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Preface

In 1997 the American Geophysical Union's (AGU) Committee on Global Environmental Change proposed that AGU develop a position statement on climate change. Over the next year, an AGU panel crafted a statement, while considering comments from members responding to a draft posted on AGU's Web site in early 1998. The AGU Council discussed, modified, and adopted a final statement in December of 1998. AGU published the statement, *Climate Change and Greenhouse Gases*, in *Eos* on February 2, 1999.

AGU position statements are intended primarily for nontechnical audiences. They are necessarily brief and lack references to the published scientific literature. The authors of this statement felt that a thorough review of the peer-reviewed scientific literature of climate change and greenhouse gases would help scientists and nonscientists understand the scientific basis for assertions made in the statement. Their article, which was itself rigorously peer reviewed, was published in *Eos* on September 28, 1999. This reprint also includes AGU's policy on advocacy of public issues, procedures for developing position statements, and the position statement itself. The full text of this reprint, with its list of references (not included in the printed version of *Eos*, due to space limitations) may also be found on the AGU Web site: http://www.agu.org/eos_elec/99148e.html.

Climate Change and Greenhouse Gases

Infrared (IR) active gases, principally water vapor (H_2O), carbon dioxide (CO_2), and ozone (O_3), naturally present in the Earth's atmosphere, absorb thermal IR radiation emitted by the Earth's surface and atmosphere. The atmosphere is warmed by this mechanism and, in turn, emits IR radiation, with a significant portion of this energy acting to warm the surface and the lower atmosphere. As a consequence the average surface air temperature of the Earth is about 30°C higher than it would be without atmospheric absorption and reradiation of IR energy [*Henderson-Sellers and Robinson*, 1986; Kellogg, 1996; *Peixoto and Oort*, 1992].

This phenomenon is popularly known as the "greenhouse effect," and the IR active gases responsible for the effect are likewise referred to as "greenhouse gases." The rapid increase in concentrations of greenhouse gases since the industrial period began has given rise to concern over potential resultant climate changes.

The AGU Council approved a position statement on Climate Change and Greenhouse Gases in December 1998. The statement and a short summary of the procedures that were followed in its preparation, review, and adoption were published in the February 2, 1999, issue of *Eos* (p. 49) [AGU, 1999, also at AGU's Web site]. The present article reviews scientific understanding of this issue, as presented in peer-reviewed publications. This understanding serves as the underlying basis of the position statement.

Greenhouse Gases and the Earth-Atmosphere Energy Balance

The principal greenhouse gas concentrations that have increased over the industrial period are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and chlorofluorocarbons CFC-11 (CCl_3F) and CFC-12 (CCl_2F_2) [*Hansen et al.*, 1998; *Schimel et al.*, 1996]. The observed increase of CO_2 in the atmosphere from about 280 ppm in the preindustrial era to about 364 ppm in 1997 (Figure 1) [*Friedli et al.*, 1986; *Hansen et al.*, 1998; *Keeling and Whorf*, 1998] has come largely from fossil fuel combustion and cement production.

These sources amounted to approximately 6.5 Pg C/yr (1 Pg = 10^{15} g) in 1996 [*Marland et al.*, 1999]. Land use changes produce a non-negligible but more uncertain contribution of about 1.6 ±1.0 Pg C/yr [*Fan et al.*, 1998; *Schimel et al.*, 1996]. These anthropogenic sources of CO_2 exceed the estimated uptake of CO_2 by the atmosphere and oceans, implying a significant but as yet unidentified terrestrial sink [*Enting and Pearman*, 1987].

The atmospheric concentration of CH_4 has increased from about 700 ppb in preindustrial times to about 1721 ppb in 1994 (Figure 1) [*Houghton et al.*, 1996]. Fossil-fuel related sources of CH_4 amount to approximately 70-120 Tg CH_4/yr (1 Tg = 10^{12} g). Increases in CH_4 sources resulting from rice cultivation, animal husbandry, biomass burning, and landfills contribute about 200-350 Tg CH_4/yr [*Schimel et al.*, 1996].

The atmospheric concentration of N_2O has increased from about 275 ppb in preindustrial times to about 312 ppb in 1994 (Figure 1) [*Houghton et al.*, 1996]. Estimated anthropogenic emissions of N_2O for the 1980s range from 3 to 8 Tg N/yr [*Houghton et al.*, 1996]. The main anthropogenic sources are from agriculture and industrial sources including adipic acid and nitric acid production [*Schimel et al.*, 1996].

