

## **An Occam's razor view of the lead-lag dispute in global warming**

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There can surely be no doubt that the global-mean surface air temperature and the concentrations of greenhouse gases (esp. CO<sub>2</sub>) in the Earth's atmosphere are increasing quite rapidly. Whether the increase in anthropogenic CO<sub>2</sub> is primarily responsible for an increase of our planet's global temperature is, in spite of considerable evidence, a point of constant and often virulent contention. Those who do not acquiesce to the theory that it is anthropogenic CO<sub>2</sub> that is the culprit behind this temperature increase, we will call the non-anthropogenists (or NA's for brevity). This group, which clearly represents the minority scientific opinion<sup>10</sup>, utilize as a main weapon the argument that temperature leads CO<sub>2</sub> in the climatic record. The principle of causality therefore, in their opinion, clearly points to the fact that it is some extra planetary source, (usually attributed to the solar flux) which is responsible for the undeniable global warming. For example, "The observation that two things have risen together for a period of time says nothing about one trend being the cause of the other. To establish a causal relationship it must be demonstrated that the presumed cause *precedes* the presumed effect"<sup>1</sup>. In other words, CO<sub>2</sub> increases must precede temperature increases in order to prove anthropogenic forcing of the climate. The thrust of this article is to demonstrate, simply and parsimoniously, that the argument of causality, the '*precedes*' issue, is irrelevant in the present debate. The temperature-CO<sub>2</sub> cycle is a feedback cycle. Such mechanisms are always nonlinear and these nonlinearities may obliterate causality. We show this effect by way of a simple model- a model that mimics to some extent, the present day temperature-CO<sub>2</sub> relationship. A related causality-correlation issue can be expressed by this often quoted statement, "Correlation does not prove causality, but non-correlation proves non-causality."<sup>2</sup> We discuss the fallacy of the second part of this statement, a discussion that should be of interest to all. We begin with the issue of lead-lag in the temperature record and follow by showing why the 'non-correlation=non-causality' statement is bogus.

### **The Lead-Lag Dispute in Global Warming**

An excellent example of the debate between the NA's and the A's (the anthropogenists) is the recent congressional testimony of Al Gore. Congressman Barton of Texas made the following statement in reference to Al Gore's documentary film, "An inconvenient truth".

*"In your movie, you display a timeline of temperature and compared to CO<sub>2</sub> levels over a 600,000-year period as reconstructed from ice core samples. You indicate that this is conclusive proof of the link of increased CO<sub>2</sub> emissions and global warming. A closer examination of these facts reveals something entirely different. I have an article from*

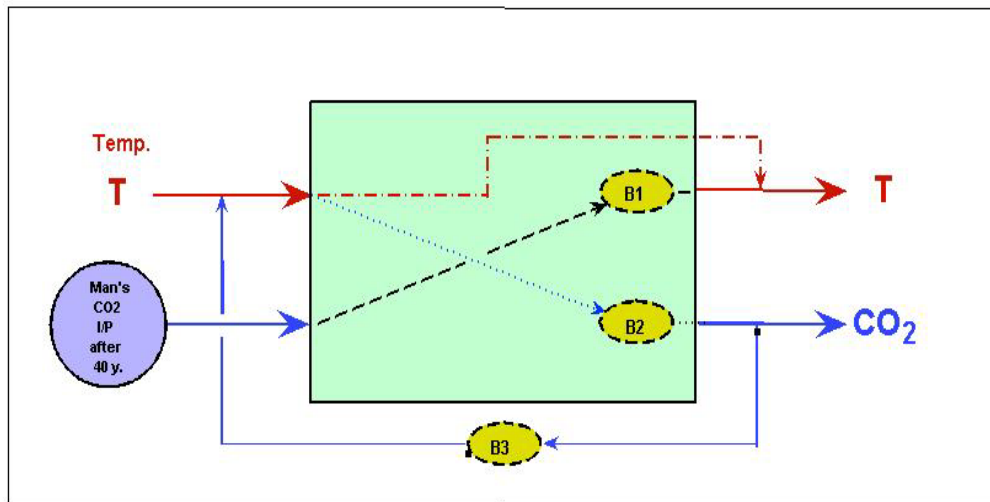
*Science magazine which I will put into the record at the appropriate time that explains that historically, a rise in CO<sub>2</sub> concentrations did not precede a rise in temperatures, but actually lagged temperature by 200 to 1,000 years. CO<sub>2</sub> levels went up after the temperature rose. The temperature appears to drive CO<sub>2</sub>, not vice versa. On this point, Mr. Vice President, you're not just off a little. You're totally wrong."*<sup>3</sup>

