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

STATEMENT OF

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PREFACE

This statement is based largely on recent studies carried out with my colleagues S. Lebedeff, D. Rind, I. Fung, A. Lacis, R. Ruedy, G. Russell and P. Stone at the NASA Goddard Institute for Space Studies.

My principal conclusions are: (1) the earth is warmer in 1988 than at any time in the history of instrumental measurements, (2) 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, and (3) 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.

1. Current global temperatures

Present global temperatures are the highest in the period of instrumental records, as shown in Fig. 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 1980's.

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 Fig. 2, which shows seasonal temperature anomalies for the past few decades. The most recent two seasons (Dec.-Jan.-Feb. and Mar.-Apr.-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.

2. Relationship of global warming and greenhouse effect

Causal association of current global warming with the greenhouse effect requires determination that (1) the warming is larger than natural climate variability, and (2) the magnitude and nature of the warming is consistent with the greenhouse warming mechanism. Both of these issues are addressed quantitatively in Fig. 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 thirty year (1951-1980) mean. A 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 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 CO_2 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 attachment A (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 attachment A. However, the magnitude of temperature changes computed with our climate model in various test 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 (Fig. 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 temperature 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 0.6-0.7°C. Simulated greenhouse warming for the past century is in the range 0.5°-1.0°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.

<u>Conclusion</u>. 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.

3. 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). Dr. Manabe will address this important issue in his testimony today. Most of these studies have been for the case of doubled atmospheric CO_2, 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 are illustrated in Fig. 4, which shows computed July temperature anomalies in several years between 1986 and 2029. In the 1980's 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 1980's and the 1990's for greater than average warming in the Southeast and Midwest United States, as illustrated in Attachment A and in Fig. 4. 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 1990's the eastern United States is cooler than climatology (the control run mean).

Conclusion. It is not possible to blame a specific heatwave/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 1980's and the 1990's indicate a tendency for an increase of heatwave/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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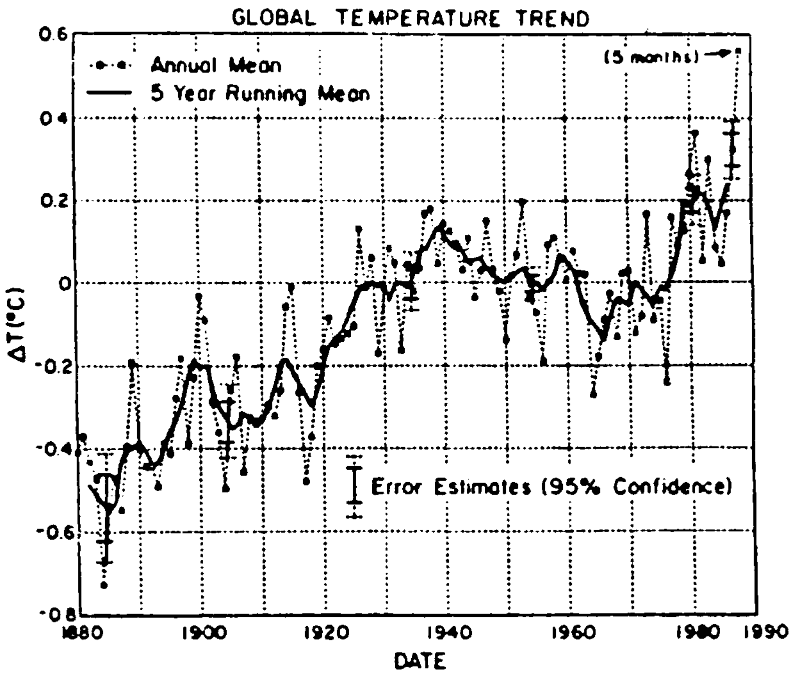

Fig. 1. Global surface air temperature change for the past century, with the zero point defined as the 1951-1980 mean. Uncertainty bars (95% confidence limits) are based on an error analysis as described in reference 6; inner bars refer to the 5-year mean and outer bars to the annual mean. The analyzed 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.

