GLOBAL WARMING UPDATE

RECENT SCIENTIFIC FINDINGS

George C. Marshall Institute
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I. INTRODUCTION

A great deal of research has been devoted in recent years to the technical problems involved in calculating the man-made greenhouse effect. This study, the third in a series by scientists associated with the George C. Marshall Institute, considers recent findings on the extent of human-induced global warming. One of the main reasons for concern over this aspect of climate change is the fact that the earth's temperature has risen by approximately half a degree Celsius in the last 100 years. This increase coincided with a substantial increase in the amount of carbon dioxide and other greenhouse gases in the atmosphere. The increased concentration of these greenhouse gases in the atmosphere is apparently the result of human activity, such as burning coal, oil and gas.

Several scientific groups have concluded that the greenhouse effect caused by the manmade emissions of carbon dioxide and other gases has produced much or all of the recent rise in global temperatures. They predict that there will be an increase in greenhouse gases equivalent to a doubling of carbon dioxide by the middle of the 21st century, and that this will cause the temperature of the earth to rise by as much as 5°C.

According to these scientists, a temperature rise of this magnitude would cause major disruptions in the earth's ecosystem, including severe summer drought in the mid-western United States and other agricultural regions. The

worst-case scenarios predict a major rise in sea level as a result of the greenhouse warming, inundating areas of New York, Miami and other coastal cities as well as low-lying river deltas and islands. The lives of hundreds of millions of individuals would be disrupted.

The available data on climate change, however, do not support these predictions, nor do they support the idea that human activity has caused, or will cause, a dangerous increase in global temperatures. As we make this statement, we are aware that it contradicts widespread popular opinion, as well as the technical judgments of some of our colleagues on the magnitude and importance of the greenhouse warming. But it would be imprudent to ignore the facts on global warming that have accumulated over the last two years. These facts indicate that theoretical estimates of the greenhouse problem have greatly exaggerated its seriousness.

Enormous economic stakes ride on forthcoming government decisions regarding carbon taxes and other restrictions on CO_2 emissions. Due attention must therefore be given to the scientific evidence, no matter how contrary to popular opinion its implications appear to be.

II. ARE THE GREENHOUSE FORECASTS RELIABLE?

Concentrations of carbon dioxide and other greenhouse gases in the atmosphere have increased substantially in the last 100 years, mostly as a result of burning coal, oil and gas, as well as other human activities. The increase in the totality of greenhouse gases is equivalent to a 50% rise in carbon dioxide. According to computer simulations of the greenhouse effect, this large increase in greenhouse gases should have produced a rise of about 0.5°C in the average temperature of the earth's surface. The dashed line in Figure 1 on the following page shows the 0.5°C temperature rise in the last 100 years, calculated from a theoretical model of the effect of greenhouse gases.

The theoretical result for the greenhouse effect is in good agreement with actual measurements of the average temperature on the earth's surface, shown as the solid line in Figure 1. The measurements reveal that the earth's temperature has gone up about 0.5°C since 1880. This agreement seems to suggest that the increase in greenhouse gases was the cause of the temperature rise. It implies further that the greenhouse predictions for the next century must be taken seriously.

However, another look at Figure 1 places this conclusion in doubt. The chart shows that nearly the entire ob-

served rise of 0.5°C occurred before 1940. However, most of the manmade carbon dioxide entered the atmosphere after 1940. The greenhouse gases cannot explain a temperature rise that occurred before these gases existed.

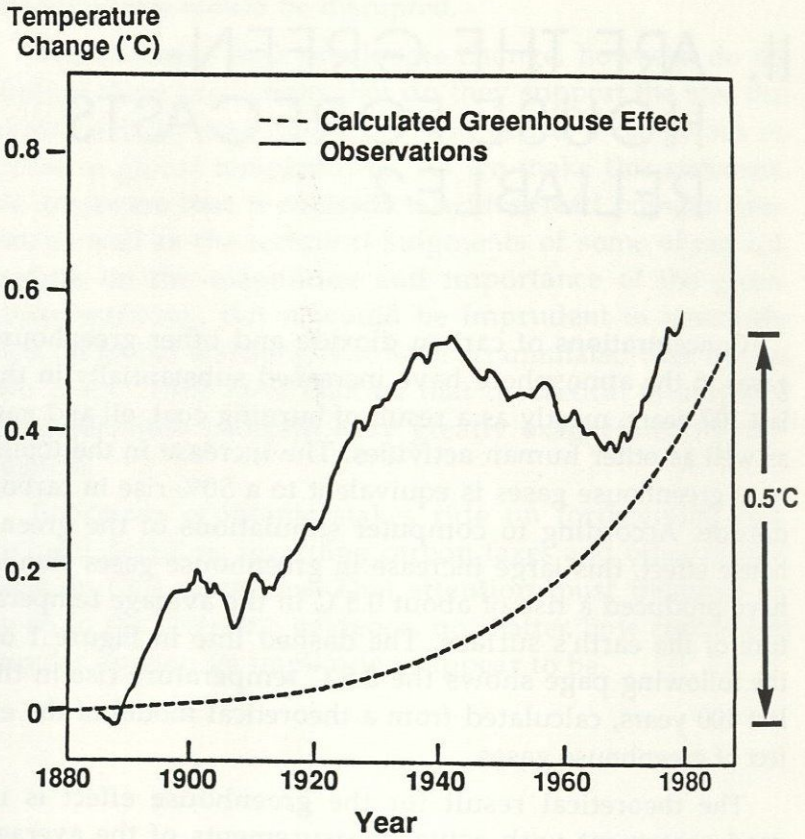

Figure 1. Calculated warming due to the increase in greenhouse gases in the last 100 years (dashed line), compared with observed temperature changes (solid line). [1]

Furthermore, from 1940 to 1970, carbon dioxide built up rapidly in the atmosphere. According to the greenhouse calculation, the temperature of the earth should have risen rapidly. Instead, the chart shows that the temperature actually *dropped*.

