

Chapter 2

THE GREENHOUSE EFFECT: IMPACTS ON CURRENT GLOBAL TEMPERATURE AND REGIONAL HEAT WAVES

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- The earth is warmer in 1988 than at any time in the history of instrumental measurements.
- The global warming is now sufficiently large that we can ascribe with a high degree of confidence a cause and effect relationship to the greenhouse effect.

This statement was presented to the U.S. Senate Committee on Energy and Natural Resources on 23 June 1988. It is based largely on recent studies carried out by S. Lebedeff, D. Rind, I. Fung, A. Lacis, R. Ruedy, G. Russell, and P. Stone at the NASA Goddard Institute for Space Studies.

- In our computer climate simulations the greenhouse effect now is already large enough to begin to affect the probability of occurrence of extreme events such as summer heat waves. The model results imply that heat wave/drought occurrences in the Southeast and Midwest United States may be more frequent in the next decade than in climatological (1950–1980) statistics.

CURRENT GLOBAL TEMPERATURES

Present global temperatures are the highest in the period of instrumental records, as shown in Figure 2.1. The rate of global warming in the past two decades is higher than at any earlier time in the record. The four warmest years in the past century all have occurred in the 1980s.

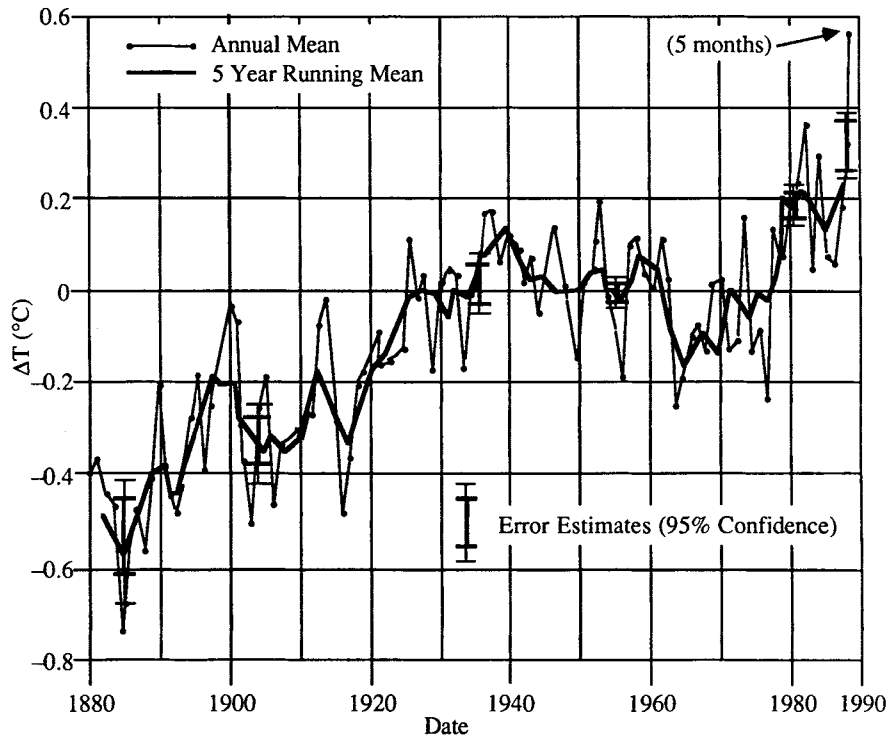
The global temperature in 1988 up to June 1 is substantially warmer than the like period in any previous year in the record. This is illustrated in Figure 2.2, which shows seasonal temperature anomalies for the past few decades. The most recent two seasons (December–January–February and March–April–May 1988) are the warmest in the entire record. The first five months of 1988 are so warm globally that we conclude that 1988 will be the warmest year on record unless there is a remarkable, improbable cooling in the remainder of the year.

