An Open Letter on Global Warming

(25 Oct. 2000)

Recently, with several colleagues, I wrote an article "Global Warming in the 21st Century: An Alternative Scenario", which was published August 29 in the *Proceedings of the National Academy of Sciences* (ref. 1; http://www.giss.nasa.gov/gpol/papers/2000/2000.HansenSatoR.pdf]. Some reports on this paper have been inaccurate or misleading. It is practically impossible to respond to each interpretation of our paper. Therefore, I attempt to clarify some of these issues in this open letter. This letter was discussed at an MIT-sponsored workshop in Washington on October 16 (ref. 2; http://www.giss.nasa.gov/research/impacts/altscenario/discussion.html).

The "Alternative Scenario" implicitly outlines a framework that may be helpful in thinking about how to deal with global warming over the next several decades. The aim of the scenario is to limit additional human-made climate forcing to about 1 Watt in the next 50 years, by halting the growth of non-CO_2 forcings ("air pollution") and limiting the additional CO_2 forcing to about 1 Watt. This framework, including observations of the forcing factors and climate change, would allow continuous assessment of progress and the possibility of adjusting the goals as understanding advances. The MIT workshop focused on the non-CO_2 portion of the scenario. A post-workshop "footnote" is added here to clarify the CO_2 portion of the scenario.

BAU and Alternative Scenarios.

Our paper is about the forcings that drive climate change. A climate forcing is an imposed perturbation of the Earth's energy balance with space. Human-made "greenhouse" gases now in the atmosphere cause a forcing of more than 2 Watts per square meter. In other words the gases that people have added to the atmosphere cause a heating of the Earth's surface as if two miniature 1-Watt Christmas tree bulbs had been placed over every square meter of the Earth's surface. This is equivalent to increasing the brightness of the sun by about 1 percent.

That refers to the forcing due to past emissions. For the future, most climate modelers employ business-as-usual (BAU) scenarios for future greenhouse gas amounts. In BAU scenarios it is assumed that greenhouse gases will increase at an accelerating rate in the 21st century. This leads to an additional human-made climate forcing of about 3 Watts by 2050. It is assumed that about 2/3 of this forcing is caused by increasing CO_2 and about 1/3 by other gases, but for the sake of simplicity the BAU forcing is usually represented as a 1 percent per year increase of CO_2.

BAU provides a valuable warning, should the world follow a course with accelerating growth rates of greenhouse gases. Paleoclimate history indicates that a forcing of the BAU magnitude would cause global warming of several degrees with substantial practical impacts.

Our thesis is that the BAU scenario should be accompanied by an alternative scenario with a much smaller climate forcing, which would lead to only moderate climate change. Contrary to what a "news summary" piece in the journal Nature states (ref. 3), we neither predict that the "alternative scenario" will occur nor assume that it will occur. It is rather a plausible scenario that we hope can help stimulate discussion about the nature of the actions required to yield only a modest climate forcing, instead of a large forcing.

Our "Alternative Scenario" adds a human-made forcing of 1 Watt in the next 50 years. This is obtained by keeping the net increase of non-CO_2 forcings at 0 Watts and the increase of the CO_2 forcing at 1 Watt, as summarized in Figure 1. The non-CO_2 and the CO_2 aspects of this scenario are equally important in the next 50 years, but on the longer run, especially if we stop the growth of the non-CO_2 forcings, CO_2 will be the issue.

Non-CO_2 Forcings: "Air Pollution"

We suggest that it is plausible to keep the non-CO_2 forcing, which we can loosely describe as air pollution, no larger in 2050 than it is today. We note that there will be multiple benefits of a climate strategy that focuses on non-CO_2 forcings as well as on CO_2. I discuss the three major non-CO_2 forcings here.

Black carbon (soot) aerosols. This is a major pollutant that has received inadequate attention. Aerosols are tiny solid or liquid droplets in the air. Black (elemental) carbon aerosols are soot formed by incomplete combustion, which often can be seen emanating from diesel-powered trucks and buses. Coal and biomass burning are also major sources.

Black carbon aerosols cause a positive climate forcing that is very uncertain in magnitude, but we estimate that it is probably of the order of 0.5 to 1 Watt per square meter on global average. It causes warming in several ways: by absorbing sunlight, by warming the lower layer of the atmosphere and thus reducing cloud cover, by making clouds slightly "dirty", and by darkening snow and sea ice surfaces when it is deposited there.

Black carbon aerosols are a principal component of air pollution. In the words of Tony Hansen (Lawrence Berkeley National Laboratory, private comm.) microscopic soot aerosols are like tiny sponges that absorb other substances including toxic organic particles. A recent study in France, Austria and Switzerland puts the annual cost of particulate pollution in those countries at 40,000 lives, 500,000 asthma attacks, and medical costs amounting to 1.7% of their gross domestic products. Air pollution in developing countries, such as India and China, is even more severe.

Methane. Methane (CH_4) causes a larger forcing than is generally recognized. As shown in Figure 2, the forcing due to increased CH_4 (0.7 Watts) is fully half as large as the forcing by CO_2 (1.4 Watts).

The observed growth rate of atmospheric CH_4 has declined by at least two-thirds since the 1970s (Figure 3). The reasons are not well understood, but probably include decreases in the growth rate of methane sources and changes in atmospheric chemistry (and thus the methane "sink").

There are numerous opportunities to reduce human emissions of CH_4. We suggest that it may be practical to keep the CH_4 of 2050 from exceeding that of today.

It has been suggested, in some responses to our paper, that an increased emphasis on methane would be seen as shifting the blame for global warming to developing countries. However, on the contrary, a focus on methane could be an opportunity for developing countries, if even modest economic incentives to reduce emissions were provided. Such an approach has been remarkably successful in dealing with CFCs.

