
IT'S NOT THE HEAT, IT'S THE TEPIDITY

CLIFFORD ASNESS AND AARON BROWN

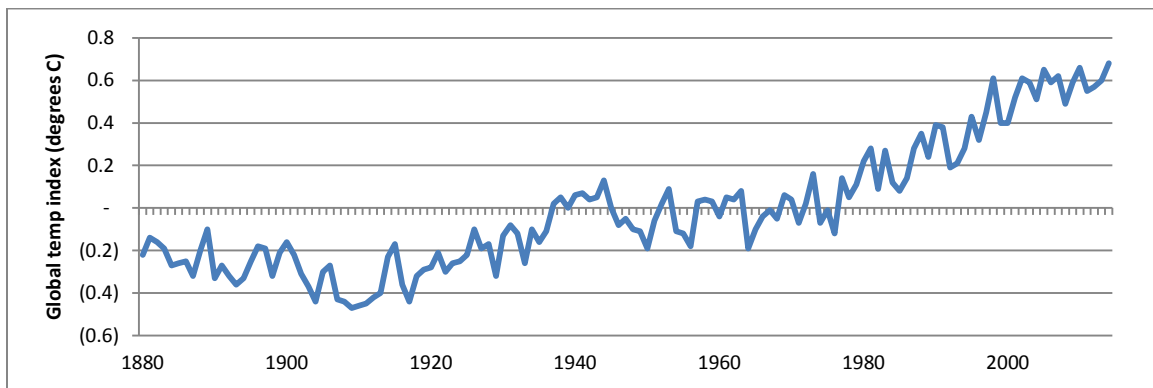
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COMMENTS VERY WELCOME

There is a graph you've probably seen a lot of lately. Articles everywhere feature it, or the data behind it, or a closely related cousin to either, highlighting temperatures at a new high, a visually strong long-term trend, and no recent temperature "hiatus." This historical series is usually presented as proof that warming must be quickly and vigorously fought or we will reach dangerously high temperatures in the next few decades. These data and the implications taken from them require careful statistical scrutiny. We emphasize *statistical* at the outset because we are not challenging climate science; we are not climate scientists. We are, however, pretty experienced at statistics and inference.

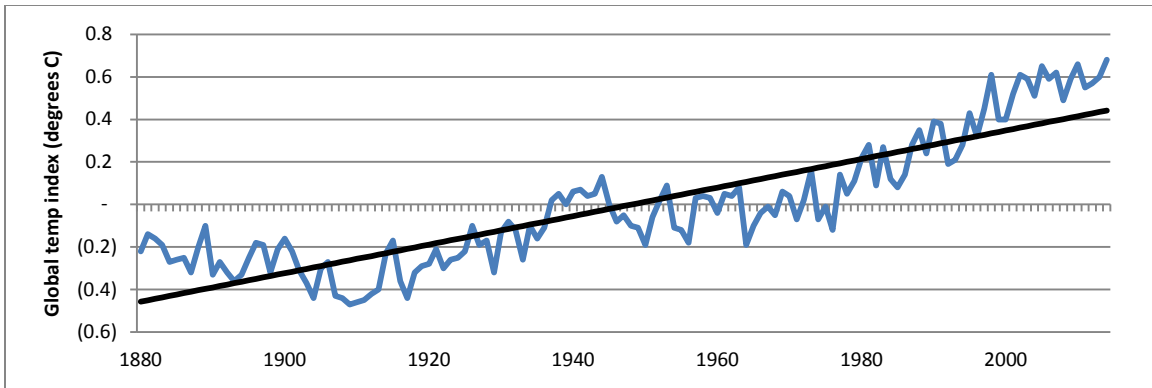
The now famous graph shows global land-ocean annual mean surface temperatures since 1880 (the chart plots deviations from the 1951 – 1980 average)ⁱⁱ:



While visually impressive it's our contention that most – we'd say "all" but we haven't seen them all – of the recent articles forget to look at the vertical axis and to ask the simple question, "are these numbers big?"

This essay is not about the science of climate change, it's about what the data say on their own. In particular, we think it is important to distinguish the level of worry you might have from looking at this chart, versus the level of worry you might have from complex climate models.