Chlorofluorocarbons CFC-12 and CFC-11 are manmade compounds that were not appreciably present in the atmosphere before 1950 (Figure 1). These compounds have been widely used as refrigerants and in spray propellants and foam blowing. Because of their role in catalyzing decomposition of stratospheric ozone, production of these compounds has been dramatically reduced in response to the Montreal Protocols and subsequent international agreements. Atmospheric concentrations of these compounds are expected to diminish substantially during the next century [*Prather et al.*, 1996].

Prediction of the future persistence of anthropogenic greenhouse gases in the atmosphere is based on mathematical models that simulate future additions and removals. The greenhouse gas concentrations predicted by these models are subject to large uncertainties in the effects of both natural processes and human activities.

For some greenhouse gases persistence can be estimated from "mean residence times," which are obtained with simple linear models and represent the time that would be required for removal of 63% of the anthro- pogenic excess of the material in the atmosphere, if anthropogenic sources were abruptly diminished to zero [*Lasaga and Berner*, 1998]. This approach yields a rough measure of the persistence in the atmosphere of anthropogenic additions of CH_4 with an estimated mean residence time of 10 years [*Prather*, 1996, 1998]; N_2O, 100 years, [*Prather*, 1996, 1998]; and CFC-11 and CFC-12, 50 and 102 years, respectively [*Prather et al.*, 1995].

The persistence of anthropogenic CO_2 in the atmosphere cannot be estimated with such a simple model because exchange with the ocean and sediments leads to a more complex behavior. Model simulations of oceanic CO_2 uptake provide response times associated with CO_2 gas exchange at the ocean surface of approximately 10 years [*Liss and Merlivat*, 1986; *Toggweiler et al.*, 1989] and downward mixing of surface waters on the order of decades to centuries [*Maier-Reimer and Hasselmann*, 1987; *Sarmiento et al.*, 1992]. But even when these oceanic CO_2 removal processes are allowed sufficient time in the models to reach their maximum capacity, they can remove

