Some Observations on Global Warming

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Abstract

This note summarizes my published papers on the analysis of global warming data and the related change in the seasonal cycle. Two figures from work in progress are also included. The increase in average temperature and the changes in the annual cycle during the last century are primarily a result of human use of fossil fuels.

1 Introduction

The subject of global warming is contentious for several reasons. One of these is that the data is so complicated that very few scientists are trained to analyze it. My work is in Bell Labs Mathematics Research Center where I specialize in the analysis of complicated time-series.[1] My work is mostly devoted to developing methods to analyze such time-series data and technological applications such as cellular phone systems, touch-tone detectors, and a variety of geophysical problems of interest to the company. During the 1980's, as a result of this work, I began to apply my analytical methods to environmental data with the results summarized in this note.

There are four questions regarding global warming that are often confused:

1. Is the global temperature increasing abnormally?
2. Is the warming due to burning fossil fuels?
3. Is the warming necessarily bad?
4. Are the detailed physical processes causing the warming understood?

I believe that the answer to the first two questions is "yes", the third is "highly likely", and the last "in general terms, but details are uncertain".

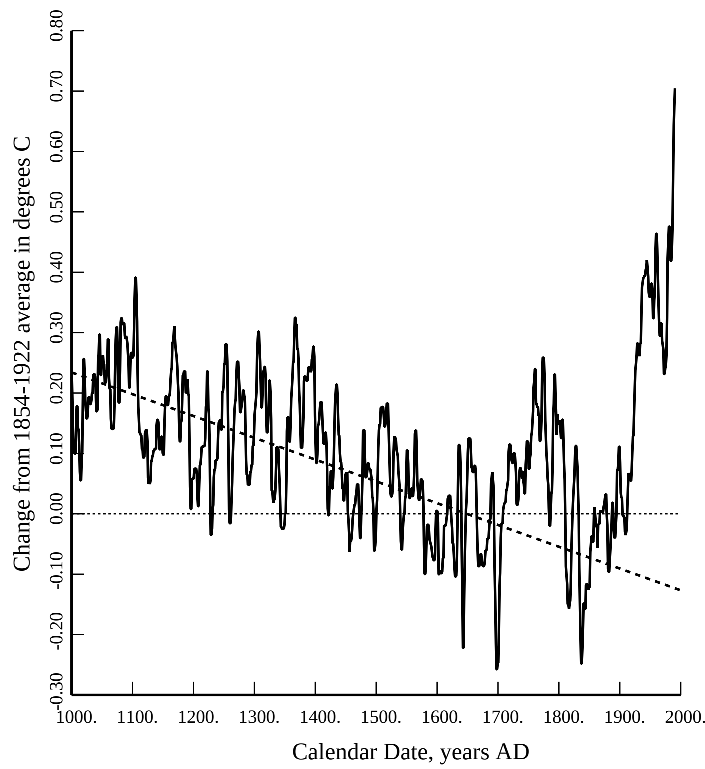

Figure 1: Average of the Mann and Jones Holocene Northern Hemisphere temperatures merged with the Jones instrumental series.

2 Climate History

Understanding the vagaries of the present climate debate requires an understanding of past climates, of the time-scales involved, and of geographic variability. Twenty-thousand years ago, the edge of the glaciers was about at Murray Hill, and the average global temperature about $4°C$ colder than at present. I have published two papers, [1, 2], on long-term climate phenomena with time-scales of thousands and hundreds-of-thousands of years. These are important in that they give a baseline for understanding long-term climate and solar fluctuations. One feature of the Earth's climate system that should be noted from paleoclimate studies is its incredible sensitivity. As a specific example, the obliquity of the rotation axis on the ecliptic varies by $\pm 3/4°$ with a period of 41,000 years. This produces such a clear signal in ocean cores, etc. that it is used as a clock to date long records. Three-quarters of a degree is equivalent to moving 50 miles north or south.

