Taking Greenhouse Warming Seriously

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1. Introduction.

In science, there is an art to simplifying complex problems so that they can be meaningfully analyzed. If one oversimplifies, the analysis is meaningless. If one doesn't simplify, then one often can't proceed with the analysis. When it comes to global warming due to the greenhouse effect, it is clear that many approaches are highly oversimplified. This is particularly true of the treatment in Gore's *Inconvenient Truth* as will be discussed shortly. We will also approach the issue more seriously in order to see whether one can reach reasonably rigorous conclusions. It turns out that one can, and the conclusions are far from alarming.

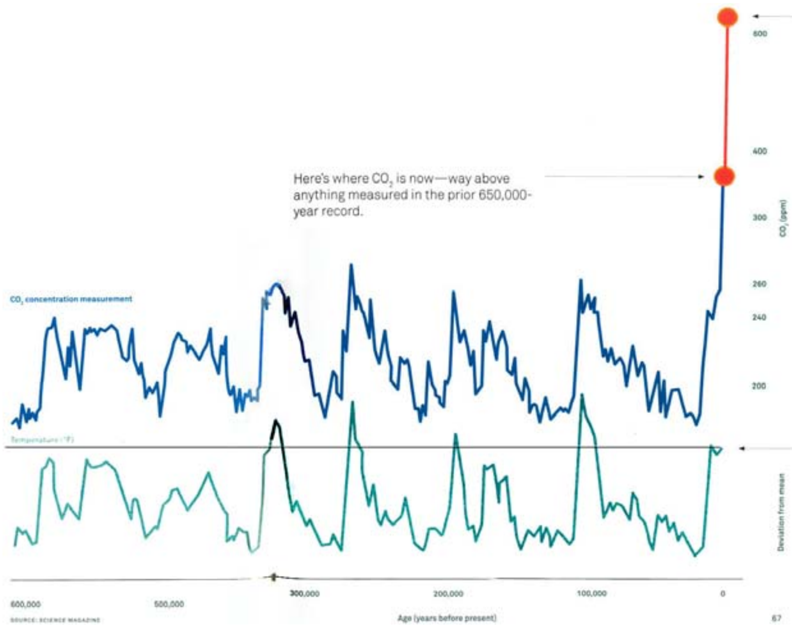

Figure 1: Atmospheric carbon dioxide levels and temperatures inferred from the Vostok ice core. From Gore, A. 2006

2. Vostok Ice Core record.

We will begin with Gore's arguments for associating changes in CO_2 with climate, and with his depiction of the greenhouse effect. For about 20 years, Al Gore has used the inferences from the Vostok[1] ice core to argue the intimate relation of temperature and CO_2. The relevant graph is shown in Figure 1. Gore points to the clear relation of CO_2 with temperature inferred from the relative presence of the isotope O^{18}. During the long, cold glacial periods, CO_2 was relatively low, while during the shorter, warmer interglacials, CO_2 was relatively high. Of course, every science student is warned that correlation is not causality, and the truth of this warning is amply illustrated by Gore's example. Three aspects of the curves need to be noted (and none of them are in the least controversial):

[1] Vostok is the location in Antarctica where a core drilled by a Russian-French team provides samples of ice going back about 600 thousand years.

1. Although current levels of CO_2 are higher than those in previous interglacials, the preceding 4 interglacials were warmer than we are at present. This is clear from Figure 1.

