WATER, AIR, AND SOIL POLLUTION

VOLUME 12 No. 1 JULY 1979

AN INTERNATIONAL JOURNAL OF ENVIRONMENTAL POLLUTION

Editor: Billy M. McCormac (Palo Alto, California, U.S.A.)

THIS ISSUE CONTAINS PAPERS PRESENTED AT THE SIXTH ENVIRONMENTAL SYMPOSIUM. MAN'S INFLUENCE ON THE CLIMATE

D. REIDEL PUBLISHING COMPANY

DORDRECHT-HOLLAND/BOSTON-U.S.A.

ISSN 0049-6979

WATER, AIR, AND SOIL POLLUTION

An International Journal of Environmental Pollution

VOLUME 12

D. REIDEL PUBLISHING COMPANY

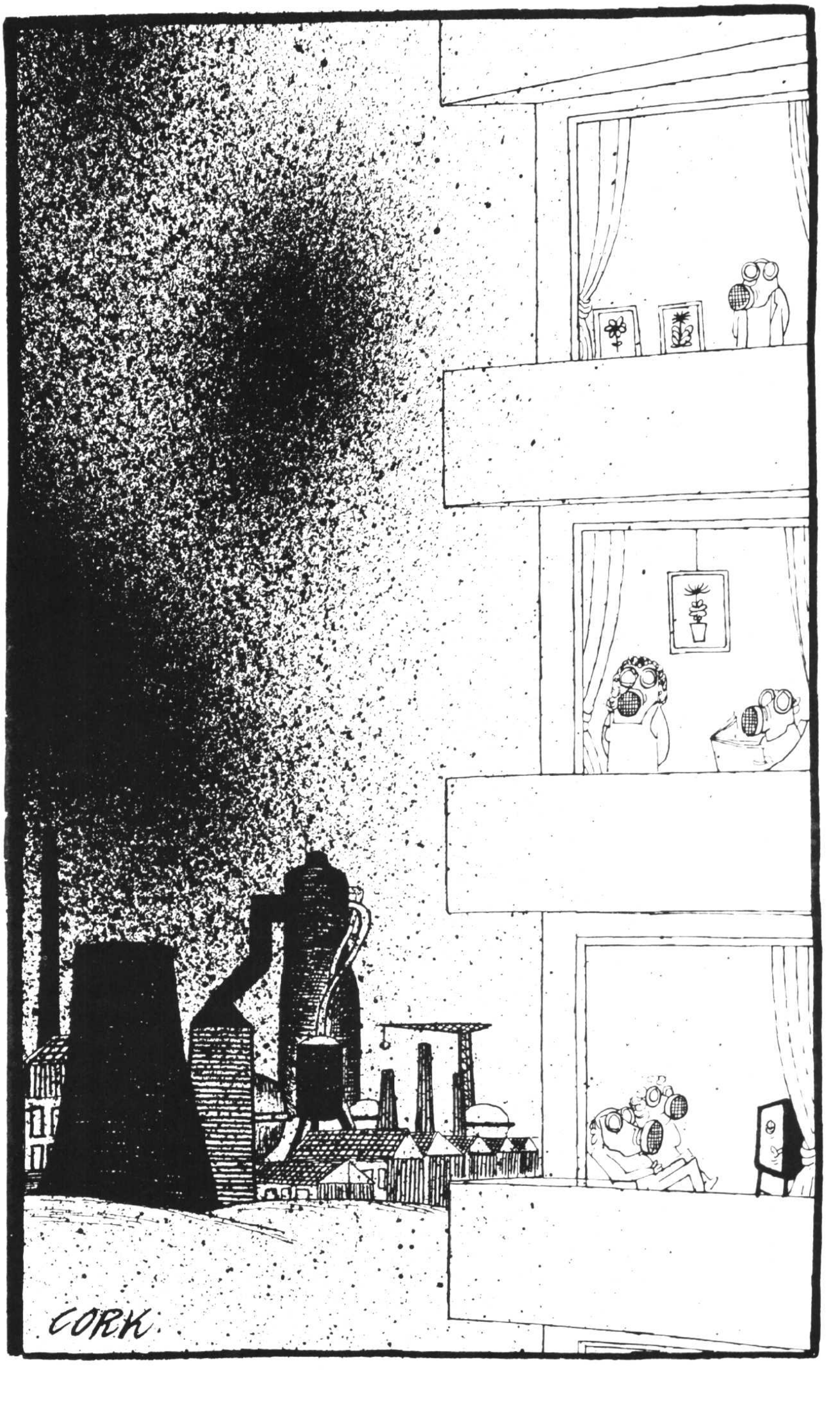
DORDRECHT : HOLLAND / BOSTON : U.S.A.