One frequently hears arguments along the lines that "temperature changes

[1]Time-series are simply data, such as temperatures, where the order is important.

during glacial periods were larger than at present" as a reason why the present warming is "natural" and hence can be ignored. Such reasoning ignores at least two factors: First, there is a *known* physical reason for the ice ages; it's simply that the Earth's orbit changes. Second, these are *slow* changes. From glacial maximum (about 20,000 years ago) to climate optimum (6000 years ago) the Earth's average temperature increased by 4 or 5 degrees C,[2] about $0.04°C$/century (most of the warming occurred in about 10,000 years). The last century has warmed about $0.8°C$, 20 times as fast.

Similarly, fast fluctuations in temperature derived from Greenland ice cores do not explain the change in average temperature. Anyone who has read the history of the Arctic explorations knows that the climate and ice conditions there varied dramatically from decade-to-decade without corresponding glaciers or tropical forests in New Jersey. Consequently, seeing similarly rapid variations in polar proxy records should not be a surprise, and can not be used to "explain" the current large changes in global average temperature.

Figure 1 summarizes some data from the "recent" past, the last thousand years. This is an average of the temperatures reconstructed by Jones [3] and Mann [4] and, starting in 1854, the instrumental data record.[3] This temperature curve illustrates several features: First, the gradual cooling evident from 1000 AD until the last century is almost certainly from changes in the earth's orbit that, if continued for several thousand years, would eventually take us into the next ice age.[4] Second, as had been inferred from the historical record, the climate has not been constant, but has had fluctuations on the decade to century time scale. These fluctuations about the orbital trend appear to be mostly solar and volcanic effects and although regional effects have been severe, the change in hemispheric average temperatures have been reasonably small.[5] Third, the rapid temperature increase in the last century is unprecedented. If the trend estimated from 1000 AD to 1700 AD is extrapolated to 1990, it predicts $-0.123°C$, $0.83°C$ lower than observed. This difference is about 10 standard deviations, something exceedingly unlikely to occur by chance.

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[2] This change in average temperature, 4 or 5 degrees C, serves as a good calibration for judging the effects of warming. Remembering that a decrease of $4°C$ corresponds to full glacial maximum, we should anticipate similarly catastrophic changes from a temperature increase of $4°C$.

[3] The two long series are derived from proxy data, such as tree rings. These have been filtered by taking five-year blocks, discarding the highest and lowest measurements, then averaging the center three. The two series are then averaged and merged with the instrumental data. The zero reference is the average from 1854, the start of the instrumental data series, until 1922, near when rapid warming began.

[4] The slope, estimated from 1000 AD to 1700 AD is $-0.036°C$/century, roughly the same magnitude as the warming following glacial maximum.

[5] The standard deviation about the trend from 1000 AD to 1700 AD is $0.086°C$. This is only slightly higher than that found, $0.081°C$ for the Northern Hemisphere instrumental data, [5], implying that the temperatures derived from paleoclimate data are quite accurate.

3 Three Major Papers

The following three sections summarize my published papers on recent climate data and the relations between carbon dioxide, changes in solar irradiance, and temperatures.

3.1 Coherence established between atmospheric carbon dioxide and global temperature

This paper [6], published in *Nature* with a summer student, Cynthia Kuo, and a post-doc, Craig Lindberg, showed that the fluctuations in temperature and atmospheric CO_2 varied together even after the large linear trends in both had been removed. There were three major results in this paper:

1. The observed coherence was large enough that, if temperature and CO_2 were as unconnected as the skeptics claim, the observed level would be expected to occur by chance in only two out of a million trials. We typically accept medical statistics as significant at the 95% point, that is, the result would occur by chance in five of one hundred trials.

2. Considering *only* temperature and atmospheric CO_2, changes in temperature *lead* those in CO_2 by about five months. This is in agreement with theory, but, with my engineering background, is very disturbing as it implies positive feedback.