Ozone. Tropospheric ozone is estimated to have caused the 3rd largest climate forcing among the greenhouse gases (Figure 2). Ozone is an oxidant that is damaging to the respiratory system and to agricultural productivity, with estimated annual costs in the United States of about $10B/year.

Recent global trends of tropospheric ozone are unclear, as some countries have taken steps that reduce ozone, while ozone has increased in other places. Ozone and its precursors in one country are believed to affect ozone levels in other countries, even across the ocean.

There are complex interactions among atmospheric gases, and actions that decrease one gas may increase another. However, by comparing the pre-industrial atmosphere with that of today we see that human emissions have greatly increased both O_3 and CH_4. We suggest that, with a focus on reducing air pollution, it will be possible to have no further growth, or even a decrease, in the sum of O_3 and CH_4 global climate forcings in the next 50 years.

CO_2 Forcings

Our alternative scenario aims to limit added CO_2 forcing to 1 Watt in the next 50 years. This would require the CO_2 growth rate to average about the same in the next 50 years as it did in the past 20

years, which was 1.5 ppm per year. This means, to first approximation, that CO_2 emissions from fossil fuel use would need to remain about the same as today or begin to decline slightly.

How does this compare with recent history? From 1945 until the oil price shock of the 1970s, fossil fuel use increased 4% per year, in lock step with economic growth. But since then fossil fuel use has increased only 1% per year (Figure 4), as economic growth has been substantially decoupled from energy growth. Our scenario requires an additional decline of the emissions growth rate, from 1% per year to zero.

Therefore, in this scenario, incremental growth of energy demand needs to be met by some combination of (1) increased energy efficiency in present uses, and (2) continued trend toward decarbonization of energy sources, including the introduction of renewable energy sources such as the wind, sun, and other processes that produce little or no CO_2. Nuclear power has the potential for a major contribution to slowing CO_2 emissions, but it faces challenges to convince the public that there are fail-safe technologies, to solve the waste disposal problem, and to streamline the license/build process as needed for economic competitiveness. We note that within 50 years renewable energy sources may include new technologies or technologies now in their infancy.

On the other hand, let's say that by 2050 we have failed to develop any alternatives to coal as the successor to oil as the oil resource inevitably declines. In that case, we point out in our paper, if climate considerations demand even slower CO_2 growth, sequestration of CO_2 provides a viable back-up strategy. Substantial sequestration should be practical, because it is expected that a larger fraction of energy will be generated at power plants, where capture of CO_2 emissions is relatively easy.

It is not our task to prescribe policies that would keep the added CO_2 forcing in the next 50 years at 1 Watt. We only note that such a flat growth rate of CO_2 forcing is plausible and nearly has been obtained already. However, common sense suggests that achievement of both energy efficiency gains and increasing contributions from renewable resources would be aided if the price of fossil fuels reflected their true cost. Thus governments may want to consider limiting subsidies for fossil fuels and perhaps gradually adding an assessment to fuel price to cover the cost of its impact on human health. Sudden jumps in energy costs tend to fall unfairly on some consumers and they are ineffective at promoting energy efficiency and alternative energies. However, gradual long-term changes, which allow introduction of viable choices for improved efficiencies, could be effective and also limit hardships. This issue should be considered carefully by political leaders as scientific understanding advances and empirical evidence increases. The ability of the public to grasp the issues and support policies that husband valuable resources should not be underestimated.

[Further discussion of CO_2 scenarios is included in the "footnote" to this "open letter".]

Summary of Forcings

In summary, our "alternative scenario" keeps the added forcing in 50 years at 1 Watt, by keeping the added CO_2 forcing at 1 Watt and having all the other forcings add up to 0 Watts. Aerosols cause a large uncertainty in this equation. If we reduce sulfates, which we should do to reduce acid rain, we will cause a positive forcing (by reducing the cooling effect of these non-absorbing aerosols). On the other hand, if we would go after black carbon aggressively, we could push the change of aerosol forcing back to zero or negative.

Unlike greenhouse gases, the aerosol forcing is not being measured. We recently had a workshop at the Geophysical Fluid Dynamics Laboratory to define aerosol measurement needs. These requirements were specified in a letter (ref. 4; http://www.giss.nasa.gov/research/impacts/altscenario/noaaletter.pdf) to the NOAA Administrator with the objective of obtaining his advocacy of accurate monitoring of the aerosol climate forcing from the satellite that provides the next opportunity, the NPOESS Preparatory Project.

Two of the four primary forcings (black carbon and ozone) are not yet included in existing or proposed international protocols. I believe that it is feasible to halt further growth of these non-CO_2

forcings, which can loosely be termed air pollution. However, better understanding of aerosol and ozone physics is needed, as well as monitoring of both constituents.

Summaries of Interpretations and Representations

Science and Nature. *Science* (ref. 5) printed a brief factual summary of the contents of our paper. In contrast, *Nature* (ref. 3) made several misstatements and quoted only critics of our paper. They described our "alternative scenario" as "Hansen's assumption" and "his prediction", while in fact we made clear that it is only a scenario that we think can usefully accompany the "business-as-usual" (BAU) scenario, thus providing a basis for discussing what is needed to avoid large climate change. Whether the alternative scenario is achieved will depend upon whether actions are taken to limit air pollution, improve energy efficiency, and develop renewable energy sources. We have always included both a BAU and moderate scenario in our climate projections (refs. 6, 7).

My primary objection to the *Nature* article is that it was published as a "News" article, while in fact it was an editorial. This was made clearer to me when I submitted a "letter to the editor" to correct their misinterpretations (Attachment A), because they objected to my letter and edited it in a way that altered the meaning. Perhaps they concur with the negative construction of our paper (see below). That is their right, but they should put it on an editorial page, not under "News".