ISSN 0049-6979

Printed in The Netherlands

WATER, AIR, AND SOIL POLLUTION

Volume 12 No. 1 1979


CORK

Sixth Environmental Symposium

MAN'S INFLUENCE ON THE CLIMATE

COMMITTEE

General Chairman: Art Bayce, IES, Safety Specialists, Inc.
Donald Blackwell, SAE, FMC Corporation
Ronald Costella, SAE, FMC Corporation
Harold H. Greenfield, AIChE, Lockheed M&S Co.
Robert Kiang, ASME, SRI International
Stanley Kulakow, ASCE, Creegan & D'Angelo
Shirley B. Radding, ACS, SRI International
Edward V. Stearns, AIAA, Lockheed M&S Co.
Ross Westover, ACS, Canada College

SPONSORS

Local Northern California and San Francisco Bay Area Sections of:
American Chemical Society
American Institute of Aeronautics and Astronautics
American Institute of Chemical Engineers
American Society of Civil Engineers
American Society of Mechanical Engineers
Institute of Environmental Sciences
Society of Automotive Engineers

SIXTH ENVIRONMENTAL SYMPOSIUM

Man's Influence on the Climate

Chairman's Summary

ARTHUR E. BAYCE

IES, Safety Specialists, Inc., 3284 F. Edward Avenue, Santa Clara, CA 95050 U.S.A.

Climate has always affected the activities of mankind. However, it is becoming more and more evident that man himself has entered the loop and, by his activities, is contributing to changes in climates, often to his detriment.

The purposes of this symposium were not only to examine man's global, industrial and agricultural activities as they affected world and local climates, but also to identify which of these constituted problems in our present day and future worlds. Most important, it is hoped that the suggestions and conclusions drawn here will stimulate further thinking so that some solutions may be developed to resolve these problems.

The keynote address presented by Dr. Robert C. Fleagle (Department of Atmospheric Sciences, University of Washington, Seattle), covers several areas. One is the recent advances in techniques that will add to our knowledge about climate: core sampling; satellite measurements of albedo; and numerical models that simulate climate changes. He emphasizes the point that climate should be considered a *resource* and that we need to reduce our uncertainty in our knowledge of climate and the mechanism of change, so that we can take some rational actions. He also suggests that the concept of property rights may be applied to climate; that is, to be the property of a nation, or of the world. In discussing regional effects he pointed out that an increase in average temperature goes with an increase in population density.

The first session, *The Effects of the Physical Environment on Climate*, chaired by Dr. John P. Monteverdi (San Francisco State University, San Francisco) covers topics of a tutorial nature to provide a basis for the discussions of the following sessions.

Dr. Peter Lester (Department of Meteorology, San Jose State University, San Jose) in his discussion on *Global Patterns of Temperature and Development of the General Circulation* covers the planetary general circulation, its characteristics and causes. He gives a detailed discussion on the effects of various types of radiation, the heat balance, and the temperatures distribution over the earth.*

Dr. Steven Pease (Department of Meteorology, San Francisco State University, San Francisco) on the *Impact of Certain Urban Areas Upon Mesoscale Radiation Budgets; Implications for Local Climate Change* discusses the feasibility of solar radiation systems. He discusses surface effects including that of the composition of urban surfaces, the geometry (which affects long and shortwave radiation), and the surface water. The different effects on shortwave radiation by the central core of a city *vs* that of the suburbs *vs* that of the countryside is brought out.*

