Climate Closure

In the battle of public opinion over climate change, we can play to science's strengths by shifting tactics: Instead of struggling to prove humans are to blame, let's prove denialist fantasies wrong.

A straightforward line of reasoning demonstrates that the only viable explanation of postindustrial warming is an anthropogenic source. This explanation is compatible with the “pause” in the warming since 1998, and it demonstrates that, in a statistical sense, such a pause is extremely likely. Credit: Shaun Lovejoy.

By S. Lovejoy 20 October 2015

Global warming science has concentrated on proving the theory that the postindustrial warming is largely caused by human activities. Yet no scientific theory can be proved beyond all doubt, and our attempts to convince people of the science are entering a period of diminishing returns.

For example, the Fifth Assessment Report (https://www.ipcc.ch/report/ar5/) (AR5, 2013) of the International Panel on Climate Change (IPCC) reiterated its 2007 statement "that human influence has been the dominant cause of the observed warming since the mid-20th century," only upgrading it from "likely" to "extremely likely." Meanwhile, those who reject this anthropogenic hypothesis have continued to push their theory that the warming is a giant fluctuation of solar, nonlinear dynamics that are internal to the atmosphere or other natural origin. For brevity we will call this group the "denialists," following the suggestion of *Gillis* [2015].

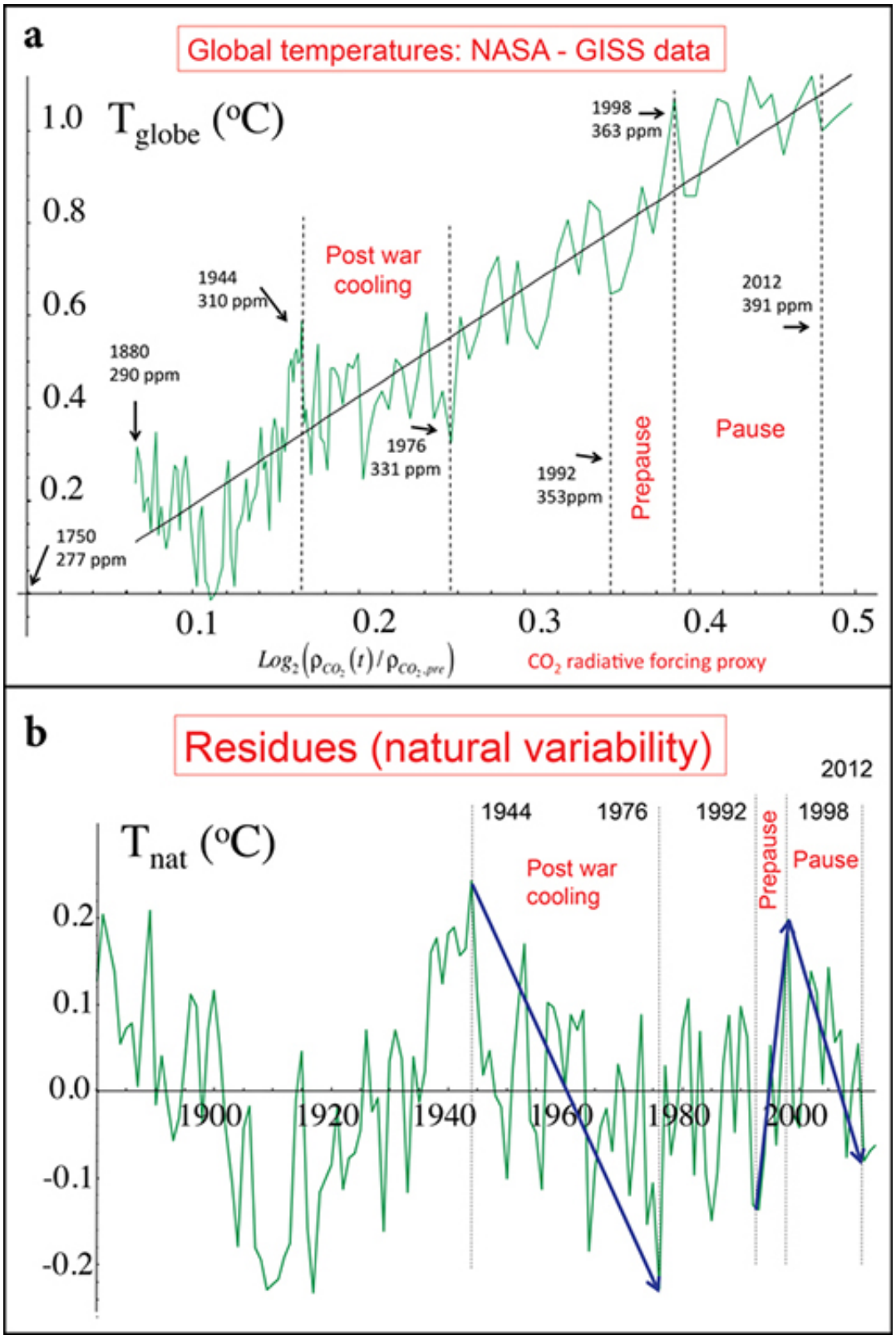
Although no scientific theory can ever be proved in a mathematically rigorous sense, even elegant theories can be disproved by a single decisive experiment.
In order to end the scientific part of the debate—to reach "climate closure"—it is therefore necessary to demonstrate that the giant fluctuation theory has such a low probability that we can confidently dismiss it. To do this, we can use a fundamental asymmetry in scientific methodology: although no scientific theory can ever be proved in a mathematically rigorous sense, even elegant theories can be disproved by a single decisive experiment.

