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Changing Weather?
Facts and Fallacies about Climate Change

A Report Prepared by Accu-Weather, Inc.
For the Global Climate Coalition

Norman J. MacDonald, M.S., Certified Consulting Meteorologist
Joseph P. Sobel, Ph.D., Senior Vice President, Accu-Weather, Inc.

Consultants:
C.L. Hosler, Ph.D., Consulting Meteorologist
Joel N. Myers, Ph.D., President, Accu-Weather, Inc.
Michael A. Steinberg, M.S., Senior Vice President, Accu-Weather, Inc.

Accu-Weather, Inc.
619 W. College Avenue, State College, PA 16801 (814) 237-0309

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Executive Summary

After examining relevant historical land, water and satellite weather data, conducting numerous personal interviews with scientists active in the field, reviewing pertinent literature on the subject, and analyzing global weather data published by various organizations, the authors have concluded that:

1. While slight global warming has occurred within the past 100 years, this increase falls within the limits of natural climate variability and does not signal an internally forced ("greenhouse") global warming;

2. No convincing observational evidence exists to support recent claims that man-made global warming is masked by external or internal sources; and

3. No convincing, observational evidence exists that hurricanes, tornadoes and other extreme temperature and precipitation events are on the rise because of the recent slight increase in the Earth's surface temperature. Rather, the greater attention severe weather events now receive may simply reflect two non-weather related facts: a) More people live in areas that were once sparsely populated or even uninhabited, and (b) local media are now able to quickly report extreme weather events that are occurring, or have just occurred, in distant parts of the globe.

A. WHY WEATHER CHANGES - THE VARIABILITY OF THE TERRESTRIAL CLIMATE

Does climate change?

Yes.

The Earth's climate has changed drastically and often over geological time. All the reasons for these changes are not completely understood, but we know climate changes occurred long before the first human appeared. Many theories have been advanced to explain these climate changes, including theories about the sun's strength and the Earth's orbit, volcanism, meteorite showers and most recently "the greenhouse effect." This phrase refers to atmospheric increases in certain gases such as carbon dioxide and relates those increases to possible increases in global temperatures.

Significant long-term changes in the Earth's climate have occurred in the past and, no doubt, will occur again. This has lead some people to ask when the next significant change in climate will occur, and whether human activity has inadvertently accelerated the onset of climate change. While it is impossible to answer these questions unequivocally, studies of observational data and an understanding of the theoretical issues of climate do offer some insight. Put briefly, while climate does change, man's activities do not appear to be a significant agent of change.

Nevertheless, some people predict apocalyptic climate changes in the next decade while others expect the climatological "status quo" to prevail well into the future. For our part, we have not found convincing evidence to support the hypothesis that extreme weather events, presumed to be associated with global warming, are already increasing. Nor are we alone in this opinion. During the past few years, there has been a shift of opinion in the general scientific community away from the concept that an apocalyptic climatic change is on our doorstep in the near future to a more moderate "wait and see" attitude.

There is no question that the Earth has been subjected to many climatological extremes over geological time, measured in thousands, even millions, of years. Numerous ice ages have come and gone, with warm and even very warm periods intertwined. Although the reasons for such changes are not completely understood, a significant fraction are now attributed to changes in the Earth's orbit around the sun, to changes in the energy output of the sun, volcanism and to meteorite impacts.

The climatic changes over the past million years or so have been striking, with cycles of major glaciation and deglaciation. The cycles, determined from the studies of oxygen isotopes in ice cores, show significant peaks in the glaciation intervals of one hundred thousand, forty-three thousand, twenty-four thousand, and nineteen thousand years (Imbrie & Imbrie, 1980). The generally accepted hypothesis for this periodic behavior is that orbital variations of the Earth have "forced" the climate to change. This is referred to as the Milankovitch mechanism. These orbital variations consist of three factors: changes in the obliquity (tilt) of the Earth's rotation axis, the precession of the equinoxes along the Earth's elliptic orbit, and changes in eccentricity of the orbit. These variations are schematically illustrated in Figure 1. Each of these orbital changes affects the total amount and the seasonal amounts of solar radiation that reach the Earth's atmosphere, and their geographical distribution. The latter is considered to be the major cause of climatic change through the Milankovitch mechanism.

In addition to the Milankovitch mechanism, changes in the energy output from the sun and meteorite impacts may have been instrumental in causing climatic change. Changes in the energy output from the sun are thought to be small, on the order of 0.1 percent, and most likely associated with the sunspot cycle. The "little ice age" in the eighteenth century was associated with, and may have been caused by, a decrease in the energy output of the sun during the so-called "Maunder minimum"

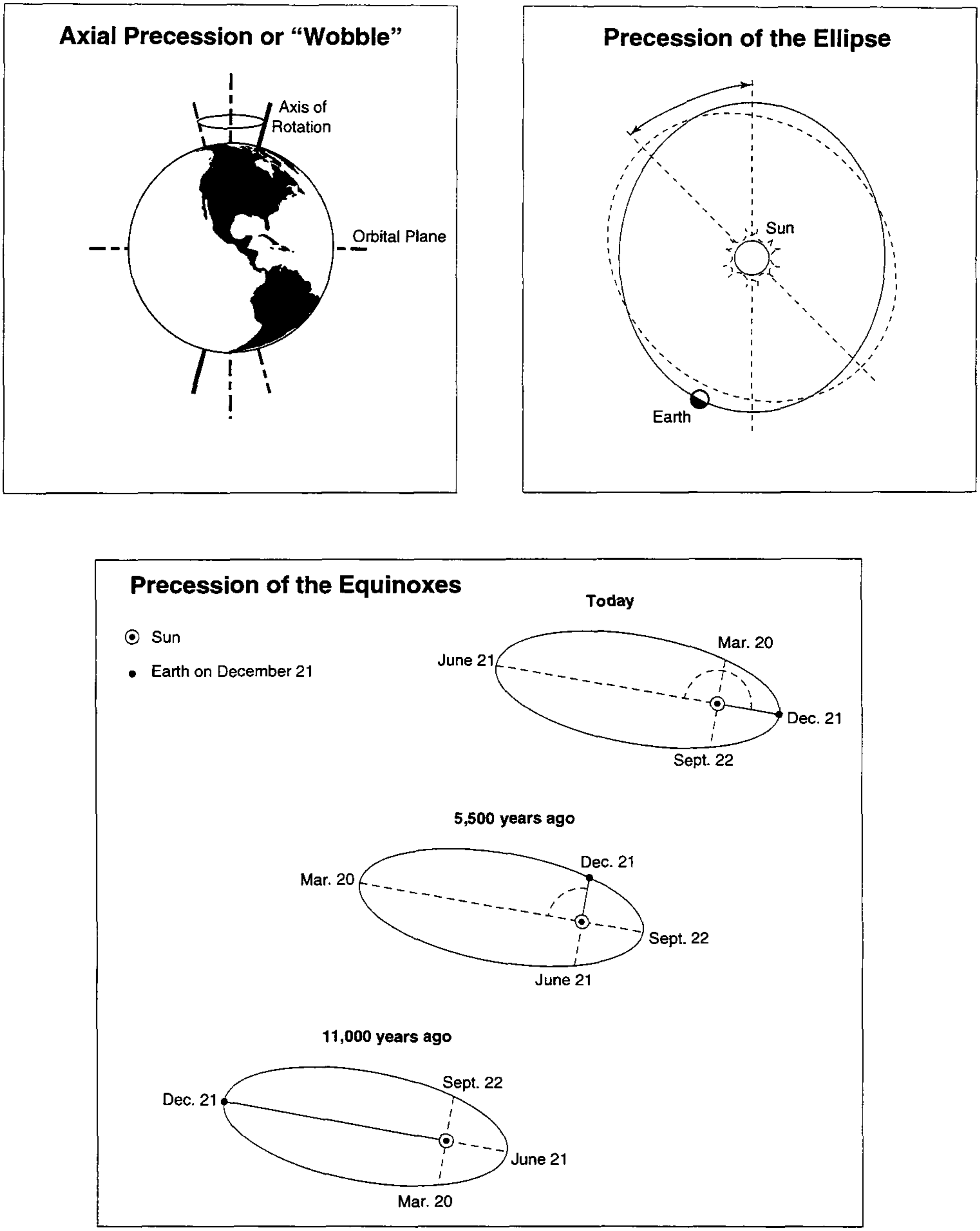


Figure 1: Schematic Illustrations of Orbital Changes of Earth
(From Lindzen - 1994)

of sun spot activity.* Many scientists also accept the theory that a giant meteorite struck the Earth in the area of the Yucatan Peninsula. The impact caused an explosion that, in turn, transported material into the high levels of the atmosphere, effectively blocking solar radiation for several years. This event not only caused a brief change to a colder climate but reduced the photosynthesis process, which is believed to have subsequently produced an abrupt reduction in the plant life on which most of the dinosaur population depended.

Extra-terrestrial variables however, are not at the heart of today's argument about the so-called "greenhouse effect." In Figure 2, we illustrate in graphic form the common conception of the greenhouse effect. The crude idea is that the atmosphere is transparent to visible radiation from the sun,** which heats the Earth's surface. The Earth's surface in turn heats up the atmosphere by radiating energy in the form of infrared (IR) radiation back out to space. The IR radiation increases as the temperature of the Earth's surface rises. The temperature adjusts until a balance is achieved. If the atmosphere were <u>also</u> transparent to IR radiation, then the IR radiation produced by an average surface temperature of -18° Celsius (C) would balance the incoming solar radiation, i.e., the temperature of the Earth would be -18° C. However, the atmosphere is <u>not</u> transparent to the infrared, because of the radiative absorbing properties of such "greenhouse gases" as water vapor, carbon dioxide and methane. The energy absorbed by the greenhouse gases is partially radiated back to the Earth's surface, increasing temperatures. This warming is called the "greenhouse effect," for it makes the Earth's average surface temperature $+15^{\circ}$ C rather than -18° C.

* Oddly enough, the sun is actually cooler when sunspots are conspicuous by their absence. The areas between sunspots, the so-called "plage" areas, are relatively hot, thus radiating more energy to space than that reduced by the sunspots.

** A significant fraction of solar radiation is reflected back out to space by clouds and the surface of the Earth.

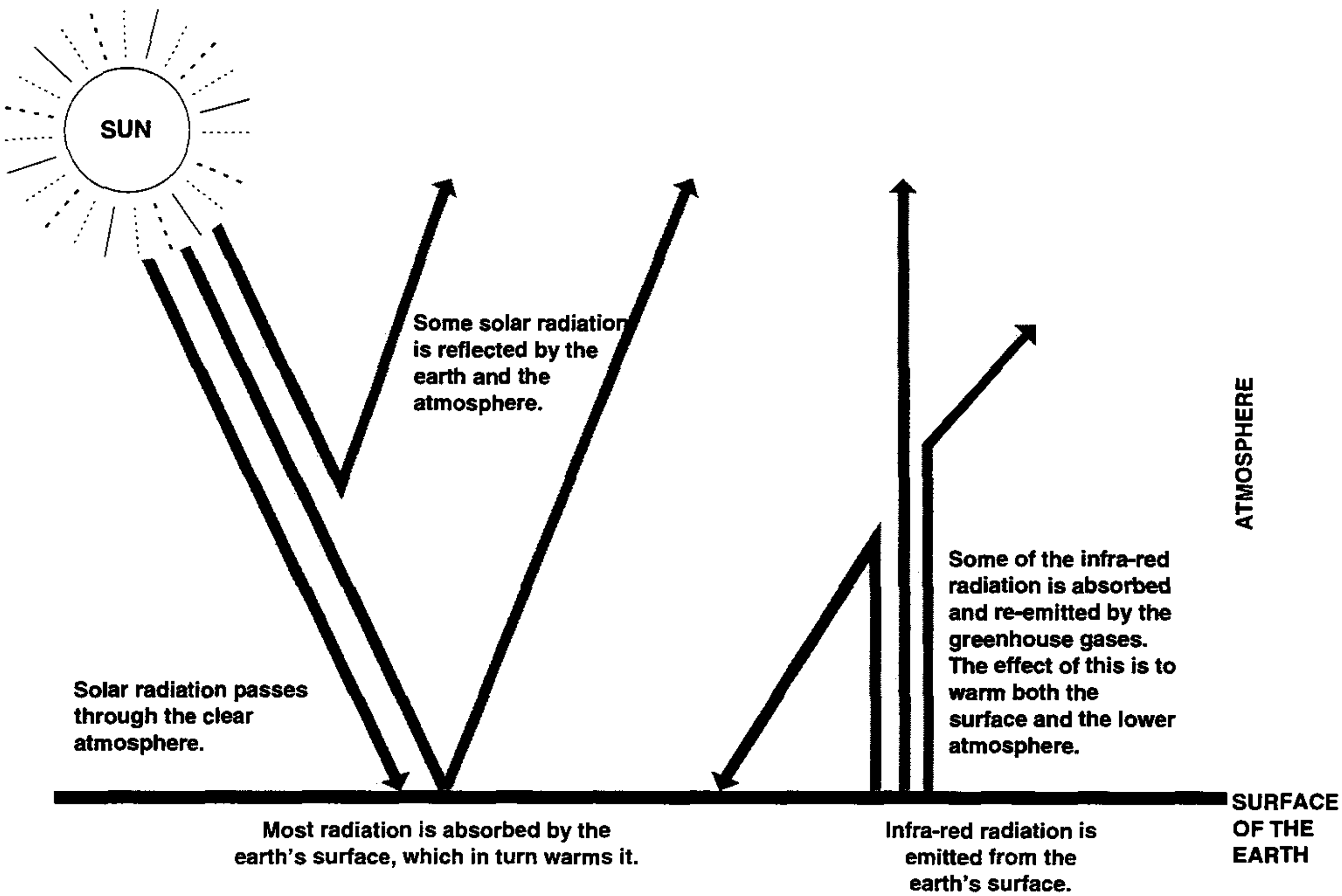


Figure 2: Popular Conception of Greenhouse Effect

The main absorbers of IR in the atmosphere are water vapor and clouds. We note here that since water in its various forms is the principle absorber of IR, even if all the other greenhouse gases were to disappear, we would still be left with the bulk of the current greenhouse effect. Nevertheless, it is presumed that large increases in carbon dioxide and other minor greenhouse gases can lead to significant increases in temperature. As we will see, carbon dioxide has been increasing. So have some of the other greenhouse gases. A widely held contention is that these increases will continue as they have for the past century, thereby enhancing the greenhouse effect.

It is worth noting that the radiation model just described is overly simplistic. Indeed, calculations of the incoming versus outgoing radiation energy flux show that the tropics receive more heat from the sun than they radiate back out to space. Conversely, the polar regions radiate more heat back out to space than they receive from the sun. The simplistic model shown in Figure 2 shows the radiation process only, whereas, in fact, heat is also transported vertically and horizontally by the wind and by ocean currents in order to establish thermal balance. The importance of this concept has been treated in detail by Piexoto and Oort (1992), who show that without a horizontal transport of heat from the equatorial regions toward the poles, the tropics would become excessively hot and the polar regions uninhabitably cold.

Much of the surface of the Earth, especially the oceans, also cools by evaporation. Most of the evaporative moisture ends up in convective clouds (clouds with strong upward and downward motion of the air), which carry the air and its contents upward, where moisture condenses into rain and snow. Just as evaporation takes heat away from the environment (cooling), the condensation of water vapor releases heat. The atmosphere receives heat from condensation at altitudes well above the surface of the Earth. It is at these heights that the atmosphere must balance the heat deposited by convection from the surface with cooling by thermal radiation. It is worth noting that in the absence of convection, pure greenhouse warming would lead to a globally averaged surface temperature of +72^{o} C (Lindzen, 1994).

These physical facts are important not only in understanding how the heat budget of the Earth/atmosphere system is balanced, but also to the concepts that must be included in climate (computer) models. As we will discuss later, mathematical climate models either neglect some of these concepts in their modeling schemes or treat them in a cavalier fashion.

