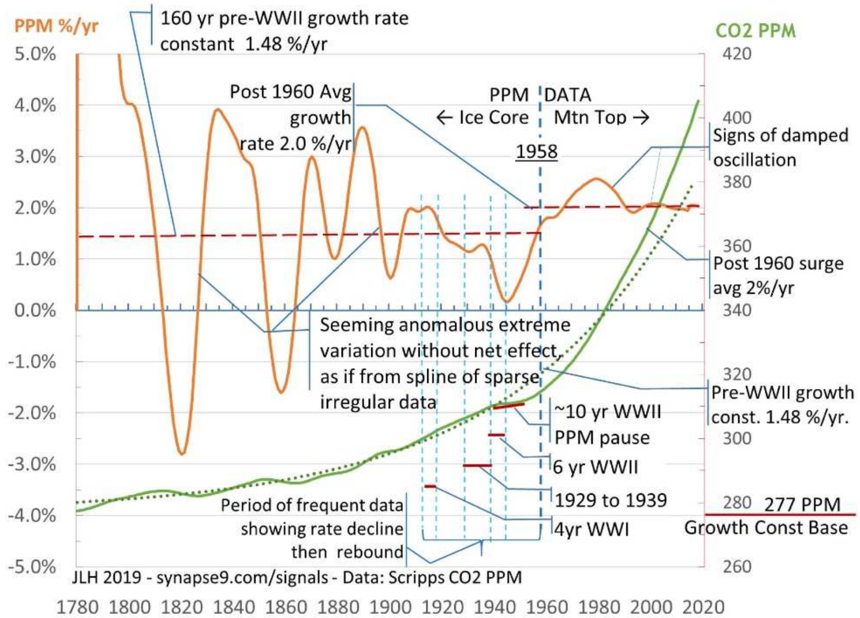

Fig 2. The Scripps CO2 data on the Rt axis (lower curve) is smoothed with a spline of the raw data to 1958 and merging Atmospheric sources after that. Annual dy/Y growth rates (upper curve, Lt axis) using a 5yr average (Eqn 2). The dashed lines show the growth constants found, shifting from 1.48 %/yr before to 1.90 %yr after WWII.

Eqn: Five-point smoothing for dy/Y annual growth rates for splined Scripps CO2 data.

$$f(Y_n) = (Y_{n+2} - Y_{n-2})/(4 \cdot N_{n-2}) \quad (2)$$

Of most concern in Fig 2 is the apparent wild fluctuation in the annual growth rate of CO2 PPM in the first 160 years. It either requires finding a rather dramatic physical process or something dramatically wrong with the underlying data. If the data were accurate, the wild swings in growth rates imply dramatic declines in atmospheric CO2 around 1820 and 1860. I found no such process and the peaks and troughs of the PPM growth rates don't seem to match rises and falls of earth temperature (Fig 4). So I've concluded that they are largely due to replacing the very erratic and variable ice-core PPM data with a spline: see also Supplementary Material (Preliminary Study A, Fig 7). A spline treats all the data points as having real values however sparse and irregular the real data is, and so would tend to force wild swings in growth rates, chasing outlier data points above and below the average line. Study A plots the raw data points with the spline so one can see where the latter is justified and not.

1.3. The near-linear relation between CO2 PPM and Warming

Now that we have a clear pattern of the long term systemic CO2 PPM growth constants, we can ask if there is a way to turn that into a prediction of the real accelerating rate of current climate change. Fig 3 shows the important correlation between CO2 PPM and the relative rate of greenhouse heating in watts per sq meter. What we see is is a gentle curve, nearly linear between 350 and 450 PPM. What that means is that some linear scaling of the CO2 PPM might indicate the true history of the greenhouse heating effect.

