BEFORE THE OFFICE OF ADMINISTRATIVE HEARINGS
FOR THE MINNESOTA PUBLIC UTILITIES COMMISSION
STATE OF MINNESOTA

In the Matter of the Further Investigation in to
Environmental and Socioeconomic Costs
Under Minnesota Statute 216B.2422, Subdivision 3

OAH Docket No. 80-2500-31888

MPUC Docket No. E-999-CI-14-643

Direct Testimony and Exhibits of

Professor Richard Lindzen

June 1, 2015

PROFESSOR RICHARD LINDZEN

OAH 80-2500-31888

MPUC E-999/CI-14-643

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I. INTRODUCTION

Q. Please state your name, address, and occupation.

A. My name is Richard S. Lindzen. My business address is Bldg. 54, Room 1724, M.I.T., Cambridge, Massachusetts 02139. I am a meteorologist and the Alfred P. Sloan Professor of Meteorology in the Department of Earth, Atmospheric and Planetary Sciences at the Massachusetts Institute of Technology.

Q. Please describe your educational background and professional experience.

A. I obtained three degrees from Harvard University between 1960 and 1964, culminating with a Ph.D. in Applied Mathematics in 1964. After I obtained my doctorate, I served in various meteorological research positions, including as a NATO post-doctoral fellow at the University of Oslo and as a research scientist at the National Center for Atmospheric Research. For almost 50 years, I have taught meteorology at MIT, Harvard, the University of Chicago, and other distinguished universities. My full professional history is detailed in my CV, which is attached as Lindzen Exhibit 1.

II. OVERVIEW OF OPINIONS

Q. What are the purposes of your testimony in this proceeding?

A. The purposes of my testimony in this proceeding are to testify about scientific bases for concerns about increasing levels of CO2 and to assist in the proper calculation of the "social cost of carbon" (SCC).

Q. Could you summarize your opinions?

A. The global temperature predictive models relied upon by the Intergovernmental Panel on Climate Change (IPCC) are flawed, as they, among numerous other problems, overestimate increases in global temperatures. Recent, observational data proves that the IPCC models overestimate global temperature increases and overstate any effect of anthropogenic greenhouse gases relative to natural factors. Therefore, the economic damages models that rely on IPCC estimates are also flawed.

- There is no indication that the Earth's climate is "changing" in any manner that is not otherwise naturally-occurring and consistent with climate change patterns that occurred long before the recent concern over anthropogenic emissions.
- The IPCC's estimation of "climate sensitivity," or the increase in temperature that will occur upon a doubling of atmospheric carbon dioxide concentrations, is done incorrectly. The IPCC's conclusions are based on an incomplete and incorrect understanding of the impact of natural phenomena (e.g., clouds, aerosols, and volcanic activity) that are crucial to the determination of sensitivity.
- Recent data and studies show that any increase in temperature upon a doubling of carbon dioxide concentrations will probably result in only mild warming at most, which will be beneficial to the planet and to society as a whole.
- Current economic damages models attempting to determine a "social cost" of carbon are inherently biased high because they rely on IPCC's flawed and overestimated conclusions regarding the

effect of increases of carbon dioxide concentrations on global climate.

Q. Could you summarize your principal conclusions as to the concerns about climate change expressed by the United Nations Intergovernmental Panel on Climate Change (IPCC)?

A. The bases for CO2 concerns are substantially overstated. The last four United Nations Intergovernmental Panel on Climate Change (IPCC) reports have all been summarized with the iconic claim that man-made emissions account for most of the warming since the 1970s. But the warming referred to is small and is not something that can be perceived within the noise of normal climate variability. Moreover, the IPCC claim relies on climate models that suffer from serious flaws. The models do not comport with observational data, and all IPCC models fail to predict the cessation of discernible warming over almost the past 20 years. The models appear to replicate the previous warming only by the fairly arbitrary inclusion of uncertain aerosols (reckoned to be anthropogenic emissions as well) in the models and choosing these to cancel excess warming. However, recent studies reduce the uncertainty associated with aerosols and make it implausible for them to serve as the "fudge factor" that climate modelers have assigned to them. These recent aerosol studies limit climate sensitivity values (the amount by which a doubling of CO2 from preindustrial levels would raise equilibrium global temperatures) extremely unlikely to exceed 2C.

Further, the IPCC's argument for attributing the warming since the 1970s to anthropogenic causes depended on the assumption that natural variability is small. In fact, natural variability (given the absence of warming over the past 18 years) is at least as large as any anthropogenic contribution. Hence, the IPCC's argument for the attribution of recent warming to anthropogenic factors breaks down. That is to say, we can no longer claim that man's contribution to warming has been identified in the data.

Q. Could you summarize your principal conclusions as to naturally caused climate change versus anthropogenic climate change?

A. Earth's climate is always changing. Although the IPCC and others have pointed to warming since the 1970s, in fact, there was an almost indistinguishable period of warming from presumably non-man-made causes between 1895 and 1946. The two periods (1895-1946 and 1957-2008) are essentially indistinguishable, though the early one is acknowledged by the IPCC to be natural while the other is claimed to be due in large measure to humans. Put simply, there is nothing seemingly unusual or unprecedented about the recent warming episode, and like the earlier episode, it appears to have ended (in the case of the most recent episode, about 18 years ago). Of course, it has long been recognized that Earth has had many warm periods (the Medieval Warm Period, the Holocene Optimum, several interglacial periods, and the Eocene (which was much warmer than the present). Tellingly, climatologists in the past referred to the warm periods as 'optima' since they were associated with thriving life forms. Most plant forms evolved during periods of high CO_2 (often ten times present levels).

Q. Could you summarize your principal conclusions as to climate "sensitivity values" and feedback mechanism?

A. On its own (i.e., without the operation of so-called "feedback mechanisms"), a doubling of CO_2 is generally claimed to lead to a warming of about 1C. This is generally considered too small to promote great concern. The IPCC's projected climate sensitivity values (between 1.5C and 4.5C) rest on assumed feedback mechanisms that are unproven and speculative. These asserted feedbacks relate to clouds (and water vapor), and, to a much lesser extent, changes in surface properties. However, as the IPCC acknowledges, all the feedbacks depend on unresolved features which have to be parameterized and are highly uncertain. Scientists do not agree on the existence and magnitude of these feedbacks, as the presidents of the National Academy of Sciences in the U.S. and the Royal Society in the U.K. have acknowledged.

In my opinion, the IPCC's estimated sensitivity values are substantially overstated because they depend on feedback effects that have not been shown to exist. For example, studies show that warming leads to reduced cirrus cloud coverage, which acts to counteract the warming (i.e., acts as a negative feedback) by allowing more infrared radiation to escape into outer space. This is known as the "Iris effect."

In my opinion, a climate sensitivity value of 2C or more is highly unlikely. Evidence indicates that climate sensitivity may fall within a range of from about 0.85C to 1.5C. I note that a value of 1.5C is within the IPCC's own projections.

Q. Could you summarize your principal conclusions as to the relative roles of temperature versus fossil fuel emissions in determining increases in atmospheric CO2?

A. Even the connection of fossil fuel emissions to atmospheric CO2 levels is open to question. In the ice core records of the ice ages, it appears that CO2 levels may follow temperature increases, rather than vice versa. Recent studies suggest that only about half of atmospheric CO2 concentrations may be due to fossil fuel emissions. For example, although data from the Oak Ridge National Laboratory shows that CO2 emission rates of increase roughly tripled between 1995 and 2002, the rate of increase in atmospheric CO2 concentrations remained essentially unchanged during that time. It appears that we are currently unable to relate atmospheric CO2 levels to emissions and even less to relate CO2 levels to temperature and still less to regional changes.

In any event, the contribution of U.S. emissions is already less than those of the rapidly developing countries, and any reductions that the US makes (and much less that Minnesota makes) will have an undetectable influence on global mean temperature regardless of what climate sensitivity is and what geochemical model one uses.

Q. Could you summarize your principal conclusions as to the concerns about droughts, flooding, other extreme weather phenomena, and sea ice?

A. Concerns arising from the potential impact of global warming on drought, flooding, storminess, sea ice, and similar issues are largely unproven. There is no evidence that these matters are increasing due to warming (or in most cases increasing at all). Even where trends exist, such as summer Arctic ice cover, the reduction has reversed in the last few years; also, Antarctic sea ice has been increasing throughout the satellite era. Sea level rise has been occurring since the end of the last glaciation. Changes in instrumentation make it impossible to say whether the rate is actually increasing. Warming should actually reduce the incidence of extreme weather.

Q. Could you summarize your principal conclusions as to the costs and benefits of controlling CO2 emissions?

A. Over the past 200 years, there has been modest warming of about 0.8C, and there has been a general improvement in the human condition. Costs of warming are unproven and are generally based on model projections and speculations concerning impacts rather than observed data. In contrast, the benefits of both warming and increased CO2 are clearer. CO2 is a plant fertilizer, and the increasing levels over the past two centuries are significant contributors to increased agricultural productivity. Noteworthy is the fact that levels of CO2 below 150 parts per million by volume would probably end life on the planet – an unusual property for something commonly referred to as a pollutant. Warming also leads to decreased winter mortality. Warming itself, at the levels that might realistically be anticipated (i.e., under 2C for the foreseeable future) is estimated to be net beneficial. The policy risks of limiting the clean burning of fossil fuels are clear and are likely to exceed such risks of climate change as may exist, particularly when the economic and social impacts of higher energy prices are considered.

