Climate Models and Climate Reality: A Closer Look at a Lukewarming World

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Perhaps the most frank example of the growing disconnection between forecast and observed climate change was presented by University of Alabama's John Christy to the Senate Subcommittee on Space, Science, and Competitiveness Committee of the U.S. House of Representatives on December 8 (Figure 1).

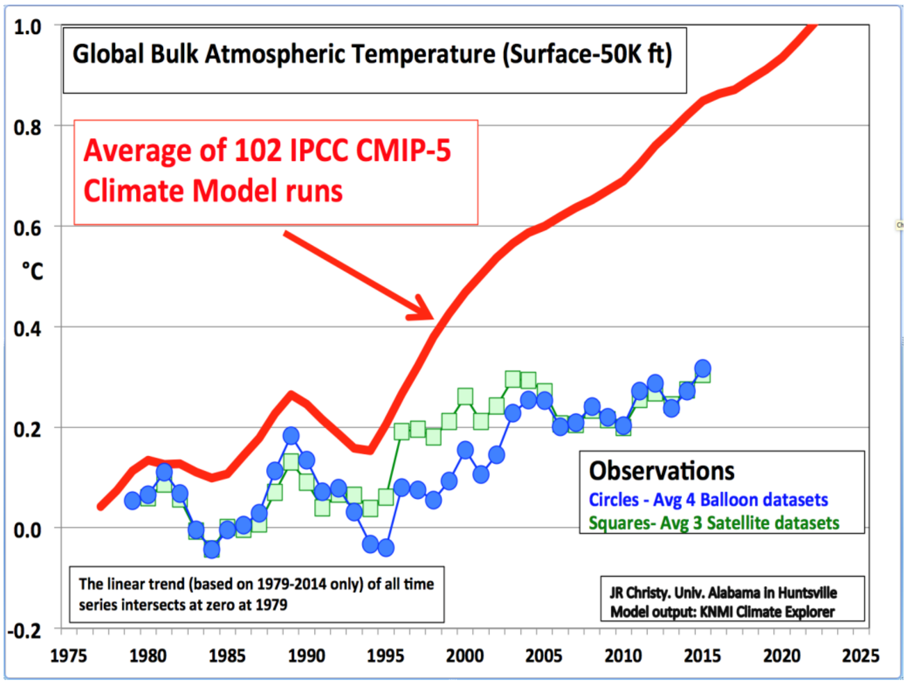

Figure 1. Global average mid-tropospheric temperature variations (5-year averages) for the average of 102 models runs (red line). Circles (balloons) and squares (satellites) depict the observations.

It isn't the usual comparison between global average surface temperature and the current family of general circulation climate models. Instead, it's the forecast and observed temperatures for the middle troposphere.

The troposphere is the earth's active weather zone, and it extends from the surface to around 40,000 feet. It's deeper where the atmosphere is warm, as in the tropics, and shallower at higher latitudes. All significant storms, from massive winter cyclones to gullywashing summer thunderstorms are formed and contained in the troposphere.

The data in Figure 1 are smoothed out by using five-year running means, which filters out year-to-year variability and emphasizes more systematic, long-term behavior.

Twice a day, weather balloons are launched simultaneously around the planet in order to get a snapshot of the physical properties of today's atmosphere. The temperature, humidity, barometric pressure and wind data provide the basis for the next iteration of global weather forecasting models. The instrumentation is largely standardized and calibrated for accuracy.

There are four different analyses of these datasets, and the blue dots in Figure 1 are their running mean average.

The temperature of the mid-troposphere can also be sensed from above, by orbiting satellites that measure the vibration of diatomic oxygen, which turns out to be a much more accurate thermometer than, say, a standard mercury-in-glass instrument. There are several global analyses of these data, one by Christy's crew, another from Remote Sensing Systems, a California consultancy, and a third by the U.S. National Oceanic and Atmospheric Administration. The green squares in Figure 1 are the average of these three datasets.

Note that the satellite and balloon-sensed temperatures are independent observational measurements.

The red line in Figure 1 is the five-year running mean of the average of 102 computer model simulations that generate temperatures in this layer, compiled in the latest (2013) scientific assessment of the UN's Intergovernmental Panel on Climate Change.

