What science can and cannot tell us about greenhouse warming

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The slow but inexorable buildup of greenhouse gases in the atmosphere due to human activities is widely viewed as constituting an increasingly serious threat to the global environment and to human welfare over the course of the next few centuries. It is proving extremely difficult to achieve a consensus as to what needs to be done to avert this threat because of the long time scale over which the buildup is occurring, the wide range of uncertainty inherent in the predictions of its impact upon the climate and the environment, and the widely differing societal perceptions concerning the potential seriousness of 'greenhouse warming' and related environmental changes. In the years ahead, scientific understanding can play a valuable role in shaping public opinion and guiding national and international policy on greenhouse gas emissions to the extent that (1) the research community is able to demonstrate continuing progress in narrowing the range of uncertainty inherent in the predictions of global climate change (2) the vast majority of individual scientists are able to maintain their independence from the various political constituencies with interests in this this issue, and (3) the public retains its confidence in the integrity of the scientific enterprise.

Key Words: Greenhouse Warming, Climate Change, Energy Policy

Introduction

In response to mounting public concern about the possible impacts of human activities upon global climate, scientists are increasingly being called upon to offer impartial, expert advice concerning the current status and future course of greenhouse warming. Officially sanctioned consensus statements such as the those that appear in the periodic reports of the Intrergovernment Panel on Climatic Change (IPCC)[1] paint a generally balanced and consistent picture into which new information is being incorporated as it becomes available and integrated with what is already known. Because this integration process takes time, these documents may appear conservative and at times even outdated to those accustomed to keeping abreast of the latest news. In contrast, the less digested statements of individual scientists tend to be more diverse and sometimes even contradictory. In their well intended efforts to air opposing points of view, the mass media tend to accentuate the differences of opinion. With a bit of selective editing, propagandists who are so inclined to do so have little trouble creating the impression that the scientific community is divided into irreconcilable camps of believers and nay sayers on the global warming issue with no common ground of scientific understanding to unite them. In some of the more extreme cases, uncertainty has been equated with ignorance and honest differences of opinion in the interpretation of scientific evidence attributed to financial and political motives. If public opinion within democratic nations becomes dominated by such cynical views, ignorance will indeed prevail.

What science can tell us about greenhouse warming

In fact, an overwhelming majority of scientists agree on much of the background information surrounding the global warming controversy, including the facts that:

- atmospheric concentrations of greenhouse gases are increasing: carbon dioxide has already increased by over 30% relative to pre-industrial levels and a number of other greenhouse gases are increasing as well [2]

- a doubling of carbon dioxide relative to pre-industrial concentrations is likely to occur by the middle or late 21st century [3]
- unless some hitherto unknown carbon sink emerges, carbon dioxide concentrations will reach 4-6 times pre-industrial levels if and when the current global inventory of known oil and coal deposits is exhausted [4]
- after atmospheric carbon dioxide levels peak, many millennia will be required for them to drop back to their current levels [4]
- higher concentrations of greenhouse gases favor warmer temperatures at the earth's surface [5]
- temperatures at the earth's surface warmed by about 1 degree Celsius during the 20th century: the increase was particularly rapid during the 1920's and again during the 1980's and '90's. The largest increases have occurred over high latitudes during winter [6].

Predicting the rate and the ultimate amount of the human-induced warming requires a detailed knowledge of the chemical and biological processes that determine how much of the carbon dioxide liberated by the burning of fossil fuels remains in the atmosphere, the effect of greenhouse gases and aerosols upon the transfer of visible and infrared radiation through the atmosphere, the complex processes and feedbacks that control the distribution and optical properties of clouds, and the role of atmospheric and ocean circulations in mediating climate change. Very few scientists have expertise in more than one or two of these areas. Hence, to understand how the 'climate system' behaves it is necessary to rely on computer models, similar in many respects to the models used in operational weather prediction, with radiation modules designed by radiation specialists, cloud modules designed by cloud physicists, etc. About a dozen groups of scientists worldwide have constructed climate models. Each model is comprised of a different set of modules, each representing a slightly different vision of how radiative transfer, cloud physics, the ocean circulation and other processes should be treated. This collection of models offers, not a single prediction, but a suite of predictions as to how much the earth will warm and, more generally, how climate will change in response to increasing greenhouse gas concentrations.