3. The annual cycle in the temperature data was more complicated than had been assumed.

3.2 The Seasons, Global Temperature, and Precession

This paper [7], published in *Science*, was the result of studying the complications on the annual cycle mentioned in item 3 above, and to describe a test of the Friis-Christensen and Lassen hypothesis that the recent warming is primarily solar. This paper reported the discovery that the timing of the seasonal cycle was being disrupted by CO_2, a possibly more serious problem than the change in average temperature. The main findings of this paper are:

1. In much of the world, the frequency of the annual temperature cycle is that of the *anomalistic* year (the time from perihelion to perihelion, 365.2596 days) and *not* the tropical year that the calendar approximates. This means that the process commonly used to remove the annual cycle from temperature data is biased. Removing this bias makes interpreting the data easier and more reliable.

2. The timing of the seasonal cycle has changed radically in recent years (since about 1950) compared to earlier data.

3. The variance of the frequencies of the annual temperature cycle for the last fifty years has doubled with respect to those of the previous fifty years.

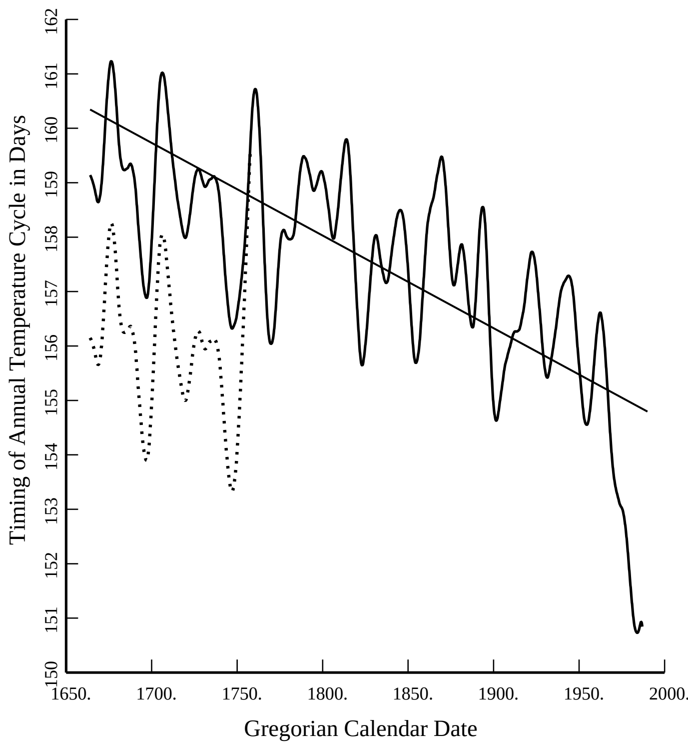

Figure 2: Figure 1 from the *Science* paper, showing the changes in the timing of the seasonal cycle in the Central England temperature series. The slope of the straight line is the presession constant. Note that the change since 1950 is larger than anything in the preceeding 300 years. The dotted line shown between 1670 and 1752 is before correcting for the change from Julian to Gregorian calendars

4. The average change in the timing of the seasons is coherent with CO_2.

5. Changes in the amplitude of the annual cycle have switched from being driven by changes in solar irradiance to being forced by CO_2.

6. The Friis-Christensen and Lassen hypothesis is rejected.

7. The amplitude of the annual temperature cycle is being supressed.[6]

8. Contrary to many claims by the skeptics, the temperature data is good enough to measure the change in the time of perihelion (about 25 minutes/year) and, even in the seventeenth century data, to detect a 3-day error made during the change from the Julian to Gregorian calendar.

[6] My experience with the statistics of frequency-modulated cellular phone systems makes me dread the possible consequences of this, but the details are too complex to treat here.

There are several problems with a rapid shift in the seasonal cycle:

- Many species have reproductive cycles timed by light and the length of day while the survival rate of offspring depends critically on temperature, so extinctions are possible. I have been told that some have already occurred.
- Because circulation and rainfall patterns are also shifted, planning for agriculture, water systems, etc. becomes more difficult.
- Because the change in the seasonal cycle varies geographically, more violent storms are a probable consequence.