Q. Have you prepared a report that contains your opinions?

A. Yes. My report is attached as Lindzen Exhibit 2.

Q. Are you familiar with the history of the IPCC climate change models and predictions?

A. Yes. I have been involved with the IPCC models, predictions, and reports for more than 20 years. In 1995, I contributed to the IPCC Second Assessment. In 2001, I was a lead author in a chapter of the IPCC report.

Q. Do you have an opinion regarding their accuracy or their suitability as a basis for regulatory action to reduce greenhouse gas emissions?

A. Yes. Because the models use an inappropriately high climate sensitivity and do not properly address feedbacks, aerosols, and other factors and issues outlined in my report, the IPCC models should not be used to estimate the social cost of carbon. They do not provide accurate or reliable information. Indeed, the IPCC insists that its model results be considered as 'scenarios' rather than predictions.

III. <u>CLIMATE SENSITIVITY</u>

Q. What is climate sensitivity?

A. Climate sensitivity is a measure of the change in global equilibrium temperature (i.e., the amount of warming) that would result if CO_2 concentrations doubled from preindustrial levels of approximately 275 ppm.

Q. Has any particular climate sensitivity value been proven?

A. No.

Q. What does the current IPCC report say about climate sensitivity?

A. The IPCC notes that its models display a sensitivity range between 1.5C and 4.5C.

Q. What is the role of feedback mechanisms in determining climate sensitivity?

A. Without feedback mechanisms (primarily the effect of water vapor), a doubling of CO_2 concentrations is generally expected to lead to an increase of 1C. This amount of warming is generally considered too small to be of great concern. Accordingly, the IPCC projections depend heavily on the existence of positive feedback mechanisms, which are speculative and unproven.

Q. What does the latest, peer-reviewed research suggest for climate sensitivity values?

A. Recent research demonstrates that a climate sensitivity value of 2C or more is highly unlikely. Evidence indicates that climate sensitivity may fall within a range from about 0.85C to 1.5C.

Q. What are aerosols and what is their impact on climate sensitivity?

A. Aerosols are minute particles suspended in the atmosphere. Climate modelers have often arbitrarily included the effects of aerosols in their models and used them essentially as a “fudge factor” to “cancel” excess warming and allow their models to more closely match observational data. However, new evidence, including a recent paper (Stevens, 2015), reduces the uncertainty that previously allowed climate modelers to use aerosols to cover up deficiencies in the models. These studies point to low climate sensitivity values which would imply minimal danger or even net benefit from climate change.

IV. TEMPERATURE

Q. What is the Earth's experience with warm periods?

A. Earth has had many warm periods, including the Medieval Warm Period, the Holocene Optimum, several interglacial periods, and other periods. During the Eocene, the Earth was much warmer than it is today. This is no dispute about the existence of natural warming in the thermometric record. Climate always changes.

Q. Have observed temperatures been consistent with IPCC model predictions?

A. No. Figure 9 of my testimony demonstrates that the models have consistently "run hot" or significantly overestimated warming for decades. There has been no warming for at least the last 18 years, which the models cannot explain. Further, the models produce substantially divergent results for the future. The models do not provide a reliable basis for predictions.

V. EXTREME WEATHER, CHANGES IN SEA ICE, AND OTHER PHENOMENA

Q. Are there other indicators of climate change associated with rising CO2 emissions, such as sea level rise, unusual storm activity, or Arctic ice cover losses?

A. No. There is no evidence of increases in hydro-meteorological disasters. Antarctic sea ice has been increasing throughout the satellite era, and summer artic ice cover reduction has reversed in the last few years. Sea level rise has been occurring since the end of the last glaciation. The primary driving force for storm development is the temperature difference between the tropics and the poles, a difference that should be decreasing if there is global warming, which is supposed to be greater at the poles.

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Exhibit 1

to

Direct Testimony of

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Exhibit 2

to

Direct Testimony of

Professor Richard Lindzen

June 1, 2015

Scientific bases for concern over increasing levels of CO2

Richard S. Lindzen, Alfred P. Sloan Professor of Atmospheric Sciences, Emeritus
Massachusetts Institute of Technology

Contents

1. Bases for CO_2 concerns – climate sensitivity.

The last 4 United Nations Intergovernmental Panel on Climate Change reports have all been summarized with the iconic claim that man-made (ie anthropogenic) emissions account for most of the warming since the 1970's. This is usually rephrased to claim that the earth is warming and man is responsible. Each report claims slightly increased subjective confidence in this claim, and the claim is generally presented as the reason for concern (viz IPCC, 2013). This section examines this claim in detail. We note several crucial problems with the claim:

- Even if true, the warming referred to is small and (as shown in Section 2) not unique.

- The claim refers to models with markedly different sensitivities to added greenhouse gases. Yet all the models appear to replicate the recent warming. This is achieved by fairly arbitrary inclusion of uncertain aerosols (reckoned to be anthropogenic emissions as well) in the models and choosing these to cancel excess warming. Recent studies reduce the uncertainty associated with aerosols and limit one to low sensitivity which would imply minimal danger or even net benefit.

- The claim explicitly depends on other (natural) sources of climate change are small. The assumption is based on the fact that the models used display very little natural variability, but this is contradicted by the absence of warming in the data for the past 18 years. Therefore, even the argument for the attribution of the small warming to anthropogenic emissions breaks down.

The first thing that has to be recognized is that increasing CO_2 and even warming per se are not bases for concern. Neither is the unquestioned existence of the greenhouse effect. Concern depends on at least two factors: 1. Warming due to increasing CO_2 has to be large compared to natural variability; and 2. There has to be a clear connection between such warming and concerns over such matters as extreme weather. The second item is the focus of Section 5. In addition, there has to be a clear quantitative relation between specific emissions of CO_2 and CO_2 levels in the atmosphere. This is discussed in Section 4. With respect to the first item, the fact that the greenhouse effect implies that additional CO_2 will cause some warming is insufficient evidence for concern. The amount of warming associated with specific additions of CO_2 is of crucial importance. This is what is referred to as climate sensitivity. As a matter of convention, sensitivity is often defined as the equilibrated warming resulting from a doubling of CO_2. Because of the logarithmic dependence of warming on CO_2 concentration, it does not matter what the base value is for a doubling. That is to say, doubling from 1000 ppmv to 2000 ppmv will have the same value as doubling from 280 ppmv to 560 ppmv. Because of the heat capacity of the oceans, it takes time to reach equilibrium, and that time increases sharply as the equilibrium sensitivity increases. The characteristic time to reach equilibrium is generally taken as the time to reach about 2/3 of the equilibrated value. For a sensitivity of 5 degrees C, this is on the order of many decades, while for a sensitivity of 1 degree C, it is only on the order of a few years. For sensitivities less than 1 degree C, the response is almost immediate. For certain purposes, therefore, one sometimes uses transient sensitivity: ie, the warming reached by a certain date (for example by 2100).

Climate claims are produced by models wherein the equations for the motion, composition and radiative transfer are numerically approximated. These models are referred to as General Circulation Models known as GCMs (though these days it is often assumed that GCM stands for Global Climate Model). IPCC claims are based on a large number of such models – differing pronouncedly in quality. In climate GCMs, climate sensitivity is nominally determined by the model based on its approximations and parameterizations of the physics. Note that the processes determining sensitivity are cloud scale processes that none of the models can actually resolve. To resolve processes like clouds, turbulence, etc. would require resolution on the order of meters or less. The models usually don't have resolution better than 100 km. Thus, they require fairly ad hoc approximations when dealing with unresolved scales. Despite this, the models are indeed complex. This complexity is needed, in principle, to provide information on regional scales, and to deal with other details. However, the success of models to provide regional information is doubtful since different models differ even with respect to sign on such matters. This is acknowledged in the Working Group 1 reports of the IPCC (Working Group 1 deals with the science as opposed to Working Group 2 which deals with the impacts based on usually worst case scenarios or Working Group 3 which deals with mitigation).

If one wishes to focus on global mean temperature, and assumes climate sensitivity, then much simpler models suffice. These very simple models are known as energy balance models. Such models are used by the IPCC for scenario development. We will use such a model to examine the problems in inferring sensitivity from the observed temperature change. That said, we will also see that the observed temperature is most easily simulated with low sensitivity – that is to say that such models do not require extreme adjustments with aerosols in order to simulate observations.

The IPCC presents estimates of radiative forcing (a precise definition of radiative forcing is given in Section 3) by both greenhouse substances and substances that reflect incoming solar radiation. Their estimates are shown in Figure 1. It is the balance between the net incoming solar radiation and the outgoing long wave (infrared) radiation emitted by greenhouse substances that determine the system temperature. Note that greenhouse substances actually cool the system. The greenhouse effect stems from the fact that increasing the amount of greenhouse gases elevates the level from which they cool, and since the temperature of the troposphere (the lowest 7-16 km of the atmosphere depending on latitude) decreases with height, the new level is cooler, and, therefore emits less radiation. This reduction in cooling is what is commonly referred to as warming.

