Environmental Effects of Increased Atmospheric Carbon Dioxide

ARTHUR B. ROBINSON ‡, SALLIE L. BALIUNAS †, WILLIE SOON †, AND ZACHARY W. ROBINSON ‡

‡Oregon Institute of Science and Medicine, 2251 Dick George Rd., Cave Junction, Oregon 97523 [info@oism.org]
†George C. Marshall Institute, 1730 K St., NW, Ste 905, Washington, DC 20006 [info@marshall.org]

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ABSTRACT A review of the research literature concerning the environmental consequences of increased levels of atmospheric carbon dioxide leads to the conclusion that increases during the 20th Century have produced no deleterious effects upon global weather, climate, or temperature. Increased carbon dioxide has, however, markedly increased plant growth rates. Predictions of harmful climatic effects due to future increases in minor greenhouse gases like CO_2 are in error and do not conform to current experimental knowledge.

SUMMARY

World leaders gathered in Kyoto, Japan, in December 1997 to consider a world treaty restricting emissions of ''greenhouse gases,'' chiefly carbon dioxide (CO_2), that are thought to cause ''global warming'' – severe increases in Earth's atmospheric and surface temperatures, with disastrous environmental consequences.

Predictions of global warming are based on computer climate modeling, a branch of science still in its infancy. The empirical evidence – actual measurements of Earth's temperature – shows no man-made warming trend. Indeed, over the past two decades, when CO_2 levels have been at their highest, global average temperatures have actually cooled slightly.

To be sure, CO_2 levels have increased substantially since the Industrial Revolution, and are expected to continue doing so. It is reasonable to believe that humans have been responsible for much of this increase. But the effect on the environment is likely to be benign. Greenhouse gases cause plant life, and the animal life that depends upon it, to thrive. What mankind is doing is liberating carbon from beneath the Earth's surface and putting it into the atmosphere, where it is available for conversion into living organisms.

RISE IN ATMOSPHERIC CARBON DIOXIDE

The concentration of CO_2 in Earth's atmosphere has increased during the past century, as shown in figure 1 (1). The annual cycles in figure 1 are the result of seasonal variations in plant use of carbon dioxide. Solid horizontal lines show the levels that prevailed in 1900 and 1940 (2). The magnitude of this atmospheric increase during the 1980s was about 3 gigatons of carbon (Gt C) per year (3). Total human CO_2 emissions – primarily from use of coal, oil, and natural gas and the production of cement – are currently about 5.5 GT C per year.

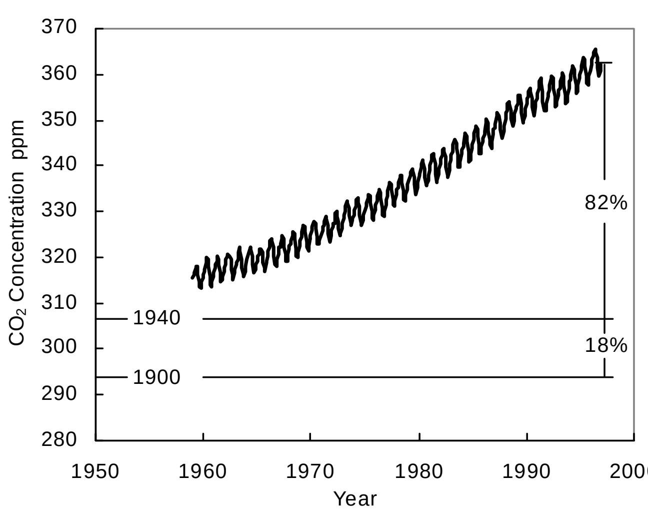

Fig. 1. Atmospheric CO_2 concentrations in parts per million by volume, ppm, at Mauna Loa, Hawaii. These measurements agree well with those at other locations (1). Periodic cycle is caused by seasonal variations in CO_2 absorption by plants. Approximate global level of atmospheric CO_2 in 1900 and 1940 is also displayed (2).

To put these figures in perspective, it is estimated that the atmosphere contains 750 Gt C; the surface ocean contains 1,000 Gt C; vegetation, soils, and detritus contain 2,200 Gt C; and the intermediate and deep oceans contain 38,000 Gt C (3). Each year, the surface ocean and atmosphere exchange an estimated 90 Gt C; vegetation and the atmosphere, 60 Gt C; marine biota and the surface ocean, 50 Gt C; and the surface ocean and the intermediate and deep oceans, 100 Gt C (3).

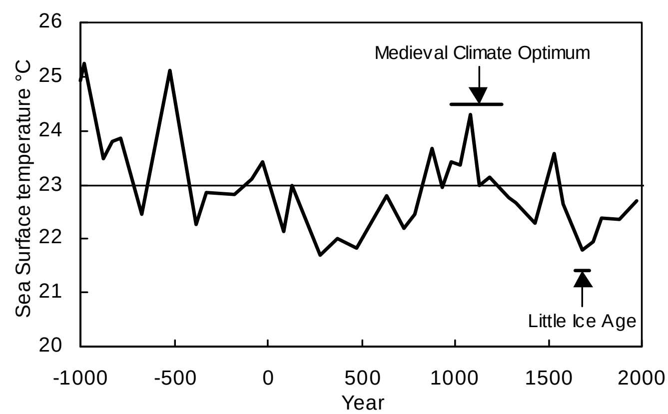

Fig. 2. Surface temperatures in the Sargasso Sea (with time resolution of about 50 years) ending in 1975 as determined by isotope ratios of marine organism remains in sediment at the bottom of the sea (7). The horizontal line is the average temperature for this 3,000 year period. The Little Ice Age and Medieval Climate Optimum were naturally occurring, extended intervals of climate departures from the mean.

So great are the magnitudes of these reservoirs, the rates of exchange between them, and the uncertainties with which these numbers are estimated that the source of the recent rise in atmospheric carbon dioxide has not been determined with certainty (4). Atmospheric concentrations of CO_2 are reported to have varied widely over geological time, with peaks, according to some estimates, some 20-fold higher than at present and lows at approximately 18th-Century levels (5).

The current increase in carbon dioxide follows a 300-year warming trend: Surface and atmospheric temperatures have been recovering from an unusually cold period known as the Little Ice Age. The observed increases are of a magnitude that can, for example, be explained by oceans giving off gases naturally as temperatures rise. Indeed, recent carbon dioxide rises have shown a tendency to follow rather than lead global temperature increases (6).

There is, however, a widely believed hypothesis that the 3 Gt C per year rise in atmospheric carbon dioxide is the result of the 5.5 Gt C per year release of carbon dioxide from human activities. This hypothesis is reasonable, since the magnitudes of human release and atmospheric rise are comparable, and the atmospheric rise has occurred contemporaneously with the increase in production of CO_2 from human activities since the Industrial Revolution.