All of the data have been scaled the same in the vertical dimension, with a maximum weighting around 12,000 feet above the surface. The sensing technique in the satellite picks off a bit of data above the troposphere, in the placid stratosphere, and the balloon and computer model data were scaled in the same fashion. So this is a true apples-to-apples-to-apples test.

What's the advantage of looking at these temperatures versus those at the surface?

Rain and snow are largely dependent upon the temperature difference between the surface and the mid-troposphere. When there's little difference, air in the lower atmosphere does not rise, meaning that the vertical motion required to form a cloud is absent. When the difference is large, moisture-laden surface air is very buoyant and can result in intense rain events.

Getting the vertical difference systematically wrong in a climate model means getting the rainfall wrong, which pretty much invalidates regional temperature forecasts. A dry surface (think: desert) warms (and cools) much more rapidly than a wet one. If the computer models are somehow getting surface temperatures right that could only be a fortuitous result if the mid-tropospheric temperatures are as far off as Christy's data shows.

Indeed, the models have this temperature differential dead wrong. Over the period of study, they say it should be increasing only very slightly. But, in fact, in the real world it is growing at a rate *nine times* what is predicted by the models over this study period.

Which brings us to those surface temperatures.

They're a bit slipperier than the mid-tropospheric ones. The laboratories responsible for the three principal histories keep changing history, much more frequently than the satellite or balloon records are reconfigured.

At Cato's Center for the Study of Science our investigations have led us to the hypothesis that the anthropogenic influence on the earth's climate—specifically through emissions of greenhouse gases—is near the low end of the "mainstream" (e.g., IPCC) assessed range of influence. And further, that models developed to simulate the behavior of the earth's climate have generally overestimated the influence of anthropogenic greenhouse gas emissions. Our new book, *Lukewarming: The New Science That Changes Everything* details the latest scientific findings supporting a complex, yet modest human impact on the earth's climate.

At last December's Fall Meeting of the American Geophysical Union (AGU), we summarized our thinking on the issue in a presentation titled "Quantifying the Lack of Consistency between Climate Model Projections and Observations of the Evolution of the Earth's Average Surface Temperature since the Mid-20th Century." It reflected the state (at that time) of our continual updates to work originally presented to Congress in 2009, expanded upon at the Third Santa Fe Conference on Global and Regional Climate Change in 2011, written up into a paper, presented at the AGU's Science Policy Conference in 2013, and regularly updated in comments on national and international climate change assessments and proposed federal regulations designed to restrict greenhouse gas emissions.

The work is a straightforward demonstration that climate models project a greater rise in the global average temperature than has been experienced, one avoids the pitfalls of other types of comparisons and is immune from claims of cherry-picking, as it includes all time periods since 1950 ending in the present. Accompanying this demonstration of model infidelity, we present a case that a major part of the reason that climate models run too hot is that the earth's equilibrium climate sensitivity is substantially less than portrayed by the climate models. We will revisit this at the end of this paper.
Everyone by now is familiar with the "pause" or "slowdown" in the rate of global warming that has taken place over the past 20 years of so, but few realize is that the observed warming rate has been beneath the model mean expectation for periods extending back to the mid-20th century—60+ years.
We demonstrate this fact with our comparison of the observed warming rate to that of the range of climate model-predicted warming rates for all periods from 1951 ending with the most recent available data. In our AGU presentation, we included the observations of the global average surface temperature compiled by the UK's Hadley Center. The Hadley Centre compilation has long been preferred by the IPCC.

And while the Hadley Centre's surface temperature compilation is not the only one, its recent behavior is more consistent with the low rates of warming being revealed in the mid-tropospheric compilations, in which a substantial amount of the overall data is in fact below approximately 12,000 feet. Here, we add the other two major compilations, from NASA and the Department of Commerce's National Oceanic and Atmospheric Administration. We've also included two less prominent surface temperature compilations from Cowtan and Way (2013) and Berkeley Earth, inclusions which do little more than demonstrate their overall similarity (Figure 2). We have also updated our AGU presentation with our best guess for 2015 average temperatures. Thanks, in part, to a strong El Niño, 2015 is going to be the warmest year in any of the surface temperature compilations. You can see from Figures 1 and 2, however, that this warmth does very little to narrow the disparity between the predicted and observed temperatures.