In fact, Gore did not get it wrong, as has been so eloquently demonstrated by Eric Steig<sup>4</sup>. The main issue in Barton's argument, often also enunciated by others<sup>1,2,3</sup>, is not that CO<sub>2</sub> leads temperature, but it is temperature that apparently leads CO<sub>2</sub>. Hence, using the cause and effect argument, the A's must have it wrong (this is only one of many different arguments). Steig's answer is very cogent, but deals in most part with the correlation of temperature and CO<sub>2</sub> on very long time scales. The whole thrust of our model is based on a time scale of the past 180 years, or so.

As is well known, the climate is highly nonlinear<sup>5</sup>, and so a question worth asking is, what effect, if any, do model nonlinearities have with respect to the principle of causality (i.e., output cannot occur before input). It is, after all, this issue that is of such contention. In order to attempt to answer this question in as clear and simple manner as possible, we have constructed a parsimonious temperature-CO<sub>2</sub> feedback model that follows, on a coarse scale, the observed variation of these two variables. The reason for the simplicity of the model is three-fold. In the first place, if it should happen that a simple feedback model demonstrates by virtue of the inherent nonlinearities that causality is masked, then surely it cannot be argued (logically that is) that a complex feedback model will not. In fact, we would argue that complexity will further obscure any causality that might have existed in ancient times. The second reason stems from the "Principle of Parsimony, or, Occam's razor", made famous by William of Ockham<sup>6</sup>, perhaps the most influential philosopher of the 14th century. It states,

*"One should not increase, beyond what is necessary, the number of entities required to explain anything."*

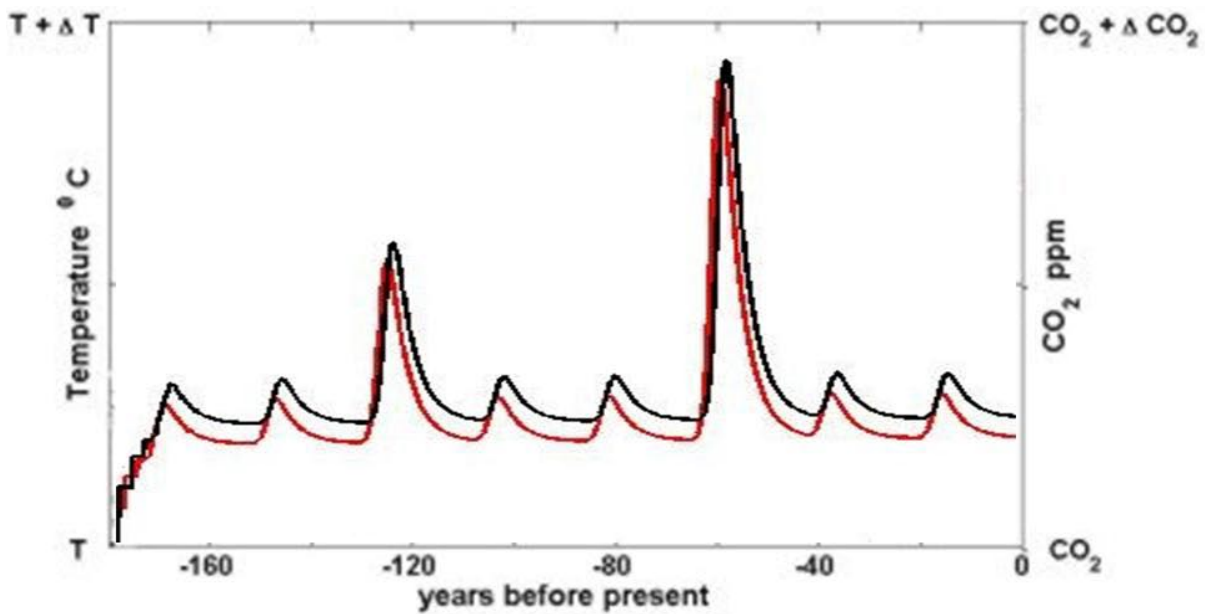
Third and finally, a cogent approach to the analysis of a complex task, is to break that task into simpler sub-tasks. This correspondence deals with one sub-task in an attempt to understand one phenomenon regarding the Earth's climate. As it turns out, it is a sub-task at the forefront of the dispute between the NA's and the A's. The parsimonious model which we use to investigate the issue of causality is illustrated in Figure 1.