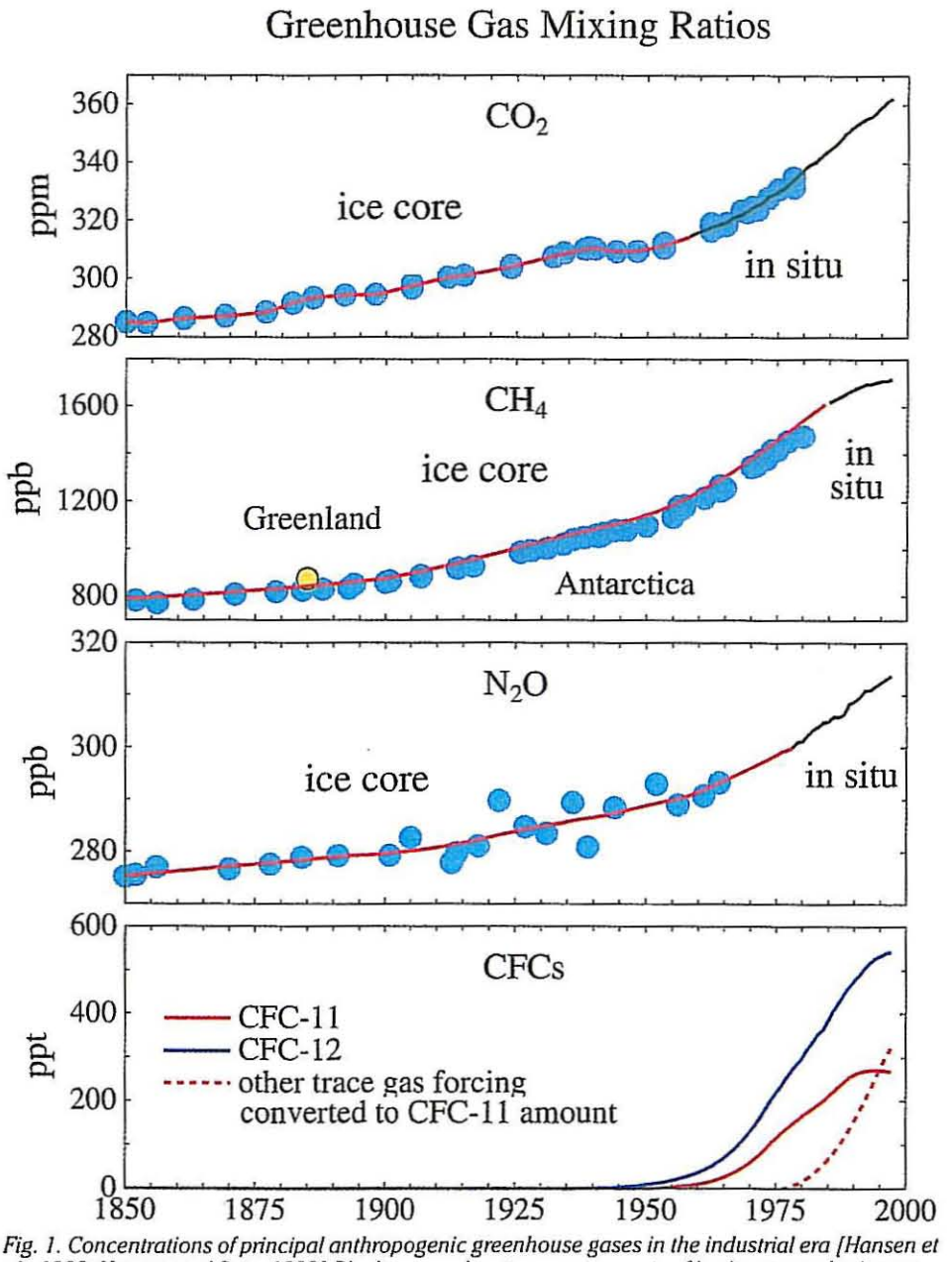

Fig. 1. Concentrations of principal anthropogenic greenhouse gases in the industrial era [Hansen et al., 1998; Hansen and Sato, 1999] Black curves denote measurements of in situ atmospheric samples collected in recent years [NOAA, 1999a, b, c; Houghton et al., 1995]. Points denote concentrations determined from air bubbles trapped in polar ice sheets using ice cores obtained in Antarctica (blue) or Greenland (yellow); red curves denote fits to these points [Etheridge et al., 1996, 1998; Machida et al., 1995]. Data for CFCs are from in situ samples since 1977 [NOAA, 1999d]. Mixing ratios of CFC-11 and CFC-12 prior to the first in situ atmospheric measurements were estimated from industrial production data and assumed atmospheric lifetimes of 50 and 100 years, respectively [AFEAS, 1993; Hansen et al., 1998; Hansen and Sato, 1999].

only about 70 to 85% of the anthropogenic CO_2 added to the atmosphere [*Archer et al.*, 1998; *Broecker and Peng*, 1982; *Sarmiento et al.*, 1992].

Additional CO_2 might be removed by burial in soils or deep sea sediments through mechanisms that, although poorly understood, are generally believed to require times extending to thousands of years [*Harden et al.*, 1992; *Schlesinger*, 1990; *Stallard*, 1998]. Removing some of the anthropogenic CO_2 by this mechanism may require reactions with carbonate sediments in the deep sea that occur on timescales of thousands of years [*Archer et al.*, 1998; *Boyle*, 1983; *Sundquist*, 1990]. On the basis of such analyses, it is now generally believed that a substantial fraction of the excess CO_2 in the atmosphere will remain in the atmosphere for decades to centuries, and about 15-30% will remain for thousands of years.

The additional anthropogenic greenhouse gases that have been introduced into the atmosphere increase the IR energy absorbed by the atmosphere, thereby exerting a warming influence on the lower atmosphere and the surface, and a cooling influence on the stratosphere [*Peixoto and Oort*, 1992; *Ramanathan et al.*, 1985].

The radiative influence resulting from a given incremental increase in greenhouse gas concentration can be quantified and compared as the change in downward IR flux at the tropopause, a quantity known as the radiative forcing. Climate model calculations indicate that to good approximation the global warming influence of the several greenhouse gases is equal for equal forcing [*Wang et al.*, 1991, 1992], lending support to the utility of the concept of climate forcing and response.

Of the several anthropogenic greenhouse gases, CO_2 is the most important agent of potential future climate warming because of its large current greenhouse forcing, its substantial projected future forcing [*Houghton et al.*, 1996], and its long persistence in the atmosphere (see above). Understanding climate response to a specified forcing is one of the major challenges facing the climate research community. The equilibrium response of the nonlinear climate system depends in complex ways on various feedbacks, such as changes in water vapor concentration and cloudiness that can augment or diminish climate response from that which would occur in the absence of such feedbacks.