Union of Concerned Scientists (UCS). The UCS sent to its members an "Information Update" discussing our paper, providing me with a copy the day before it went out. The essence of their discussion seems to be that our paper is controversial, potentially harmful to the Kyoto Protocol, and not a helpful contribution to the climate change discussion as it "may fuel confusion about global warming among the public". They describe "first reactions from within the scientific community", which perhaps are accurate but they seem a bit like commissioned criticisms.

While I am not convinced that the views in the Information Update necessarily reflect those of UCS members, I appreciate the willingness of the UCS leadership to distribute this "Open Letter" to the membership. I hope that this letter will clarify some of the points addressed in the UCS Information Update (IU).

The UCS IU says that our team proposes to "focus first on the reduction of non-CO_2 GHGs – essentially to buy time – and then, by mid-century, shift attention back to CO_2 and fossil fuel sources". However, on the contrary, we recommend immediate attention to improved energy efficiency, continuing decarbonization of the fuel source, and development of renewable energy sources, as required to achieve a flat or declining CO_2 emissions growth rate. This attention to CO_2 is equally as important as the attention to air pollution in limiting the net forcing to 1 Watt in the next 50 years.

The UCS IU states that "the author team seems unduly convinced that reducing fossil fuel emissions would be economically wrenching to the United States". On the contrary, it is our opinion that the actions we recommend (removing barriers to energy efficiency, development of clean fuels, development of renewable energy sources that produce little or no CO_2) will stimulate the economy, create jobs, reduce reliance on foreign sources of energy, improve our economic competitiveness, and create a more healthful environment, while at the same time slowing the growth rate of CO_2. Perhaps the discussion in the "Footnote on CO_2 scenarios" below can clarify this topic.

The New York Times. The first *New York Times* article on our paper (Aug. 19, 2000, ref. 8) was not as far off as some other newspaper reports. But the first sentence implied that I had changed my opinion, and that I now said that "emphasis on carbon dioxide may be misplaced". First, we are not de-emphasizing CO_2, and, second, we have long championed the importance of the other forcings. In fact, in 1976 five of us at GISS published a paper in *Science* pointing out for the first time that gases such as CH_4 and N_20 provided a forcing that was not negligible compared to that of CO_2.

A second article (ref. 9) aggravated the misunderstanding. It did not mention the half of our strategy aimed at preventing the CO_2 forcing in the next 50 years from exceeding 1 Watt. Instead it repeated the statement that we proposed to focus first on non-CO_2 gases, and the entire article discussed

only non-CO_2 gases and black carbon. After the first article, I sent a "letter to the editor" of *The New York Times* to try to correct the mis-impressions, but it was not published. After the second article I decided to write the present "Open Letter".

The Washington Post and Rolling Stone. The most accurate summaries of our paper, in my opinion, were an article in the *Rolling Stone* (ref. 10) and an editorial in *The Washington Post* (ref. 11, Attachment B). The *Rolling Stone* article included a recorded interview and the *Post* editorial followed a substantive telephone conversation and reading of our paper. The *Post* editorial concluded:

> "Dr. Hansen and a team of colleagues wrote that most of the global warming so far observed actually comes from other greenhouse gases such as methane, chlorofluorocarbons and gases that combine to create ozone in smog. They suggested a strategy of focusing first on cutting those gases and black particles of soot that also trap heat. Some of the gases involved are already in decline because of other international restrictions; going after others amounts to an attack on air pollution, which the scientists argue should be attractive action in all parts of the world, independent of concerns about warming, because of health benefits of cleaner air.
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> "That optimistic scenario immediately caused some environmentalists to worry that the report would become a weapon for those who are skeptical about warming – who oppose any action. Dr. Hansen himself said it undoubtedly will be used that way, but that would be a misreading of the study. The new report does not challenge either the evidence that surface temperatures are going up or the growing consensus that human activities are contributing to the increase. It continues to cite the need for reductions in carbon dioxide emissions. There is no suggestion, nor should there be, that response to global warming should wait until the science is more certain.
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> "What it does do is remind us that climate issues are complex, far from fully understood and open to a variety of approaches. It should serve as a caution to environmentalists so certain of their position that they're willing to advocate radical solutions, no matter what the economic cost. It suggests that the sensible course is to move ahead with a strong dose of realism and flexibility, focusing on approaches that are economically viable, that serve other useful purposes such as cutting dependence on foreign oil or improving public health, and that can help support international consensus for addressing climate change. If the Hansen report pushes the discussion in that direction, it will turn out to be good news indeed."

Would that every scientist could, at least once in their career, have an editor read one of their papers with such understanding and insight! And to think, as I was speaking to her, that I felt she was leaning toward the negative construction of our paper. However, there are two borderline misinterpretations of our paper even in the *Post* editorial, which indicates that we must accept some responsibility for not making a subtle point more clear.

First, we did not mean to convey that the non-CO_2 gases caused more warming than CO_2. In fact, they have contributed equally, 1.4 Watts for CO_2 and 1.4 Watts for non-CO_2 gases. The confusion arose from our observation that fossil fuel burning is responsible for aerosol cooling as well as CO_2 warming, so the net effect of fossil fuels was probably less than 1.4 Watts. We noted that fossil fuel use also produced some of the non-CO_2 gases (a portion of CH_4 and O_3, for example), but that these were not essential products of fossil fuel burning. We considered this comment to be an interesting observation, but it is not essential to the thesis of our paper, so perhaps it would have been better to avoid that subsidiary discussion.

The second possible misinterpretation is the statement that we "suggested a strategy focusing first on cutting those gases and black particles of soot". Later she does write that our paper "continues to cite the need for reductions in carbon dioxide emissions". Actually, we expect that equal emphasis is needed on non-CO_2 and CO_2 forcings to keep the net forcing at 1 Watt. Perhaps we could have made this clearer. But it is not obvious that there really is a misunderstanding. After all, we <u>are</u> saying that by eliminating air pollution growth and taking common sense steps to slow CO_2 growth we can buy several decades with little increase of the net climate forcing. This time can be used to develop understanding of exactly how and why each of these forcings is changing, as well as to develop the technologies that will allow us to minimize longer term change.