**Figure 1. A parsimonious model for the lead-lag problem.** The ellipses B1, B2 and B3, represent proportions and delays in the feedback mechanism. i.e., there are 3 multiplicative constants and 3 delays. All are linear and simply described.. The blue ellipse represents anthropogenic input of CO<sub>2</sub>, 40 years after a somewhat stable temperature has been achieved.

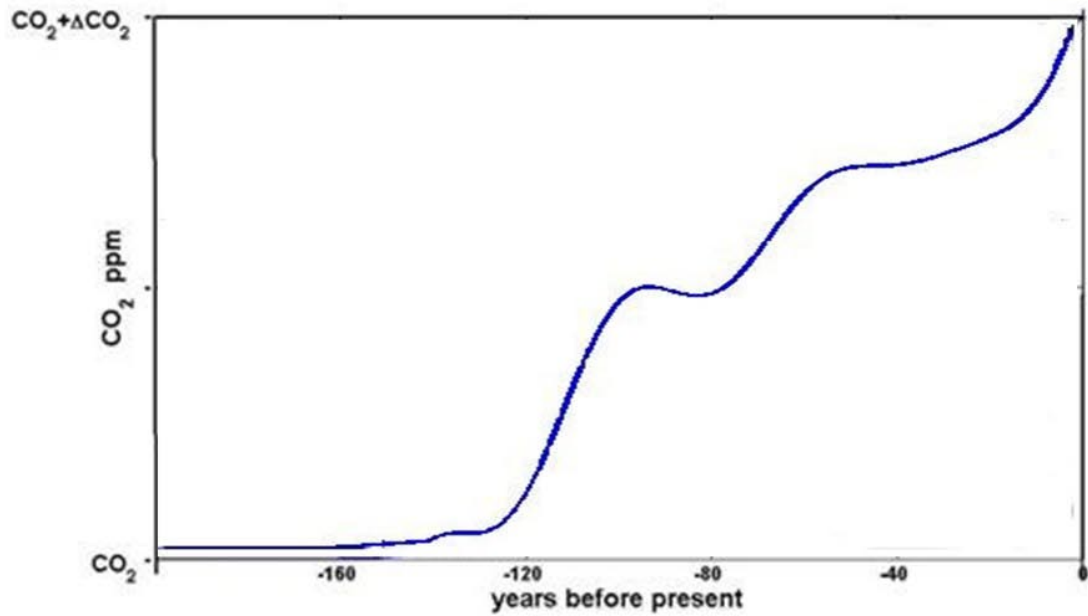
### A Parsimonious Model for the Lead-lag Problem