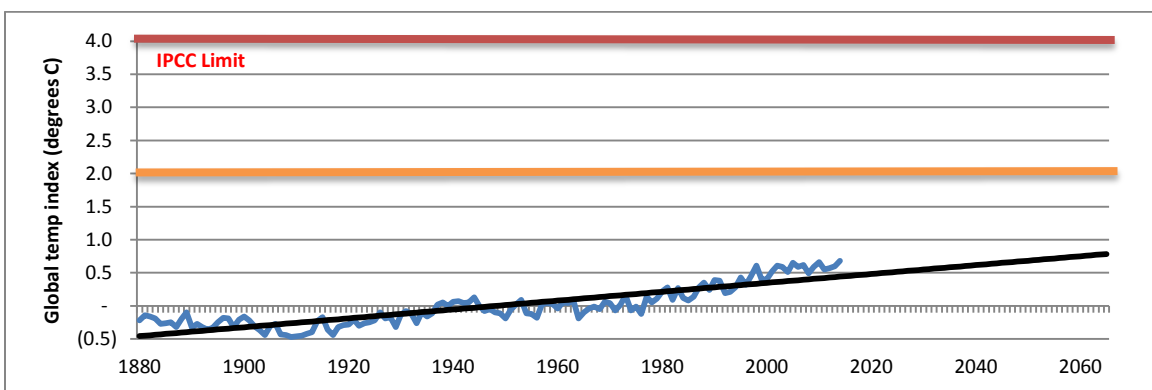
With a chart like this, whether about climate or anything else, a natural thing is to draw a straight line through the data (we used a linear least square regression, but you get about the same thing with other statistical techniques or just doing it by eye). This is a guess at what the long-term trend is, and could be a base case for thinking about how hot things are likely to get in the future (extrapolating a trend must be done with skepticism but it seems to be a reasonable starting point for discussion).



It shows a warming trend of 0.67° Celsius per century. That doesn't sound too scary, and as we'll see that if that remains the trend, according to the experts, it's indeed not too scary. It's surprising that in the myriad of recent articles highlighting this graph, pointing to the trend, the lack of a hiatus in warming, and the recent highs, none we've seen mention (we apologize to any we've missed!) that the actual magnitude of 0.67° C per century is quite small and itself doesn't take us to a dangerous level until much farther in the future than climate scientists forecast.

Of course the real but rather small trend doesn't prove that global warming is a minor issue, far from it. We're just saying the graph taken on its own is actually pretty reassuring, at least compared to predictions, and declared danger points, of the IPCC and similar groups. If things continue along the way they have for the last 135 years, the point at which we reach dangerous temperatures is a very very long time from now. Those predicting that we face a big problem much sooner aren't arguing this from these data, instead they have to be arguing that historical warming trends will change drastically in the near future; that they will not continue at the trend of the past hundred years or so. The historical record to date, and in particular this ubiquitous graph, can't be the basis of an argument that we will hit dangerous levels soon. To argue that we will hit them in this, or even next century requires us to explain away this graph, to explain why the rate of warming will increase.

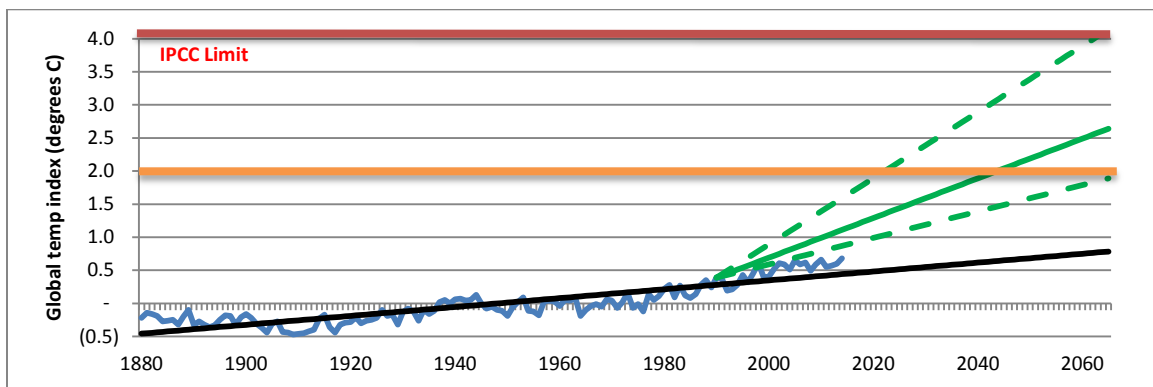
To see this, let's take a step back and use larger axes. We're going to drag the timeline (the horizontal axis) out another 50 years to 2065, and extend our trend line, and enlarge the scale (the vertical axis) to go up to the 4° C of warming that has been used as a somewhat arbitrary danger level since the 1970s (we call that the IPCC limit below - later, and in our end notes, we discuss what happens if this danger level is reduced to 2° C, a level we also show in the following graphs).