Water, Air, and Soil Pollution **12** (1979) 5–7. 0049-6979/79/0121-0005$00.45

Mr. Michael Basso (Bay Area Quality Management, San Francisco) discusses *Inversions and Their Importance in Air Quality.* Three types of inversions are discussed including subsidence which is the most important, followed by radiation inversion and sea breeze inversion.*

Mr. Joel Michaelson (Department of Geography, University of California, Berkeley), in the *Impact of the North Pacific Ocean on Circulation Patterns Over the Far West,* relates the winter reason anomalies in the far west as influenced by ocean surface temperatures.*

Mr. Joel Bartlett (KPIX–TV, San Francisco) covers *Environmental and Legal Considerations in Weather Modification Activities.* In recent times there has been an increase in cloud seeding activities. Typical problems that may be caused by cloud seeding include flooding and down range effects.

The second session on *Man's Global Activities as They Impact Climate* was chaired by Dr. Larry W. Tombaugh (Department of Forestry, Michigan State University, East Lansing, Michigan). He briefly discusses the effects of deforestations which is equivalent to the global release of CO_2 by fossil fuels.

Dr. Charles Keeling (Scripps Institute of Oceanography, La Jolla, California) detailed various aspects of the question: *Will CO_2 Build-up Continue to Occur and Cause Global Warming?* The amount of CO_2 produced by man is ten times that of natural occurrences. Assuming no sinks, this could raise the mean temperature by 2 to 3°C. We could anticipate the amount of CO_2 to double in 50 years. If it became 4 to 8 times as much, we would have very high temperatures. It could disturb deep water circulation. The problem is enhanced by population increase. At La Jolla, a Reservoir Box Model has been developed. This includes three divisions, the atmosphere, the oceans and land. The oceans are divided into surface layers and sub-surface layers, the land biota into short and long term materials, that is, materials that break down readily and those that require a longer time. The chemistry of the oceans has an important influence on the CO_2 balance. Though 10% of the carbon in ocean water is in the form of carbonate and the balance is in the form of bicarbonate, it is the carbonate that reacts with the CO_2 in the air to form bicarbonate. The alkalinity of the ocean needs to be measured – this is the only independent variable.*

Dr. Owen B. Toon, (Ames Research Center, NASA, Moffett Field, California) detailed the *Effects of Stratospheric Aerosols.* These include natural aerosols such as those put forth by volcanoes which inject sulfuric acid and sulfates into the troposphere. Their effects may be felt up to two years after an eruption. The man-made aerosols include Al_2O_3 introduced by space shuttles, sulfur gas and carbon soot by supersonic aircraft, SO_2 and CO_2 by coal burning and industrial processes. COS was discovered only a few years ago; no one knows its origin.*

Dr. Frederick G. Sawyer (Environmental Consultant, Irvine, California) gives his views on the consequences of over-regulation and the actions of industry and government.

The Third Session was chaired by Dr. Stanley Greenfield (Teknetron, Berkeley, California) and covers *Industrial Activities and Their Impact on Climate.*

Dr. Hanwat B. Singh (SRI International, Menlo Park, California) presents in his paper, *Industrial Pollutants and the Global Atmosphere: Possible Effects on Climate,* gives a discussion of pollutants in lower concentrations such as halocarbons, hydrocarbons, SF_6 and N_2O which may have an effect far beyond that expected from their concentrations because of their catalytic effects.*

Dr. L. Randall Koenig (Rand Corporation, Santa Monica, California) in his paper *Anthropogenic Influences on Weather and Climate on the Metropolitan Scale,* discusses how various industrial plants with their cooling towers and other engineering structures affect the climate in the immediate area and downwind from the installations.