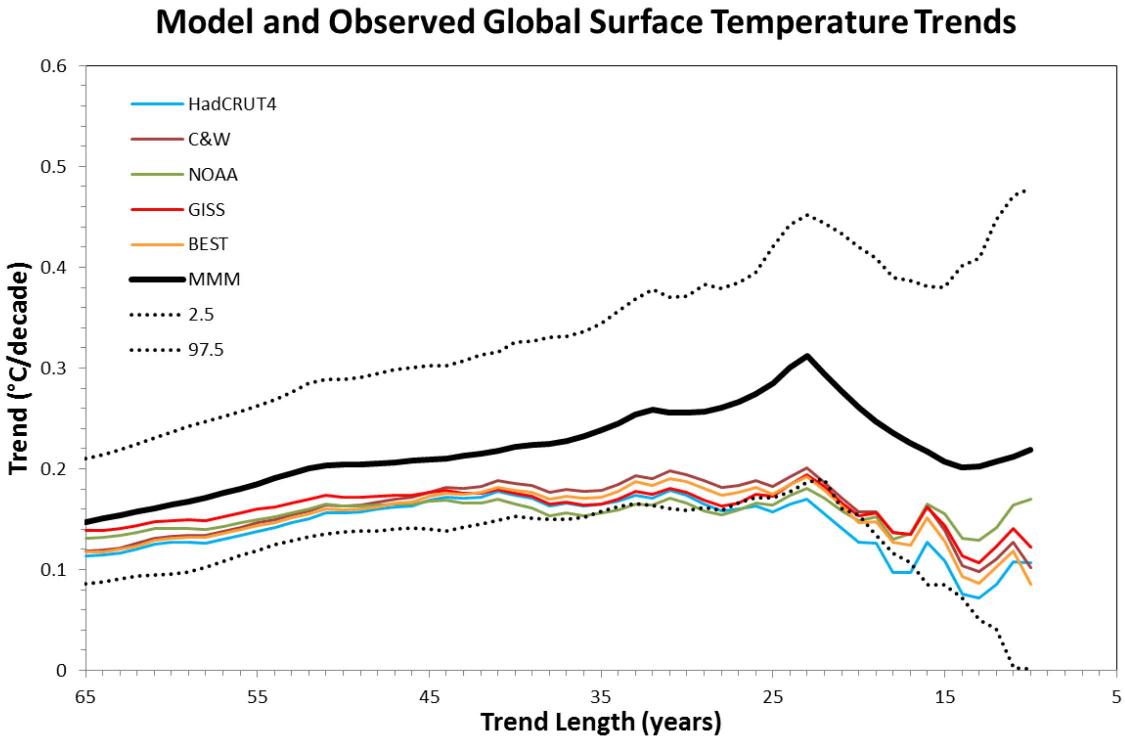

Figure 2. The annual average global surface temperatures from 108 individual CMIP5 climate model runs forced with historical (+ RCP4.5 since 2006) forcings were obtained from the KNMI Climate Explorer website. Linear trends were computed through the global temperatures from each run, ending in 2015 and beginning each year from 1951 through 2006. The trends for each period (ranging in length from 10 to 65 years) were averaged across all model runs (black line). The range containing 95 percent (dotted black lines) of trends from the 108 model runs is indicated. The observed linear trends for the same periods were calculated from the annual average global surface temperature record compiled by several different agencies described in the legend (colored lines) (the value for 2015 was estimated from January through October, average).

During all periods from 10 years (2006-2015) to 65 (1951-2015) years in length, the observed temperature trend lies in the lower half of the collection of climate model simulations, and for several periods it lies very close (or even below) the 2.5th percentile of all the model runs. Over shorter periods, such as the last two decades, a plethora of mechanisms have been put forth to explain the observed/modeled divergence, but none do so completely and many of the explanations are inconsistent with each other.