The fall in temperature between 1940 and 1970 is particularly difficult to explain as a greenhouse phenomenon, because, as noted, this entire period was one of strong economic growth and increasing emission of greenhouse gases. According to the greenhouse predictions, it should have been a period of rapidly accelerating temperature rise. Even allowing for a delay in the earth's response to the increase in greenhouse gases, the 1970s should have been appreciably warmer than the 1940s.

The fact that this was not the case indicates that the greenhouse effect could not have been the only cause or even the principal cause of the climate change that took place between 1880 and 1970. As the report of the U.N. Intergovernmental Panel on Climate Change states:

> "It is still not possible to attribute any or all of the warming of the last century to greenhouse gas-induced climate change."[2]

Heating by greenhouse gases cannot explain the rapid rise in temperature prior to 1940, and cannot explain the fact that the temperature dropped between 1940 and 1970. *The predictions of the greenhouse theory are contradicted by the temperature record to such a degree as to indicate that the anthropogenic greenhouse effect has not had any significant impact on global climate in the last 100 years.*

The Missing Greenhouse Signal

There are other checks on the reliability of the greenhouse forecasts. These forecasts are based on computer simulations of global climate that not only predict a general warming of the earth, but also predict certain special characteristics of the warming. These special characteristics make up the so-called *greenhouse signal.*

For example, calculations of the greenhouse effect show a particularly large temperature increase at high latitudes. A pattern of warming that showed greater temperature increases at high latitudes than at low latitudes would be a sign that the greenhouse effect is probably the cause of the warming. It would be a "greenhouse signal."

According to the climate calculations, several types of greenhouse signal should have appeared clearly in the temperature records for the last 100 years. The detection of these signals would indicate that the greenhouse effect is already substantial and the greenhouse theories are relatively reliable.

Warming in the Northern Hemisphere. All the greenhouse calculations predict that there should have been more warming in the Northern Hemisphere than in the Southern Hemisphere, as a result of the increase in greenhouse gases in the last 100 years. According to these calculations, the Northern Hemisphere should already be warmer than the Southern Hemisphere by about 0.5°C.[3] *However, the observed temperatures show no significant difference in temperature trends in the two hemispheres.*[4] (Figure 2, p. 7)

Warming at High Latitudes. The greenhouse computations also predict more warming at high latitudes than at tropical latitudes, particularly in the Northern Hemisphere. According to one representative calculation, the high latitudes should already have warmed by about 1°C more than the low latitudes as a consequence of the greenhouse warming.[5] *However, the temperature records shown in Figure 3 (p. 8) indicate no significant difference in trends between the high and low latitudes.*

In fact, the records for the period after 1940 show no net warming trend at all, although it was in this more recent period that most of the greenhouse gases entered the atmosphere. Instead, the charts show a greater warming trend at low latitudes than at high latitudes in the last 50 years —

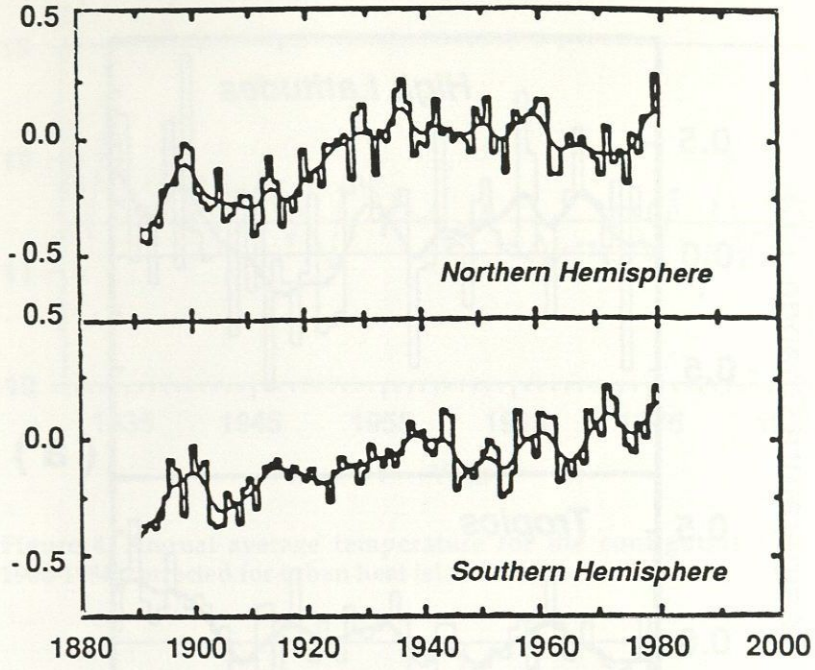

Figure 2. Observations of mean temperature in the Northern and Southern Hemispheres.

directly opposite to the greenhouse predictions.

Warming in the U.S. According to other greenhouse computations, the continental U.S. should have warmed 0.5-1.0°C in the last 100 years, with most of the warming expected in the last 50 years. *However, a compilation of temperature records for the U.S. reveals no statistically significant warming trend over the last 50 years.*[6] (Figure 4, p. 9) It is striking that in the largest area in the world for which reliable, well-distributed temperature records are available, the greenhouse predictions are not confirmed.