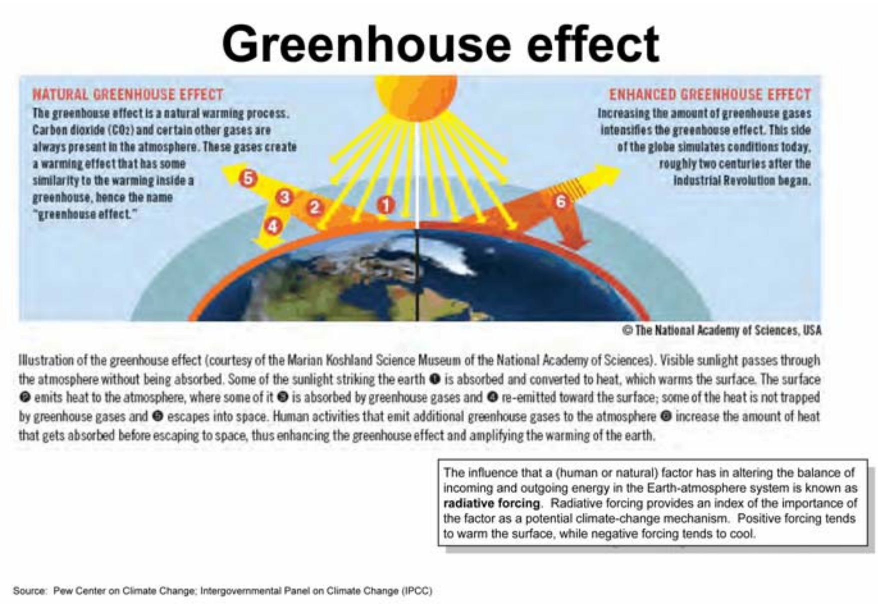

Figure 2: Oversimplified depiction of greenhouse effect

2. Although the temporal resolution of the Vostok ice core is relatively poor (about 1500 years), it is sufficient to see that the cooling associated with glaciation preceded the decrease in CO_2. For deglaciation, the Vostok core shows almost simultaneity between increasing temperature and increasing CO_2, but higher resolution studies (Caillon, et al, 2003) show that here too increasing temperature preceded increasing CO_2 by hundreds of years.

3. The way in which CO_2 contributes to warming is by means of its impact on what is referred to as radiative forcing. We will define this more carefully later in this paper. However, for present purposes, it suffices to note that the radiative forcing associated with a change in CO_2 from 180ppmv to 280ppmv is a little more than half of what one would get from a doubling of CO_2 from preindustrial values, and the change in temperature shown in Figure 1 is about 10C. Now, the most sensitive models cited by the IPCC yield about 4.5C for a doubling of CO_2 or about 2.5C for the changes in CO_2 shown in Figure 1. Thus, if CO_2 were the causal factor, the sensitivity of the Earth's climate would have to be about 4 times larger than the sensitivity of the most sensitive current model. However, as recently shown by Rodwell and Palmer (2007) and by Annan et al (2005), high sensitivities are extremely improbable. Thus, it is virtually impossible for CO_2 to have caused the temperature changes associated with the Vostok climate changes.

3. The climate greenhouse effect.

We next turn to the greenhouse effect, itself. In Figure 2 (taken from a popular exhibit at the National Academy's Koshland Museum, but equivalent to the figure in *Inconvenient Truth*) we see a common depiction of the greenhouse effect. It is generally recognized to be incorrect, but defended on the grounds that the general public would not be able to follow the correct treatment. The idea is that sunlight is primarily in the visible portion of the spectrum due to the high emission temperature of the sun (about 6000 degrees Kelvin[2]) while the radiation from the earth is in the infrared portion due to its lower emission temperature (about 288 degrees Kelvin). Greenhouse gases are those substances that are reasonably transparent in the visible but capable of absorbing and emitting in the infrared. The 'emitting' part, though conveniently ignored in some oversimplified treatments, will turn out to be very important. In any event, the oversimplified argument then proceeds as follows. Part of the sunlight reaching the earth is reflected by clouds, and the earth's surface. The remainder (Net Incoming Solar Radiation) warms the earth and this warming is balanced by the earth's infrared (or thermal) radiation. However, the presence of greenhouse substances (the most important of which are water vapor and clouds) inhibits this cooling by thermal radiation, and serves as a blanket which causes the earth to be warmer than it otherwise would be. It is commonly claimed that the natural component of this blanket keeps the earth about 33 degrees Centigrade warmer than it would be in the absence of this blanket. The claim is a little silly insofar as it requires getting rid of the greenhouse impact of clouds while retaining them to reflect sunlight. Getting rid of clouds as reflectors would reduce this difference substantially. This, however, is a relatively minor point. The general idea proposed in the oversimplified treatments is that adding man made greenhouse gases to those naturally present will cause the temperature to increase further. The doubling of CO_2 is used as a benchmark for estimating the sensitivity of climate to such increases. It is generally acknowledged that simply doubling CO_2 should lead to a warming of about 1 degree Centigrade. However, in current models, the natural greenhouse substances act in such a manner as to greatly amplify this warming. This is referred to as positive feedback.