Dr. Robert W. Bergstrom (Systems Applications Inc., San Rafael, California) discusses *The Roles of Modeling in Examining the Impact of Pollutant Emissions on Climate.* Since one cannot put the earth in a laboratory it is difficult to verify models. There is a need for models to similate conditions. The existing global models can predict significant changes but one cannot be sure that they are real. Local models may be accurate, but are they significant?*

The Fourth Session, chaired by Dr. J. Y. Wang (Department of Meteorology, San Jose State University, San Jose, California), discusses *Agricultural Activities Affecting Weather and Climate.*

Dr. Jerry L. Hatfield (Department of Meteorology, University of California, Davis, California) reviews the *Soil-Plant-Atmosphere Complex,* in which he emphasizes the importance of proper soil management. The effects of erosion are more than poor crop production. The changes in the surface energy budget can change the local climate.

Dr. Catherine M. M. Felton (Department of Meteorology, San Jose State University, San Jose, California) considers the importance *Water Usage and Microclimate* on agricultural systems. This includes the effects of various types of irrigation including the overhead and drip systems.

Dr. J. Y. Wang, the session chairman, presented a paper on the *Effects of Agrochemicals on Weather and Climate.* In his discussion he stressed the importance of using proper monitoring equipment in making measurements. The reliability of instruments used in obtaining data must be high or the findings deduced from the data would be inaccurate.

*Contribution does not appear here.

THE IMPACT OF MAN ON CLIMATE

ROBERT G. FLEAGLE
Department of Atmospheric Sciences, University of Washington, Seattle, WA 98195, U.S.A.

(Received 8 February, 1979)

Abstract. In the past decade the realization has grown that (a) our society is becoming increasingly vulnerable to fluctuations in climate, and (b) human activities may have important influences on climate in coming years. The effects of steadily increasing use of fossil fuels seem likely to be most serious through increasing atmospheric concentration of CO_2 and raising the temperatures of the global atmosphere. Also, introductions of chlorofluoromethanes and NO_x into the stratosphere either by transport and diffusion from the surface or by jet or rocket exhaust in the stratosphere may lead to depleting the Earth's O_3 shield and to significant effects on climate and health.

Regional influences on the large scale climate are highly uncertain but should not be dismissed lightly. Such influences include the effects of release of large quantities of heat from urban areas or from 'power parks', large irrigation or desalination projects, and extensive forest clearing. Injection into the atmosphere of particles and gases from industry, vehicles, and homes affects the atmosphere in a variety of ways and may result in regional changes in climate.

1. Introduction

A highly important property of climate is that it is always changing. This is not a new statement. Ice ages of the remote past, the settlement of Greenland in the Middle Ages, and the mid-western dust-bowl of the 1930's are a few of the prominent markers in a continuous sequence of changing climates which have been known for many years. However, in the past decade the interest of the public, of government, and of the scientific community in the subject of climate change has expanded greatly, and important new activities are occurring. What accounts for the sudden interest in climate change? Several factors operating together are important.

First, great progress has been made in the ability to observe and measure climate and to investigate possible mechanisms of climate change. For the first time it is possible to talk reasonably about various theories of climate change. Important advances which have brought this about are (a) analysis of long cores taken from ocean sediments and from Greenland and Antarctic ice which provide quantitative data on certain climatic variables; (b) development of satellites capable of measuring changes in radiation received from the Sun and reflected and emitted from the Earth; (c) the demonstration that numerical models are capable of simulating present climate and, presumably, climate change.

The second factor is new evidence that human activities throughout the world are affecting climate in a variety of ways. These effects probably have not been larger than the climate changes occurring from natural causes, and therefore up to the present it has been hard to distinguish the anthroponomic signal from the natural noise. However, the prospect is that human effects will increase markedly as world population and per capita

Water, Air, and Soil Pollution 12 (1979) 9–21. 0049–6979/79/0121–0009 $01.95

energy consumption continue to increase; and therefore prudence demands that we examine what we may be doing to the climate so that appropriate measures may be taken in time if that should be necessary. There is evidence, too, that in certain respects the atmosphere may be more sensitive to small effects than had formerly been recognized. So, simple order of magnitude comparisons could be quite misleading in assessing the importance of small changes.