RELATIONSHIP OF GLOBAL WARMING AND GREENHOUSE EFFECT

Causal association of current global warming with the greenhouse effect requires determination that the warming is larger than natural climate variability, and the magnitude and nature of the warming is consistent with the greenhouse warming mechanism. Both of these issues are addressed quantitatively in Figure 2.3, which compares recent observed global temperature change with climate model simulations of temperature changes expected to result from the greenhouse effect.

The present observed global warming is close to 0.4°C, relative to “climatology,” which is defined as the 30-year (1951–1980) mean. A

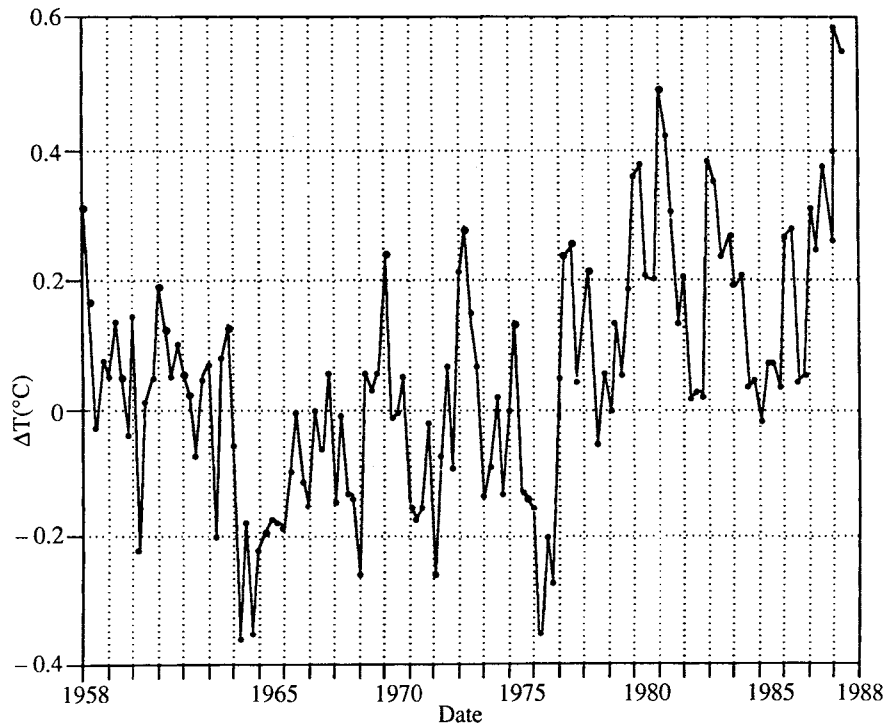
FIGURE 2.1
Global Temperature Trend: 1880–1988



Global surface air temperature change for the past century, with the zero point defined as the 1951–1980 mean. Uncertainty bars (95% confidence limits) are based on an error analysis as described in reference 6; inner bars refer to the 5-year mean and outer bars to the annual mean. The analyzed uncertainty is a result of incomplete spatial coverage by measurement stations, primarily in ocean areas. The 1988 point compares the January–May 1988 temperature to the mean for the same 5 months in 1951–1980.

warming of 0.4°C is three times larger than the standard deviation of annual mean temperatures in the 30-year climatology. The standard deviation of 0.13°C is a typical amount by which the global temperature fluctuates annually about its 30-year mean; the probability of a chance warming of three standard deviations is about 1%. Thus we can state with about 99% confidence that current temperatures represent a real