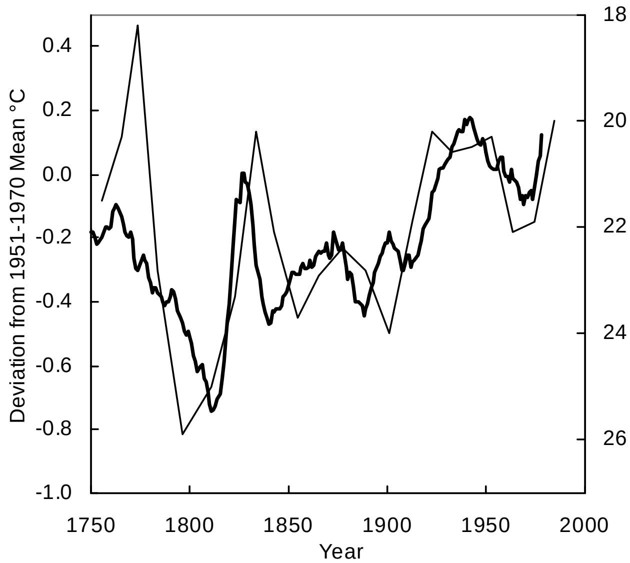

Fig. 3. Moving 11-year average of terrestrial Northern Hemisphere temperatures as deviations in ºC from the 1951-1970 mean – left axis and darker line (8,9). Solar magnetic cycle lengths – right axis and lighter line (10). The shorter the magnetic cycle length, the more active, and hence brighter, the sun.

ATMOSPHERIC AND SURFACE TEMPERATURES

In any case, what effect is the rise in CO_2 having upon the global environment? The temperature of the Earth varies naturally over a wide range. Figure 2 summarizes, for example, surface temperatures in the Sargaso Sea (a region of the Atlantic Ocean) during the past 3,000 years (7). Sea surface temperatures at this location have varied over a range of about 3.6 degrees Celsius (ºC) during the past 3,000 years. Trends in these data correspond to similar features that are known from the historical record.

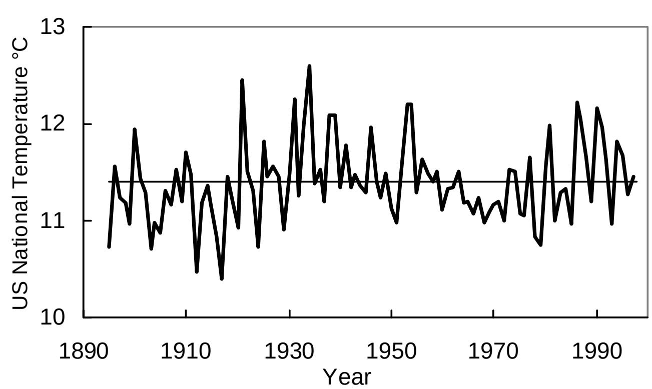

Fig. 4. Annual mean surface temperatures in the contiguous United States between 1895 and 1997, as compiled by the National Climate Data Center (12). Horizontal line is the 103-year mean. The trend line for this 103-year period has a slope of 0.022 ºC per decade or 0.22 ºC per century. The trend line for 1940 to 1997 has a slope of 0.008 ºC per decade or 0.08 ºC per century.

For example, about 300 years ago, the Earth was experiencing the ‘‘Little Ice Age.’’ It had descended into this relatively cool period from a warm interval about 1,000 years ago known as the ‘‘Medieval Climate Optimum.’’ During the Medieval Climate Optimum, temperatures were warm enough to allow the colonization of Greenland. These colonies were abandoned after the onset of colder temperatures. For the past 300 years, global temperatures have been gradually recovering (11). As shown in figure 2, they are still a little below the average for the past 3,000 years. The human historical record does not report ‘‘global warming’’ catastrophes, even though temperatures have been far higher during much of the last three millennia.

What causes such variations in Earth’s temperature? The answer may be fluctuations in solar activity. Figure 3 shows the period of warming from the Little Ice Age in greater detail by means of an 11-year moving average of surface temperatures in the Northern Hemisphere (10). Also shown are solar magnetic cycle lengths for the same period. It is clear that even relatively short, half-century-long fluctuations in temperature correlate well with variations in solar activity. When the cycles are short, the sun is more active, hence brighter; and the Earth is warmer. These variations in the activity of the sun are typical of stars close in mass and age to the sun (13).

Figure 4 shows the annual average temperatures of the United States as compiled by the National Climate Data Center (12). The most recent upward temperature fluctuation from the Little Ice Age (between 1900 and 1940), as shown in the Northern Hemisphere record of figure 3, is also evident in this record of U.S. temperatures. These temperatures are now near average for the past 103 years, with 1996 and 1997 having been the 42nd and 60th coolest years.

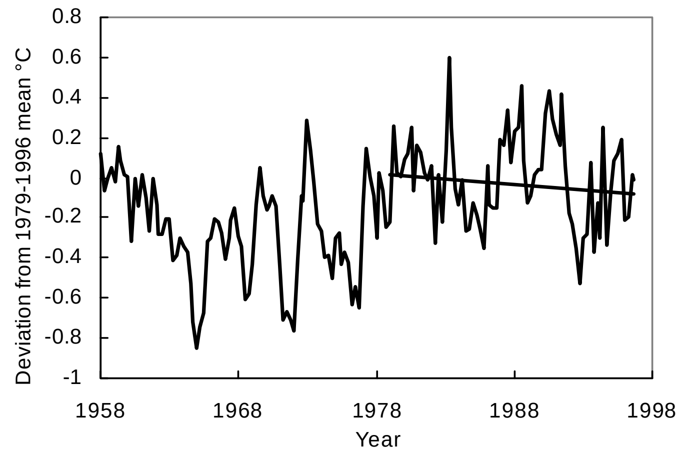

Fig. 5. Radiosonde balloon station measurements of global lower tropospheric temperatures at 63 stations between latitudes 90 N and 90 S from 1958 to 1996 (15). Temperatures are three-month averages and are graphed as deviations from the mean temperature for 1979 to 1996. Linear trend line for 1979 to 1996 is shown. The slope is minus 0.060 ºC per decade.

Especially important in considering the effect of changes in atmospheric composition upon Earth temperatures are temperatures in the lower troposphere – at an altitude of roughly 4 km. In the troposphere, greenhouse-gas-induced temperature changes are expected to be at least as large as at the surface (14). Figure 5 shows global tropospheric temperatures measured by weather balloons between 1958 and 1996. They are currently near their 40-year mean (15), and have been trending slightly downward since 1979.

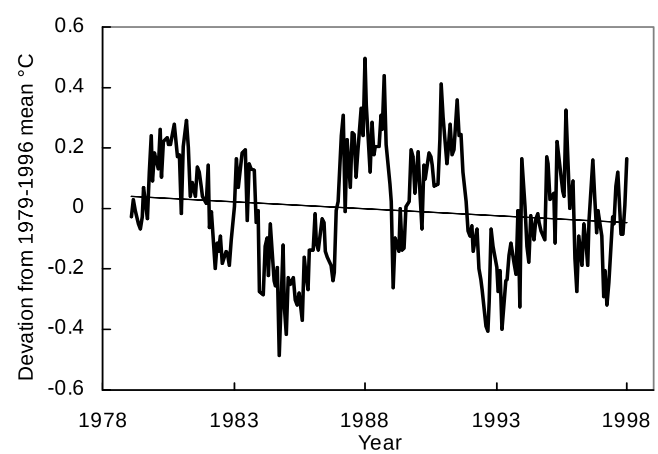

Fig. 6. Satellite Microwave Sounding Unit, MSU, measurements of global lower tropospheric temperatures between latitudes 83 N and 83 S from 1979 to 1997 (17,18). Temperatures are monthly averages and are graphed as deviations from the mean temperature for 1979 to 1996. Linear trend line for 1979 to 1997 is shown. The slope of this line is minus 0.047 ºC per decade. This record of measurements began in 1979.