In addition to the convection and greenhouse effect, other internal climatic forcing functions can play an important role in non-geological climatic change. For example, the interaction between the ocean and atmosphere is known to produce significant short-term changes in the global climate. The quasi-periodic appearance of El Nino Southern Oscillation (ENSO)* is a prime example of this, and the impact of El Nino on global weather has been well documented for several decades. Most ENSO incidents are associated with some global warming, but they are confined to relatively small areas. Isolated volcanic activity, on the other hand, appears to influence the global climate, but only for relatively short periods of time, on the order of a year or so. The recent eruption of Mount Pinatubo illustrates this pattern well.

* ENSO events, also known as El Nino, are naturally occurring phenomena not associated with greenhouse gas emissions.

B. CLIMATIC CHANGE OVER THE PAST CENTURY (THE OBSERVATIONS)

Do observed data indicate significant global temperature changes?

No.

Global air temperatures as measured by satellites and land-based weather stations show an increase of only some 0.45° C over the past century. This may be no more than normal cliamtic variation. However, biases such as urban heat islands may be responsible for some, if not all, of this increase. Moreover, much of the observed temperature increase during the past century occurred before the rise in greenhouse gases.

Reliable global weather observations extend back to the end of the 19th century. This information is essentially confined to observations of the temperature of the air near the surface of the Earth. Detailed observations of the distribution of water in its various forms, the wind and other elements both at the surface and higher levels of the atmosphere are available only for the past half century. Consequently, searches for signals of climate change over the past one hundred years have been restricted essentially to the observations of global and regional temperatures. Before we present the observations involved in the climatic change to date, it is important to consider the general problem of "bias" in such data. The problem with generating "unbiased" air temperature and sea surface temperatures is described in detail in "Climatic Change - The IPCC Scientific Assessment 1992" and numerous other sources (Jones, 1990). We summarize the sources of bias below.

BIASES IN AIR TEMPERATURE DATA

(1) The urban bias, or heat island effect, has been introduced into the observations during the past half century. Many of the temperature observations have been and are taken at or very close to large airports or urban areas. Both have been expanding under the pressure of increased population and industrialization for the past half century. The net result has been the creation of "heat islands." The effect can be especially noticeable

up (to several ^{o}C) in those urban areas that have grown rapidly over the past half century.

(2) Changes in instrumentation and the movement of instrument shelters have taken place, especially in recent years. It is assumed this bias is most likely small and probably random in time and space.

(3) Some "heat island" effects, especially during the growing season, may have been introduced in rural agricultural areas during the past half century. The increase in irrigation systems in many parts of the world has allowed the areal extent of crops grown in "desert" areas to expand. Expansion is accompanied by an increase in local water vapor concentration and evaporation. Wetting the ground also raises nighttime temperatures by increasing soil conductivity and raising the dew point thus limiting the amount the temperature can drop.

(4) The fact that temperature observations made on land are far more numerous than those taken on the ocean, also introduces a bias into observational data. In many large geographical areas, especially in the Southern Hemisphere, only one observation (for example on an island) will be assumed to represent temperatures over thousands of square miles of water. In addition, many of the thermometers used to take temperature observations on ships are not properly calibrated. These observations are also assumed to represent temperatures over tens of thousands of square miles of ocean.

Any of these biases may introduce errors into the estimates of the true nature of the behavior of air temperatures, especially over the oceans in the Southern Hemisphere. Efforts have been made by some climatologists (Jones, 1990b) to ascertain the impact of urbanization on land temperature measurements by removing all stations with a population in 1970 of over 100,000. The elimination of those data reduced the temperature trend by 0.1° C over 100 years. An absence of data in the polar regions of the Southern Hemisphere prior to the middle of the twentieth century also makes the temperature observations uncertain, particularly in the Southern Hemisphere.

BIASES IN SEA SURFACE TEMPERATURE* DATA

The bias listed under item (4) above is even more applicable to sea-surface temperatures. Moreover,

(1) The manner in which water temperatures are sampled has changed considerably over the past century. The types of buckets used in making measurements have changed. The depths to which the bucket is lowered into the ocean has not always been consistent.

(2) Adjustments of ocean temperatures taken by ships have been made to make them consistent with the observations made on land (islands) thus creating a bias toward higher temperatures.

(3) In some areas out of the shipping lanes, the assumption has been made that the air temperature measured on an island is representative of the ocean temperatures, again producing a bias toward higher temperatures.

Given all the uncertainties in the measurements, climatologists have done their best to reconstruct global air and sea surface temperatures. A summary of many can be found in the publication "Trends '93," Oak Ridge National Laboratory (1994). The sea surface temperature data are much more suspect if one is attempting to determine any trends from the records. But acting, we presume, on the assumption that the biases mentioned above are randomly distributed throughout the samples, sea surface

* For a more detailed discussion of all the real and potential bias in both air and sea temperature measurements see (IPCC 1992 pg. 209-212).

temperatures have been generated by Bottomley et al. (1990) as displayed in the Climatic Change, IPCC (1992).

Figure 3 presents average annual global air temperature anomalies (Oak Ridge National Laboratory 1994) from 1880 to 1993. Figure 4 presents hemispheric data for the sea surface temperature departures. When the two time series are combined in Figure 5 (from IPCC 1993) the temperature increase over the record is approximately 0.5^{o} C. The most significant increase in air temperature prior to the 1970s occurred from about 1916 or 1917 to the mid-1940s. That, in turn, was followed by some cooling in the 1960s and some warming in recent decades.

Some climatologists have argued that the apparent rise in air temperature from the mid 1970s (shown in Figure 3) through the 1980s is proof that human-induced global warming has begun. However, the apparent temperature increase since the 1970s, especially in air temperature (Figure 3) may be biased. Moreover, such increases most often appear in daily minimum (nighttime) but not maximum (daytime) temperatures. This suggests that global warming, if it exists, may not be the threat some advocates envision.

Recent satellite observations of global air temperatures also cast doubt on the reality of the apparent rise in surface temperatures since the 1970s. For example, the sensors* on satellite platforms provide nearly complete Earth coverage in as little as one day and can obtain measurements from various levels in the atmosphere (Spencer and Christy, 1990). Unlike surface thermometers, the satellite measures the integrated air temperature over several thousand feet in the vertical. The temperature of the upper atmosphere must change in order to balance temperature changes at the surfaces. If there are no significant changes in the temperature of the upper atmosphere then it can be presumed that no significant changes are occurring

* Microwave radiometers. For details see Spencer and Christy, (1990).

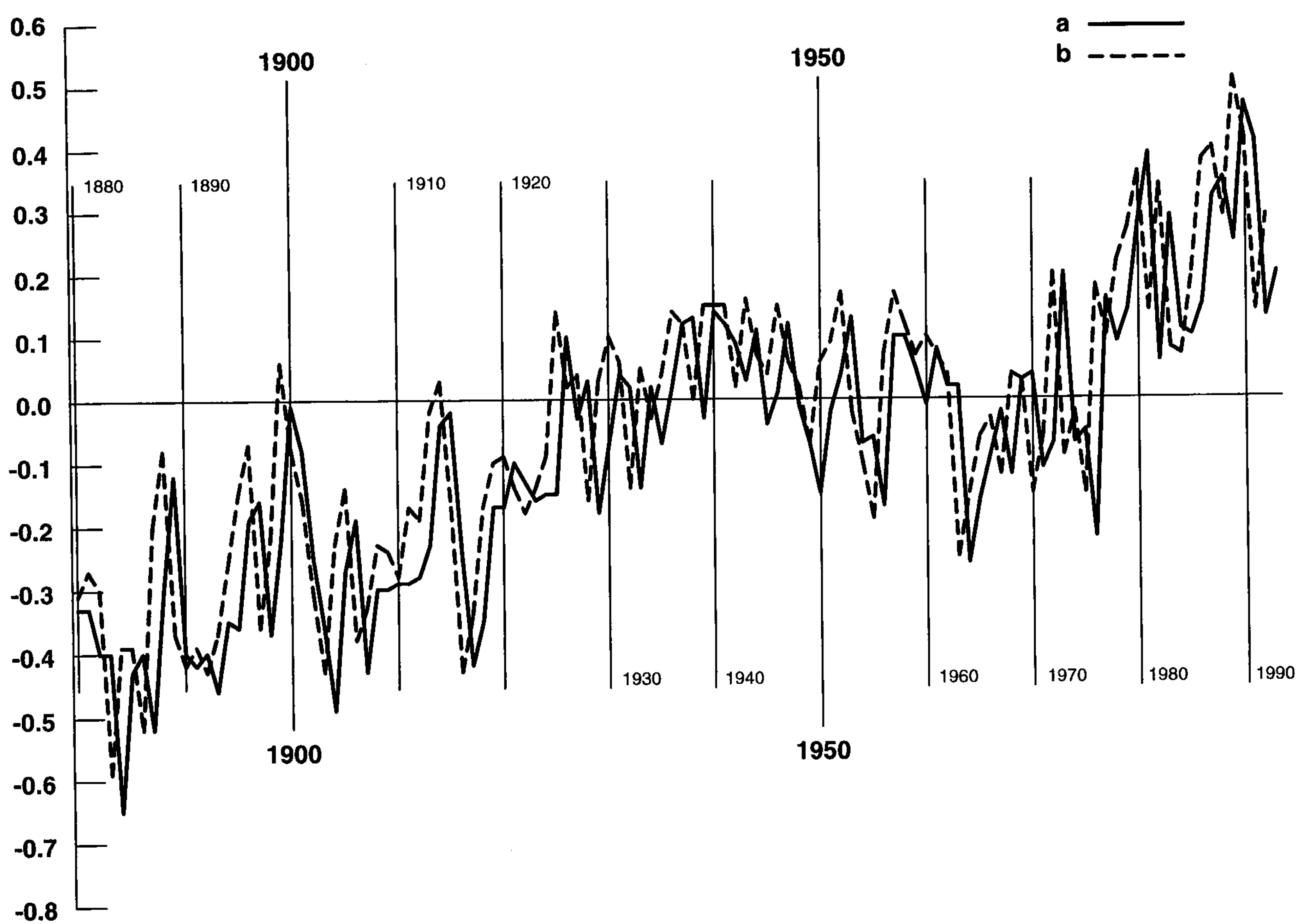


Figure 3: Global Temperature Anomalies 1880-1993 (a) Wilson / Hansen; (b) Jones / Wigley
(From Trends)

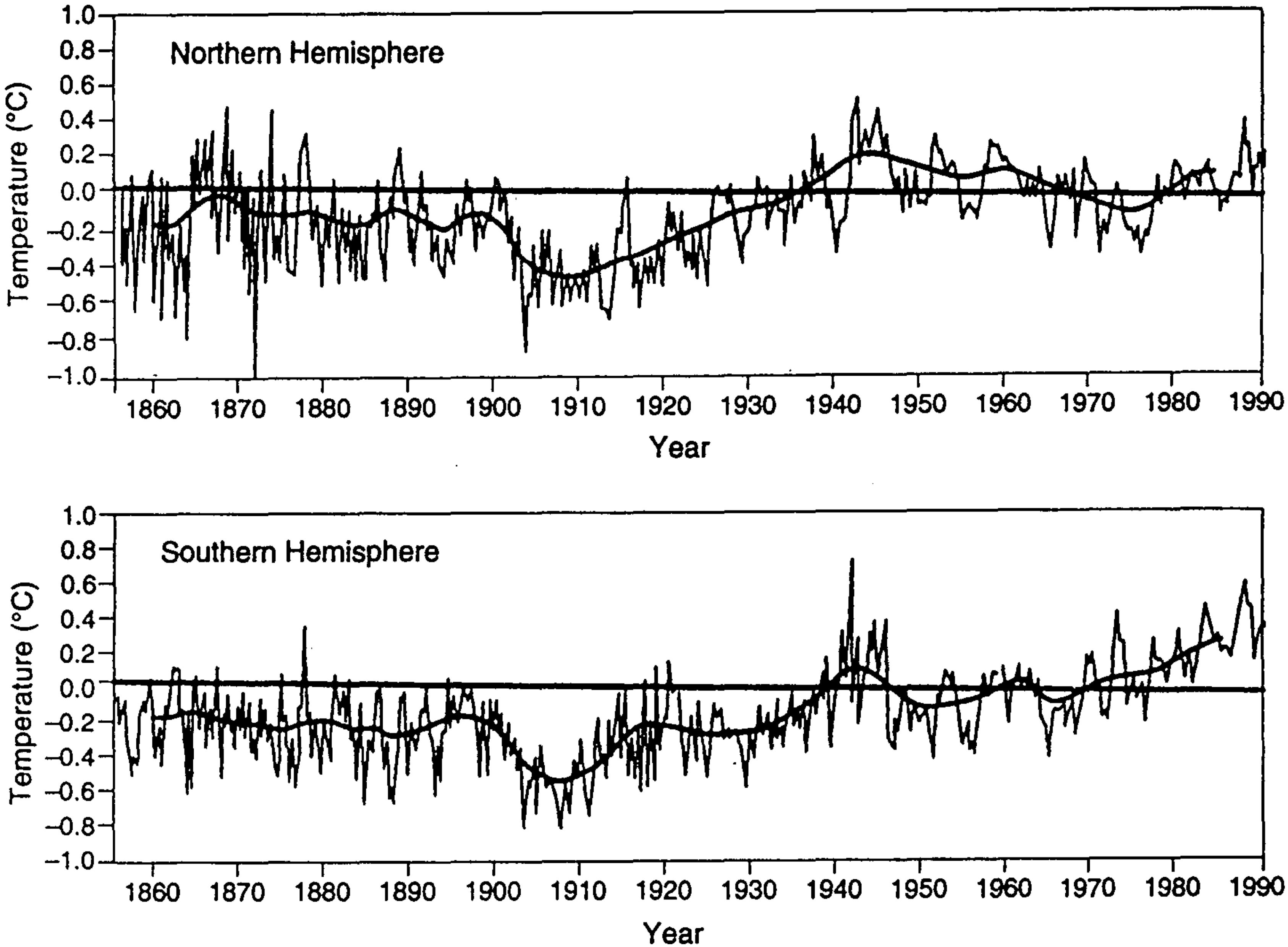


Figure 4: Annual Globally Average Sea Surface Temperature (1860-1990)

[from Michaels (1992)]