In principle, empirical inferences of climate sensitivity would be of great value, but development of such inferences is confounded by the natural variability of the climate system [*Santer et al.*, 1996], by local or regional effects that can be different from the global effects, and by the simultaneous working of multiple transient forcings and responses. For these reasons a principal means for understanding climate system response to forcing is by use of computer models of the Earth's climate system.

Climate Change and Carbon Dioxide

The most commonly considered indicator of climate change is the surface air temperature. Extensive efforts have been made to examine the trends in global and regional mean temperatures over time [*Ghil and Vautard*, 1991; *Hasselmann*, 1993; *North and Kim*, 1995; *North et al.*, 1995; *Schlesinger and Ramankutty*, 1994] and in the global patterns of temperature change [*Hegerl et al.*, 1997; *Hegerl et al.*, 1996; *Jones and Hegerl*, 1998; *Santer et al.*, 1995].

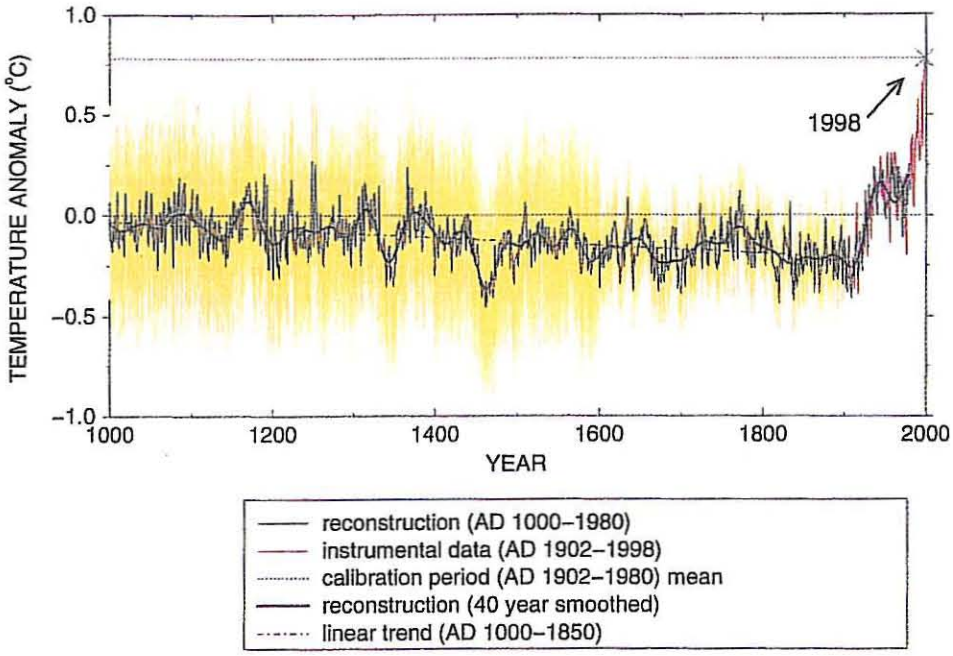

Fig. 2. Reconstruction of Northern Hemisphere temperature anomaly trend from 1000 A.D. to present [Mann et al., 1999; see also Mann et al., 1998] from dendroclimatic, coral, and ice-core proxy records as calibrated by instrumental measurements [Jones and Briffa, 1992]. Thin curves give reconstruction and raw data from 1000-1998 A.D. Smoothed version (thick solid), linear trend from 1000 to 1850 A.D. (long dashed), and two standard error limits (shaded) are also shown.

Worldwide temperature measurements, carefully screened for instrumental and measurement artifacts, such as effects of urbanization, have been used to estimate that global mean annual surface temperatures have increased between 0.3 and 0.6°C during the last 150 years [*Hansen and Lebedeff*, 1987; *Jones et al.*, 1997; *Nicholls et al.*, 1996]. However, it must be stressed that the increase has not been monotonic, with interannual fluctuations in the global annual mean temperature equal to an appreciable fraction of the overall rise over this time period. No single explanation can account for this variability.