Several things should be noted from Figure 1. First, CO2 is not the only anthropogenic greenhouse gas. While it is the most important one, it contributes (as of 2014) only about 1.7 Watts per square meter. Other gases bring the value to about 2.8 Watts per square meter.

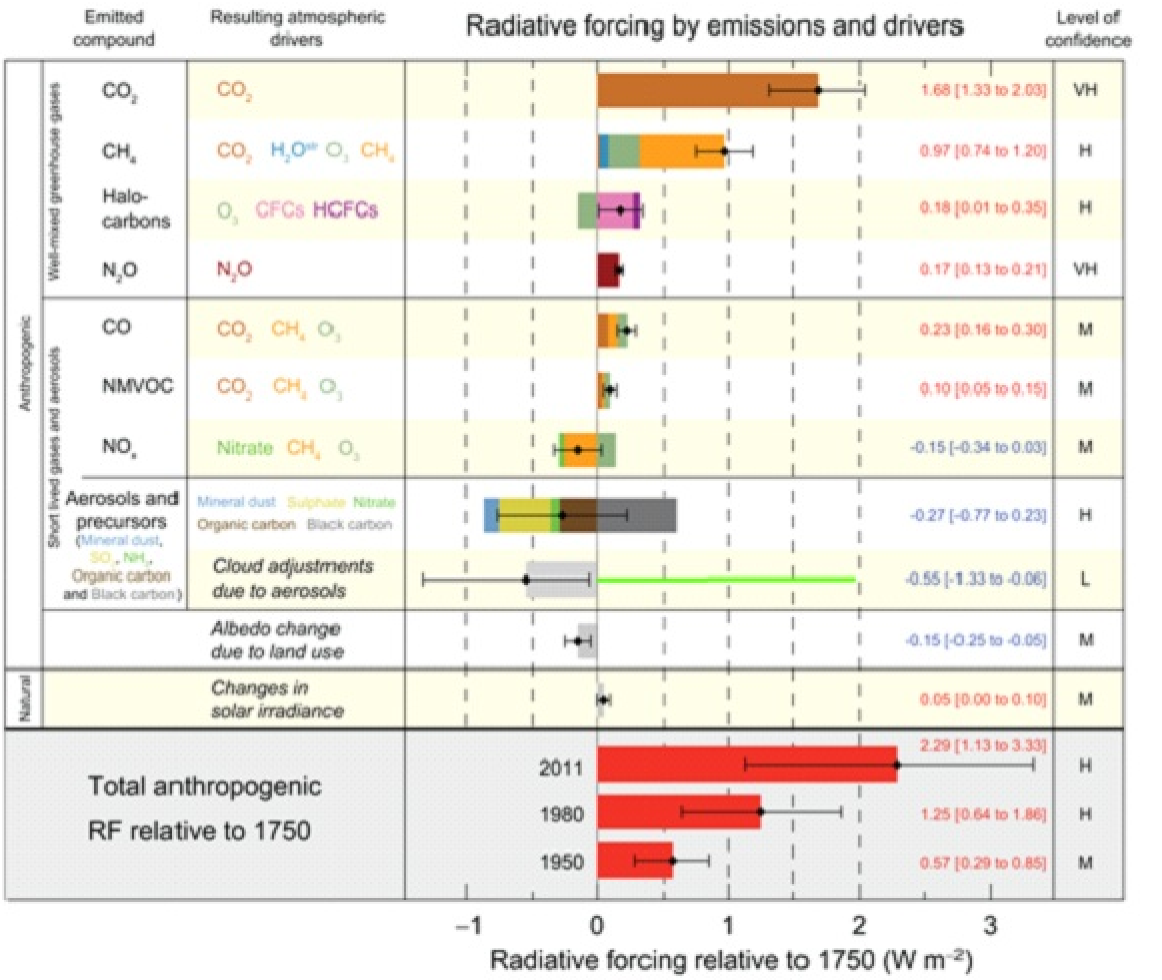

Figure SPM.5 | Radiative forcing estimates in 2011 relative to 1750 and aggregated uncertainties for the main drivers of climate change. Values are global average radiative forcing (RF[14]), partitioned according to the emitted compounds or processes that result in a combination of drivers. The best estimates of the net radiative forcing are shown as black diamonds with corresponding uncertainty intervals; the numerical values are provided on the right of the figure, together with the confidence level in the net forcing (VH – *very high*, H – *high*, M – *medium*, L – *low*, VL – *very low*). Albedo forcing due to black carbon on snow and ice is included in the black carbon aerosol bar. Small forcings due to contrails (0.05 W m^{-2}, including contrail induced cirrus), and HFCs, PFCs and SF_6 (total 0.03 W m^{-2}) are not shown. Concentration-based RFs for gases can be obtained by summing the like-coloured bars. Volcanic forcing is not included as its episodic nature makes is difficult to compare to other forcing mechanisms. Total anthropogenic radiative forcing is provided for three different years relative to 1750. For further technical details, including uncertainty ranges associated with individual components and processes, see the Technical Summary Supplementary Material. {8.5; Figures 8.14–8.18; Figures TS.6 and TS.7}

Figure 1. Radiative forcing from IPCC (2013). The green line was added to the aerosol contribution to indicate that aerosols can cause the freezing of supercooled water into ice particles and thus contribute to warming as well as cooling.

The second thing to note is that aerosols are a poorly known source of cooling (though the latest IPCC report has substantially reduced this uncertainty), and a recent paper (Stevens, 2015) further reduces the uncertainty. This reduced uncertainty will prove important to our discussion since the uncertainty allowed modelers to use aerosols to cancel excess warming. Finally, it should be noted that all the items in Figure 1 represent small perturbations to the overall radiative budget which involves balances between insolation and outgoing infrared radiation on the order of 200 Watts per square meter. The large values are associated with what are far and away the most important greenhouse substances which are water vapor and clouds. These will be of central importance when we turn to what determines climate sensitivity in Section 3: namely feedbacks.

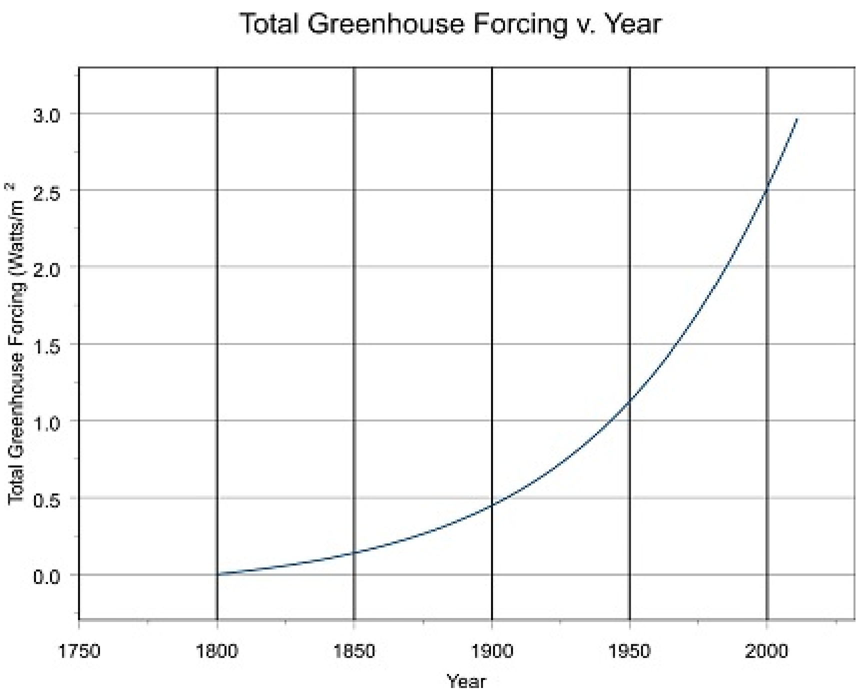

Figure 2. Total greenhouse forcing as function of time.

Figure 2 shows a smoothed time series for the evolution of anthropogenic greenhouse forcing (including all IPCC sources). The smoothing simply means that small irregularities in the evolution of greenhouse forcing are ignored; they are irrelevant to our discussion. The value reached in 2014 is 2.8 Watts per square meter, which is about 75% of what is commonly expected from a doubling of CO_2. Most models also include forcing by volcanoes. This forcing is shown in Figure 3. We calculate the response to these forcings using the energy balance model described in Lindzen and Giannitsis (1998). This is effectively the same model widely used for scenario development by the IPCC. Figure 4 shows the response to anthropogenic greenhouse gases. Recall that global mean temperature (or, more accurately, global mean temperature anomaly) increased about 0.75C since the end of the little ice age in the 19th Century. We see that models with sensitivity in excess of about 1C all show greater warming. However, the difference between higher and lower sensitivity is less than one might expect because higher sensitivities are associated with slower responses. This

