The CO2 Newsletter, created, published, and edited by William N. Barbat, ran from 1979 to 1982.

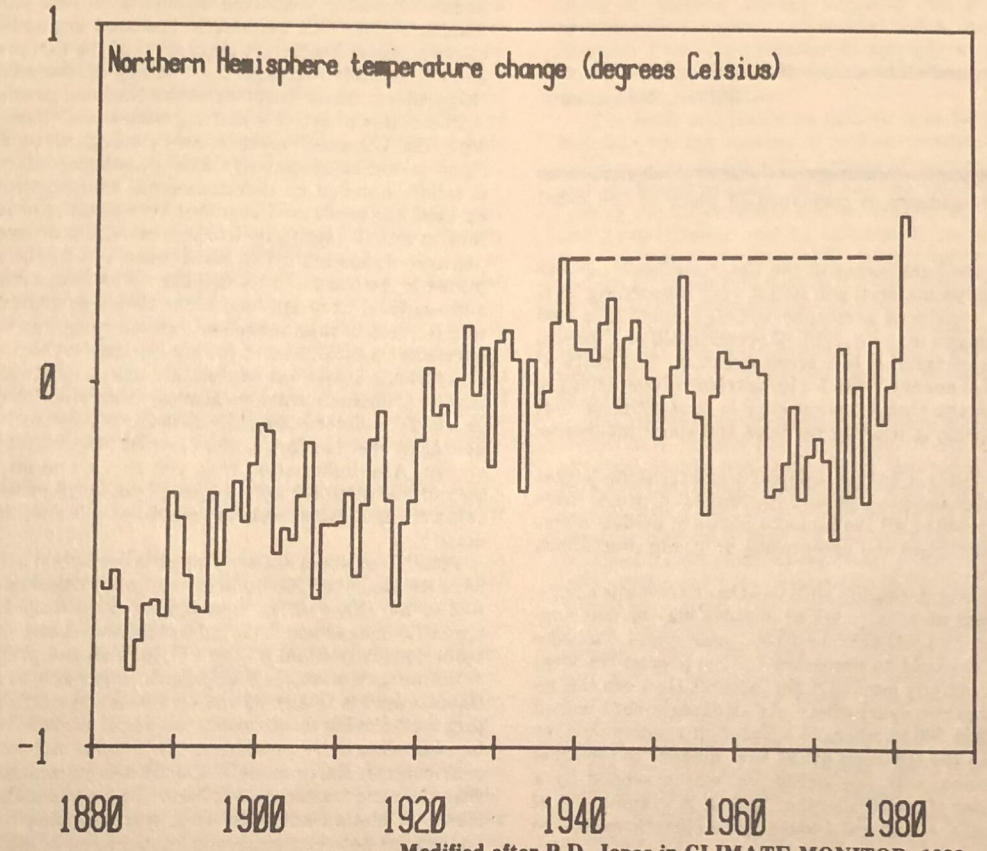
In 2025, the family of Mr. Barbat donated an original set of all issues to Dr. Marc Hudson, and agreed that these could be digitised and placed online as a resource for anyone who wants to understand how long we've known about the carbon dioxide and global warming problem.

CO_2 Newsletter©

Volume 3, Number 4 **May-June, 1982**

A bimonthly summary of advances in knowledge of the CO2-greenhouse problem, and of the social, political, and economic implications.

1981 sets modern heat record



Modified after P.D. Jones in CLIMATE MONITOR, 1982.

The Climatic Research Unit of the University of East Anglia has reported what may be the first meterological indicator of a significant climatic trend in the publication of **Climate Monitor** (v10, n5). "1981 has been the warmest year over the Northern Hemisphere since 1881, the first year when some reliability can be accredited to a hemispheric average," P.D. Jones reports. He noted that the 1981 average temperature exceeded the previous high value of the past century (1938) by 0.12°C. "Whether this year proves to be the starting point of the expected rise in surface air temperature due to increasing levels of CO_2 in the atmosphere or just a 'random' extreme value, only time will tell."

Jones further noted that "Ice conditions during the winter season were generally favourable in the Arctic for commercial operations, allowing an extra 2-3 weeks of operation north of Alaska . . . 1981 was again a warm year over the Antarctic although not as warm as the eastern half of the continent in 1980."

The suddenness of the Northern Hemisphere warming comes somewhat as a surprise because the comparative coolness of the Northern Pacific Ocean was expected to act as a large flywheel to retard any secular warming trend. The sea surface temperatures in the **eastern** part of the North Pacific appear to be the key controlling factor for precipitation throughout much of the U.S. Warm sea temperatures block the southward flow of cyclonic storms, leading to widespread drought as during the Dustbowl years of the 1930s. The Northern Hemisphere warmth of the 1930s apparently exceeded temperatures of the previous several centuries based on Dansgaard's oxygen isotope measurements of the Camp Century ice core from northwest Greenland.

The great volume of ash injected into the stratosphere by the volcano Chicon (Chiconal) in southern Mexico in March 1982 may provide a significant cooling effect for several years by screening out part of the entering sunlight. Optically thick ash was noticed as Mauna Loa in April, and ash was detectable by the backscattering from a pulsed laser at Langley Research Center, Virginia, in early June, according to M. Patrick McCormick of NOAA. (The movement of ash in the stratosphere relative to the earth's surface motion is from east to west.)

Early indications are that when Chicon's ash spreads out over a wide latitudinal belt, the global cooling effect may approach that of the Agung volcano (1963), which was exceeded in size in the last century only by Krakatoa (1883). McCormick notes that an atypical period of significantly increased volcanic activity throughout the Pacific region began with the eruption of Mt. St. Helens in May 1980.

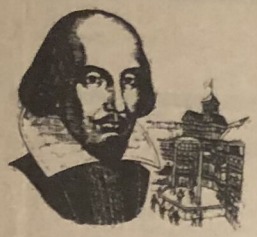
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"Our doubts are traitors and make us lose the good we oft might win by fearing to attempt."

—William Shakespeare

(The following correspondence is published in place of the usual editorial.)

"Dear Bill:

"Thanks for sending the back issues of the CO_2 Newsletter. I have read or scanned most of the material and find it very interesting. It is apparent that you are convinced atmospheric CO_2 buildup is a real danger to the world, and you may be right. Whether 2 billion Chinese, among others, could be convinced is a large question. The costs of changing to other forms of energy, even for industrialized countries are astronomic. I agree with you that atomic energy is an alternative that should be expanded, especially breeder reactors and spent fuel reprocessing.

"In reading the Newsletter, I believe I detect a mental attitude that may be a problem. As with the pro- and anti-continental drifters, there is a real danger in emphasizing all the bits and pieces of evidence that tend to support your hypothesis and denigrating or giving short shrift to the opposing evidence.

"There is special difficulty in dealing with weather or climatic cycles. Trends observed in recent months, years or decades may be meaningless in terms of 100-year, or 1,000-year, or 10,000 year cycles. To make reasonable predictions, it would be necessary to first predict the level and duration of volcanic activity (among other factors). How can this be done? Also, one can find cycles everywhere! As an experiment I looked at the last digit of the first 500 numbers in a five-digit random-number table. The numeral 4 was the last digit of the first number in the table and every 10th recurrence, with one exception, was preceded by a distinctively large number of numerals other than 4. A graphic plot of the recurrence pattern of the numeral 4 looks like a climatic cycle—so beware of cycles!