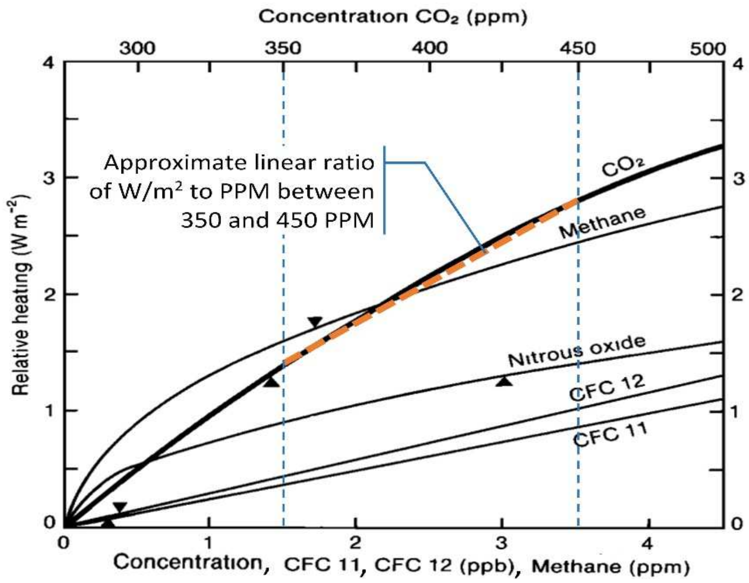

Fig 3. Relative heating rates for CO2 PPM: From Figure 6 in Mitchell (1989): "Greenhouse heating due to trace gases, showing [top scale] concentration of CO 2. […] The triangles denote 1985 concentrations".

It will not be a perfect proxy for various reasons. At higher PPMs, the relative heating tapers off a bit, and CO2 is currently only about 70 % of the total GHG climate forcing but perhaps 90% of the rate of increase (IPCC 2014, EPA 2017): see also Supplementary Material (Composition of GHGs, Fig 10, 11). How much climate change is due to unrecorded human GHG emissions or environmental GHG producing and sequestering processes is naturally hard to determine too. We can assume that all these factors are integrating by natural atmospheric processes without omission, of course, so the total atmospheric CO2 may still make a useful proxy for the rate of warming when scaled to fit the history of temperature change.

1.4. Fitting Climate Change & Atmospheric CO2

The similarity and differences between the rising shape of earth temperatures and that of CO2 concentrations is the subject of Fig 4. The HadCRUT4 earth temperature data (upper line, lt. axis) and the Scripps CO2 PPM data (lower line, rt. axis) are roughly scaled to look like each other, based on the linear forcing relation between PPM and the greenhouse effect. If that's true, the difference between the long term smooth accumulation of CO2 then both the rapid annual fluctuation and multi-decade great waves of temperature change are certain to be due to processes other than the greenhouse effect.

The greatest similarity is, of course, the post-WWII "great acceleration" of both warming and CO2, seemingly associated with the great acceleration of post-WWII economic development that created our very consumptive modern world. To sort out the differences, I have first added to Fig 4 the red dashed and blue dotted lines, representing the visual midlines of rapid annual variation and highlighting the "great waves" of temperature associated paleoclimate waves extending into modern times (Fig 5).