I particularly liked the positive, optimistic *Rolling Stone* article. But I admit being prejudiced by the magazine cover.

Constructions and the Bottom Line

Negative construction. The negative construction that has been placed on our article is that it is harmful, because it can be used by global warming skeptics to argue against the need to slow CO_2 growth rates.

Positive construction. A positive construction would be something along the lines of the last paragraph of *The Washington Post* editorial. One might even recognize in the alternative scenario the outline of a strategy to slow global warming quickly.

The bottom line. Our job is not to place any construction on the paper. Our bottom line is that in our letter to *Nature*: "Our aim is to produce the most objective quantitative analysis that we can. In the end, that is likely to serve the public best."

Footnote on CO_2 Scenarios

The MIT workshop emphasized the non-CO_2 aspects of the "alternative scenario". However, the question was raised of how the total forcing, and particularly the forcing for CO_2, differs between our scenario and that of IPCC.

Scenarios

Our philosophy is that at least two or three very different scenarios are needed to bracket the climate problem. This should help people think about and outline strategies for dealing with the issues. We are now using the following two scenarios for climate model simulations.

Business-as-Usual (BAU). BAU is a "gloom and doom" or, less pejoratively, a relatively pessimistic scenario. It is a valuable scenario that provides a warning of potential climate change if rapid growth of climate forcings occurs. This level of forcings is conceivable if the climate change issue is ignored, particularly if coal becomes the primary energy source as oil resources are depleted. IPCC's current Special Report on Emissions Scenarios (SRES) includes multitudinous scenarios, but so far IPCC climate simulations are mainly for BAU scenarios that are commonly represented by 1% CO_2 growth per year.

Alternative Scenario. This is an optimistic scenario. As discussed above, non-CO_2 forcings are assumed to total the same in 2050 as today. This would require a concerted global effort on air pollution, including black carbon aerosols and ozone, but it would have many practical benefits, especially for human health.

The emissions of CO_2 in the alternative scenario are assumed to remain about the same as they are today. In other words the growth rate of CO_2 emissions, which declined from 4% per year during 1945-1975 to 1% per year during 1975-2000 (Fig. 4), will need to decline somewhat further. Exactly how far it needs to decline will become clearer in coming years as empirical data on CO_2 change accumulate and as understanding of the carbon cycle improves. Moreover the target for CO_2 in 2050 (445 ppm, i.e., $\Delta CO_2 \sim$ 75 ppm in the alternative scenario) may change in decades ahead as the status of other forcings is observed and as empirical evidence and understanding of climate change become clearer.

Underpinnings of Scenarios

Scenarios for CO_2 emissions are commonly developed by attempting to project factors such as population growth, economic growth, and technological change (fuel choices). The difficulties can be demonstrated by considering population, which is perhaps one of the more predictable factors.

The current IPCC SRES scenarios use lower estimates of future population than earlier IPCC scenarios. The present forty SRES scenarios have populations in 2050 ranging from 8.7 to 11.3 billion people.

For the purpose of considering the population factor I queried Joel Cohen of Rockefeller University, one of the world experts on population. Specifically I asked about the growth rate curve, which in recent decades passed two key points: the peak in percent annual growth and the peak in absolute annual growth. He said "Currently the rate of increase is estimated at 1.3%/year." [The peak was 2.1%/year.] "In general fertility has dropped more rapidly over the past 1/3 century than anyone anticipated, and especially recently. Now it is dropping in countries with low female literacy. Having many children is going out of fashion worldwide. Why this is happening is poorly understood and there is nothing to prevent the fashion from reversing." When I asked for his best guess for population in 2050 he said: "Assuming business as usual, i.e., no nuclear wars, comet impacts, uncontrollable viruses, excessive volcanoes, etc., I would not be surprised by any population in the range 7-9 billion." Note that his estimated range has almost no overlap with that of IPCC and it is much more "optimistic".

Other factors, such as technology 50-100 years in the future, are even more problematic. My point is that scenario construction in the manner of IPCC is exceedingly difficult. It is a useful exercise, and it helps in assessing the importance of different factors. But by itself it is not sufficient to provide a framework that would allow policy makers to move forward and have a basis for judging progress in dealing with the climate change issue.

Certainly we are not suggesting that the IPCC scenario families, which become progressively more complex and diverse with each report, are contributing to stagnation in policy discussions. We only suggest that it may be useful to supplement those scenarios with a small number of scenarios (two or three) that are simply and concretely based on climate forcings. Among other things, these scenarios focus attention on the growth rate of the fundamental CO_2 emissions curve (Fig. 4). The emissions curve (Fig. 4) integrates over all social and technological factors. [The emissions curve can be tied to future atmospheric CO_2 amount by the approximation that 50-60% of the CO_2 emission remains "air borne", as has been true in the past several decades for emission rates from 4 to 1% per year. This estimate will be refined by empirical data and carbon cycle models.] Another advantage of having a small number of well-defined fixed scenarios is that they lend themselves well to the technique of "sticking our head out the window" (see below).

I believe that there are at least two conclusions that we can draw now about climate forcings in 2050. First, it is unlikely that the added CO_2 forcing in the next 50 years could be much less than 1 Watt. This is because of the inertia in fuel choices caused by the energy infrastructure. The time constant for changing from one major fuel to another, illustrated in Figure 4, tends to be at least several decades. Therefore, even in an optimistic "alternative scenario" we must assume that there will be a significant increase of CO_2 forcing in the next 50 years. However, it is conceivable to achieve a decline in annual CO_2 emissions before 2050, which would make it easier to limit additional CO_2 forcing after 2050.

