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Lack of evidence for a slowdown in global temperature

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The climate science community has reached a near consensus that the warming rate of global surface temperature has exhibited a slowdown over the last decade to decade and a half. However, genuine robust statistical evidence of its existence is lacking. We test the hypothesis by numerous statistical tests applied to global temperature time series and find no evidence to support claims of a slowdown in the trend.

Introduction

Climate change resulting from increases in atmosphere concentrations of greenhouse gases generally lead to increased temperatures of the Earth's thermal reservoirs. The vast majority of the excess heat ultimately is deposited within the Earth's oceans (approximately 90%). The added ocean heat content is perhaps the most clear evidence that the Earth is out of energy balance. Ocean heat content is measured by a variety of instrumentation that have evolved over the past decades. A review of the history of ocean temperature measurements is provided by Abraham et al. (2013). Combined with ocean measurements are reanalysis studies, which infill measurement gaps with numerical simulations (Balmesada et al. 2013a, 2013b). Summaries of recent ocean heat content results can be found in Nuccitelli et al. (2013) and Abraham et al. (2014), among others. All of these studies show a continued uptake of heat since at least 1970.

As an alternative to heat content measurements, some studies have used satellites to measure energy flow at the top of the Earth's atmosphere. These studies reinforce ocean measurements in that they too result in an energy imbalance of approximately 0.5 – 1 W m^{-2} (Trenberth et al. 2009; Trenberth and Fasullo 2010; Trenberth et al. 2014).

When focus is given to the relatively small thermal reservoir of the lower atmosphere, it is found that the trend is less monotonic than the oceans with much larger inter-annual fluctuations and shorter response time. It remains to be determined whether the recently observed fluctuations superimposed on a longer trend constitute a measurable change in the warming process. This topic has received recent attention such as Karl et al. (2015) who have incorporated improvements to measurement techniques. Here, a different approach to quantifying the so-called "hiatus" is described.

New research (Cahill et al. 2015) searched for changes in the warming rate of global surface temperature by applying a test designed for exactly that: change-point analysis. The change-points they identified, i.e. the times at which the warming rate changed, include those which are undeniably present, with their analysis estimating them at about 1912, 1940, and 1970. But no change-point was found after 1970, and when the authors attempted to force a recent change-point not only did it fail statistical significance, it led to convergence problems for the estimate.

Yet much of the climate science community seems to embrace the slowdown or hiatus claim, not merely as a hypothesis to be investigated but as an established fact. Rather than study the reality of the phenomenon, scientists have by and large taken to attempting to understand its causes. In fact *Nature Climate Change* and *Nature Geophysics* have recently joined forces to produce a special issue devoted to the topic. In our opinion, all such attempts will be beneficial whether the "slowdown" is real or not. But we argue that the question "is the slowdown real" deserves serious attention too, which it has not yet received.

Cahill et al. (2015) investigated multiple global temperature datasets, including those from NASA GISS, NOAA, HadCRU, and the revised version of HadCRU from Cowtan and Way (2014). Here, we will utilize only the NASA data, to which we will apply a suite of tests for rate changes in addition to change-point analysis.

Isolating the issue

Some important steps can be taken to isolate and focus on the genuine issue at hand. First, the analysis of Cahill et al. (2015) identifies the search period: with their final change-point in 1970, the relevant question to answer is whether the trend has changed since 1970. Hence we will study the data from 1970 onward in an attempt to show that it reveals some trend pattern other than just a linear rise at constant rate.

A simplifying procedure is to remove a linear trend (estimated by least squares regression) from the data since 1970, then test whether or not the residuals show any trend. If none is detected in the residuals, one cannot claim solid evidence of any recent change in warming rate.

A complication is introduced by the strong autocorrelation in monthly global temperature time series. We therefore study annual averages, rather than monthly values, a process that does not seriously weaken the certainty with which trends can be estimated and trend changes confirmed (e.g., Foster and Brown 2015). Annual averages will still show autocorrelation, but its effect can be neglected. Nonetheless, its presence slightly increases the chance of detecting a trend change when there is none.

It has been suggested that whatever "slowdown" may have occurred did not extend as far as 2014, so that a proper search for evidence of a slowdown should include 2013 but not 2014. Consequently, we chose to study the data from 1970 through 2013 but omit the record-setting hottest year 2014.