It says yes, over the last 135 years the Earth has warmed, but not nearly to the danger point (the top of the graph at 4.0 on the y-axis) and if we continue at this pace (the crux of the issue) it won't become scary until more than 500 years from now (not by the end of the 50 years we've added to the x-axis). That's quite a different message from what we've read in the articles accompanying the original version of this chart.

Of course, this raises the very important issue of whether or not 4°C is the right danger line. No one knows the answer to this question, but 4°C seems the most common figure used by the experts. It's what the IPCCⁱⁱⁱ uses in its most recent report. No one denies that there are some risks and costs to any amount of warming, and on the other hand, almost no one is predicting that warming at or slightly beyond 4°C will cause extinction of the human race either. Risks go up with the amount of warming. We just don't know how fast. Despite the uncertainties, there seems to be a scientific consensus that less than 1°C or 2°C of warming would make global warming no more serious than several other environmental issues, but warming above 4°C would likely make global warming a unique danger. Even if the danger point is 2°C this trend doesn't reach it until over 130 years from now.

Next let's add to the graph the IPCC 1990 "business as usual" (the IPCC's term for what happens if no efforts are made to restrain CO₂ emissions) predictions for future warming. These are shown in the next graph as the three green lines^{iv}, which show the expected (middle) case along with the good (lowest) and bad (highest) cases. The black line is still the linear trend implied by history and the blue line is still the actual temperature data. We start the green lines in 1990 when the forecasts were made.

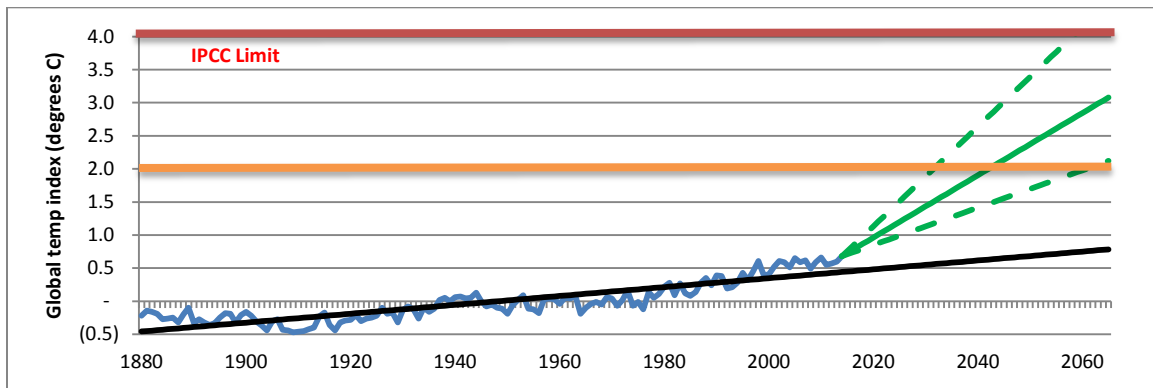


The rate of warming since these forecasts were made, albeit over a period too short to judge such things, so far appears to be less than even the lowest IPCC estimate and substantially less than their higher forecasts. Someone who predicted in 1990 that global temperatures would remain constant (i.e. no warming) through 2014 would have been closer to the truth than someone who bet on average warming rate from the IPCC middle prediction (if you take their lower rate and consider the natural variation the IPCC represents in the "wiggles" — not shown in our graph — around that rate it's not far off, but then again it's also not much warming). The IPCC gets points for predicting correctly in 1990 that the subsequent 25 years would warm faster than the long-term trend up to that date, but even their lowest scenario showed about double the increase that has actually occurred to date.