The third of the factors responsible for the growing interest in climate is the increasing awareness of the vulnerability of our society to climate changes, resulting from growing technological complexity and interdependence. For example, a comparatively minor seasonal and regional drought in the Soviet Union in 1972 resulted through the world trade market in a dramatic rise in the world price of wheat. And the occurrence of *El Nino* in the waters off the coast of Peru, influenced significantly by changes in the air flow over the eastern equatorial Pacific, has resulted in drastic drops in the Peruvian fish catch and in the economy of that country. There are many other examples, including cold periods in Brazil which result in rising coffee prices, and severe winters in the eastern United States which cause fuel shortages and industrial shut-downs over a wide area. In fact, it can be observed that, though it was never planned, we have developed our technological society in such a way that such vital commodities and services as agricultural production, water resources, food and fuel supplies, police and fire protection, health services, and transportation and communication are precariously balanced on the unchanging state of the weather and climate we call 'normal'. Yet, records tell us that highly abnormal weather occurs frequently and that the long-term statistics of the daily weather, which we call climate, change continuously.

The impacts of abnormal weather and climate depend upon the resilience of the social system to a particular atmospheric event, and, of course, resilience depends upon many factors including population density, available storage, complexity of production and distribution systems, and governmental responsiveness. Resilience, therefore, may be greatly different for different populations, different regions and different social systems.

2. Climate as a Resource

Another change in perspective has occurred in the past decade, largely within the debate which has swirled around the National Climate Program Act which became law last September 17. This is the recognition that substantial economic and social benefits can be achieved by using knowledge of the spatial and temporal changes in climate. This new perspective was cogently presented by Roger Revelle and discussed at the International Workshop on Climate Issues in April 1978 at Laxenburg, Austria (reported in a report of the Climate Research Board, 1979). There it was recognized that, like water or land, we make use of differences in climate to realize economic benefits. For example, two farms which are identical except that they are so located that they experience different climates may have quite different property values. We can identify the climate of each farm as a resource.

We may also consider the potential use to be made of climate as a resource. Economic benefits might be achieved by modifying or perturbing a climatic element in a particular region. For example, large solar collectors will utilize the potential of the chosen climate for producing energy; in so doing the climate of that region may be disturbed or changed. A simple analogy here might be a shirt made from a piece of cloth; the cloth as a resource has a certain potential value which is realized by making the shirt, thereby disturbing the pristine piece of cloth.

Property rights associated with climate as a resource will vary with the particular case. Climate differences associated with land surfaces are readily associated with the land, whereas aspects of climate which vary over large regions might better be treated as property of the nation, or, in some cases, as the common property of the people of the world.

If climate can be considered as a resource associated in most cases with common property on regional, national or global scales, it follows that responsibility for its conservation and protection should be similarly a common responsibility. The remainder of this discussion of the impact of man on climate reflects this viewpoint.

3. The Climate Record

Our understanding of possible future changes in climate is necessarily based to a considerable extent on the record of past climates. What is known about the climate record? The subject has been reviewed recently in two reports issued by the National Academy of Sciences (U.S. Committee for Global Atmospheric Research Program, 1975; Geophysics Research Board, 1977). To summarize this extensive subject very briefly, climate has changed in the past on essentially all time scales from hundreds of millions of years to a few weeks, the latter limit representing not the absence of variability but the limit of the definition of climate, as used in this paper. Changes of shorter period we call weather changes and these are not considered here. For most of the past billion years global climate was warmer than it is at present and the Earth was probably free of polar ice. However, during this long and generally warm period short cold periods of the order of 10 million years in duration occurred. Coming closer to the present, for the past 50 million years, global temperatures have declined, and for the past 2 million years there has been a series of major glacial-interglacial oscillations with periods remarkably close to 100 thousand years. Oscillations of smaller amplitude have been detected at periods of about 20 thousand and 40 thousand years. Mid-latitude temperature changes accompanying the glacial-interglacial oscillations probably amounted to 6°C to 10°C.