3.3 Dependence of global temperatures on atmospheric CO_2 and solar irradiance

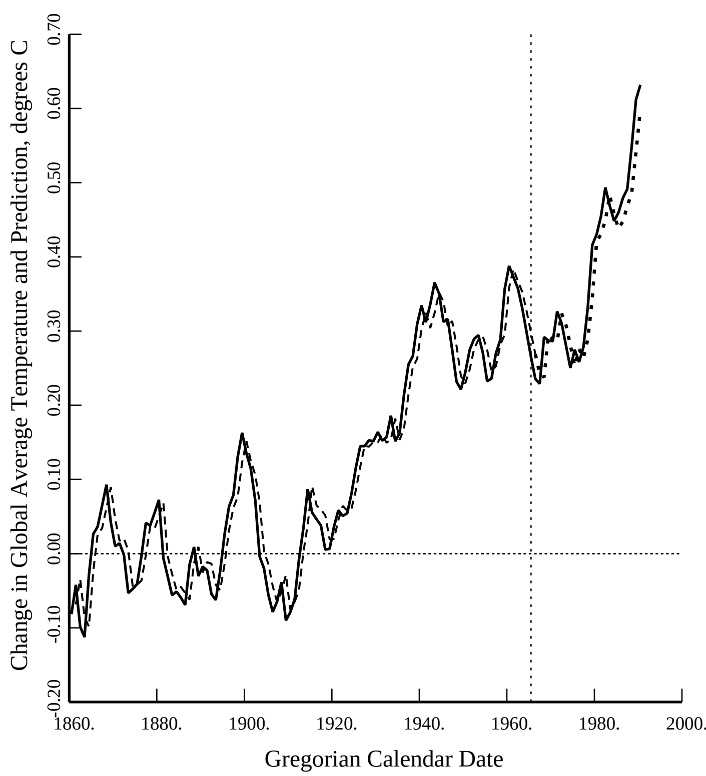

Figure 3: The Jones-Wigley global temperature series, corrected for precession, together with the fit described in Table 1 of [5]. Data from 1854 to 1965 was used to estimate the model parameters, which were then used to generate the curve from 1966 on.

This paper [5], published in *Proceedings of the National Academy of Science* continues the work of the last two. The major results are:

1. The measured atmospheric concentration of CO_2 can be accurately predicted by fossil fuel consumption.

2. Both changes in solar irradiance and greenhouse gasses are necessary to describe the observed change in temperature with reasonable accuracy.

3. A simple model for the temperature T at year t is

$$T(t) = \bar{T} + \alpha T(t-1) + sL(t) + cC_L(t) \ .$$

   In this equation $\bar{T}$ is the "average" temperature, $L(t)$ is solar luminosity, and $C_L(t)$ is the logarithm of atmospheric CO_2. The term $\alpha T(t-1)$ is a feedback from the temperature of the previous year and includes the temperature to CO_2 feedback, plus thermal inertia effects.

   Data from the interval 1854 to 1965 was used to estimate the constants, and the model was run forward. The standard deviation for a one-year prediction error in the validation interval (1966-1990) was $0.027°C$ for the global temperature series. Estimated values of the parameters are $\alpha = 0.8817$, $s = 0.0069$, and $c = 0.255$ for the global series.

4. The model implies that, unperturbed by CO_2 or changes in solar irradiance, the standard deviation of the global average temperature is $\sigma_p/\sqrt{1-\alpha^2}$ about $0.064°C$, and $0.081°C$ in the Northern Hemisphere.

5. The estimated sensitivity to doubling CO_2 is $c/(1-\alpha) = 2.16°C$ or $3.9°F$.

6. The estimated sensitivity to variations in solar irradiance is $s/(1-\alpha) = 0.058°C/(W/m^2)$. Because the solar irradiance data was, of necessity, reconstructed from proxy data, this estimate is reassuringly close to the value $0.053°C/(W/m^2)$ predicted from the Stefan-Boltzmann law.

