No "slowdown" in the story of global warming

Much has been written about the supposed "slowdown" in the rate of global warming between 2001 and 2014. But focusing on this narrow 14-year window ignores the broader story, says **Niamh Cahill**

Climate change is arguably the most important scientific story of our time, and for the clear majority of scientists the story is as follows. Since the 1970s, the Earth has been getting warmer. Yes, temperatures on planet Earth have evolved over millennia, shifting between warm and cold periods lasting hundreds or thousands of years. And, of course, on much shorter time-scales we find that some years are hotter or cooler than others. But the rate of temperature change we are now seeing is different. Over the past several decades, the planet has been heating up, and this increase in temperature is almost entirely attributed to human activity.

The scientifically accepted narrative is that this warming trend has led to melting ice sheets and glaciers, rising sea levels and volatile weather conditions. Continuing down this path will lead us to a frightening future. The consensus within the scientific community is that we must counteract the current rate of warming or face the consequences.

But even though temperatures have been increasing overall since the 1970s, it has been noted that between 2001 and 2014, global temperatures stopped rising quite so fast;[1] the rate of change slowed in what has been referred to as a "hiatus" or "slowdown" period.

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To some so-called "climate skeptics", this is seen as a curious development. It has long been established that global warming is caused by the increase in greenhouse gas emissions produced by human activity, but this "slowdown" has been construed as casting doubt on this causality. If greenhouse gas emissions have continued, the skeptics ask, how is it that the rate of temperature increase has stalled? This interpretation of the data risks undermining public understanding of global warming, unless we recognise that there is nothing unusual about the "slowdown" period itself.

Room for uncertainty

The change in global temperatures is seen worldwide in land and sea-surface measurements. Agencies such as NASA and the National Oceanic and Atmospheric Administration (NOAA) in the United Sates, and the Hadley Centre in the United Kingdom, have compiled these data since the 1880s (see "The data"). Land temperatures are measured at meteorological stations, and sea-surface temperatures are measured using ships, buoys and satellites. The records are updated monthly.

For each set of data that is collected, there are short-term variations in the temperatures recorded. These differences tell us little in isolation, but they do introduce uncertainty about exactly what is happening to global temperatures. Specifically, the variation in measurements creates uncertainty about the exact rate at which temperature change has occurred. Statisticians, who are used to dealing with uncertainty in measurements, can use this information to produce an estimate of what is most likely to have happened, as well as a range of other scenarios that are also possible, if less likely.

In this context, the 14-year "slowdown" period from 2001 to 2014 may be cast in a somewhat different light. Should we be surprised to observe a period in which temperatures increase at a slower rate than before, given the variability in our measurements? Is the "slowdown" an entirely unexpected occurrence, or is it in keeping with the previous warming trend (the rate of temperature change) when we take *uncertainty* into account? Statistically, we can answer this using a

The data

We consider five prominent global temperature data sets:

- NASA GISTEMP;[3]
- NOAA;[4]
- HadCRUT4;[5]
- the revision of HadCRUT4;[6] and
- the Berkeley Earth surface temperature.[7]

All are combined land and ocean series. Some of these[3,6,7] aspire to provide a full global mean by interpolating into some data-sparse regions of the globe, most notably the Arctic. The others simply ignore data gaps and average over the data-covered part of the world; the resulting figure will be systematically biased relative to the true global mean if the data-sparse regions deviate from the global mean rate of warming.

TABLE 1 Simulation results. Shown are the standard deviations (std. dev.) of the data in the baseline period; the warming trends during the baseline period; the warming trends during the "slowdown" period; and the likelihood that a trend at least as low as that during the "slowdown" period would be observed by chance if the baseline trend and standard deviation had continued unchanged.

Data source	1972–2000 Measure of data variability (std. dev.) (°C)	1972–2000 Baseline trend (°C/yr)	2001–2014 "Slowdown" trend (°C/yr)	Likelihood of the 2001–2014 trend
Hadley Centre, UK	0.103	0.0172	0.0030	31%
NASA, USA	0.103	0.0173	0.0074	73%

significance test, and the question then becomes: "Is the 2001–2014 trend significantly different from the previous trend?"

