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TO: AIAM Technical Committee

FROM: Gregory J. Dana
Vice President and Technical Director

RE: **GLOBAL CLIMATE COALITION (GCC) - Primer on Climate Change Science - Final Draft**

Enclosed is a primer on global climate change science developed by the GCC. If any members have any comments on this or other GCC documents that are mailed out, please provide me with your comments to forward to the GCC.

GJD:ljf

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December 21, 1995

To: Members of GCC-STAC

Attached is what I hope is the final draft of the primer on global climate change science we have been working on for the past few months. It has been revised to more directly address recent statements from IPCC Working Group I and to reflect comments from John Kinsman and Howard Feldman.

We will be discussing this draft at the January 18th STAC meeting. If you are coming to that meeting, please bring any additional comments on the draft with you. If you have comments but are unable to attend the meeting, please fax them to Eric Holdsworth at the GCC office. His fax number is (202) 638-1043 or (202) 638-1032. I will be out of the office for essentially all of the time between now and the next STAC meeting.

Best wishes for the Holiday Season,

Lenny

L. S. Bernstein

APPROVAL DRAFT

Predicting Future Climate Change: A Primer

In its recently approved Summary for Policymakers for its contribution to the IPCC's Second Assessment Report, Working Group I stated:

> ...the balance of evidence suggests that there is a discernable human influence on global climate.

The Global Climate Coalition's Science and Technical Advisory Committee believes that the IPCC statement goes beyond what can be justified by current scientific knowledge.

This paper presents an assessment of those issues in the science of climate change which relate to the ability to predict whether human emissions of greenhouse gases have had an effect on current climate or will have a significant impact on future climate. It is a primer on these issues, not an exhaustive analysis. Complex issues have been simplified, hopefully without any loss of accuracy. Also, since it is a primer, it uses the terminology which has become popular in the climate change debate, even in those cases where the popular terminology is not technically accurate.

Introduction and Summary

Since the beginning of the industrial revolution, human activities have increased the atmospheric concentration of CO_2 by more than 25%. Atmospheric concentrations of other greenhouse gases have also risen. Over the past 120 years, global average temperature has risen by 0.3 - 0.6°C. Since the Greenhouse Effect can be used to relate atmospheric concentration of greenhouse gases to global average temperature, claims have been made that at least part of the temperature rise experienced to date is due to human activities, and that the projected future increases in atmospheric concentrations of greenhouse gases (as the result of human activities) will lead to even larger increases in future temperature. Additionally, it is claimed that these increases in temperature will lead to an array of climate changes (rainfall patterns, storm frequency and intensity, etc.) that could have severe environmental and economic impacts.

This primer addresses the following questions concerning climate change:

1) Can human activities affect climate?

   The scientific basis for the Greenhouse Effect and the potential impact of human emissions of greenhouse gases such as CO_2 on climate is well established and cannot be denied.

2) Can future climate be accurately predicted?

   The climate models which are being used to predict the increases in temperature which might occur with increased atmospheric concentrations of greenhouse gases are limited at present both by incomplete scientific understanding of the factors which affect climate and by inadequate computational power. Improvements in both are likely, and in the next decade it may be possible to make fairly accurate statements about the impact that increased greenhouse gas concentrations could have on climate. However, these improvements may still not translate into an ability to predict future climate for at least two reasons:

- limited understanding of the natural variability of climate, and
- inability to predict future atmospheric concentrations of greenhouse gases.

The smaller the geographic area considered, the poorer the quality of climate prediction. This is a critical limitation in our ability to predict the impacts of climate change, most of which would result from changes in a local or regional area.

3) Have human activities over the last 120 years affected climate, i.e. has the change been greater than natural variability?

Given the limitations of climate models and other information on this question, current claims that a human impact on climate has already been detected, are unjustified. However, assessment of whether human activities have already affected climate may be possible when improved climate models are available. Alternatively, a large, short term change in climate consistent with model predictions could be taken as proof of a human component of climate change.

4) Are there alternate explanations for the climate change which has occurred over the last 120 years?

Explanations based on solar variability, anomalies in the temperature record, etc. are valid to the extent they are used to argue against a conclusion that we understand current climate or can detect a human component in the change in climate that has occurred over the past 120 years. However, these alternative hypotheses do not address what would happen if atmospheric concentrations of greenhouse gases continue to rise at projected rates.