Below, we summarize a straightforward disproof that achieves this closure so that the only viable explanation of the warming is anthropogenic [*Lovejoy*, 2014a, 2014b, 2015; hereinafter L1, L2, L3]. The same methodology also shows how the anthropogenic theory is compatible with the "pause" in the warming since 1998 and, indeed, in a statistical sense, that such a pause is extremely likely. As a bonus, denialist arguments based on the uncertainties of complex numerical models are rendered irrelevant because this demonstration does not require these models [*Lemos and Rood*, 2010; *Norton and Suppe*, 2001]. Finally, the basic argument can be understood by the lay public.

A Simple Approach to Determine Human Effects

The effects of climate forcings are difficult to quantify and contribute to the large model uncertainties. However, since 1880, the forcings have been linked to economics. To a good approximation, if you double the world economy, double the carbon dioxide (CO_2), double the methane and aerosol outputs, and double the land use changes, you get double the warming. This

justifies using the global CO_2 forcing since 1880 as a linear surrogate for all the anthropogenic forcings (L1; using CO_2 equivalent yields nearly identical results).



(https://eos.org/opinions/climate-closure/attachment/presentation9)

Fig. 1. (a) Global temperature anomalies (NASA, 1880–2013) as functions of radiative forcing using the carbon dioxide (CO2) forcing

as a linear surrogate. The line has a slope of 2.33°C per CO2 doubling. Some dates and corresponding annually, globally averaged CO2 concentrations are indicated for reference. GISS, Goddard Institute for Space Studies; ppm, parts per million. Adapted from *Lovejoy* [2014b, Figure 1a]. (b) The residuals from the straight line in Figure 1a; these are the estimates of the natural variability. The vertical dashed lines are the same as in Figure 1a. The arrows indicate notable events. Adapted from *Lovejoy [2014b, Figure 1c].*

Figure 1a shows the global annual temperature plotted not as a function of the date, but rather as a function of the CO_2 forcing. Even without fancy statistics or special knowledge, it is easy to see that the temperature (plotted in green) increases very nearly linearly with some additional fluctuations; these represent the natural variability. The slope (black), 2.33°C per CO_2 doubling, is the actual historical increase in temperature due to the observed increase in CO_2: the "effective climate sensitivity." As a check on our assumptions, this figure sits comfortably in the IPCC range of 1.5°C–4.5°C per CO_2 doubling for the (slightly different) "equilibrium climate sensitivity."