We begin almost two hundred years ago, in the pre-industrial age, when the temperature (we will call it  $T$  for convenience) of the Earth was fairly stable, due to the fact that the solar flux is rather stable over time periods in the range of a several centuries. Of course, CO<sub>2</sub> is a constituent of the atmosphere (together with other greenhouse gases) and a cycle exists in which the sun heats the atmosphere, drives the ocean currents and cycles CO<sub>2</sub>; a part of which may add to that already present. This constitutes a feedback loop with some delays and some feedback coefficients. Other authors<sup>5,7,8</sup> also consider simple feedback models with different  $T$ -CO<sub>2</sub> laws. We have, deliberately made our functional relationships linear. Letting our model run with 'soft' initial conditions, produces the results in Figure 2. We have deliberately introduced a gently increasing solar flux, together with an 11 year cycle of sunspot activity (with some irregularity in the sunspot amplitudes, the main purpose of which is to serve as markers for the purpose of comparison) which increases the solar flux. This is the pre-anthropoid model. As can be observed, after the initial transient behavior attenuates,  $T$  is stable and leads CO<sub>2</sub> in the record as one would expect. We emphasize that the temperature and CO<sub>2</sub> axes, in this figure as well as in the figures to follow, are as marked without actual values. The reason is that we are not trying to explain or predict, climate, as this is not the focus of this paper. Our analysis is merely to explain an observation concerning climatic data. In this quest, a numbered scale only serves to obscure the result.



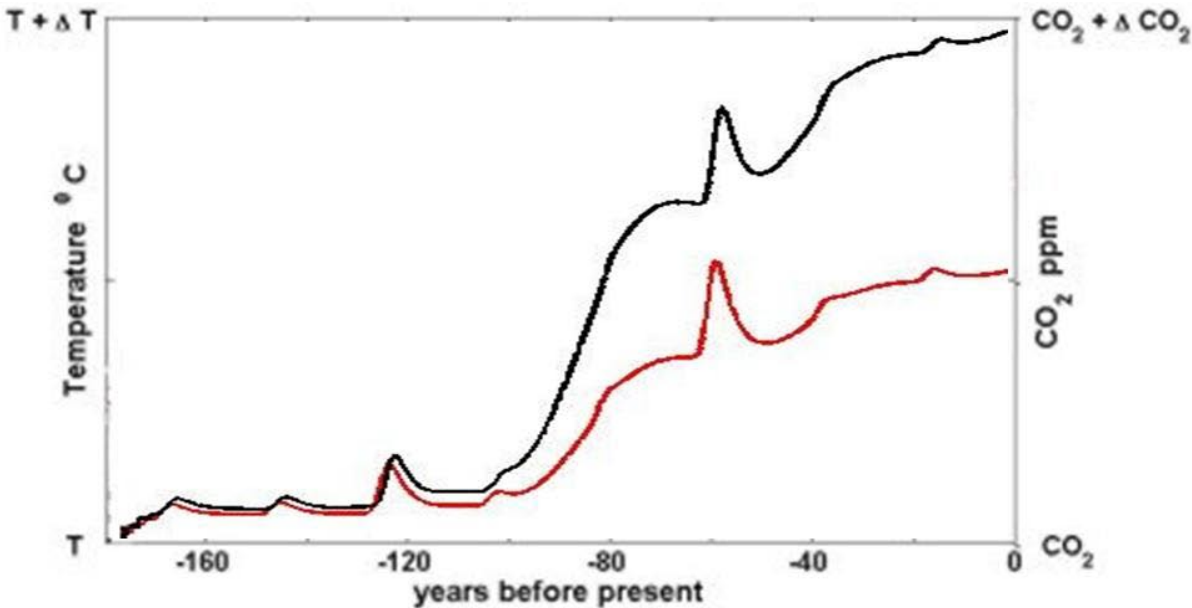
**Figure 2. Variation of temperature and CO<sub>2</sub> in the past 180 years without additional CO<sub>2</sub> forcing..** The red curve represents temperature, the blue curve is CO<sub>2</sub>.