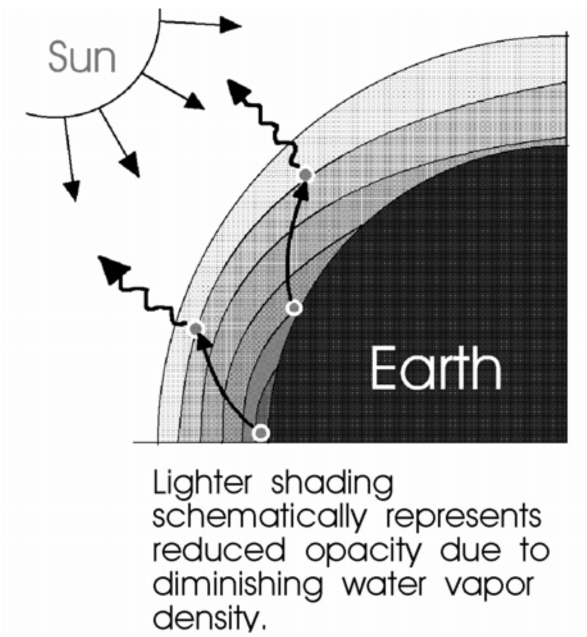

Figure 3: More realistic depiction of how the earth's surface cools. From Lindzen, 1990.

There is something very seriously wrong with this oversimplified picture. Namely, the surface of the earth does not cool primarily by thermal radiation. The situation is more nearly akin to the schematic shown in Figure 3. The main greenhouse gas, water vapor, generally maximizes at the surface in the tropics and sharply decreases with both altitude and latitude. There is so much greenhouse opacity immediately above the ground that the surface cannot effectively cool by the emission of thermal radiation. Instead, heat is carried away from the surface by fluid motions ranging from the cumulonimbus towers of the tropics to the weather and planetary scale waves of the extratropics. These motions carry the heat upward and poleward to levels where it is possible for thermal radiation emitted

[2] Degrees Kelvin refers to the temperature in degrees Centigrade to which 273 degrees are added. Minus 273 degrees Centigrade corresponds to the absolute zero of the temperature scale. Thus, the Kelvin scale begins at absolute zero, as opposed to the Centigrade scale which begins at the freezing temperature for water.

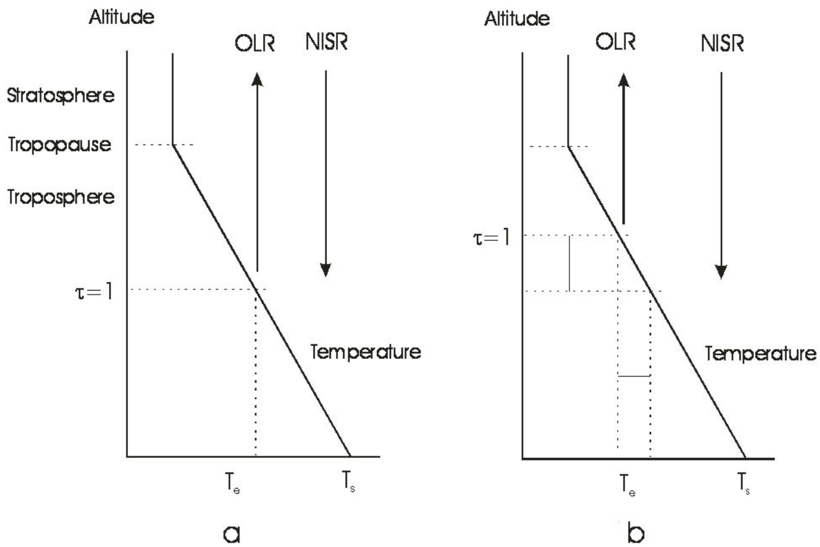

Figure 4: Schematic depiction of how greenhouse effect actually works. From Lindzen, 1995.