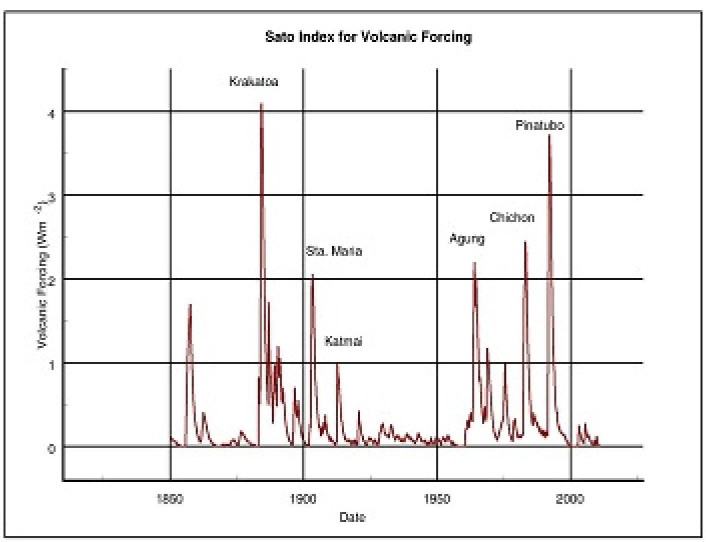

Figure 3. Volcanic forcing (Sato index from NASA/GISS)

why transient sensitivity is smaller than equilibrium sensitivity. Figure 5 shows the response to volcanic forcing. Volcanic activity tends to cluster (which is typical of random processes). For low climate sensitivity, the response to volcanos is largely restricted to the life time of the volcanoes, but for high sensitivity, the response persists for a long time, and provides a significant contribution to cooling. This serves to reduce the difference in total response corresponding to different sensitivities as we see in Figure 6 which shows the response to combined greenhouse and volcanic forcing. Of course, once again all sensitivities above 1C exceed the observed warming. However, modelers use aerosols to reduce the warming as shown in Figure 7. Table 1 shows what fraction of the greenhouse warming had to be removed in order achieve modest agreement with observations. Notice that the aerosol compensation needed to achieve agreement by the present does not increase much for high sensitivities because of the fact that response time increases with sensitivity. However, given the

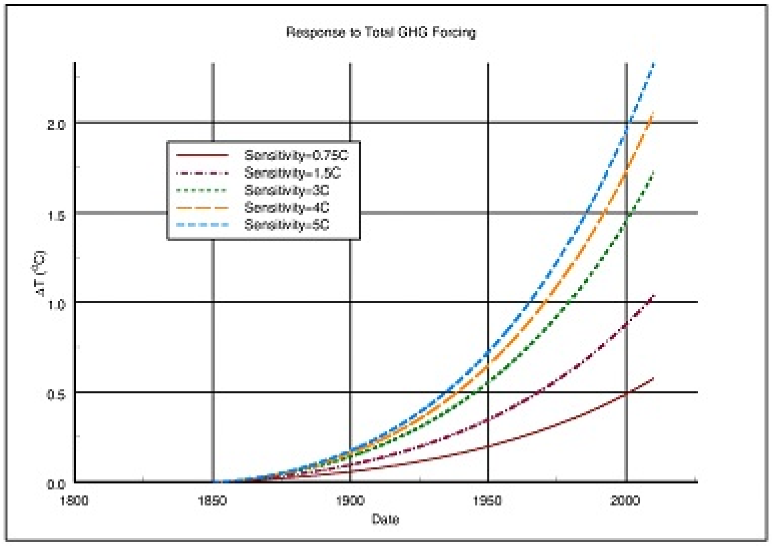

Figure 4. Temperature response to greenhouse forcing.

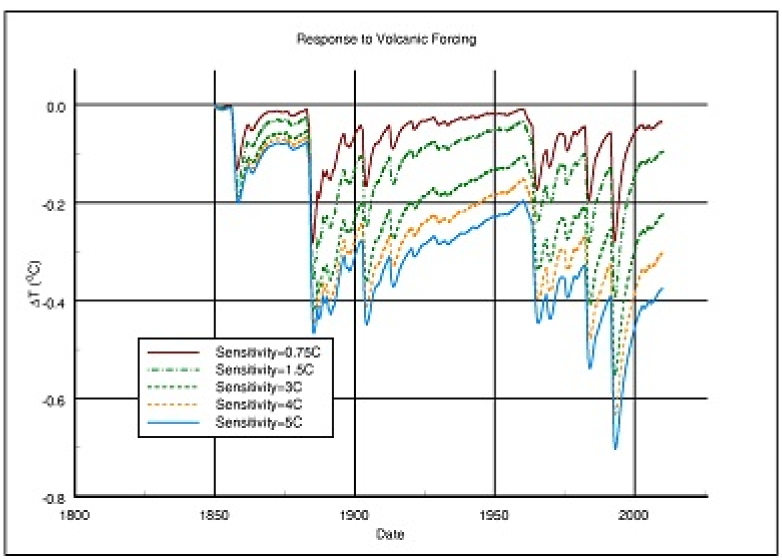

Figure 5. Temperature response to volcanic forcing.

recent results of Stevens (2015), the aerosol compensation called for by high sensitivity models might not be available. Thus, it will not be possible to bring these models into agreement with observations. The IPCC claims significant confidence that only by a combination of greenhouse warming and aerosol cooling (both subsumed under the ambiguous label of anthropogenic influences) can the observed warming of the period since the 1970's be accounted for. However, their claim is based on the fact that the models have very little internal variability so that almost all of the recent warming can be attributed to anthropogenic forcing. Natural internal variability refers to changes in temperature that occur without external forcing. Such changes occur, for example when heat is exchanged between the surface and the deeper oceans, leaving the surface disequilibrated.

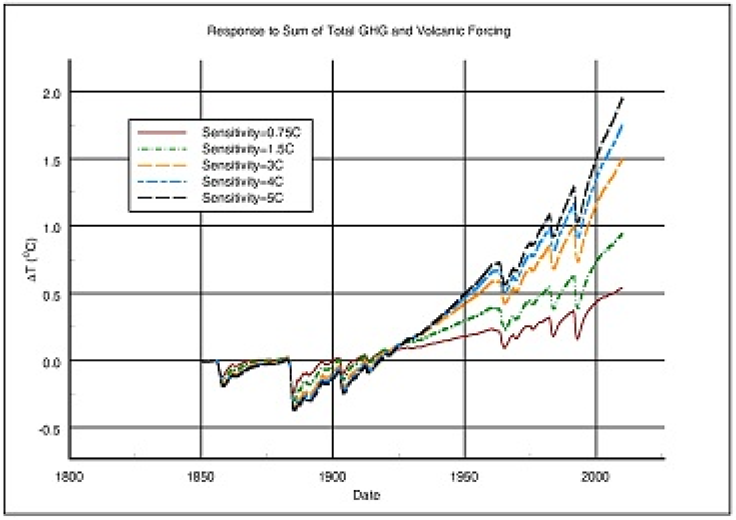

Figure 6. Temperature response to sum of greenhouse and volcanic forcing.

The behavior of the temperature in Figure 7 does not resemble the observed temperature in detail because modelers apply adjustments in a variable fashion to achieve better agreement. Observed temperature behavior is shown in Figure 8. However, model results when extended to the future diverge strongly as seen in Figure 9.

So, where does all this leave us? **First**, for purposes of perspective, it is worth noting that the temperature changes we are discussing are small.

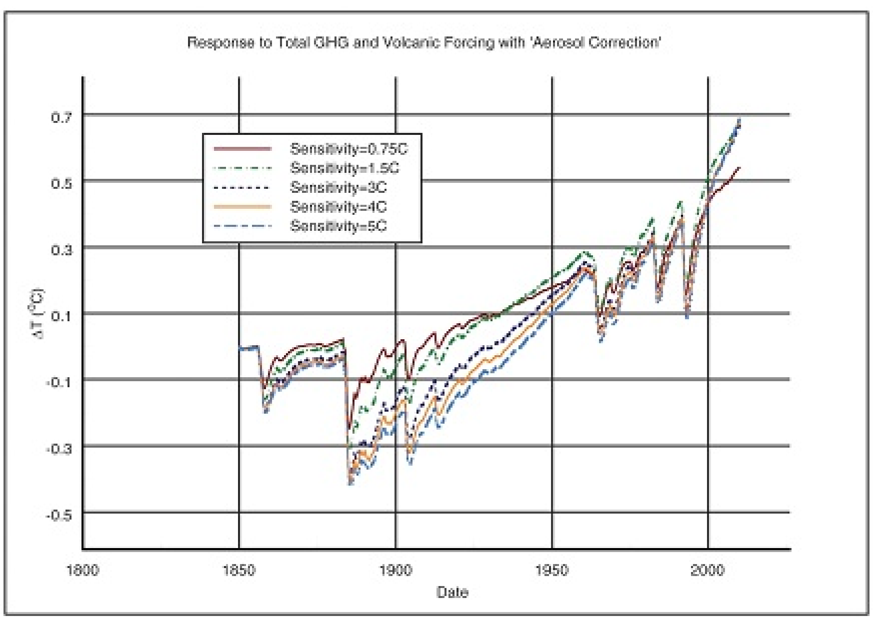

Figure 7. Temperature response ‘adjusted’ with aerosols.

Sensitivity in ^{0}C (for doubling of CO_2)	Fraction of GHG forcing cancelled by 'aerosols'
0.75	0
1.5	0. 25
3.0	0.481
4.0	0.525
5.0	0.543

Table 1. Cancellation by aerosols for various choices of sensitivity.

