Climate Change Policy Based on Accurate Trend Forecasting.

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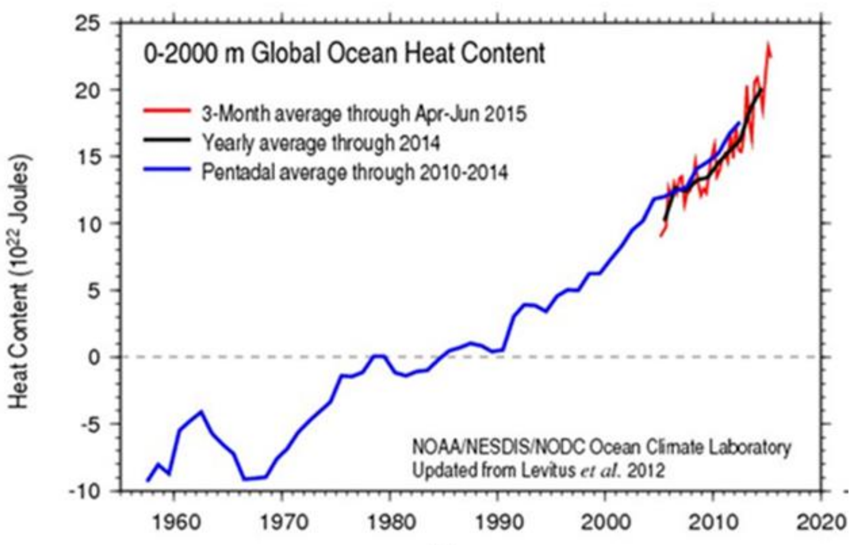
Despite recent global policy efforts to curb CO_2 emissions, we are currently in the midst of accelerating CO_2 deposition into the atmosphere. The Mauna Loa data shows that since 2010 CO_2 deposition is at 2.35 +/- .42 compared to 1.20 +/- .37 for the 6-year period ending in 1995. On average, we have doubled our CO_2 emissions over the last 20-25 years, despite whatever policies might be present. This brings up an important physical and policy point: is the response of the global climate as a function of greenhouse gas deposition (this includes rising methane levels as well) a purely, simple, linear response or is the rate of change likely to accelerate so that non-linear trend forecasting becomes an important component of sensible policy? When you are on an accelerating rate of change, the future becomes harder to predict – which adds uncertainty to the overall process. However, that uncertainty should more sharply define the policy effort to think deeper about the data and the predicted future. This uncertainly should not paralyze the policy process.

As we show below via data it is quite erroneous to assume that the linear changes of the past will hold for the future. Policy should be based on reasonable worst-case scenarios and avoiding that outcome, instead of assuming that the future of the planet will be driven by simple linear change and those subsequent changes will be more benign than what will actually happen. To best illustrate this point we use data on both the rate of Arctic Sea Ice loss and the recently compiled (by NASA) global land+sea temperature measurements (since 1880) to demonstrate that we are now clearly in the non-linear regime where change is escalating each year. Sensible climate policy should now incorporate and strongly weight the information provided by the last few years of data to better recognize the increased necessity of acting **sooner and not later on effective climate policy.**



Beyond the data presented here, there are also compelling reasons to believe that the system response will be non-linear. The fundamental physical driver behind climate change is the systematic heating of the oceans since the industrial revolution. The most recent calibrated ocean heating data is shown in Figure 1. This heating is driven primarily by the waste heat generated from an industrial society; 94% of this waste heat eventually is absorbed the oceans which therefore act as an enormous planetary buffer. If that buffer should become saturated, or have a reduced efficiency of absorbing waste heat in terms of its ability to absorb and re-distribute this waste heat, the atmosphere will become more directly affected; in turn, this enables climate change.