Although temperature is usually the first variable considered in assessments of global climate change, it is important to consider other data that integrate the state of the climate system over space and time. These include temperature proxy data (such as tree ring records), borehole temperature measurements in soil, permafrost, and ice sheets, and measurements of the mass balance of valley glaciers and ice caps. Several recent proxy temperature reconstructions have suggested that the warming during the twentieth century is greater than any seen in the last 400 to 600 years [*Briffa et al.*, 1998; *Jones et al.*, 1998; *Mann et al.*, 1998; *Overpeck et al.*, 1997] and perhaps the last 1200 to 1500 years (Figure 2) [*Overpeck*, 1998; *Thompson et al.*, 1993]. A completely independent estimate [*Pollack et al.*, 1998], based on analysis of subsurface (borehole) temperature measurements, supports the unusual character of the recent global warming in the context of the last 5 centuries.

Glaciers are present on every continent except Australia; they are thus excellent geographically dispersed regional indicators of climate change. The Earth's valley glaciers, ice caps, and ice fields and their associated outlet glaciers have generally been shrinking and receding during the last century [*Haeberli*, 1990; *Meier*, 1984; *Oerlemans*, 1994]. Studies in North America [*Hall et al.*, 1992; *Marcus et al.*, 1995; *Rabus et al.*, 1995; *Williams and Ferrigno*, in press], South America [*Thompson et al.*, 1995; *Williams and Ferrigno*, 1998], Europe [*Williams and Ferrigno*, 1993; *Bayr et al.*, 1994; *Haeberli and Hoelzle*, 1995], Iceland [*Johannesson and Sigurðsson*, 1998], Africa [*Hastenrath*, 1989; *Williams and Ferrigno*, 1991], and Asia [*Thompson et al.*, 1989, 1993, 1998] have shown substantial recession of many of the ice caps and nontidewater, nonsurge-type glaciers [*Dyurgerov and Meier*, 1997] since the early nineteenth century.

The record of the past few thousand years is more difficult to piece together than the more recent record because fewer data are available. There is evidence from this period that climatic conditions were sometimes warmer and sometimes cooler than at present [*Dahl-Jensen et al.*, 1998; *Feng and Epstein*, 1994; *Prentice et al.*, 1998].

There is also evidence of large and abrupt climate changes that exceed recent experience [*Bond et al.*, 1997; *Denton and Karlen*, 1973; *Gasse and Vancampo*, 1994; *Laird et al.*, 1996; *Petitmaire and Guo*, 1996; *von Grafenstein et al.*, 1998]. These climatic variations occurred during a time when variations in atmospheric CO_2 were minimal [*Barnola et al.*, 1995; *Indermuhle et al.*, 1999].

It is clear from these records, and from many other studies of paleoclimate evidence throughout the geologic record, that the global climate system has been influenced by many factors in addition to greenhouse gases [see, for example, *Berger and Crowell*, 1982]. To evaluate geologic evidence for the influence of greenhouse gases, one must focus on records from periods when changes in atmospheric CO_2 were much larger than those that occurred during the millennia immediately preceding the recent increase in anthropogenic CO_2 production.

Larger natural variations in atmospheric CO_2 have been inferred from the geologic record of the more distant past [for an overview, see *Sundquist and Broecker*, 1985]. Variations of 80-100 ppm, observed in analyses of gas bubbles trapped in glacier-ice cores, are correlated with the glacial ("ice age") and interglacial climatic oscillations of the latest Pleistocene and Holocene Epochs (Figure 3; [*Barnola et al.*, 1987; *Berner et al.*, 1980; *Jouzel et al.*, 1993; *Wahlen et al.*, 1998]). Glacial periods are associated with low CO_2 concentrations, and interglacial periods with high CO_2 concentrations. Ice core methane profiles show a similar correlation with climate [*Chappellaz et al.*, 1990; *Delmotte et al.*, 1998; *Jouzel et al.*, 1993; *Stauffer et al.*, 1988].

Still larger past variations in atmospheric CO_2, including increases to concentrations several times higher than recent levels, have been estimated using geochemical models constrained by the sediment record [*Berner*, 1994, 1997; *Berner et al.*, 1983; *Budyko and Ronov*, 1979; *France-Lanord and Derry*, 1997; *Francois and Godderis*, 1998; *Raymo et al.*, 1988]. During the last several hundred million years, these larger and slower CO_2 changes can be correlated with general features of climate change [*Berner*, 1990; *Crowley and North*, 1991; *Fischer*, 1981].