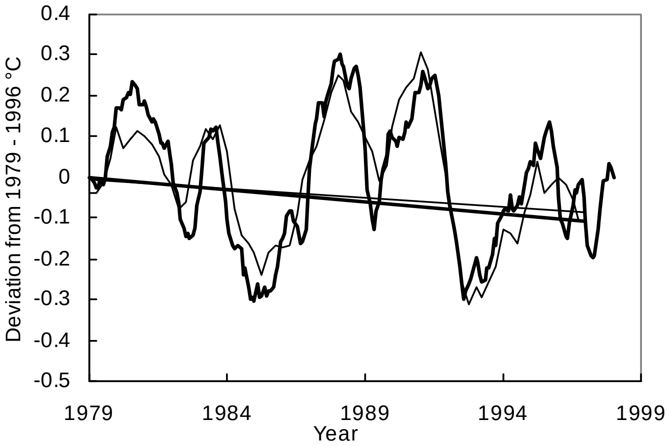

Fig. 7. Global radiosonde balloon temperature (light line) (15) and global satellite MSU temperature (dark line) (17,18) from figures 5 and 6 plotted with 6-month smoothing. Both sets of data are graphed as deviations from their respective means for 1979 to 1996. The 1979 to 1996 slopes of the trend lines are minus 0.060 ºC per decade for balloon and minus 0.045 for satellite.

Since 1979, lower-tropospheric temperature measurements have also been made by means of microwave sounding units (MSUs) on orbiting satellites (16). Figure 6 shows the average global tropospheric satellite measurements (17,18) – the most reliable measurements, and the most relevant to the question of climate change.

Figure 7 shows the satellite data from figure 6 superimposed upon the weather balloon data from figure 5. The agreement of the two sets of data, collected with completely independent methods of measurement, verifies their precision. This agreement has been shown rigorously by extensive analysis (19, 20).

While tropospheric temperatures have trended downward during the past 19 years by about 0.05 ºC per decade, it has been reported that global *surface* temperatures trended upward by about 0.1 ºC per decade (21, 22). In contrast to tropospheric temperatures, however, surface temperatures are subject to large uncertainties for several reasons, including the urban heat island effect (illustrated below).

During the past 10 years, U.S. surface temperatures have trended downward by minus 0.08 ºC per decade (12) while global surface temperatures are reported increased by plus 0.03 ºC per decade (23). The corresponding weather-balloon and satellite tropospheric 10-year trends are minus 0.4 ºC and minus 0.3 ºC per decade, respectively.

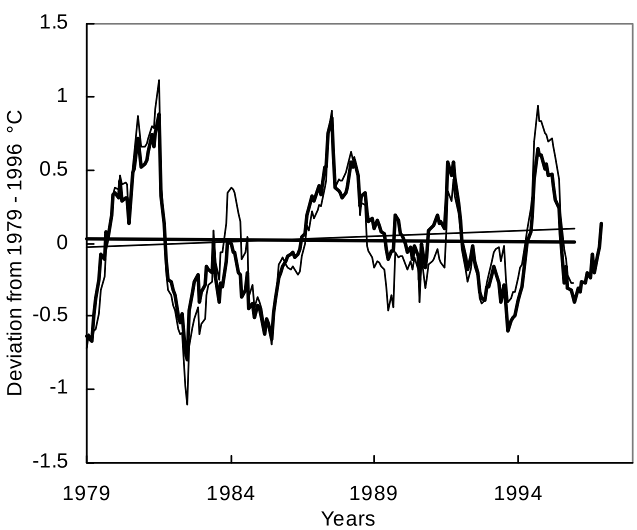

Figure 8. Tropospheric temperature measurements by satellite MSU for North America between 30º to 70º N and 75º to 125º W (dark line) (17, 18) compared with the surface record for this same region (light line) (24), both plotted with 12-month smoothing and graphed as deviations from their means for 1979 to 1996. The slope of the satellite MSU trend line is minus 0.01 ºC per decade, while that for the surface trend line is plus 0.07 ºC per decade. The correlation coefficient for the unsmoothed monthly data in the two sets is 0.92.

Disregarding uncertainties in surface measurements and giving equal weight to reported atmospheric and surface data and to 10 and 19 year averages, the mean global trend is minus 0.07 ºC per decade.

In North America, the atmospheric and surface records partly agree (20 and figure 8). Even there, however, the atmospheric trend is minus 0.01 per decade, while the surface trend is plus 0.07 ºC per decade. The satellite record, with uniform and better sampling, is much more reliable.

The computer models on which forecasts of global warming are based predict that tropospheric temperatures will rise at least as much as surface temperatures (14). Because of this, and because these temperatures can be accurately measured without confusion by complicated effects in the surface record, these are the temperatures of greatest interest. The global trend shown in figures 5, 6 and 7 provides a definitive means of testing the validity of the global warming hypothesis.

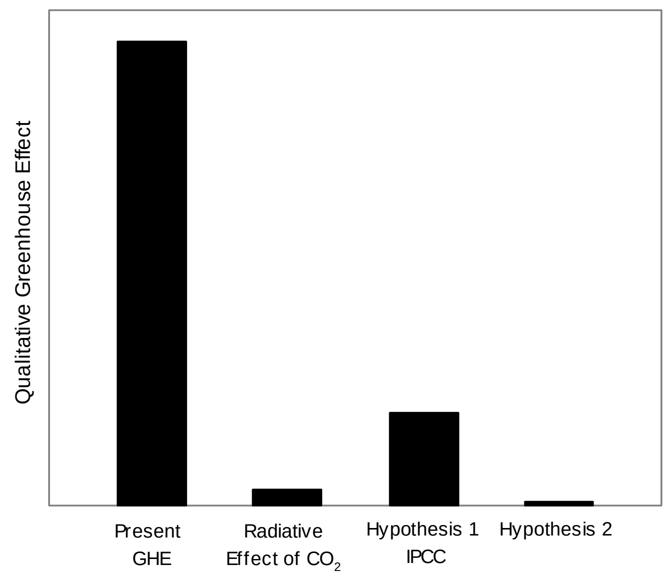

Fig. 9. Qualitative illustration of greenhouse warming. Present: the current greenhouse effect from all atmospheric phenomena. Radiative effect of CO_2: added greenhouse radiative effect from doubling CO_2 without consideration of other atmospheric components. Hypothesis 1 IPCC: hypothetical amplification effect assumed by IPCC. Hypothesis 2: hypothetical moderation effect.