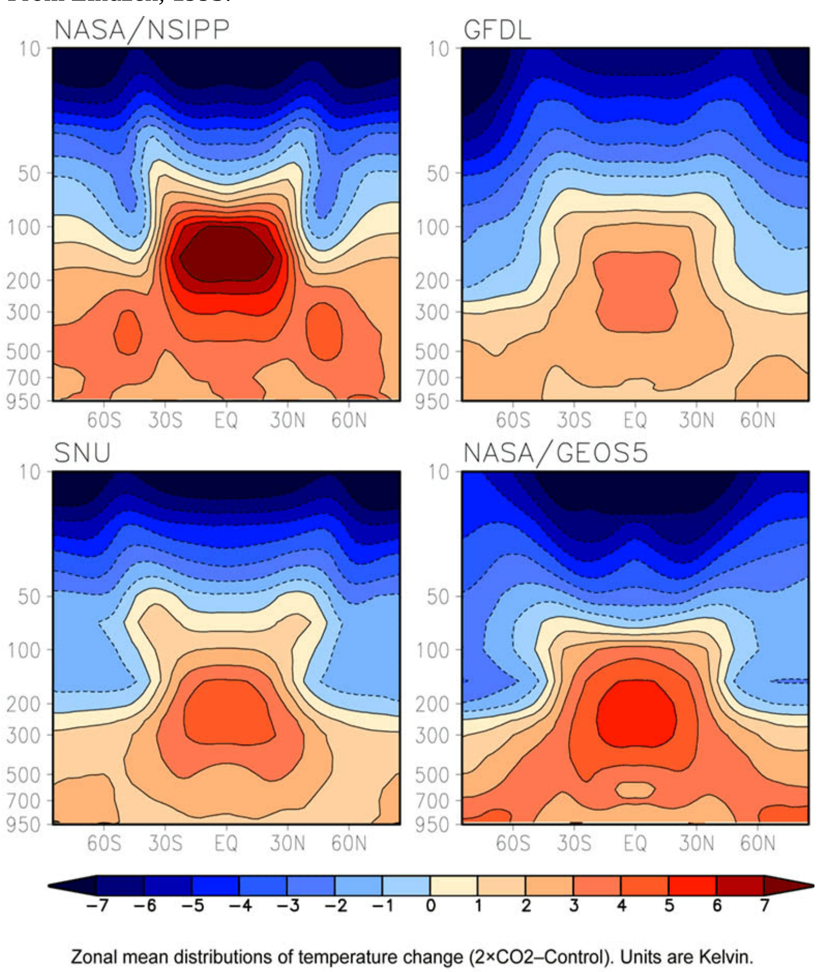

Figure 5: Zonally averaged temperature change associated with doubling of CO_2 as function of latitude and pressure level for four different GCMs. From Lee et al, 2007.

from these levels to escape to space. We will refer to this level as the characteristic emission level. Crudely speaking, the emission from this level is proportional to the 4th power of the temperature at this level. Figure 4a offers a simplified one dimensional picture of the situation. Largely because of the motions of the atmosphere, the temperature decreases with altitude to some level known as the tropopause. The height of the tropopause varies with latitude. In the tropics, the tropopause height is about 16 km. Near 30^o latitude, the tropopause height drops to about 12 km, and near the poles it is around 8 km. Below the tropopause, we have what is called the troposphere. The characteristic emission level is referred to as τ=1. τ is a measure of infrared absorption measured from the top of the atmosphere looking down. Crudely speaking, radiation is attenuated as $e^{-\tau}$. The level at which τ=1, is one optical depth into the atmosphere, and radiation emitted from this level is proportional to the 4th power of the temperature at this new level. When the earth is in radiative balance with space, the net incoming solar radiation is balanced by the outgoing longwave radiation (or thermal radiation or infrared radiation; these are all commonly used and equivalent terms) from the characteristic emission level, τ=1. When greenhouse gases are added to the atmosphere, the level at which τ=1 is raised in altitude, and, because the temperature of the atmosphere decreases with altitude (at the rate of approximately 6.5 degrees Centigrade per kilometer), the new characteristic emission level is colder than the previous level. This situation is illustrated in Figure 4b. Because τ=1 is now at a colder level, the outgoing longwave radiation no longer balances the net incoming solar radiation, and the earth is no longer in thermal balance with space; this imbalance is what we refer to as the *radiative forcing*. In order to reestablish balance, the temperature at the new τ=1 level must increase to about the temperature that had existed at the initial τ=1 level. In practice, the τ=1 level is typically in the neighborhood of 7-8 km in the tropics and at lower levels in the extratropics. It is the warming at τ=1 that is the fundamental warming associated with the climate greenhouse effect (to distinguish it from plant greenhouse which operates in a very different manner).