Best regards,
(John)
John D. Haun
Professor of Geology
(Colo. School of Mines)

(Professor Haun is president of the American Geological Institute which serves 50,000 earth scientists through 17 societies. -Ed.)

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Dear John:

Your candid response suggests that convincing the world's billions of inhabitants of the implied seriousness of a continued CO_2 buildup may be easier than convincing scientific leaders like yourself.

Your critique has three main themes which deserve answers of equal candor.

- This newsletter gives short shrift to—and denigrates opposing evidence.
- The use of observed climatic cyclicity in making predictions is not supportable.
- The CO_2 buildup is too costly to halt anyway.

The purpose of this newsletter is to fill the vacuum left by a noticeable **de-emphasis** of the entire CO_2 problem in more widely read publications. (Others share this view.) Some early controversies were publicized widely in those publications, but were rarely followed up with articles explaining the revised viewpoints of some of the originators of the controversy or explaining where fallacies were found by a comprehensive rechecking of the logic and calculations.

Strong disagreements still exist primarily over the **rate** and **degree** of anticipated climatic impacts rather than the character of expected change. To offset what may be overblown fears of ours, we have been directly urging editors of widely read periodicals to give the CO_2 problem more extensive coverage and we have recommended to them names of widely respected scientists to edit such material to help eliminate bias. This newsletter has been urging editorially that more comprehensive studies on all aspects of the CO_2 problem be performed and we have advocated greater funding of the current evaluation of the CO_2 problem under auspices of the National Academy of Sciences.

The notion of actively drifting continents offers a contrasting study with the CO_2-greenhouse theory in regard to disciplined scientific rigorousness and popularity. The greenhouse effect of atmospheric CO_2 is solidly founded on thermodynamic investigations which have been checked and rechecked over and over again to produce a rather consistent range of appraisals (consensus). Climatic cyclicity has been emphasized to maintain CO_2 awareness during the recent brief cooling period in the Northern Hemisphere. Now that surface air temperatures and sea level have attained highs that lack modern precedents, attention is likely to shift to the secular warming that could make cyclic and aperiodic variations increasingly less noticeable.

Aperiodic injections of volcanic ash into the atmosphere still present a prediction problem. Murray Mitchell (Science Advisor, NOAA) presently is determining the global cooling effect of stratospheric ash **averaged** over the last century, which we are not at liberty to publish on yet. Any information that you or anyone else can add about the magnitude, duration and probability of large possible departures from this averaged ash screening would be welcomed by the scientific community.

The CO_2 problem suffers from a lack of popularity. No rock concerts have decried the CO_2 buildup, and no bumper stickers advocating a halt to the CO_2 buildup have appeared on fossil-fueled autos. Popular scientific magazines that advertise expensive non-utilitarian autos seem unusually silent on the CO_2-greenhouse problem.

In contrast, scientific disciplinarians are able to show that active continental drift is fatally flawed on both a physical and chemical basis. No proposed driving mechanisms can begin to match the forces that would be needed to move ponderous continental masses apart on highly viscous magma. Early models of drift-driving mechanisms failed to note that alchemic transmutation had to be invoked where postulated movements of molten and solid rock were supposed to take place across boundaries between materials known to be of different elemental composition. Revised models have become so ludicrously complex to avoid invoking alchemy, that they have become the source of much Rube Goldbergian humor. Unfortunately the notion of active drift was accorded credibility in virtually all school texts to produce popularity before a truly disciplined case was made, and large research enterprises have a vested interest in perpetuating the funding and publishing of one-sided studies. This may seriously retard an understanding of climates of the geologic past.

You may be correct in your assessment that the cost of changing to non-fossil forms of energy would be astronomic. To improve our understanding, the U.S. Department of Energy recently initiated a study of the 'Consequences of CO_2 climate change for U.S. energy policy' to be conducted by Marvin Miller, David Rose and Chris Hill of MIT and Carson Agnew of Stanford. They will attempt to establish objectively what it would take to bring a halt to the CO_2 buildup at certain CO_2 levels. An objective analysis of impact costs would certainly be needed for comparison. For instance, what would it cost to hold back a rising sea from populous cities as Washington D.C., London, Hamburg, Leningrad and Shanghai and highly populated deltas of rivers as the Rhine, Nile, Ganges, Mekong, Yangtse and Yellow, or are they considered worth saving?

Yours very truly,
Bill (WNB)

Announcement

A two-day summer meeting on the 'Climatic effects of increasing atmospheric carbon dioxide' will be held at the University of East Anglia, Norwich, England, on 15-16 July 1982. Speakers will include J. Jäger (Karlsruhe, FRG), J. Shepherd (MAFF Fisheries Laboratory, Lowesoft), A. Henderson-Sellers (U. of Liverpool), N.J. Shackleton (U. of Cambridge), R.S. Kandel (CNRS, France), W.L. Gates (Oregon State U.), T.M.L. Wigley (U. of East Anglia) and P.M. Kelly (UEA). An additional speaker will be announced.

The meeting is sponsored jointly by the Royal Meteorological Society and the Climatic Research Unit of UEA, and the local organizer is T.M.L. Wigley. The scientific sessions will be held on the UEA campus, and accommodations and meals can be provided for registrants, spouses and children on the campus. Total cost, including accommodations for registrant, all meals, excursion and registration fee will be approximately £ 50. For details contact the Climatic Research Unit.

Excerpts from recent reports

From **'Socio-economic implications of an Altithermal scenario for CO_2-induced climatic change in the twenty-first century', by Karl W. Butzer, extended abstract for American Quarternary Association meeting, Seattle, June 1982, Session on 'Climate and Man':**

". . . (C)onvergent research by several different disciplines has brought into focus the very real prospect that global environmental changes are pending, as a result of the rapid increase in atmospheric carbon dioxide. The rates, amplitudes, and configurations of these expected changes have not yet been determined with precision but increasingly sophisticated simulations of the global carbon cycle, buttressed by paleoclimatic experiences, indicate that the American and Soviet breadbaskets will be increasingly threatened by drought, and there is a possibility that higher polar temperatures will lead to rapid melting of the West Antarctic and Greenland ice masses, with a corresponding 6m rise of world sea level.

". . . Expected as [these prospects] are over the next 20 to 100 years, they must be viewed in conjunction with the **Global 2000** report, summarizing the hard evidence for the Third World demographic juggernaut, the increasing global energy shortfall, and the ecological, economic, and technological limitations to ever-increasing food production. **Global 2000** studied the population, food, and energy variables in isolation, neglecting the systemic interactions between economic productivity, available capital, research funding, remedial technology, and food production. Compounding these problems, with the expected climatic change and persistent drought affecting the major world suppliers most, the concatenation of negative impacts spells a disastrous, global crisis.

". . . Of . . . immediate concern to Quatenary scientists is the magnitude of environmental change in response to the changing level of atmospheric carbon dioxide . . .

". . . Simulations of global warming and effective moisture change, on the one hand, and of glacier and sea level response, on the other, can not anticipate the full range of possible negative or positive feedbacks of environmental systems. Interglacial records directly or indirectly reflecting mass-balance changes in the Antarctic and Greenland ice sheets are critical to evaluate the possibility of catastrophic 'surges.' Equally so, paleoclimatic reconstructions must test the interrelations between higher global temperatures and regional moisture anomalies. .