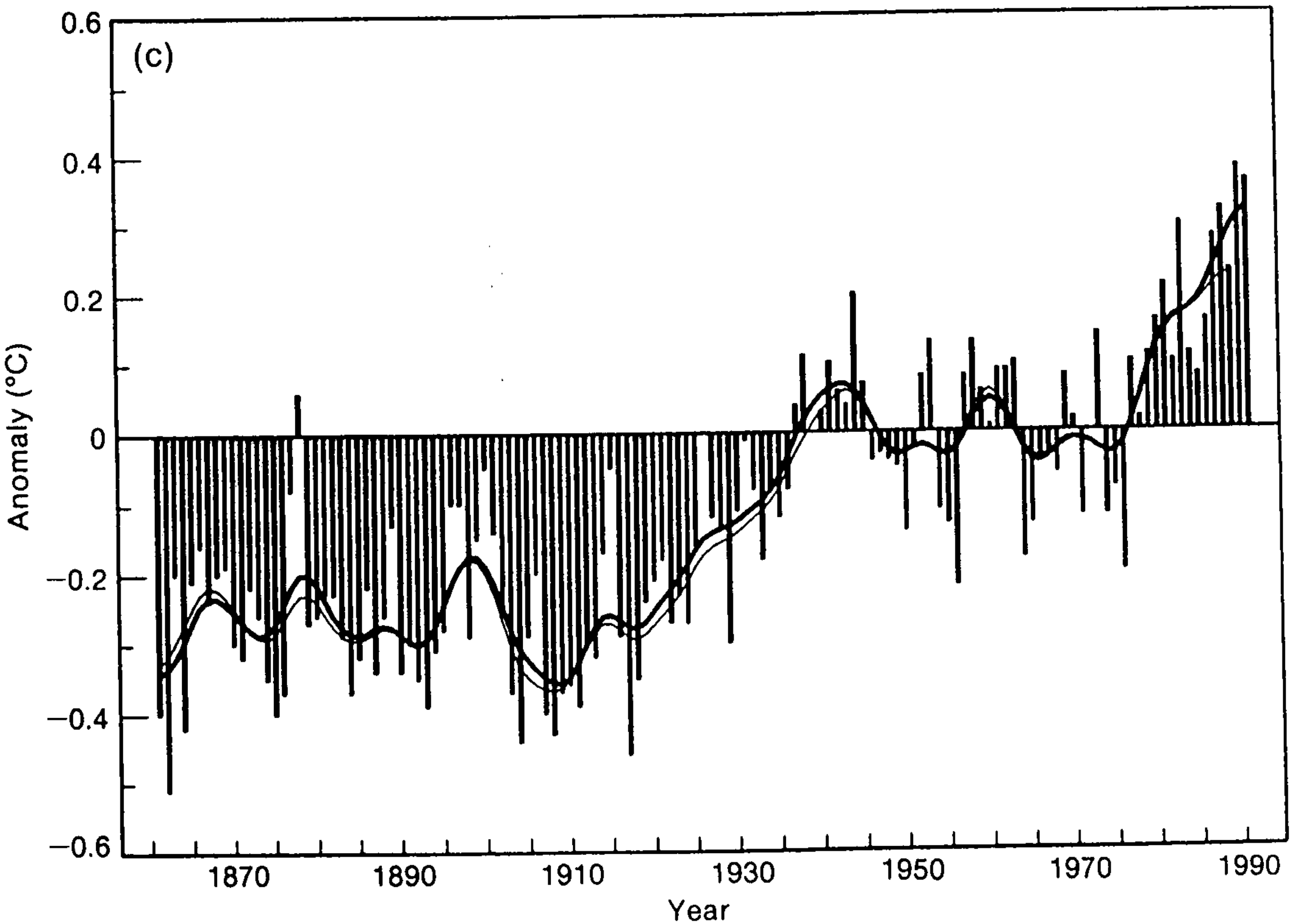


Figure 5: Sea Surface Temperature and Surface Global Temperature combined
[IPCC (1992)]

at the surface. Numerous experiments comparing the satellite temperatures to those measured by radiosondes have confirmed the accuracy of the former.

Figure 6, from Oak Ridge National Laboratory (1994) displays the lower tropospheric temperature trends (i.e., below ~10,000 feet) from 1979 through 1993, as obtained from satellite measurements. It is clear that over the past one-and-a-half decades, lower tropospheric temperatures obtained from satellites have not shown any increase; in fact, there is no evidence of <u>any</u> significant positive or negative trends over the fourteen years of data. This is in marked contrast to the Wilson/Hansen and John/Wigley data (Figure 3), which show a significant increase. In our opinion, hemispheric satellite temperature data must be considered more accurate than land readings since satellite readings are much less susceptible to such land-based biases as the urban heat island effect.

Figure 7, presents what we consider to be the most consistent and accurate global temperature trends over the past century, using the satellite data for temperature trends from 1979 to 1993. The observational data displayed in Figure 7 show, at most, a modest increase in global temperatures of about 0.5° C over the past century. The most rapid warming occurred from about 1916 or 1917 to the mid-1940s, <u>before</u> the abrupt increase in carbon dioxide concentrations discussed in detail in Section D.

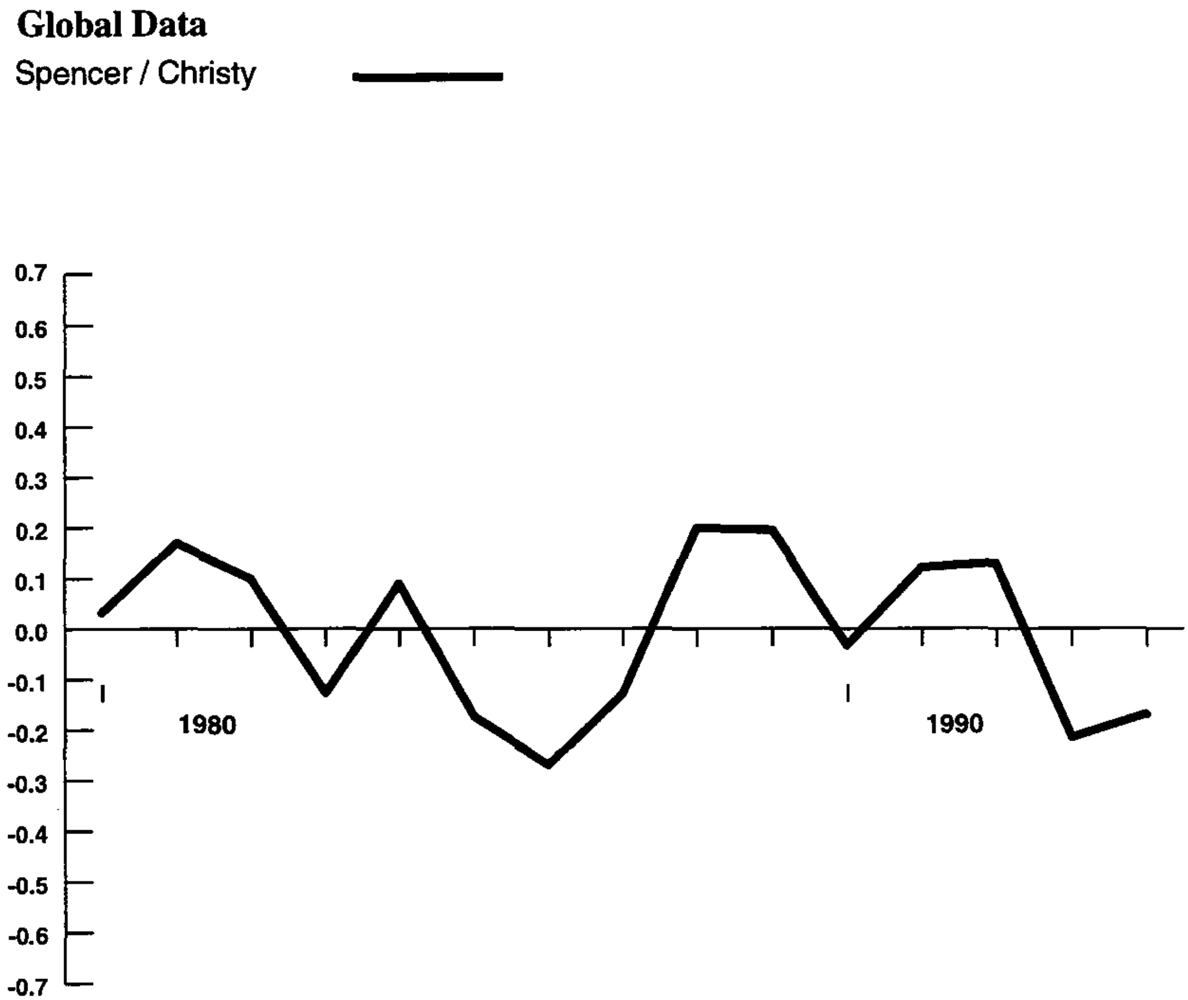


Figure 6: Global Temperature Anomalies 1979-1993 Spencer / Christy
(From Trends)

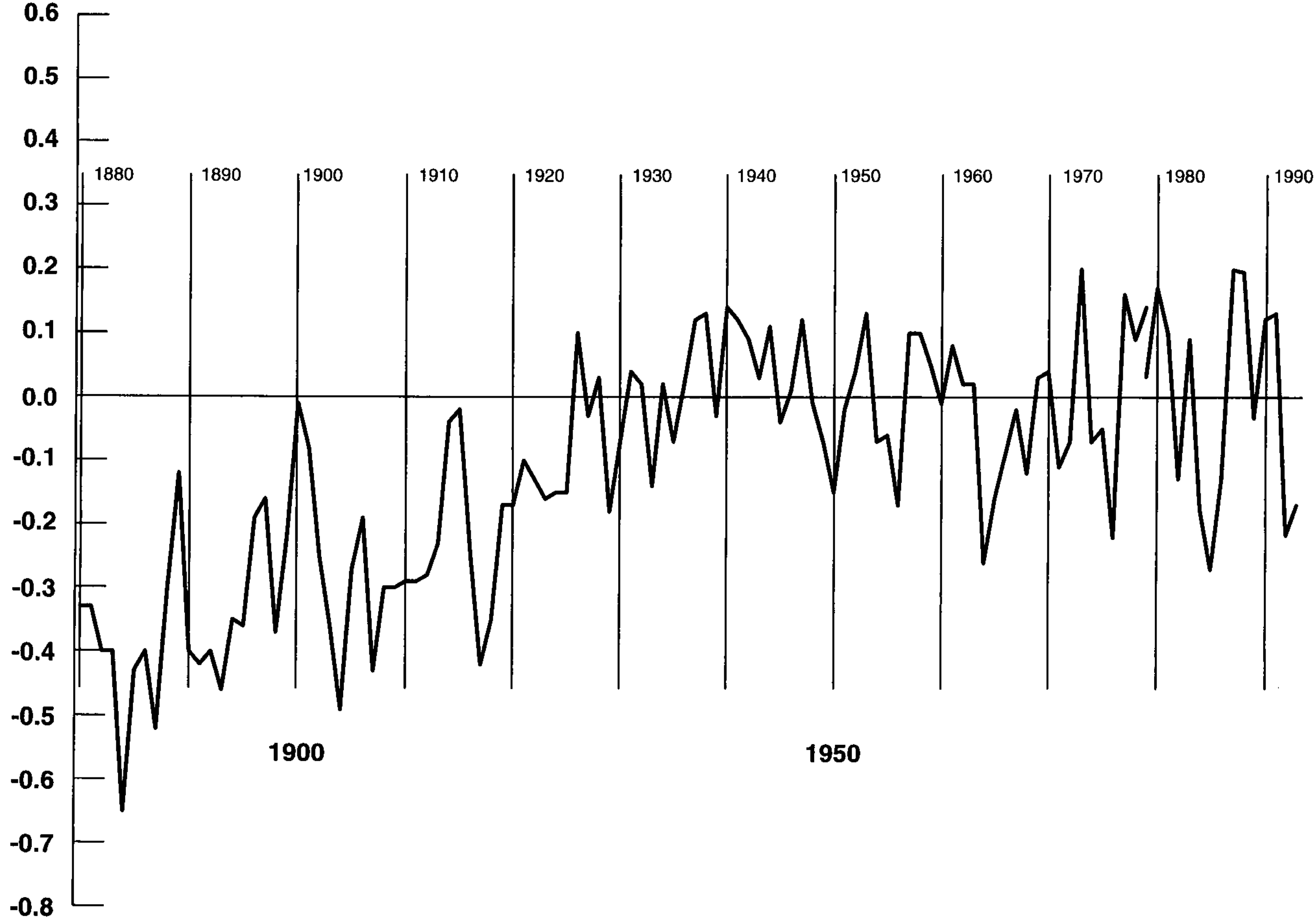


Figure 7: Most Plausible Global Air Temperature Anomalies 1880-1993
(1880 to 1978 - Wilson/Hansen
1979 to 1993 - Satellite)

C. IS TODAY'S WEATHER MORE EXTREME?

Are weather variations more extreme today than they were 50 to 100 years ago?

No.

Although some people have argued that hurricanes are becoming stronger and more frequent, that tornadoes have increased in number and that droughts and floods are becoming more common, recent work by scientists worldwide disputes this hypothesis. In fact, both theoretical arguments and observational data show that hurricane frequency is not increasing, the number of violent tornadoes is not increasing, and temperature and precipitation extremes are not more common now than they were 50 to 100 years ago.

Ever since the first one-dimensional climate models were used to make predictions of global warming a dozen or so years ago, most of the media have routinely treated global warming as a given fact. In "Global Warming Unchecked" (1993), Bernard describes in detail how global warming will cause catastrophic weather changes in the United States from the West through the Great Plains, Midwest and into the East and the South. Others have predicted an even more significant effect of global warming on such often calamitous meteorological phenomena as tropical storms. Using theoretical arguments advanced by Emmanuel (1987-88), Friedman (1989) hypothesizes that since global warming means higher sea surface temperature, that in turn will:

A. Lengthen the tropical storm and hurricane season;

B. Extend the area over which tropical storms and hurricanes can form;

C. Cause tropical storms and hurricanes to be more intense; and

D. Cause more tropical storms and hurricanes to strike the United States, thus greatly increasing insurance losses.

Other writers in the popular press (e.g., Flavin, 1994) are even more extreme. Some claim that global warming has already affected the world, not only seen in the (alleged) increase in tropical storm and hurricane intensity and frequency, but also in the number of floods, intense middle latitude storms and droughts over the recent past. They cite the many media reports of severe weather events from all corners of the world as evidence that global warming has already occurred. In one publication, statements are made that a three to four degree Celsius rise in sea surface temperature could increase the destructive potential of hurricanes by 50 percent. No climate model, even the one-dimensional models, has <u>ever</u> predicted an extreme global warming scenario in which sea surface temperature increased by three to four degrees Celsius over current temperatures.

Other factors also cast doubt on the extremist point of view and their method of reasoning. For example, statements about the "average"* rainfall or "average" temperature do not contain complete information. The average value, or as it is sometimes called the <u>mean</u>, of any element is composed of variations, or, in statistical jargon, the variance about that average. Some averages are composed of large (or high) variances of the measured quantity while others may have small variations. Indeed, the average rainfall (or temperature) may be the same at two locations but the variances about that average can be completely different. In Figure 8, we show a hypothetical time series of a variation of a weather element at two different locations over the same time interval. Both have the same average, but the variations around that average are significantly different.

Why is the concept of averages and variance important to understand? Consider the behavior of element A in Figure 8. The average is composed of extremes; it was either feast or famine over the time period shown; while variations of element B were much closer to the average over the eight intervals of time. Thus the average of some climatological element over any given period

* The terms "normal" and "average" are used here interchangeably.