Can Human Activities Affect Climate?

The Sun warms the Earth and is the source of energy for the climate system. However, as shown in Figure 1, the process by which this occurs is complicated. Only about half of the incoming radiation from the Sun is absorbed by the Earth's surface. About a quarter is absorbed by the atmosphere, and the remainder is reflected back into space by clouds, dust and other particulates without being absorbed, either by the surface or atmosphere.

The energy absorbed by the Earth's surface is reradiated to space as longwave radiation. A fraction of this reradiated energy is absorbed by greenhouse gases, a phenomenon known as the Greenhouse Effect. Greenhouse gases are trace gases - such as water vapor, CO_2, methane, etc. - which have the ability to absorb longwave radiation. When a greenhouse gas molecule absorbs longwave energy, it heats up, then radiates energy in all directions, including back down to the Earth's surface. The energy radiated back to the Earth's surface by greenhouse gas molecules is the Greenhouse Effect that further warms the surface. The warmer the surface of the Earth, the more energy it reradiates. The higher the concentration of greenhouse gases, the more energy they will absorb, and the more they will warm the Earth. The average temperature of the Earth depends on the balance between these two phenomena. Naturally occurring greenhouse gases, predominantly water vapor, account for 95-97% of the current Greenhouse Effect. They raise the average temperature of Earth's surface by about 30°C. Without this natural Greenhouse Effect, the Earth would probably be uninhabitable. The science of the Greenhouse Effect is well established and can be demonstrated in the laboratory.

Human activities can affect the energy balance at the Earth's surface in three ways:

- combustion, agriculture and other human activities emit greenhouse gases and can raise their concentration in the atmosphere, which would directionally lead to warming;

- combustion emits particulates, and gases such as sulfur dioxide which form particulate matter in the atmosphere, which would directionally lead to cooling; and

- changes in land-use, such as removing forests, can change the amount of energy absorbed by the Earth's surface, the rate of water evaporation, and other parameters involved in the climate system, which could result in either warming or cooling.

These three factors create the potential for a human impact on climate. The potential for a human impact on climate is based on well-established scientific fact, and should not be denied. While, in theory, human activities have the potential to result in net cooling, a concern about 25 years ago, the current balance between greenhouse gas emissions and the emissions of particulates and particulate-formers is such that essentially all of today's concern is about net warming. However, as will be discussed below, it is still not possible to accurately predict the magnitude (if any), timing or impact of climate change as a result of the increase in greenhouse gas concentrations. Also, because of the complex, possibly chaotic, nature of the climate system, it may never be possible to accurately predict future climate or to estimate the impact of increased greenhouse gas concentrations.

The usual approach to discussing the impact of the increased atmospheric concentrations of greenhouse gases on climate is to convert them to an equivalent amount of CO_2, then discuss the effect of some fixed increase in equivalent CO_2. Most of the discussion is about doubled equivalent CO_2. The conversion to equivalent CO_2 introduces a number of errors, because the effects of some greenhouse gases depend on their location in the atmosphere, but since the convention is well established, it will be used in this discussion. A more accurate approach is to refer to increased radiative forcing, which is the increase in energy radiated to the Earth's surface, taking into account all of the complexities in the physics of greenhouse gases.

Can Future Climate Be Accurately Predicted?

Climate models, called General Circulation Models (GCMs), are used to predict the change in temperature, rainfall, cloud cover and other climate parameters that would result from a change in equivalent CO_2 and sometimes aerosols. The estimates of climate parameters are then used to predict impacts of climate change, such as frequency and severity of tropical storms, effects on agriculture and biodiversity, etc. While most discussions of models focus on their predictions of changes in average temperature, factors such as changes in maximum and minimum temperature, soil moisture content, and prevalence of conditions which favor the formation of tropical storms are far more important in determining potential climate change impacts.