How warming at the τ=1 level relates to warming at the surface is not altogether clear. It is at this point that models prove helpful. Figure 5 shows how temperature changes when CO_2 is doubled in 4 rather different General Circulation Models (Lee et al, 2007). What we see is the temperature averaged around a latitude circle as a function of latitude and height. Following common meteorological practice, height is replaced by pressure level. Pressure decreases approximately exponentially with height. 100 hPa (hecto Pascals) corresponds roughly to 16 km; 200 hPa to 12 km; 500 hPa to 6 km; and 1000 hPa to the surface. What we see is that warming is strongly peaked in the tropical troposphere near the τ=1 level (which actually differs from model to model because the amount of water vapor differs among the models). Roughly speaking, the warming at τ=1 is from more than twice to about three times larger than near the surface regardless of the sensitivity of the particular model. This is, in fact, the signature (or fingerprint) of greenhouse warming. Stated somewhat differently, if we observe warming in the tropical upper troposphere, then the greenhouse contribution to warming at the surface should be between less than half and one third the warming seen in the upper troposphere. Fortunately, we have been measuring atmospheric temperatures with balloons since at least the 1960's and with microwave satellite sensors since 1979. Initially, the satellite data was showing slight cooling for the tropical troposphere, while surface data was showing a

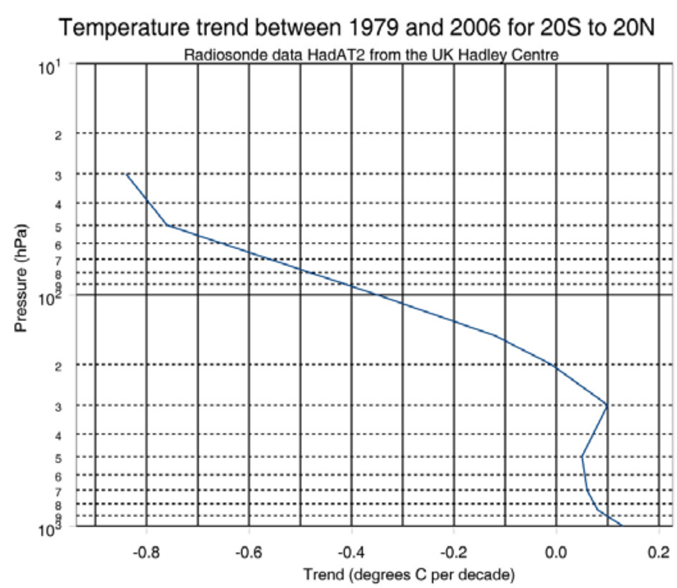

Figure 6. Temperature trend as a function of pressure level for period 1979-2006 in the tropics (20S-20N) based on balloon data analyzed by the Hadley Centre.

warming trend of about 0.13 degrees Centigrade/decade. This gave rise to deep concern resulting in studies by both the National Research Council (2000) and the US Climate Change Science Program (2006) where strong attempts were made to find warming in the troposphere. It is now believed that there is indeed warming in the atmosphere. Figure 6 is the most recent depiction of the trends based balloon data from the United Kingdom's Hadley Centre. We see that the trend in the troposphere does have a relative maximum near 300 hPa of about .1 degree C per decade, and judging from the results in Figure 5, this should be associated with a surface trend of between 0.033 and somewhat less than 0.05 degrees per decade. Contrary to the iconic statement of the latest IPCC Summary for Policymakers, this is only on the order of a third of the observed trend at the surface, and suggests a warming of about 0.4 degrees over a century. It should be added that this is a bound more than an estimate. Greenhouse warming must appear in the neighborhood of 300 hPa, but warming at 300 hPa does not have to be greenhouse warming. Note that our inferences from Figure 5 support the objections of Essex and McKitrick (2002) and Essex et al (2007) to the use of globally averaged temperature. Had we used globally averaged temperatures, it would have been almost impossible to correctly relate the underlying physics to the observations. It must also be recognized that the one-dimensional simplifications of the greenhouse effect in Figure 4 are not equivalent to taking global averages.

The above is a bound on climate sensitivity based on basic theory and modeling studies. The modeling studies establish that the ratio of upper tropospheric tropical warming to surface warming is approximately 2.5:1 regardless of the model sensitivity. The bound does not depend on any specific feedback mechanism, but it does imply that strong positive feedbacks in current models are either wrong or more than balanced by negative feedbacks missing from these models.