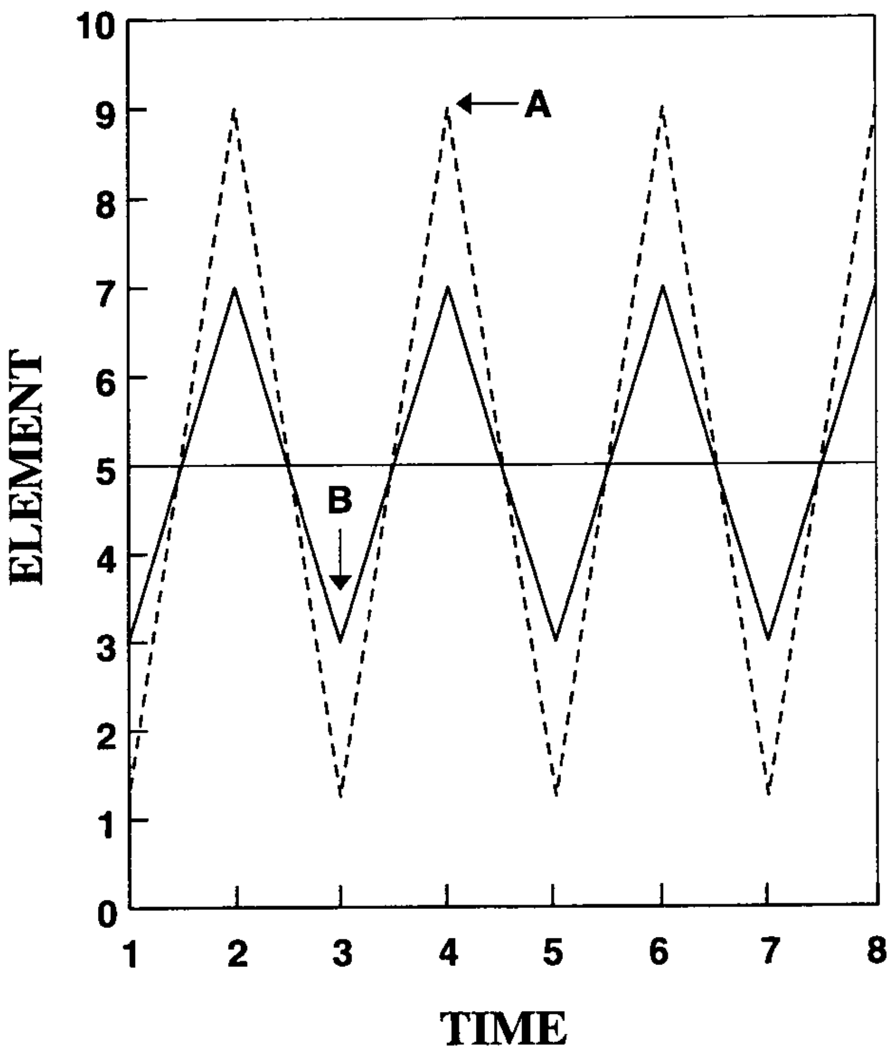


Figure 8: Two time series (A&B) with the same average of 5. Series A varies from 1 to 9; series B from 3 to 7

of time does not, by itself, contain complete information about that element's real behavior. Such is often the case in climatological or even short-term weather data. Proponents of extreme weather events associated with global warming have relied upon data from regions of high variance, since any given day, month or year will almost always have a significant departure from the average. The same basic concept of variability about the mean applies to spatial (areal) averages as well as time averages. So when the printout from the climate models is displayed,the average of some element, such as rainfall or temperature, over some region contains limited information. Consequently, statements and descriptions, such as those made by Bernard, about the time and/or spatial variances of the elements displayed in some of the printouts are pure guesswork.

Global warming alarmists have also fallen into a statistical trap and ignored physical reality as well. As discussed before, some have stated the climate models' predictions of warming of sea surface temperature by a few degrees will cause more numerous and more intense tropical storms. In addition, higher sea surface temperatures will also extend the tropical storm season. We will show later that these conclusions are not correct.

The statistical pitfall encountered by proponents of calamitous scenarios associated with global warming is common to those who assume that if two events occur simultaneously, or in phase with one another over significant periods of time, there is a cause and effect relationship. Or, stated in statistical terms, if a high correlation exists between A and B, that means that knowing the behavior of A, you can determine much of the behavior of B. But, one must be very careful in using statistical relationships to establish or even postulate physical processes that appear to be causing the correlation between A and B or using these relationships for predictive purposes. For example, every human being who lived for more than a few days has either died or is on their way to death, and all of them, at one time or another, drank water. Therefore, using a casual "cause of effect" reasoning, it follows that drinking water results in death.

In fact, we know that the opposite is true, that without water death is predictable in a short period of time. This illustrates the danger of using pure statistical relationships to infer the physical reasons for events occurring.

Using statistical information, Friedman and others assumed that the climate model outputs showing increased sea surface temperatures are correct and that sea surface temperature greater than or equal to 26^{O} C is the only critical condition necessary for the formation of tropical storms. In addition, it was assumed that both the areal extent and the length of time sea surface temperature equals or exceeds 26^{O} C would increase. This simplistic reasoning has led some to believe that the tropical storm season would lengthen and the area of tropical storm formation would expand. In other words, there would be more tropical storms over longer periods of time and over larger areas. Assumptions have also been made* that as tropical storms and hurricanes move over higher sea surface temperatures, they would increase in intensity, ergo, there would be more intense tropical storms in the future as global warming takes place.

Recently, Lighthill, et al. (1994), have shown that these simplistic arguments and assumptions are not true. Specifically, the referenced article summarizes studies of tropical storms and hurricanes conducted by the nine authors over the last decade. Based on observational studies of tropical storms in the Northern Hemisphere, the authors concluded that the development and intensity of tropical storms is not directly related to sea surface temperature. In fact, they found no correlation between the intensification (or maximum intensity) of tropical storms and sea surface temperature. Moreover, the Lighthill study also shows there is no correlation between the Northern Hemispheric air temperature anomalies over the past several dozens of years and the maximum intensities reached by tropical storms. (See Figure 9.)

* Assumption was based on theoretical arguments involving thermodynamic energy transfer processes.

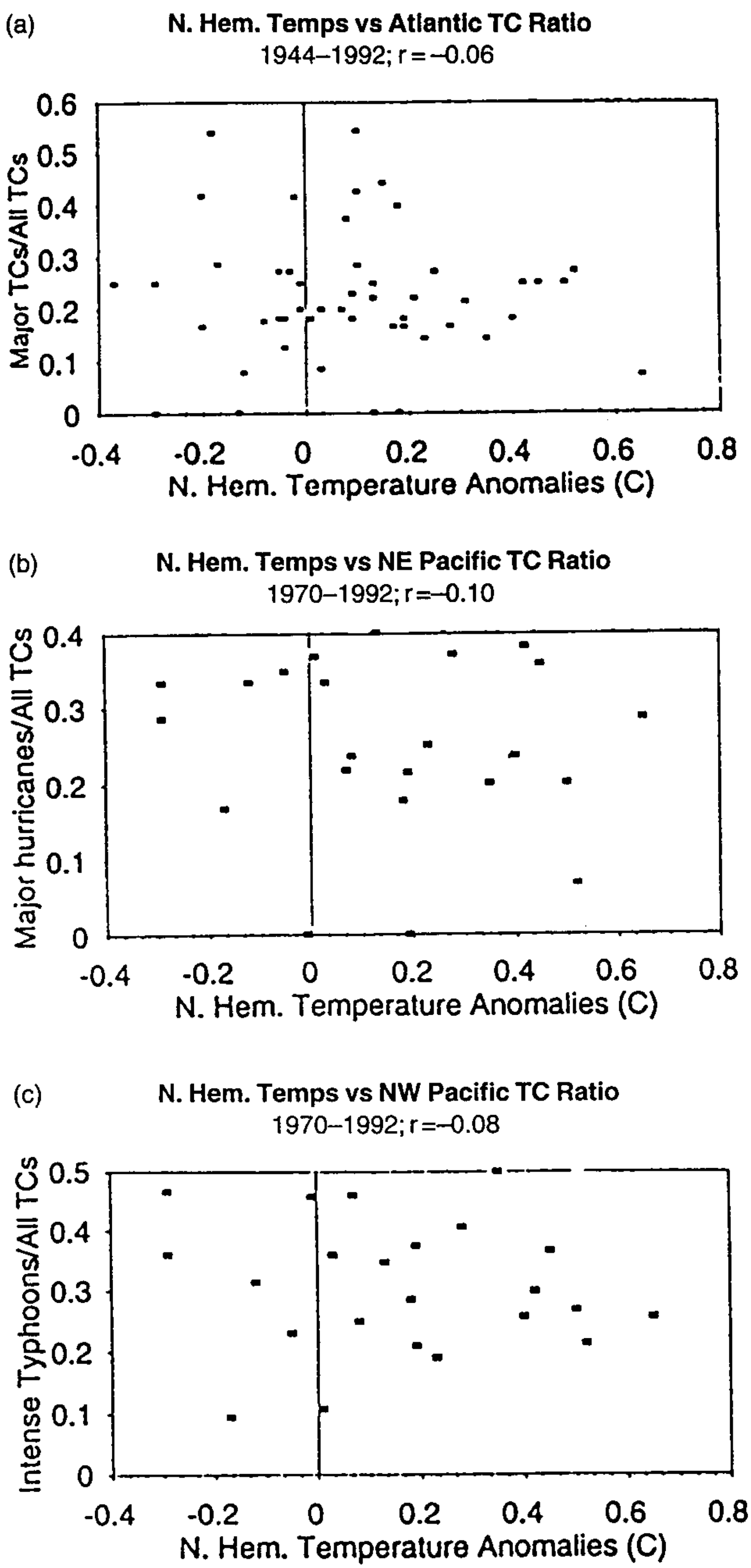


Figure 9: Fraction of Hurricanes that exceeded 50 m/sec (ordinate) and the Northern Hemisphere Land Surface Temperature (abscissa) Anomalies (Relative to 1951-1970 Average) from Lighthill, et al.

Rather, as Lighthill et al. point out, six conditions are necessary before a tropical storm forms and intensifies. A minimum sea surface temperature of 26° C is only one of those conditions. The others are:

(1) The distance from the equator needs to be at least five degrees of latitude to bring into play what meteorologists call the Coriolis Effect of the Earth's rotation. This effect generates cyclonic spiraling, or the counterclockwise rotation of the system in the Northern Hemisphere and clockwise in the Southern.

(2) The gradient of temperature decrease with height must be large enough so that the air that has become saturated with water vapor near the so-called "eye-wall" of the storm will be able to continue to rise as it moves up into the atmosphere.

(3) Low values of the vertical wind shear* are needed to avoid excessive departure from a vertically symmetric vortical structure, considered necessary to maintain or allow tropical storm evolution.

(4) Relative humidity has to be high enough in the middle troposphere to avoid drying effects of the air that becomes entrained into the eye-wall of the storm system.

(5) Finally, there must be the prior existence at low altitudes of a rather substantial amount of cyclonic vorticity, which in more common language, means there needs to be a pre-existing tendency for a counter-clockwise spinning component of the atmosphere to be present close to the surface of the ocean.

* In other words, the change in direction or speed (or both) of the horizontal wind with height near the center of the storm.

These conditions, derived from extensive observational records, emphasize that much more than just a sufficiently high sea surface temperature is needed for tropical storm formation and intensification. Condition 3, as listed above, (low vertical wind shear) is particularly important, and this is <u>independent</u> of sea surface temperature.

Condition 1 imposes a lower limit on those latitudes north and south of the equator where tropical storms can form. Similarly, an upper limit on such latitudes is imposed by condition 2. This upper limit, between 15 and 20 degrees from the equator, is set by the lower latitudinal boundary of a region in the atmosphere where downward motion of the air generates the "trade inversion." This region is part of a large scale circulation that meteorologists call a Hadley Cell. This downward motion tends to dampen any upward motion induced by heating or horizontal forcing and is therefore unfavorable for tropical storm development.

Hadley Cells are determined by the orbit and shape of the Earth and the adage that "what goes up must come down." (See Figure 10). The Hadley Cell's ascending branch, air rising from hot regions near the equator, is balanced by subsidence of the air in its descending branch, stretching poleward an average of 15 to 20 degrees of latitude. This branch of the Hadley Cell is associated with a slow, downward motion of the atmosphere. Accordingly, unlike the fast ascent of moist air in the tropical storm's eye-wall, the subsiding air in this region of the Hadley Cell loses by radiation much of the heat it gains by compression. Thus the gradient of temperature drop with height becomes far too low for condition 2 to be satisfied in this region.

This and other evidence presented by Lighthill et al. casts serious doubts on the validity of the hypothesis that any future increases of sea surface temperature must widen the band of latitudes where tropical storms can intensify. Because subsidence, that is the downward motion in the descending branch of the Hadley Cell, prevents condition 2 and condition 4 from

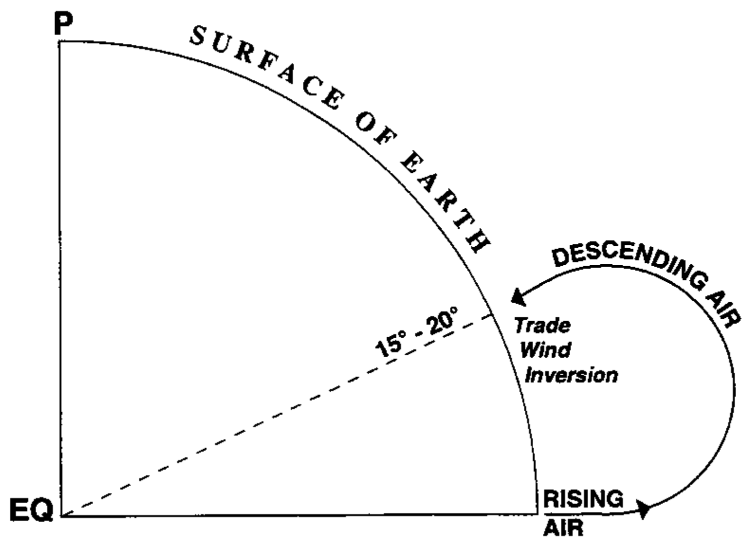


Figure 10: Schematic View of Hadley Cell
(Descending air between 15° and 20° from equator produces Trade Wind Inversion)

being reached there is little likelihood that the area of tropical storm formation will widen significantly. In short, all six conditions for tropical storm formation must be satisfied in order for there to be more frequent or more intense tropical storms. In addition, global warming would raise the temperature of the sea surface above 26° C mainly in the regions where conditions 2 and 4 cannot be satisfied. Consequently, even if global warming were to occur, it appears that there would be very little, if any, effect on tropical storm development.

In summary, Lighthill et al. present credible reasons to reject the hypothesis that more intense or more frequent tropical storms would occur, even if surface sea temperatures significantly increased in response to global warming.

As for other extreme weather events, the evidence also does not support the extremists' claim that, recently, the number of extreme weather events has increased, especially in middle latitudes. Once again we refer back to our discussion of averages versus variances and note that "climate" is defined as the average, over time, of the variations of meteorological elements that we call "weather." In most instances, variance is great in such meteorological elements such as temperature and precipitation in the temperate and polar regions. Extreme departures from "normal" weather patterns are to be expected in these areas.

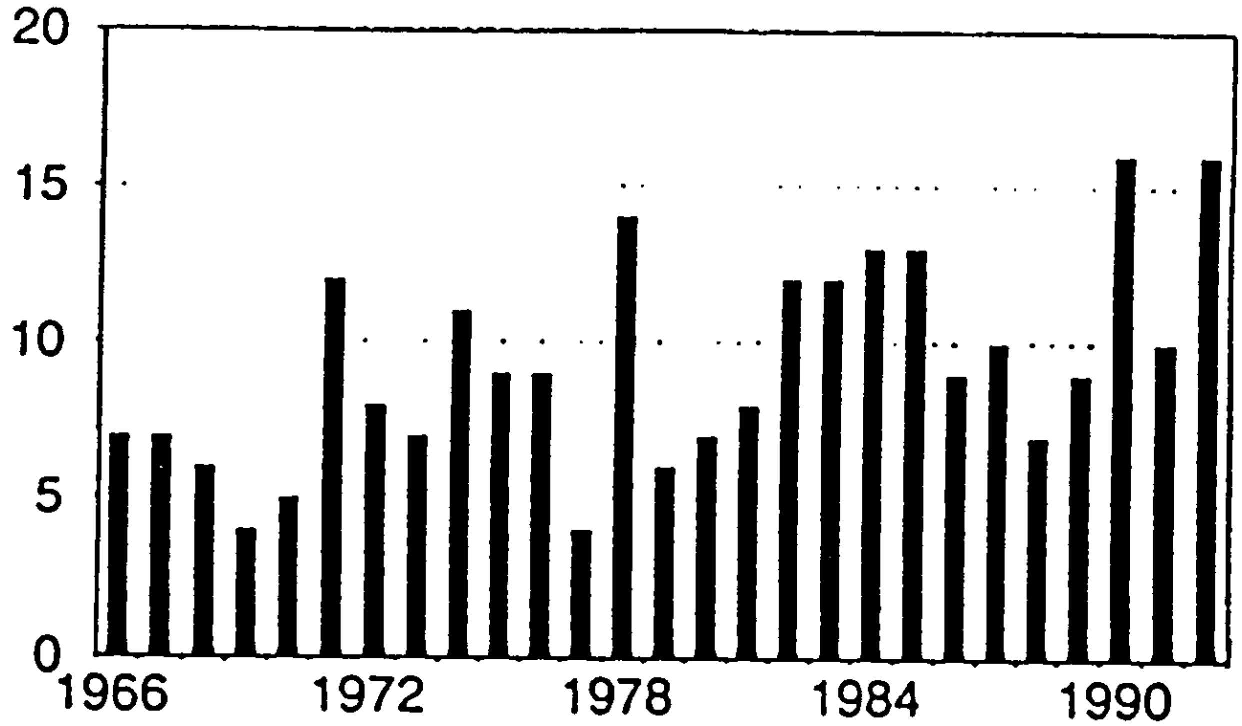
However, many people today think the weather is more extreme than it used to be. In large part this may be due to the media's high-speed electronic ability to rapidly report worldwide events, including the weather. For example, we know almost instantaneously when a tropical cyclone devastates Bangladesh, or that a drought is occurring in Australia. In the past, few people in the United States were aware of these events. The same phenomenon is of course occurring worldwide with the recent explosion of cable and satellite television.