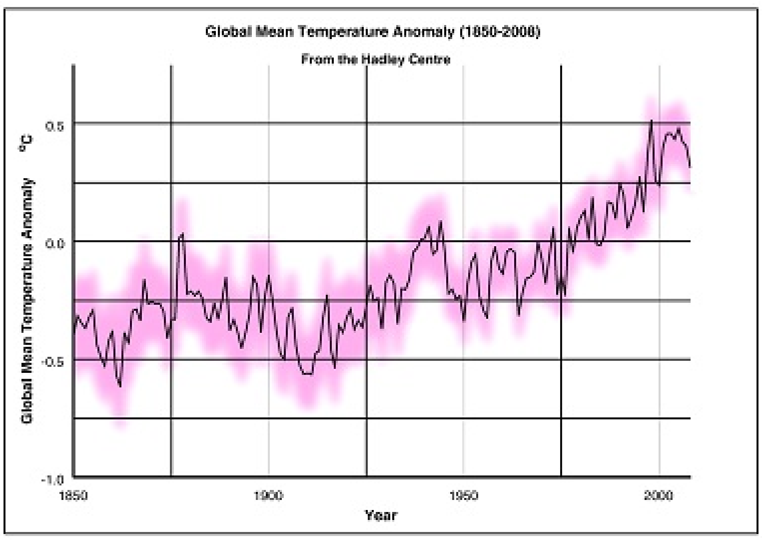

Figure 8. Observed temperature behavior. Pink envelope indicates statistical uncertainty bounds.

In Figure 10, which shows the temperature record for February 2013 in Boston, and also shows daily high and low, the average high and low, and the record breaking highs and lows for each day, the the thickness of the red line constitutes the range of change of global mean temperature anomaly for the past 150 years. The same situation would pertain to any year and month. The warming that is discussed with respect to the issue of global warming is not something that can be perceived within the noise of normal variability. **Second**, if we wish to account for the observed warming over the past 150 years on the basis of greenhouse gases, volcanoes and aerosols, then the new bounds on aerosols rule out sensitivities over about 2C. **Third**, given that all IPCC models fail to predict the cessation of discernible warming over almost the past 20 years, we have to conclude that natural variability is at least as large as any anthropogenic contribution. But, the IPCC argument for attributing the warming since the 1970's to anthropogenic forcings depended on the assumption that natural variability was small (based on the model behavior). This, we now see, is untrue, and hence the IPCC argument for the attribution of recent warming to anthropogenic forcing breaks down. That is to say, we can no longer claim that man's contribution to warming has been identified in the data. **Fourth,** ironically, the presence of natural variability now provides for a remote possibility of higher sensitivity, provided that natural variability provided part of the cancellation of the excess warming associated with high sensitivity. This has been suggested in a recent paper (Brown et al, 2015)). The idea is that the same natural variability that accounts for the cessation of warming over the past 18 years, might also have cancelled warming that might otherwise have occurred during the earlier period. Not only does this destroy the original argument for attribution, but it also involves special pleading of a particularly egregious sort since it is just as likely that natural variability accounted for much of the warming episode itself, in which case the sensitivity would have to be very low.

Still, when everything is considered, it would appear that equilibrium sensitivity in excess of about 2C depends on the arbitrary coincidence of factors and is thus highly unlikely. Many recent peer reviewed papers indeed noted the that climate sensitivity is likely to small (Lewis, 2013 , Lewis and Crok, 2014, Lewis and Curry, 2014 Annan and Hargreaves, 2011, Ring et al, 2012, Aldrin et al, 2012). Further support for low sensitivity will be presented in Section3. Indeed, the lower value of sensitivity (ie, 1.5C), is currently within the range of IPCC projections. Thus, the danger that might be associated with a highly sensitive climate is implausible, but not yet rigorously impossible. As usual, it is difficult if not impossible for science to prove things to be impossible. Such a situation is far removed from either settled science or any likelihood of apocalypse. This is separate from the issue of whether any proposed emissions policy would discernibly influence the situation. However, if the situation is that there is no impending danger, then even this would not matter.

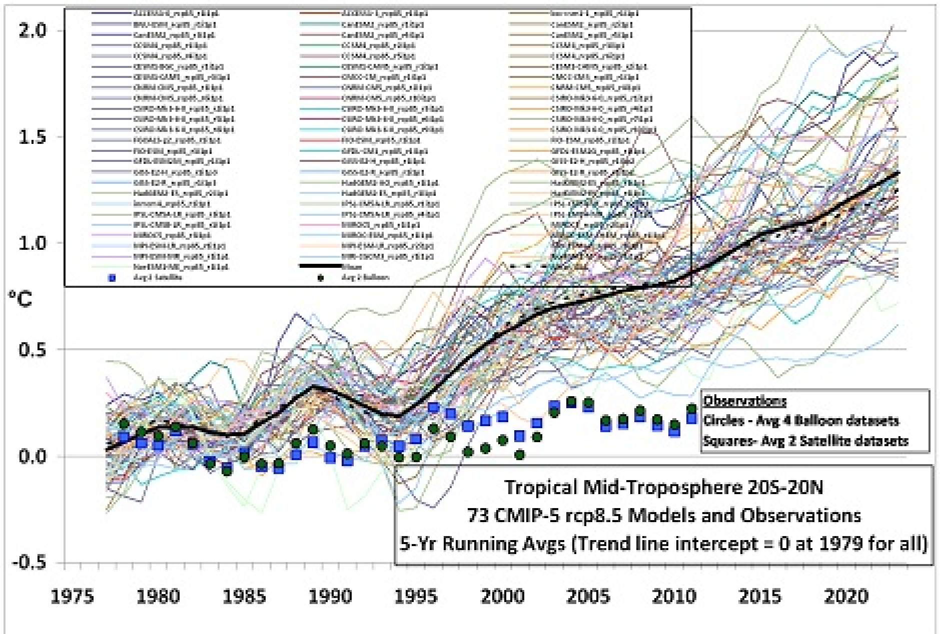

Figure 9. Observed model projections compared with observed temperature.

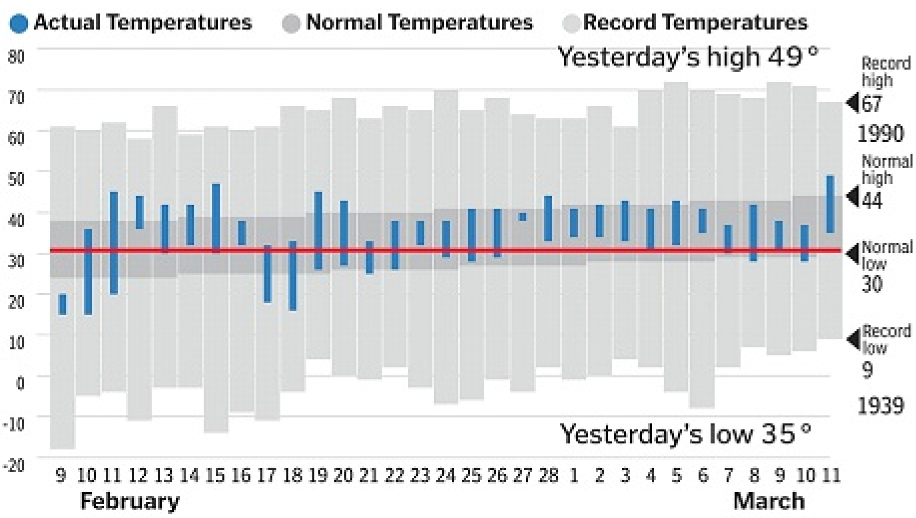

Figure 10. Boston temperatures for the period Feb 9 - March 11 2013. Blue bars show temperature range for day; dark gray bars show average highs and lows for a given date; light gray bars show record highs and lows for a given date. The thickness of the red line represents the range of global mean temperature since 1850.

2. Climate change v. anthropogenic climate change.

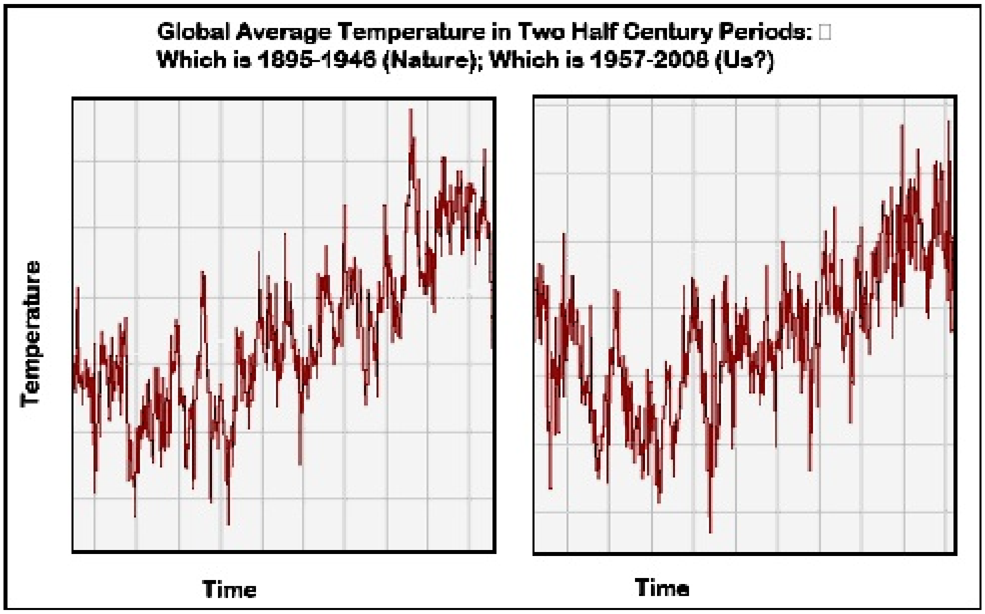

Figure 11. Time history of temperature for two periods in the instrumental record. One warming episode refers to a period where the warming could not be due to anthropogenic emissions; the other has been claimed by the IPCC to be due to man. Note that time and relative temperature scales are identical in both graphs.