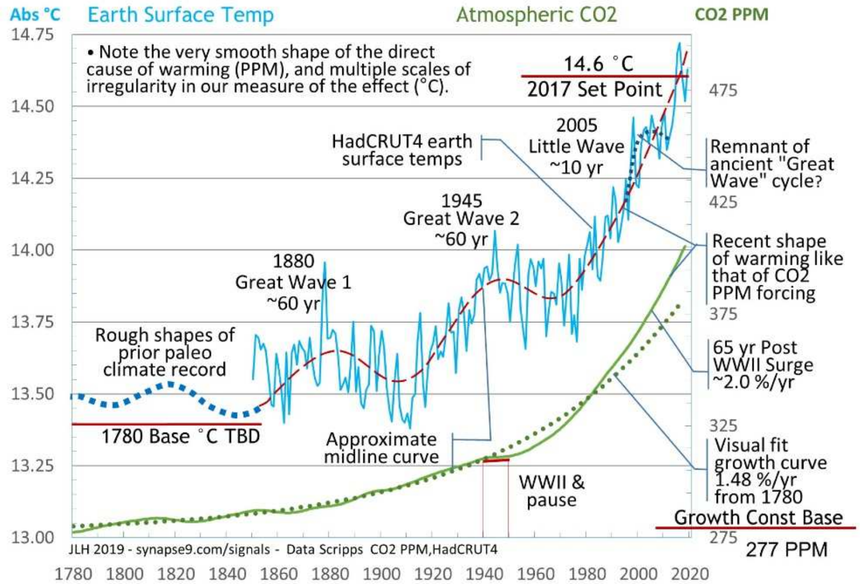

Fig 4. Comparison of 1780 to 2018 earth CO2 PPM and °C curves: Whether a linear relation exists between the two curves depends on whether the differences can be found to come from other processes.

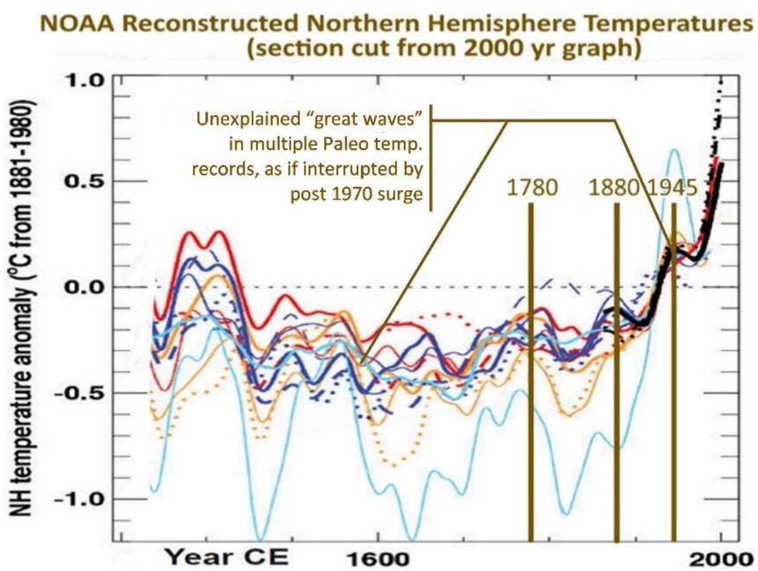

Fig 5. A 900 yr portion of a 2000 yr Northern Hemisphere paleotemperature record combining all methods, NOAA (2007): The title and marks in brown) are added (and an extraneous red line removed). Note how the recent great wave pattern seems affected by the great acceleration in climate forcing.

How to generally apply linear scaling to the CO2 PPM curve so that it fits the period of great acceleration in the °C curve seems reasonably clear. The erratic annual jumps seem due to weather and interactions with ocean currents only sparsely sampled by temperature measurements. What is visually clear, though, is that variation is both constant and not accumulative, so it has a well-defined midline. How to fit the great waves in temperature is not clear. One useful observation is that after WWII the long paleo history of multi-decade great waves seems to come to an end as if the great acceleration of greenhouse effect heating was somehow interfering with the cycle driving the long history of multi-decade waves. It also helps to notice the "little-wave" in 2005, looking like a diminished echo of the preceding multi-decade waves. It took a full year to develop my current educated guess as to what that interrupted process might be. It only needs to be plausible for the purpose here, that the great waves are some climate cycle that stops working as warming intensifies, an assumption reinforced by how very it works for fitting the PPM curve to the ºC curve.

What I found plausible is that the great waves might represent multi-decade variation in upper atmosphere convection, regional-scale troposphere to stratosphere heat transfer, creating variably long-standing radiative hotspots. You can see the clear patterns of great upper atmosphere hotspots in satellite images of outgoing radiation, that ring the globe on both sides of the equator: see Supplementary Material (E. Upper Atmosphere Cooling). If that convection was somewhat intermittent before, slowly rising and falling as seen on the paleoclimate data, the great acceleration of climate forcing from the post-WWII economy might force that ring of cells to flow continuously.