The observational evidence, however, suggests that weather extremes are not significantly different today than they were in the past. Hurricane* data are a prime example. Figure 11 presents data on the frequency of typhoons and hurricanes in the northeast and northwest Pacific Ocean during the past few decades (Lighthill et al. 1994). The data show that typhoons and hurricanes have not increased in number or intensity during the past few decades. Figure 12 (National Weather Service, 1992) summarizes the number of tropical storms that became hurricanes in the Atlantic Ocean from 1880 through 1992. It is apparent from these data that the number of North Atlantic hurricanes has not increased significantly in recent years. These results complement the data in Figure 11 and substantiate our conclusion that the number of hurricanes has not increased in recent time. Moreover, when one considers that satellite observations have been significantly more effective in locating and tracking storms for the past couple of decades, it is possible that the number of tropical storms actually may have decreased in recent years. Some storms that we detect now probably would have gone unnoticed 50 to 100 years ago. This is probably true in the Pacific Ocean as well as the Atlantic.

Questions have also been raised as to the possibility that severe, localized storms, such as tornadoes, are on the increase. Figure 13 presents data by Ostby (1993) on the frequency of tornadoes observed in the 48 contiguous states from 1953 through 1993. The top curve is the sum of weak, strong and violent tornadoes. Weak tornadoes are those with peak winds less than 112 mph, while strong tornadoes have peak winds from 113 to 206 mph. Violent tornadoes contain winds from 207 to 318 mph. As the reader can easily see, the increase in the total number of tornadoes is due to an increase in the number of weak, but not strong or violent, tornadoes over the past 40 years. Ostby attributes the increase in reports of weak tornadoes to several factors including: greater population and public awareness of

* Tropical storms that reached hurricane force (sustained winds greater than or equal to 74 mph).

(b) **Northeast Pacific Hurricanes** (1966–1992)



(c) **Northwest Pacific Typhoons** (1960–1992)

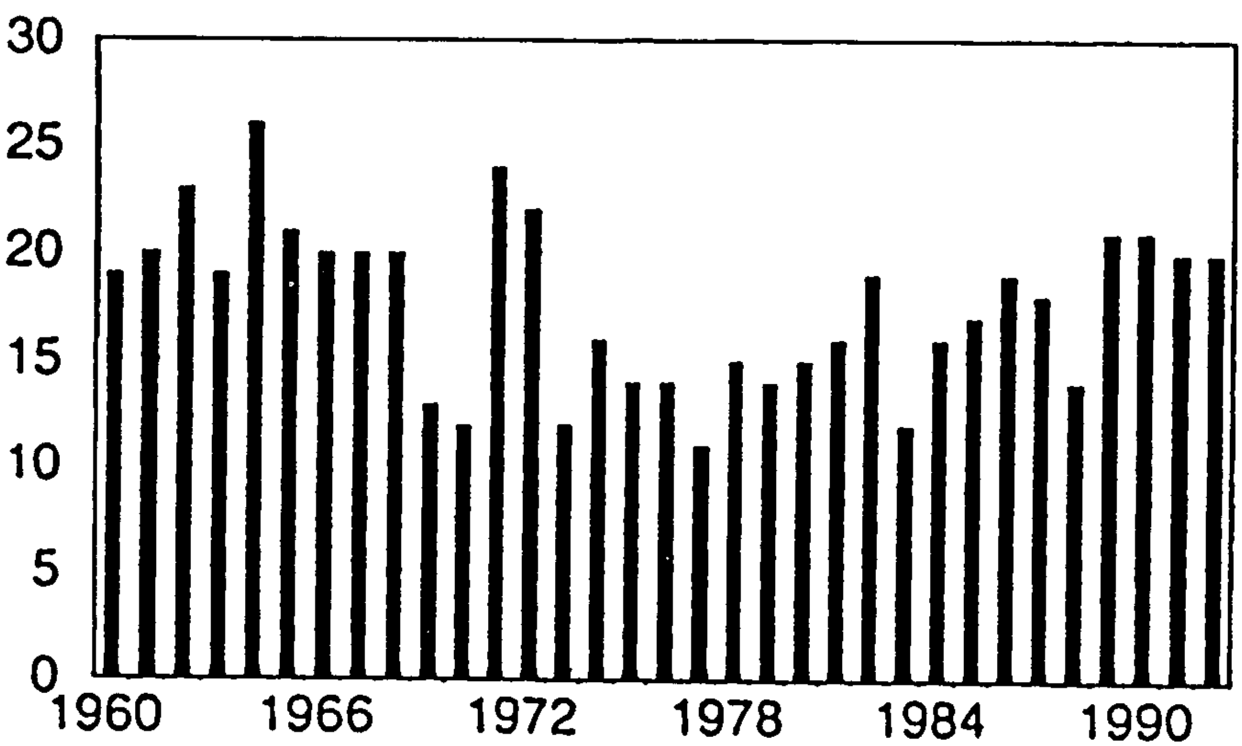


Figure 11: Histogram showing number of hurricanes and typhoons per year

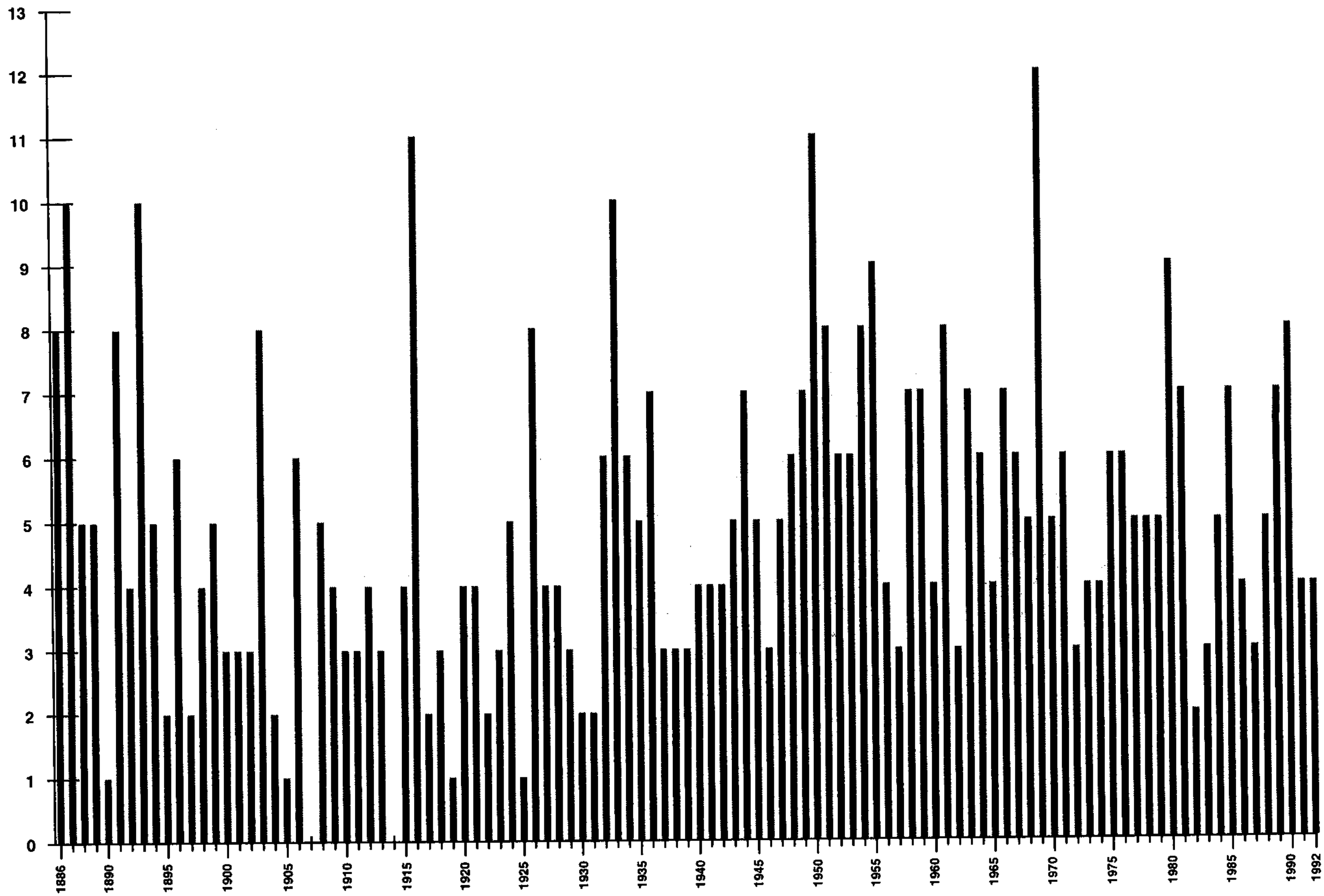


Figure 12: Number of tropical storms which eventually became hurricanes

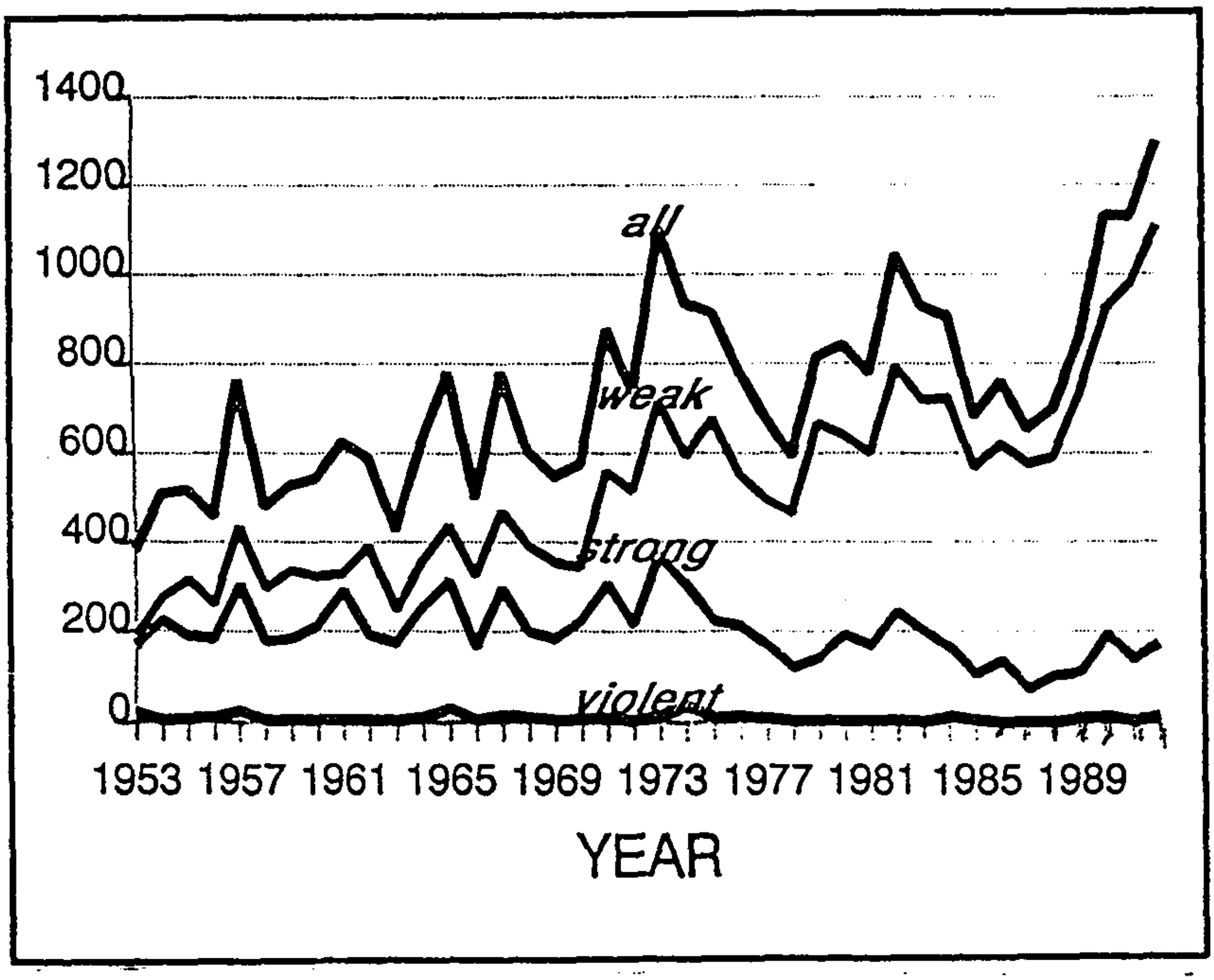


Figure 13: Number of tornadoes/year (from Ostby)

tornadoes in tornado-prone areas, storm-chasing, and the advent of the video camera. Greater population and public awareness are especially relevant because tornadoes are small storms and in days of more thinly dispersed population, many weak tornadoes undoubtedly went unreported. As the data show there is no evidence of an increase in strong or violent tornadoes over the 40-year sample. In fact, there appears to be an overall downward trend of such storms during the past 20 years.

People have also expressed concern about precipitation, including the recent heavy rainfall and flooding in California during January 1995. Some have questioned whether those events are unusual, and whether variability of the weather produced by global warming is the cause. We present the rainfall records for Los Angeles (Civic Center) from 1878 through 1993 in Table I and Figure 14. Table I shows the monthly record rainfall in Los Angeles over the 115 years. As one can see, five monthly record-high rainfall amounts occurred <u>before</u> this century. The heaviest annual total rainfall occurred in 1884. Figure 14 presents the number of months, over 10-year intervals, with total monthly rainfall greater than 7.00 inches. The greatest number of months with rainfall greater than 7.00 inches occurred from 1930-1939. The total for the five previous decades is 20, while the total number of months with rainfall greater than 7.00 inches over the most recent five decades is 19. Once again no observational evidence suggests any significant change in the frequency of excessive rainfall during recent decades.