Rapid Warming in the 1980s. Moreover, the greenhouse theory indicates that a rapid rise in global temperatures should have occurred in the 1980s, as a result of the large

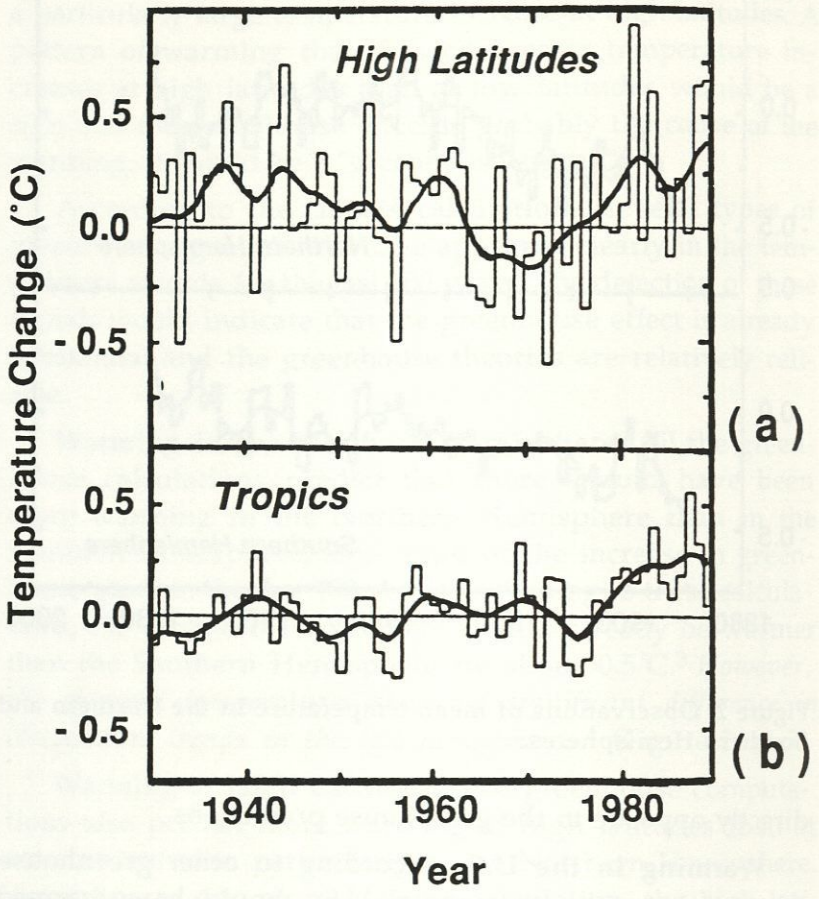

Figure 3. Observed variations in annual mean temperature in (a) high latitudes in the Northern Hemisphere; (b) the tropics.

increase in greenhouse gases in recent years. *However, precise satellite measurements of global temperatures show no significant warming during the 1980s.*[7] Figure 5 (p. 9) shows the results of satellite measurements of the earth's temperature, obtained by looking down at the surface of the planet from above.

The satellite results do not show the predicted trend to

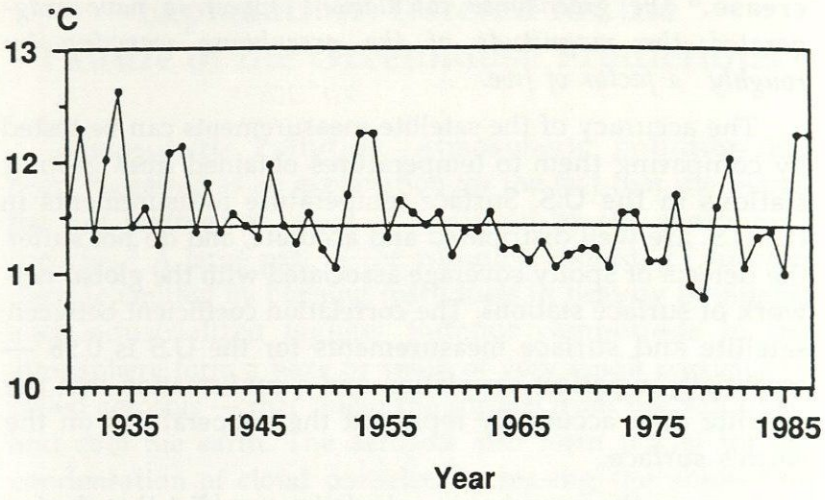

Figure 4. Annual average temperature for the contiguous U.S. 1900-1984, corrected for urban heat island effect.

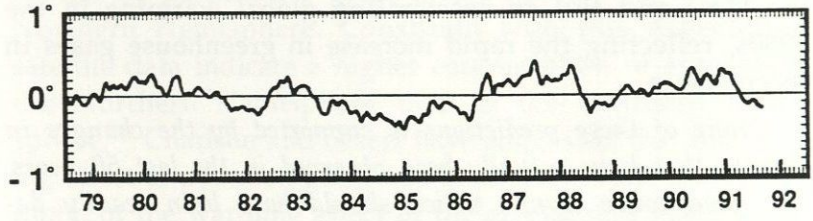

Figure 5. Satellite measurements of global average temperatures from 1979-1991. The data show an average increase of 0.06°C over the decade of the 1980s. The 1992 IPCC Report gives 0.3°C/decade as the consensus of the computer models for the increase in greenhouse warming over a decade — five times the observed increase in the 1980s.

higher temperatures in the 1980s. Temperature increases in some years are balanced by decreases in others. The average increase in the satellite data is 0.06°C/decade. The IPCC report gives .3°C/decade as the consensus of the theoretical predictions for the greenhouse-induced temperature in-

crease.[8] *The greenhouse calculations appear to have exaggerated the magnitude of the greenhouse warming by roughly a factor of five.*

The accuracy of the satellite measurements can be tested by comparing them to temperatures obtained from ground stations in the U.S. Surface temperature measurements in the U.S. are well distributed and accurate, and do not suffer the defects of spotty coverage associated with the global network of surface stations. The correlation coefficient between satellite and surface measurements for the U.S is 0.98 — essentially a perfect correlation and a confirmation that the satellite data accurately represent the temperatures on the earth's surface.