"A review of the continental records sensitive to interglacial temperatures and moisture conditions, different from those of the Holocene, quickly shows that some mid-latitude areas were warmer during parts of some interglacials and that some regions were either wetter or drier than today. But the sum of the evidence still is too spotty to allow global reconstructions of moisture deviations, and the difficulty is compounded by the paleoclimatic complexity of the deep-sea isotopic record. It is equally tenuous to establish sound temporal correlations within continental deposits of the interglacial complex equivalent to stage 5, as it is to assign earlier interglacial floras, lake sediments, dune beds, etc. to any one previous warm isotopic stage.

"Attention is therefore best focused on the early to mid-Holocene when mid-latitude and high-mountain temperatures seem to have averaged 1.5 to 2.5° C above those of today. This Altithermal or Hypsithermal interval, dating from about 8000 to 5000 years ago, suggests useful analogs for a future climatic scenario. The provisional consensus among most modellers is a global temperature increase of between 1 and 4°C, depending primarily on the phasing out of fossil fuels and the rate of destruction of tropical biomass; an intermediate deviation of 2-3°C currently seems the most plausible for the mid-21st century.

"Available evidence shows that higher mid-Holocene temperatures allowed a longer growing season and poleward extension of the tree line in Alaska, Canada, and northern Europe, together with an upward shift of montane eco-zones in Europe, the American West, southeastern Australia, and elsewhere. Rainfall increased throughout the Sahara, in East Africa, Arabia, the Thar Desert, the Kalahari and Karoo of southern Africa, and across Australia. . .

"In the Midwest and on the Great Plains, climate was distinctly drier than today, with expansion of prairie at the expense of forest in Minnesota, Illinois, and Missouri. . . There are no properly-dated pollen or lake sequences of this age in southern Russia, Central Asia, and Mongolia, although a shrunken, saline lake in the then non-forested Van Basin of eastern Turkey suggests that continental positions, comparable to the western and central U.S.A., may also have been drier in Eurasia. This interpretation is strongly supported by the extensive Caspian Basin, as reflected in a mid-Holocene sea level 25m lower than during historical times.

"The basic mid-Holocene pattern is as follows: (a) substantially augmented growing seasons in cool environments now marginal for agriculture; (b) distinctly drier climate in most mid-latitude arid, semi-arid, and subhumid regions, with an inherent trend to desertification, including the major wheat-and-corn-producing belts of the United States and Soviet Union; and (c) moderately increased precipitation in the tropical and subtropical arid zone, primarily in what are now pastoral and irrigated lands of Africa, Arabia, India-Pakistan, and Australia, but excepting the more productive mediterranean environments of Europe and South Africa. This pattern is reasonably consistent (spatially and temporally) and well documented, and it provides a usable, qualitative working model for expected climatic zonation during the mid-twenty-first century. . .

"The agricultural implications suggested by the mid-Holocene model for the 21st century are mixed and, in important ways, negative overall. Dust Bowl conditions would become commonplace on the Great Plains, with an increased incidence of drought in the Midwest. A substantial part of the present winter-wheat belt would have to revert to grazing, with large-scale replacement on the corn-soybean production of Illinois, Iowa, and Missouri by winter wheat. The corn belt would shift, climatically, to Wisconsin, Minnesota, and Canada, where podsolized soils are poorer and drainage less than ideal. Irrigation waters in the West would be substantially reduced and less reliable. Overall United States crop acreage and average yields would plummet, and corn with its attendant livestock industry would be widely replaced by wheat of substantially lower productivity. Similar problems would plague food production in the Ukraine and Central Asia. By comparison, the potential expansion of agriculture onto the marginal soils of the present mixed-coniferous forest belt of Canada and northern Europe would be relatively insignificant.

". . . Increased moisture in low-latitude deserts and the semiarid zone of Africa, Asia, Australia and parts of South America would primarily affect the productivity of low-efficiency pastoral economies, locally supplemented by irrigation agriculture. Even increased yields in the primary tropical agricultural belt would not add substantially to the world food-supply, probably serving instead as a stimulus to further demographic growth. Long-range benefits in the tropics could only be assured by a switch to labor-intensive horticulture on the Chinese model or a western-style modernization, that would require heavy and sustained capital investment—in countries generally lacking both industrial capacity and energy resources.

"These world food-supply prospects are grim, even allowing for substantial negative feedback within both the environmental and the adaptive systems. In particular, the United States, now the world's major food exporter, would barely remain self-sufficient, while the Soviet Union would be heavily dependent upon food import. Unless demographic trends in low-latitude, Third World nations are reversed, and agricultural productivity at least doubled, Canada's and Australia's sustained capacity to export would be inadequate to meet the world demand for food.

"There is then substantial reason to believe that a continuation of present environmental trends will spell an economic crisis of global proportions within the lifetimes of our children and grandchildren. The negative impacts of such cumulative change will affect some countries,

such as the two present superpowers, the United States and the Soviet Union, far more than others, creating severe tensions in the global sociopolitical network. This pending crisis of the 21st century can therefore be expected to take three forms:

(a) A substantial reduction of the world food supply, at a time of maximum demographic pressures upon global resources and shrinking energy reserves;

(b) selective decline of productivity among the major economic and food-producing nations, implying a fundamental readjustment between developed and developing world regions; and

(c) differential impacts within undersupplied nations of special complexity, as resources become inadequate to maintain controlled ecosystems, raising the probability of severe internal disruptions and confrontations within existing socioeconomic subsystems.

"This application of . . . foreign paleoclimatic experience may convince some of Washington's [funding critics] that the relevance of research can seldom be anticipated until many years have passed, and that proper functions of 'pure' research remains as essential as ever . . ."

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From **'Workshop summary', by Michael C. MacCracken and Harry Moses, in Proceedings of the Workshop on First Detection of Carbon Dioxide Effects, June 8-10, 1981, U.S. Department of Energy CONF-8106214, published May 1982:**

"For more than a decade, numerical models have predicted that increasing CO_2 concentrations would cause a warming of the global climate, with amplified warming in polar regions and cooling in the atmosphere. Such changes, however, are not now obvious in the climatic record, although it is possible that the changes are being observed by natural climatic fluctuations or by the perturbing influence of other factors. Indeed, a number of observational studies have found, after attempting to account for the possible climatic changes caused by such other factors as volcanoes and changes in solar activity, that the predicted global warming may be occurring. Studies of the polar regions and the stratosphere, however, do not yet show the expected changes.

". . . These measurements (of atmospheric CO_2 at Mauna Loa Observatory) clearly indicate an upward trend from about 315 to 340 ppm (a rise of 8 percent) over the 23-year record. Less representative measurements made earlier this century with instruments known to be of poor reliability indicate that CO_2 concentrations in the 19th century were probably 270 to 290 parts per million (ppm) . . . indicating that CO_2 concentrations have probably risen 17 to 26 percent during the past 100 years.

"If these estimates are correct, then it follows directly from the results of numerical models that the global climate should by now have warmed by several tenths of a degree Celsius. While a number of individual researchers have suggested that this has occurred, many others disagree for a wide variety of reasons . . .