The same is true for temperature records. The authors have examined a representative sample of record-high temperatures during the past century for a geographical cross-section of the United States. These locations were selected because their data would not be greatly biased by the urban heat island effect and because they represented different climate zones (see Figure 15a through 15c). Note that if a record-high temperature for a specific calendar date matches one on the same date of any previous year it is assigned to the most recent date. Thus, there

Table I

Los Angeles (Civic Center)
Monthly Record Rainfalls

(1878-1993)

	Amount	Year
January	14.94	1969
February	13.37	1884
March	12.36	1884
April	7.53	1926
May	3.57	1921
June	1.39	1884
July	0.27	1886
August	2.26	1977
September	5.67	1939
October	6.96	1889
November	9.68	1965
December	15.80	1889
Annual	40.29	1884

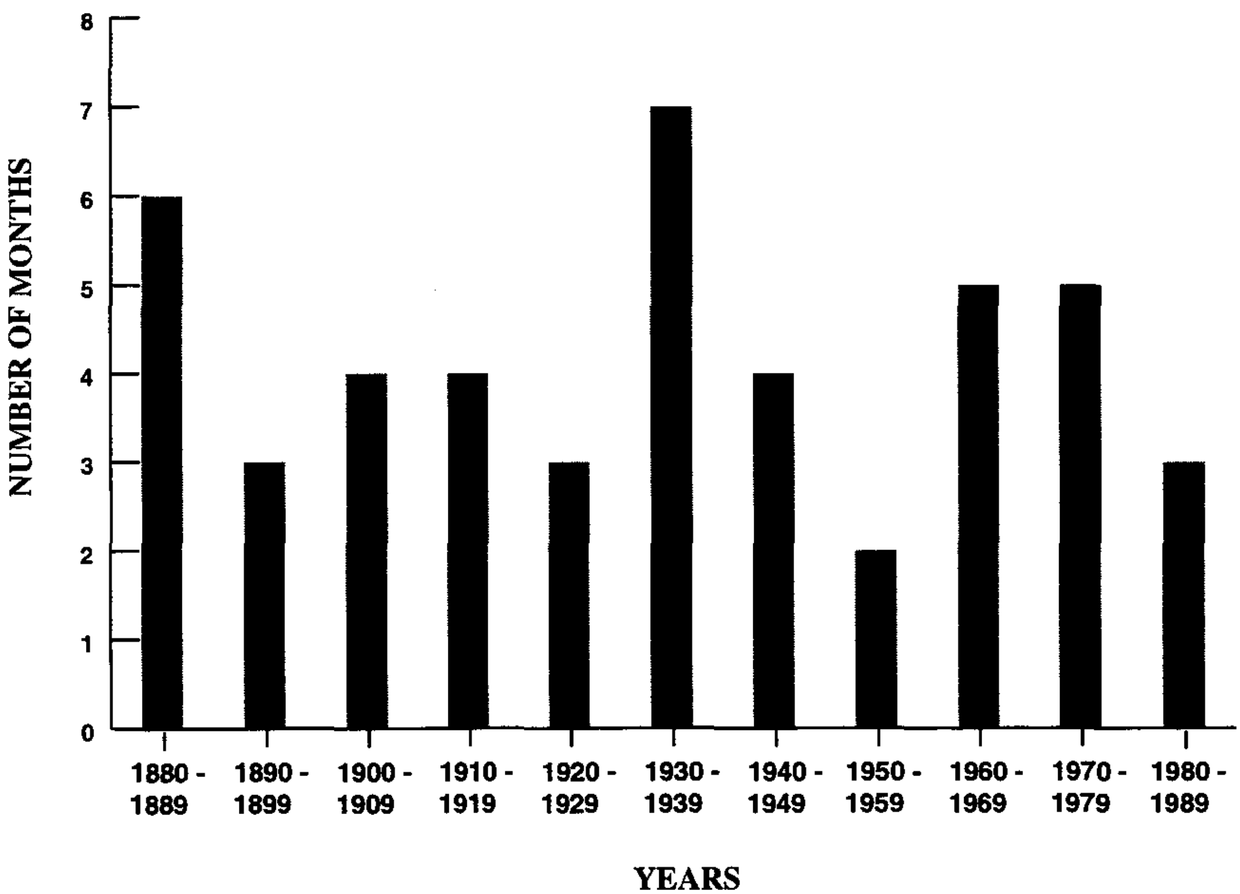


Figure 14: Months with 7.00 inches or more of rain at L.A. Civic Center

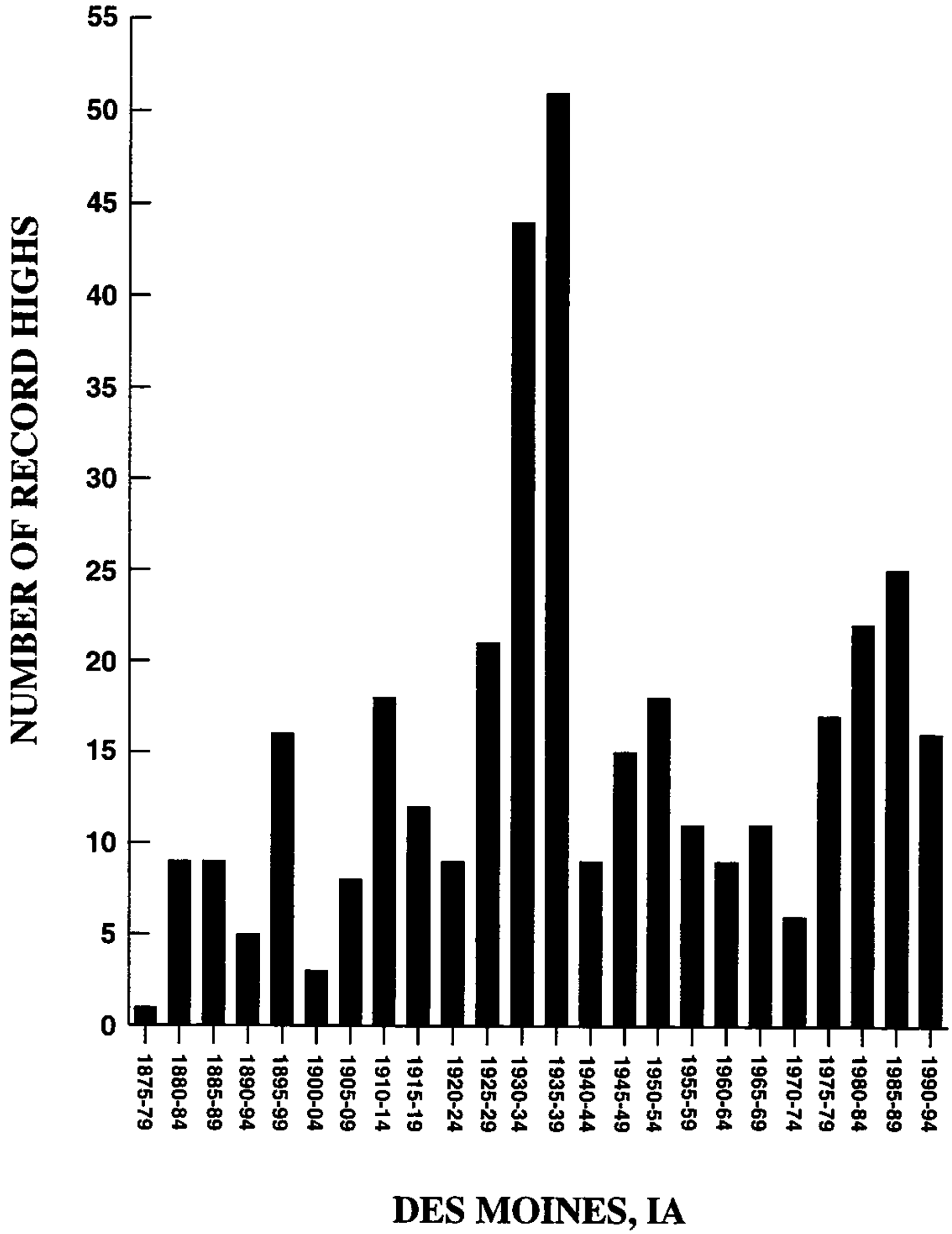


Figure 15A: Des Moines High Temperatures
The total number of times a daily record high temperature was reached or exceeded (based on records through December 1, 1994) at five year intervals from 1875 to December 1, 1994

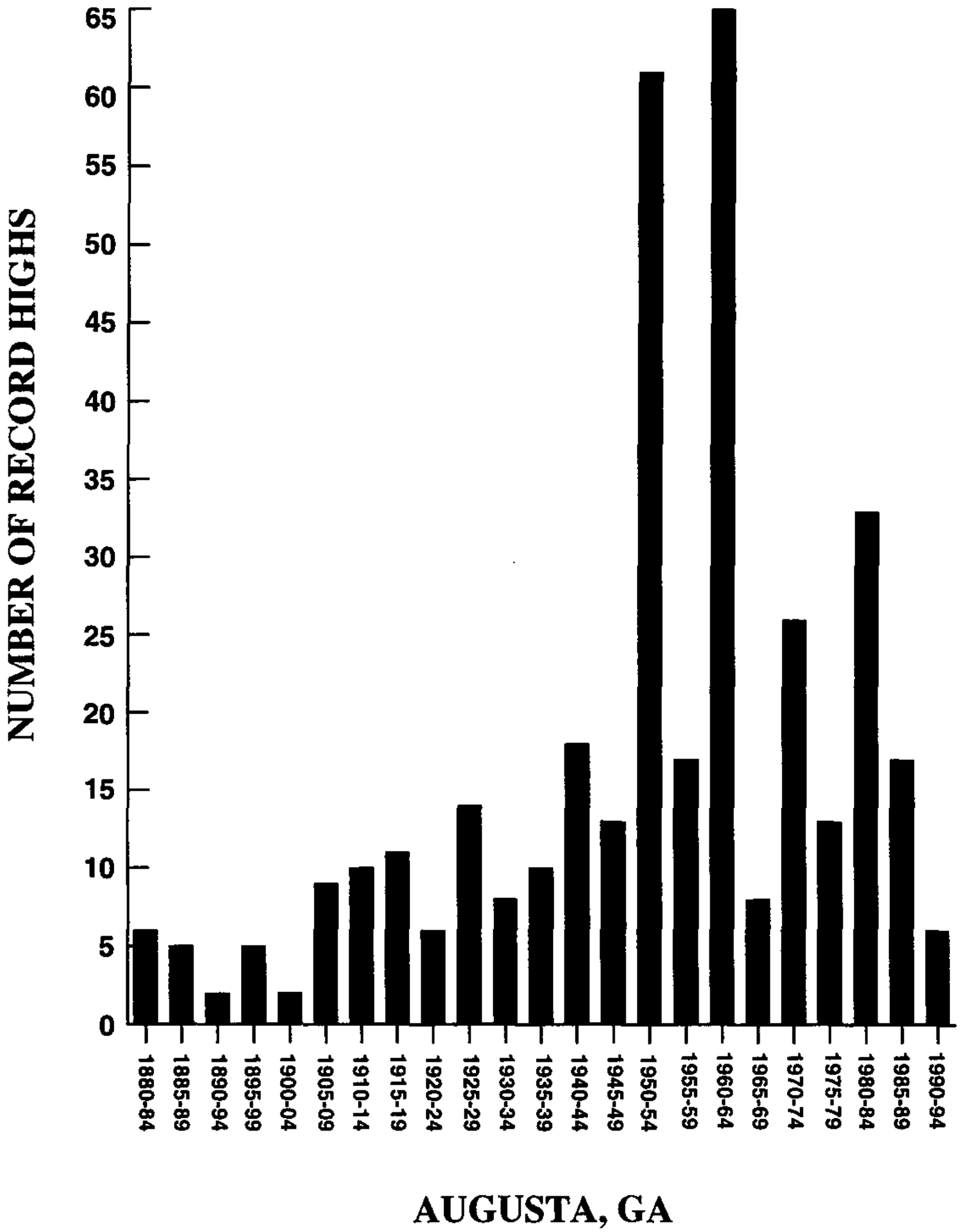


Figure 15B: Augusta High Temperatures
The total number of times a daily record high temperature was reached or exceeded (based on records through December 1, 1994) at five year intervals from 1880 to December 1, 1994

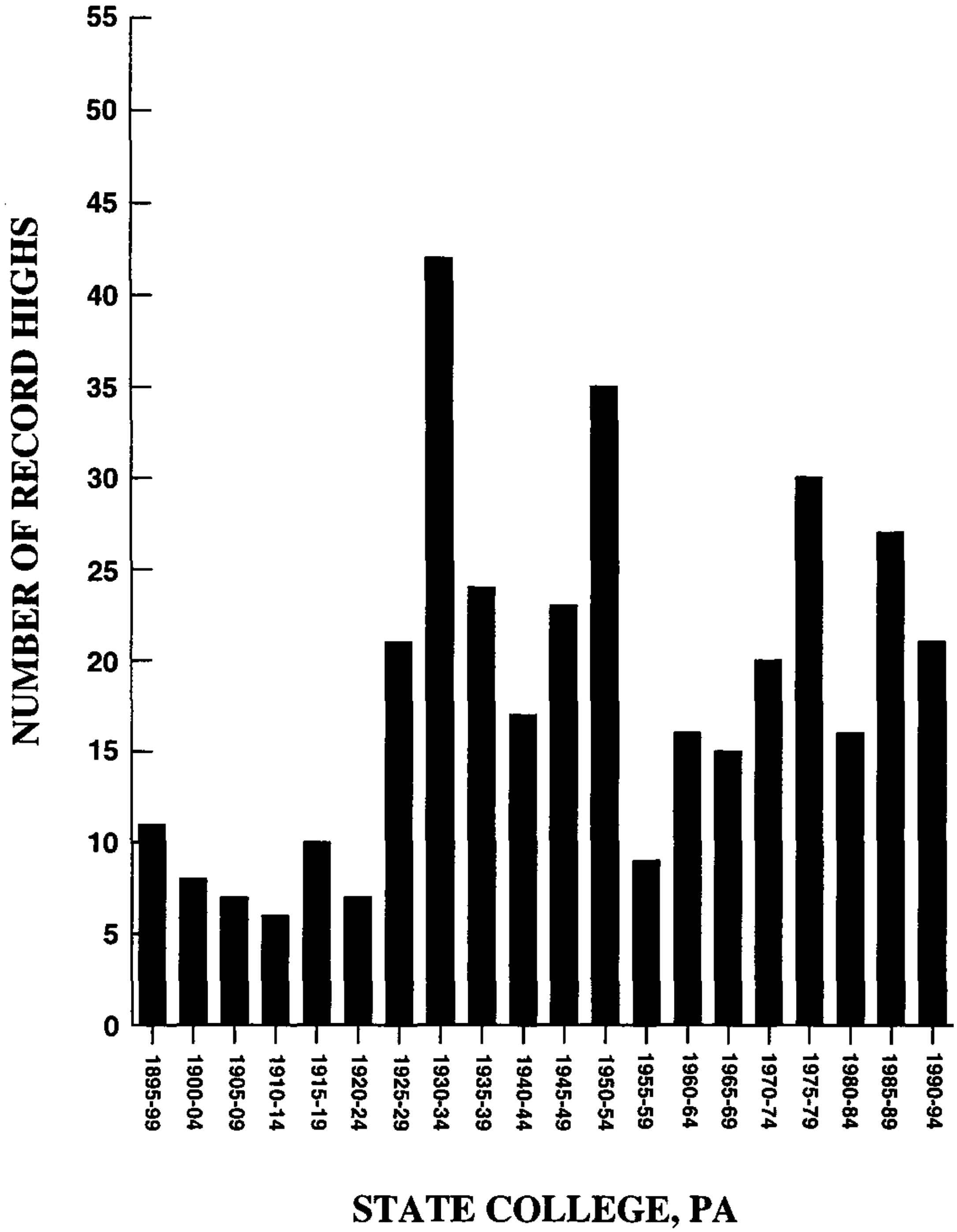


Figure 15C: State College High Temperatures
The total number of times a daily record high temperature was reached or exceeded (based on records through December 1, 1994) at five year intervals from 1895 to December 1, 1994

is a built-in bias, albeit probably small, toward the appearance of more record highs in recent years. Nevertheless, one can see that many daily high temperature records were set at the four locations prior to the last decade or two. There is no consistent evidence in Figure 15 that record-breaking high temperatures have been restricted to or are occurring more frequently in recent years.

In summary, we have found no observational evidence to support the argument that more extreme weather events (a higher variance from the normal) have occurred in recent decades.

As noted earlier, it is impossible to forecast future day-to-day variations in the weather, based on predicted average values. The climate model printouts only present the averages of weather elements over large geographical areas. Bernard and others who argue otherwise assume (incorrectly) that knowing average temperatures makes it possible to determine the range of variance around these averages. However, these averages do not tell us about the daily variances produced by the different tracks (movement) of migratory high- and low-pressure systems. The formation and development of "blocking weather systems" (i.e., the normal transitory nature of highs and lows ceases for extended periods of time) also contribute to daily variances in temperature and precipitation. Such conditions are often associated with weather extremes, especially droughts and heat-waves in the middle latitudes*. As discussed previously, the average of a time series (or a spatial average) in itself does not present any information as to the variance around that average. Therefore, detailed forecasts of atmospheric changes such as Bernard advances are best viewed as uninformed speculation.