4. Defense of anthropogenic causality.

How then did the recent IPCC Summary for Policymakers reach their conclusion that most of the surface warming over the past 30 years is due to anthropogenic forcing? The answer is almost as silly as the use of the Vostok data was in *Inconvenient Truth*: the modelers could not think of anything else that could account for recent warming. The specific response of Alan Thorpe, head of NERC, the primary funding agency for climate research in the UK, is revealing:

"*The size of the recently observed global warming, over a few decades, is significantly greater than the natural variations in long simulations with climate models (if carbon dioxide is kept at pre-industrial levels). Only if the human input of greenhouse gases is included does the simulated climate agree with what has been recently observed. Measurements prior to the modern instrumented record are probably insufficiently frequent and detailed to say whether such a global warming over a few decades has occurred before. However in any case, the real issue is whether human activity is causing the current warming because, if so, then we are able to do something about it.*

Climate models attempt to include all the natural factors that might lead to significant climate variations on the time scales of interest, i.e. years to decades to centuries. Clearly factors *currently unknown to science can't be included, but we have no reason to suppose they exist.*"

Several features of this response (which clearly demonstrates the debased current state of climatescience) should be noted immediately:

1. Evidence is restricted to model outputs.
2. Evidence is said to include the irrelevant claim that only by assuming human causality is policy relevance assured.

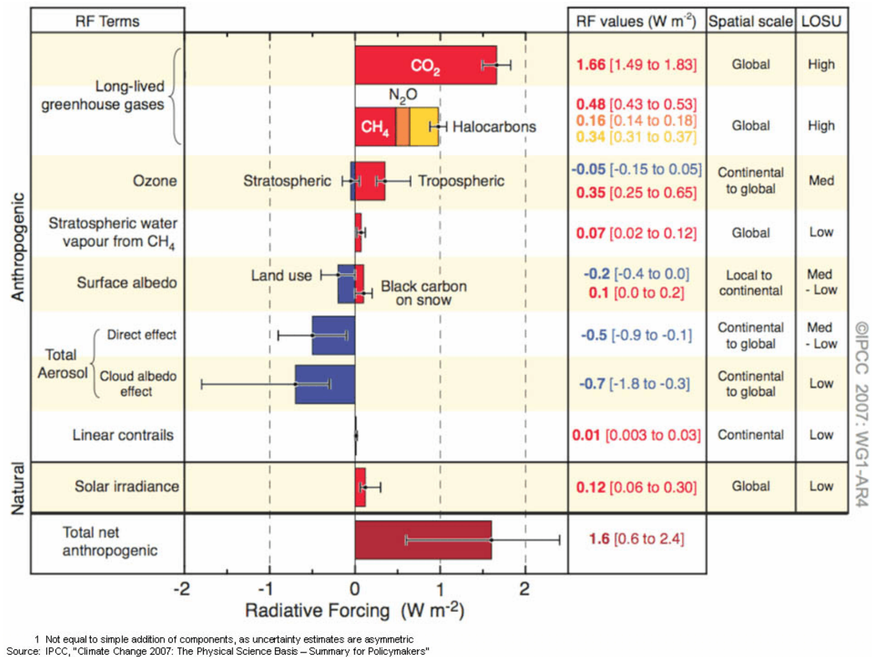

Figure 7: Current radiative forcing from anthropogenic sources. IPCC WG1 Summary for Policymakers, 2007.

3. The assertion that there is no reason to suppose that there are factors omitted from the models is clearly false as we shall show shortly. So too is the claim that such factors are currently unknown to science.