One concern that has been recently been raised—some nine months after our AGU presentation—is by Cowtan et al., 2015 is that the vast majority of extant comparisons (for example, the IPCC Assessment Reports, or our own work) between climate model projections and observations of the earth's surface temperature are not precisely apples-to-apples for two reasons: 1) observed temperature compilations include regions of missing data (i.e., incomplete geographic data coverage) while climate models include the entire surface, and 2) observed compilations combine air temperature measurements over the land with sea surface temperatures into a global average, while climate model compilations use air temperatures over both land and oceans. The combination of these factors is shown to lead to a slight warming bias in the models when compared to the observations. A more appropriate model dataset has been developed and made available for researchers to compare the models with the UK Hadley Centre data through 2014. We've used these data to see how this concern impacts our analysis. The results are shown in Figure 3. While this adjustment brings the observed trends closer to the multi-model mean, it remains clear that the observed trends lie near, and in some cases continue to fall beneath, the lower bound containing 95 percent of all model runs (i.e., the 2.5th percentile distribution of model projections).

(Because the 100+ model results are binned very close to a normal frequency distribution), the 2.5th percentile is analogous to the .05 confidence limits for a two-tailed (above or below the model average) distribution.)

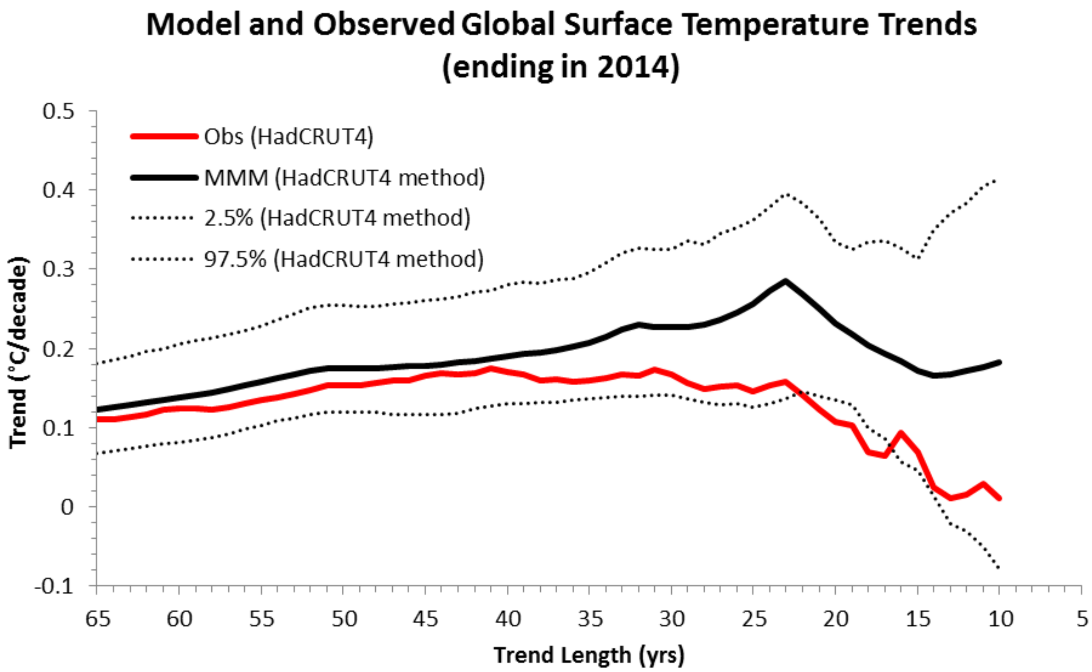

Figure 3. The annual average global surface temperatures, derived from a similar methodology used by the UK's Hadley Centre in compiling temperature observations, from 109 individual CMIP5 climate model runs forced with historical (+ RCP4.5 since 2006) radiative changes. These were obtained from the University of York website (http://www-users.york.ac.uk/~kdc3/papers/robust2015/index.html, see Cowtan et al., 2015 for more details. Linear trends were computed through the global temperatures from each run, ending in 2014 and beginning each year from 1951 through 2005. The trends for each period (ranging in length from 10 to 64 years) were averaged across all model runs (black line). The range containing 95 percent (dotted black lines) of trends from the 109 model runs is indicated. The observed linear trends for the same periods were calculated from the annual average global surface temperature record compiled by the UK's Hadley Centre (red line).