GCMs are three-dimensional grid models which cover the whole Earth, the atmosphere to a sufficient height to include all climate processes, and the oceans in multiple depth layers. GCMs are also referred to as coupled atmosphere-ocean climate models. Most of the debate about the prediction of climate change centers around the quality of both the models and the input data they use, and the degree to which both can be improved. The concerns about these models can be grouped into five categories:

(1) limits in scientific understanding of climate processes,

(2) how they model "feedbacks,"

(3) how they describe the initial conditions, i.e., the current state of the climate,

(4) how well we understand the natural variability of climate, including the possibility that the climate system is chaotic, and

(5) the computational power required to accurately model climate.

A sixth concern, not directly related to GCMs, but important to the question of whether future climate can be accurately predicted, is whether future atmospheric concentrations of greenhouse gases can be accurately predicted. The problem has two components, economic and scientific. The economic question is whether we can accurately predict both the future level of global economic activity and the technology which will be employed. Past predictions in both areas have been highly inaccurate. The scientific question is whether we understand the fate of greenhouse gases well enough to accurately predict the effect their emissions will have on atmospheric concentrations. For example, only about half of the CO_2 emitted from human activities ends up in the atmosphere. The remainder is believed to be absorbed by increased plant growth or in the oceans. Estimates of the amount of CO_2 absorbed by these two sinks are highly uncertain. There is also a great deal of scientific debate on what, if any, impact higher temperatures and related climate change will have on the rate of CO_2 absorption by plants and the ocean.

Limited Scientific Understanding of Climate Processes

Quantifying what we don't know about climate processes is an impossible task. However, the huge volume of important new findings about the processes that are critical to climate generated over the past few years make it obvious that there is a great deal more to be learned about the basic science of climate. For example, in 1995, Prof. Cess and his co-workers at the State University of New York published a paper on the energy balance around clouds which indicated that the values being used in climate models were incorrect by 25%. Cess *et al.* were unable to identify the physical processes which led to this different estimate of energy absorption. Since clouds are a critical part of the climate system, a correct characterization of their properties is essential. Other recent studies indicate that vegetation may be absorbing much more CO_2 than previously believed, allowing less of it to accumulate in the atmosphere.

Feedbacks

Climate models predict that the direct effect of doubling equivalent CO_2 from pre-industrial levels is relatively small. Global average temperature would rise by 0.5 - 1°C, an amount which is not generally considered to represent a problem. However, even that rise in temperature would cause a variety of changes, some of which would act to further increase temperature, others of which would act to decrease temperature. These secondary changes are called "feedbacks." The popular usage is that a positive feedback is one which acts to further increase temperature, and a negative feedback is one which acts to decrease temperature. The technical definition is that a positive feedback is one which exaggerates the initial perturbation, which could either increase or decrease temperature, and a negative feedback is one which decreases the initial perturbation. Since the popular usage is so common, it will be used in this paper.

The most important positive feedback is the impact which rising temperatures will have on the amount of water vapor in the atmosphere. Water vapor is the most important natural greenhouse gas in the atmosphere, accounting for the majority of the natural Greenhouse

Effect. As temperature increases, more water evaporates, the concentration of water vapor in the atmosphere rises, the Greenhouse Effect is enhanced, and temperatures rises further. An example of a negative feedback is that more evaporation of water results in the formation of more clouds. Low level clouds reflect sunlight, preventing its energy from reaching the Earth's surface, thus providing a cooling effect. As noted below, high level clouds provide a positive feedback.

Modeling feedbacks is one the major challenges in developing accurate climate models. The role of clouds is a particularly difficult modeling task. Low level clouds reflect sunlight and therefore are a negative feedback. However, clouds are made up of water vapor and therefore also absorb radiation. For high level clouds the absorption of radiation is more important than the reflection of radiation; they provide a positive feedback. Better estimates of the energy balance around clouds are becoming available, and preliminary modeling results indicate that the use of these better estimates improves the ability of GCM's to match current conditions.

Prediction of Current Conditions

GCMs are supposed to be theory-based models, not empirical models. As such they should be able to match current climate conditions using only the independent variables that determine climate (solar radiation, greenhouse gas concentrations, the current temperature of the oceans, etc.) as inputs. GCMs fail this test because they do not accurately predict the transfer of energy from the oceans to the atmosphere, a critical climate parameter. To correct this error, most GCMs are adjusted with "flux corrections," that on a point-by-point basis adjust the amount of heat being transferred from the oceans to the atmosphere to match actual conditions. The "flux corrections" can be quite large, as much as 10 - 20 times the effect of doubling equivalent CO_2. Having to make this large a correction to obtain model results which provide a reasonable description of the baseline is a cause for serious concern.