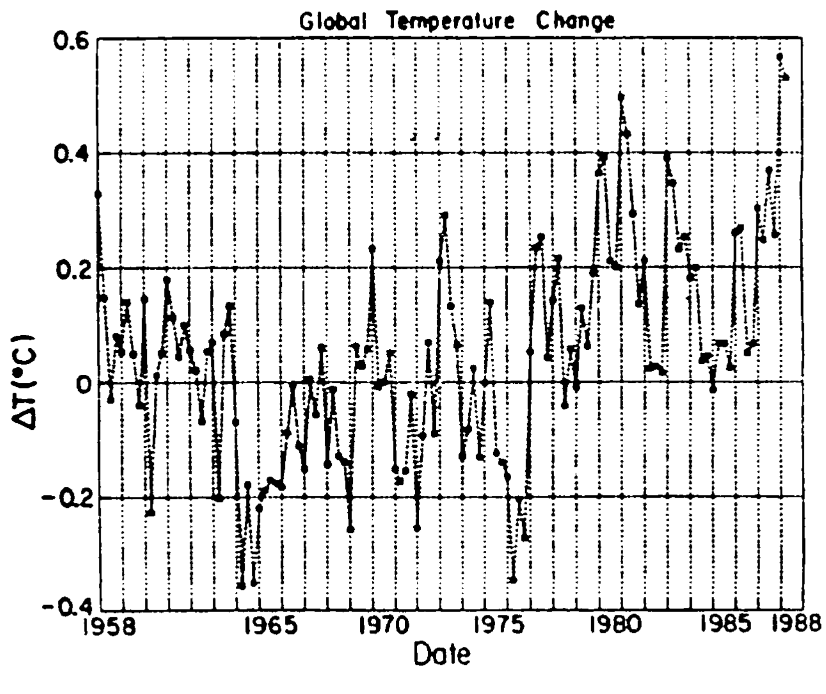

Fig. 2. Global surface air temperature change at seasonal resolution for the past 30 years. Figures 1 and 2 are updates of results in reference 6.