Therefore our focus is to study the time series of linearly de-trended annual average land-ocean global temperature anomaly (NASA GISTEMP LOTI) from 1970 through 2013. Temperature data are shown in Figure 1, and the residuals from a linear fit in Figure 2.

Change-point analysis

The essence of the analysis of Cahill et al. (2015) is to model the data as a continuous, piecewise linear function of time. The change point (moment at which the slope changes) is allowed to vary, testing all reasonable possibilities from beginning to end, and that which gives the best fit is selected if it passes statistical significance. Each such model fit, for a fixed change point, can be used to compute a single-trial, statistical test for significance in isolation; but when multiple change points are tested the result must be adjusted for multiple trials. In many cases, compensating for multiple trials will show that results, which are apparently significant, are in fact not. In no case will any result which fails statistical significance when treated as a single trial, be significant when multiple trials are accounted for.

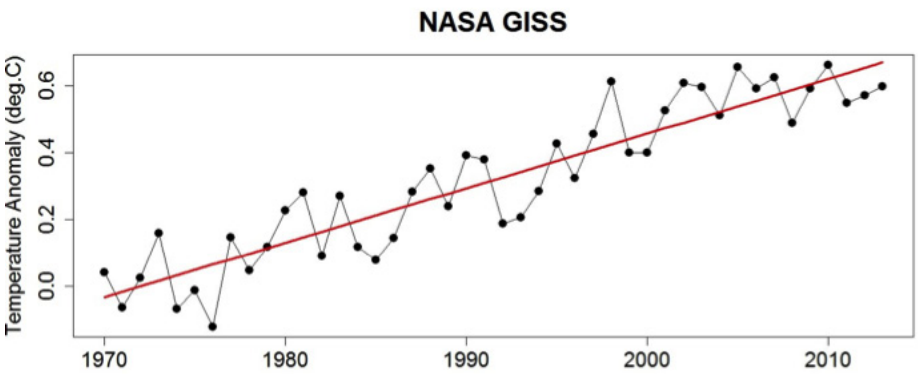

Figure 1: Annual average land-ocean temperature anomalies (°C) from 1970 through 2013 from the NASA GISS temperature dataset.

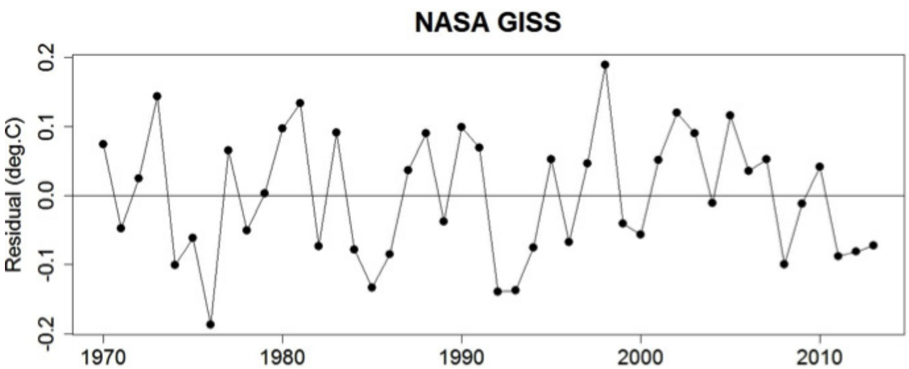

Figure 2: Residuals from a linear fit to annual average land-ocean temperature anomalies (°C) (from Figure 1).

To search for more general changes, we divided the residual data into segments of a fixed time length, for instance 10-year segments, such that the final one culminated with 2013 (the end of the data, when a slowdown has been claimed to occur). We then applied the one-way analysis of variance (ANOVA) to test whether any of these segments showed evidence of behaving differently than any of the others. In many cases the first segment had fewer years' data than the others, but that is not a problem for ANOVA. Trying all possible segment lengths from three years to 20 years, no compensation for multiple trials was needed because once again, none of the attempts yielded significant results.

The graph of temperature data gives the visual impression that the final three years of our time span (2011 through 2013) may have been distinctly different from what came before. Hence we also did a t-test of that three-year episode compared to the prior data from 1970 through 2010. One must bear in mind the null hypothesis that these three years come from the same distribution as their predecessors, so it is necessary to apply the equal variance version of the t-test. Doing so gives a p-value of 0.1109, again failing to establish any change with statistical significance.

