What Do We Know about Human Influence on Climate Change?

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Contemporary Issues Series 96

November 1999

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Introduction

Prediction of the future is a difficult problem, whether for economic activity or for climate change. The two fields are interdependent to some extent. Climate has some influence on economic activity; historically, warmer climates have been associated with bountiful harvests and economic prosperity.[1] The growth of population and of economic activity determines the growth of greenhouse gases in the atmosphere, principally carbon dioxide (CO_2) from the burning of fossil fuels and methane (CH_4) from cattle raising and rice growing. The radiative forcing of such gases then should produce climate changes, with the magnitude and other details calculated from theory. As in economics, a principal objective is the validation of the theoretical predictions by data gathered from observations of the system.

The focus of climate science is certainly atmospheric science and meteorol-

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This article first appeared in Eos (Transactions of the American Geophysical Union), *Vol. 80, No. 16, April 16, 1999, pp. 183, 186-187,*

ogy, but the subject is so complex that it involves many other areas of the earth sciences (such as oceanography in all of its aspects, hydrology, glaciology, geology, and solar-terrestrial relations) as well as different disciplines, such as physics, chemistry, and even biology. This complexity makes climate science both fascinating and controversial. It also undergoes rapid change as new facts and analyses emerge. Yet public interest in the possibility of climate change due to human activities has become so intense that the subject has to be addressed even before final judgments are possible.

Those who are skeptical of the IPCC conclusion have viewed the statement about human influence as so equivocal as to be meaningless.

The most widely quoted attempt to address climate changes of the past and to speculate about the future is the series of reports produced by the United Nations Intergovernmental Panel on Climate Change (IPCC). Its first Scientific Assessment Report (1990), involving atmosphere and oceans, concluded that the climate record is "broadly consistent" with what might be expected from the human-enhanced greenhouse (GH) effect, as calculated by general circulation models (GCMs).

The second scientific assessment, published in 1996, no longer made this claim; instead, it found it necessary to introduce a previously overlooked factor, the cooling effects of human-caused atmospheric sulfate aerosols, to reach the conclusion that "the balance of evidence suggests there is a discernible human influence on global climate."[2] This ambiguous statement in the report's Summary for Policymakers does not do justice to the vast compilation of data and model results brought together in the report itself by some 100 climate scientists. Their important work (more than 500 pages, but lacking an index) has been largely ignored by the public, while attention has focused on the politically negotiated five-page summary.

Those who are skeptical of the IPCC conclusion have viewed the statement about human influence as so equivocal as to be meaningless. On the other hand, the media and many policy experts have welcomed its convenient formula, which they regard as scientific *proof* of a coming climate catastrophe.

In fact, the IPCC statement is in many ways a truism. There certainly must be a human influence on some features of the climate, locally if not globally. The important question is whether the available evidence supports the results of the model calculations. Unless validated, the predictions of future warming based on GCMs cannot be relied on.

What follows is a personal view of the current state of climate science, how it relates to model results, and what might be expected in the future as human activities continue to raise the level of greenhouse gases in the atmosphere. A disclaimer is in order. Any brief treatment of this complex subject by an individual author inevitably selects certain facts as important and rejects other pieces of evidence as inadequate or unproven. Even so, such a treatment has the advantage of providing a consistent story, compared to a committee report that often dissolves into a mire of uncertainties. It also provides a convenient target for debate and thus may lead, if not to progress, then at least to a sharpening of data collection efforts and theoretical research.

A Look at the Evidence

The subject of climate change must rest on observations of the climate in all of its aspects; with temperature as the most important and easily measured parameter. On the one hand, we are inundated with data, many of which do not add appreciably to the discussion. On the other hand, we lack crucial information about the past that may never be recovered.

Individual temperature measurements using thermometers date back only about 300 years. The record for the Northern Hemisphere begins about 1860. Only since 1979 have weather satellites been able to cover the complete globe, including the 70 percent of the surface covered by oceans. Yet we have increasing amounts of proxy data from tree rings, ocean sediments, ice cores, and other evidence that tells us about climate in the distant past.

Paleoclimate Evidence

To gain perspective on the subject of climate change, one needs to first look at the past. While the data are not strictly global and not always of the best quality, certain conclusions can be reached. The Earth's climate has never been steady; it has either warmed or cooled without any human intervention. The measured variations have often been large and rapid—larger and more rapid than those predicted by climate models for the year 2100.