In a significance test, we assume some default behaviour under a set of conditions referred to as the null hypothesis (see "A significant test for a slowdown"). In this case, we assume that there has been no "slowdown" in global warming based on the null hypothesis of a constant warming trend. If something happens that would be unexpected under this assumption – and here we are talking about a low-probability scenario, such as a big change in temperature trends – we consider that to be a significant event.

For global temperature, we want to test whether the 14-year "slowdown" between 2001 and 2014 was a low-probability event – and therefore a significant event – or a plausible continuation of what happened between 1972 and 2000, which is the period from the beginning of the current quasi-linear warming trend up to the start of the "slowdown". To perform this test, we assume that the 1972–2000 baseline trend holds throughout the period 1972–2014. We then simulate data based on this trend (and recall that there is a range of possibilities due to random short-term variability), and we look for any 14-year period which shows a temperature trend similar to that seen between 2001 and 2014, based on the assumption that there would be nothing inherently special about this particular period. From this we determine how probable was the trend between 2001 and 2014. The higher the probability that a similar 14-year trend could have occurred at *any time* between 1972 and 2014, the less surprised we should be to see it happening from 2001 to 2014.

A significant test for a slowdown

For our purpose, a significant slowdown or acceleration in global warming is a behaviour of global mean temperature which is unlikely to occur under the null hypothesis of a constant warming trend (including its variability as observed in a suitably defined baseline period). In other words, a significant change in warming trend refers to a temperature evolution which is unlikely to be a result of a random variation found in the baseline period. Our null hypothesis is defined as "the long-term trend and short-term noise continue unchanged". Any claim of a significant slowdown or acceleration would require data that are highly unlikely (e.g. 5% or 10% likelihood, depending on the desired confidence level) under the null hypothesis condition.

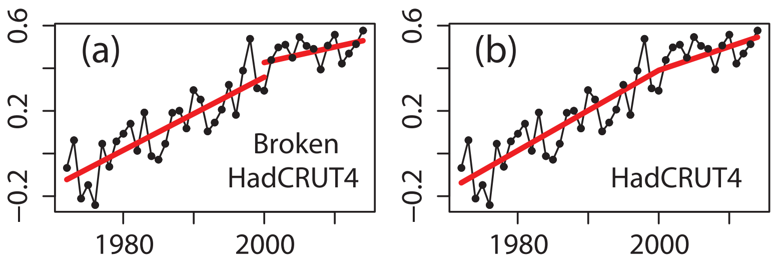

FIGURE 1 Trend change models for the HadCRUT4 data set, allowing for a slope change in 2001: (a) shows a broken trend and (b) shows a continuous trend.

Regardless of the global temperature data set used to generate our simulations, the results show that there is nothing particularly unusual about what happened to global temperatures during the "slowdown" period (see Table 1). We had a 31% chance (for the Hadley Centre data) or a 73% chance (for the NASA data) of seeing a 14-year trend as low or lower than the trend between 2001 and 2014. The most commonly used cut-off for what might be considered unexpected is 5%. Anything above 5% is typically not considered to be a significant event.

In Figure 1(a) we break the trends between the two time periods, 1972–2000 and 2001–2014. Visually there does appear to be a difference. However, to provide a reliable result we need to ensure a connection between the two trends, as shown in Figure 1(b), which of course makes physical sense. Isolated pieces of trend line with sudden changes between them would not provide a physically plausible model for global temperature, given the thermal inertia of the system. A change in the factors that affect Earth's climate can change the rate of warming, but the effects are seen over years and decades. There is no clean break with the past. However, if we insist on looking at the 2001–2014 "slowdown" as an isolated time period, then we need to at least account for the fact that information is being disregarded. In either case, results show that the difference in trends between 1972–2000 and 2001–2014 is not statistically significant.

In other words, there was nothing unusual about what happened to global temperatures between 2001 and 2014. Caution is needed when looking at this time period in isolation because we should not ignore what happened previously. We must look at the global temperature story in its entirety. When we do so, using a technique known as change-point analysis,[2] we find three periods between 1880 and 1980 with significantly different rates of global temperature change (see Figure 2, Table 2 and the box "Choosing the number of change points").