* The drought in the late 1980s in the Midwest was associated with strong blocking action, as a large high-pressure system, extending vertically and horizontally in the atmosphere, stalled over the Southern Great Plains and effectively blocked the normal flow of moist air from the Gulf of Mexico, thus reducing the rainfall potential.

Lindzen (1994) has presented a more rational way of understanding general changes in the character of short-lived weather systems in the middle and high latitudes, should global warming occur. For example, Lindzen presents strong evidence* that the sea surface temperatures and air temperatures in the tropics have not changed significantly during cold or warm regimes in past geological epochs. Consequently, if one assumes that the tropical temperatures will not change significantly during an anthropogenically forced global warming, the equator-to-pole temperature differences would decrease. (The warming would have to be limited to the middle and high latitudes). The MIT Planetary Circulation Research Project, (Starr et al. 1970) (Piexoto 1974) also has established that the meridional (north to south) temperature gradient best represents the amount of zonal potential energy available for conversion to the eddy kinetic energy that leads to storms and fair weather systems. For example, a decrease in the zonal potential energy eventually leads to lower eddy kinetic energy and thus to not only fewer but less intense storm systems. Accordingly, it is more likely that should global warming occur, the transient weather systems would likely become more benign, not more intense.

* The jury is still out deciding whether the evidence is accurate without a shadow of a doubt (Broccoli 1994).

D. CHANGES IN GREENHOUSE GAS EMISSIONS AND POSSIBLE MASKING OF GREENHOUSE WARMING

Greenhouse gases have in the atmosphere have increased. As a result, has global warming begun?
No.

The amounts of carbon dioxide, methane and other greenhouse gases have increased in the atmosphere in the last century. A rapid increase began in the 1950s. But the small observed global temperature rise is not in phase with this increase. Most of the temperature rise occurred before the increase in greenhouse gases. Proponents of greenhouse warming argue that other factors are currently masking temperature increases. Our analysis of temperature data in the Southern and Northern Hemispheres indicates that sources such as aerosols are not masking a substantial global temperature increase.

The major greenhouse gas in the terrestrial atmosphere is water vapor. Minor greenhouse gases that are produced either naturally or by human activity include carbon dioxide, methane, chlorofluorocarbons and nitrous oxide. Of these minor gases, the most important, by far, is carbon dioxide. However, even carbon dioxide absorbs only about 5 percent of the total amount of infrared radiation from the Earth, compared to 90 percent to 95 percent absorbed by water as clouds and water vapor.

There is no question that atmospheric concentrations of carbon dioxide and the other minor greenhouse gases have increased. Figure 16, presents the history of carbon dioxide, methane and nitrous oxide concentrations from 1750 to the beginning of this decade. Observations prior to 1958 were obtained from ice cores, but since then they are based on direct atmospheric sampling. The increase had been exponential from 1950 into the 1980s but, the IPCC (IPCC 1994) has documented that the long-term growth rates of carbon dioxide and methane are currently much lower now than they were ten years ago. Although recently the rates of growth have been greater than the long-term

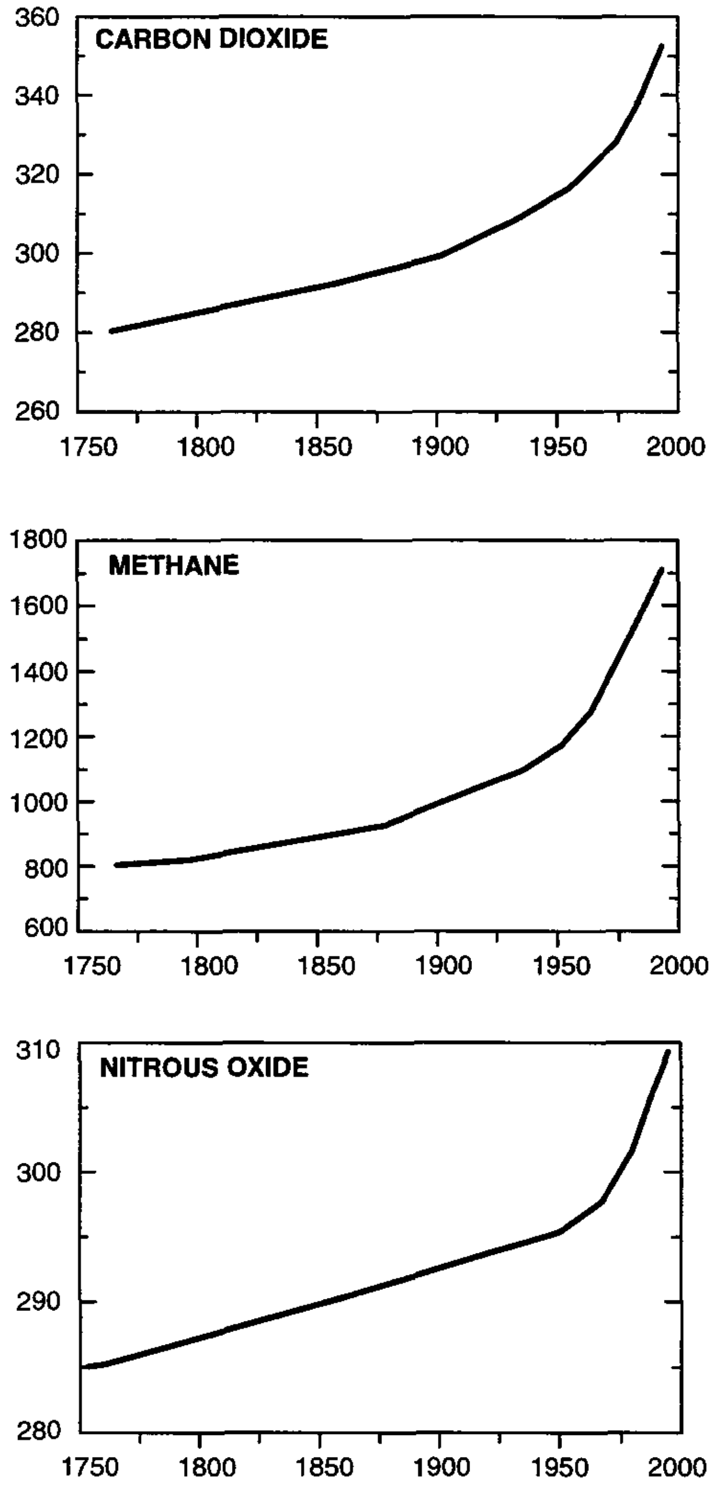


Figure 16: Atmospheric Concentrations of Carbon Dioxide, Methane and Nitrous Oxide
(From IPCC 1990)

average, the IPCC also stated that "short-term changes in growth rate are common in the past record of CO_2." They also stated that "because of the variability at the year-to-year time-scale, growth rates, averaged on a decadal time-scale, should be considered when looking at anthropogenic trends." This new information from the IPCC suggests that any warming caused by greenhouse gas emissions will occur more gradually than previously predicted. Moreover, greenhouse forcing attributable to all anthropogenic gases represents an increase equivalent to about a 50 percent increase in carbon dioxide. Also, the atmosphere now holds about 50 percent of the carbon dioxide produced by combustion and other processes. The remainder has been absorbed by plant life, the oceans and other physical processes.

How have these trends toward increased emissions and atmospheric concentration of greenhouse gases been interpreted?

Simplistic models of the greenhouse effect (See Figure 2) "predict" rapid increases in carbon dioxide in the atmosphere during the past century should have significantly increased global temperatures, especially in recent years. Yet there is no consistent, obvious signal announcing the presence of catastrophic global warming in any of the data the authors examined. There is a general consensus in the scientific community that there has been a gradual increase of about 0.45° C, plus or minus 0.15° C, in the average global temperature since the late 1800s. However, that increase is certainly within the limits of natural variability. Most important, a significant fraction of the air temperature's increase occurred between 1916 and the mid-1940s, that is before the rapid increase in carbon dioxide emissions. Indeed, there is very little evidence of any warming in the global air temperature during the past one to two decades.

The absence of any global warming signal has been a source of consternation to parts of the scientific community. That, in turn, has led to theories that volcanoes, solar activity, or even what is loosely called "air pollution" have masked (or overwhelmed) the warming signal. According to this theory aerosols have systematically increased in the atmosphere since the mid-1800s. If so, proponents argue, these aerosols may have caused some cooling in the past 50 years that has offset the expected increase in temperature due to carbon dioxide emission increases.

To understand how this may have occurred (or may be occurring), it is necessary to examine the role that aerosols may play in the greenhouse scenario. Specifically, "man-made" aerosols include water soluble, inorganic compounds such as sulfates, nitrates and ammonia. The precursor to sulfate formation is sulfur dioxide, the concentration of which has increased over the past half century at an even faster rate than carbon dioxide. Other organic compounds are also found in the atmosphere. Periodically volcanoes are large sources of carbon dioxide. Dimethyl sulfides, also present in the atmosphere, are produced by phyto plankton and decaying organic matter.

The possible influence of aerosols on the radiation budget of the Earth is threefold: first, the aerosols can scatter and absorb incoming solar radiation. This results in a cooling effect by reducing the amount of energy received at the Earth's surface from the sun.

Second, aerosols can cause an indirect radiative influence by affecting the reflection and energy absorption characteristics of clouds. Cloud droplets form in the lower atmosphere by condensation of water on existing aerosol particles. Consequently, the concentration, size and water solubility of the aerosol particles on which cloud droplets in a cloud form have an immediate influence on the concentration and size of cloud droplets. The concentration of droplets increases as their size decreases. The net effect is to increase the reflectivity of the clouds (in meteorological terms, the "albedo") to incident solar radiation. Although clouds are absorbers of infrared radiation, the increase in cloud droplet concentration (and diminished size of each droplet) does not significantly affect the infrared absorption of clouds, especially in the lower part of the atmosphere, where most clouds are found and thus the net affect is a cooling affect. Sulfate aerosols are conjectured to be the main culprit in this possible "masking," although particles of smoke from bio-mass combustion may be important in some instances.

Finally, aerosols may also affect a cloud's lifetime. Solution droplets evaporate more slowly causing clouds to last longer. By increasing the concentration of water droplets while diminishing their size, precipitation would be inhibited, contributing to the extension of the lifetime of the clouds.

How important can this masking? A few years ago (Charlson 1992), it was thought that climate cooling by aerosols was comparable to anthropogenic greenhouse warming. Therefore, the greenhouse effect would be hidden from the data, but still ominously present. This opinion has changed significantly recently. In 1994 Penney & Charlson (1994) stated: "The clear sky forcing by anthropogenic aerosol components cannot be estimated with confidence..." and, "cloudy sky forcing by anthropogenic aerosols are little more than guesses..."

What do the observations tell us of the proposed aerosol masking effect? If the statements made in Charlson's article in 1992 are correct, i.e., that 94 percent of the global amount of sulfur dioxide is found in the Northern Hemisphere, then any greenhouse warming effect on air temperature should be more evident in the Southern Hemisphere. Figures 17 and 18 present air temperature data for the Northern and Southern Hemispheres respectively from 1970 through 1993. As we discussed previously, the Wilson/Hansen data in Figure 17 show some evidence of an increase in temperature in the Northern Hemisphere. In the same figure, even though the variance of the Spencer and Christy data is quite high, there is no obvious warming trend in the satellite data.

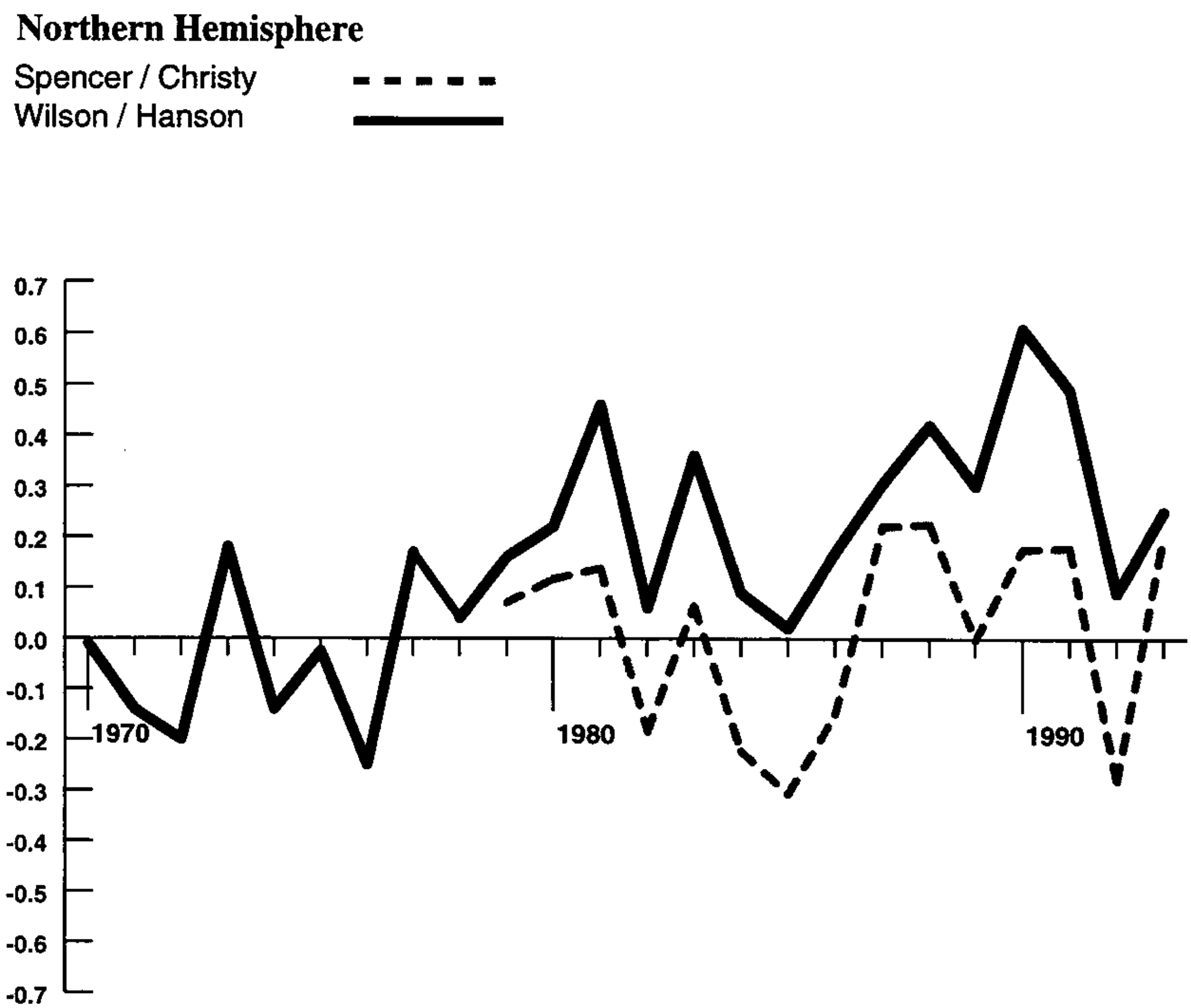


Figure 17: Wilson / Hanson and Spencer / Christy Annual Air Temperature Anomalies for Northern Hemisphere
(From Trends)