Second, it is improbable that this "optimistic" CO_2 level will be achieved by accident. This conclusion follows from scenario-building such as discussed by John Reilly at the MIT workshop. Only a small percentage of "non-intervention" scenarios yield a CO_2 increase as small as the magnitude in our "alternative scenario". Although we do not attempt to prescribe policy choices in our discussion, these results suggest that it would be wise to pursue measures that slow CO_2 emissions and serve other useful purposes.

Sticking Our Head Out the Window

Weather prognosticators are well advised to occasionally stick their head out the window. Similarly we can learn a lot about climate forcings by comparing forcing scenarios with recent and current trends of climate forcings and climate change.

In 1987 we constructed three scenarios for climate forcings out to 2050 (ref. 7). Scenario A, designed to approximate an estimate of Ramanathan et al. (ref. 12), added a forcing of about 5 Watts between 2000 and 2050. Scenario B had a linearly increasing forcing, adding about 2 Watts between 2000 and 2050. In scenario C the greenhouse gases stopped increasing in 2000, so the forcing added was 0 Watts between 2000 and 2050. In my congressional testimony in 1988 all of the maps that I showed were for scenario B. We considered scenarios A and C to be less realistic, mainly useful for bracketing the problem [Scenario A was described as "on the high side of reality", scenario B as "the most plausible", and scenario C as "a more drastic curtailment of emissions than has generally been imagined".]

The real world since 1987 has followed a path between scenarios B and C. If the same rate of growth were maintained for the next 50 years, the added forcing between 2000 and 2050 would be about 1.5 Watts (ref. 13), thus closest to, but somewhat less than, scenario B. [The observed global temperature change is consistent with the simulations for scenario B, but the record is too short for a more meaningful comparison (Figure 6).] These estimated forcings exclude tropospheric ozone, because adequate measurements do not exist, and, of course, aerosols are not considered for the same reason.

The CO_2 scenarios in the current SRES scenarios (their Figure SPM-2a) have a growth rate for fossil fuel CO_2 emissions in the decade 1990-1999 that is about 50% larger than the growth rate for actual emissions, based on the fossil fuels emissions data in our "alternative scenario" paper (which in turn is based on Marland and Boden through 1997 and Brown et al. for 1998 and 1999, see ref. 1). This conclusion adds slightly to our perception that IPCC scenarios are pessimistic. [The principal scenario in the 1996 IPCC report, IS92a, was a 15% reduction from the principal 1990 scenario. Observed CH_4 change falls below the lowest IS92 scenario and observed CO_2 falls on the lowest IS92 scenario (Fig. 2 of ref. 1).] Our main point is that much can be learned by comparing scenarios with observations as years go by, so it is helpful to present scenarios in a straightforward way and compare these with data. These comparisons will begin to be more and more meaningful in the next several years.

Implications

The framework of the "alternative scenario" may be a useful complement to "business as usual" scenarios. A scenario that begins with current rates of change (of CO_2 emissions) and asks "how much must we alter these trends to yield only a moderate climate forcing" may be less forbidding. A framework with clearly specified goals or benchmarks (for atmospheric CO_2 and other forcings) allows for year to year comparisons with developing reality and it may be helpful in adjusting the goals as our understanding improves.

The anonymous *Washington Post* editor concluded "It suggests that the sensible course is to move ahead with a strong dose of realism and flexibility, focusing on approaches that are economically viable, that serve other useful purposes such as cutting dependence on foreign oil or improving public health, and that can help support international consensus for addressing climate change." Presumably she refers to an approach that removes barriers to energy efficiency and subsidies for fossil fuel use, as well as reducing air pollution.

Finally, we note the potential educational value of keeping a scorecard on annual changes of fossil fuel CO_2 emissions, atmospheric CO_2 amounts, human-made climate forcings, and global temperature, as well as other quantities. Discussions can occur with different levels of detail. It should be possible not only to make the story understandable, but to use it to help people understand how science research works. We are already well into the planetary experiment that we are conducting. How it proceeds will

be determined by actions and policies occurring on decadal time scales, and these should and will be determined by the people and their representatives. Our job is to provide information that can help them to make wise decisions.

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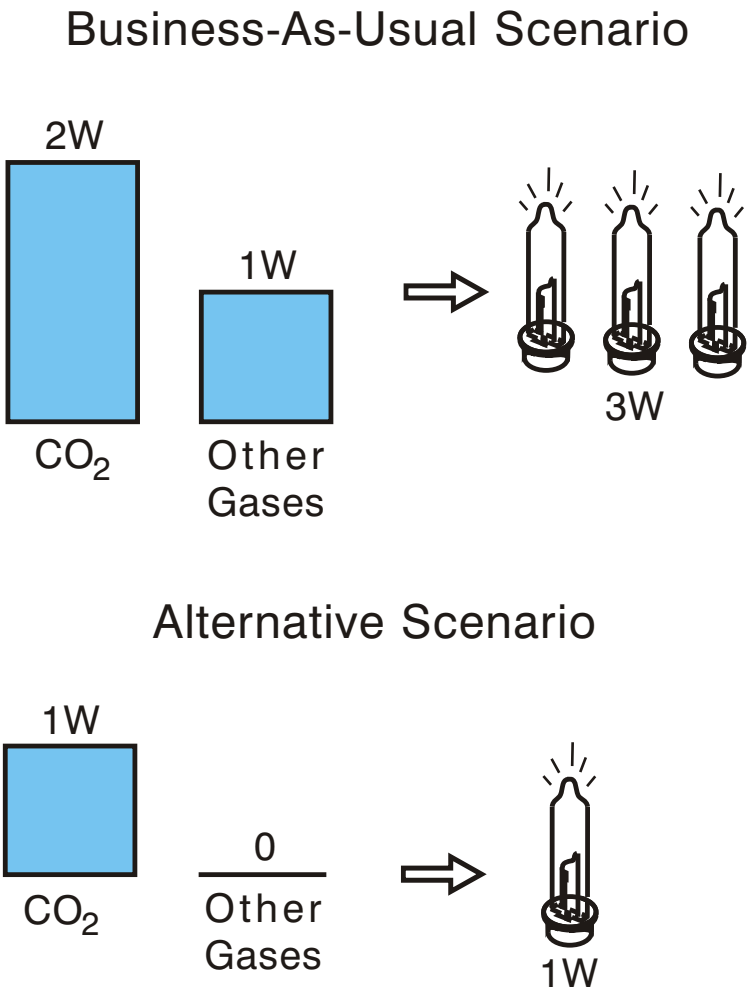

Figure 1. Climate forcings between 2000 and 2050 in "business-as-usual" and "alternative" scenarios.