THE GLOBAL WARMING HYPOTHESIS

There *is* such a thing as the greenhouse effect. Greenhouse gases such as H_2O and CO_2 in the Earth's atmosphere decrease the escape of terrestrial thermal infrared radiation. Increasing CO_2, therefore, effectively increases radiative energy input to the Earth. But what happens to this radiative input is complex: It is redistributed, both vertically and horizontally, by various physical processes, including advection, convection, and diffusion in the atmosphere and ocean.

When an increase in CO_2 increases the radiative input to the atmosphere, how and in which direction does the atmosphere respond? Hypotheses about this response differ and are schematically shown in figure 9. Without the greenhouse effect, the Earth would be about 14 ºC cooler (25). The radiative contribution of doubling atmospheric CO_2 is minor, but this radiative greenhouse effect is treated quite differently by different climate hypotheses. The hypotheses that the IPCC has chosen to adopt predict that the effect of CO_2 is amplified by the atmosphere (especially water vapor) to produce a large temperature increase (14). Other hypotheses, shown as hypothesis 2, predict the opposite – that the atmospheric response will counteract the CO_2 increase and result in insignificant changes in global temperature (25-27). The empirical evidence of figures 5-7 favors hypothesis 2. While CO_2 has increased substantially, the large temperature increase predicted by the IPCC models has not occurred (see figure 11).

The hypothesis of a large atmospheric temperature increase from greenhouse gases (GHGs), and further hypotheses that temperature increases will lead to flooding, increases in storm activity, and catastrophic world-wide climatological changes have come to be known

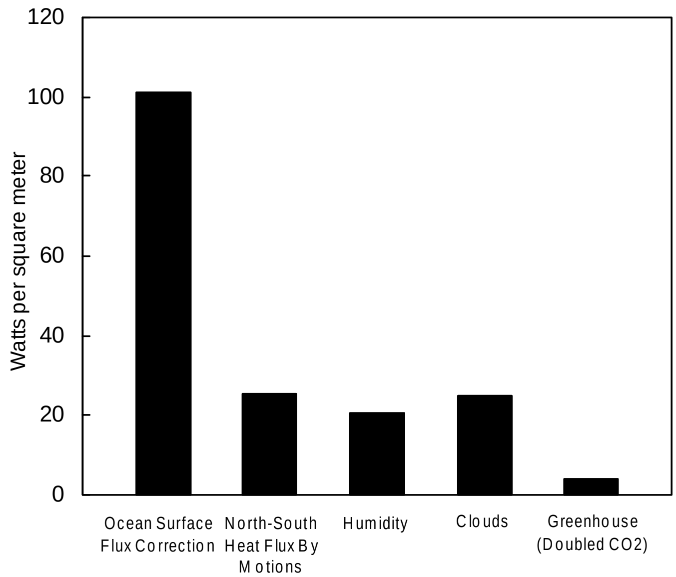

Fig. 10. The radiative greenhouse effect of doubling the concentration of atmospheric CO_2 (right bar) as compared with four of the uncertainties in the computer climate models (14, 28).

as ''global warming'' – a phenomenon claimed to be so dangerous that it makes necessary a dramatic reduction in world energy use and a severe program of international rationing of technology (29).

The computer climate models upon which ''global warming'' is based have substantial uncertainties. This is not surprising, since the climate is a coupled, non-linear dynamical system – in layman's terms, a very complex one. Figure 10 summarizes some of the difficulties by comparing the radiative CO_2 greenhouse effect with correction factors and uncertainties in some of the parameters in the computer climate calculations. Other factors, too, such as the effects of volcanoes, cannot now be reliably computer modeled.

Figure 11 compares the trend in atmospheric temperatures predicted by computer models adopted by the IPCC with that actually observed during the past 19 years – those years in which the highest atmospheric concentrations of CO_2 and other GHGs have occurred.

In effect, an experiment has been performed on the Earth during the past half-century – an experiment that includes all of the complex factors and feedback effects that determine the Earth's temperature and climate. Since 1940, atmospheric GHGs have risen substantially. Yet atmospheric temperatures have not risen. In fact, during the 19 years with the highest atmospheric levels of CO_2 and other GHGs, temperatures have fallen.

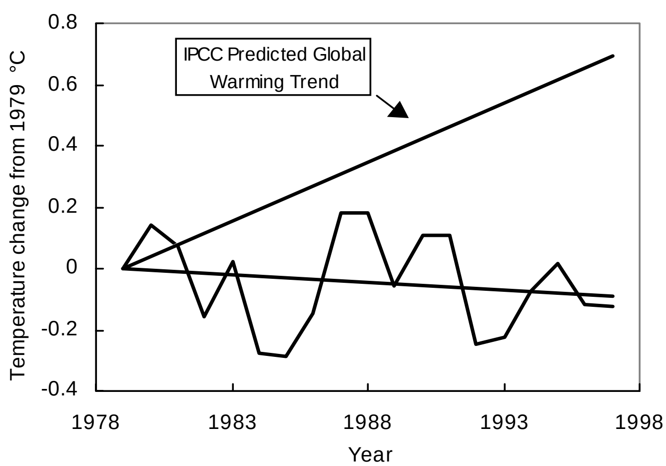

Fig. 11. Global annual lower tropospheric temperatures as measured by satellite MSU between latitudes 83 N and 83 S (17, 18) plotted as deviations from the 1979 value. The trend line of these experimental measurements is compared with the corresponding trend line predicted by International Panel on Climate Change (IPCC) computer climate models (14).

Not only has the global warming hypothesis failed the experimental test; it is theoretically flawed as well. It can reasonably be argued that cooling from negative physical and biological feedbacks to GHGs will nullify the initial temperature rise (26, 30).

The reasons for this failure of the computer climate models are subjects of scientific debate. For example, water vapor is the largest contributor to the overall greenhouse effect (31). It has been suggested that the computer climate models treat feedbacks related to water vapor incorrectly (27, 32).

The global warming hypothesis is not based upon the radiative properties of the GHGs themselves. It is based entirely upon a small initial increase in temperature caused by GHGs and a large theoretical amplification of that temperature change. Any comparable temperature increase from another cause would produce the same outcome from the calculations.

At present, science does not have comprehensive quantitative knowledge about the Earth's atmosphere. Very few of the relevant parameters are known with enough rigor to permit reliable theoretical calculations. Each hypothesis must be judged by empirical results. The global warming hypothesis has been thoroughly evaluated. It does not agree with the data and is, therefore, not validated.

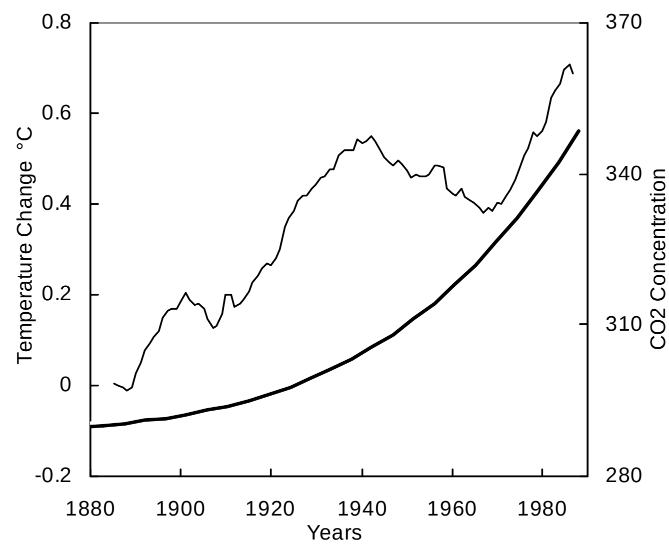

Figure 12. Eleven-year moving average of global surface temperature, as estimated by NASA GISS (23, 33, and 34), plotted as deviation from 1890 (left axis and light line), as compared with atmospheric CO_2 (right axis and dark line) (2). Approximately 82% of the increase in CO_2 occurred after the temperature maximum in 1940, as is shown in figure 1.