Flux corrections are correcting for one of two possible errors: missing climate processes, or errors in the description of the climate processes used in the model. New data, such as a better description of the energy balance around clouds, should lead to improvements in models and a reduction in the flux corrections.

Whether modeling capability will improve to the point where the flux corrections can be eliminated or reduced to a more reasonable level is an open question. To eliminate the flux corrections it is necessary to accurately model all climate processes and have an accurate description of initial conditions. Distribution of heat in the oceans is poorly understood, and the cost of collecting the necessary data makes it unlikely that a better understanding will be developed anytime soon.

Natural Variability and the Possibility that Climate is Chaotic

Thus far, GCMs have been described as relatively mechanical models - plug in the right processes and initial conditions and the model will describe climate. However, climate has natural variability, on both long and short time scales. The existence of Ice Ages and the warm periods between them is proof of climate's natural variability on very long time scales. But climate is also naturally variable on shorter time scales. For example, the milder temperatures in the North Atlantic at about 1000 AD allowed the Vikings to settle Iceland and Greenland, and explore the North American coast. The colder temperatures of the Little Ice Age after 1400 wiped out the Viking settlement in Greenland and nearly did the same to Iceland. This was climate variability on a time scale of several centuries. To accurately model future climate, we need an good estimate of the natural variability of climate on still shorter periods, decades to a century, which is currently unavailable.

Understanding the natural variability of climate on a decadal time scale and its causes would greatly improve our understanding of current climate data. Reasonable temperature records exist for only the last 120 years. Data on factors which could be causes for the variability of climate, such as changes in ocean circulation, is either non-existent or available for much shorter time periods. Until we have a better understanding of natural variability, it will be impossible to determine whether a part of the rise in average temperature experienced over the past century is due to human activities.

In addition, climate may be a chaotic system, which is extremely sensitive to very small changes in initial conditions. Weather is known to be chaotic, and since climate is the long-term average of weather, it, too, may be chaotic. In discussing the ability of GCMs to simulate climate, IPCC WG I, in section 6.2.6 of its Second Assessment Report, does not use the term chaotic, but states

> The models produce a high level of internal variability, as observed (Chapter 5), leading to a spread of possible outcomes for a given scenario, especially at the regional level.

This is a functional definition of chaotic behavior. The reference to Chapter 5 is to a discussion of the ability of models to describe observed climate over the last 120 years. If climate is chaotic, our ability to predict future climate or the effect of anthropogenic changes such as the increase in greenhouse gas emissions will be limited.

Computational Limits

GCMs are huge models which require supercomputers to run in any reasonable time. Computational limitations require that they use large grid sizes, typically 500 km. on a side. These cells are larger than many of the important physical features in the system they are trying to model, for example, the width of the Gulf Stream. Computational limits also mean that some critical factors, such as the atmospheric interactions between greenhouse gases and the chemistry of aerosol formation, are not included in the model. The rapid increase in computational power may make it possible to overcome these limitations in the future, but at present they severely limit the quality of GCM predictions.

Capabilities of GCMs

Even with flux corrections, GCMs still cannot describe climate features on a 1000 mile scale which are critical to any discussion of the impacts of climate change. Also, there is considerable concern about the ability of GCMs to predict future climate because the flux correction is constant with changing equivalent CO_2. There is no reason to assume that the flux correction should remain the same if climate changes in response to increased CO_2. As a result, statements such as: "Doubling CO_2 will lead to x°C. increase in temperature." do not seem justified.

While climate models currently are incapable of accurate predictions of future climate, rapid improvement in their capability is possible. Better understanding of climate processes, such as the role of clouds, could significantly improve the models as could the ever increasing power of computers. Whether we can ever accurately predict future climate is still uncertain because of two problems. First, as mentioned above, climate may be chaotic. Second, even if climate is not chaotic, a model's predictions are only as good as the input data used. Our ability to predict future greenhouse gas emission rates depends on being able to predict the future level of global economic activity and the technology which will be used to generate that activity. Past predictions in both areas have been highly inaccurate.