"THE SEARCH FOR THE CO_2-INDUCED CLIMATE RESPONSE

"The 1965 report by the Environmental Pollution Panel [Panel members included R. Revelle, chairman, W. Broecker, H. Craig, C.D. Keeling, and J. Smagorinsky] of the President's Science Advisory Committee . . . commented on the search for a climatic response as follows:

"One might suppose that the increase in atmospheric CO_2 over the past 100 years should have already brought about significant climate changes, and indeed some scientists have suggested this is so. The English meteorologist, G.S. Callendar (1938, 1940, 1949), writing in the late 1930's and the 1940's on the basis of the crude data then available, believed that the increase in atmospheric CO_2 from 1850 to 1940 was at least 10%. He thought this increase could account quantitatively for the observed warming of northern Europe and northern North America that began in the 1880's. From . . . our estimate of the CO_2 partition between the atmosphere, the ocean, and the biosphere, we see that the actual CO_2 increase in the atmosphere prior to 1940 was only 4%, at least from fossil fuel combustion. This was probably insufficient to produce the observed temperature changes. [But it should be noted that up to 2.5% of the atmospheric carbon dioxide (after partition with the ocean and the biosphere) could also have been aided by the oxidation of soil humus in newly cultivated lands.]

"As Mitchell (1961, 1963) has shown, atmospheric warming between 1885 and 1940 was a world-wide phenomenon. Area-weighted averages for surface temperature over the entire Earth show a rise in mean annual air temperature of about 0.5°C (0.9°F). World mean winter temperature rose by 0.9°C (1.6°F). Warming occurred in both hemispheres and at all latitudes, but the largest annual rise (0.9°C of 1.6°F) was observed between 40° and 70°N latitudes. In these latitudes, the average temperatures rose by 1.6°C (2.8°F).

"The pronounced warming of the surface air did not continue much beyond 1940. Between 1940 and 1960 additional warming occurred in northern Europe and North America, but for the world as a whole and also for the northern hemisphere, there was a slight lowering of about 0.1°C (0.2°F) in the mean annual air temperature (Mitchell, 1963). Yet during this period more than 40% of the total increase from fossil fuel combustion occurred. We must conclude that climatic 'noise' from other processes has at least partially masked any effects on climate due to past increases in atmospheric CO_2 content."

Since this 1965 assessment, little has changed. There have been many additional studies seeking to find the climatic response to increasing CO_2 and, if evident, to develop an empirical estimate of the effect and help verify why we cannot yet detect the response predicted by the models . . .

"One approach to resolving the conflict in observational and model results has been to try to attribute at least some of the fluctuations in the record, particularly the global cooling from the 1940s to 1960s, to other factors. An early explanation by Bryson (1968) maintained that the cooling was due to an increase in tropospheric aerosols. Ellsaesser (1975), however, finds no evidence of a recent upward trend and measurements of aerosol properties and model studies also indicate that tropospheric aerosols cannot be a controlling factor in any case (as reviewed by Kellogg 1979).

"A second suggested external factor has been volcanic injection of stratospheric aerosol. The very large volcanic injections of Krakatoa (1883), Santa Maria (1902-1904), Katmai (1912), and Agung (1963) certainly appear to be reflected in the temperature record . . . These studies clearly indicate a strong statistical relationship, but when volcanic effects are subtracted out, there is no agreement on whether a CO_2 effect remains. Bryson, for example, finds no remaining linear or exponential trend that might be attributed to the CO_2 increase; Mitchell (1981) finds a small trend indicating a temperature increase of only a few tenths of a degree to date and less than one degree for a CO_2 doubling, and Vinnikov and Groisman (using apparently identical data sets as Bryson) find a residual increase of 0.4 to 0.6 K to date and conclude that the trend indicates a 2 to 3 K warming for a CO_2 doubling. Hansen et al. (1981) estimate a 0.4 K increase to date when they include volcanic influences and assume about a 2.8 K warming for a CO_2 doubling . . .

". . . The primary difficulty is that the volcanic aerosol hypothesis is unable to explain the cooling that occurred from the 1940s to 1960s, a period for which there is not a record of a corresponding increase in volcanic injection of stratospheric aerosol . . .

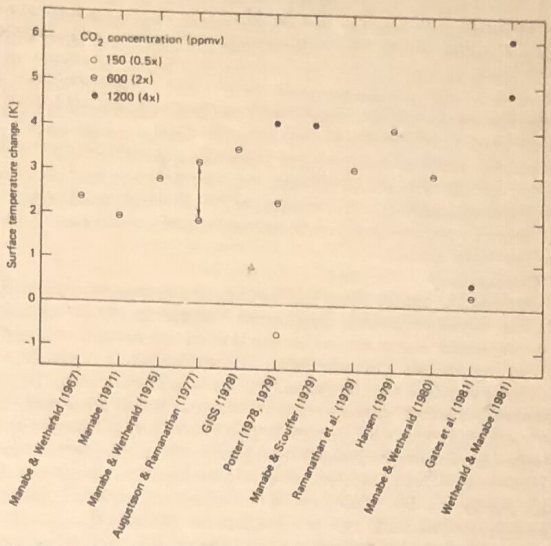
"Many investigators have sought to attribute part of the temperature variations to changes in solar radiation. Since no long-term record of sufficient accuracy exists, reliance has been placed on such indices of solar activity as sunspots . . . umbra/penumbra ratio . . . and recently, solar diameter . . . Broecker, using only the sunspot index, gets an optimum fit with a 3 K increase for a doubling of CO_2; Hoyt estimates the residual CO_2 effect as 0.4 K when umbra/penumbra effects only are subtracted out, corresponding to an increase of 2.0 to 3.1 K for a CO_2 doubling; and Hansen, et al. include volcanoes and umbra/penumbra effects and estimate a 1.4 to 5.6 K (2.8 K preferred) increase due to a doubling of CO_2 concentrations . . .

"An alternative approach to resolving the apparent conflict between model results and observations has been to point out that the model results assume that a new equilibrium has been established, whereas in the real world the need to warm the oceans before the atmosphere can be warmed results in a delay in the appearance of the warming. This phenomenon is attributed to the ocean's large heat capacity (thermal inertia) as compared to that of the atmosphere. Empirical and model studies of this effect (which evaluate, for example, the time-dependent climatic response to volcanic injection of stratospheric aerosol), indicate that a period of 6 to 20 years or more is required before new equilibrium climate conditions are reached . . .

"Etkins and Epstein (1981, this volume) propose another mechanism that may cause a delay and change in character of the postulated CO_2-induced climate response. Using sea-level records, they suggest that the warming earlier this century initiated deterioration (e.g., calving) of the polar ice sheets. This, in turn, has drained heat from the ocean-atmosphere system to melt the ice, thereby causing a cooling of the surface-air temperature in the middle decades of this century that has not been overcome by the CO_2 effect until quite recently . . .