Under the auspices of the IPCC, a number of modeling groups have conducted simulations of the climate expected in the event of a doubling of equivalent greenhouse gas concentrations relative to pre-industrial values [7]. Estimates of the resulting rise in global-mean surface air temperature range from 1.5 to 4.5 C. The high-end estimates are comparable to the degree of warming that the earth's climate has undergone since the peak of the last ice age 20,000 years ago, while the low-end estimates are more comparable to what it experienced during the 20th century. Depending upon the rate industrial growth, such a doubling of equivalent carbon dioxide relative to pre-industrial concentrations can be expected to occur toward the middle or later part of the 21st century [8]. The amount of global warming at the time of peak greenhouse gas concentrations in the more distant future could two or three times larger than in this doubled carbon dioxide scenario.

While the uncertainties in the predictions of the models are large and difficult to quantify at this point, scientists generally agree that they represent the best available synthesis of what is known about the response of the climate system to the buildup of greenhouse gases. The true range of uncertainty should become more clearly apparent and should begin to narrow in the years ahead, as the processes that shape climate become more clearly understood and as it becomes possible to track the observed climate changes and compare them with model predictions.

What science cannot tell us about greenhouse warming

For issues such as global warming, the interface between science and policy is typically framed in terms of 'risk management'. Natural scientists are called upon to estimate the risks of harmful consequences and the benefits that might be realized under various policy scenarios (e.g., no regulation, weak regulation, strong regulation). The economists, in turn, are called upon to estimate the societal costs inherent in those risks, as well as the costs that would be incurred in taking preemptive regulatory actions designed to mitigate the risks. On the basis of comparison of the various costs and benefits, policy makers can decide whether it's worth taking regulatory action or whether it will be better, in the long run, just to let global warming take its course and trust that the environment and society will adapt to it. The governmental decision process is much like the one that an individual goes through when weighing the merits of taking out an insurance policy on personal property or medical care. Whether action is deemed to be warranted depends upon how the risks and benefits are framed and how far in the future they lie.

The risk management approach can be applied in a quantitative manner only if the issue in question is framed in such a way that relevant risks, however small they might be, are quantifiable. In view of the large range of uncertainty inherent in the model predictions of greenhouse warming, it is difficult enough to quantify the most obvious risks (and potential benefits) such as the retreat of alpine glaciers, permafrost zones, and sea ice, the poleward expansion of the range of tropical plant species and diseases, or the increasing frequency of water shortages in semi-arid agriculture regions. The more hypothetical 'catastrophe scenarios' feared by some environmentalists, such as the earth's climate being abruptly shifted into a different regime [9] or part of the West Antarctic ice sheet breaking off and triggering a sudden rise of sea-level [10] cannot be addressed in the conventional risk management framework because the associated risks are virtually impossible to quantify at this point.

Just as the prospect of immediate risks is more likely to induce an individual to take out an insurance policy than risks that are perceived as lying far off in the future, so it is that immediate environmental problems such as the destruction of wildlife habitat or locally severe air or water pollution are much more likely to spur action on the part of today's policy makers than the risks associated with greenhouse warming, whose most serious consequences aren’t predicted to be felt for another century or two. The human tendency to discount the gravity of threats perceived as lying far off in the future is highly influential in the mathematical formulation of the risk management approach as applied by mainstream economists [4]. How heavily it should be weighted when the interests of future generations are at stake is more a question of ethics than of economics.