In sum, the greenhouse calculations predict that during the last 50 years we should have detected: (i) a greater temperature rise in the Northern Hemisphere than the Southern Hemisphere; (ii) a greater temperature rise at high latitudes than at low latitudes; (iii) a substantial warming in the U.S.; and (iv) an accelerating global warming in the 1980s, reflecting the rapid increase in greenhouse gases in recent years.

None of these predictions is supported by the changes in climate that have actually been observed in the last 50 years. The greenhouse signal, which should have been readily detectable in temperature records, is not present.

It is clear that since the greenhouse gases have a heat-insulating effect, some degree of warming is likely to occur if their concentration in the atmosphere is increased. The question is: How much? If the greenhouse effect were as large as the commonly accepted forecasts predict, it would have produced a clear greenhouse signal in the temperature records of the last 100 years. But the signal is not present. Apparently, the greenhouse effect is considerably smaller than has been estimated.

Explanations Offered for the Failure of the Greenhouse Predictions

Atmospheric Pollution. Atmospheric pollution has been suggested as an explanation for the fact that the planet has not warmed as much as predicted by the greenhouse theories.[9] A large part of the pollution consists of sulphur dioxide emitted by burning fossil fuels in heavily populated and industrialized regions. Sulphur compounds in the atmosphere form a haze or smog of very small particles — called aerosols — that shield the surface from the sun's rays and cool the earth. The aerosols also form nuclei for the condensation of cloud particles, increasing the amount of cloud cover and cloud brightness. The increased cloud cover further shields and cools the earth.

Effect of Pollution on Northern Hemisphere Temperatures. The cooling effect of the pollutant particles or aerosols should be particularly great in the heavily industrialized Northern Hemisphere. Consistent with this expectation, satellite data indicate a higher concentration of aerosols in the Northern Hemisphere than in the Southern Hemisphere.[10] Charlson and others have suggested that this cooling effect of pollution-generated haze and clouds may cancel much of the warming effect of the greenhouse gases in the Northern Hemisphere.[11,12]

However, an excess of Northern over Southern Hemisphere aerosols would not, in itself, explain the failure of the Northern Hemisphere to warm as predicted. For that explanation to be valid, the concentration of Northern Hemisphere aerosols would have to have been increasing rapidly at the same time that the greenhouse gases were increasing. If the concentration of Northern Hemisphere aerosols were approximately constant in time, this unchanging factor could not mask the effect of a rapid rise in the concentration of greenhouse gases in recent decades. Northern Hemi-

sphere temperatures would be lowered uniformly by the aerosols, but a rising trend due to the accelerating greenhouse effect would still be apparent against the constant background.

But Thomas Karl of the National Climate Data Center points out that sulphur emissions in the U.S. have neither been increasing rapidly, nor have they been approximately constant. They have, in fact, been decreasing in the U.S. since 1970.[13] Therefore, they could not have masked the expected greenhouse temperature increase in the U.S.

Is it possible that pollution in Eastern Europe and the former USSR has spread to the U.S. and masked the greenhouse effect here? Aerosol pollution in these regions, which has probably increased in recent decades, could be carried to the U.S. by the large-scale circulation of the atmosphere, thus explaining the fact that the U.S. has not warmed in recent years.

However, this explanation cannot be valid, because the lifetime of anthropogenic aerosols in the atmosphere is only a matter of days.[14] Thus, pollution originating in Eastern Europe, and travelling eastward with the general circulation of the atmosphere, does not stay in the air long enough to affect conditions in the U.S.*

Karl, et al. also note that no evidence exists for the view that an increase in cloud cover has been caused by pollution. The regions and seasons of increased cloud cover within the U.S. do not correspond with the regions and seasons of maximum pollutant concentration, as would be expected if pollution were the cause of the increased cloud cover. [15]

Delays in Warming Caused by Oceans. The warming of

* The general movement of air masses in the Northern Hemisphere is from west to east. Pollution originating in Europe must travel nearly 3/4 of the way around the globe to reach the U.S. The trip takes weeks, but, as noted, the aerosols are washed out of the atmosphere in days.

the earth lags behind the actual increase in greenhouse gases because the oceans absorb much of this heat, but warm up very slowly. It has been suggested that this delay in warming caused by the oceans can amount to decades or even centuries, and may account for the fact that the greenhouse signal has not yet appeared in the temperature record.[16]

However, the calculations including the effect of ocean circulation demonstrate a much shorter delay, with approximately 3/4 of the full warming appearing in the first 10 years after the increase in greenhouse gases takes place.[17] (Figure 6) The effect of this delay on the greenhouse warming to date would be a reduction of 0.1°C, which is not enough to explain the absence of the greenhouse signal.

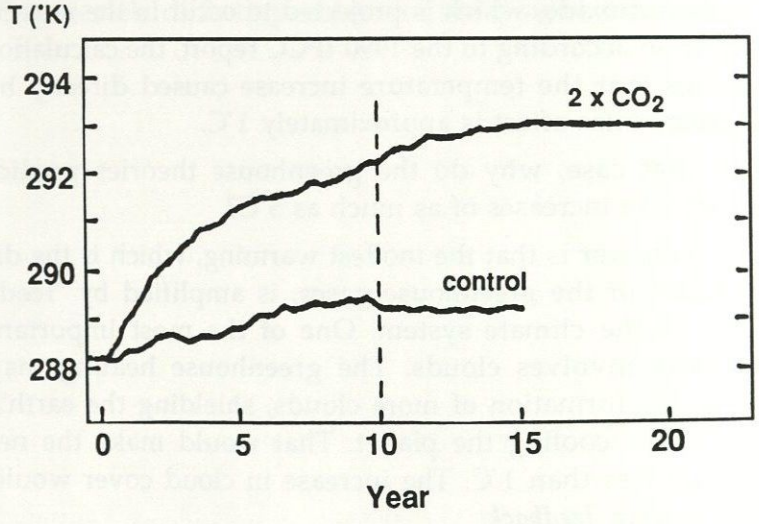

Figure 6. Globally averaged surface-air temperature versus time, showing the response of the earth's climate to a doubling of CO_2. The calculations, which include the effects of ocean circulation, show that approximately 3/4 of the full warming produced by CO_2 occurs within 10 years.