It is very revealing that for these data, that crucial step isn't even needed, because no possible change point gives a result which is even apparently significant. The best fit is a change point in 2006, but it yields a p-value of 0.074 even if it were the only possibility tested; not as low as the cutoff limit 0.05 which is the de facto standard for statistical significance. The clear and dominant conclusion from change-point analysis is that real evidence for any recent trend change is nonexistent.

Other patterns

We searched the residuals for other patterns that might reveal a trend change, starting with polynomials of degree 2 through 10. Such a search also must be compensated for multiple trials since many possibilities are tested (one of the inherent complications involved in stepwise regression). But again, compensation for multiple trials was not needed because none of the results were even apparently significant.

As a last attempt to find evidence of a trend in the residuals, we allowed for models in which not only the slope (the warming rate) changes, but the actual value itself. These are discontinuous trends, which really do not make sense physically (cf. the discussion in Cahill et al. 2015) but because our goal is to investigate as many possible changes as is practical, we applied these models too. This is yet another version of change-point analysis, in which we test all practical values of the time at which the slope and value of the time series change. Hence it too must be adjusted for multiple trials.

Once again we neglected to apply any compensation for multiple trials because none of the tested change-points returned a significant result. As with all the tests we have applied, the evidence for any change in the surface temperature trend since 1970 not only fails to pass statistical significance, it fails by a large margin. The best fit using a discontinuous model is shown in Figure 3, despite its failure to pass statistical significance.

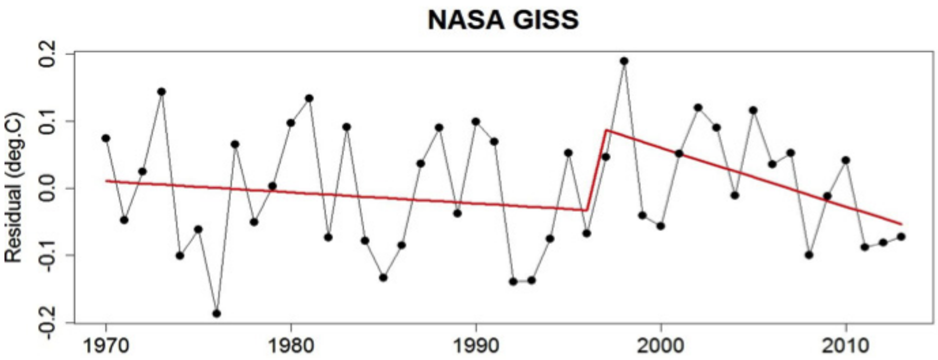

Figure 3: Best-fit model of residuals using a change point with change in both slope and value.

Conclusion

A barrage of statistical tests was applied to global surface temperature time series to search for evidence of any significant departure from a linear increase at constant rate since 1970. In every case, the analysis not only failed to establish a trend change with statistical significance, it failed by a wide margin.

Our results show that the widespread acceptance of the idea of a recent slowdown in the increase of global average surface temperature is not supported by analytical evidence. We suggest two possible contributors to this. First, the natural curiosity of honest scientists strongly motivates them to investigate issues which appear to be meaningful even before such evidence arrives (which is a very good thing). Second, those who deny that man-made global warming is a danger have actively engaged in a public campaign to proclaim not just a slowdown in surface temperature increase, but a complete halt to global warming. Their efforts have been pervasive, so that in spite of lack of evidence to back up such claims, they have effectively sown the seeds of doubt in the public, the community of journalists, and even elected officials.

An unfortunate habit in public discourse has been to graph only the data since the supposed "pause" began and state only the trend estimate since that moment, in order to avoid having to show that such a practice implicitly models temperature with a "broken" trend like that of Figure 3. Claims based on failing to reveal what happened before a purported trend change, are inevitably misleading.

It is certainly possible that some change in the trend has occurred since 1970, and it is very beneficial to look for causes, whether it is present or not. But we suggest that scientists should stop speaking of a "slowdown" in temperature increase as though it were a known fact, when it simply isn't. Furthermore, the inclusion of 2014 and the first part of 2015 which are both at record levels makes the case clearer that global warming is continuing without halt or reduction.

Data and computer code (in R) to reproduce this analysis are available as supplemental information; please contact Grant Foster at tamino_9@hotmail.com.

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