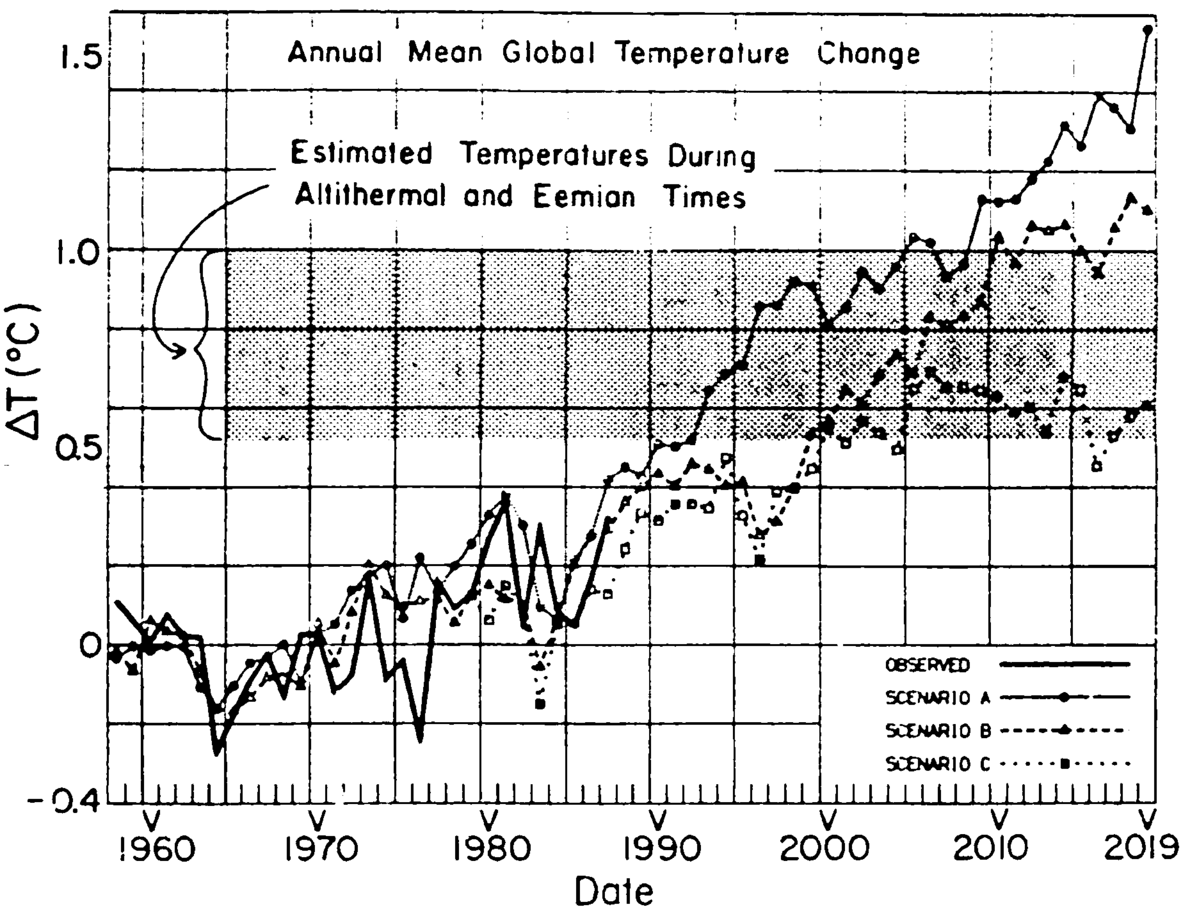

Fig. 3. Annual mean global surface air temperature computed for trace gas scenarios A, B and C described in reference 1. [Scenario A assumes continued growth rates of trace gas emissions typical of the past 20 years, i.e., about 1.5% yr^{-1} emission growth; scenario B has emission rates approximately 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 before present, respectively. The zero point for observations is the 1951-1980 mean (reference 6); the zero point for the model is the control run mean.