Figure 1 informs us of a few things:

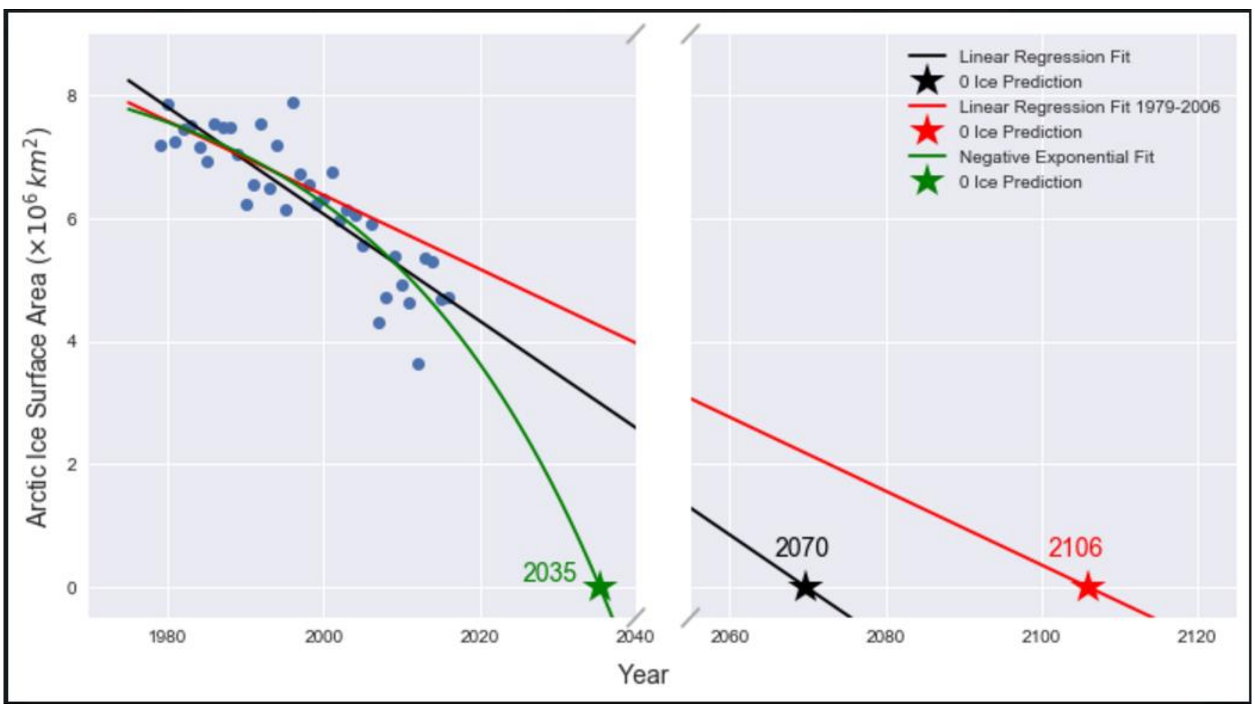
a) The rise in ocean heating since the mid-1990s is fairly linear although the most recent data falls a bit above the linear extrapolation.

b) Since 1990, the oceans have experienced reduced efficiency in terms of handling waste heat input and are clearly retaining more heat. In turn, this inevitably changes the horizontal (ocean currents) and vertical temperature distributions within the oceans and this directly drives jet stream patterns which determine regional weather.

c) Because of b) we would expect the signature of climate change as increasing weather volatility to start to emerge around 1990 and continue to escalate simply because more energy is being added to the system.

Our oceans now have reduced capacity to re-distribute this extra heat through its normal channels (e.g. deep ocean transport. Our rate of waste heat generation is accelerating as human industry rapidly converts planetary resources into more and more consumer goods. At some point we expect these continued increases in ocean heat content would likely lead to a non-linear response in the atmosphere and we believe the data now shows such a response.