At this stage, we introduce mankind into the picture. The anthropogenic CO<sub>2</sub> input that is imposed, is shown in Figure 3.



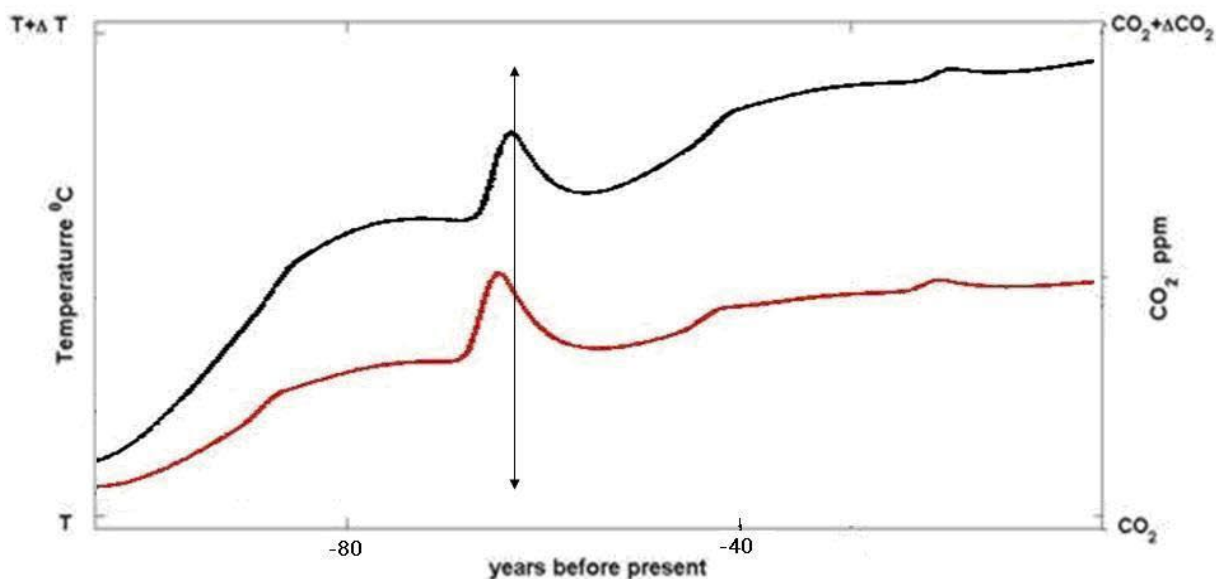
**Figure 3. Anthropogenic input of CO<sub>2</sub>.**

The anthropogenic input is represented by a simplified version of what is believed to have been the actual input<sup>11</sup>, delayed from the initialization of the model by 40 years and scaled. The scaling is so arranged that the increase in CO<sub>2</sub> at the present is approximately three times the initial level of 280ppm. As it turns out, this scaling does not affect the conclusions. Figure 4a illustrates the resulting behavior on a time scale of 140 years following the industrial revolution.



**Figure 4a. Variation of temperature and CO<sub>2</sub> in the past 200 years following the introduction of anthropogenic CO<sub>2</sub>, circa 160 years bp. The red curve represents temperature, the blue curve is CO<sub>2</sub>.**

A rescaling of this figure is shown below, in Figure 4b, in order to illustrate the conclusion with more clarity..



**Figure 4b.** A zoomed version of Figure 4a for the sake of clarity. The red curve represents temperature, the blue curve is CO<sub>2</sub>. The vertical arrow serves to emphasize the lead of the temperature curve

As expected, the amount of CO<sub>2</sub> increases, with a proportional increase in  $T$ . Most importantly,  $T$  *leads* CO<sub>2</sub>. In spite of the fact that it is CO<sub>2</sub> that has caused the increase of  $T$ , we made it so, it is not CO<sub>2</sub> that leads  $T$ . Causality, that factor so prominently employed by NA's, has been feedbacked into irrelevancy. Anthropogenic driving has been totally masked.