If this is not strong evidence that the climate models predict too much warming, there is an additional comparison that can be made, one which is largely free from the sampling issues raised above—an examination of the climate model behavior in a the mid-troposphere.

In addition to analysis performed by John Christy (the results of which are shown in our Figure 1), we performed a trend analysis similar to the one described in our AGU presentation on the mid-tropopsheric data (as described above). We compare the collection of climate model trends with the collection of trends observed from both satellites and weather balloons. The climate model and the weather balloon observations have been weighted to simulate the observations from the satellites so the comparison is directly apples-to-apples-to-apples, as was the case in Figure 1. Figure 4 displays our results.

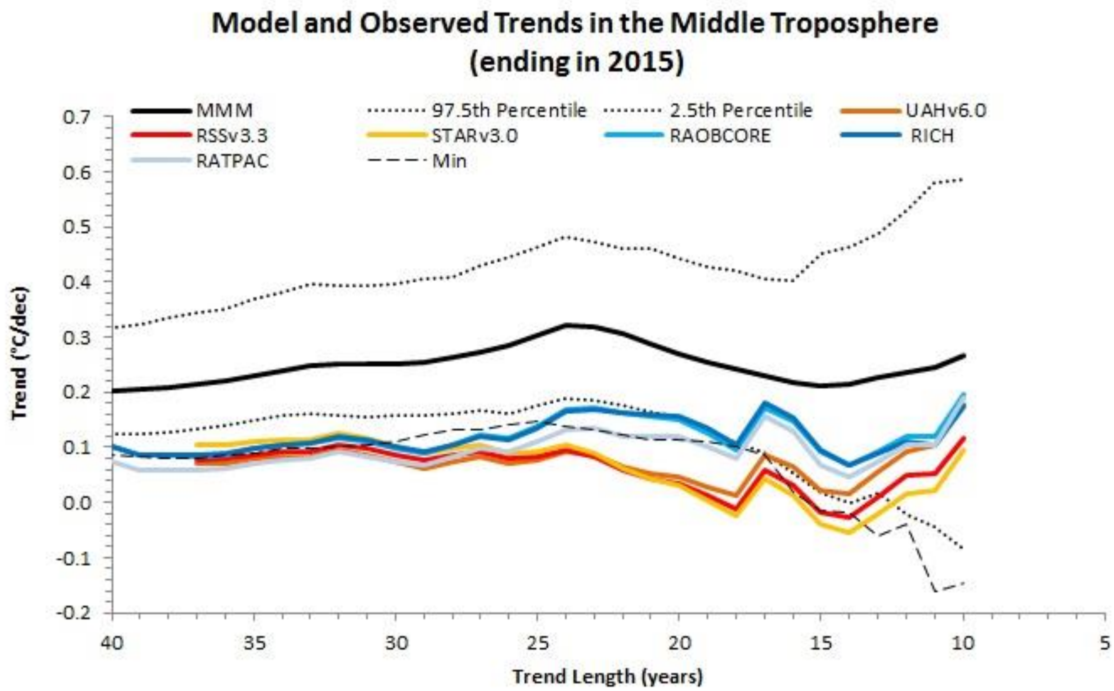

Figure 4. The annual average global mid-tropospheric temperatures derived from 102 individual CMIP5 climate model runs forced with historical (+ RCP4.5 since 2006) forcings were obtained from John Christy (personal communications). Linear trends were computed through the global temperatures from each run, ending in 2015 and beginning each year from 1975 through 2006. The trends for each period (ranging in length from 10 to 40 years) were averaged across all model runs (black line). The range containing 95 percent (dotted black lines) and the minimum (dashed black line) of trends from the 102 model runs are indicated. The observed linear trends for the same periods were calculated from the annual average global mid-tropospheric temperature record compiled by several different agencies (and include compilations derived from satellite observations as well as weather balloon observations) described in the legend (colored lines) (the value for 2015 was estimated from January through October, average (data provided by John Christy).