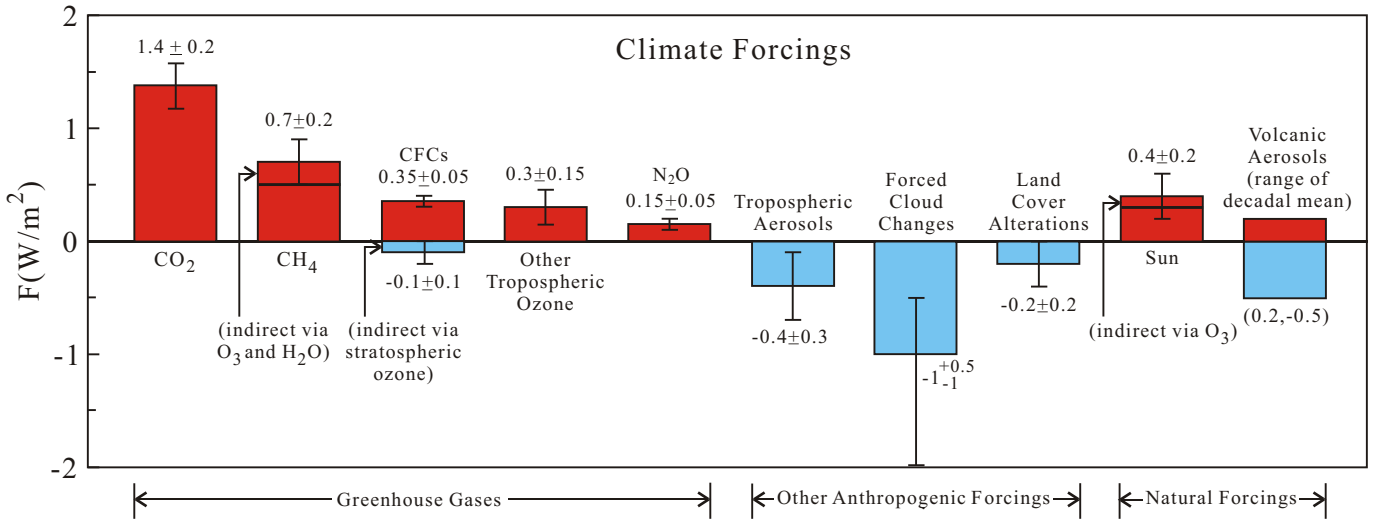

Figure 2. Estimated climate forcings between 1850 and 2000 (from reference 1).

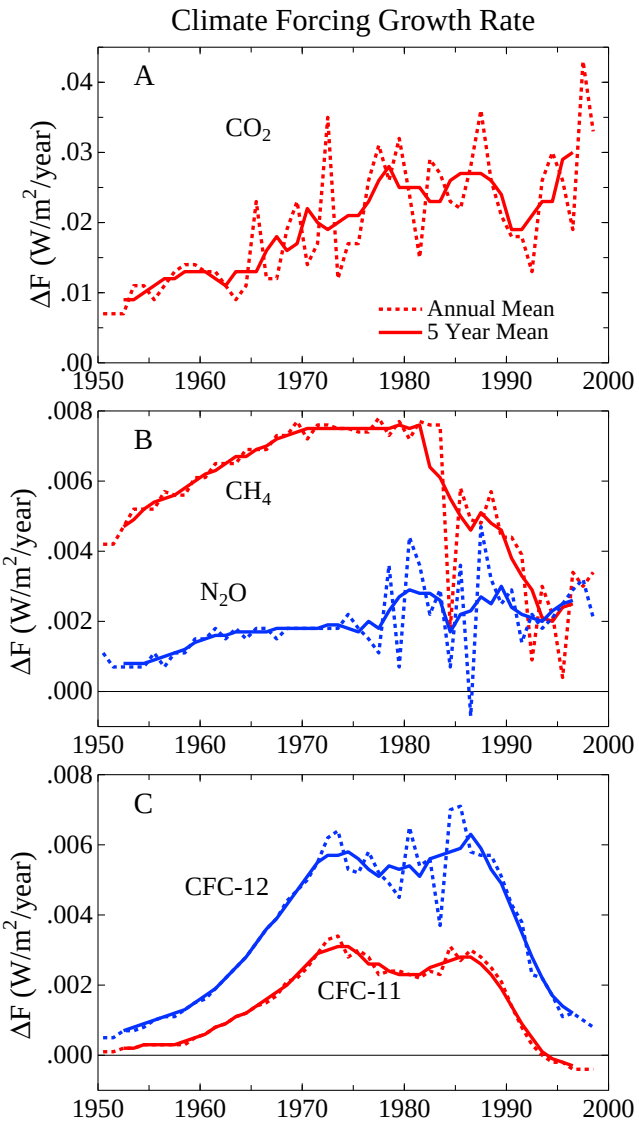

Figure 3. Growth rates of climate forcings by individual greenhouse gases (from reference 1).

