Is the climate warming or cooling?

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[1] Numerous websites, blogs and articles in the media have claimed that the climate is no longer warming, and is now cooling. Here we show that periods of no trend or even cooling of the globally averaged surface air temperature are found in the last 34 years of the observed record, and in climate model simulations of the 20th and 21st century forced with increasing greenhouse gases. We show that the climate over the 21st century can and likely will produce periods of a decade or two where the globally averaged surface air temperature shows no trend or even slight cooling in the presence of longer-term warming.
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1. Introduction

[2] Anthropogenic climate change is one of the most contentious scientific issues of our time. Not surprisingly the issue has generated numerous blogs and websites with a wide range of views on the subject. According to a number of these sources the climate is no longer warming, in fact, some claim the planet has been "cooling" since 1998 [e.g., *Investor's Business Daily*, 2008].

[3] It is true that if we fit a linear trend line to the annual global land-ocean surface air temperature [*Smith et al.*, 2005] shown in Figure 1 for the period 1998 to 2008 there is no real trend, even though global temperatures remain well above the long-term average. The unusually strong 1997–1998 El Niño contributed to unusual warmth in the global temperature for 1998 at the start of this period resulting in only a small, statistically insignificant positive trend. However, if we fit a trend line to the same annual global land-ocean temperatures for the 1977–1985 period or the 1981–1989 period we also get no trend, even though these periods are embedded in the 1975–2008 period showing a substantial overall warming. Furthermore, if we drop 1998 and fit the trend to the period 1999–2008 we indeed get a strong, statistically significant positive trend. It is easy to "cherry pick" a period to reinforce a point of view, but this notion begs the question, what would happen to the current concerns about climate change if we do have a sustained period where the climate appears to be cooling even when, in the end, the longer term trend is warming?

[4] The reality of the climate system is that, due to natural climate variability, it is entirely possible to have a period as long as a decade or two of "cooling" superimposed on the longer-term warming trend due to anthropogenic greenhouse gas forcing. Climate scientists pay little attention to these short-term fluctuations as the short term "cooling trends" mentioned above are statistically insignificant and fitting trends to such short periods is not very meaningful in the context of long-term climate change. On the other hand, segments of the general public do pay attention to these fluctuations and some critics cite the most recent period as evidence against anthropogenic-forced climate change. Here we analyze both the observed record and a series of climate model simulations for the occurrence of both positive and negative decadal trends in the globally averaged surface air temperature to show that it is possible, and indeed likely to have a period of as long as a decade or two with no trend in an anthropogenically forced climate.

2. Data and Methods

[5] For this analysis we examine the observed globally averaged surface air temperature time series for the period 1901–2008 produced using the method described by *Smith et al.* [2005]. This data set is routinely updated and used in climate monitoring activities by the National Climatic Data Center. Coupled climate model simulations of globally averaged surface air temperature were obtained from the Coupled Model Intercomparison Project 3 (CMIP3) [*Meehl et al.*, 2007] database of climate model simulations archived at the Program for Climate Model Diagnosis and Intercomparison (PCMDI) at the Lawrence Livermore National Laboratory.

[6] Our analysis consisted of fitting least-squares trends to running 10-year periods in the global surface air temperature time series for: 1. the observed record, 2. an ensemble of long control simulations, 3. an ensemble of 20th century simulations, and 4. an ensemble of simulations forced with the Special Report on Emissions Scenarios (SRES) [*Nakicenovic and Swart*, 2000] A2 forcing scenario for the 21st century. This resulted in probability distribution functions of decadal trends for each of the 4 sets of time series.

3. Results

[7] Figure 2 shows the average annual global surface air temperature from a single simulation of the ECHAM5 coupled climate model [*Roeckner et al.*, 2003] forced with the SRES A2 forcing scenario. The A2 scenario postulates a "business as usual" future with little reduction in anthropogenic emissions resulting in large greenhouse gas concentrations by the end of the 21st century. We chose this simulation randomly from the CMIP3 database of climate model simulations. In this simulation by the end of the 21st century the global climate warms by approximately 4°C, consistent with the other climate model simulations used in the Fourth Assessment Report (AR4) of the

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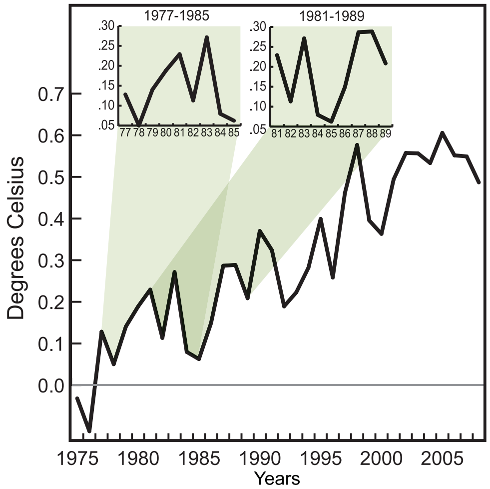

Figure 1. Globally averaged surface air temperature for land and ocean based on the data set by *Smith et al.* [2005].

Intergovernmental Panel on Climate Change [2007]. An individual simulation, as opposed to a multi-model, multi-realization average, reveals interesting decadal scale features that can provide insight into the single trajectory that the actual climate is taking. We highlight two periods in Figure 2, 2001–2010 and 2016–2031. Both of these periods show a small, statistically insignificant negative trend based on a simple least-squares trend line and there are other periods, such as the last seven years of this simulation, that show a similar lack of trend. This behavior occurs without any simulated volcanic eruptions or solar variability (natural forcing) that could result in a widespread cooling for some period of years and thus is presumed entirely due to natural internal variability.