A critical problem in climate modeling is the prediction of regional climate change. Most of the impacts of climate change will be felt on the regional or local level. The change in global average temperature and rainfall will not help predict the effect of climate change on farmers in the mid-West. The ability to predict regional climate change is poorer than the ability to predict global climate change. The IPCC sums up the situation as follows:

> Confidence is higher in hemispheric-to-continental scale projections of coupled atmospheric-ocean models than in the regional projections, where confidence remains low.

Have Human Activities Over the Last 120 Years Affected Climate?

As part of its contribution to the IPCC (Intergovernmental Panel on Climate Change, the UN body charged with assessing the peer-reviewed literature on the science, impacts and economics of climate change) Second Assessment Report, WG I (Working Group I, the sub-group assessing science), after considering the uncertainties in the scientific information, concluded:

> Nevertheless, the balance of evidence suggests that there is a discernable human influence on global climate.

This statement is stronger than those which appeared in the draft of the underlying report, where the authors stated:

> Any claims of positive detection and attribution of significant climate change are likely to remain controversial until uncertainties in the total natural variability of (the) total climate system are reduced.

As used by the IPCC,

> "Detection of change" is the process of demonstrating that an observed change in climate is highly unusual in a statistical sense, but does not provide a reason for the change. "Attribution" is the process of establishing cause and effect relations, including the testing of competing hypotheses.

At the conclusion of the WG I Plenary Session that approved the statement on a human impact on climate, the authors of the underlying report were instructed to modify their report to bring it into agreement with the summary statement. This process is the reverse of what is called for by the IPCC rules of procedure and normal scientific practice.

WG I considered four types of information in evaluating whether the observed change in climate was in fact "highly unusual in a statistical sense," and whether it could be attributed to human influences. A discussion of each type of information follows. Specific scientific studies are mention in three cases; they are the studies which have received the most publicity, but are not the only studies in the category.

1) Model-based estimates of natural variability - The Max Planck Institute (MPI), a German government laboratory and developer of one of the GCMs, ran their model for 1000 years into the future with only random perturbations to assess "natural" variability of temperature. They then determined, with 95% confidence, that the changes in temperature observed over the last 100 years could not be explained by their measure of "natural" variability. German politicians and press have reported this result as meaning that there is 95% confidence that the temperature changes of the last 100 years have been caused by human emissions of greenhouse gases, a significant overstatement of the scientific finding.

   The MPI finding does not prove that the temperature changes of the last 100 years are due to human greenhouse gas emissions for two reasons:

- o Models are simplifications and therefore less variable than the real world. Actual "natural" variability of temperature is almost certain to be larger than the estimate from the MPI computer study.

- o The temperature change of the past 100 years may be due to natural changes in climate. Changes of this magnitude have occurred naturally in the past without any human influence. Section 3.6.3 of IPCC WG I's contribution to the Second Assessment Report states:

  "The warming of the late 20th century appears to be rapid, when viewed in the context of the last millennium. But have similar, rapid changes occurred in the past? That is, are such changes a part of the natural climate variability? Large and rapid changes did occur during the last ice age and in the transition toward the present Holocene period which started about 10,000 years ago. Those changes may have occurred on the time scale of a human life or less, at least in the North Atlantic, where they are best documented. Many climate variables were affected: atmospheric temperature and circ, precipitin patterns and hydrological cycle, temperature and circulation of the ocean."

2) Pattern-based studies - The Hadley Centre, a U.K. government laboratory and the developer of another GCM, has added sulfate aerosol effects to its model and calculated temperature from 1860 to 2050. The addition of aerosol effects provides an improved, but still relatively poor, match for observed temperature from 1860 to the present, and addresses one of the key concerns about climate models, their inability to "backcast" the temperature record. The study ties the increase in temperature over the past 100 years to emissions of greenhouse gases and aerosols.

There are two concerns about the Hadley Centre's work:

- o They considered only the direct effect of sulfate aerosols, i.e., their scattering of incoming sunlight. They did not consider the indirect effects of the aerosols - their impact on cloud formation - which could have an equally large impact on temperature.