This implies that most, in fact nearly three-quarters of the recent warming is a result of human consumption of fossil fuel. Figure 4 made with data from the British Antarctic Survey's Faraday Station on the Antarctic Peninsula shows both severe warming, about $5.4°C$/century, and a one-month shift in the seasonal cycle. Although this data set is only 45 years long, it is of superb quality. Other (longer) climate data from this region show similar characteristics. At the Faraday Station the average 1986 to 1995 temperature was $-3.45°C$ so, if the temperature continues to increase at the rate of the last fifty years, the average annual temperature there will be above freezing by 2055 AD.

4 Cautions, Notes, and Recommendations

Climate data, and papers analyzing it, should be used with a healthy skepticism. Because of the long time scales involved, we must often use data derived from proxy sources with the possibility that they are biased. Another problem is that there are some indications that the sun has been in a slightly "inactive"

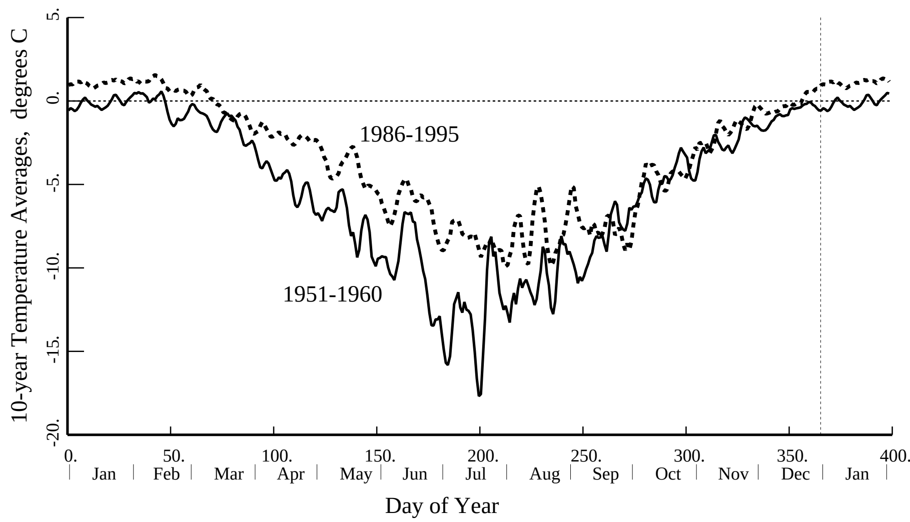

Figure 4: Annual temperature curves from the British Antarctic Survey's Faraday station on the Antarctic Peninsula. The lower curve is the average for the first ten years of the record, 1951 to 1960, and the upper is for the last ten years, 1986 to 1995. It is obvious that there has been considerable warming, about $5.4°C/$century, In addition one can see that the annual cycle has shifted almost a month later, a rate equivalent to 80.5 days/century.

phase during the period where reliable measurements are available. In addition, the oceans are capable of storing vast quantities of heat. However, because we have very few measurements of deep ocean temperatures, little is known except that the temperatures are increasing slowly in some oceans. The combination of the two effects may result in the true level of global warming being seriously underestimated by surface temperatures and proxy solar irradiances. Thus the actual sensitivity of the climate to CO_2 may be considerably higher than the number given above. It is unlikely to be significantly lower.

Turning briefly to the papers that offer alternative "explanations" for the recent warming, I have examined some of the more plausible of these alternatives (such as the Friis-Christenson and Lassen one mentioned above) and have not seen one that is convincing. The Appendix gives criteria to judge such papers.

To conclude, the majority of papers in the reviewed scientific literature that study global warming find evidence of human influence on the climate. These should not be ignored because of small uncertainties. In my opinion, the evidence that humans are significantly altering our environment by use of fossil fuels is compelling. Given the sensitivity of the climate and society to a change in average temperature of a few degrees it is completely irresponsible to continue as we have been and a large reduction in the global emission of carbon dioxide must be made soon.

Finally, note that this document is *not* a reviewed scientific paper, but mostly a summary of the results in my papers. Figures 1 and 4 are from work in progress. Although the opinions expressed are mine, and not those of Bell Laboratories or Lucent Technologies, the company has supported my efforts to determine the truth about global warming.