"A few other investigators have attempted to use empirical data to check the models rather than try to decompose the record of past climate fluctuations. Newell and Dopplick (1979) and Idso (1980) have combined data and highly simplified models to suggest that the models are grossly overpredicting the climatic response to increasing CO_2 concentrations. Most investigators . . . believe that, as a consequence of improper assumptions, interpretations drawn by Newell and Dopplick and by Idso from their results are invalid and that, therefore, adoption of a drastically reduced CO_2-induced climatic response is not a valid resolution of the present apparent conflict between results from global

- From 'Workshop summary' by Michael C. McCracken and Harry Moses in Proceedings of the Workshop in First Detection of Carbon Dioxide Effects, published as U.S. Department of Energy CONF-8106214, May 1982.



Surface temperatures change as a function of three changes in the CO_2 concentration (reducing the CO_2 concentration by half, doubling it and quadrupling it) as determined by various investigators. (Updated from Washington and Ramanthan 1980.) The low value given by Gates et al. (1981) assumes fixed sea-surface temperatures, and is therefore considerably smaller than results from more realistic models that consider interactive oceans.

models and observations.

". . . (A)nalysis of stratospheric temperature trends (Angell and Korshover 1978b, and updated by Klein this volume), however, indicates that there may be some stratospheric cooling, in qualitative agreement with the model results. But these temperature decreases appear almost too sharp to be caused by the slowly changing CO_2 concentrations . . ."

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From **THE LONG-TERM IMPACTS OF INCREASING CARBON DIOXIDE LEVELS, edited by Gordon J. MacDonald, Ballinger, 1982:**

"Preface

"Although it has been known for about a hundred years that changing the concentration of carbon dioxide (CO_2) in the earth's atmosphere could bring about changes in climate, it has been only in the last half dozen years that significant attention has been paid to this question in the professional and public press.

"The explosion of public interest in the CO_2 problem has resulted in large part from the meticulous observations of Charles David Keeling and his associates at the Scripps Institution of Oceanography. They have demonstrated beyond question that the atmospheric concentration of CO_2 has increased by about 7 percent between 1958 and 1981 . . . In a little more than one-billionth of all earth's history, carbon dioxide has increased in concentration by one-fourteenth—and man is responsible . . .

"There are numerous uncertainties about the direction and magnitude of anticipated changes. The benefits and costs of these changes to society will depend on the timing and magnitude of the changes and the appropriateness of human responses. Significant uncertainties exist in the timing, magnitude, and temporal and spatial extent of possible climatic and environmental change. The uncertainties are great enough to suggest that now is not the proper moment to undertake far-reaching actions designed to mitigate potential adverse effects of increasing CO_2. Nor are the possible benefits well enough understood to permit a complacent view of the future.

". . . If the world continues to increase its burning of carbon-based fuels by 4.3 percent a year, and if the current partition of CO_2 among atmosphere, biosphere, and oceans is maintained, as well as the current mix of fuels, coal, gas, and oil, then the concentration of carbon dioxide in the atmosphere will double about the year 2035. Alternative assumptions about rates of increase of the world's use of carbon-based fuels and the nature of atmosphere, ocean, and biosphere interactions lead to doubling dates around the middle of the twenty-first century.

. . . Atmospheric models that estimate the change in mean surface temperature for a doubling of CO_2 concentration lead to an increase of 2-3°C . . . What is of great significance is that a change of 2-3°C in average surface temperature is much greater than has been observed in historical times. Eight thousand years ago the temperature may have been a degree warmer, but we have to go back to the periods of glaciation and its intervals of warming to find changes of the magnitude in mean surface temperature that may take place within the twenty-first century . . .

". . . We have constructed two models for radiative equilibrium: one treating the atmosphere as quasi-gray, and the other dividing the infrared emission region into nine bands. The quasi-gray atmosphere model predicts an increase of average surface temperature of 2.8°K for a doubling of CO_2, a result in agreement with the nine-band model . . .

"An analytical model of the atmosphere has been constructed (JASON climate model). Calculation of this zonally averaged model shows an increase of average surface temperature of 2.4°K for a doubling of CO_2. The equatorial temperature increases by 0.7°K, and the poles warm up by 10 - 12°K. These values refer to an equilibrium state where the ice caps have completely melted. In time-dependent heat budget models, the increase in temperature during the summer is greater than during the winter . . .

"1. The impacts of increasing carbon dioxide—an overview

"Steady, hot summer winds in 1979, accompanied by low precipitation over the grain-growing areas of European Russia reduced Soviet wheat crops by about 15 percent below the planned goal . . . On the average, growing conditions [in the U.S. in 1980] were almost as bad as in the Soviet Union as in 1979. The United States, in parts of the Midwest, Southwest, and Southeast suffered a history-breaking drought . . .

"The climatic events of 1979-1980 were not unique for the decade of the seventies. In January, 1972, the wheat crop in European Russia suffered from inadequate snow cover, followed by prolonged heat and drought in spring and summer. In the late fall the ripened wheat was covered by snow. As a result, the Soviet Union rapidly entered the world grain markets, already strained by the poor monsoon in Indian in the same year . . .

"The Soviet Union and India were not the only countries affected by abnormal climatic conditions in the early 1970s. The six West African countries west of the Sahel—Mauretania, Senegal, Mali, Upper Volta, Niger, and Chad—were driven to the edge of political and economic ruin by a drought that began in 1968 . . .

"The examples of the impact of climatic stress on the course of world events in the 1970s are representative of similar incidents throughout history. The distribution of population in the United States was greatly altered as a result of the 1933-36 drought of the Dust Bowl when total United States production of wheat was only three-quarters of that in preceding and subsequent years . . .

". . . Melting of glaciers and ice sheets will bring about changes in sea level that, even if small, are of importance to people living in areas subject to sea floods (i.e., Netherlands and Venice). Large shifts in sea level could bring about major population shifts . . .

"The warming by one degree associated with the 'altithermal' of some 8,000 years ago brought about major demographic shifts as well as changes in regions of high agricultural productivity as the mid-continental regions suffered drought conditions . . .

". . . In the late 1950s, carbon in the form of carbon dioxide was being added at a rate of about 1 Gton per year; in 1978 the rate was approximately 2.6 Gtons per year . . .

. . . For the latitude of Washington D.C., the August temperature, after a doubling of the carbon dioxide content, is 9°C warmer than at

present, but the February temperature is only 2°C warmer . . .

"The amplification of the warming in the polar regions presents special problems. Generally, it is assumed that the polar ice sheets would respond to a warming trend over a time scale of thousands of years since the melting would proceed slowly at the surface exposed to the atmosphere. Mercer (1978), however, has pointed out that the characteristics of the West Antarctic ice sheet are such that melting could proceed rapidly. The ice is grounded below sea level with a present summer surface temperature of -4° - -5°C . . . An increase in summer temperature [to] 0° - 1°C could lead to rapid melting of the shelves and disintegration of the main ice sheet. The time scale for such a process is not known, but observed surges raise the possibility that the West Antarctic ice sheet could discharge one-third to one-half of its volume in one hundred years . . . A warming of 5°C in Antarctica could take place in thirty to seventy-five years, depending on the rates and kinds of carbon fuels burned.

"Conclusions

"Despite the many uncertainties about the nature of the carbon cycle and the effect of carbon dioxide on climate, it seems highly probable that continued increases in the worldwide use of carbon-based fuels will lead to significant climatic shifts in the twenty-first century . . .