- o Adding historical sulfate aerosol effects to the model requires a large number of assumptions about fuel usage rates and emission factors which cannot be tested. The validity of this approach is suspect.

The draft IPCC report discussed the Hadley Centre study and similar work and concluded:

> While some of the pattern-based studies discussed here have claimed detection of a significant climate change, no study to date has positively attributed all or part of that change to anthropogenic causes. Nor has any study quantified the magnitude of a greenhouse gas effect or aerosol effect in the observed data ...

This statement may also change as a result of the instructions given to authors to bring their report into agreement with the summary statement.

3) Studies of the vertical temperature profile of the atmosphere - Climate models predict that an increase in greenhouse gases should lead to a warmer troposphere but a cooler lower stratosphere. The fact that this pattern has been observed is being used to argue for the fundamental correctness of climate models and for the validity of their predictions that human emissions of greenhouse gases will cause changes in climate. However, the effect may be due to stratospheric ozone depletion rather than to the buildup of greenhouse gases in the troposphere. IPCC WG I's part of the Second Assessment Report (Section 8.4.2.1) cites two studies which could be interpreted as supporting this conclusion. If stratospheric ozone depletion is the cause it is "a human forcing of climate" but a different one from the buildup of greenhouse gases in the troposphere. Model agreement with the stratospheric ozone effect does not "prove" that the model is correct in predicting the effects of greenhouse gases in the troposphere.

4) Statistical models fitted to observations - T. R. Karl and three other researchers at National Climatic Data Center (NCDC) evaluated U.S. climate data since 1910 using an index of specific weather events which included: above normal minimum temperatures, above normal precipitation from October to April, below normal precipitation from May to September, and a greater than normal proportion of precipitation coming from heavy rainfalls. These are the types of climate "signature" that many scientists believe will be the first indication of climate change. Karl *et al.* concluded that there is a 90 - 95% probability that climate in the U.S. since 1976 has been affected by the increase in greenhouse gases in the atmosphere.

MIT researchers question the choice of factors included in the NCDC index, since the index is strictly empirical and has not been developed from basic principles. However, the parameters in the index are variables which other researchers have claimed could change as the result of climate change. As in the case of the other studies claiming to show that there has already been a human impact on climate, one can question whether the observed changes are the result of greenhouse gases or other climate influences.

The limitations which prevent climate models from accurately predicting future climate also limit their ability to assess whether a human impact on climate has already occurred. Claims that human activities have already impacted climate are currently unjustified. However, the improvements in climate models could make an assessment of human impacts on climate possible. Alternatively, a sufficiently large, short term change in climate consistent with model predictions could be used as proof of a human impact on climate.

Are There Alternate Explanations for the Climate
Change Which Has Occurred Over the Last 120 Years?

Several arguments have been put forward attempting to challenge the conventional view of greenhouse gas-induced climate change. These are generally referred to as "contrarian" theories. This section summarizes these theories and the counter-arguments presented against them.

Solar Variability

Contrarian Theory

Solar radiation is the driver for the climate system. Any change in the intensity of the solar radiation reaching the Earth will affect temperature and other climate parameters. Dr Robert Jastrow, Director of the Mt. Wilson Observatory, and others have shown a close correlation between various sun spot parameters, which they believe are a measure of solar intensity, and global average temperature for the past 120 years, the period for which reasonable quality data exist for both sun spots and global average temperature. The correlation has been pushed back to about 1700 using less accurate data for both temperature and sun spots. In addition, observations of Sun- like stars indicate that they show the amount of variability in radiation intensity needed to account for recent changes in the Earth's climate.

More recently, Tinsley and Heelis at the Univ. of Texas have proposed a mechanism by which changes in solar activity can impact on climate in by a mechanism other than the direct change in the intensity of solar radiation impacting on the Earth's atmosphere.

Counter-arguments

Direct measures of the intensity of solar radiation over the past 15 years indicate a maximum variability of less than 0.1%, sufficient to account for no more than 0.1°C temperature change. This period of direct measurement included one complete 11 year sun spot cycle, which allowed the development of a correlation between solar intensity and the fraction of the Sun's surface covered by sun spots. Applying this correlation to sun spot data for the past 120 years indicates a maximum variability on solar intensity of 0.1%, corresponding to a maximum temperature change of 0.1°C, one-fifth of the temperature change observed during that period.