The rate of Arctic Sea Ice loss provides a good example of the difference between linear and non-linear fits to the data that extrapolate to the issue of "when will the Arctic Ocean be free of ice in September". The data, complied from the National Snow and Ice Data Center (NSIDC) is shown below where we plot average September sea ice vs time – where time starts in 1979 the first year of satellite measurements. In figure 2 we show three fits to this data that are extrapolated to zero ice extent in September:



- Fit 1: Linear regression over the period of 1979 – 2006 which leads to a zero ice date of 2106 and hence no hint of a problem and hence no need for policy.
- Fit 2: Linear regression now over the entire period of record. Here we note that 2007 was the first year that suggests non-linear behavior or at least a change in the slope of the line. In 2012 the record minimum September sea ice extent was achieved. Using all of the data we now get a zero ice date of 2070, considerably shorter than the previous estimate but still relatively long in policy-decision years.
- Fit 3: A non-linear damped exponential fit to the data which has us reaching zero ice in the year 2035, which is now less than 20 years away! Note also that while this non-linear fit to the data is the best one (in the statistical sense) there are a number of recent points that are disturbingly still below this line (the 2012 point remains outstanding) suggesting that the accelerating sea ice decline maybe even more rapid that this shows.

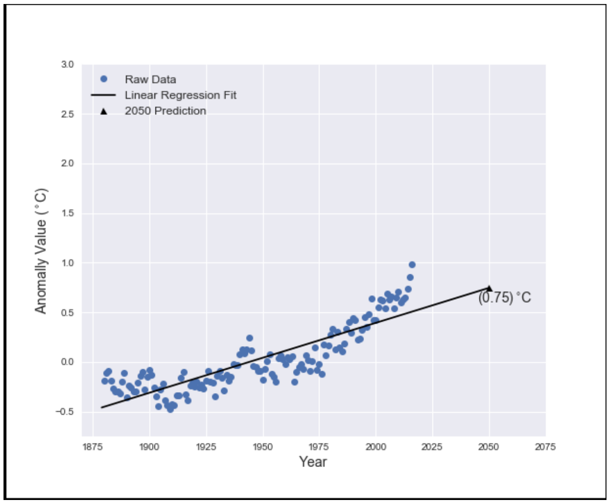
The difference between the linear and non-linear fit predictions is 30-40 years, which is significant in terms of human decision making timescales. In the year 2017, in the linear policy world, we would just punt on the issues since the crises point is way into the future. However, if the non-linear approach is best, but we remain stuck with our linear mindset then it's quite likely that policy will be set after the time when children can visit Santa's home on a cruise ship (for which now Greenpeace has launched the Santa Relocation Project).

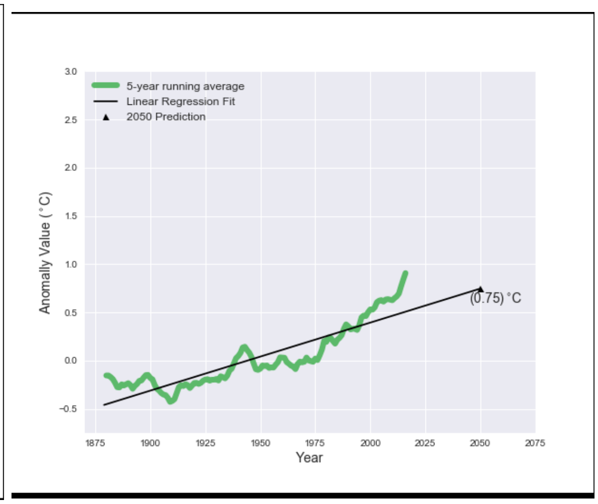
This is highly analogous to the Dec 12 2015 Paris accord to "keep a global temperature rise this century well below 2 degrees C …" at a time data indicate we are already at 1 to 1.5 C and clearly on the way to smash through 2 C (see also the data presented below). Overall, the Paris Accord is another example of linear based policy which seems quite of out touch with what is actually happening.