Reasons for the Poor Quality of the Greenhouse Forecasts

It is straightforward to calculate the temperature increase directly caused by the addition of greenhouse gases to the atmosphere. These gases absorb certain wavelengths in the infrared radiation emitted from the planet's surface. The amount absorbed can be calculated from properties of the greenhouse gases that have been measured in the laboratory. The absorbed radiation heats the atmosphere. The atmosphere radiates part of the absorbed heat up to space and part back to the surface of the earth. The heat returned to the earth's surface increases its temperature, producing the greenhouse warming. These processes constitute the direct heating effect of the greenhouse gases.

For a greenhouse gas increase equivalent to a doubling of carbon dioxide, which is projected to occur in the next 50 years or so according to the 1990 IPCC report, the calculation indicates that the temperature increase caused directly by the greenhouse effect is approximately 1°C.

In that case, why do the greenhouse theories predict temperature increases of as much as 5°C?

The answer is that the modest warming, which is the direct effect of the greenhouse gases, is amplified by "feedbacks" in the climate system. One of the most important feedbacks involves clouds. The greenhouse heating may lead to the formation of more clouds, shielding the earth's surface and cooling the planet. That would make the net warming less than 1°C. The increase in cloud cover would be a *negative feedback.*

Or the greenhouse warming may lower the relative humidity of the air, leading to the formation of fewer clouds. That means more sunlight reaches the ground, and the final warming is greater than 1°C. In this case, the clouds

have created a *positive feedback.*

Which is correct? Do clouds make the greenhouse effect larger or smaller? No one knows. In a recent study of the greenhouse effect, the U.K. Meteorological Office made a change in the properties of the clouds assumed in the calculation and found that the predicted greenhouse warming dropped from 5.2°C to 1.9°C. Results obtained by other climate forecasting groups range from a warming of less than 1°C in the next century to as much as 5°C, largely as a consequence of the different assumptions by each group regarding cloud feedbacks and other types of feedbacks.

A global warming of 1°C, spread over 50 years or more, might not matter much, but 5°C would be a serious problem. Narrowing this enormous range of uncertainty would require calculating, *inter alia,* how large the cloud feedback is, and whether it is positive or negative, and that presents an extremely difficult problem for the climate forecaster.

III. THE CAUSE OF RECENT CLIMATE CHANGES

Yet the earth's temperature did rise in the last 100 years. Since there is no discernible greenhouse signal in the temperature record, and moreover, most of the temperature rise occurred before the bulk of the greenhouse gases were in the atmosphere, it is clear that the rise was not caused by the greenhouse effect. But what *did* cause the earth to become warmer in that interval?

In 1991, a paper appeared in *Science* which shed light on this question.[18] This paper was based on a new analysis of changes in the sun. It showed an almost perfect correlation between the ups and downs of solar activity on the surface of the sun and the ups and downs of global temperature change.

The correlation is shown in Figure 7 on the following page. The figure shows that all the significant changes in global temperature in the last 100 years faithfully track the changes in solar surface activity. The agreement is too close to be readily dismissed as coincidence. This close correlation is in contrast to the marked disagreement between the global temperature record for the last 100 years and the predictions of the greenhouse theory, shown in Figure 1.

What physical mechanism can explain the correlation

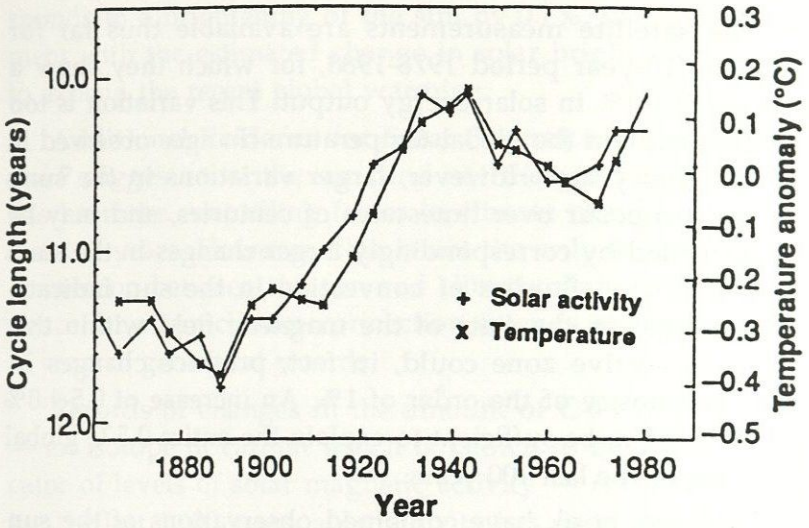

Figure 7. Comparison between global temperatures (x) and solar surface magnetic activity, measured by the length of the solar cycle(+). The cycle length has an inverse correlation with sunspot numbers: short cycles mean high sunspot numbers and a high level of surface magnetic activity.

between global climate and the sun's surface magnetic activity? This magnetic activity is caused by strong magnetic fields which erupt on the sun's surface in sunspots, bursts of energetic particles and radiation. The changes in the surface magnetic fields do not in themselves transfer enough energy to the earth and its atmosphere to have a direct impact on climate.