If solar variability has accounted for 0.1°C temperature increase in the last 120 years, it is an interesting finding, but it does not allay concerns about future warming which could result from greenhouse gas emissions. Whatever contribution solar variability makes to climate change should be additive to the effect of greenhouse gas emissions.

The Tinsley and Heelis proposed mechanism may revive the debate about the role of solar variability. To date is has not entered the climate change debate.

Role of Water Vapor

Contrarian Theory

In 1990, Prof. Richard Lindzen of MIT argued that the models which were being used to predict greenhouse warming were incorrect because they predicted an increase in water vapor at all levels of the troposphere. Since water vapor is a greenhouse gas, the models predict warming at all levels of the troposphere. However, warming should create convective turbulence, which would lead to more condensation of water vapor (i.e. more rain) and both drying and cooling of the troposphere above 5 km. This negative feedback would act as a "thermostat" keeping temperatures from rising significantly.

Counter-arguments

Lindzen's 1990 theory predicted that warmer conditions at the surface would lead to cooler, drier conditions at the top of the troposphere. Studies of the behavior of the troposphere in the tropics fail to find the cooling and drying Lindzen predicted. More recent publications have indicated the possibility that Lindzen's hypothesis may be correct, but the evidence is still weak. While Lindzen remains a critic of climate modeling efforts, his latest publications do not include the convective turbulence argument.

Anomalies in the Temperature Record

Contrarian Argument	Counter-arguments
The temperature record of the last 120 years cannot be explained by greenhouse gas emissions, which rose steadily through that period. If greenhouse gases were the explanation for recent climate, one would have expected temperature also to have risen steadily through the period. However, temperature rose from 1870 to 1930, then the leveled off to 1940, dropped between 1940 and 1970, and has been rising since 1970.	While atmospheric concentrations of greenhouse gases have risen steadily since 1870, their total increase has been too small for greenhouse warming to be distinguishable above the cooling effect of aerosols and the variability caused by all of the other factors which affect climate (volcanic eruptions, solar variability, random variability possibly due to the chaotic nature of climate, etc.). This does not mean that a further increase in greenhouse gas concentrations will not add to measurable warming.
Satellite measurements covering over 98% of the globe indicate that global average temperature has decreased slightly over the past 15 years, during a time when land-based temperature measurements indicated a series of record high temperatures.	Satellites measure the average temperature of a column of air from the surface to about 6 km. above the surface, while the land-based measurements are surface measurements. Also, the land-based measurements are for land only. The oceans, which cover 70% of the Earth's surface, are not included. The oceans would be expected to warm more slowly than the land surface, lowering global average temperature. While raw data from the satellite measurements indicate a cooling of 0.06°C/decade, correcting the raw data for known effects (volcanos and periodic warming of the Eastern tropical Pacific Ocean as part of the El Nino cycle), yields 0.09°C/decade warming. The corrected satellite measurements still do not agree with the land-based temperature record, but they both show warming.

Detailed temperature records do not agree with predictions about greenhouse warming. Prof. Patrick Michaels of the University of Virginia presented a series of hypotheses about how greenhouse warming should affect temperature. Only two will be discussed in detail.

First, if greenhouse gases were responsible for the increase in global average temperature, one would expect daytime maximum temperatures to increase. What is actually happening is that daytime maximum temperatures are staying constant, while nighttime temperatures are increasing. Michaels argues that the increase in nighttime temperatures is due to the urban heat island effect.

Second, one would also expect Northern Hemisphere temperatures to have increased more than Southern Hemisphere temperatures, since greenhouse gas concentrations are higher in the Northern Hemisphere. However, Southern Hemisphere temperatures have increased more than Northern Hemisphere temperatures. Michaels argues that the smaller increase in the Northern Hemisphere is due to cooling by aerosols, a position which is now becoming generally accepted.

While some scientist argue that greenhouse warming has already occurred, most say that it cannot be separated from all of the other factors affecting climate, including the urban heat island effect and aerosol cooling. Thus, the fact that the recent temperature record does not agree in detail with a greenhouse gas warming scenario does not diminish the potential threat from substantially higher atmospheric concentrations of greenhouse gases.