Whether adaptation to a prescribed level of greenhouse warming should be viewed as a viable option is conditioned by perceptions concerning the resilience of the biosphere and the ability of human society to adapt to changing conditions. Depending on how they are selected, the 'lessons of history' can be used to support opposing opinions on these questions. Optimists cite examples such as the rapid recovery of ecosystems from catastrophes such as oil spills and dramatic unforeseen technological advances of the information age, while pessimists cite the growing list of species extinctions and ponder whether environmental disasters were responsible for the demise of once flourishing civilizations. The emerging mathematical theory of nonlinear systems provides a language and some basic concepts for framing a rational debate on these issues, but inferences drawn from mathematical theory in the absence of supporting observational evidence have to be regarded as highly speculative. For some time to come, societal perceptions concerning the resilience of the biosphere and the ability of human society to adapt to changing conditions are likely to be shaped more by intuition than by scientific understanding. Nor does science offer a formula for assigning economic values to such abstract concepts as the carrying capacity of the planet, the habitability of semiarid tropical regions, and the sustainability of species, landscapes, habitats and climates. As concerned citizens, atmospheric scientists have their opinions on these matters, but they cannot be regarded as expert opinions.

While much of the current greenhouse warming controversy is framed in the context of a scientific debate between believers and naysayers in the scientific community, the motivating force behind it is contrasting perceptions and values concerning the seriousness of the threat, and differing views concerning the legitimacy and efficacy of government regulations, all of which lie largely outside the sphere of science. In an effort to support their position, environmentalists quite understandably tend to align themselves with members of the scientific community who are among the more vocal in expressing concerns about the potential dangers of global warming, while opponents of government regulation draw support from the more vocal skeptics. In the author's experience, the extent of this ‘natural selection’ process is quite limited, but the more blatant examples are well publicized. If the public were to perceive such polarized science as the norm, the credibility of the climate research community would be undermined, leaving it no longer capable of rendering independent, authoritative, impartial advice.

Parallels with the ozone hole issue

The parallels, contrasts, and connections between the greenhouse warming and ozone hole issues are illuminating. The discovery of the Antarctic ozone hole during the 1980's constitutes the first conclusive evidence that human activity is capable of altering global climate in ways that are potentially harmful and not quickly reversible [11]. It also constitutes the first conclusive evidence that the nations of the world are capable of taking actions to mitigate perceived environmental threats. The ozone hole and greenhouse warming issues are unfolding on widely differing time scales. They are consequences of different kinds of human activities, yet their effects on the climate system may not be entirely unrelated.

Within a decade of the discovery of the ozone hole, the scientific community was able to make a convincing case that it is caused by chemical reactions involving free chlorine and chlorine compounds released by the breakdown of chlorofluorocarbons (CFC's, also known by the trade name of freons) that began to be used extensively in refrigeration during the 1950's. The societal response to these surprising new findings was almost instantaneous. Through the Montreal Protocol of 19xx, the nations of the world agreed to substitute, in place of CFC's, another family of chemicals with shorter atmospheric lifetimes that break down before they reach the stratosphere. CFC concentrations at the ground have already started to decline in response to these measures [12].

Although the rescue of the ozone layer would appear to have all the earmarks of a success story, the problem of ozone depletion shouldn't be regarded as entirely solved at this point. Owing to the long lifetime of CFC's in the atmosphere, their concentrations decay so slowly that even with a total worldwide ban on their manufacture, it would take about a century for them to drop back to, say, 1/3 of their present levels. While major industrial players such as the DuPont

Corporation have been supportive of the ban, CFC's are still being manufactured, some legally under 'grandfather clauses' and some illegally in third world countries. In the United States a segment of the population believes that the Montreal Protocol poses a threat to national sovereignty and to individual rights and are working, through the political process, to weaken the restrictions on ozone destroying chemicals.

In comparison to the ozone hole, greenhouse warming, is predicted to be slower to develop and would take much longer to be halted and ultimately reversed should the consequences prove to be unacceptable. The longer time scale also renders greenhouse warming more difficult to detect and the effectiveness of preemptive actions such as those proposed in the Kyoto protocol more difficult to assess. While some reputable scientists still question the level of certainty that can be attached to the statement published in the 1995 IPCC report: "The balance of evidence suggests a discernible human influence upon global climate" few, if any question the reality of the ozone hole or the finding that human activity is responsible for it.