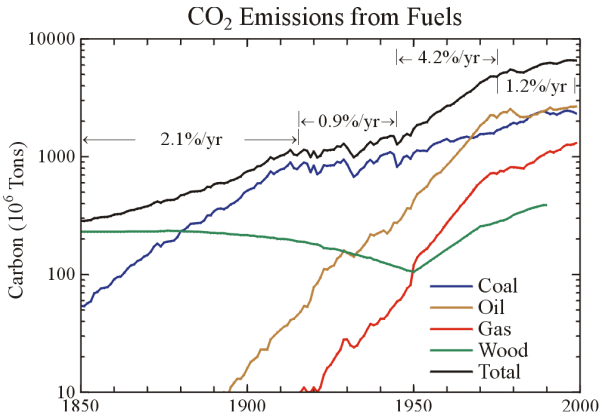

Figure 4. CO_2 emissions from fuel use (from reference 1; estimate for wood from N. Makarova)

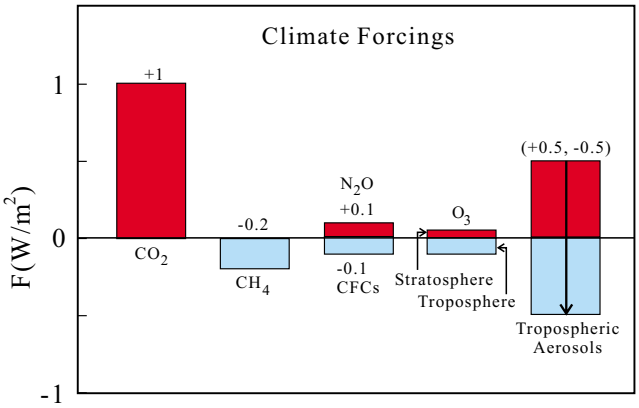

Figure 5. A scenario for additional climate forcings between 2000 and 2050. Reduction of black carbon moves the aerosol forcing to lower values (from reference 1).

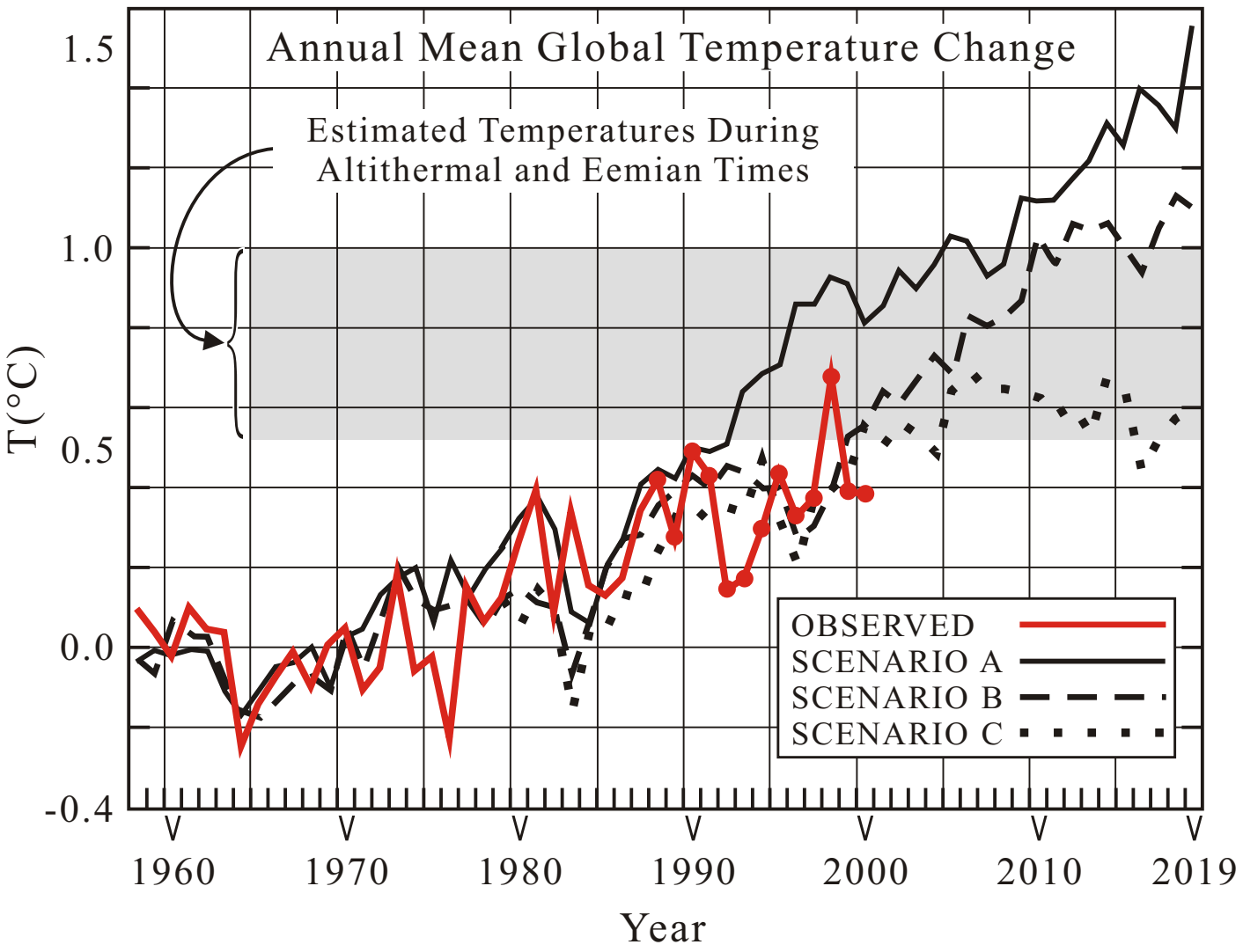

Figure 6. Annual-mean global surface temperature. Scenarios are computations completed in 1987 (from reference 7). Filled circles are subsequent observations.