The new high in temperature estimated by NASA GISS after 1940 is not present in the radiosonde balloon measurements or the satellite MSU measurements. It is also not present in surface measurements for regions with comprehensive, high-quality temperature records (35). The United States surface temperature record (see figure 4) gives 1996 and 1997 as the 38th and 56th coolest years in the 20th century. Biases and uncertainties, such as that shown in figure 13, account for this difference.

GLOBAL WARMING EVIDENCE

Aside from computer calculations, two sorts of evidence have been advanced in support of the ''global warming'' hypothesis: temperature compilations and statements about global flooding and weather disruptions. Figure 12 shows the global temperature graph that has been compiled by National Aeronautic and Space Administration's Goddard Institute of Space Studies (NASA GISS) (23, 33, and 34). This compilation, which is shown widely in the press, does not agree with the atmospheric record because surface records have substantial uncertainties (36). Figure 13 illustrates part of the reason.

The urban heat island effect is only one of several surface effects that can confound compiled records of surface temperature. Figure 13 shows the size of this effect in, for example, the surface stations of California and the problems associated with objective sampling. The

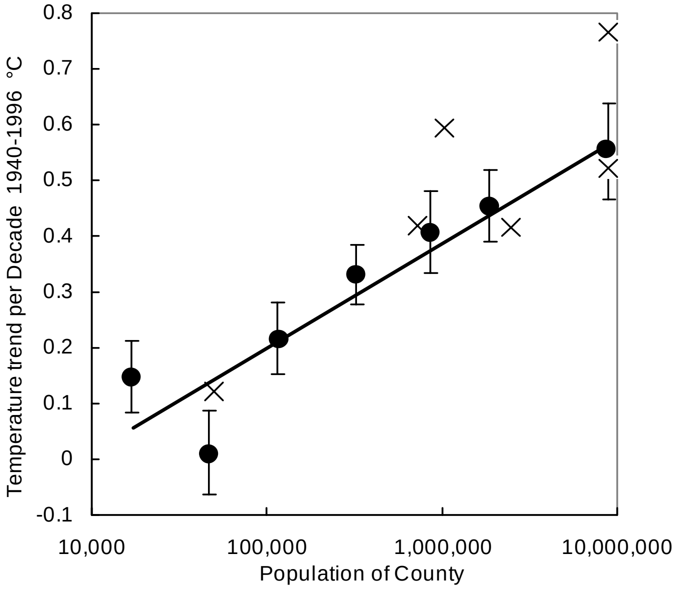

Fig. 13. Surface temperature trends for the period of 1940 to 1996 from 107 measuring stations in 49 California counties (39, 40). After averaging the means of the trends in each county, counties of similar population were combined and plotted as closed circles along with the standard errors of their means. The six measuring stations in Los Angeles County were used to calculate the standard error of that county, which is plotted alone at the county population of 8.9 million. The ''urban heat island effect'' on surface measurements is evident. The straight line is a least-squares fit to the closed circles. The points marked ''X'' are the six unadjusted station records selected by NASA GISS (23, 33, and 34) for use in their estimate of global temperatures as shown in figure 12.

East Park station, considered the best situated rural station in the state (37), has a trend since 1940 of minus 0.055 ºC per decade.

The overall rise of about plus 0.5 ºC during the 20th century is often cited in support of ''global warming'' (38). Since, however, 82% of the CO_2 rise during the 20th century occurred after the rise in temperature (see figures 1 and 12), the CO_2 increase cannot have caused the temperature increase. The 19th century rise was only 13 ppm (2).

In addition, incomplete regional temperature records have been used to support ''global warming.'' Figure 14 shows an example of this, in which a partial record was used in an attempt to confirm computer climate model predictions of temperature increases from greenhouse gases (41). A more complete record refuted this attempt (42).

Not one of the temperature graphs shown in figures 4 to 7, which include the most accurate and reliable surface and atmospheric temperature measurements available, both global and regional, shows any warming whatever that can be attributed to increases in greenhouse gases. Moreover, these data show that present day temperatures are not at all unusual compared with natural variability, nor are they changing in any unusual way.

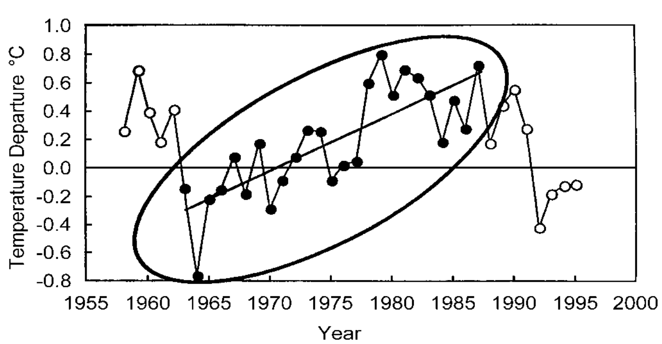

Fig. 14 The solid circles in the oval are tropospheric temperatures for the Southern Hemisphere between latitudes 30 S and 60 S, published in 1996 (41) in support of computer-model-projected warming. Later in 1996, the study was refuted by a longer set of data, as shown by the open circles (42).

SEA LEVELS AND STORMS

The computer climate models do not make any reliable predictions whatever concerning global flooding, storm variability, and other catastrophes that have come to be a part of the popular definition of ''global warming.'' (See Chapter 6, section 6-5 of reference 14.) Yet several scenarios of impending global catastrophe have arisen separately. One of these hypothesizes that rising sea levels will flood large areas of coastal land. Figure 15 shows satellite measurements of global sea level between 1993 and 1997 (43). The reported current global rate of rise amounts to only about plus 2 mm per year, or plus 8 inches per century, and even this estimate is probably high (43). The trends in rise and fall of sea level in various regions have a

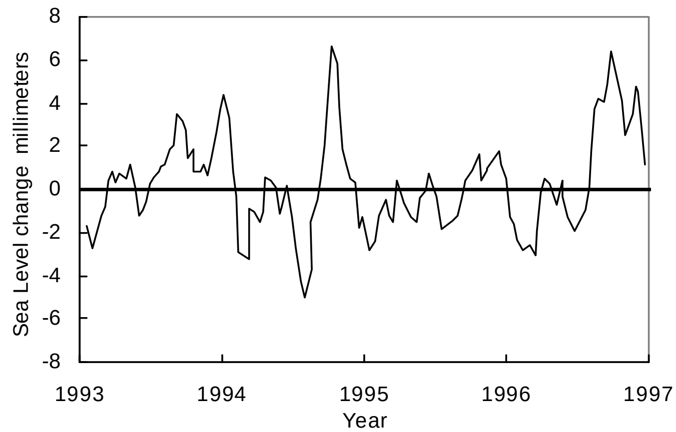

Fig. 15. Global sea level measurements from the Topex/Poseidon satellite altimeter for 1993 to 1997 (43). The instrument record gives a rate of change of minus 0.2 mm per year (43). However, it has been reported that 50-year tide gauge measurements give plus 1.8 mm per year. A correction of plus 2.3 mm per year was added to the satellite data based on comparison to selected tide gauges to get a value of plus 2.1 mm per year or 8 inches per century (43).

wide range of about 100 mm per year with most of the globe showing downward trends (43). Historical records show no acceleration in sea level rise in the 20th century (44). Moreover, claims that global warming will cause the Antarctic ice cap to melt and sharply increase this rate are not consistent with experiment or with theory (45).