Greenhouse warming is inherently a more complex issue, fraught with greater scientific and technological uncertainties, than the ozone hole. Evaluating the costs, the potential energy generating capacities and the risks associated with the various energy sources that have been proposed as substitutes for the burning of fossil fuels is a complex and controversial subject in its own right and beyond the scope of this article. It suffices to say that the societal costs of achieving major reductions in greenhouse gas emissions would be enormous compared to the costs of substituting an alternative family of chemical compounds for CFC's. The costs of environmental and human adaptation to greenhouse warming could also prove enormous, but the truth of such a claim cannot be debated on the basis of hard (value free) scientific evidence at this time. A critical factor in the ozone hole debate was the increased risk of skin cancer, which is well appreciated by the public and amenable to the conventional risk assessment methodology. In contrast, the greenhouse debate involves consideration of the increased risk of remotely possible 'catastrophe scenarios', together with a host of more quantifiable environmental changes like increased loss of tropical biota, which may or may not have serious implications for human health and well being.

The chemical industry was involved in and supportive of the research that led to the Montreal protocol, and was instrumental in providing an acceptable substitute for CFC's. Many different industries have a stake in the greenhouse warming issue. Insurance and reinsurance companies are understandably concerned about any possibility of increasing climate-related risks, while auto makers worry about the adverse effects of curbs on gasoline consumption upon the sale of profitable sports utility vehicles.

Although greenhouse warming and the ozone hole have tended to be viewed by the scientific community as largely separate issues, they are not entirely unrelated. Ozone is itself one of the atmosphere's most important greenhouse gases, whose future concentrations will play a role in shaping atmospheric temperatures. Increasing carbon dioxide concentrations, in turn, have the effect of making the polar wintertime stratosphere colder, rendering the Northern Hemisphere ozone layer more susceptible to attack by chemical reactions involving the CFC's that remain in the atmosphere [13].

Making policy decisions in the face of scientific uncertainty

As nations and various private and public interest groups continue to debate whether the risks inherent in greenhouse warming are serious enough to warrant taking steps to reduce the rate of consumption of nonrenewable fossil fuels, the following points are worth bearing in mind:

Greenhouse warming is a long term problem. The 1 F rise in global-mean surface air temperature during the 20th century is roughly equivalent to the temperature contrast between the northern and southern suburbs of a large urban area such as Washington DC: equivalent to raising the high temperature on a hot summer day from, say. 99 F to ~100 F. It is neither the cause nor a major contributor to the heat waves, droughts and severe weather events of the past few decades. The scientific controversy surrounding this modest and relatively harmless temperature rise centers on whether it should be viewed as a precursor of much more pronounced human induced climatic change in the 21st century and beyond, as greenhouse gas concentrations in the atmosphere continue to rise. Thus far concentration of carbon dioxide has increased from 280 parts per million (ppm) in the pre-industrial era to ~370 ppm. If all known oil and coal deposits are consumed over the course of the next few centuries, carbon dioxide levels can be expected to eventually rise to over 1000 ppm.

The stakes are high. Even the comparatively modest measures proposed in the Kyoto protocol to slow down the rate of buildup of greenhouse gases would be extremely costly to implement and not without environmental and societal risks of their own. In defense of ‘business as usual’ it is argued that until the costs of adaptation and mitigation are better known there is no point in imposing restrictions that could prove harmful to the world economy. The argument for acting now to reduce the rate of fossil fuel consumption is that the buildup of carbon dioxide in the atmosphere / ocean system is cumulative and, for all practical purposes, irreversible. Hence, if the current generation elects to postpone action on this issue, it will commit future generations to higher atmospheric carbon dioxide levels, thereby placing them at greater risk of harmful consequences.

Science doesn’t give us all the answers. Given the current uncertainties in the model predictions, it cannot be claimed with absolute certainty that the predicted buildup of carbon dioxide and other greenhouse gases in the atmosphere will have dire environmental and/or societal consequences, nor can it rightfully be claimed that such a large and for all practical purposes irreversible buildup is not worth being seriously concerned about and taking actions to avert. For some time to come, decisions as to whether or not to place limits on the burning of fossil fuels are going to have to be made without the benefit of rigorous cost / benefit analyses.