This is a devastating indictment of climate model performance. For periods of time longer than about 20 years, the observed trends from all data sources fall beneath the lower bound which contains 95 percent of all model trends and in the majority of cases, falls beneath even the absolute smallest trend found in any of the 102 climate model runs.

One other very encouraging result, using the satellite and balloon data, is that the observed trends are very flat, meaning that they are constant, neither increasing nor decreasing depending upon length of record. Greenhouse physics actually predicts this, so what we are seeing may very well in fact be the greenhouse-gas-generated response, not random noise. It is simply that the rate of warming is far beneath what has been forecast.

The amount of that overprediciton comports well with a growing body of scientific findings and growing understanding that the sensitivity of the earth's surface temperature to rising atmospheric greenhouse gas levels—as directly determined from observations— lies towards (and yet within) the low end of the mainstream (IPCC AR5) assessed likely range.

Since 2011, at least 14 studies published in the peer-reviewed scientific literature provide strong evidence that the equilibrium climate sensitivity (ECS)—how much the earth's average surface temperature will rise under a doubling of the atmospheric carbon dioxide concentration—lies near the low end of the IPCC estimates (Figure 5). This recent research includes investigations of the earth's thermal response to changes in climate forcings that have taken place over the past century, millennium, and over glacial periods.

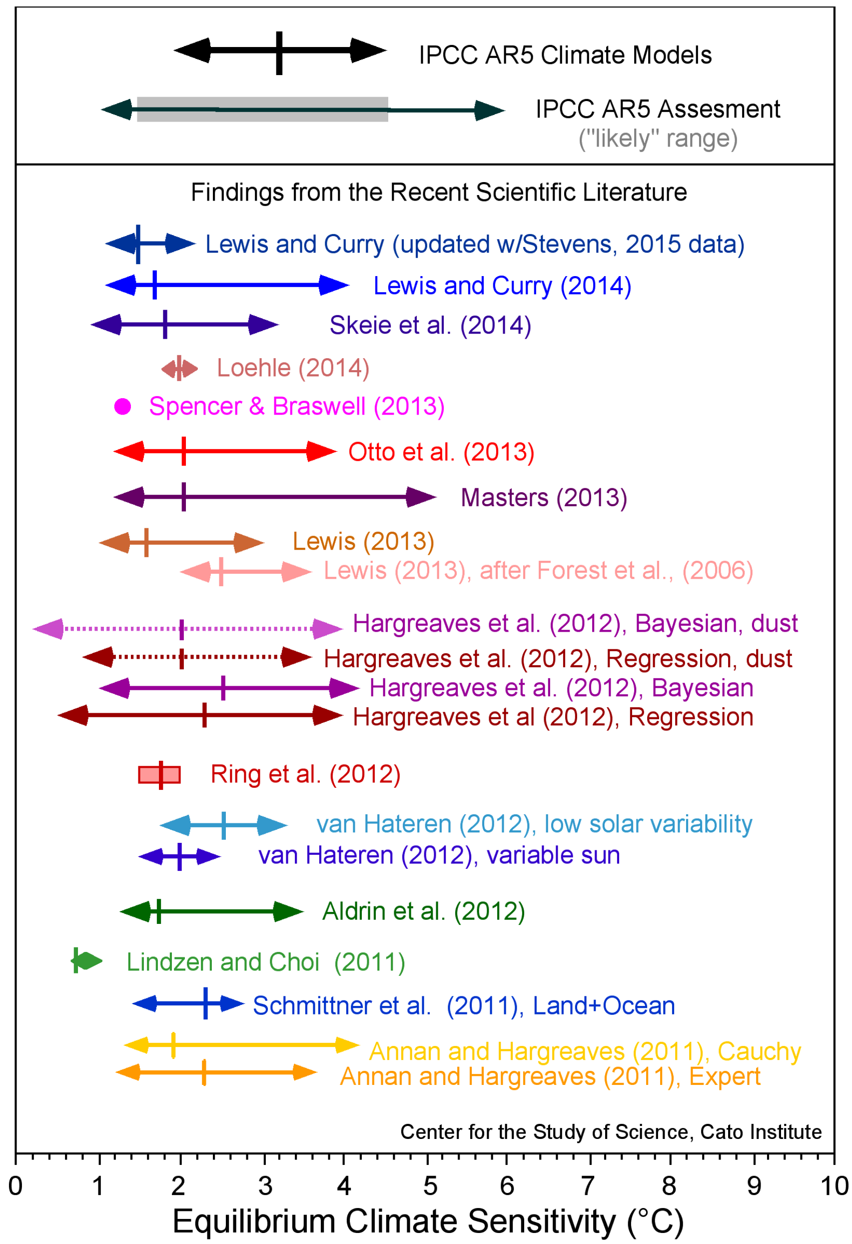

Figure 5. Equilibrium climate sensitivity (ECS) estimates from new research beginning in 2011 (colored), compared with the assessed range given in the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) and the collection of climate models used in the IPCC AR5. The "likely" (greater than a 66% likelihood of occurrence) range in the IPCC Assessment is indicated by the gray bar. The arrows indicate the 5 to 95 percent confidence bounds for each estimate along with the best estimate (median of each probability density function; or the mean of multiple estimates; colored vertical line). Ring et al. (2012) present four estimates of the climate sensitivity and the red box encompasses those estimates. The right-hand side of the IPCC AR5 range is actually the 90% upper bound (the IPCC does not actually state the value for the upper 95 percent confidence bound of their

estimate). Spencer and Braswell (2013) produce a single ECS value best-matched to ocean heat content observations and internal radiative forcing.