In the last 3,000 years, i.e., during recorded human history, temperatures in the North Atlantic have changed by as much as 3°C within a few decades.[3] During the most recent Ice Age, the variability was even greater. Is the climate more stable during warmer periods? We cannot be sure, but the evidence points in this direction.[4]

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What has caused the climate to vary? All sorts of theories have been propounded and many have been buttressed by data. It is clear, however, that different causes can be acting simultaneously, with their importance depending primarily on the time scale involved. The frequent ice ages of the last few million years appear to be linked to changes in the absorbed incident solar radiation, in turn affected by orbit changes of the Earth—the so-called astronomical theory. Longer-term climate changes seem to be linked to continental drift and other tectonic events.

Shorter variations, on the time scale of decades, appear to be caused by atmosphere-ocean interactions and changes in ocean circulation. Alternatively, they could be due to external causes, such as the slight variations in the general solar irradiance (the so-called solar "constant")[5] or in the highly variable solar activity (mostly of the solar ultraviolet radiation or of particle emission from the Sun). There also are suggestive correlations of these solar variations with cloudiness[6] and with temperature,[7] but as yet no convincing physical mechanism.

What about the association of climate change with atmospheric greenhouse gases? On the time scale of hundreds of millions of years, carbon dioxide (CO_2) has sharply declined; its concentration was as much as 20 times the present value at the beginning of the Cambrian Period, 600 million years ago.[8] Yet the climate has not varied all that much, and glaciations have occurred throughout geologic time even when CO_2 concentrations were high.

On a time scale of decades and centuries, there seems to be an association between temperature and CO_2 concentration, as judged by measurements of Greenland and Antarctic ice cores. (The association is even better for the greenhouse gas methane.) Yet the causal connection is not at all clear. Only recently has it been possible to obtain sufficient resolution to demonstrate that the increase in CO_2 *lags* by about 600 years behind the rapid warming that signals deglaciation—the end of an ice age and the beginning of an interglacial warm period.[9]

Atmospheric Greenhouse Gases (GHGs)

Scientists generally agree that the increase in atmospheric GHGs, like CO_2, methane, nitrous oxide, etc., over the last hundred years or so is due to human activities. Attention has focused mainly on CO_2

as the most important anthropogenic GHG.

Less than half of the released CO_2 remains in the atmosphere. The rest is absorbed by the ocean and by the biosphere, thereby speeding up the growth of agricultural crops and forests. Informed opinion holds that half of the released CO_2 is absorbed into the shallow oceans within 30 years,[10] and that the mean residence time in the atmosphere is about 75 years. A smaller portion, or "tail," may remain in the atmosphere for more than a century.[11] The residence time of methane is much shorter—only about 12 years.

For reasons as yet unexplained, the rate of increase of CO_2 has slowed considerably in the last decade or so, and methane has stopped increasing altogether.

For reasons as yet unexplained, the rate of increase of CO_2 has slowed considerably in the last decade or so, and methane stopped increasing altogether.[12] This makes it extremely difficult to predict future concentrations of CO_2 and methane, the latter depending primarily on the rate of population growth.

With respect to CO_2, estimates of emissions vary greatly, depending on energy scenarios. These are determined not only by population growth and economic growth, but also by the availability of fossil fuels, which, in turn, is a strong function of technology and of price. Much to the surprise of many "experts," the price of oil has decreased in the last two decades, even as readily available low-cost resources are being depleted.

There is considerable disagreement about the probable date when atmospheric GHG concentration might reach double the pre-industrial level. Estimates vary from the year 2050 all the way to never.[13]

Temperature Data

There is general agreement that the global climate warmed between about 1880 and 1940, following several centuries of the "Little Ice Age," which in turn was preceded by the "Medieval Climate Optimum" around A.D. 1100. There is less agreement about the causes of this recent warming, but the human component is thought to be quite small [see box.]

This conclusion seems to be borne out also by the fact that the climate cooled between 1940 and 1975, just as industrial activity grew rapidly after World War II. It has been difficult to reconcile this cooling with the observed increases in greenhouse gases. To account for the discrepancy, the 1996 IPCC report focused attention on the previously ignored (direct) cooling effects of sulfate aerosols (from coal burning and other industrial activities), which reflect a portion of incident sunlight.