FIGURE 2.2
Global Temperature Change: 1958–1988

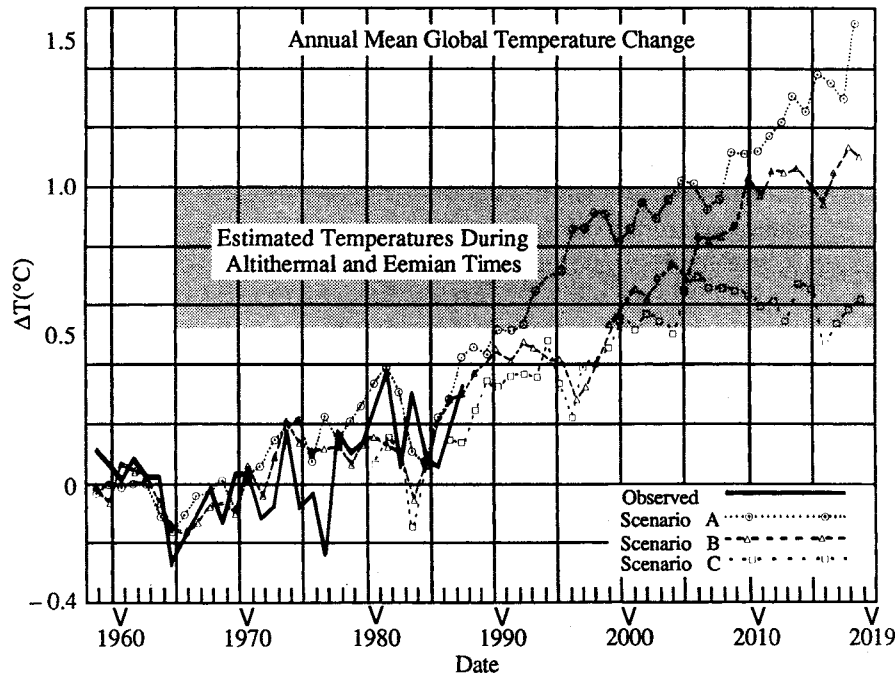


Global surface air temperature change at seasonal resolution for the past 30 years. Figures 2.1 and 2.2 are updates of results in reference 6.

warming trend rather than a chance fluctuation over the 30-year period.

We have made computer simulations of the greenhouse effect for the period since 1958, when atmospheric CO₂ began to be measured accurately. A range of trace gas scenarios is considered so as to account for moderate uncertainties in trace gas histories and larger uncertainties in future trace gas growth rates. The nature of the numerical climate model used for these simulations is described in reference 1. There are major uncertainties in the model, which arise especially from assumptions about (1) global climate sensitivity and (2) heat uptake and transport by the ocean, as discussed in reference 1. However, the magnitude of temperature changes computed with our climate model in various test

FIGURE 2.3
Computed Global Temperature Change: 1960–2020



Annual mean global surface air temperature computed for trace gas scenarios A, B, and C described in reference 1. (Scenario A assumes continued growth rates of trace gas emissions typical of the past 20 years, i.e., about 1.5% year⁻¹ emission growth; scenario B has emission rates approximately fixed at current rates; scenario C drastically reduces trace gas emissions between 1990 and 2000.) Observed temperatures are from reference 6. The shaded range is an estimate of global temperature during the peak of the current and previous interglacial periods, about 6,000 and 120,000 years B.P., respectively. The zero point for observations is the 1951–1980 mean (reference 6); the zero point for the model is the control run mean.

cases is generally consistent with a body of empirical evidence (reference 2) and with sensitivities of other climate models (reference 1).

The global temperature change simulated by the model yields a warming over the past 30 years similar in magnitude to the observed warming (Figure 2.3). In both the observations and model the warming is close to 0.4°C by 1987, which is the 99% confidence level.

It is important to compare the spatial distribution of observed tem-

perature changes with computer model simulations of the greenhouse effect, and also to search for other global changes related to the greenhouse effect, for example, changes in ocean heat content and sea ice coverage. As yet, it is difficult to obtain definitive conclusions from such comparisons, in part because the natural variability of regional temperatures is much larger than that of global mean temperature. However, the climate model simulations indicate that certain gross characteristics of the greenhouse warming should begin to appear soon, for example, somewhat greater warming at high latitudes than at low latitudes, greater warming over continents than over oceans, and cooling in the stratosphere while the troposphere warms. Indeed, observations contain evidence for all these characteristics, but much more study and improved records are needed to establish the significance of trends and to use the spatial information to understand better the greenhouse effect. Analyses must account for the fact that there are climate change mechanisms at work, besides the greenhouse effect; other anthropogenic effects, such as changes in surface albedo and tropospheric aerosols, are likely to be especially important in the Northern Hemisphere.