1.5. Projecting Climate Change to 2030, 2040, and 2050

It was quite exciting to discover the final small change in assumptions allowing the scaling of the CO2 curve to fit the temperature data like a glove. To have the PPM°C proxy curve thread right up the middle of the HadCRUT4 temperature anomalies. To see how I had to understand first what kind physical process the great waves were, and then see that implied *skirting the bottom* of the recent great waves, as now shown, deduced from considering the great waves might represent a process periodic closing and opening of high heat altitude convection releasing heat to the stratosphere, not some unknown source of heating. That might very plausibly be interrupted by a great acceleration of greenhouse heating in the lower atmosphere.

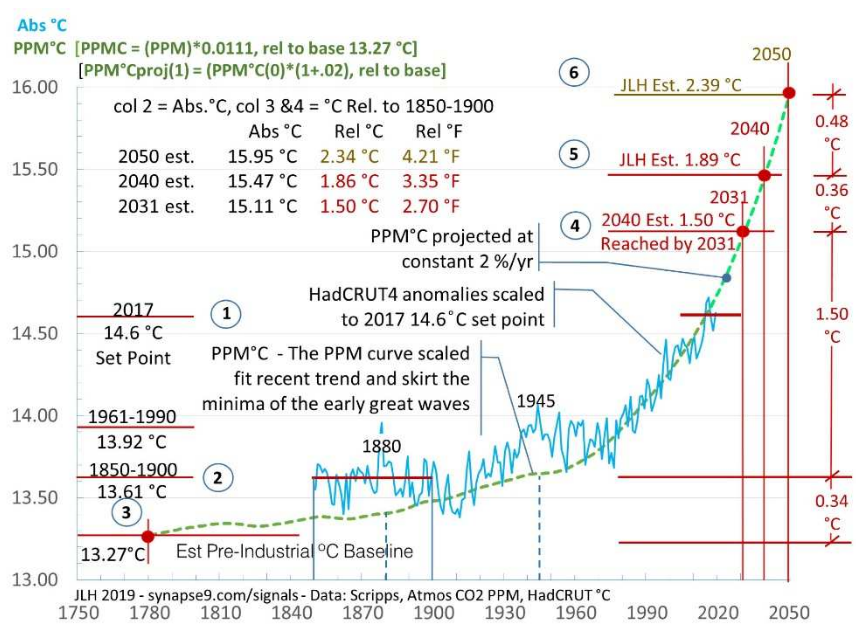

Fig 6. Fitting the CO2 PPM curve to the abs °C HadCRUT4 anomalies: Using a linear scale factor of 0.0111 and Pre-Industrial base point of 13.27 °C to convert PPM to PPM°C. Picked to fit the midline of the great acceleration, and the midline of the minima of the two great waves (Eqn 3). From 2018 to 2050 the current stable growth state of 0.2 %/yr is used (Eqn 4)

PPM converted to PPM°C PPM°C = PPM*0.0111, relative to 13.27 ºC base (3)

By adjusting the linear base and scale factors to best fit the HadCRUT4 data

PPM°C projection PPMCproj(1) = (PPM°C(0)*(1+.02), relative to 13.27 ºC base] (4)

The steps taken in generating Fig 6, circled #1 through #6

(1) Choosing the 14.6 ºC set point for the 2017 HadCRUT4 earth temperature.
(2) Calculating the average HadCRUT4 temperatures between a) 1961 to 1990 and b) 1850 to 1900 most commonly used earth temperature baselines used respectively by Brittish Meteorology and the IPCC.
(3) Adjusting the variables of the PPMºC curve (Eqn 3) to fit the HadCRUT4 data the best and determine the Pre-Industrial baseline temperature of 13.27 ºC.
(4) Project the PPMºC curve at its terminal growth constant rate of 2 %/yr from its end in 2018, first to 2031, and record the ºC values on the results table.
(5) Extend the projection to 2040 and record the ºC values on the results.
(6) Extend the projection to 2040 and record the ºC values on the results.