Paleoclimate model simulations (using models similar in many ways to the models used in modern climate projections) support the importance of CO_2 in explaining global mean temperatures in the geologic past [*Berger et al.*, 1998; *Bush and Philander*, 1997; *Kasting and Ackerman*, 1986; *Ottobliesner*, 1996; *Tarasov and Peltier*, 1997; *Weaver et al.*, 1998].

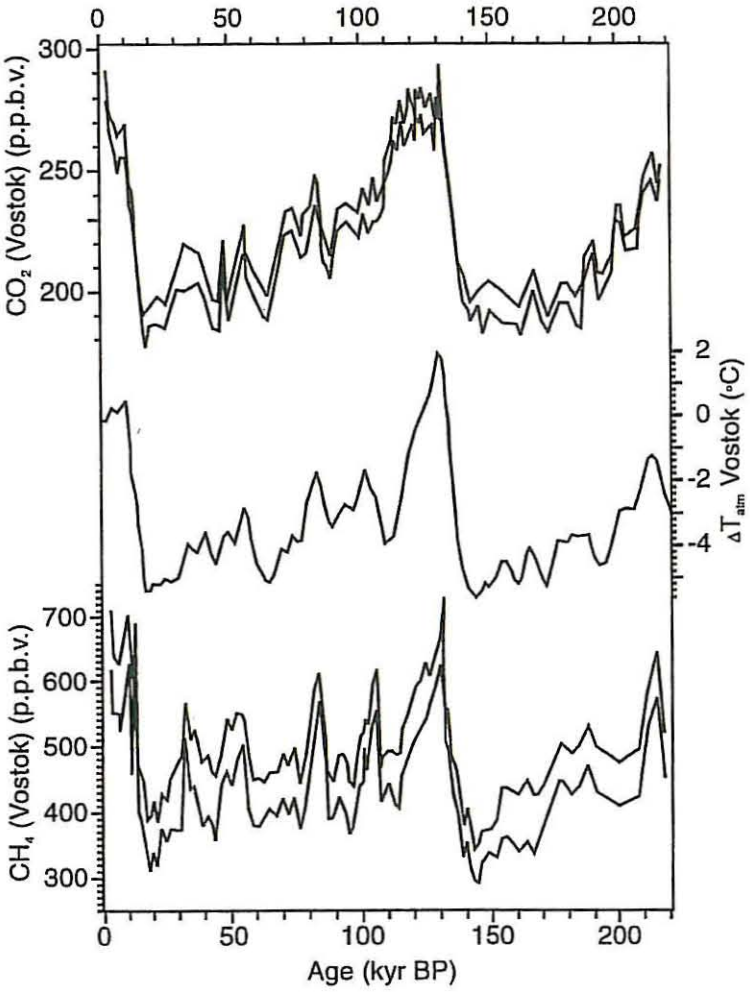

Fig. 3. Carbon dioxide concentration (top), proxy temperature (middle), and methane concentration from analyses of ice cores from Vostok, Antarctica [Jouzel et al., 1993].

Model simulations have also shown the importance of changes in other climate controls, for example the configuration of Earth's orbit [*Berger and Loutre*, 1997; *Kutzbach et al.*, 1988] and the geographical distribution and elevation of continental areas [*Barron*, 1985; *Kutzbach et al.*, 1989].

Significant gaps remain in understanding the relationships among these diverse climatic influences. However, the prevailing paradigm in paleoclimate research treats the radiative effects of atmospheric CO_2 as an integral component in a complex system of many variables and interactive influences on global climate.

The complexity of the long-term coupling of CO_2 and climate is enhanced by the extent to which climate variability is hypothesized to have influenced past atmospheric CO_2 concentrations. Glacial/interglacial CO_2 variations during the Pleistocene epoch appear to have involved a combination of changes in global carbon cycling that were probably driven by some aspect of climate change [*Boyle*, 1988; *Broecker*, 1982; *Broecker and Henderson*, 1998; *Crowley*, 1995; *Heinze et al.*, 1991; *Shackleton*, 1977; *Sundquist*, 1993]. Likewise, for timescales of millions of years and longer, atmospheric CO_2 appears to have been affected by the influence of climate on weathering and erosion rates [*Berner*, 1990, 1994; *Berner et al.*, 1983; *Walker et al.*, 1981].