We now illustrate the issue of linear vs. non-linear trend extrapolation to global temperature measurements. It is important to make the caveat that the Authors don't believe that global temperature, especially over the land surface, is the most physically meaningful quantity (i.e. how is it measured, how many thermometers do you need, where do you put the thermometers, does the thermometer environment change over time?). The use of both land and ocean is a far more sensible approach than just using land based data. For instance, urbanization effects over the period of record are not likely to influence ocean based temperatures. Nonetheless, these data are commonly used in public discussion about climate change.

For our study we make use of the composite Land-Ocean temperature anomalies, again with respect to the baseline of 1951-1980, as provided by NASA Goddard (https://data.giss.nasa.gov/gistemp/graphs_v3/Fig.A2.txt).

We start by simply plotting the raw data with a standard, unweighted, linear regression fit projected out to the year 2050 and compare that to the standard 5 year running average plot. Both predict a temperature anomaly of +0.75 C.

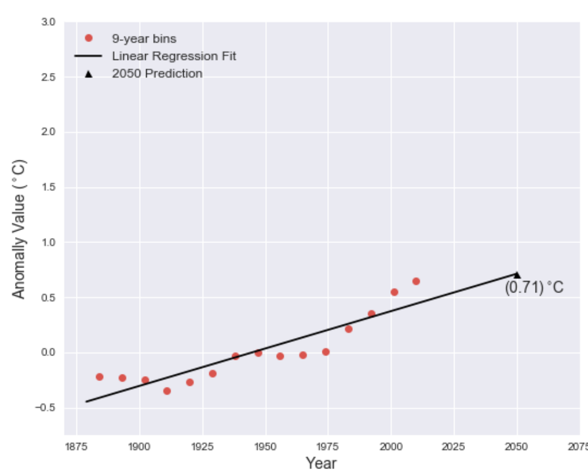




However, this temperature anomaly refers to the 1951-1980 period. To compare to the Paris Accord we need to renormalize and refer the anomaly to the typical 1881-1910 period that is used for the "pre industrialized" level when using this data set. In this case, the predicted 2050 temperature anomaly is +1.01 C – well beneath the stated goal of the Paris Accord, under the policy statement that "the linear trend is the most appropriate". That statement, however, is not very scientific as just your eye, let alone statistical tests, suggests that recent years are systematically departing from the linear trend and perhaps another kind of fit is in order. Indeed, should this data be equally weighted as if all temperature points are independent and equally valid? Or should this systematic departure of the recent data carry with it more weight as being indicative of an actual manifestation of climate change?

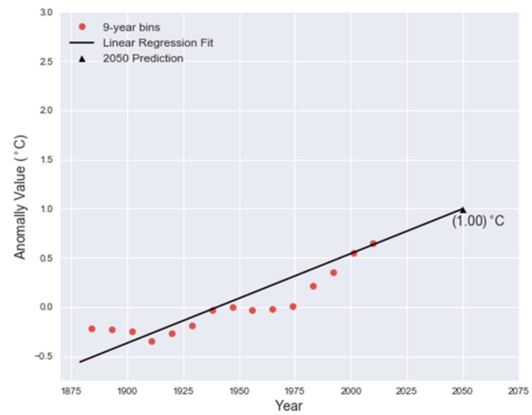
For this kind of data, it is often better to average the data over some timescales. We will bin the data in units of 9 years. This gives us 15 bins from 1880 to 2014 and we will initially leave the 2015 and 2016 data points out. Note that there are no special rules for how to bin and smooth data – one just wants enough binning to see the waveform, but not too much binning to see the noise. The resulting plot is shown below; this time in 1950 ΔT = **0.71**, not appreciably different from what was obtained before.

This data depiction clearly shows the well-known "mid-century" cooling that followed the period of warming earlier in the record. This cooling has been used to suggest that a similar even will happen in the near future. While the origin of this cooling is unknown, a very likely hypothesis is that industrial pollution from aerosols dominated human atmospheric pollution leading to this period of global cooling. This is plausible because a) there was little law or regulation



concerning industrial pollution and b) during this period total greenhouse gas emissions was ~ 3-4 times less than today (the 1958 Mauna Loa data show 0.6—0.7 ppm per year; 2015 was ~2.5 ppm).