"There exists a number of means by which the rate of increase of atmospheric carbon dioxide can be slowed if this becomes a desirable goal. All, however, only postpone the time at which large changes in atmospheric composition and climate take place. Conservation measures designed to reduce the use of carbon-based fuels are in the short term most likely to be effective. The increased use of natural gas, if available, would lengthen the time available or solar energy economy would postpone carbon-induced climate shifts . . ."

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From **'Archaeological evidence for climatic change during the last 5000 years', by Robert McGhee, Chapter 6 in CLIMATE AND HISTORY, STUDIES IN PAST CLIMATES AND THEIR IMPACT ON MAN, T.M.L. Wigley, M.J. Ingram and G. Farmer, editors, Cambridge University Press, 1981 (based on a conference on Climate and History held at the University of East Anglia in July 1979):**

. . .

The Saharan region. One of the more prominent attempts in this field is that dealing with past climates of the Saharan region, based on evidence from rock paintings showing animals which are today found only in moister regions of Africa. Such use of prehistoric paintings is fraught with danger, since they are notoriously difficult to date with accuracy, and we can never be certain as to how they should be interpreted . . . Several scholars have argued that the Saharan rock paintings, along with other evidence suggests a relatively moist cimate in the Sahara during a period roughly to the Atlantic phase in Europe (c.6000-3000 BC). The evidence for the existence of this 'Neolithic Wet Phase' has recently been questioned by Shaw (1976), partly on the basis of redating of the rock paintings. Many of the paintings depicting savannah animals are now dated to the Upper Pleistocene pluvial phase which ended approximately 11,000 years ago . . . Some of the animals depicted may have remained in relict highland areas after this time, and their extinction may have been at the hands of Man rather than the result of decreasing moisture. Shaw (1976) interprets the present evidence as indicating a continuous desiccation, with occasional relatively moist interludes, of the Saharan environment since the end of the last pluvial, and sees the development of the Saharan Neolithic at approximately 6000 BC not as a response to moister conditions but as an adaptation to a drying climate and decline of animals which had been previously hunted. Nevertheless, archaeological evidence for the existence of a pastoral Neolithic economy over large regions of the Sahara appears to indicate that the area was moister than at present, and the decline of the Saharan Neolithic during the third millennium BC is probably related to the establishment of present environmental and climatic conditions . . ."

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From **'Response of the West Antarctic Ice Sheet to CO_2-induced Climatic Warming', by Charles Bentley, Volume II, Part I of Environmental and Societal Consequences of a Possible CO_2-induced Climate Change, U.S. Department of Energy DOE/EV/10019-02, April 1982:**

". . . Nature of the Problem

"In recent years there has been a rapidly increasing interest in the possibility that the West Antarctic ice sheet . . . may shrink rapidly in the near future. The West Antarctic ice sheet is in principle more vulnerable than the East Antarctic or Greenland ice sheets because most of its rock bed lies far below sea level. Simplified theoretical analyses suggest that such an ice sheet h as no stable position between an extension all the way to the edge of the continental shelf, and complete disappearance. Such analyses, however, ignore such factors as the probable stabilizing influence of the confining borders and grounded areas of the ice shelves that fringe the grounded part of its perimeter, and changes in the snow precipitation rate as the size of the ice sheet changes.

"Models put forward within the last decade have suggested, partly from theory and partly by analogy with the Laurentide ice sheet which formerly covered much of North America, that if the West Antarctic ice sheet once starts to shrink rapidly, it could disappear completely in only a few centuries or even less. Concern about the possible vulnerability of the West Antarctic ice sheet has been emphasized by recent estimates of future climatic warming due to CO_2-buildup in the atmosphere. A recent report by the Climate Research Board of the National Research Council reviews several predictions made using global circulation models and finds them all to imply that a doubling of the CO_2 in the atmosphere, a level that may very well be reached before the middle of the 21st century, would cause a polar heating of 4°C to 8°C. **In view of the limited realism of the models, polar scientists must view these predictions with some reserve and press for more sophisticated models that predict changes in the polar environment, including the ocean, more realistically.** Nevertheless, the general urgency of the CO_2 problem has made it imperative to pay serious attention to the currently available, state-of-the-art, predictions . . .

"However, there is widespread disagreement about both the past and future behavior of the West Antarctic ice sheet; the 'disaster' model of rapid shrinkage is regarded as unconvincing by many glaciologists. Some point out that in historical times, during which oceanic tide gauges have been in operation, the ice sheet has not been melting at a rate corresponding to its complete disappearance in 200 years, because the rate of the sea level rise that would be implied is an order of magnitude greater than that observed. Others argue that warming will affect a marine ice sheet little until a critical threshold is surpassed, after which shrinkage may be rapid. According to this argument, during the present interglacial temperatures have remained below the critical level. During the last interglacial about 125,000 years ago, however, temperatures for a time were higher than during the present interglacial and may have exceeded the critical level: sea level was probably about 6 m higher than at present, and a likely explanation (although not the only one) is the disappearance of the West Antarctic ice at that time.

"Disputed though it may be, the possibility of a rapid shrinkage is great enough to demand further research. Before predictions can be made the current state of the ice sheet must first be determined . . .

"A concern in both the short-term and long-term contexts is that climate change today, whether natural or man-made, may lead to large and irreversible changes in the future, even if the climate change itself were reversed . . . the ice sheet is a complex dynamic system whose response to warming involves glaciological processes not yet fully understood . . .

"Still another uncertainty is introduced when one considers that the West Antarctic ice sheet straddles a large and volcanically active intracontinental rift system, rather than the stable cratonic environment that is assumed in most modeling. Regional heat flow values could be as much as twice those used in modeling the basal melting or basal sliding characteristics of the Laurentide ice sheet, and those higher values may influence the vulnerability of the ice sheet to external factors . . ."

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From **'Carbon Dioxide Review 1982', edited by William C. Clark, pending publication by Clarendon Press 1982:**

Preface [William C. Clark]

". . . The 'Why' of the CO_2 question is beginning to be understood, the 'So what' remains elusive. . .

"Official reports, though invaluable, are constrained by their official status. Because they are looked upon to provide authoritative assessments of present understanding and its policy implications, they have usually sought to reflect a comprehensive perspective and a consensus of informed scientific opinion. But the goal of authoritativeness has its costs. Comprehensive perspectives are gained at the expense of focused attention on the few key issues that might make a difference. Consensus is bought at the price of blunting open debate over major uncertainties and controversies. More generally, the goal of authoritativeness sits uncomfortably with the need for rapid but always tentative incorporation of new ideas and viewpoints into our evolving understanding of the CO_2 question. . .

"The Carbon Dioxide Question: Perspectives for 1982, by William C. Clark, Kerry H. Cook, Gregg Marland, Alvin M. Weinberg, Ralph M. Rotty, P.R. Bell, Linda J. Allison, Chester L. Cooper

". . . Our findings . . . are summarized below and examined at length in the remainder of this essay.

"- Fossil fuel burning throughout the world in 1981 released about 5.3 gigatons of carbon . . . to the atmosphere as CO_2. The growth rate of car-

bon emissions, which have averaged over 4.5%/yr from 1950 to 1973, has since dropped to less than 2.5%/yr . . . if all typically estimated quantities of recoverable fossil fuels were to be burned, maximum CO_2 concentration of less than 2000 parts per million (ppm) might be reached in two to three centuries.