Similarly, claims that hurricane frequencies and intensities have been increasing are also inconsistent with the data. Figure 16 shows the number of severe Atlantic hurricanes per year and also the maximum wind intensities of those hurricanes. Both of these values have been decreasing with time.

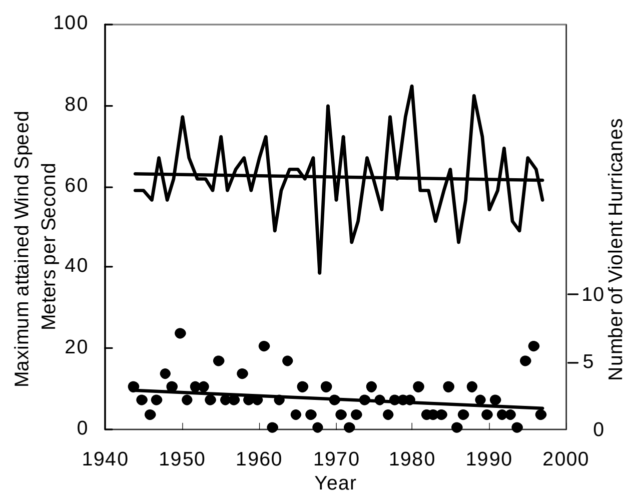

Fig. 16. Annual numbers of violent hurricanes and maximum attained wind speeds during those hurricanes in the Atlantic Ocean (46). Slopes of the trend lines are minus 0.25 hurricanes per decade and minus 0.33 meters per second maximum attained wind speed per decade.

As temperatures recover from the Little Ice Age, the more extreme weather patterns that characterized that period may be trending slowly toward the milder conditions that prevailed during the Middle Ages, which enjoyed average temperatures about 1 ºC higher than those of today. Concomitant changes are also taking place, such as the receding of glaciers in Montana's Glacier National Park.

FERTILIZATION OF PLANTS

How high will the carbon dioxide concentration of the atmosphere ultimately rise if mankind continues to use coal, oil, and natural gas? Since total current estimates of hydrocarbon reserves are approximately 2,000 times annual use (47), doubled human release could, over a thousand years, ultimately be 10,000 GT C or 25% of the amount now sequestered in the oceans. If 90% of this 10,000 GT C were absorbed by oceans and other reservoirs, atmospheric levels would approximately double, rising to about 600 parts per million. (This assumes that new technologies will not supplant the use of hydrocarbons during the next 1,000 years, a pessimistic estimate of technological advance.)

One reservoir that would moderate the increase is especially important. Plant life provides a large sink for CO_2. Using current knowledge about the increased growth rates of plants and assuming a doubling of CO_2 release as compared to current emissions, it has been estimated that atmospheric CO_2 levels will rise by only about 300 ppm before leveling off (2). At that level, CO_2 absorption by increased Earth biomass is able to absorb about 10 GT C per year.

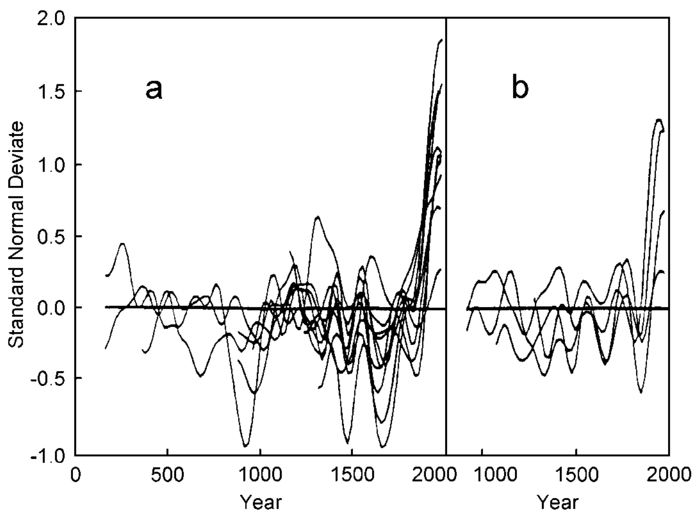

Fig. 17. Standard normal deviates of tree ring widths for (a) bristlecone pine, limber pine, and fox tail pine in the Great Basin of California, Nevada, and Arizona and (b) bristlecone pine in Colorado (48). The tree ring widths have been normalized so that their means are zero and deviations from the means are displayed in units of standard deviation.

As atmospheric CO_2 increases, plant growth rates increase. Also, leaves lose less water as CO_2 increases, so that plants are able to grow under drier conditions. Animal life, which depends upon plant life for food, increases proportionally.

Figures 17 to 22 show examples of experimentally measured increases in the growth of plants. These examples are representative of a very large research literature on this subject (49-55). Since plant response to CO_2 fertilization is nearly linear with respect to CO_2 concentration over a range of a few hundred ppm, as seen for example in figures 18 and 22, it is easy to normalize experimental measurements at different levels of CO_2 enrichment. This has been done in figure 23 in order to illustrate some CO_2 growth enhancements calculated for the atmospheric increase of about 80 ppm that has already taken place, and that expected from a projected total increase of 320 ppm.

As figure 17 shows, long-lived (1,000- to 2000-year-old) pine trees have shown a sharp increase in growth rate during the past half-century. Figure 18 summarizes the increased growth rates of young pine seedlings at four CO_2 levels. Again, the response is remarkable,

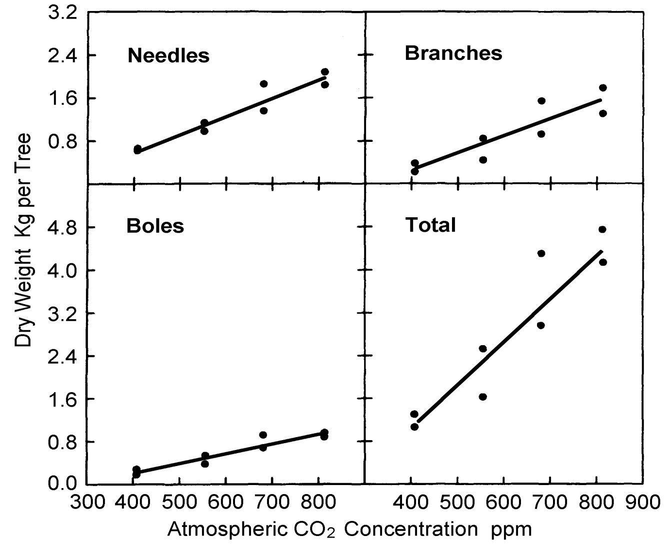

Fig. 18. Young Eldarica pine trees were grown for 23 months under four CO_2 concentrations and then cut down and weighed. Each point represents an individual tree (56). Weights of tree parts are as indicated.

with an increase of 300 ppm more than tripling the rate of growth.