Note that only the warming from about 1978 until 1998 is, according to the IPCC, potentially attributable to emissions. The reason for this is seen in Figure 2. Until the 70's, greenhouse forcing was simply too small. However, as can be seen in Figure 8, there was an earlier warming from about 1918 until 1940. In Figure 11, we display the temperature records for the periods 1895-1946, and 1957-2008, periods which surround the two warming episodes. As is evident, the two periods are essentially indistinguishable though one is presumably natural while the other is claimed to be due in large measure to man. Put simply, there is nothing seemingly unusual or unprecedented about the recent warming episode, and like the earlier episode, it appears to have ended (in the case of the most recent episode, about 18 years ago). Of course, it has long been recognized that earth has had many warm periods (the Medieval Warm Period, the Holocene Optimum, several interglacial periods, the Eocene (which was much warmer than the present), etc. The point is simply that climate always changes. While there are occasional disputes about some of the earlier warm episodes, there can be no dispute about the existence of a non-anthropogenic warming episode in the thermometric record.

Tellingly, climatologists in the past referred to the warm periods as ‘optima’ since they were associated with thriving life forms. It is conceivable, however, that man emerged only during the period of glaciation cycles because only in such challenging climates was there an evolutionary advantage for intelligent mammals. Most plant forms, however, evolved during periods of high CO_2 (often ten times present levels). These periods were mostly (though not always) warm periods. However, there is also evidence of cold periods associated with higher levels of CO_2. The famous ice cores from Antarctica do show low values of CO_2 associated with glacial periods and higher values associated with interglacials. However, it appears that changes in CO_2 followed rather than led changes in temperature. This should not be surprising. Increased temperatures are associated with decreasing ability of oceans to hold CO_2, and also with greater rates of biospheric decay on land. This will be an important consideration in Section 4.

3. Sensitivity and feedbacks.

In Section 1, we considered the consequences of different choices of climate sensitivity. In this section we will discuss what physically determines sensitivity. As already noted, greenhouse warming results from the fact that the addition of greenhouse gases (ie gases with absorption and emission in the infrared spectrum characteristic of the earth's temperature), elevates the characteristic level from which radiation is emitted to space. The emitted flux increases sharply with temperature, but the temperature of the troposphere decreases with altitude. Thus, the amount of emitted radiation decreases with the addition of the greenhouse gas (or substance since clouds are a major greenhouse substance). This decrease represents the radiative forcing shown in Figure 1. To compensate for this, the entire troposphere warms in order to bring the radiation to space in balance with the net incoming solar radiation. The usual value given for the radiative forcing due to doubling CO_2 is about 3.5 watts per square meter. However, as we see in Figure 1, even this is subject to substantial uncertainty. Moreover, the value depends on ignoring the role of upper level cirrus clouds. Note that, in the absence of upper level cirrus clouds, the characteristic emission level is determined primarily by water vapor with relatively small contributions from CO_2. Where upper level cirrus clouds are present, their infrared opacity is so great that the tops of these clouds determine the emission level. Of course, clouds (mostly at lower levels in the troposphere) also reflect sunlight, and thus also play a major role in determining the net incoming solar radiation (ie the incoming solar visible radiation minus that part reflected by the surface, clouds, and aerosols).

Now, all the above factors (upper level cirrus coverage, humidity, low level cloud cover, and surface properties which depend on snow and ice cover) can depend on temperature. Thus, when added greenhouse gases alter temperature, these factors provide feedbacks that can either amplify or diminish the direct effect of the greenhouse gases. Without feedbacks, a doubling of CO_2 is generally claimed to lead to a warming of about 1C. This is generally considered too small to promote great concern. The paper that probably did more to promote concern than any other was Manabe and Weatherald (1975). In this paper, a simple one dimensional model was used to show that the assumption of constant relative humidity would lead to a positive feedback that would approximately double the response to increasing CO_2. The point is that relative humidity is the ratio of humidity (ie the amount of the main greenhouse gas, water vapor) to its saturated value. But, the saturated value increases with temperature. Thus, if relative humidity were to remain constant, humidity, itself, would increase. This proved extremely important. The mathematical treatment of feedbacks is given in Lindzen et al (2001). It leads to the following equation:

$$\text{Response} = \frac{\text{Zero Feedback Response}}{1 - \text{Sum of feedback factors}}$$

The so-called water vapor feedback contributes 0.5 to the sum of feedback factors (viz Manabe and Weatherald, 1975, as well as IPCC, 2013), and this, by itself, doubles the response. However, for example, adding other feedback factors contributing an additional 0.5 to the sum, would bring the response to infinity, and still more positive feedback would destabilize the climate system. The IPCC model based estimate of sensitivity between 1.5 and 4.5C implies that, in addition to the so-called water vapor feedback of 0.5, there are, in the models, other feedbacks with feedback factors ranging from -.17 up to about +0.28, depending on the model. The crucial point is that the putative existence of starting feedback factor of 0.5 opens up the possibility of very large sensitivities with relatively small additions to the sum of feedback factors. These additional feedbacks are associated in the models with clouds, and, to a much lesser extent, changes in surface properties. However, as the IPCC acknowledges, all the feedbacks depend on unresolved features which have to be parameterized and are highly uncertain. When various scientific bodies refer to consensus, they are referring to the relatively trivial matters such as the observation that CO2 is increasing, that there is a greenhouse effect, and that there has been a small warming since the end of the Little Ice Age in the 19th Century. On the whole, the last item has been a beneficial change. However, in a public message by the presidents of the National Academy of Sciences and the Royal Society, the fact that the actual climate sensitivity is a matter current research is openly acknowledged (Rees and Cicerone, 2010). Quoting from their letter, "Straightforward physics tells us that this rise is warming the planet. Calculations demonstrate that this effect is very likely responsible for the gradual warming observed over the past 30 years and that global temperatures will continue to rise – superimposing a warming on all the other effects that make climate fluctuate. *Uncertainties in the future rate of this rise, stemming largely from the "feedback" effects on water vapour and clouds, are topics of current research*." The peculiarly disappointing aspect of this research is that it has not changed the range of model results since the Charney Report of 1979 (Charney et al, 1979). Following the brief Charney Report, the National Academy assembled a panel to prepare a major study (Nierenberg et al, 1983). The chair of this panel, William Nierenberg, Director of the Scripps Oceanographic Institution, became an outspoken skeptic of global warming alarm.

It is important at this stage to explain why I referred to the water vapor feedback as the 'so-called water vapor feedback.' The point is that the water vapor feedback is only relevant in regions free of upper level cirrus, but, in the tropics where the feedback processes are concentrated, upper level cirrus coverage is highly variable. One cannot evaluate the water vapor feedback without knowing the area over which it applies. The upper level cirrus are produced by ice thrown off of deep cumulus towers. How much ice is thrown off depends on how efficiently rain forms within the towers. Inefficient rain production leaves more liquid to freeze and detrain forming cirrus. The exact nature of these processes is unclear, but studies show that warming leads to reduced cirrus coverage (Rondonelli and Lindzen,2008, Horvath and Soden, 2008) which acts to counteract the warming (ie acts as a negative feedback). This is referred to as the Iris Effect (Lindzen et al, 2001). Since the feedbacks due to water vapor and upper level cirrus cannot be disentangled, the only remaining approach is to consider the two together as a long wave (or infrared) feedback. This combined long wave feedback can be measured from space, and several studies show it to be negative or small rather than positive and large (Lindzen and Choi, 2011, Choi, et al, 2014, Trenberth and Fasullo, 2009). Without the water vapor feedback in the above equation, there is little scope for high sensitivity. Thus, if the water vapor is simply zero (rather than negative as the data suggests), the remaining model feedbacks lead to a range of sensitivity of from about 0.85C to 1.4C. Should the long wave feedback be negative as various studies suggest (Lindzen and Choi, 2011, Choi, et al, 2014, Cho et al,2012) then sensitivity would be even less. There are currently attempts to find new short wave feedbacks that might increase sensitivity (Trenberth and Fasullo, 2009, Bony and Dufresne, 2005), but this would completely change the long-standing basis for concern. No longer would the water vapor feedback be credited with increasing sensitivity, but rather entirely new and hitherto unknown feedbacks would have to be invoked. It seems unlikely that such feedbacks would return sensitivities in excess of 2C. The Iris Effect has been a source of considerable controversy. Interestingly, a recent paper (Mauritsen and Stevens, 2015) notes that the inclusion of the iris effect in their model uniquely corrects a variety of serious model deficiencies (inadequate change in evaporation with changes in temperature, errors in outgoing radiation associated with temperature changes – both major factors in determining climate sensitivity).