Of course, all models have inputs, some more, some fewer. This is a simple model and, consequently, only has a few inputs.. Nonetheless, a fair question to ask is, what effect do these inputs have? Very simply, the following. If the delay of the effect which CO<sub>2</sub> has on the increase of  $T$  (i.e., the residence time) is lessened, so is the lag of CO<sub>2</sub>. In fact, since ours is a simple model, CO<sub>2</sub> can never lead  $T$ . At best, CO<sub>2</sub> and  $T$  can be made to be exactly in-phase. Perhaps more complex models may be engineered so that CO<sub>2</sub> can lead  $T$ . This, however, will not further the cause of the NA's.

The conclusion is simply this. It is impossible, logically at least, to question the effect of anthropogenic CO<sub>2</sub> on global warming by appealing to lead-lag arguments. They do not apply. When the cause of warming is anthropogenic CO<sub>2</sub>, either temperature leads CO<sub>2</sub> or, perhaps for more complicated models, CO<sub>2</sub> leads temperature. We hope that this parsimonious demonstration will put to rest the fallacious argument that anthropogenic CO<sub>2</sub> can not be the cause of global warming because of causality arguments.

Before continuing with our second, very closely related issue, to which we alluded in the 'introduction', we would like to strongly recommend a pearl of a paper<sup>8</sup> by G. Roe and M. Brown. It is a must read for all. These authors also deal with a feedback model, but in a

much more detailed manner, due in part to the fact that their focus is the uncertainties involved with climate prediction. As we have emphasized above, our focus is much different, the issue of cause and effect.

### Causality versus Correlation

We now turn, very briefly indeed, to the causality related issue of ‘non-correlation proves non-causality’. (In other words, lack of correlation between CO<sub>2</sub> and temperature proves that they are unrelated). It does not; much to the contrary. It is very easily shown, theoretically and by virtue of a simple example<sup>9</sup> that variables which are in fact dependent, may be completely uncorrelated. We elaborate for the sake of completeness. The link between uncorrelatedness and independence lives in nonlinearities. To see this, we consider two random variables,  $x$  and  $y$ , with marginal probability density functions (pdf’s)  $p(x)$ ,  $p(y)$  and joint pdf  $p(x,y)$ . The definition of independence, in terms of these pdf’s, is,  $p(x,y)=p(x)p(y)$ . We now form general nonlinear functions,  $f(x)$  and  $g(y)$  and take the expectation of the product,  $E[f(x)g(y)]$ , to obtain,

$$E[f(x)g(y)] = \iint f(x)g(y)p(x,y)dx dy = \int f(x)p(x)dx \int g(y)p(y)dy = E[f(x)]E[g(y)]$$

We see, therefore, that independence implies the factorization of the nonlinear correlation.

By setting  $f(x)=x$  and  $g(y)=y$ , we note that independence implies uncorrelatedness. On the other hand, the fact that dependence does not imply correlatedness, can be best seen by means of a simple example. Consider the dependent relationship  $y = x^2$ . Then,  $E[xy] = E[x^3] = E[x^3]E[x]$ . Assuming that  $p(x)$  is symmetric, we observe that  $E[xy] = 0$ .  $x$  and  $y$  are uncorrelated but dependent. If  $x$  and  $y$  are independent, however, they are necessarily uncorrelated. In the present context, this means that lack of correlation between CO<sub>2</sub> and global mean temperature does not prove lack of dependence.

This paper, in no manner, is designed to imply that anthropogenic CO<sub>2</sub> is, or is not, the cause of global warming. We leave such ruminations to those who are experts in this undeniably complex field.

We would like to thank Phil Austin, Michael Bostock and Garry Clarke for modulating our anthropogenic thoughts. We wish to emphasize that the conclusions in this paper are ours and we take full responsibility for them.

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<sup>3</sup>During Former Vice President Al Gore's testimony to the Energy and Commerce Committee in March, 2007.

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