Of course, just looking at a chart is not climate science. Rather, it's climate-knowledge-free statistics. Perhaps temperatures will snap back to model predictions as feedback loops kick in? Or

perhaps lower amounts of warming than 4°C will have catastrophic effects? Again, that's for experts to investigate, all we're saying is that if you look at the chart it suggests global warming is a much smaller and less immediate threat than the IPCC thought in 1990. And, this is the part we find so confusing, remember, this is the chart trumpeted everywhere, implicitly and often explicitly, as verifying that global warming is a huge proximate danger.

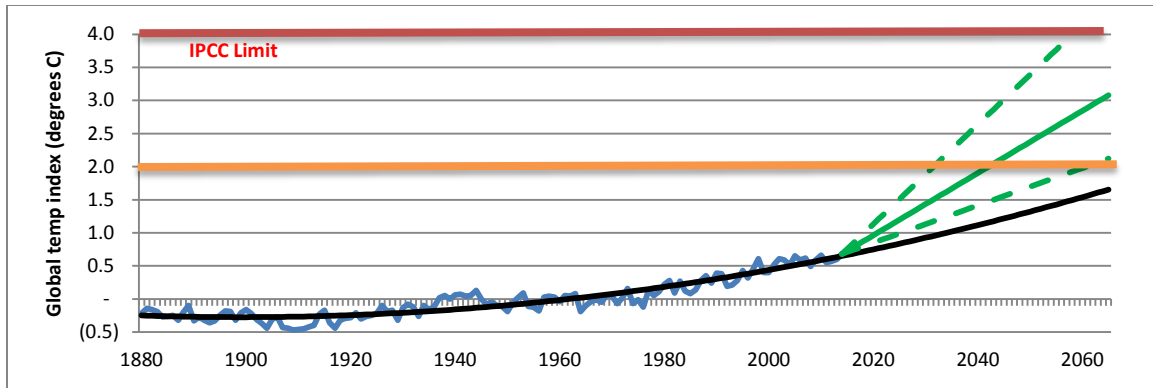
The most recent IPCC report^v is far more complicated than the 1990 one. We picked its "A1FI scenario" as the best comparison to the 1990 estimates^{vi}. Here is the graph with those. Below are the same three green lines, with the same interpretations, with the green lines (IPCC forecasts) now starting from the end of 2014.



Again, the IPCC projections could certainly turn out to be correct, but there's little sign of that in the data (admittedly, again, data analysis, not climate science, is what we do). They are predicting a sharp increase in the rate of warming that has not yet been observed. Other evidence for warming, such as decline in Arctic sea ice from 1980 to 2012 or sea level increases since the early 1900s, if measured accurately, could easily be consequences of the moderate degree of actual warming we have already observed, not evidence that the rate of warming is about to make a dramatic increase. While we aren't climate scientists we are reasonably confident that ice melts from actual warming not future forecasted warming, whether forecasted accurately or not. So things like ice melt must be evidence of the warming that has occurred, i.e. the rather modest warming we and others graph, not evidence for or against a model forecasting the future. It is certainly not new evidence independent of the 0.67° Celsius per century warming trend, but rather the same evidence repeated. Other consequences of warming, like ice melt, can be reported as confirmation of warming, perhaps to convince those who doubt the direct temperature data, but not as evidence that the problem is bigger than the amount of warming we've seen.

In other words, when you see a picture of a polar bear stranded on a tiny piece of rapidly melting ice, it may indeed be a consequence of the 0.67° per century warming we've seen, and it may indeed be a serious problem, but it can't be the consequence of, or the proof of, a model for the future, as forecasts of the future have, as of now, not harmed any polar bears. On the other hand, to be fair, if we already see consequences of 0.67° per century of warming it seems intuitive that if the models' forecast of much faster warming are correct, the consequences would be severe.

If you want to use the chart and argue for a faster rate of warming, one solution is to fit a curve to the data instead of a straight line. We accomplish this, again with statistical brute force not climate science, by adding a square term to the regression and show the graph below.