Several of these research findings were published subsequent to the 2013 release of the IPCC's *Fifth Assessment Report* (AR5), and thus were not included in that Assessment. Others were considered in the IPCC AR5, and still others were ignored. And while the IPCC AR5 did reflect some influence on these new low ECS estimates—by expanding its "likely" range of ECS estimates downward to include 1.5°C (the low end was 2.0°C in the 2007 IPCC *Fourth Assessment Report*) and omitting a "best estimate" value (which had previously been given as 3.0°C in the 2007 report)—it still doggedly held on to its high end "likely" estimate of 4.5°C. This was a disservice to the latest science, but was a necessary step to preserve the IPCC's reliance on climate projections made by models with an ECS averaging 3.2°C and ranging from 2.1°C to 4.7°C—the same models recently evaluated by Christy and in our AGU presentation. Had the IPCC fully embraced an ECS near 2.0°C—that which the recent literature suggests—it would have had to throw out much of the rest of the report. We explained the IPCC's conundrum in this post on Cato's blog. A more detailed and extremely compelling report on how the IPCC should have handled the new ECS findings was put together by the Global Warming Policy Foundation. Any serious examination of the extant ECS literature would be remiss not to carefully consider the content of the GWPF report (which convincingly argues for an ECS of 1.75°C or even a bit lower).

One may argue that ECS estimates based upon one or two centuries of observations may not fully capture very long-term climate responses, and that therefore such ECS estimates are likely too low. While the magnitude (or even the existence) of the underestimate is difficult to assess, what is certain is that whatever the influence may be, it is only fully manifest on timescales far beyond even multiple human generations. In other words, when attempting to assess the coming climate changes over the next century or so, observationally based ECS estimates—estimates derived directly from the extant temperature histories both of the surface temperature as well as oceanic heat content—are very appropriate. This is even more so for estimates of the "transient" climate sensitivity—the temperature rise at the time of a doubling of the atmospheric CO2 concentration, as that is likely to occur sometime in the second half of this century, before the ECS is realized. Again, the recent estimates from real - world behavior of the atmosphere and ocean are far beneath climate model expectations; see the GWPF report for a recent round-up.

That the actual ECS (at least as assessed over century times scales) is likely much lower than the average value of the climate models incorporated in the IPCC's AR5 is an efficient explanation for why climate models tend to overpredict the amount of global warming which has taken place—which has huge significance in assessing the utility of climate model projections for future climate change.
Based upon these and other lines of evidence (laid out in our numerous scientific publications, books, blogs articles, social media (see publications listed here and here for example)), we conclude that future global warming will occur at a pace substantially lower than that upon which US federal and international actions to restrict greenhouse gas emissions are founded.

It is high time to rethink those efforts.

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