Summarizing the situation so far, we find the following:
a. The basis for attributing warming in the period 1978-1998 (the only period the IPCC claims can be attributed to anthropogenic emissions) is no longer valid since natural variability is unambiguously present in nature if not in models.
b. The physical basis for high climate sensitivity, the water vapor feedback, appears to be cancelled and even turned negative by other processes (presumably the variation of upper level cirrus).
c. While the possibility of high climate sensitivity cannot be rigorously disproved, it would depend on processes that have not yet been identified. Feedbacks (other than the water vapor feedback) in current models would be grossly insufficient.

4. The relative roles of temperature v. emissions in determining increases in atmospheric CO2.

Policies stemming from concerns over CO2 assume that we know how to control atmospheric levels of CO2. There are substantive reasons to question even this. Figure 12 shows the estimated emissions published by the Carbon Dioxide Information Analysis Center (CDIAC) at Oak Ridge National Laboratory. Figure 13 shows the atmospheric levels of CO2. Despite a rapid acceleration of emissions in 2002 (the rate essentially tripled), the rate of increase in CO2 remained essentially unchanged. Systematic instrumental observation of CO2 dates back to only 1958. Data for earlier times are obtained from the analysis of air bubbles in ice cores. Dating of such air bubbles is imprecise and involves a spread of about 18-20 years (MacFarling et al, 2006). Subject to this caveat, the data in Figure 14 (which comes from a smoothed and adjusted

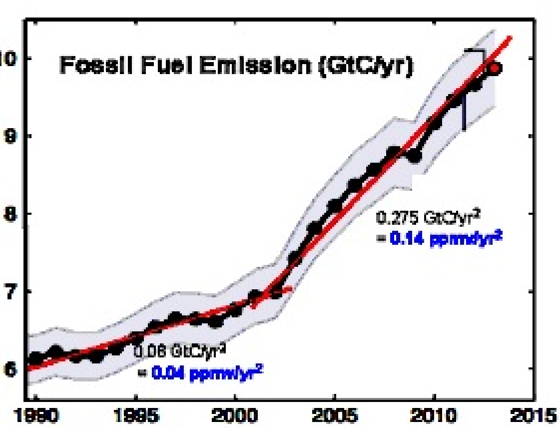

Figure 12. Fossil fuel emission rates v. time.

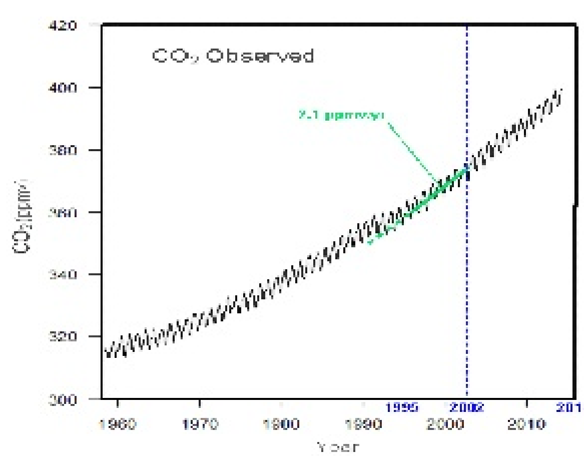

Figure 13. Atmospheric CO2 as a function of time at Mauna Loa Observatory.

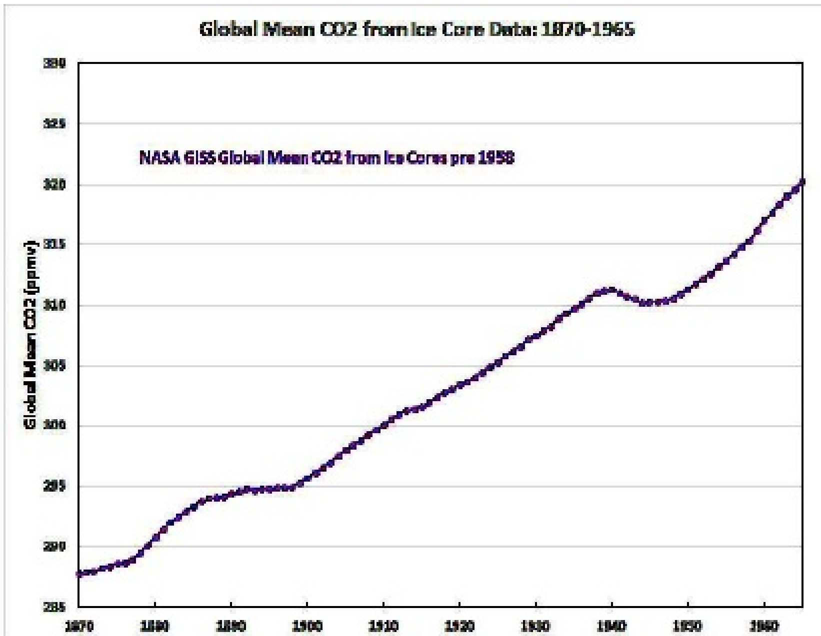

Figure 14. Global mean CO2 obtained from ice cores.

version of this data from NASA's Goddard Institute for Space Studies) shows a noticeable decline in CO2 during the period following 1940. This was a period of modest cooling, and the decline suggests that temperature may be influencing levels of atmospheric CO2. The usual rule of thumb that half of emitted CO2 appears as atmospheric CO2 is based on the Bern model for CO2 geochemistry. This model appears to assume that temperature does not contribute to secular changes in atmospheric CO2. If this assumption is inappropriate (and it certainly seems so), then the contribution of emissions to atmospheric CO2 may be significantly less. The only point here is that even the connection of emissions to atmospheric CO2 is open to question.

That said, it remains the case that the contribution of US emissions is already less than those of the rapidly developing countries, and that any reductions that the US makes (and much less that Minnesota makes) will have an undetectable influence of global mean temperature regardless of what climate sensitivity is and what geochemical model one uses.

5. Climate and extreme weather, sea ice, etc.

As noted in Section 1, warming per se is not catastrophic. Rather, concerns arise from the potential impact of such warming on drought, flooding, storminess, sea ice, etc. Despite assertions by the President's Science Adviser, Dr. John Holdren, there is no evidence that these matters are increasing due to warming (or in most cases increasing at all). On these issues there is often profound disagreement between the IPCC and the political assertions. The absence of evidence for increases in various hydro-meteorological disasters is amply discussed in Pielke, Jr. (2014). Even where trends exist, such as summer arctic ice cover, the reduction has reversed in the last few years; also, antarctic sea ice has been increasing throughout the satellite era. Although satellite data has only been available since the late 70's, anecdotal evidence for summer sea ice reductions in the early 1920's is amply available. Sea level rise has been occurring since the end of the last glaciation. Changes in instrumentation make it impossible to say whether the rate is actually increasing (Wunsch, Ponte and Heimbach, 2007). With respect to extratropical storminess, both basic theory and models imply that global warming will reduce storminess and extremes (viz any textbook on dynamic meteorology: eg Holton and Hakim, 2013, Lindzen, 1990). The issue here is that the primary driving force for storm development is the temperature difference between the tropics and the poles. Since global warming is supposed to be greater at the poles, this difference should be decreasing. Extremes in temperature such as those shown in Figure 10 result from the advection of air from distant points. Reduced storm intensity also reduces the strength of such advection. It is sometimes suggested that warming could contribute to tropical storms because of increases in evaporation and humidity. However, observations show that we have had 10 years of unusually low hurricane activity (Pielke, Jr., 2014) . As the IPCC delicately notes, "There is medium evidence and high agreement that long-term trends in normalized losses have not been attributed to natural or anthropogenic climate change." (IPCC, SREX, 2012)

6. Benefits v. costs.

In view of the above, it is not evident why one attaches costs to the emissions of CO2. To be sure, the burning of fossil fuels can lead to emissions of actual pollutants, but CO2 is not, itself a pollutant, and effective means of eliminating the actual pollutants are generally required and implemented. Over the past 200 years, there has been modest warming of about 0.8C, and there has been a general improvement in the human condition. Such costs as are inferred are generally based on model projections and speculations concerning impacts rather than observed relations. Moreover, the benefits of both warming and increased CO2 are clearer. CO2 is the basic chemical for photosynthesis. It is essential to plant life, and at least on the order of 150 ppmv are needed to sustain life. CO2 is a fertilizer, and the increasing levels over the past two centuries are significant contributors to increased agricultural productivity (Idso, 2000, Driessen and Arnold, 2014). Warming itself, at the levels that might realistically be anticipated (ie under 2C for the foreseeable future) are estimated to be net benefits. In considering excess deaths attributable to extreme warm events, one should also consider the far larger number of excess deaths due to extreme cold events (Goklany, 2012, Guo et al, 2014). Guo et al (2014) note, quite remarkably, that excess deaths are associated primarily