Extrapolating curves is notoriously unreliable – even less reliable than extrapolating straight lines! But it does seem to fit the historical data reasonably well. The squared term empirically improves the fit and indeed leads to forecasts of accelerating warming. It predicts roughly twice the amount of warming by 2065 than the linear extrapolation does, and hits the IPCC limit in 132 years versus 530 for the straight line. While this could be cause for concern, it’s still obviously much less dire than the IPCC’s models (slower warming over a longer period equals less dire).^{vii} Even looking at the 2° amber line the accelerating curve doesn’t hit it for 66 years vs. the IPCC middle (expected) case striking it in 44 years. In fact the accelerating squared fit doesn’t catch the IPCC middle (expected) case until 200 years from now!

What is our conclusion from all of this? If you believe in a significant probability of catastrophic global warming in the next 50 years, you cannot base this belief on the last 135 years of global mean temperature data compiled by NASA. But this is not the text usually accompanying this graph. If you work from just the historical temperature data, even aggressively fitting the data, global warming appears to be a manageable problem at least until very late in this century, and if 4°C is the true danger point, much later than that. It follows that we can’t base our confidence in global disaster on any consequences of the fact that things are warmer now than they were a century ago, such as sea level rise or the string of “warmest year on record” announcements, as those are part and parcel of the modest warming we’ve seen.^{viii}

That leaves three ways you might support the argument for impending catastrophe. One is, again, to rely on climate models and other technical arguments, despite, not because of the data.^{ix} The second possibility is a non-empirical belief that human impacts are inherently unnatural and threaten a delicate environmental equilibrium.^x The third possibility is that our examining when we’ll hit 4°C understates the danger. Specifically, while 4°C might be the approximate danger point, if you wait until you’re near it to take action, you may pass the point where you can prevent going through it.^{xi} These can all be reasonable positions (although not all people who hold them argue them reasonably) but none of them can call on the famous chart we study for support – an action that, again, has become perplexingly common.

As we said at the beginning, this is not an essay about the intricacies of climate change, neither the science nor the policy implications. It’s an essay about data analysis and how data gets used and sometimes abused. Popular coverage of the issue seems deeply confused as journalists, and many advocates, use the graph we showed — or similar data, or straightforward consequences of the mild warming in the historical data — as support for models that predict dramatically different behavior in the near future (and even in the recent past). You can believe the models if you like, or

you can look at the data and assume the most likely future is an extrapolation of the past. What you cannot do is both.^{xii}

Finally, the data do say a lot of things (we leave any quarrels about the data itself to others). They say the world has indeed warmed for more than a century. They say there has not been a recent hiatus as some critics contend. While not statistically distinct they indeed say the most recent measurements are at a record high. They even suggest that warming has accelerated over time. However, what we don't find in the data is evidence that warming is dangerously fast, that we are anywhere near the generally agreed danger point or will be anytime soon, nor that the actual scenarios forecasted by the models seem to be playing out in the near term. Yet, as proof of these last three is precisely how most commentators use the data and the famous graph we focus on.

Put simply – the history of global temperature, and specifically the recently famous graph, shows the opposite of what almost all articles presenting it argue. If the next 135 years repeat the experience since 1880, we are in good shape. How much we should worry about future warming, and the answer may indeed be a lot, is entirely about how much one believes in the models' forecasts that the future will look very different from the data.

ⁱ Here is a sampling of recent articles from technical publications, newspaper articles, posts on popular blogs, educational materials and opinion pieces (some use only the data not the graph, or either but use very close cousins to our data):

- Anup Shah, Anup, Climate Change and Global Warming Introduction. <http://www.globalissues.org/print/article/233>
- Brekhus, Keith. Attention Climate Change Deniers: NASA, NOAA Report 2014 Was Warmest Year Recorded. <http://www.politicususa.com/2015/01/16/attention-climate-change-deniers-nasa-noaa-report-2014-warmest-year-recorded.html>
- DeLong, Brad. Department of "WTF?!": Yes, Clifford Asness's Views on Global Warming Are Insane: Why Do You Ask? <http://www.bradford-delong.com/2014/10/yes-clifford-asnesss-views-on-global-warming-are-insane-why-do-you-ask.html>
- Hansen, J.E., R. Ruedy, M. Sato, and K. Lo, NASA GISS Surface Temperature (GISTEMP) Analysis, DOI: 10.3334/CDIAC/cli.001. <http://cdiac.ornl.gov/trends/temp/hansen/>
- Kinver, Mark. 2014 warmest year on record, say US researchers. <http://www.bbc.com/news/science-environment-30852588>
- Romm, Joe. 2014 Was The Hottest Year On Record Globally By Far. <http://thinkprogress.org/climate/2015/01/05/3607735/2014-hottest-year-by-far/>
- Schulman, Jeremy. Was 2014 Really the Warmest Year? Here's Why It Doesn't Matter. Focus on the trend. <http://www.motherjones.com/environment/2015/02/was-2014-really-warmest-year-nasa-noaa>
- Global Temperatures: Global Mean Temperatures as an Indicator of Global Climate Change. http://ete.cet.edu/gcc/?/globaltemp_teacherpage/.
- NASA, NOAA, Pope Francis make climate change hottest topic. <http://www.utsandiego.com/news/2015/jan/16/nasa-warmest-year/>