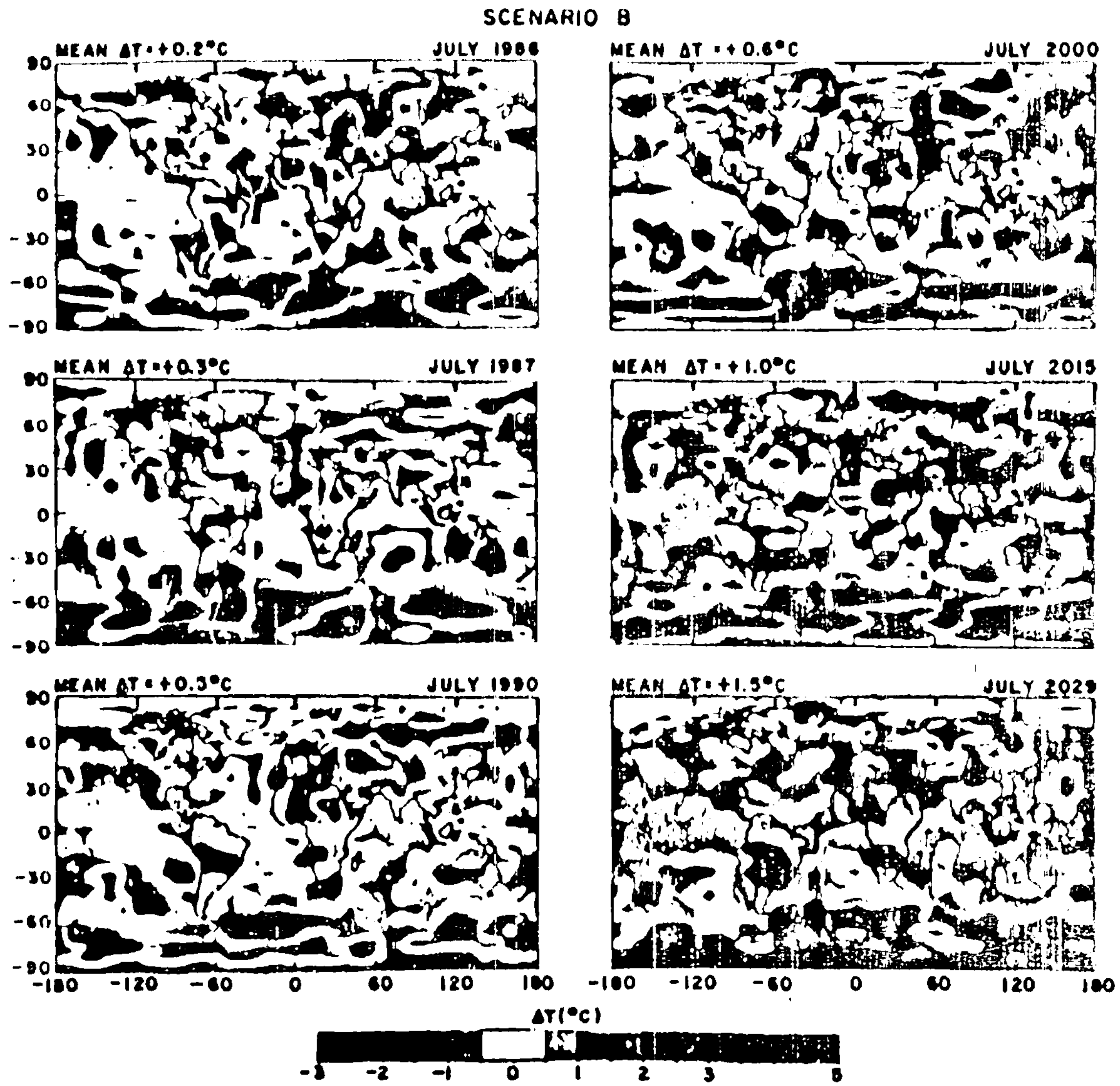

Fig. 4. Simulated July surface air temperature anomalies for six individual years of scenario B, compared to a 100 year control run with 1958 atmospheric composition (see Attachment A).

ATTACHMENT A

Global Climate Changes as Forecast by the GISS 3-D Model

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We use a three-dimensional climate model, our Model II with 8° by 10° horizontal resolution, to simulate the global climate effects of time dependent variations of atmospheric trace gases and aerosols. Horizontal heat transport by the ocean is fixed at values estimated for today's climate and uptake of heat perturbations by the ocean beneath the mixed layer is approximated as vertical diffusion. We make a 100 year control run and perform experiments for three scenarios of atmospheric composition. These experiments begin in 1958 and include measured or estimated changes in atmospheric CO_2, CH_4, N_2O, CFCs and stratospheric aerosols for the period from 1958 to the present. Scenario A assumes continued exponential trace gas growth, scenario B assumes a reduced linear growth of trace gases, and scenario C assumes a rapid curtailment of trace gas emissions such that the net climate forcing ceases to increase after 2000. Principal results from the experiments are: (1) Global warming to the level attained at the peak of the current interglacial and the previous interglacial occurs in all three scenarios; however, there are dramatic differences in the levels of future warming, depending on trace gas growth. (2) The greenhouse warming should be clearly identifiable in the 1990s; the global warming within the next several years is predicted to reach and maintain a level at least three standard deviations above the climatology of the 1950s. (3) Regions where an unambiguous warming appears earliest are low latitude oceans, China and interior areas in Asia, and ocean areas near Antarctica and the North Pole; aspects of the spatial and temporal distribution of predicted warming are clearly model-dependent, implying the possibility of model discrimination by the 1990s and thus improved predictions, if appropriate observations are acquired. (4) The temperature changes are sufficiently large to have major impacts on people and other parts of the biosphere, as shown by computed changes in the frequency of extreme events and by comparison with previous climate trends. (5) The model results suggest some near-term regional climate variations, despite the fixed ocean heat transport which suppresses many possible regional climate fluctuations; for example, during the late 1980s and in the 1990s there is a tendency for greater than average warming in the Southeast and Central U.S. and relatively cooler conditions or less than average warming in the western U.S. and much of Europe. Principal uncertainties in the predictions involve the equilibrium sensitivity of the model to climate forcing, the assumptions regarding heat uptake and transport by the ocean, and the omission of other less certain climate forcings.