Figure 19 shows the 30% increase in the forests of the United States that has taken place since 1950. Much of this increase is likely due to the increase in atmospheric CO_2 that has already occurred. In addition, it has been reported that Amazonian rain forests are increasing their vegetation by about 34,000 moles (900 pounds) of carbon per acre per year (57), or about two tons of biomass per acre per year.

Figure 20 shows the effect of CO_2 fertilization on sour orange trees. During the early years of growth, the bark, limbs, and fine roots of sour orange trees growing in an atmosphere with 700 ppm of CO_2 exhibited rates of growth more than 170% greater than those at 400 ppm. As the trees matured, this slowed to about 100%. Meanwhile, orange production was 127% higher for the 700 ppm trees.

Trees respond to CO_2 fertilization more strongly than do most other plants, but all plants respond to some extent. Figure 21 shows the response of wheat grown under wet conditions and when the wheat was stressed by lack of water. These were open-field experiments. Wheat was grown in the usual way, but the atmospheric CO_2 concentrations of circular sections of the fields were increased by means of arrays of computer-controlled equipment that released CO_2 into the air to hold the levels as specified.

While the results illustrated in figures 17-21 are remarkable, they are typical of those reported in a very large number of studies of the effect of CO_2 concentration upon the growth rates of plants (49-55).

Figure 22 summarizes 279 similar experiments in which plants of

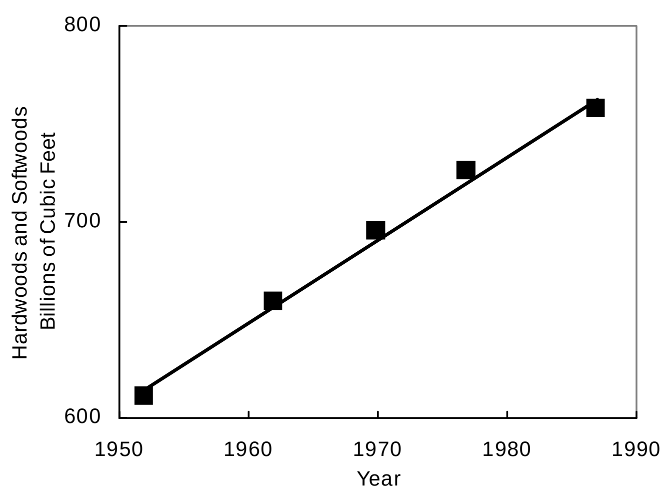

Fig. 19. Inventories of standing hardwood and softwood timber in the United States compiled from *Forest Statistics of the United States* (58).

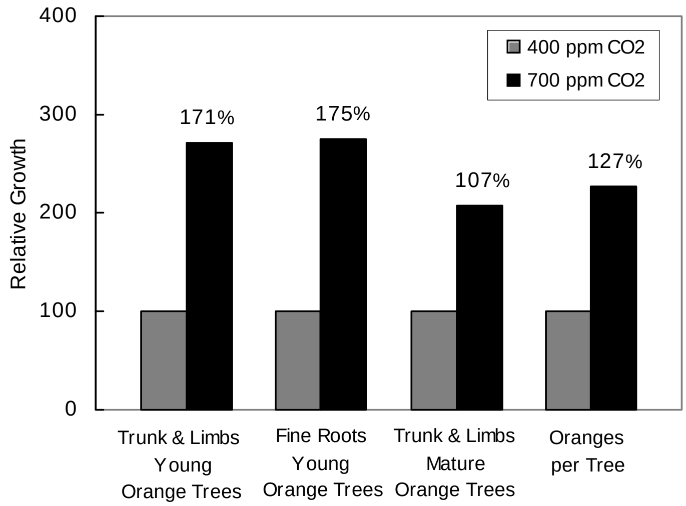

Fig. 20. Relative trunk and limb volumes and fine root biomass of young sour orange trees; and trunk and limb volumes and numbers of oranges produced per mature sour orange tree per year at 400 ppm CO_2 (light bars) and 700 ppm CO_2 (dark bars) (59, 60). The 400 ppm values were normalized to 100. The trees were planted in 1987 as one-year-old seedlings. Young trunk and limb volumes and fine root biomass were measured in 1990. Mature trunk and limb volumes are averages for 1991 to 1996. Orange numbers are averages for 1993 to 1997.

various types were raised under CO_2-enhanced conditions. Plants under stress from less-than-ideal conditions – a common occurrence in nature – respond more to CO_2 fertilization. The selections of species shown in figure 22 were biased toward plants that respond less to CO_2 fertilization than does the mixture actually covering the Earth, so figure 22 underestimates the effects of global CO_2 enhancement.

Figure 23 summarizes the wheat, orange tree, and young pine tree enhancements shown in figures 21, 20, and 18 with two atmospheric CO_2 increases – that which has occurred since 1800 and is believed to be the result of the Industrial Revolution and that which is projected for the next two centuries. The relative growth enhancement of trees by CO_2 diminishes with age. Figure 23 shows young trees.

Clearly, the green revolution in agriculture has already benefited from CO_2 fertilization; and benefits in the future will likely be spectacular. Animal life will increase proportionally as shown by studies of 51 terrestrial (63) and 22 aquatic ecosystems (64). Moreover, as shown by a study of 94 terrestrial ecosystems on all continents except Antarctica (65), species richness (biodiversity) is more positively correlated with productivity – the total quantity of plant life per acre – than with anything else.

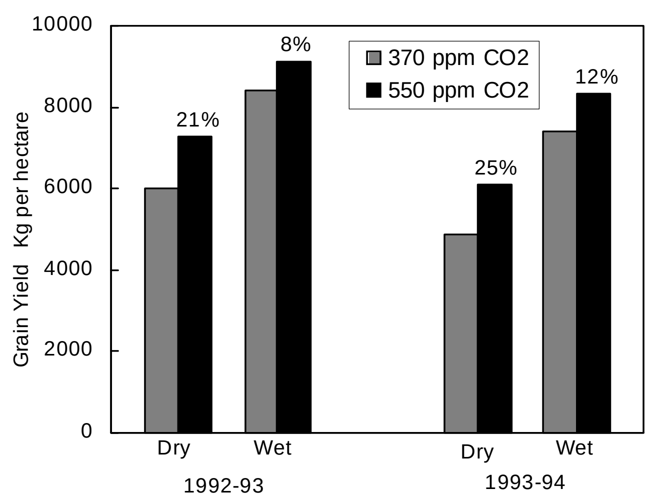

Fig. 21. Grain yields from wheat grown under well watered and poorly watered conditions in open field experiments (61, 62). Average CO_2-induced increases for the two years were 10% for wet and 23% for dry conditions.