Thus current interpretation of the geologic record suggests that greenhouse gases both respond and contribute to climate change. Atmospheric CO_2 is viewed as one of many components of the climate system that interact in complex ways over a wide range of timescales. A change in one of these interactive components is likely to affect other aspects of the global climate system. This interactive relationship between CO_2 and climate implies that the geologic record is not likely to reveal analogs of simple climate forcing by anthropogenic CO_2 emissions [*Crowley*, 1997; *Hay et al.*, 1997; *Sundquist*, 1986]. There is no known geologic precedent for large increases of atmospheric CO_2 without simultaneous changes in other components of the carbon cycle and climate system.

Predicted Climate Change from Increased Greenhouse Gases

Some of the predicted responses to increases in greenhouse gases include increases in mean surface air temperature, increases in global mean rates of precipitation and evaporation, rising sea level, and changes in the biosphere. Many of these predictions are based largely on computer models that simulate fundamental geophysical processes.

Most model simulations of Earth's climate indicate that an increase in the atmospheric concentration of a greenhouse gas will lead to an increase in the average surface air temperature of the Earth [*Kattenberg et al.*, 1996, table 6.3]. For example, the 18 model runs (using 7 independent models) quoted by Kattenberg et al. predict an equilibrium temperature increase of 2.0 ± 0.6°C for simulations using double the current level of atmospheric CO_2.

An increase in surface air temperature would cause an increase in evaporation and generally higher levels of atmospheric water vapor. The positive feedback associated with this leads to the expectation that an increase in surface air temperatures would lead to a more intense hydrological cycle, with more frequent heavy precipitation events [*Houghton et al.*, 1992; *Kattenberg et al.*, 1996]. However, because of the coarse spatial resolution of present general circulation models, simulations of the regional and seasonal distribution of precipitation are poor [*Kattenberg et al.*, 1996].

Another possible consequence of greenhouse-gas-induced climate change is elevated sea level. The main factors that contribute to sea level rise are thermal expansion of ocean water and the melting of glaciers, both of which are in response to higher air temperatures. Although it has been well established that meltwater from the world's small glaciers has contributed to sea level rise during the last century [*Dyurgerov and Meier*, 1997; *Meier*, 1984], the mass balance of the ice sheets in Greenland and Antarctica is unknown. However, recent geodetic airborne laser altimeter measurements indicate that between 1993 and 1998 the southeastern part of the Greenland ice sheet thinned overall, with a thickening at a rate of 0.5 ± 0.7 cm/yr at elevations above 2000 m (not corrected for crustal motion) and a thinning at the low elevations at rates up to 1 m/yr [*Krabill et al.*, 1999].

Worldwide measurements from tidal gauges during the last 100 years indicate that mean sea level has risen between 10 and 25 cm (18 cm mean) [*Douglas*, 1991, 1992; *Gornitz*, 1995; *Warrick et al.*, 1996]. This rate is greater than would be expected from the archaeological and geological record of sea level from the last two millennia [*Warrick et al.*, 1996]. Most modeling studies, including simulations of the combined effects of increasing greenhouse gases and aerosols, predict that the trend in rising sea level will continue in the future [*Titus and Narrayanan*, 1995; *Warrick and Oerlemans*, 1990; *Warrick et al.*, 1996; *Wigley and Raper*, 1992, 1993].

A possible biological effect may be seen in evidence that there has been an increase in the active growing season at high latitudes in the Northern Hemisphere [*Keeling et al.*, 1996; *Myneni et al.*, 1997].

Predictive Capabilities and Uncertainties

The models that have been used to study climate change are necessarily simplified representations of the climate system. Despite the inevitable limitations, climate model simulations accurately reproduce the large-scale seasonal distributions of pressure and temperature. In addition, the large-scale structure of precipitation and ocean surface heat flux also closely resembles the observed estimates [*Gates et al.*, 1998].

Confidence in models is also gained from their emerging predictive capability. An example of this capability is the development of a hierarchy of models to study the El Niño-Southern Oscillation (ENSO) phenomena [*Neelin and Latif*, 1998]. These models are becoming capable of predicting sea surface temperature anomalies in the tropical Pacific 6 to 12 months in advance [*Latif et al.*, 1998]. The models cannot predict specific storms related to ENSO, but they can predict the lower frequency responses of the climate system, such as anomalies in monthly and seasonal averages of the sea surface temperatures in the tropical Pacific [*Neelin and Latif*, 1998].