Since the last glacial epoch about 10 thousand years ago, there have been three periods of alternate glacier expansions and contractions, with corresponding temperature variations of 1°C to 2°C.

The past thousand years of record have been dominated by the 'Little Ice Age', from about 1430 to 1850 when North Atlantic and European ice advanced and temperatures were generally about 1 °C lower than before or since. Since 1850 temperatures have risen somewhat, and over periods of 30 years regional precipitation has been observed to vary by 10 to 20% and temperatures to vary by 1°C to 2°C. Average surface temperatures for the Northern Hemisphere for the past 80 years are shown in Figure 1. This Figure indicates that between 1940 and 1970 the general warming which had prevailed up to that time reversed, and there were clear indications of cooling with increasing ice cover. Since 1970 the cooling 'trend', a term which inevitably seems to creep into these discussions, appears to have ceased. It is worth noting that 'trends' often vanish without a trace immediately after they are extrapolated to the future, a situation that exposes how little is known about the mechanisms of climate change.

On a still shorter time scale, we observe significant interannual regional changes in climate. In fact, these are the changes we are most likely to respond to. And climate anomalies of one or two seasons duration are grist for the Sunday supplements.

4. Possible Origins of Climate Variability

As my earlier comments suggest, we know too little about the mechanisms of climate change to predict the future or even to explain a change in climate after it has occurred. However, we do know quite a lot about the various processes which in combination are responsible for climate variation, and it may be worthwhile to quickly identify them. These processes are equally important for natural and for man-induced climate changes.

Changes in the energy received from the Sun obviously can produce change in climate. The clearest evidence is provided by the annual cycle of the seasons in which temperature and all the other atmospheric properties which constitute climate change as solar irradiance changes. Recently, it has been shown also that cores from the ocean

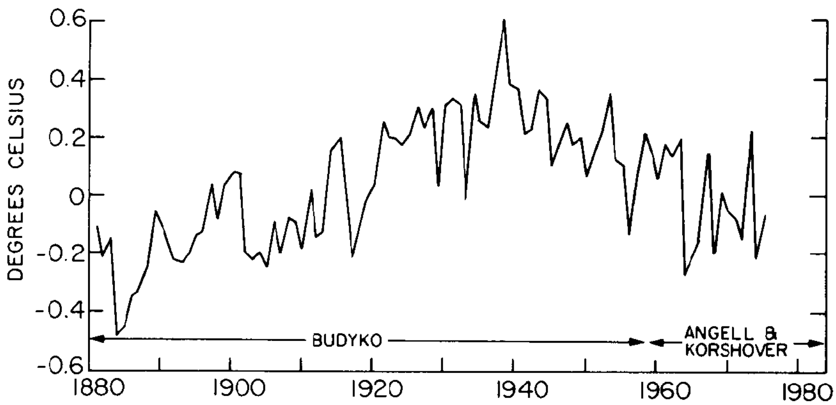


Fig. 1. Recorded changes of annual mean temperature of the Northern Hemisphere (after Mitchell, 1977).

bottom and from ice indicate climatic periodicity very close to the periods of changes in solar irradiance due to slow changes in the orbital parameters of the Earth's rotation about the Sun. These periods are the periods of 100 thousand, 40 thousand, and 20 thousand years which I referred to earlier.

Properties of the Earth's surface provide another set of climate influences: Radiational properties influence the radiation absorbed and emitted, thermal conductivity and specific heat influence the heat storage, and the type and amount of vegetation influence evaporation and other processes. So changes in any of these properties may affect climate. Examples are easily recognized.

The amount and distribution of small particles in the atmosphere, volcanic dust, industrial air pollution, windblown dust and bits of vegetation affect the radiation received and emitted by the atmosphere. And the gaseous composition of the atmosphere affects the amount of radiation absorbed and emitted by the atmosphere. In some cases atmospheric properties may be quite sensitive to small changes in gaseous composition. More of this later.