DISCUSSION

There are no experimental data to support the hypothesis that increases in carbon dioxide and other greenhouse gases are causing or can be expected to cause catastrophic changes in global temperatures or weather. To the contrary, during the 20 years with the highest carbon dioxide levels, atmospheric temperatures have decreased.

We also need not worry about environmental calamities, even if the current long-term natural warming trend continues. The Earth has been much warmer during the past 3,000 years without catastrophic effects. Warmer weather extends growing seasons and generally improves the habitability of colder regions. ''Global warming,'' an invalidated hypothesis, provides no reason to limit human production of CO_2, CH_4, N_2O, HFCs, PFCs, and SF_6 as has been proposed (29).

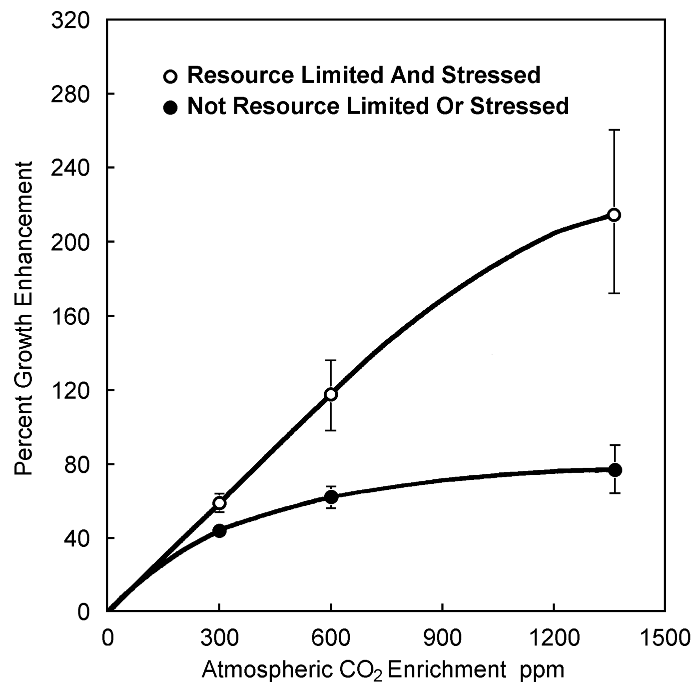

Fig. 22. Summary data from 279 published experiments in which plants of all types were grown under paired stressed (open circles) and unstressed (closed circles) conditions (66). There were 208, 50, and 21 sets at 300, 600, and an average of about 1350 ppm CO_2, respectively. The plant mixture in the 279 studies was slightly biased toward plant types that respond less to CO_2 fertilization than does the actual global mixture and therefore underestimates the expected global response. CO_2 enrichment also allows plants to grow in drier regions, further increasing the expected global response.

Human use of coal, oil, and natural gas has not measurably warmed the atmosphere, and the extrapolation of current trends shows that it will not significantly do so in the foreseeable future. It does, however, release CO_2, which accelerates the growth rates of plants and also permits plants to grow in drier regions. Animal life, which depends upon plants, also flourishes.

As coal, oil, and natural gas are used to feed and lift from poverty vast numbers of people across the globe, more CO_2 will be released into the atmosphere. This will help to maintain and improve the health, longevity, prosperity, and productivity of all people.

Human activities are believed to be responsible for the rise in CO_2 level of the atmosphere. Mankind is moving the carbon in coal, oil, and natural gas from below ground to the atmosphere and surface, where it is available for conversion into living things. We are living in an increasingly lush environment of plants and animals as a result of the CO_2 increase. Our children will enjoy an Earth with far more plant and animal life as that with which we now are blessed. This is a wonderful and unexpected gift from the Industrial Revolution.

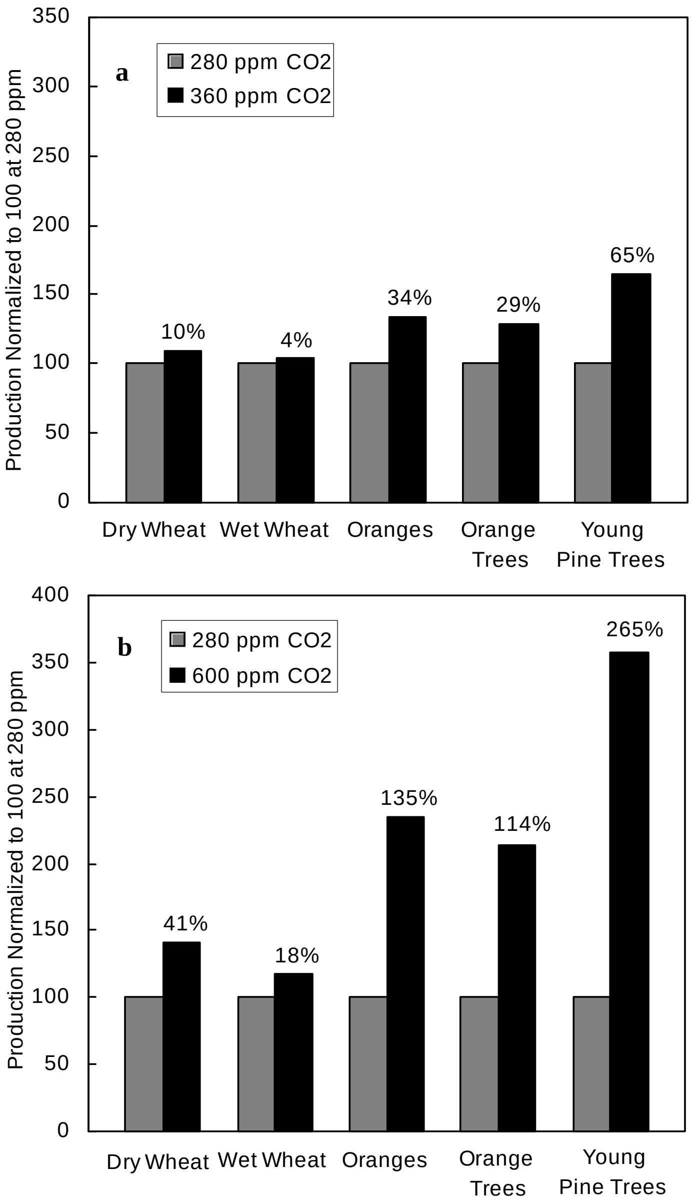

Fig. 23. Calculated growth rate enhancement of wheat, young orange trees, and very young pine trees already taking place as a result of atmospheric enrichment by CO_2 during the past two centuries (a) and expected to take place as a result of atmospheric enrichment by CO_2 to a level of 600 ppm (b).

In this case, these values apply to pine trees during their first two years of growth and orange trees during their 4th through 10th years of growth. As is shown in figure 20, the effect of increased CO_2 gradually diminishes with tree age, so these values should not be interpreted as applicable over the entire tree lifespans. There are no longer-running controlled CO_2 tree experiments. Yet, even 2,000 year old trees still respond significantly as is shown in figure 17.

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