The difference (residues) between the actual temperature and the anthropogenic part is the natural variability, which is plotted in Figure 1b. We can confirm that this is reasonable since the average amplitude of the residues (±0.109°C) winds up being virtually the same as the *errors* in 1-year global climate model hindcasts (https://en.wikipedia.org/wiki/Backtesting#Hindcast) (±0.105°C and ±0.106°C from *Smith et al.* [2007] and *Laepple et al.* [2008], respectively). So knowing only the slope of Figure 1a and the global annual CO_2, we could *predict* the global temperature for the next year to this accuracy (L3). Clearly, this residue must be close to the true natural variability.

Disproving Natural Causes

The range of the straight line in Figure 1a is an estimate of the total anthropogenic warming since 1880—about 1°C. What is the probability that the denialists are right and that this is simply a giant natural fluctuation? This would be a rare event but how rare?

To check that comparisons of the current period against the historical record are valid, L1 reconstructed records of volcanic and solar activity. That study concluded that the statistics of the industrial epoch variations are no different from the preindustrial ones. Volcanic activity was highly intermittent but no more so than usual; solar activity, which denialists often blame for the

observed warming, has, if anything, diminished over the last 50 years [*Foukal et al.*, 2006].

Then, L1 used preindustrial temperature series drawing on several sources to estimate the likelihood of a given amount of natural temperature change. Applying the usual statistical approach—the bell curve—to these data leads to the conclusion that the chance of a 1°C fluctuation over 125 years being natural is in the range of 1 in 100,000 to 1 in 3,000,000. This is a rough estimation: for long periods, the standard deviation of temperature *differences* is twice the 0.1°C value. Hence a 1°C fluctuation is about five standard deviations, or a 1 in 3,000,000 chance.

However, nonlinear geophysics tells us that the extremes should be far stronger than the usual bell curve allows. L1 shows that 1°C, century-long global-scale fluctuations are more than 100 times more likely than the bell curve would predict. This gives a probability of at most 1 in 1000, which is still small enough to confidently reject this possibility.

A Necessary "Pause"

One can apply the same type of analysis to the hiatus in the warming (the relatively flat part of the fluctuating line in Figure 1a after 1998), also referred to as the pause. Figure 1b shows that it is actually a natural cooling event sufficiently large (≈0.3°C) that it has masked the more or less equal anthropogenic warming over the period.

Although this cooling is somewhat unusual, it is not rare: similar 15-year coolings have a natural return period of 20–50 years.
Although this cooling is somewhat unusual, it is not rare: statistical analysis shows that similar 15-year coolings have a natural return period of 20–50 years (L2). Additionally, in this case, the cooling immediately follows the even larger prepause warming event (1992–1998; Figure 1b). That is, the pause is no more than a return to the mean; it can be accurately hindcast (L3).

Alternatively, *Karl et al.* [2015] has recently produced a temperature series with new ocean and other bias corrections. In this warmer series, the amplitude of the corresponding natural cooling is 0.09°C less than that shown in Figure 1b. Since the return period for this smaller natural cooling is only about 10 years (L2, Figure 2), decadal trends cannot (and did not) detect any statistically significant pause at all.

In any case, far from supporting denialist claims that the warming is over, this return is a necessary consequence of the theory of anthropogenic warming that predicts that the natural variability will cause fluctuations to stay near the long-term anthropogenic trend in Figure 1:

without it, the warming would have soon become unrealistically strong.

Quod Erat Demonstrandum

The scientific method is much more effective at rejecting false hypotheses than in proving true ones. By estimating the probabilities of centennial-scale preindustrial temperature changes, with 99.9% confidence we are able to reject the denialist hypothesis that the industrial age warming was from solar, volcanic, or other natural causes, leaving anthropogenic origin as the only alternative.

The scientific debate is now over; the moment of closure has arrived. Although climate scientists must move on to pressing scientific questions such as regional climate projections and the space–time variability, our species must tackle the urgent issue of reducing emissions and mitigating the consequences of the warming.

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