The properties so far referred to, solar irradiance, the Earth's surface, and composition of the atmosphere, are sometimes considered as external parameters influencing climate, that is external to the primary climate system which consists of the atmosphere, the ocean, and the cryosphere. In addition, one must recognize that the atmosphere, ocean, and cryosphere respond to thermal forcing with very different time constants, and that therefore climate changes of great complexity might be generated through interactions of the atmosphere, ocean, and cryosphere. Taken in isolation, the atmosphere itself is a fluid system which, it has been proposed, may have more than one possible climate given a fixed set of external parameters.

So there are many influences on climate and many possible mechanisms of climate change. The fact that we have no recognized theory of climate is not an indication of intellectual poverty, but the reverse. There are so many mechanisms operating together that we have been unable to sort them out.

5. Human Effects on Climate

I have referred to both natural and to man-induced climate changes and have lumped them together in discussing the various external parameters which influence climate. In many cases, the physical distinction between them is not very clear; the important difference is that the man-induced changes may be subject to a greater degree of control or modification. Even that may be open to question.

Recently, a panel of the Committee on the Atmospheric Sciences of the NAS-NRC made a study of the impacts of weather and climate on society. The panel members represented a variety of disciplines including: meteorology, climatology, economics, geography, sociology, and engineering. In the panel's judgement, the most important effects on climate resulting from human activities are likely to be: effects of increase in atmospheric CO_2 concentration, effects of trace gases on stratospheric O_3, and regional effects of a variety of large activities. I will turn now to a review of the significance of these three subjects.

5.1. EFFECTS OF CO_2 INCREASE

The now classical observations of Keeling (reviewed by Keeling and Bacastow, 1977) show conclusively that the concentration of CO_2 in the atmosphere has increased by about 5% in the past 20 years. Estimates indicate that a similar increase had occurred in the previous 30 years. The rate of addition of CO_2 to the atmosphere has been about half the rate produced by burning of fossil fuels. The remainder may go into the ocean and into vegetation. Estimates have been made which indicate that extensive forest clearing which is occurring in tropical areas probably is adding to the CO_2 concentration, but the roles of the biosphere and the ocean remain as important problems. Projections are quantitatively uncertain, but it appears plausible that the present CO_2 level will be doubled by mid-twenty-first century and quadrupled by the end of the century. The possible consequences are sobering, and the implications for responses by the world's institutions, governmental and non-governmental, are of a new order. Concern stems from the elementary fact that CO_2 is a strong absorber of IR radiation and that therefore increase of CO_2 should result in increasing the blanketing effect of the atmosphere. However, there are possible secondary effects, so that simple radiation calculations (one-dimensional models they are sometimes called) do not suffice.

Numerical model experiments using the hydrodynamic and thermodynamic equations which govern the atmosphere have been carried out to examine the increased CO_2 concentration. Manabe and Wetherald (1975) used a model which represented generalized global topography, thermodynamic changes including release of latent heat, radiation, and evaporation from oceans but no heat storage or transport by the oceans; a model which had been shown to simulate realistically the present climate including many details of the general circulation. They introduced an arbitrary CO_2 concentration double the present concentration and carried the model calculations forward in time until a new statistical equilibrium had been reached. The result, as shown in Figure 2, indicates a general warming of the troposphere and cooling of the stratosphere. The global average surface temperature increase is 2.9°C with values as large as 10°C in polar regions. There are possibly important processes not represented in this experiment including the march of the seasons, ocean storage and transport, and cloud reactions. These effects conceivably might counteract or even reverse the calculated results. Also, it is well to recognize that we don't understand the extent to which the global biomass acts as a source or a sink for CO_2, nor do we understand well enough transfer to and from the ocean. Therefore, we cannot be fully confident of extrapolations of past trends into the future. On the other hand, the Manabe–Wetherald result has stood for more than 4 years and experiments using other models have tended to support the results. And most studies suggest buildup of CO_2 in the atmosphere at an increasing rate. So a prudent