However, satellite observations of the sun have shown that when its surface magnetism changes, its energy output also changes. When the sun's surface magnetic activity goes up, its energy output increases; when the surface magnetic activity diminishes, its energy output decreases.

Apparently, the changes in surface magnetism and changes in energy output are two independent manifestations of a deeper phenomenon occurring in the body of the

sun — two effects of one underlying cause.*

The satellite measurements are available thus far for only the 10-year period 1978-1988, for which they show a change of 0.1% in solar energy output. This variation is too small to explain the global temperature changes observed in the last 100 years. However, larger variations in the sun's magnetism occur over timescales of centuries, and may be accompanied by correspondingly larger changes in the sun's energy output. Studies of convection in the sun indicate that changes in the state of the magnetic field within the sun's convective zone could, in fact, produce changes in solar luminosity of the order of 1%. An increase of 0.5-1.0% is estimated to be sufficient to explain the entire 0.5°C global warming of the last 100 years.

Baliunas, et al. have combined observations of the sun and solar-type stars to obtain the relationship between solar luminosity and changes in the sun's surface magnetic activity.[19] Their results indicate that the marked increase in

* One possible physical mechanism relating solar magnetism to solar luminosity is the inhibiting effect of magnetic fields in the solar interior on convective energy transport in the sun.

Suppose, for instance, that when the surface of the sun is not erupting in sunspots and flares, the magnetic field in the solar interior is a smooth, well-ordered azimuthal field. At such times, this subsurface field is most effective in blocking the convective transport of energy to the surface, and the sun's luminosity decreases. At these times, the surface is also relatively quiet and undisturbed, i.e., the sun is at a minimum in its 11-year cycle.

When the surface of the sun is magnetically active, with many sunspots, it is plausible to assume that the subsurface magnetic field is in a relatively disordered state. At such times, the field is less effective in blocking the transport of energy, hence the sun is more luminous.

These qualitative conclusions agree with the satellite observations, which show that the sun's luminosity and surface magnetic activity rise and fall in phase. The key to the physical mechanism is the suggestion that when the average magnetic field on the sun's surface is at a minimum, the subsurface field is at a maximum.

solar surface activity recorded in the last 100 years corresponds to a brightening of the sun by 0.7%, in good agreement with the estimated change in solar brightness needed to explain the recent global warming.

Additional Evidence for Solar Control of Climate. Figure 7 suggests that the sun, and not the greenhouse effect, has been the controlling factor in climate changes over the last 100 years. However, this is not the only evidence for a connection between the sun and climate change. Other evidence for a sun-climate connection extends over thousands of years of geological records.

Records of changes in the amount of C-14 in tree rings — an isotope of carbon which is known to be a good indicator of levels of solar magnetic activity — reveal that during the last 6,000 years, solar activity has risen and fallen by substantial amounts every 200-300 years. Figure 8 (p. 20) shows one of the carbon-14 records. A comparison between the carbon-14 record and the record of ancient climates, obtained from geologic evidence of the advance and retreat of glaciers, reveals that all but one of the major decreases in solar activity in the last 8000 years were accompanied by cold spells in the climate record.

The most recent and best-known instance was the Little Ice Age of the 17th century. This cool period in the earth's climate history coincided with the pronounced 17th-century lull in solar activity known as the Maunder Minimum.

Evidence for a Small Greenhouse Effect

Figure 7 shows changes in solar activity and changes in global temperatures in the last 100 years so closely correlated that the two curves seem to be wrapped around one another. This close correlation suggests a means of estimating

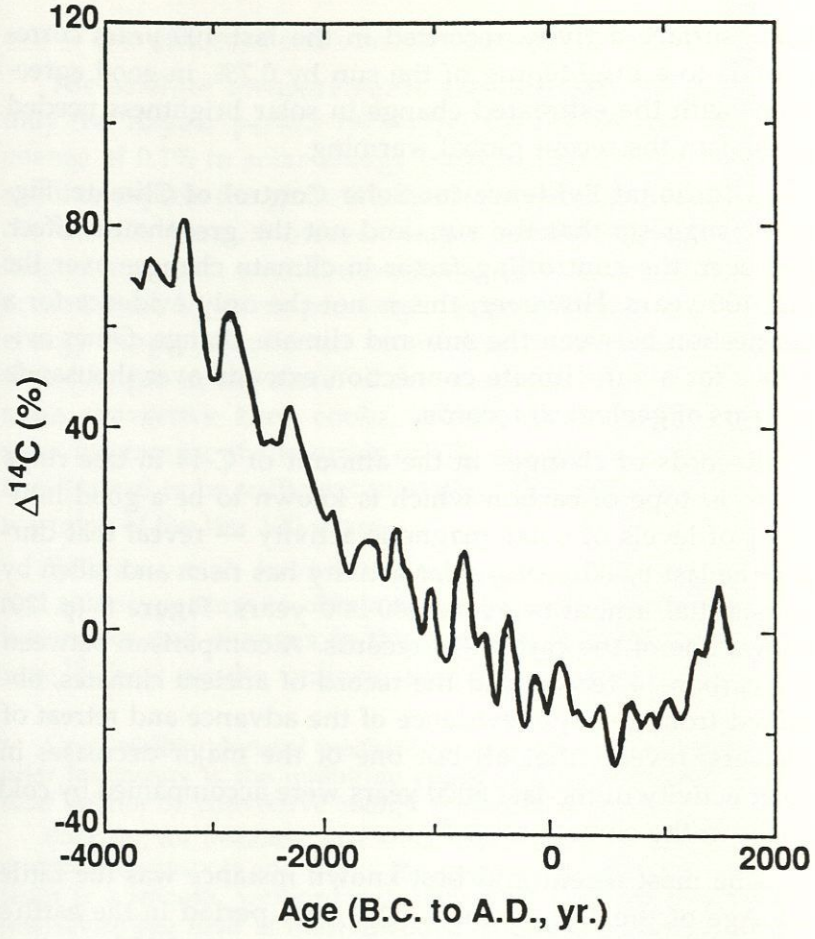

Figure 8. Concentrations of Carbon-14 in tree rings over the last 6,000 years, resulting from changes in solar magnetic activity. The average peak-to-peak separation is approximately 200 years. The decline from 4,000 B.C. to 500 A.D., and subsequent rise, are the product of long-term changes in the geomagnetic field and are not related to solar activity.

a limit to the size of the greenhouse effect.