Conclusions about the Contrarian Theories

The contrarian theories raise interesting questions about our total understanding of climate processes, but they do not offer convincing arguments against the conventional model of greenhouse gas emission-induced climate change. Jastrow's hypothesis about the role of solar variability and Michaels' questions about the temperature record are not convincing arguments against any conclusion that we are currently experiencing warming as the result of greenhouse gas emissions. However, neither solar variability nor anomalies in the temperature record offer a mechanism for off-setting the much larger rise in temperature which might occur if the atmospheric concentration of greenhouse gases were to double or quadruple.

Lindzen's hypothesis that any warming would create more rain which would cool and dry the upper troposphere did offer a mechanism for balancing the effect of increased greenhouse gases. However, the data supporting this hypothesis is weak, and even Lindzen has stopped presenting it as an alternative to the conventional model of climate change.

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BACKGROUNDER

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Science and Global Climate Change: What Do We Know? What are the Uncertainties?

About This Backgrounder

In the past two decades, many scientists have raised concerns about the future of the earth's climate. In 1971, several leading scientists raised concerns about global cooling, leading to predictions of a coming ice age. Some scientists still recognize a cooling potential.

In the mid-1980's, the concern shifted to global warming, with a number of scientists stating their belief that the earth was warming as a result of an increasing concentration of greenhouse gases in the atmosphere. Some scientists predicted dramatic increases in temperature, which would lead to the melting of polar ice-caps, rising of sea levels, and other catastrophic results. Today, after several years of investigation, many of these dire predictions are moderating.

Global climate policy decisions must be made with the benefit of an adequate scientific understanding of how and why climate changes. Scientists remain divided on a number of climate change issues: Are increases of man-made gases contributing to global warming? Have global temperatures increased over the century? How accurate are forecasts based on computer modeling? Are sea levels rising? and How will increases in carbon dioxide (a greenhouse gas) affect the world's plant life?

This backgrounder responds to these questions, which are being debated in the scientific community today, and provides a resource section for additional reading.

Are increases of man-made greenhouse gases contributing to global warming?

Scientists agree that the greenhouse effect is a real, naturally occurring phenomenon. Greenhouse gases trap the sun's warmth in the lowest layers of the atmosphere, keeping Earth warm enough to sustain life. Without the natural greenhouse effect, the average surface temperature on Earth would fall below zero Fahrenheit. Indeed, in the natural greenhouse effect, atmospheric water vapor and clouds play a far greater role than other greenhouse gases. To put this in perspective, even if all other greenhouse gases were to disappear, water vapor and clouds would still leave us with 98 percent of the current greenhouse effect.

Scientists also agree that atmospheric levels of greenhouse gases (such as CO2) are increasing as a result of human activity. But scientists differ on whether the increase in the concentrations of these gases will cause an "enhanced greenhouse effect," or warming of the planet, because the role of greenhouse gases in climate change is not well understood.

Issue #7: Methods of computing global mean temperatures and global mean temperature variations. This is a fundamental issue on which many people, even within the IPCC, are confused. IPCC scientists made it clear that there is no reliable global mean average temperature, since it depends on how one wants to define the mean and what data sets are used. Global mean temperature may vary from 10 to 15 C, depending on how its defined. Departures from the global mean temperature (the parameter generally discussed) is actually a quite complicated parameter to compute. Since "global temperature" trends (meaning deviations from the mean) are one of the central political issues, a clear understanding of how these numbers are derived would seem essential. I question if IPCC would ever want to attempt this, since all the explanation could do is decrease people's confidence in the numbers which they provide.

Issue #8: A clear and detailed explanation of the phrase "discernible human influence." is needed . The Synthesis Report states that the evidence for a discernible human influence comes from "changes in global mean surface air temperature and from changes in geographical, seasonal, and vertical patterns of atmospheric temperature." Missing from the IPCC report are the necessary graphs and statistics which support this point. During the plenary at Madrid, the explanation was offered that the current interpretation is based basically on "visual inspection of the data", leaving the interpretation totally up to the individual scientist making the statement. Clearly, a much more defensible and quantitative justification for this statement is needed.

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