"- Land-use changes (forest clearing, burning, reforestation, abandonment of farmland, etc.) throughout the world in 1981 led to the net release of less CO_2 than did fossil fuel burning. The best current estimates suggest a net release of about 2Gt/yr . . . No one any longer suggests land-use changes will produce a significant fraction of man's total future releases of CO_2. If there is a carbon dioxide problem in the future, it will be due to the burning of fossil fuels, not the burning of forests.

"- These revised estimates of the anthropogenic sources decrease considerably our estimate of the rate at which atmospheric CO_2 concentrations are likely to rise . . . Unless concerted actions to alter CO_2 release rates are taken, an atmospheric CO_2 level of more than 600 ppm seems most unlikely within the next 50 years but almost certain before the end of the next century.

". . . Ice core studies suggest that natural fluctuations of atmospheric carbon dioxide in the past have been larger than any changes yet produced by man. Moreover, natural increases in CO_2 may have followed or accompanied rather than preceded periods of natural climate warming . . .

"- An emerging consensus places the globally averaged temperature increased due to doubled CO_2 at 2-3°C. Lower estimates were based on models that left out important physical processes or scales of interaction. Models giving higher estimates have not been published in the open literature. The maximum global temperature increase likely to result from burning all known recoverable resources of fossil fuels is probably less than 6°C. Recent studies of the timing of climate response to increasing CO_2 suggests that the oceans may delay warming by several decades. Global rates of CO_2-induced temperature increase are likely to average about 0.1°C/decade for the remainder of this century and will probably never exceed 0.5°C/decade . . .

"- Recent research has focused attention on the detection of CO_2-induced climate change. Russian and English groups have published well-documented synopses of Northern Hemisphere temperature records extending back to 1881. Neither these nor other observational data, however, prove or disprove current theories of CO_2-induced climate change. The difficulty is that changes in climate occur naturally from other causes: solar variations, orbital relationships, volcanic aerosols, and 'trace' greenhouse gases like methane and ozone have all been implicated. These other factors could either mask or mimic a CO_2-induced warming . . .

"- The dominant effects of increased CO_2 will almost certainly occur through climate change . . . Unfortunately, we still lack estimates even of the order of magnitude of important effects at the regional and temporal scales of concern to real polities and markets . . .

. . .

"Future increases of atmospheric CO_2: the airborne fraction

". . . This relative insensitivity to the future growth rate of releases from changing land use applies as well to uncertainties in present releases of CO_2 from changing land use. It is often overlooked that if Woodwell's 20 Gt C/yr figure had been correct, the CO_2 problem would have been better, rather than worse . . . Future anthropogenic CO_2 releases—which could not for long include a land-use contribution of 20 Gt C/yr—would therefore go mostly into the oceanic and biospheric sinks, resulting in very slow rates in increase in atmospheric CO_2 . . . The future contribution of changing patterns of land use is substantially less important than that of changing growth rates in fossil fuel releases or changing values of the airborne fraction.

"How fast will concentrations of atmospheric CO_2 rise in the future? If either the Lovinses' view of the global future . . . turns out to be accurate or if the French nuclear energy strategy [*] is adopted by the rest of the developed world, then atmospheric CO_2 will rise very slowly indeed, perhaps not doubling its preindustrial level until the twenty-third century. If, on the other hand, the world returns to high energy growth rates that characterized the third quarter of the present century, and fuels this growth with coal, then many of us now working on the CO_2 question could see a 600 ppm world within our lifetime. All things considered, however, we probably have twice as much time to wait for doubled levels of atmospheric CO_2 as seemed likely even a few years ago.

"Changing the rate of CO_2 increase: a feasibility perspective

". . . Naive though such notions may be, it should not be overlooked that the future of CO_2 emissions could lie in the hands of a very few countries . . . any problem will most likely be a coal problem. But only three nations—the USSR, the United States, and China—are likely to produce all the coal worth worrying about . . . On the consumption side, over half of today's world energy use takes place in the same three countries. And despite the more rapid future growth anticipated for today's less developed countries, the USSR, the United States, and China are still likely to be consuming about half of the world's energy in 2025 . . .

" . . . The various factors that combine to determine global energy use and CO_2 emissions are characterized by profound inertia . . . This means that the slower rates of CO_2 growth referred to earlier are in one sense delusory. If world CO_2 production continues to grow at 2%/yr, the annual release by the time a concentration of 600 ppm is reached will be more than seven times what it is today. Atmospheric concentrations could be rising at 10 ppm/yr. If an upper limit to atmospheric CO_2 were thought desirable, action would obviously have to be taken to retard its rise well before the desired ceiling was reached . . .

"Though CO_2 concerns do not justify immediate advocacy of a zero-growth policy for fossil fuel use, it is possible that increased understanding of the CO_2 questions, coupled with a return to high economic growth rates, **could** justify serious efforts to constrain future growth of fossil fuel use beginning as early as 1990 . . .

The nature and timing of climate change

". . . We . . . confine ourselves here to highlighting a few areas of emerging consensus and continuing controversy . . .

"Temperature response

" . . . The NAS study in 1979 reviewed results available at that time [*] and concluded that the most likely ΔT_s [global average temperature rise with CO_2 doubling] was 3.0° ± 1.5°C. The 4.5°C upper estimate relies heavily on the highest estimates of ΔT_s. . . 3.5° and 3.9° [which] come from unpublished studies by Hansen and his colleagues at the National Aeronautics and Space Administration's Goddard Institute for Space Studies (GISS) . . . No other GCM result exceeds 3.0°C, and no other modeling result at all since 1963 has exceeded 3.2°C. A ΔT_s of 4.5°C would be considerably more alarming than the range of 2°-3°C thought to be the most likely by many other studies and reviews . . .

"Much controversy has surrounded the possible lower limit for ΔT_s. The National Academy's lower estimate is 1.5°C, and Manabe and Stouffer have published a 2.0°C result [*]. Three recent calculations, however, predict negligible ΔT_s's . . . These calculations are described in some detail by Ramanthan [*], Watts [*], and the forthcoming CO_2 assessment by the NAS. They show that the omission of key physical processes (notably the direct tropospheric heating by CO_2 and several aspects of the critical water vapor feedback) causes the low ΔT_s values . . .

Hydrological response

. . . One recent GCM result predicts that increasing CO_2 will lead to an increase in summer soil dryness at middle and high latitudes . . . When seasonal forcing is included in the model, warm temperatures occur earlier in the year, causing earlier snowmelt and spring rains and allowing earlier evaporation of soil moisture . . . Evaporation, precipitation, and cloud formation generally occur on space scales smaller than those resolved in GCMs. These processes are, therefore, parameterized

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and not treated explicitly in the models . . .

"Transient responses

". . . (S)teady-state and transient (time-dependent) temperature responses to increasing CO_2 differ, at least in part because of the heat capacity of the oceans. Moreover, the oceans may not cause a spatially uniform lag in the atmosphere's response to CO_2 forcing . . . different regions could respond at different rates . . . Bryan et al., however, found that temperature responses of the sea surface and the surface air become uniform with latitude after 25 and 10 years of integration, respectively, in an ocean model where CO_2 was quadrupled instantaneously [*]. The results of these few studies of the transient response indicate that the actual temperature increase will lag several decades behind the equilibrium temperature for a given CO_2 concentration. Over the next 50 years or so, actual temperatures seem likely to be about half of the steady-state predictions . . .