Despite these gains there are a number of features of the climate system that are still rather crudely represented in climate models. The coarse resolution of these models (typically 3° or roughly 300 km) restricts their ability to accurately represent terrain effects and to simulate processes that occur on smaller scales. Other shortcomings occur in the representation of aerosols, precipitation, and clouds and changes in solar irradiance. For these and other reasons there remain substantial scientific uncertainties in model predictions, including uncertainties in the predictions of local effects of climate change, occurrence of extreme weather events, effects of aerosols, changes in clouds, shifts in the intensity and distribution of precipitation, and changes in oceanic circulation [*Hansen et al.*, 1998; *Houghton et al.*, 1996; *Mahlman*, 1997].

A principal source of uncertainty in modeling climate change during the industrial period arises from uncertainties in the representation of the influence of anthropogenic aerosols. Aerosols scatter and absorb short wave (solar) radiation and modify the reflectivity of clouds. Both effects are thought to decrease the absorption of short wave radiation by the Earth, exerting a cooling influence on climate, despite the fact that tropospheric aerosols are short lived in the atmosphere (a few days) [*Charlson et al.*, 1992; *Kaufman and Fraser*, 1997; *Twomey et al.*, 1984; *Haywood et al.*, 1999].

Recent climate modeling studies which include the effects of aerosols [*Hasselmann*, 1997; *Hegerl et al.*, 1997; *Houghton et al.*, 1995; *Kattenberg et al.*, 1996; *Mitchell et al.*, 1995; *Roeckner et al.*, 1996] show improved comparisons between the simulated and observed global temperature trends during the industrial period. However, given the present large uncertainties in aerosol forcing, such improvement may only be fortuitous.

An additional uncertain contribution to radiative forcing of climate change during the industrial period arises from possible changes in solar irradiance. Based on reconstructions of solar irradiance and climate response in the preindustrial era, together with instrumental records and solar observations during the industrial period, Lean and Rind [1998] estimate that solar forcing may have contributed about half of the observed surface warming since 1900.

Uncertainties regarding clouds and the hydrological cycle and their representation in climate models also introduce uncertainty into present understanding of the response of the climate system to increases in atmospheric greenhouse gases. It has been indicated in model calculations that warming in the lower atmosphere as a result of greenhouse gases would increase the abundance of water vapor in the atmosphere and intensify the hydrologic cycle [*Gates et al.*, 1992; *Kattenberg et al.*, 1996].

These changes might be expected to lead to an enhancement of cloudiness. Clouds reduce the net absorbed short wave radiation in the climate system because of their high reflectivity (a cooling influence); however, they also radiate energy back down to the surface and lower atmosphere (a warming influence). The overall effect of these opposing influences is a net cooling [*Ramanathan et al.*, 1989] although this varies regionally, with cloud type, and with geography. The question of whether average cloudiness would be increased or decreased in a greenhouse-enhanced world is not yet established. Issues such as these contribute to the present uncertainty in climate sensitivity.

Summary

In summary, the atmospheric concentrations of the principal anthropogenic greenhouse gases (CO_2, CH_4, N_2O, CFC-11, and CFC-12) have increased significantly during the industrial period. Elevated concentrations are predicted to persist in the atmosphere for times ranging to thousands of years. The increased atmospheric levels of these gases, especially CO_2, increase the IR energy absorbed by the atmosphere, thereby producing a warming influence at the Earth's surface.

Global mean temperatures have increased between 0.3 and 0.6°C during the last 150 years. This change has not been monotonic, but it is unusual in the context of the last few centuries. On the timescale of the last few thousand years there have been larger climatic variation during times when variations in CO_2 have been relatively low. It is clear that atmospheric CO_2 is not the only influence on global climate. However, there have been large natural variations of CO_2 in the geologic past, and these changes are correlated with general features of climate change. There is no known geologic precedent for large increases of atmospheric CO_2 without simultaneous changes in other components of the carbon cycle and climate system.

Changes in the climate system that are confidently predicted in response to increases in greenhouse gases include increases in mean surface air temperature, increases in global mean rates of precipitation and evaporation, rising sea level, and changes in the biosphere. Substantial uncertainties remain in the magnitudes and geographical distribution of these changes and in the rates at which they may be expected to occur. The significant recent progress in the scientific understanding of climate change and the uncertainties in predictions of climate change are documented in the peer-reviewed literature. Peer-reviewed scientific research provides the scientific basis for the AGU position statement on Climate Change and Greenhouse Gases and must continue to be utilized in informed decision making on this issue.

The complete listing of references, along with the article and figures, may be obtained at Web site: http://www.agu.org/eos_elec/99148e.html.

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