As noted on page 4, the calculations of the greenhouse effect show that prior to 1940 its climate impact must have been fairly modest, no more than 0.1°C. Thus, the green-

house effect could not have been responsible for the entire 0.5°C rise that was observed to occur prior to 1940. An increase in the sun's brightness is a more likely candidate for the cause of that early rise.

However, according to the calculations, after 1940 the greenhouse effect should have increased rapidly. Thus, if the calculations were correct, in the post-1940 period the pattern of global temperature changes should have begun to show a marked divergence from the pattern of solar activity changes, as greenhouse gases began to have an appreciable impact on the climate. The divergence should have become particularly pronounced in recent decades.

But this gradually developing separation between the temperature chart and the solar activity chart does not appear. The agreement between the two charts continues to be remarkably close after 1940. Allowing for the uncertainties in both charts, room remains for only a very small greenhouse contribution of a few tenths of a degree at most, in the post-1940 period.

As noted, the increase in the concentration of all the greenhouse gases in the last 100 years is equivalent to a 50% rise in the amount of carbon dioxide in the atmosphere. It appears that this increase has produced a modest global warming of no more than a few tenths of a degree. If the 50% increase in carbon dioxide up to the present time has produced a warming of a few tenths of a degree, the 100% rise projected for the next century will produce a warming of twice that amount, or roughly half a degree in round numbers.

This upper limit on global warming in the next century is five times smaller than the value cited in the IPCC report as "the best estimate" for the magnitude of the greenhouse effect produced by a 100% rise in CO_2. It is, however, consistent with the greenhouse warming inferred from satellite temperature measurements (p. 9).

IV. NEW RESULTS ON GLOBAL FLOODING

Major new findings relating both to the greenhouse effect and to its impact on human affairs appear almost monthly in the technical literature. With roughly one billion dollars a year going into climate change research in the U.S. alone, such rapid progress is not surprising. New results on the magnitude of the threat posed by global warming have already been reported in the first two months of 1992.

Threat of Major Floods

Melting of the polar ice sheets and a consequent rise in sea level have been viewed as among the most alarming potential effects of the greenhouse warming. An increase in sea level of several feet, projected by some experts, would cause destructive flooding of low-lying areas over the entire globe. The 1990 IPCC report gives a "best estimate" of about 66 cm. (2 feet) for the sea level rise expected from the greenhouse effect in the next century.[20] A March 1992 press article refers to global warming as the source of "rising seas inundating island nations, wiping out coastal marshlands and creating millions of environmental refugees."

New Evidence for a Future Drop in Sea Level. However,

recent research indicates that sea levels will fall rather than rise in response to the greenhouse warming. In 1992, a Canadian-American team of scientists reported that the warming could be expected to lead to a growth in the size of the ice sheets, locking up more water and causing sea levels to drop by as much as two feet in the next century.[21]

Their conclusions were based on an examination of the geological record over the last 130,000 years. This examination indicated that a warm climate, similar to that projected by greenhouse calculations for the next century, favored the formation and growth of ice sheets, rather than their shrinkage.

How can a temperature increase cause ice sheets to grow? The answer to this seeming paradox is that Arctic and Antarctic air is normally too cold to hold much moisture. Therefore, these regions experience relatively little snowfall. With rising temperatures, the air holds more moisture, snowfall increases, and the size of the ice sheets also increases.

In 1980, some experts considered a 25-foot rise in sea level in the next century to be a possibility.[22] In 1985, the estimate was reduced to three feet.[23] In 1989, it was reduced again to one foot. Now the predicted "rise" has passed through zero heading downward, and become negative.[24] (Figure 9, p. 24) According to these results, the problem of rising sea levels and destructive floods has disappeared for the foreseeable future.

Lessons Drawn from the History of Sea Level Predictions. Two lessons may be learned from this series of developments. One is that the flooding of coastal cities and low-lying islands like the Maldives no longer appears to be a serious possibility. That is important, because some journalists and policymakers still refer to a catastrophic rise in sea level as a major threat requiring prompt measures aimed at restricting the burning of coal, oil and gas.

The second lesson is that the apocalyptic forecasts of scientists in this area must be greeted with extreme caution, if not skepticism, by policymakers and the public. If the government had undertaken a massive program for construction of seawalls on the U.S. coast five or ten years ago on the basis of what was then the accepted scientific wisdom, policymakers would look foolish now and a great deal of money would have gone into a wasteful and fruitless effort.