ⁱⁱ NASA-GISS, GLOBAL Land+ocean Temperature Index in degrees Celsius, base period: 1951-1980 using elimination of outliers and homogeneity adjustment (GHCN-v3 1880-01/2015 + SST: ERSST 1880-01/2015). There are many variants of this graph, some using land measurements only, some using different adjustment methodologies, some averaging differently. We picked this one because it seems the most popular in recent widely read articles, and it also is cited heavily in the technical literature.

ⁱⁱⁱ Quoting from the report, "Some risks of climate change are considerable at 1° or 2°C above preindustrial levels. Global climate change risks are high to very high with global mean temperature increase of 4°C or more above preindustrial levels in all regions for concern, and include severe and widespread impacts on unique and threatened systems, substantial species extinction, large risks to global and regional food security,

and the combination of high temperature and humidity compromising normal human activities, including growing food or working outdoors in some areas for parts of the year. The precise levels of climate change sufficient to trigger tipping points remain uncertain, but the risk associated with crossing multiple tipping points in the earth system or in interlinked human and natural systems increases with rising temperature.” The report talks about 4°C or more above preindustrial levels, whereas our chart shows warming above the 1950 – 1980 average. Unfortunately the preindustrial temperature data cannot be measured very precisely, so it’s possible we should draw our danger line a few tenths of a degree higher or lower than we did. You could argue for a few more tenths one way or the other depending on precisely which global temperature index you choose. None of these adjustments would make much difference to our point. And given the basic uncertainties in how warming affects the Earth, these minor corrections would be false precision anyway.

^{iv} The IPCC predictions we are using are stated as warming rates without specifying either the initial point or precise definition of mean global surface temperature. We just added them to the actual temperature at the end of the year the report was released. Other places in the reports have predictions that do specify temperature predicted ranges at specific points in the future, and give the definitions. While these are generally consistent with the predictions of warming rates, they are not tied to them precisely. Therefore, someone might argue for shifting our IPCC prediction lines up or down by a constant few fractions of a degree. This would not matter for the purposes of this essay. Also, the IPCC represents these same scenarios as waves or wiggles around these warming rates, representing stylized natural variation.

^v <http://www.ipcc.ch/report/ar5/wg2/>

^{vi} The 2014 report has too many scenarios and variations to discuss here, but they differ mostly in the shape of the increase and the secondary and local effects rather than the general average global trend over the next fifty years. Moreover, A1FI represents a consensus forecast, essentially a median of many models that commands widespread general agreement among climate scientists, while many of the other scenarios are the result of individual models or classes of models. Furthermore, in 1990 they produced straight line projections like we show here, in 2014 they do not, though we have represented them so here based on their warming rates.

^{vii} Ironically, if we used land only measures not land+ocean, as is the recent norm in climate science, we hit the dangerous 4°C point faster, though still far slower than consensus model forecasts like those from the IPCC we highlight in the text. Instead of the linear extrapolation of land+ocean temperatures hitting 4°C in 530 years it hits in 184 years, and for the quadratic it moves up from 132 to 66 years. The point of this essay, that the data show warming that is far less worrying than headlines declare, and that worries are based on models not the commonly trumpeted data which actually argues for less worry, would be unchanged if we switched back to this land-only measurement rather than land+ocean measurements most currently favor.