First, we see a positive rate of warming early in the twentieth century, which was lower than the rate we are currently experiencing and was likely a result of increasing solar luminosity and greenhouse gases. The negative rate of warming between the 1940s and 1970s coincides with an increase in aerosol pollution of the atmosphere, which has a cooling effect. The final period, from the 1970s onwards, is the current quasi-linear warming trend. The analysis finds no significant difference in the rate of global temperature change from 2001, or at any time after 1980.

The story remains the same

Reported global temperatures will fluctuate from year to year, in part because of the uncertainty in our measurements, but mainly because of the somewhat chaotic nature of the climate system. Over a short period of time, these fluctuations may take on the semblance of a pattern or trend. But such things are arguably inconsequential when set in the wider context: temperatures, on average, have been increasing since the 1970s and continue to do so. Any other reading of the story, as told by the data, is a distraction.

The intention here is to highlight potential pitfalls that have been encountered with the analysis of global temperatures and to present the most appropriate analysis techniques. We do not intend to dwell on the supposed "slowdown", but to clarify this misunderstanding once and for all. We need to re-establish focus on what is truly important: the global warming trend, and its implications for our planet and its inhabitants. ■

Note

This article is based on "Global temperature evolution: recent trends and some pitfalls" (bit.ly/2vWaEbc).

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Choosing the number of change points

The model takes the number of change points, m, as a fixed parameter. To determine the most appropriate value of m, and thus the number of change points, we use the deviance information criterion (DIC).[8] The DIC works by penalising the deviance (a measure of the quality of the model's fit to data) by its complexity, determined by the effective number of parameters. In general, as model complexity increases, the deviance will decrease, so adding this penalty will select parsimonious models that fit the data well but are not too complex. The DIC is negatively orientated (i.e. a smaller value indicates a better model). When running the models, we chose a range of values (e.g. from 0 to 5). Parameter convergence is monitored; models that do not show convergence are rejected and, from the remainder, DIC is used to decide on the most appropriate model for the data.

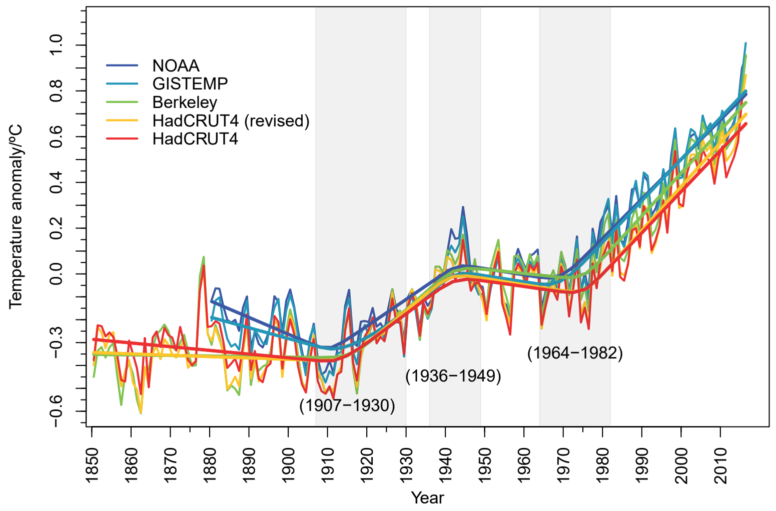

FIGURE 2 Overlaid on the raw data are the mean curves predicted by the three-change-point model. The grey time intervals display the total range of the 95% confidence limits for each change point. There has been no detectable trend change in any of the global temperature records at any time since 1980.

TABLE 2 Average rates of temperature change per year (with 95% confidence intervals) for the three change point (CP) periods shown in Figure 2.

Data set	Average rates of temperature change (°C) per year with 95% CIs		
	Between CP 1 and CP 2	Between CP 2 and CP 3	After CP 3
NOAA	0.012 ± 0.001	−0.003 ± 0.002	0.017 ± 0.001
GISTEMP	0.014 ± 0.005	−0.003 ± 0.003	0.018 ± 0.001
HadCRUT4	0.013 ± 0.003	−0.002 ± 0.002	0.018 ± 0.001
HadCRUT4 (revised)	0.014 ± 0.003	−0.003 ± 0.002	0.019 ± 0.001
Berkeley	0.016 ± 0.003	−0.002 ± 0.002	0.019 ± 0.001

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