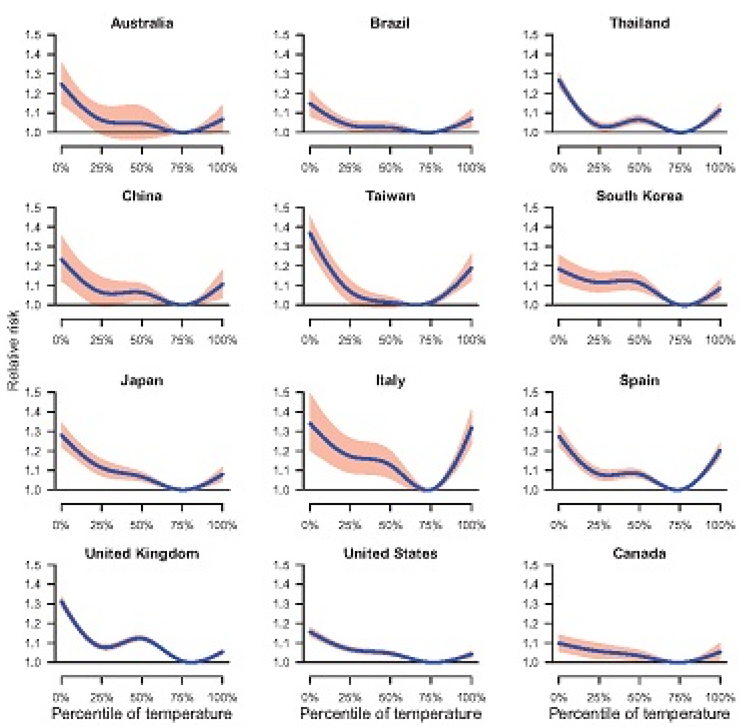

Figure 15. Relative risk of mortality (y-axis) as a function of mean daily temperature plotted as a percentile of the entire temperature record. Temperature for each country was pooled.

with colder temperatures even in warm climates. Figure 15 is taken from Guo et al (2014). Moreover, as noted in Section 5, warming should actually reduce the incidence of extremes. Warming apart, CO_2 is not a pollutant. As Casey and Macatangay (2010), note, NASA studies show that concentrations under 5000 ppmv (12.5 times present ambient levels, and much higher than the burning of all fossil fuels would produce) present no risk to health.

In summary, we have well identified benefits – including those from modest warming – and implausible dangers involving uncertain costs. There is, moreover, the evident negative impact of proposed measures on prosperity, and the obvious importance of prosperity for environmental resilience. The policy risks of limiting the clean burning of fossil fuels are clear and are likely to exceed such risks of climate change as may exist.

References

Aldrin, M., et al., 2012. Bayesian estimation of climate sensitivity based on a simple climate model fitted to observations of hemispheric temperature and global ocean heat content. *Environmetrics*, doi: 10.1002/env.2140.

Annan, J.D., and J.C Hargreaves, 2011. On the generation and interpretation of probabilistic estimates of climate sensitivity. *Climatic Change*, 104, 324436.

Bony, Sandrine and J.-L. Dufresne, 2005, Marine boundary layer clouds at the heart of tropical cloud feedback uncertainties in climate models. *Geophysical Research Letters*, DOI: 10.1029/2005GL023851

Brown, P.T., W. Li, E.C. Cordero and S.A. Mauget, 2015, Comparing the model-simulated global warming signal to observations using empirical estimates of unforced noise. *Nature*, 5:9957/DOI: 10.1038/srep09957

Casey, J.T. and A. Macatangay, 2010, *Carbon Dioxide – Our Common Enemy*, NASA Report. available at http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20090029352.pdf

Charney, Jule G. , Akio Arakawa, D. James Baker, Bert Bolin, Robert E. Dickinson, Richard M. Goody, Cecil E. Leith, Henry M. Stommel, and Carl I. Wunsch, 1979*, Carbon Dioxide and Climate: A Scientific Assessment*, National Research Council, Ad Hoc Study Group on Carbon Dioxide and Climate (Washington, DC: National Academy Press).

Cho H, Ho CH, Choi YS (2012) The observed variation in cloud-induced longwave radiation in response to sea surface temperature over the Pacific warm pool fromMTSAT-1R imagery. *Geophys Res Lett* 39: L18802

Choi, Y.-S. , Cho, H., Ho, C.-H., Lindzen, R.S., Park, S.K. & Yu, X. (2014) Influence of non-feedback variations of radiation on the determination of climate feedback. *Theor Appl Climatol* DOI 10.1007/s00704-013-0998-6

Driessen, P. and R. Arnold, 2014, *Miracle Molecule: Carbon Dioxide, Gas of Life*, Availble as Kindle book from Amazon.com, 40 pp.

Goklany, I., 2012, *Humanity Unbound How Fossil Fuels Saved Humanity from Nature and Nature from Humanity*, Cato Policy Analysis No. 715, 33 pp.

Guo, Y., Gasparrini, A., Armstrong, B., Li, S., Tawatsupa, B., Tobias, A., & Williams, G. (2014). Global Variation in the Effects of Ambient Temperature on Mortality: A Systematic Evaluation. *Epidemiology*, 25(6), 781-789

Holton, J.R. and G.J. Hakim, 2013, *An Introduction to Dynamic Meteorology*, 5th Edition, Academic Press, 532 pp.

Horvath, A. and B.J. Soden, 2008, Lagrangian Diagnostics of Tropical Deep Convection and Its Effect upon Upper-Tropospheric Humidity, *Journal of Climate*, DOI: 10.1175/2007JCLI1786.1

Idso, C. et al, 2000, Ultra-enhanced spring branch growth in CO2-enriched trees: can it alter the phase of the atmosphere's seasonal CO2 cycle? Environmental and Experimental Botany, Volume 43, Issue 2, April 2000, Pages 91-100

IPCC, 2013, *Climate Change 2013: The Physical Science Basis*. Cambridge University Press. Available at http://www.ipcc.ch/report/ar5/wg1/

IPCC, 2012, *Managing the risks of extreme events and disasters to advance climate change adaptation*. Cambridge University Press. Available at http://www.ipcc-wg2.gov/SREX/

Lewis, N. 2013. An objective Bayesian, improved approach for applying optimal fingerprint techniques to estimate climate sensitivity. *Journal of Climate*, doi:10.1175/JCLID1200473.1.

Lewis, N. and M. Crok, 2014, *A Sensitive Matter: How The IPCC Buried Evidence Showing Good News About Global Warming*, Global Warming Policy Foundation Report No. 13, 65 pp. http://www.thegwpf.org/content/uploads/2014/02/A-Sensitive-Matter-Foreword-inc.pdf

Lewis, N. and J.A. Curry, C., 2014. The implications for climate sensitivity of AR5 focring and heat uptake estimates. *Climate Dynamics*, 10.1007/s003820142342y.

Lindzen, R.S. and C. Giannitsis (1998) On the climatic implications of volcanic cooling. *J. Geophys. Res.*, 103, 5929-5941.

Lindzen 1990, *Dynamics in Atmospheric Physics*, Cambridge University Press, New York, 310pp.

Lindzen, R.S., and YS. Choi, 2011. On the observational determination of climate sensitivity and its implica tions. *Asia-Pacific Journal of Atmospheric Science*, 47, 377-390.

Lindzen, R.S., M.-D. Chou, and A.Y. Hou (2001) Does the Earth have an adaptive infrared iris? *Bull. Amer. Met. Soc*. 82, 417-432.

MacFarling et al, 2006, Law Dome CO2, CH4 and N2O ice core records extended to 2000 years BP. Geophysical Reaearch Letters, 33, L14810, doi:10.1029/2006GL026152

Manabe, S. and R.T. Wetherald, 1975, The effects of doubling the C02 concentration on the climate of a general circulation model. *J. Atmos. Sci*., 32, 3-15.

Mauritsen, T. and B. Stevens, 2015, Missing iris effect as a possible cause of muted hydrological change and high climate sensitivity in models, *Nature Geoscience*, DOI: 10:1038/NGEO2414.

Nierenberg, W. et al., 1983, *Changing Climate: Report of the Carbon Dioxide Assessment Committee*, Board on Atmospheric Sciences and Climate, Commission on Physical Sciences, Mathematics, and Resources, National Research Council (Washington, DC: National Academy Press),

Pielke, R. Jr., 2014, *The Rightful Place of Science:Disasters and Climate Change*, Consortion for Science, Policy and Outcomes at Arizona State University, 114 pp.

Pierrehumbert, R.T., 2010, *Principles of Planetary Climate*, Cambridge Univ. Press, 652 pp.

Rees, Martin and Ralph Cicerone, 2010, What's happening to the climate is unprecedented, *Financial Times*, April 9, 2010.

Ring, M.J., et al., 2012. Causes of the global warming observed since the 19th century. *Atmospheric and Climate Sciences*, 2, 401415, doi: 10.4236/acs.2012.24035.

Rondanelli, R.F. and R.S. Lindzen (2008) Observed variations in convective precipitation fraction and stratiform area with SST. *J. Geophys. Res*.113, D16119, doi:10.1029/2008JD010064.

Stevens, B.J., 2015, Rethinking the lower bound on aerosol radiative forcing, *Journal of Climate*, doi: 10.1175/JCLI-D-14-00656.1

Trenberth, K.E. and J.T. Fasullo, 2009, Global warming due to increasing absorbed solar radiation, *Geophysical Research Letters*, Vol. 36, L07706, doi:10.1029/2009GL037527

Wunsch, C., R.M. Ponte, and P. Heimbach, 2007, Decadal Trends in Sea Level Patterns: 1993-2004, *Journal of Climate*, DOI: 10.1175/2007JCLI1840.1