But the reflective effect of sulfate aerosols is no longer considered as valid as at the time of the second IPCC report. Leading modelers all agree that aerosol forcing is more uncertain than any other feature of the climate models.[14] Models have not yet incorporated the much larger indirect cooling effects of sulfate aerosols (by increasing cloudiness), or the quite different optical effects of carbon soot from industrial and biomass burning

Looking for Human Fingerprints in the Global Climate Record

The IPCC arrived at the ambiguous conclusion that "the balance of evidence suggests there is a discernible human influence on global climate," based on "fingerprints" in the climate record, i.e., an increasing correlation (with time) between observed and calculated global temperature patterns.[i] However, this positive trend in correlation depended entirely on the arbitrary choice of the time interval 1940 to 1990. During most of this period, temperatures were actually decreasing. A different choice of interval could have produced a zero, or even a negative, trend.

Another piece of evidence cited in the IPCC report to support a human influence depended on showing an increasing temperature trend in the middle troposphere of the Southern Hemisphere.[ii] Again, detecting this "fingerprint" is related entirely to the choice of time interval.[iii] More complete data sets give a contrary result—a greater warming trend in the Northern than in the Southern middle troposphere.

Following the publication of the IPCC report in 1996, an increasing number of researchers adopted the view that much or most of the pre-1940 warming was due to natural causes and represents a recovery from the Little Ice Age. Some would assign a substantial portion to greenhouses gases.[iv] Others claim that most of the temperature increase is caused by solar variability.[v] If one applies the "fingerprint" criterion used by the IPCC, however, one notes that the pattern correlation has a *negative* trend during the major warming between 1900 and 1940,[vi] thereby denying the existence of an appreciable human contribution.

Perhaps the strongest argument against an appreciable human contribution comes from the observed cooling between 1940 and 1975 and the lack of warming since 1979 (in the weather balloon and satellite data).

and of mineral dust arising from disturbances of the land.

The temperature observations since 1979 also are in dispute. On the one hand, surface observations with conventional thermometers show a rise of about 0.1°C per decade (which is less than half that predicted by most GCMs). On the other hand, data gathered by remote sensing from instruments in weather satellites, as well as independent data from balloon-borne radiosondes, show no warming trend in the lower troposphere between 1979 and 1997, and could even indicate a slight cooling.[15] Temperature measurements on Greenland ice cores show a cooling trend between 1940 and 1995.[16] It is likely, therefore, that the surface data are contaminated by the warming effects of "urban heat islands." Some data support this hypothesis,[17] others do not.[18]

While it is certainly true that human life is affected by temperatures at the surface, the GCMs are best validated by observations in the troposphere. GCMs predict a warming trend that *increases* with altitude up to about 250 millibars (~12 km), rising to about 0.5°C per decade.[19] This prediction is in clear disagreement with all observations, whether from the surface, balloons, or satellites, which show only a slight warming, or even a cooling trend.

Climate Models

The large discrepancy between model results and observations of temperature trends (whether from satellites or from the surface) demands an explanation. The 20 or so models developed around the world by expert groups differ among themselves by large factors.

Their "climate sensitivities" (defined as the temperature increase for a doubling of GHG forcing) vary from as low as 1°C to as high as 5°C. The IPCC gives a conventional range of 1.5°C to 4.5°C from a doubling of greenhouse gas concentrations.

A comparison of models has established that a major uncertainty relates to how clouds are treated.[20] Since they are too small to be resolved by current models (which have a rather coarse resolution of about 200 km), they are treated in a highly approximate fashion. In many models, clouds add to the warming, but in others, clouds produce a cooling effect.

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The situation is even more confused with respect to water vapor. Water vapor is the most important greenhouse gas in the atmosphere, contributing over 90 percent of the radiative forcing. In current climate models, water vapor is modeled as a positive feedback, thereby amplifying the warming effects of a CO_2 increase. Scientists widely agree that a warming produced by an increase in CO_2, or by any other cause, will lead to more evaporation and, therefore, to a higher level of water vapor. It is the water vapor concentration in the upper troposphere, not in the boundary layer, however, that determines whether the feedback is positive or negative.[21] On the crucial question of water vapor feedback, opinions differ widely and probably will continue to do so until the necessary data are at hand.

There are other omissions. Climate models generally do not incorporate the large changes in surface reflectivity ("albedo") that have come about through land clearing for agriculture and, more recently, through reforestation in some parts of the world. None of the climate models incorporates the effects of a variable Sun. It has always been assumed that solar variability is simply too small, but this view is now changing. Even if the radiative forcing from changes in the general solar irradiance is less than that from GHGs, the variability of the Sun in the ultraviolet is much greater. Evidence is now forthcoming that UV-caused variations of the ozone layer or changes in solar particulate emissions ("solar wind") could (indirectly) influence atmospheric circulation or cloudiness, which in turn can cause significant climate changes.[22]

If the climate were to change according to model predictions, one would expect to see fewer *severe storms.*

Even though the models are not yet validated as far as temperature trends are concerned, some human influences on climate are already noticeable. Observations indicate that the diurnal temperature range has been decreasing in the Northern Hemisphere and perhaps in the Southern Hemisphere as well.[23] These could be traced to possible increases in aerosols or cloudiness. There is evidence also for winter warming, but not yet for the expected warming at high latitudes predicted by the climate models. On the other hand, observed stratospheric cooling appears in line with what one might expect from the increase in CO_2, as well as from the small depletion of stratosphere ozone.[24] Yet until GCM "climate sensitivity" is fully validated, one cannot accept the predictions of large future temperature increases.