Tests for “explanations” of global warming

1. A model should have a plausible physical reason. I don’t require that all the details be understood, but the basic idea should not violate known physical laws.

2. The model must be causal, that is, it shouldn’t predict a response before the forcing changes.

3. Models that predict lower temperature as a result of increased solar output are unacceptable. Similarly, models that require response to solar irradiance that differ, on average, too much from the Stefan-Boltzmann law should be rejected.

4. Models that predict net cooling from greenhouse gases are rejected. We have known that “greenhouse” effects in the atmosphere keep the Earth well above the blackbody temperature for over a century and the physics doesn’t change. Without greenhouse gases in the atmosphere, the average global temperature would be approximately -16 degrees C, about 31 degrees C below the measured value.

5. The model must be sufficiently quantitative to be testable.

6. There must be reasonable data. If the proposed effect was so obscure that nobody took note of it before now (and people record data on an amazing number of different things), or it left no traces in paleoclimate data, my bias is that the proposed effect is unlikely.

7. The data should be believed by most leading scientists.

8. Data should be verifiable. Temperature data, for example, has been recorded by different governments, published in numerous papers, plus there are proxy indicators such as tree-ring characteristics.

9. The explanation should not depend on arbitrary transformations of data.

10. If the cause is some “natural” fluctuation of the climate system, there must be an explanation of why it has just turned on in the last century. Furthermore, if it has turned on because of human activity, how do we distinguish that from CO_2?

11. The model must be simple enough to be comprehensible. This is basically Einstein’s maxim: “as simple as possible, but not simpler”.

12. The data analysis done to confirm the model *must* account for the time-series nature of the problem. Climate data is strongly serially-correlated, and cannot be treated as uncorrelated observations. I reject any effect that only appears significant when the statistics are done incorrectly.

13. The model should make statistical, as well as physical sense. If the misfit between theoretical predictions of the model and observed data is too bizarre, or if the residuals are clearly correlated with CO_2 or solar data, I will likely reject it.

14. Comparison between model and data should be done over at least a century. There are lots of variations on the 11-year solar cycle time scale, the 18.6-year Lunar cycle, El-Nino, and several others, that have been there for as long as we have data. These mostly seem to move climate patterns, such as storm tracks, between regions in an oscillatory manner and don't change the global average appreciably.

15. In addition to explaining warming, alternative explanations should also explain the changing seasonal cycle.

16. Finally, like any other legitimate scientific hypothesis, a valid model of the climate should make testable predictions.

References

[1] D. J. Thomson. Time series analysis of holocene climate data. *Phil. Trans. R. Soc. Lond.*, A 330:601–616, 1990.

[2] D. J. Thomson. Quadratic-inverse spectrum estimates: applications to paleoclimatology. *Phil. Trans. R. Soc. Lond.*, A 332:539–597, 1990.

[3] P.D. Jones. High-resolution palaeoclimatic records for the last millenium: interpretation, integration, and comparison with general circulation model control run temperatures. *Holocene*, 8:477–483, 1998.

[4] M.E. Mann, R.S. Bradley, and M.K. Hughes. Northern hemisphere temperatures during the past millennium: Inferences, uncertainties, and limitations. *Geophys. Res. Let.*, 26:759–762, 1999.

[5] D. J. Thomson. Dependence of global temperatures on atmospheric CO_2 and solar irradiance. *Proc. Natl. Acad. Sci. USA*, 94:8370–8377, 1997.

[6] C. Kuo, C. Lindberg, and D. J. Thomson. Coherence established between atmospheric carbon dioxide and global temperature. *Nature*, 343:709–714, 1990. (Reprinted in pp 395-400 of **Coherence and Time Delay Estimation**, G. C. Carter, Ed., IEEE Press, 1993.).

[7] D. J. Thomson. The seasons, global temperature, and precession. *Science*, 268:59–68, 1995.