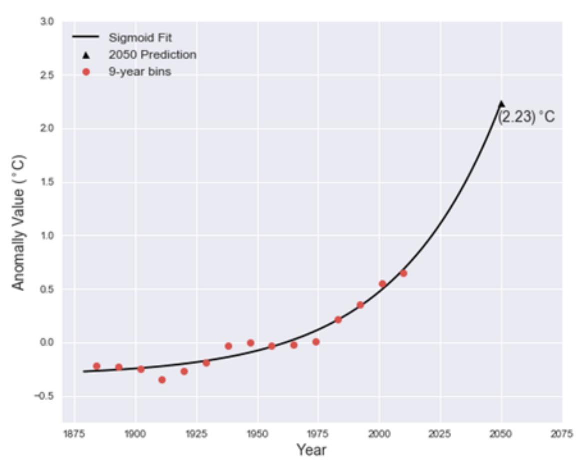
Now we address the issue of weighting and here we weight by simply adding the 2015 and 2016 as two additional points to the diagram. The resulting weighted fit is shown below and ΔT has risen to 1 C (or 1.25 C) above pre-industrialized levels. The scientific reasoning behind this form of weighting is simple: a) the years 2015 and 2016, are two successive record breaking years and b) this is likely an indication that we indeed are now in the non-linear regime of climate response to ocean heating. Hence, weighting the linear fit can manipulate it to some degree and one therefore needs some reasonable scientific validity for the weights. In the case of the above figure, we simply put more weight on the two most recent data points however; the fit to the data is still poor.



To improve the fit we will consider non-linear functions, a symmetrical sigmoidal function which has four parameters, given by the form:

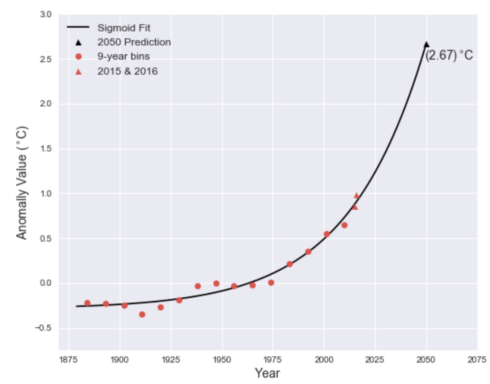
$$y = D + \frac{A - D}{1 + \left(\frac{x}{C}\right)^B}$$

The resultant fit significantly reduces the scatter of the data points and predicts a temperature anomaly at least 1.5 degree C **higher** than the previous at **2.23** C. In lay terms, this means that the "scientific" choice of fitting the proper curve should have strong policy implications. If for instance we "believe" that linear fits are the best, then our future is far less dire, than that predicted by this improved functional form. Furthermore, this approach predicts a value of **2.49** C by 2050 as the pre-industrialized temperature rise which now violates the Paris accord. Hence, if this non-linear trend



extrapolation is the best way to represent the future, then clearly climate change policy needs to become more aggressive and enacted immediately.

Finally, we now weight this functional fit with the 2015 and 2016 data: This weighting predicts ΔT = **2.67 which puts us quite close to a 3 C rise in global temperature above the pre-industrialized level, by the year 2050.**



So what do we do? Do we keep our heads in the sand and just wait for a few more years' worth of data to make a decision, or do we use better scientific principles to guide our policy making and recognize we are now in the non-linear regime which no longer offers the luxury of time, either for global average temperature changes or melting Arctic sea ice. At the moment, we are adding a few x 10^{22} joules of heat annually to the ocean; that of course is an incomprehensible number. This heat content is equivalent to every human using **50-100 gallons of gas per day!** Continuing at this rate is insane. Eventually, this enormous consumption will affect the physical systems of the planet. That eventually is now here and has revealed itself in the strong non-linear increase in global average temperature over the past few years.

NEED TO ADD FINAL PARAGRAPH