The most sensitive variable is, of course, the elevated growth constant 2 %/yr from 1960 on. Shifting to the 2 %/yr growth constant almost triples the total 2050 climate change (~2.7 ºC) from the 1780 baseline, compared to extending pre-WWII growth constant of ~1.5 %/yr resulting in a total 2050 climate change (~1.0 ºC) from the 1780 baseline. That until very recently, this sharply increased growth constant was not recognized would partly explain the repeated puzzlement for the past decade of recent observations that events have progressed much faster than predicted (Dunlop & Spratt 2018). Even the 2018 IPCC (2018) estimate for 2040 is an approximately linear projection.

The projected trend of future temperatures shown in Fig 6 will be soon be found useful or not. If these rates of warming were to happen, it would change our global response plans quite a bit. There could be a long list of possible other factors to consider, of course. Basing the study on only long term raw data of the whole system response, rather than on equations and theory, means that most other factors operating in the climate, such as cloud cover humidity, and other GHGs are by default already reflected in the behavior of the data. Of course, presenting the data as something of a dynamic life story of familiar historical process, and using familiar units, helps makes it relevant to the common observer's frame of reference.

One more strength of this method of curve fitting is that curve fitting over the entire period from 1780 to the present gives many more difficult fitting constraints, such as to fit the multiple scales of variation. That greatly limits the choices so that options for adjustment quickly diminish. I think that's what makes what I've called "visually fitting" a less than haphazard process, that you need to find a fit to all the scales of variation, and discover reasons for departures when necessary, a very rigorous process in the end. That makes it a manual "regression" process, forcing the adjustment of scaling factors by smaller and smaller amounts. Of course, using algorithms for mathematical degrees of fit might help sometimes, but algorithms generally can't be used to fit curves with multiple scales of variation. That would take new research on each type of variation.

1.6. Discussion

The clear takeaway is that it appears that do a magnificent job of spreading new technology, we also must do a magnificent job or changing the now long-established self-organized growth maximization design of the world economy. Using our old ways of thinking, scientists have studied that problem for centuries, unable to find how to tame the natural runaway growth of the economy without killing it. Now people seem to realize that failing to find a way to tame it will itself surely kill it, even if it only causes ocean rise eliminating much of human history, for example. We'd all like to know how to solve this problem, how to bring an economy designed like a rocket ship, with no brakes or steering, to instead make a graceful landing that retains all its important advances. Presently the whole economic system getting ever more unbalanced and rapidly making things much worse for itself. In all the years I've worked on the problem, and then discovering that JM Keynes (1935) himself discovered the basic soft landing solution (ibid Ch 16[3], taming the often very unwise use of profits to evade responsibility, I've always had the hope that sometime the world community would be in such a jam that we'd consider the logical way out of our existential crisis. That would be truly wonderful!

That would give us both the means and motivation to apply the world's resources in our common interest in responding to our common problems. That's where I think we can find an answer in looking at the needs of the system as a whole and accepting our shared responsibility for the threats to everything from which we profit.

JLH

2. Acknowledgments

This work has been self-funded for many years, so I'm grateful for having had the time and resources, and very grateful too for sometimes being encouraged. My greatest debt is to my extremely numerous correspondents over the years and to my editors for asking for the best.

3. Sources

3.1. Data Sources,

Note: Figures 7 to 22 and discussion of them are in the Supplementary Materials (Studies A to I). An additional list of data sources is provided there as well.

1. Atmospheric CO2 PPM 1501-2015 Figs 1, 2, 4, 6, 7, 8, 9, 14, 15, 17
   http://scrippsco2.ucsd.edu/data/atmospheric_co2/icecore_merged_products
   Atmospheric CO_2 record based on splined ice core data before 1958, and averaged yearly measurements from of Mauna Loa and the South Pole after and including 1958.

2. HadCRUT4 earth temperatures 1850-2017 – Fit 4, 6
   Rosner - OurWorldInData.org: https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions

[3] Chapter 16, Keynes' General Theory of Employment, Interest and Money. https://synapse9.com/ref/Keynes-ebook-TheGeneralTheoryCh16notes.pdf

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