Before proceeding to a discussion of item 3, it will be helpful to consider an interesting feature of what has become the iconic claim of the Summary for Policymakers. Figure 7, taken from the Summary for Policymakers, lists all the current sources of anthropogenic forcing used in current models, as well as the estimated magnitude of their contribution to the radiative forcing (in units of watts per square meter). For reference purposes, the radiative forcing associated with a doubling of CO_2 is about 3.5 watts per square meter. The first three items in Figure 7 represent the main sources of anthropogenic greenhouse forcing. They are also the most accurately known of the anthropogenic forcings. Adding them up gives us a radiative forcing of about 3 watts per square meter, which is about 86% of the radiative forcing associated with a doubling of CO_2. That is to say we are almost at the radiative forcing associated with the benchmark of doubled CO_2. For the models used for Figure 5, we see that a doubling of CO_2 leads to surface warming of from about 1.5-3.5 degrees Kelvin (or Centigrade). By contrast, the observed warming over the past century or so amounts to only about 0.6 degrees Centigrade. On the face of it, this would seem to confirm that current models are much too sensitive to anthropogenic greenhouse forcing, assuming that all the observed warming was due to increasing greenhouse gases. Moreover, we have already shown that such warming actually accounts for only a small part of the observed warming. How then, can it be claimed that models are replicating the observed warming? Two matters are invoked. First, observe in Figure 7, that once one goes beyond the first three items, the terms are essentially unknown (viz Anderson et al, 2003 for aerosols). Thus, they can be used to essentially arbitrarily cancel half the anthropogenic greenhouse forcing as seen in the last item in Figure 7. This would still leave us with more warming than is observed. The second factor arises from a possibly important difference between the model runs used to simulate past climate and those used for Figure 5. The results in Figure 5 were arrived at by running the models to steady equilibria, while the simulations were time dependent runs that were stopped at the time corresponding to the last observation of temperature used for the comparison. In these transient runs, it takes time for the surface to respond to the forcing because the ocean takes time to respond, and the atmospheric transport tends to tie the land and ocean areas together. For reasons that would be somewhat too complex to include here, the ocean delay is proportional to both the climate sensitivity and the assumed thermal diffusivity of the oceans (Hansen et al, 1985, Lindzen and Giannitsis, 1998). Thus the excessive sensitivity of the models contributes to the delay. It is also the case that current models generally assume excessive thermal diffusivity. Despite this, it was still necessary to arbitrarily remove half the anthropogenic greenhouse forcing. The need to cling to the high sensitivities is readily explained by Thorpe's insistence on policy relevance. Without high sensitivity, this would be greatly diminished. Indeed, to maintain the ominous projections, it is necessary to assume that the aerosol cancellation will soon disappear (Wigley and Raper, 2002). However, these arguments are only possible if one chooses to ignore the fact that observations are failing to display the distribution of warming that is associated with greenhouse warming.

This brings us to the last item: namely, are other processes truly unknown? There are, in fact, numerous phenomena that current models fail to replicate at anywhere near the magnitudes observed. These range from the Intraseasonal Oscillations of the tropics (sometimes referred to as the Madden-Julian Oscillation, and having time scales on the order of 40-60 days) to El Niño (involving time scales of several years) to the Quasi-biennial Oscillation of the tropical stratosphere to the longer time scale phenomena like the Little Ice Age and the Medieval Warm Period (involving centuries). For at least El Niño, we are pretty sure that the phenomenon involves the fact that the oceans are never in equilibrium with the surface. Irregular exchanges of heat between the deep abyssal waters and the near surface thermocline regions imply that the oceans serve as large sources and sinks of heat for the atmosphere, and these exchanges take place over time scales from months to centuries or longer. There is, in fact, no reason to suppose current models are treating such matters adequately. In addition, there is ample evidence that current models are exaggerating climate sensitivity. The fact that so little of recent observed warming can be attributed to greenhouse warming is a crucial sign of this. Moreover, specific mechanisms have been identified such as the iris effect (Lindzen et al, 2000) which is based on observations that current models fail to replicate. This effect should provide a powerful negative feedback. More recently, Hansen (2005) has claimed that observed changes in ocean temperature (Levitus, 2005) implied model sensitivity was correct. While there are significant difficulties with Hansen's analysis – most notably that it assumes that the ocean is slave to the atmosphere on the time scales examined as well as with Hansen's interpretation (Lindzen, 2002), it remains of interest that more recent data suggests no significant ocean warming (Gouretski and Koltermann, 2007). Thus, Hansen's argument, itself, leads again to much smaller sensitivity. As mentioned earlier, ocean delay is itself proportional to climate sensitivity, and the work of Lindzen and Giannitsis (1998) and Douglass et al (2006) strongly suggested that the observed delay time is too short to allow large sensitivities.

5. Concluding remarks.

We have shown in a simple, but reasonably rigorous manner, that the record of the Vostok ice core offers no support to the notion that CO_2 is a driving mechanism for past climate. Moreover, using basic theory and modeling results, we can reasonably bound the anthropogenic contributions to surface warming since 1979 to a third of the observed warming, leading to a climate sensitivity too small to offer any measure of alarm or need for action. We next show that the defense of the attribution of recent warming to man involves an observed warming that is smaller than expected, and where the attribution, itself, is not based on scientific arguments. Finally, we note substantial corroborating work showing low climate sensitivity.

In normal science, all the above would lead to an earnest effort to find out what is wrong with models, but possibly for reasons suggested by Thorpe, this does not appear to be happening in significant measure.

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