Scientific progress occurs at its own pace. Mindful of the success of the government sponsored "Manhattan Project" and many industrial technological development efforts, it has been suggested that scientists should propose a specific methodology, budget and time line for narrowing the wide range of uncertainty in the present long range climate predictions. Most scientists readily agree on the need for a coordinated long term effort to upgrade the global climate observing system and to build a stronger modeling infrastructure in support of long range climate prediction. However few, in good conscience, could commit their research groups and their institutions to delivering specific "research products" on specified time lines. They would argue that advances in scientific understanding are not 'deliverables' that can be predicted, programmed and managed. In their experience, some scientific advances, like the discovery of the ozone hole, have occurred totally unexpectedly; some, like the development of a predictive capability for El Nino, were founded upon basic research results that would have been regarded as esoteric at the time by goal oriented program managers; and some, like the containment of nuclear fusion, have been delayed for decades for lack of the requisite scientific breakthroughs.

Scientific evidence is value-free. The contrasting perceptions and values that are fueling the global warming controversy are important and need to be aired, but they should not be allowed to influence climate assessments and forecasts. Maintaining the objectivity, independence and credibility of the advice that the scientific community provides to the public on the greenhouse warming issue will be vital to the integrity of the decision making process in the years ahead. Those who seek to distort this advice to make it reflect any particular set of values, or to demean it by misrepresenting it as biased, polarized, or unfounded are doing future generations a disservice.

ENDNOTES

1. The Intergovernmental Panel on Climate Change (IPCC) was jointly established by the World Meteorological Organization and the United Nations Environment Program in 1988 in order to (i) assess available scientific information on climate change, (ii) assess the environmental and socio-economic impacts of climate change and (iii) formulate response strategies. Its latest findings are published in *Climate Change 1995: The Science of Climate Change, Summary for Policymakers and Technical Summary of the Working Group I Report* (Cambridge University Press, 1996). An updated assessment for the year 2000 is currently in preparation.

2. *Climate Change 1995,* p. 18

3. *Climate Change 1995,* p. 27

4. J.F. Kasting, "The Carbon Cycle, Climate, and the Long Term Effects of Fossil Fuel Burning," *Consequences,* 4 (1998): available on the Internet at *http://www.gcrio.org/CONSEQUENCES/vol4no1/carbcycle.html*

5. Greenhouse gases such as carbon dioxide and water vapor, exert a profound influence on climate. In the absence of the so called 'greenhouse effect' (the trapping of outgoing infrared radiation by these gases) the surface of the earth would be so cold as to be barely habitable. A century ago, the Swedish scientist Svent Arrhenius noted that the accumulation of industrially produced greenhouse gases in the atmosphere could enhance this already strong greenhouse effect, thereby raising the temperature of the planet. More detailed information on the greenhouse effect can be found on the Internet at *http://www.ogp.noaa.gov/OGPFront/Mono4/RTNpg16.html.*

6. *Climate Change 1995,* p. 31-33 and the following websites
http://www.cru.uea.ac.uk/tiempo/floor2/data/gltemp.htm
http://cdiac.esd.ornl.gov/trends/temp/jonescru/jones.html
http://cdiac.esd.ornl.gov/ftp/trends/temp/jonescru/global.dat

7. These experiments take into account the radiative effects of not only carbon dioxide, but also other greenhouse gases such as, methane and nitrous oxide (hence the term 'equivalent' carbon dioxide concentration), as well as aerosols injected into the atmosphere by human activity.

8. *Climate Change 1995,* p. 25-30

9. see W.H. Calvin, "The Great Climate Flip-Flop," *The Atlantic Monthly,* January 1998, available on the Internet at *http://www.theatlantic.com/atlantic/issues/98jan/climate.htm*

10. M. Oppenheimer, "Global Warming and the Stability of the West Antarctic Ice Sheet," *Nature,* 393 (1998): p. 325

11. *http://www.ogp.noaa.gov/OGPfront/mono2.html*

12. S. A. Montzka, J.H. Butler, J.W. Elkins, T.M. Thompson, A.D. Clarke and L.T. Lock, “Present and Future Trends in the Atmospheric Burden of Ozone Depleting Halogens. *Nature*, 398 (1999): p. 690.

13. D. Rind, D. Shindell, and P. Lonergan, “Climate change and the middle atmosphere. Part IV: Ozone response to doubled CO2” *Journal of Climate*, 11 (1998): p. 895

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