Climate change

Sir – Your news article[1] (v. **407**, p. 7), *Climate change expert stirs new controversy*, requires several clarifications. Intimations that the paper was sloppy or not properly reviewed are baseless. The paper, published in the prestigious *Proceedings of the National Academy of Sciences*, was peer-reviewed according to their procedures. As an Academy member, I sent the paper to two experts, including an Academy member, for review. Their reviews, their identities, and a delineation of our changes in response to the reviews, were submitted with our paper to the Editor.

We did not state that other gases are more responsible than carbon dioxide for past warming. We calculated a forcing of 1.4 W/m^2 for CO_2 and 1.4 W/m^2 for other greenhouse gases (GHGs).

Our "alternative scenario" for future climate forcings was not stated to be a prediction. We noted the value of "business as usual" (BAU) scenarios, with continued rapid growth of GHG emissions, as a warning of potential large climate change. We suggested that, for the sake of comparison, BAU scenarios be accompanied by a scenario with moderate GHG growth rates.

BAU scenarios have added climate forcing of about 3 W/m^2 in the next 50 years, with 2 W/m^2 from CO_2 and 1 W/m^2 from other GHGs. We note that the CO_2 forcing would be 1 W/m^2 if the CO_2 growth rate could be kept equal to that of the past two decades. We suggest that the net increase in other anthropogenic forcings could be near zero, if there were a concerted effort to limit emissions of CH_4, O_3 precursors, and black carbon (soot) aerosols. Aerosols and O_3, two of the four largest anthropogenic climate forcings, are not included in the Kyoto Protocol.

We recommend investments in technology to improve energy efficiency and develop nonfossil energy sources to slow the growth of CO_2 emissions and expand future policy options. However, we note that an added emphasis on air pollution would unite the interests of developed and developing countries.

A recent study[3] in France, Switzerland and Austria puts the annual costs of particulate pollution in those countries at 40,000 lives, 500,000 asthma attacks, and medical costs amounting to 1.7% of their gross domestic products. Air pollution in developing countries, such as India and China, is even more severe.

Smaglik[1] notes the glee with which industrial lobbyists greeted our paper. We note positive reactions covering a range from the *Washington Post*[4] to *Electricity Daily*[5]. The common sense strategy implicit in our paper conceivably may provide a meeting point for persons from a wide spectrum of political viewpoints.

We realize that our paper may be misused by those who doubt the reality or significance of global climate change. Our aim is to produce the most objective quantitative analysis that we can. In the end, that is likely to serve the public best.

James Hansen
Goddard Institute for Space Studies, 2880 Broadway, New York 10025, USA

1. Smaglik, P. *Nature* **407**, 7 (2000).
2. Hansen, J., Sato, M., Ruedy, R., Lacis, A. & Oinas, V. *Proc. Nat. Acad. Sci.* **97**, 9875-9880 (2000).
3. Kunzli, N. *Lancet* September 1 (2000).
4. *Washington Post*, August 28 (2000).
5. *Electricity Daily* **15**, no. 41 (2000).

Hot News on Warming

Text from *The Washington Post* Monday, August 28, 2000: Page A18

IF YOU"RE trying to decide whether to be an optimist or a pessimist on global warming, recent news is enough to leave you dizzy. An icebreaker found open water at the North Pole, prompting a new wave of attention to the thinning polar ice cap. That seemed like bad news, although some oceanographers said summertime cracks in Arctic ice aren't new, and this one shouldn't be over-interpreted. Texas, the state that produces the most greenhouse gas emissions, for the first time took steps to study the extent of those emissions and consider possible ways to reduce them. That was good news, although it doesn't guarantee state action. And Dr. James Hansen, a leader in drawing government attention to global warming, published a report suggesting that it may be "more practical to slow global warming than is sometimes assumed" by focusing in the short term on cutting heat-trapping gases other than carbon dioxide. That was surprising news, at least to those of us who have seen the climate-change fight centering on reducing carbon dioxide emissions.

It's long been known that carbon dioxide isn't the only gas that helps hold heat in the atmosphere. Six "greenhouse gases" were included in the Kyoto protocol, the international agreement that calls for cutting emissions by 2012. But carbon dioxide, the most abundant greenhouse gas, has dominated the public debate. It has been a subject of contention because it is a byproduct of burning fossil fuels, such as coal and gas, that drive modern industrial society. American opponents of the Kyoto protocol have argued that the reductions it requires could wreck the economy.

Dr. Hansen and a team of colleagues wrote that most of the global warming so far observed actually has come from other greenhouse gases such as methane, chlorofluorocarbons, and gases that combine to create ozone in smog. They suggested a strategy of focusing first on cutting those gases and black particles of soot that also trap heat. Some of the gases involved are already in decline because of other international restrictions; going after others amounts to an attack on air pollution, which the scientists argue should be attractive action in all parts of the world, independent of concerns about warming, because of the health benefits of cleaner air.

That optimistic scenario immediately caused some environmentalists to worry that the report would become a weapon for those who are skeptical about warming—who oppose any action. Dr. Hansen himself said it undoubtedly will be used that way, but that would be a misreading of the study. The new report does not challenge either the evidence that surface temperatures are going up or the growing consensus that human activities are contributing to the increase. It continues to cite the need for reductions in carbon dioxide emissions. There is no suggestion, nor should there be, that response to global warming should wait until the science is more certain.

What it does do is remind us that climate issues are complex, far from fully understood and open to a variety of approaches. It should serve as a caution to environmentalists so certain of their position that they're willing to advocate radical solutions, no matter what the economic cost. It suggests that the sensible course is to move ahead with a strong dose of realism and flexibility, focusing on approaches that are economically viable, that serve other useful purposes such as cutting dependence on foreign oil or improving public health, and that can help support international consensus for addressing climate change. If the Hansen report pushes the discussion in that direction, it will turn out to be good news indeed.