^{viii} We can “stress test” our findings using some other assumptions. We have been fitting our lines and curves to the full 135 years of data. While those are the data ubiquitously graphed and cited these days, the IPCC actually highlights the post-1950 period as when humans really began affecting the warming rate, and estimates that a bit more than 50% of the warming we’ve seen over this period has been man-made. We go further by fitting our line over the 1965-2014 period (visually that seems to be about when the slope changed and indeed estimates of the slope over this period are bigger, and thus more conducive to the warming case, than from 1950-2014). You do get a bigger slope over this period, 1.57° Celsius per century over 1965-present vs. 0.67° Celsius per century over the full period (over 1965-2014 the squared term does not matter much at all). At this rate we will hit the 4.0° Celsius danger point in just over 200 years instead of the 500+ years we found in our first linear trend exercise. Much faster, but still way slower than the major model forecasts and well short of a time frame anyone would be sounding the alarm about. But, here, according to the IPCC, we are actually being too alarmist. The IPCC only assigns a bit more than half the warming since 1950 to man-made causes. We ignored this earlier as we were also including the earlier period where the argument that temperature was affected by emitted carbon is weaker. We cannot ignore it now. If we take sixty percent of the 1.57° rate we get 0.94° Celsius per century and don’t hit 4.0 until 385 years from now. Now, perturbing our experiment should go both ways. As we noted earlier, using 4.0° Celsius for the extreme danger point is certainly not fixed in stone. That is the point noted by the most authoritative sources, but recently many have been discussing lower danger points, with 2.0° Celsius often being mentioned. Using the full rate of warming (the slope) from 1965-present we will hit 2.0° Celsius in 84 years, and using sixty percent of that slope as, again, the man-made part, we hit it in 174 years. All still comfortably longer than models forecast (“comfortably” if things continue at the same rate as in the past, not comfortably if the models are

right, a possibility we do not dismiss!). We'd also note that even estimating over this shorter 1965-2014 period and haircutting by 40% we get just under 1°C of expected warming per century. Even if you ignore the IPCC and believe that all the empirical warming is man-made, and thus don't haircut the empirical trend by 40%, you get 1.57°C per century rate. In contrast the three IPCC scenarios correspond to warming rates per century of 2°C (low, best case), 3°C (middle, expected case), and 5°C (high, worst case). This again underscores how you need a model to worry much about the future as the data, no matter how you slice it, just doesn't get you there.

^{ix} Believing models is fine, but you should acknowledge that you're expecting a sudden major change in the rate of warming, and you absolutely should not appeal to the long-term rather mild change we've experienced to buttress your case. You also need to explain why the model forecasts haven't been showing up in the temperature record. You shouldn't lead your article with the now famous chart we study, you should show it reluctantly as evidence you must overcome and say, "Yes, but. . ." You should state clearly that you are choosing a model over the actual temperature measurements, perhaps a model with feedback that threatens to accelerate the process in the very near term. You should not claim current temperatures as evidence in your favor but rather an anomaly you need to explain as your model does not, at least as of now. We aren't arguing that you can't or shouldn't build such a model.

^x In that case you have to fear catastrophe from any significant anthropogenic effects. Even small amounts of warming could touch off self-reinforcing reactions, and if not warming, some other effect of CO₂ or any other emission or non-emission environmental impact. Once again, you should be clear that your position is not based on empirical evidence. It may be true but the chart doesn't make that argument. We have a lot of sympathy with the view that all-else-equal complex systems should be disturbed as little as possible as equilibrium can be delicate. It is entirely rational to be concerned that anthropogenic influences could push things past tipping points. History is full of examples of human activities causing unintended disasters (not to mention some pretty horrible intended disasters). But there's nothing in the data to suggest this has happened, as of now, with respect to CO₂ and temperature. It might have happened, or it might happen soon, but you need a model to tell you that as the ubiquitous graph we begin with tells you the opposite. Similarly, some have argued that severely limiting carbon output is an "insurance policy" we should take out regardless of evidence-to-date as, and again we agree, disturbing complex non-linear systems always has some degree of extreme danger. If the cost of this insurance is very low we'd sign on to it without hesitation. If the cost is high then it comes down to your faith in models – as again, and really our only point, that's all we have to go on.

^{xi} That seems to be quite a reasonable fear in general. But, in this case we're talking over 500 years (linear fit) and over 100 years (squared extrapolation) before we hit 4°C. Either is a long time for mitigation, adaptation, and natural decline in carbon use. Also, there are a lot of current trends that are scary if extrapolated out 100 or 500 years, and anything we do to fight one might exacerbate another, or create new ones. So if you want to use this argument to support aggressive action on climate change, you need some reason beyond the data to single out global temperatures from everything else on paths that will become dangerous in the distant future.