[8] This behavior is not unique to this particular realization of the ECHAM5 model and to illustrate this, we show in Figure 3 the probability distribution functions of decadal trends in annual average global surface air temperature in the observed record [*Smith et al.*, 2005] and several numerical experiments. The black line is calculated from the observed record, magenta from pre-industrial control simulations containing no anthropogenic or natural forcing factors that have been detrended due to model drift in these

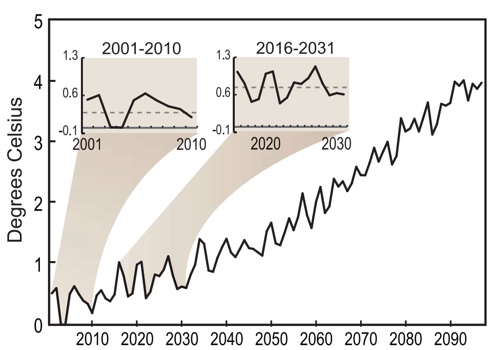

Figure 2. One realization of the globally averaged surface air temperature from the ECHAM5 coupled climate model forced with the SRES A2 greenhouse gas increase scenario for the 21st century.

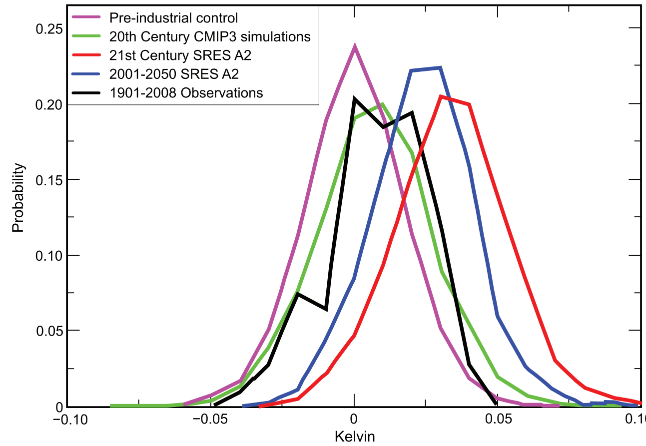

Figure 3. Probability distribution functions for decadal trends (kelvin/year) in globally averaged surface air temperature for the observed record (black), a set of pre-industrial control runs (magenta), the 20th century simulations (green), and the 21st century simulations forced with the SRES A2 scenario for the first half of the 21st century (blue) and entire 21st century (red).

experiments, the green line from simulations of the 20th century with both natural and anthropogenic forcing, the blue line from simulations for the first half of the 21st century forced with the A2 emissions scenario, and the red line from simulations of the entire 21st century under the A2 scenario. We used all available simulations in the CMIP3 database for the IPCC AR4 in the construction of these distributions.

[9] Not surprisingly the probabilities for the long control runs are symmetrical around a zero trend, with more or less equal chances of a positive or negative decadal trend over the entire global surface air temperature time series. For the 20th century simulations (using observed natural and anthropogenic forcing) there is a shift in the distribution to more positive values but there is still a significant chance of a negative decadal trend. The observed record shows a very similar distribution to the 20th century simulations, especially considering that only one version of the observed record was used in this analysis adding credence to the conclusions in the IPCC AR4 that the observed warming since 1950 is very likely due to increasing greenhouse gases. Finally for the simulations of the entire 21st century there is still about a 5% chance of a negative decadal trend, even in the absence of any simulated volcanic eruptions. If we restrict the period to the first half of the 21st century the probability increases to about 10% revealing that the trend in surface air temperature has its own positive trend in the A2 emissions scenario.

[10] Another interesting question is the percentage of the decadal trends that are statistically significant in each of the modeling experiments and the observed record. We calculated the percentage of both negative and positive decadal trends outside of the 95% confidence interval of the control experiment (as defined from the control variance). As the observations and the transient experiments include increasing greenhouse gas forcing, we expect to find more statistically significant positive trends and fewer statistically significant negative trends. Table 1 shows that this is indeed

Table 1. Percentage of Statistically Significant, 95% Confidence Level, Positive and Negative Decadal Trends by Modeling Experiment and the Observed Record

Experiment	Negative Trends (%)	Positive Trends (%)
Observations, 1901–2008	1.0	3.0
Control	2.65	2.65
20th Century	1.97	8.63
A2, 2000–2050	0.0	26.0
A2, 2000–2099	0.0	47.4

the case. The control experiment has an equal percentage of statistically significant positive and negative trends. The observations and the 20th century simulations show similar small percentages although the model results reveal a somewhat broader distribution. The difference may in part be due to the single realization for the observed record. However, for the A2 forcing scenario, both for the first half and the entire 21st century there are no statistically significant negative trends. But, consistent with the positive shift in the probability distributions, the percentage of statistically significant positive trends increases from 26% for the first half of the 21st century to 47% for the entire century.

[11] What does this say about the variability of the climate system? Climate models are often criticized for producing a more or less monotonic-type response to anthropogenic forcing in 21st century simulations. Part of this may be due to the lack of volcanic and solar forcing in the SRES scenarios of anthropogenic forcing increase for the 21st century and part could be due to the fact that large-scale oscillatory climate features, such as the El Niño-Southern Oscillation are not well simulated. However, even considering these criticisms, it is clear that the models can and do produce sustained multi-year periods of "cooling" embedded within the longer-term warming produced in the 21st century simulations. Therefore, it is reasonable to expect that the natural variability of the real climate system can and likely will produce multi-year periods of sustained "cooling" or at least periods with no real trend even in the presence of long-term anthropogenic forced warming. Claims that global warming is not occurring that are derived from a cooling observed over such short time periods ignore this natural variability and are misleading.

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