"Other causes of climate change: the detection problem

"Climate change occurs at all time scales. Besides increasing CO_2, potential causes include [*]:

"- Human activities that change the planetary albedo or add other climatically active gases to the atmosphere;

"- Natural changes in external boundary conditions, such as volcanic aerosols, the solar 'constant,' tidal effects, orbital variation, and, on a much longer time scale, the positions of continents and heights of mountains; and

"- 'Intransitivity,' or the possibilitly that the physical laws governing climate may allow for multiple long-term trajectories [*].

". . . (C)urrent conventional wisdom holds that nothing will be done about CO_2 until, at the minimum, a clear signal of actual warming is detected. Regardless of how warranted this view may prove, it seems evident that unambiguous detection of the predicted changes would affect substantially the terms and credibility of the CO_2 debate . . .

". . . Present observational evidence does not 'prove that a CO_2-induced climatic warming is occurring. On the other hand, it must be emphasized that the evidence does not allow the rejection of CO_2-climate theories . . .

"One mark of progress in detection is the refinement of long-term, extensive surface temperature records for the Northern Hemisphere. Partial records have been available for some time, but both English and Russian groups have recently published well-documented hemispheric synopses dating back to 1881 [*. . .]. Generally high correlations between these and other observational series suggest that methodological problems of combining individual stations and different instrumentation techniques across space and time are not insurmountable . . .

"The longer we are willing to wait for an answer to our detection question, the larger becomes the predicted climate change, the longer becomes the observational record, and the smaller becomes our risk of reaching erroneous detection conclusions. On the other hand, if we wait until the signal is unequivocal before doing anything, valuable opportunities may be missed and unnecessary costs incurred . . .

". . . What actions—social or scientific—are contingent upon detection? What are the relative penalties of undertaking those actions later than sooner, or mistakenly rather than never? Finally, to what extent will disagreements over premature 'first detections' mean that no one pays attention when and if we are assured of a CO_2-induced change? The absence of clear answers to such questions is all the more reason for insisting that they be asked in the rush to first detection . . .

"How will increasing atmospheric carbon dioxide affect people?

". . . (T)here are signs that a consensus on the basic elements of the 'So what?' question may be emerging, however distant even order-of-magnitude answers remain . . .

". . . Increasing CO_2 is hardly the major challenge facing humanity. Instead, it is reasonably viewed as one of the major chips that may figure in the balance of future world affairs . . . There is a growing recognition that a useful evaluation of CO_2 effects must weigh the larger influences of population growth, energy and economic development, and technical change as well.

"The most important effects of CO_2-induced climate change will probably involve the supplies of food, fiber, and water that people seek to obtain from their environment. Water supply implications of climate change have been less studied . . . They are receiving increasing attention, however, in light of the recent model predictions of increased summer dryness in middle latitudes in a warmer climate [*]. But both local climate change and a global rise in sea level, if large enough, could eventually affect where and how future populations can live . . ."

Note: [*] = reference deleted.

Potential sources of capital to halt the CO2 buildup

With several indicators now showing what appears to be the CO_2-greenhouse 'signal' through background climatic 'noise', the chances are greatly improved that political leaders may soon choose to halt the CO_2 buildup rather than risk a runaway greenhouse effect. Also the prominence of the CO_2 problem must eventually pervade the self-proclaimed environmental protection movement.

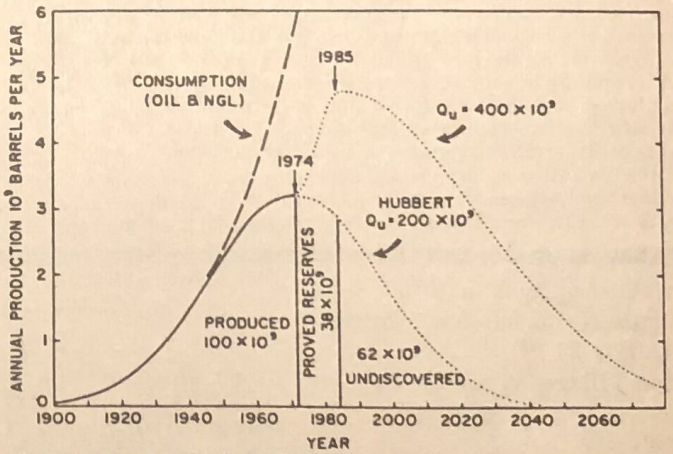
Neither 'conservation' of fossil fuels nor replacing high-CO_2-producing fuels with lesser-CO_2-producing ones can halt the buildup. Nor can the public be expected to willingly give up the current high level of energy consumption that provides a bountiful, varied diet, comfortable homes, convenient transportation, and many amenities including mechanized leisure, which people often resent an objective accounting of. (For instance, a study by a conservationist in the early 1970s found that more gasoline was consumed driving a fuel-efficient auto from Indiana to a wilderness outing in Montana than driving a large camping vehicle from Indiana to be parked at a Kentucky lake.)

A complete changeover to non-fossil energy systems is a monumental challenge that will require a great amount of imaginative engineering, capital, and cooperation. Presently the most attractive option economically is to replace fossil-energy systems as they wear out with non-fossil systems so that the normal replacement costs can be deducted from the new systems' costs to avoid accounting for non-fossil systems from a zero base.

A significant amount of energy capital might be freed soon from an unexpected source. The constitutionality of the Windfall Profits Act of 1980 is now being tested in the U.S. District Court in Cheyenne, Wyoming. Several billion dollars from this large tax on domestic oil production currently are designated by the Act to provide subsidies for planned synfuels plants, much to the chagrin of the anti-CO_2 advocates. In the event that the Act should be declared unconstitutional, this same amount of money would be available immediately for private enterprise to invest, and it is likely to be directed mainly toward petroleum exploration in the U.S. and elsewhere so long as no attractive alternative exists. The investment climate for the only non-fossil energy alternative presently feasible on a grand scale—nuclear fission—would have to be greatly improved by governmental agencies and private intervenors in order to capitalize on any opportunity to direct such investments toward halting the CO_2 buildup.

Another large source of energy capital consists of the vast funds which are continually being reinvested to replace depleted oil and gas wells in the U.S. (A previous large source of oil exploration funds—income tax shelters—dried up when the maximum personal tax rate was reduced from 70% to 50%.) The massive investments devoted to maintaining high levels of domestic production cannot forever continue to be successful. As M.O. Turner (currently president of the American Institute of Professional Geologists) pointed out in 1974, even if the amount of oil ultimately found in the U.S. should double in response to increased price, reduced taxes and less governmental regulation, "It would still require nearly 10 years to achieve a substantial increase in oil production, and the inevitable decline would only be delayed". (See graph.)

—W.N.B.



Oil production for the United States assuming ultimate recovery (Qu) of 200 x 10^9 bbls (Hubbert, 1971) compared with hypothetical production and decline for ultimate recovery of 400 x 10^9 bbls. Bothe curves show the eventual decline in annual production. (By M.O. Turner, 1974. Published in *The Professional Geologist.* May-June 1982.)