^{xiii} We are dying to say "you can't have your temperature spike and heat it too" even though it doesn't really make much sense...

POSTSCRIPT MARCH 12, 2015 – CLIFF ASNESS

The last few days have been interesting. I knew, of course, that any article on global warming would induce strong responses. In that respect I've been pleased for two reasons. First, because of the large majority of positive responses, many noting our balance and lack of an agenda. Second, because the minority of negative responses have come about equally from people who do not believe warming is a problem at all, and people who believe that catastrophic warming is imminent or even has already occurred. Somehow I instinctively feel such strong, opposite, strident responses must mean we're onto something!

Predictably, the hard right, for want of a better phrase, has been angered that we start from and assert in our article that the historical temperature record is real (or as accurate as possible and not a conspiracy), shows a rising and in fact accelerating trend, shows no recent "hiatus", and, in our view, is most likely caused or at least substantially contributed to by man. This was not pleasing, but has to be chalked up as dog-bites-man. The next part involves some man-dog biting...

I am less pleased that a widely read [article](#) about the essay was titled, "Top hedge fund manager: Global warming isn't a danger." What we actually wrote was different, the concluding sentences are, "If the next 135 years repeat the experience since 1880, we are in good shape. How much we should worry about future warming, and the answer may indeed be a lot, is entirely about how much one believes in the models' forecasts that the future will look very different from the data." That is not an all-clear signal, it's not even an opinion about a signal.

The article quotes Gavin Schmidt, who is the director of the NASA Goddard Institute for Space Studies, as agreeing with us, although you wouldn't know it from the tone of his quotes. He probably thinks it is a criticism to say, "the paper that Asness and Brown put out is not science." However we state the same thing in the paper, "Of course, just looking at a chart is not climate science." We are making a logical point based on data analysis, what we call "climate-knowledge-free statistics," not a scientific point.

When he gets to the facts, Schmidt agrees that "looking at temperatures in a vacuum" does not suggest a dangerous rate of global warming. His prediction that the future will look very different from the past is based on a model of "emissions of CO₂" and another model of the effect of CO₂ on global mean temperature. Our point is that most popular accounts treat the historical data, and simple consequences of the mild warming we have seen over the past 135 years, as confirming the models. We agree with Schmidt that the models predict something quite different.

Environmental scientist James Hansen disagreed with the piece in strong language, "within less than a year, you will look like complete fools (if you buy this crap)." It sounds as if he's expecting a dramatic event of some kind, it seems odd that he won't give a hint about what it is. My first thought was he expected 2015 temperatures to snap up to the much higher levels predicted by the IPCC in every report since 1990. But then the data would match the models, at least for one year. No one would look like a fool for saying that prior to 2015 the warming trend was much slower. And anyway, it's hard to see how one year's temperatures, however extreme, could prove or disprove long-term models.

Upon further consideration, I think (admittedly a guess) that he's predicting something different: That he will publish proof that the existing amount of warming has already caused catastrophic

damage. In that case, people who bought the idea that 0.67°C of warming per century was mild could seem somewhat foolish (I'm not sure I'd go with "complete fools" or "crap," however). But in this case I'll have a lot of company, for example the entire IPCC and Gavin Schmidt, among many others, will look like complete fools along with me.

One minor point, in the body of the *Fortune* article it's asserted that this is the second time I've "weighed in" on climate change. No, it's the first. The one referred to as the earlier time was [Brad Delong](#) taking a joke I made, perhaps too subtly, *meant to be supportive of mainstream climate science defending it from the idea that a short period without warming would mean it is wrong*. So even if it's literally the second time I've "weighed in" let it be noted that the first was a throwaway quip and *i took the side of those most worried about climate change!*

Finally, the *Fortune* article does note that as a supposed Republican (I prefer libertarian or, better yet, classical liberal) I vigorously support [marriage equality](#) and a renewed Republican focus on [civil rights](#). While I'm not sure they are relevant to this topic, I'm glad and appreciate that the author worked these in. Finally, while nobody asked, Aaron and I are both strong believers in evolution. Let the flaming emails commence!