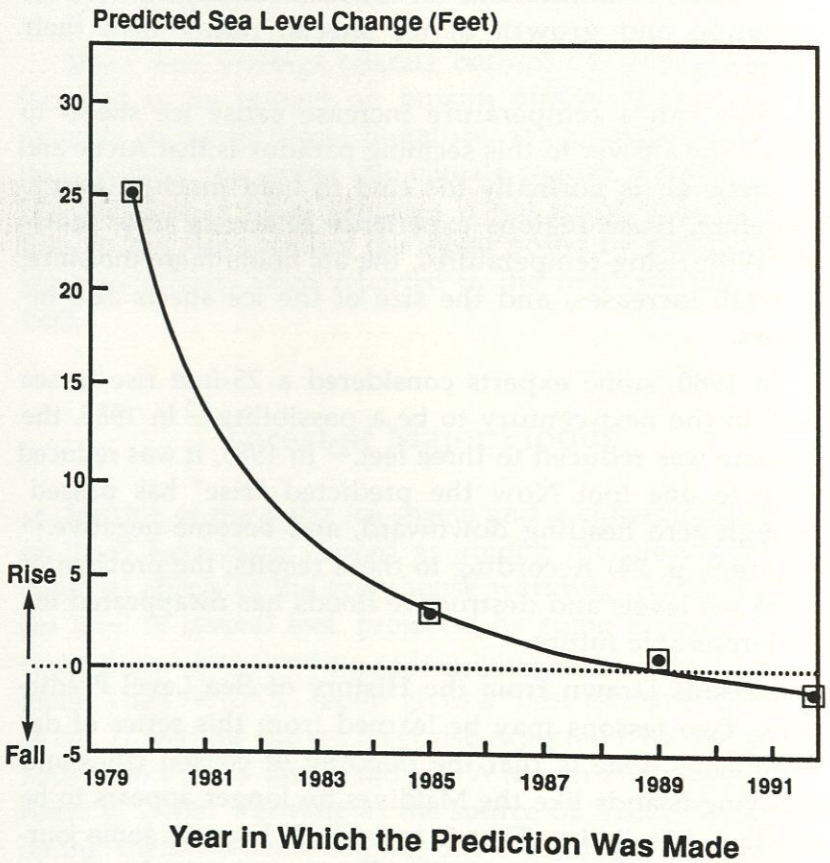

Figure 9. Predicted change in sea level resulting from the greenhouse effect, plotted against the year the prediction was made.

V. CONCLUSIONS

Computer simulations of the earth's climate predict how much warming will result from a doubling of today's levels of carbon dioxide in the atmosphere — a condition that could be reached in the second half of the 21st century. The results obtained from the computer models used by various scientific groups range from roughly 1°C to 5°C, with 2.5°C as the "best guess" proposed by the U.N. Intergovernmental Panel on Climate Change.

Reduced Estimates of the Greenhouse Effect. If the greenhouse effect were as large as any of the results yielded by these computer models, the effect would already have shown up clearly in the temperature record. The fact that the expected "greenhouse signal" is missing from the record suggests that the computer models have considerably exaggerated the size of the greenhouse effect.

Additional evidence, reported in the last year and based on satellite measurements of global temperatures, indicates that the greenhouse warming produced by a doubling of CO_2 in the next century will be less than 1°C, and may be as small as 0.5°C.

Independent support for this conclusion comes from a comparison between changes in solar activity and changes in global temperature. The very close correlation between the solar changes and the changes in temperature suggests that the sun has been the controlling influence on climate in the last 100 years, with the greenhouse effect playing a

smaller role. The solar data and the temperature data fit so closely in their time dependence as to imply that the greenhouse contribution to global warming up to the present time cannot be more than a few tenths of a degree. If the concentration of greenhouse gases rises in the course of several decades by an amount equivalent to a 100% increase in carbon dioxide, as some have predicted, the warming to be expected in the next century may be as large as twice a few tenths of a degree, or 0.5°C in round numbers.

Spread over a number of decades, a warming of half a degree would be a relatively small effect and lost in the noise of natural climate fluctuations.

These limits, while approximate, have more validity than the theoretical estimates of climate change, because they are not based on computer programs simulating the earth's climate but on the response of the real climate to a real increase in greenhouse gases over the last 100 years.

VI. POLICY IMPLICATIONS

Recent findings, based on observations of actual temperature changes, suggest that the greenhouse warming will be considerably smaller than commonly accepted estimates based on computer simulations. Temperature increases in the next century, assuming a greenhouse gas increase equivalent to a doubling of carbon dioxide in the atmosphere, will almost certainly be less than 1°C and may be less than 0.5°C. Temperature changes of this magnitude are commonplace in the earth's recent history, and are not a particular cause for concern.

How do the new results affect energy policy? Some scientists and policymakers want the U.S. to adopt laws severely restricting carbon dioxide emissions, because they regard carbon dioxide as the primary cause of global warming. Congress has asked the Department of Energy for an estimate of the cost of policies that would reduce carbon dioxide emissions by 20% in the next 10 years. According to the Department of Energy, the cost at the end of the decade can be as much as $95 billion/year. The cost of electricity would double. The cost of oil would increase by $60/barrel, and gasoline would go up $1.30/gallon. A privately funded study estimates an accumulated cost of $3.6 trillion over the next 100 years for comparable restrictions.[25,26]

But the scientific evidence does not support a policy of carbon dioxide restrictions with its severely negative impact on the U.S. economy. Important new findings on the greenhouse effect and global warming are reported nearly every month. Several of the major findings discussed in this report were released in the last year. Suppose policymakers wait five years to get still more results, before undertaking the drastic measures proposed by concerned scientists and politicians. What will that cost the U.S.?

The Marshall panel did a study on this problem, using data from the 1990 report of the U.N. Intergovernmental Panel on Climate Change. M.E. Schlesinger and X. Jiang did a similar study.[27] Both studies yielded the same answer. A five-year delay on major policy decisions regarding carbon dioxide limits will lead to a small amount of additional warming in the next century. How small will the additional warming be?

The calculations show that a five-year delay in limiting carbon emissions will make the world warmer in the next century by at most one tenth of a degree, compared to how warm it would be if there were no delay.

A very rapid evolutionary process is occuring in the field of greenhouse research, with major improvements likely in basic understanding and in the accuracy of the greenhouse forecasts in the next few years. An additional warming of one tenth of a degree in the 21st century is a very small penalty to pay for better information on government decisions that, if taken unwisely, can be extraordinarily costly to the U.S. economy.

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