We can also examine the greenhouse warming over the full period for which global temperature change has been measured, which is approximately the past 100 years. On such a longer period the natural variability of global temperature is larger; the standard deviation of global temperature for the past century is 0.2°C . The observed warming over the past century is about $0.6\text{--}0.7^{\circ}\text{C}$. Simulated greenhouse warming for the past century is in the range $0.5\text{--}1.0^{\circ}\text{C}$, depending upon various modeling assumptions (e.g., reference 2). Thus, although there are greater uncertainties about climate forcings in the past century than in the past 30 years, the observed and simulated greenhouse warmings are consistent on both of these time scales.

CONCLUSION

Global warming has reached a level such that we can ascribe with a high degree of confidence a cause and effect relationship between the greenhouse effect and the observed warming. Certainly further study of this issue must be made. The detection of a global greenhouse signal represents only a first step in analysis of the phenomenon.

GREENHOUSE IMPACTS ON SUMMER HEAT WAVES

Global climate models are not yet sufficiently realistic to provide reliable predictions of the impact of greenhouse warming on detailed regional climate patterns. However, it is useful to make initial studies with state-of-the-art climate models; the results can be examined to see whether there are regional climate change predictions which can be related to plausible physical mechanisms. At the very least, such studies help focus the work needed to develop improved climate models and to analyze observed climate change.

One predicted regional climate change which has emerged in such climate model studies of the greenhouse effect is a tendency for mid-latitude continental drying in the summer (references 3, 4, 5). . . . Most of these studies have been for the case of doubled atmospheric CO₂, a condition which may occur by the middle of next century.

Our studies during the past several years at the Goddard Institute for Space Studies have focused on the expected transient climate change during the next few decades, as described in the attachment to my testimony. Typical results from our simulation for trace gas scenario B . . . show computed July temperature anomalies in several years between 1986 and 2029. In the 1980s the global warming is small compared to the natural variability of local monthly mean temperatures; thus the area with cool temperatures in a given July is almost as great as the area with warm temperatures. However, within about a decade the area with above normal temperatures becomes much larger than the area with cooler temperatures.

The specific temperature patterns for any given month and year should not be viewed as predictions for that specific time, because they depend upon unpredictable weather fluctuations. However, characteristics which tend to repeat warrant further study, especially if they occur for different trace gas scenarios. We find a tendency in our simulations of the late 1980s and the 1990s for greater than average warming in the Southeast and Midwest United States. . . . These areas of high temperature are usually accompanied by below normal precipitation.

Examination of the changes in sea level pressure and atmospheric winds in the model suggests that the tendency for larger than normal warming in the Midwest and Southeast is related to the ocean's response

time; the relatively slow warming of surface waters in the mid-Atlantic off the eastern United States and in the Pacific off California tends to increase sea level pressure in those ocean regions and this in turn tends to cause more southerly winds in the eastern United States and more northerly winds in the western United States. However, the tendency is too small to be apparent every year; in some years in the 1990s the eastern United States is cooler than climatology (the control run mean).

CONCLUSION

It is not possible to blame a specific heat wave/drought on the greenhouse effect. However, there is evidence that the greenhouse effect increases the likelihood of such events; our climate model simulations for the late 1980s and the 1990s indicate a tendency for an increase of heat wave/drought situations in the Southeast and Midwest United States. We note that the correlations between climate models and observed temperatures are often very poor at subcontinental scales, particularly during Northern Hemisphere summer (reference 7). Thus improved understanding of these phenomena depends upon the development of increasingly realistic global climate models and upon the availability of global observations needed to verify and improve the models.

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