Impacts of Climate Change

If the climate were to change according to model predictions, one would expect to see *fewer* severe storms, in view of the reduced temperature gradient between the tropics and high latitudes. Model calculations do not indicate an increase of hurricanes, El Niño events, or other kinds of climate oscillations. The empirical evidence displayed in the IPCC report shows a *decline* in hurricanes over the last 50 years in both frequency and intensity;[25] a future warming is not expected to appreciably affect frequency or intensity.[26] Observations on El Niño events are not conclusive as yet, although there was a significant decrease during the warming period in the first half of this century.

With respect to sea-level rise, it has been assumed, conventionally, that a warming will increase the rate of rise, because of the thermal expansion of ocean water and the melting of mountain glaciers. Certainly, when viewed on a millennial scale, sea level has been rising steadily since the peak of the recent ice age some 15,000 years ago. But when examined on a decadal scale, which is more appropriate to human intervention, sea-level rise is found to slow during periods of temperature increases, for example, during the temperature rise from 1900 to 1940.[27] Evidently, increased evaporation, linked to warming, results in increased accumulation of ice in the polar regions, thereby *lowering* sea level. This conclusion seems to be backed by direct observation of ice accumulation, as well as by some modeling studies. A future modest warming should therefore slow down, not accelerate, the ongoing rise of sea levels.

The 1997 Kyoto Protocol is not sufficient to reduce significantly the ongoing growth of GHG in the atmosphere; therefore, its effect on temperature would be imperceptible.

The Economic Impact of a Possible Climate Warming

Economists have recently re-examined the 1996 IPCC (Working Group III) review of economic impacts. (Some of these studies showed large losses for agriculture but not for sea-level rise, whereas others showed the opposite; yet the total loss figures were not too different.) The re-examination shows a substantial *gain* for agriculture and little effect on other economic activities in the United States. They conclude that a warming, from whatever cause, would produce economic benefits rather than economic losses.[28] The new findings on sea-level rise (above) would reinforce this conclusion, which has not yet been widely publicized or discussed.

The Climate Treaty and Kyoto Protocol

Most regard the objective of the 1992 Climate Treaty as the reduction of GHG emissions. But Article 2 of the Treaty states that the ultimate goal is to "achieve stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system."[29] It is not clear what this means, or whether a higher or lower level of GHG will prove more "dangerous."[30] As noted earlier, however, a warmer climate is likely to be a more stable one.

The 1997 Kyoto Protocol (calling for an average cut in GHG emissions of 5.2 percent from 1990 levels by industrialized nations by the year 2010) is not sufficient to reduce significantly the ongoing growth of GHG in the atmosphere; therefore, its effect on temperature would be imperceptible. According to IPCC data, it reduces the calculated temperature increase by only 0.05°C by the year 2050.[31] As pointed out in the initial IPCC report, stabilization at the present GHG level requires that emissions be cut by 60 to 80 percent worldwide, a far greater reduction than visualized by the Kyoto Protocol. Altogether, the U.N. deliberations have emphasized emission controls and neglected sequestration of CO_2 from the atmosphere into the ocean, a fertile area for geophysical research.[32]

Conclusion

High government officials have declared repeatedly that climate science is "settled" and "compelling." The clear implication is that we know enough to act—any further research findings would be "policy-irrelevant" and not germane to the international deliberations of the parties to the climate treaty.

This review of the state of general climate change research concludes otherwise: (1) Any warming from the growth of greenhouse gases is likely to be minor, and, thus, difficult to detect above the natural fluctuations of the climate. (2) In addition, the impacts of warming and of higher CO_2 levels are likely to be beneficial for human activities and especially for agriculture. (3) Further, the ultimate goal of the climate treaty is still undefined; it could be a higher or a lower level of GHG than the current one. (4) Finally, the Kyoto Protocol, while economically harmful, would be ineffective in reducing the calculated temperature increase.

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