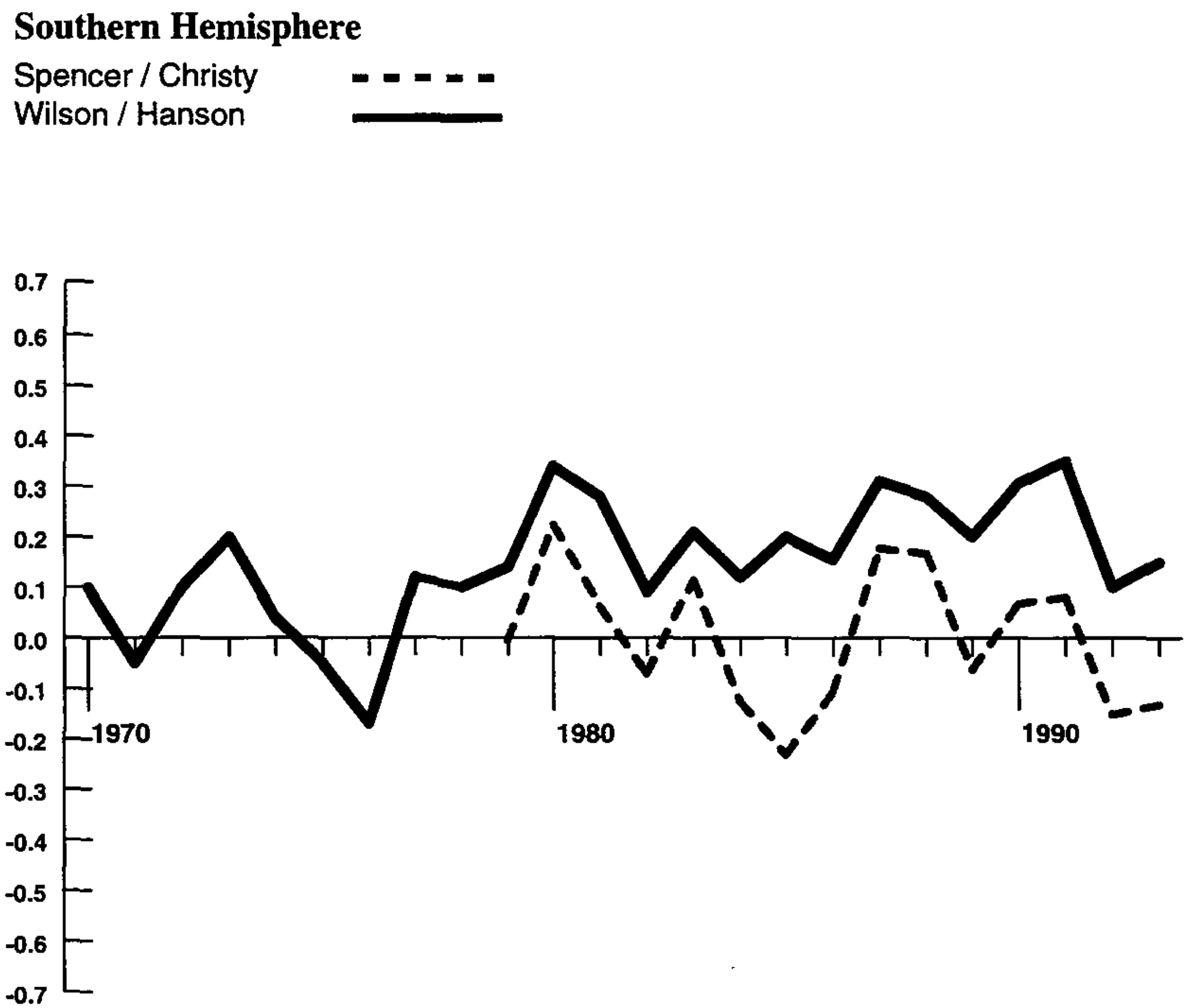


Figure 18: Wilson / Hanson and Spencer / Christy Annual Air Temperature Anomalies for Southern Hemisphere
(From Trends)

In contrast, in Figure 18 for the Southern Hemisphere, only a very small increase in air temperature is discernible in the Wilson/Hansen data, while the satellite data for the Southern Hemisphere show no evidence of any increase in the annual average temperature. This is incompatible with the theory of aerosol masking, since if masking occurred in the northern hemisphere, any warming trend would be more obvious in the Southern Hemisphere. Clearly this is not so. In short, the data are at odds with the theory of aerosol masking of a possible trend toward greenhouse global warming.

However, could other potential sources of aerosols suppress the greenhouse warming signal? Some think so. For example. Hansen (1992) has argued that recent volcanic eruptions have caused periods of reduced solar radiation, thus cooling the global atmosphere. The physical mechanism producing the cooling is analogous to the anthropogenic aerosol cooling discussed earlier. In a recent article in Nature, Christy and McNider (1994) examined the monthly satellite global temperature data from 1979 through 1993. These authors removed the short-term cooling effect of the El Chicon eruption (1982) and Pinatubo eruption in 1991*. These results are shown in Figure 19. These data shows:

a. The monthly average global temperature anomalies from 1979 to 1993 as determined by satellite sensors.
b. The ENSO effect as determined from sea surface temperature.
c. Curve A minus curve B.
d. Volcanic effect.
e. Residual time series after ENSO and volcanic effects combined are removed.

* The warming effect of ENSO was also taken out of the data.

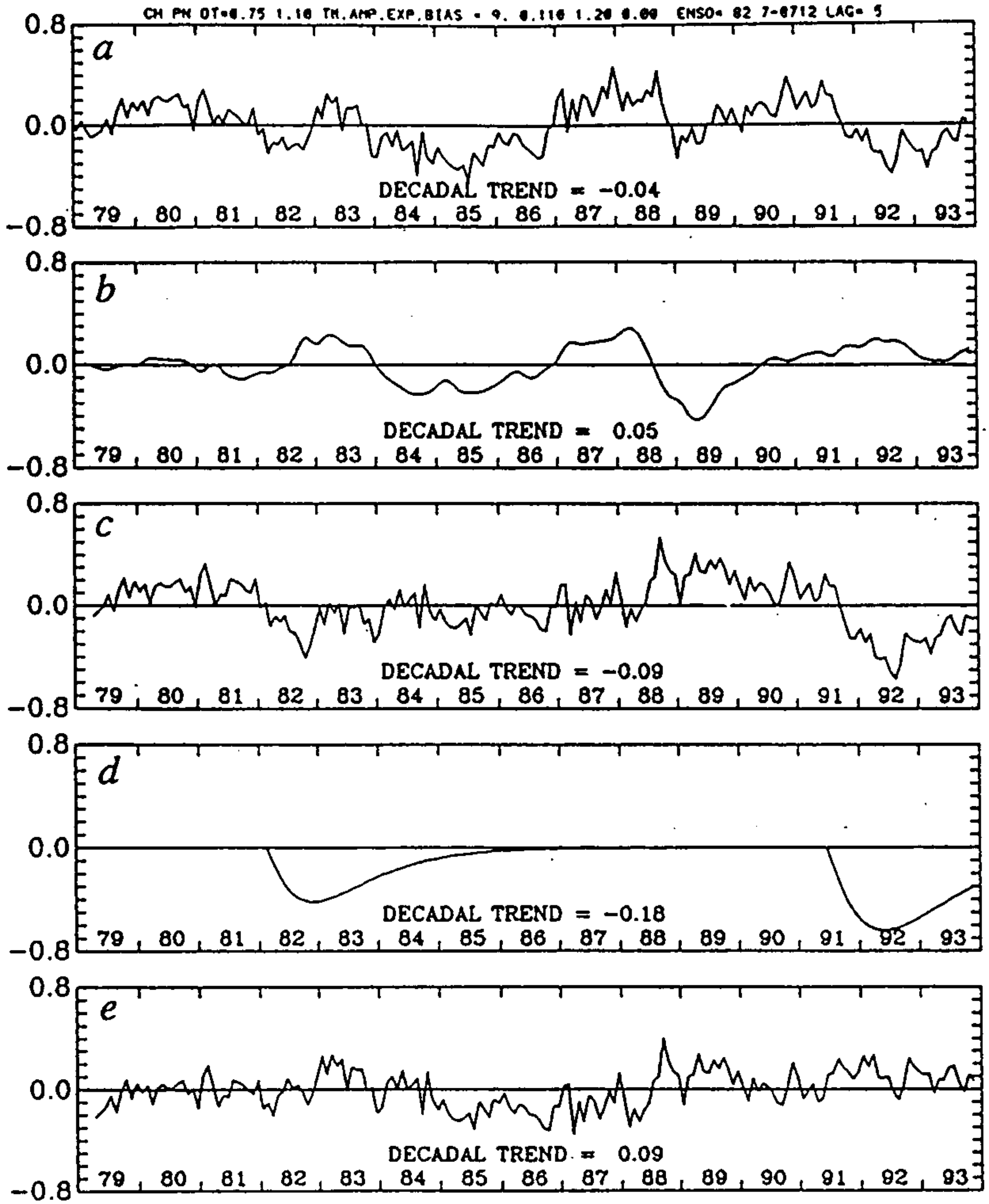


Figure 19: Monthly Average Global Temperature Anomalies from Satelitte

[from Christy & McNider (1994)]

It is of interest to note that before the data manipulation* operations were performed, the decadal trend is minus 0.04° C. Even when the substantial cooling some attribute to volcanoes is removed (as well as ENSO warming), the decadal (curve labelled E) upward temperature trend of 0.09° C is not statistically significant. In short, these data do not support the argument that volcanic activity has significantly masked a greenhouse warming signal.

Other climatologists have examined the possibility that a significant lowering of the sun's energy output has masked the warming signal. And it is certainly true that variations in the sun's energy output may well have played a role in climate change measured in geological terms. Scientists also know that heat energy from the sun varies during a sunspot cycle, which lasts approximately 11 years. The energy output in these cycles reaches a peak which when the radiant output from bright (plage) areas between the sunspots outweighs the decrease in the energy emitted where the sunspots exist. However, the change in the amount of energy from sunspot maximum to sunspot minimum is less than 0.1 percent. Many scientists therefore do not consider sun-spot activity as an important influence on short-term temperature readings. However, prolonged periods of low sunspots may produce changes on the order of 0.25° C. as happened during the Maunder minimum (1645-1717) (IPPC 1993).

During the most recent half century, the sunspot cycle has ebbed and flowed, but there have been no prolonged periods when all sun spots were absent. In fact, sunspot maxima have reached all time peaks on at least two occasions during the past half century. Therefore, if there was any solar influence, that effect would have acted to produce a warming of global temperatures rather than a masking of any greenhouse effects.

* It is not clear to the authors of this report as to precisely how the ENSO and volcanic effects are removed.

To summarize, there is no convincing evidence to date that an anthropogenically generated greenhouse warming has been masked by external or internal agents. Therefore, we agree with the IPCC conclusion stated in the IPCC publication Scientific Assessment 1993 (p. 250): "We have not yet detected the enhanced greenhouse effect...."

E. CLIMATE MODEL PREDICTIONS AND THEIR LIMITATIONS

Do climate models accurately predict the Earth's future climate? No.

A climate model is a set of mathematical equations solved on a computer which attempt to replicate the Earth's physical processes. These equations can be very simple and contain few weather variables, or they can be very complicated and contain many variables. All climate models are limited by our understanding of the physical processes at work, by our mathematical ability to solve each equation, by errors introduced during the computational process, by our selection of specific variables, and by the ability of a computer to handle the huge number of calculations that must be performed. The very first models used by scientists to study climate trends indicated that an increase in greenhouse gases would result in a significant increase in global temperature. More complex recent models indicate that increases in carbon dioxide may result in significantly lower temperature increases than first thought.

Figure 20 presents a schematic view of the global climate system originally published by Stone (1992). This graphic succinctly illustrates the complexity of the Earth's climate system. Meteorologists and climatologists attempt to construct atmospheric models that measure the impact of these variables on climatic change. The models themselves consist of mathematical equations which attempt to replicate the fundamental laws of atmospheric physics. These equations are usually solved on large super-computers and include such climate variables as temperature, humidity, wind and precipitation. These components of the weather respond to such variables as the amount of solar radiation reaching the Earth and the concentration of certain gases in the atmosphere. The climate system is so complex, however, that a model incorporating all the possible variables for all parts of the globe could not be run on even today's fastest, most advanced super-computers.

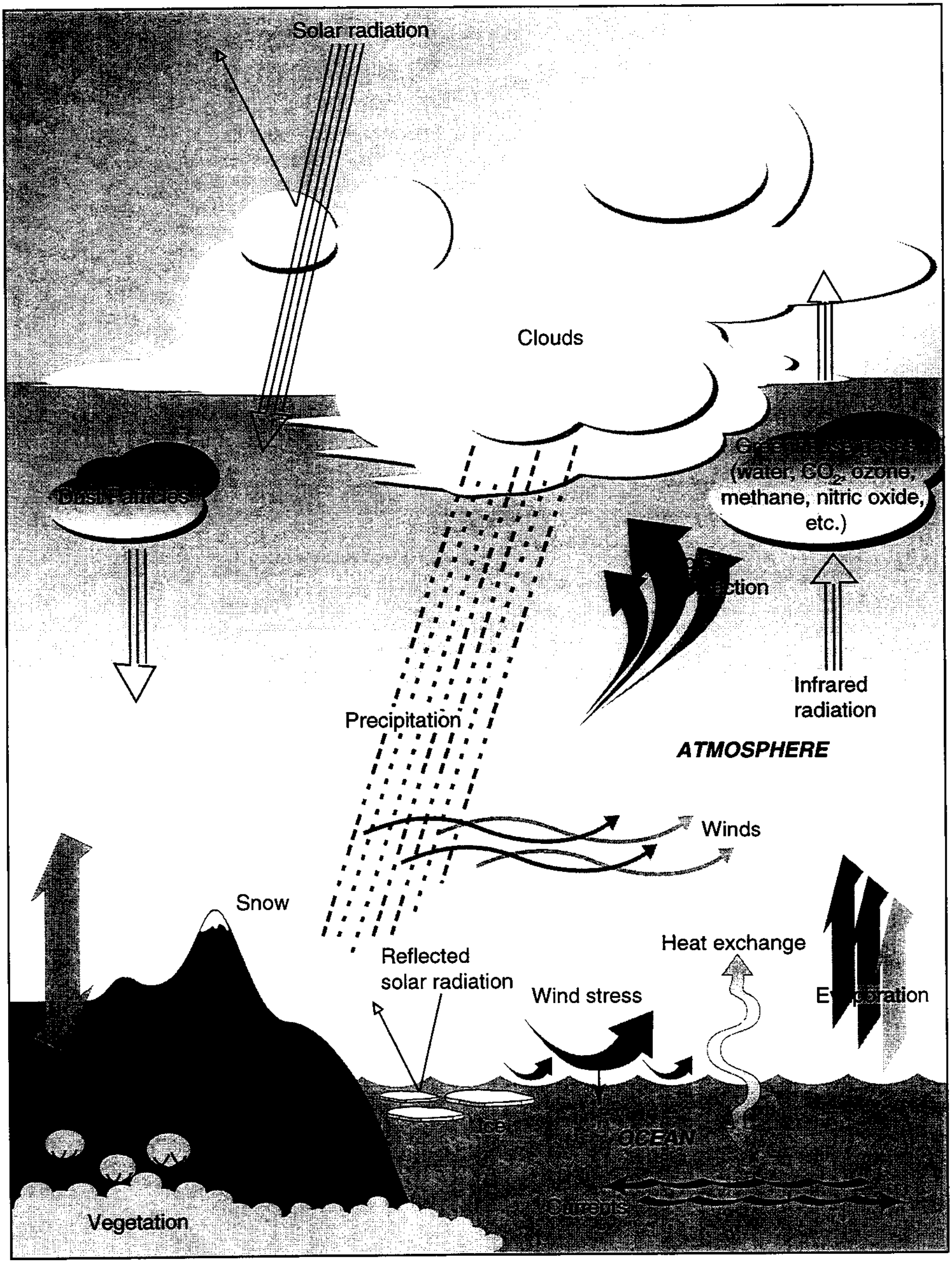


Figure 20: Schematic Illustration of the Physical Processes in the Atmosphere that must be Included in Climatic Models

As a result, scientists use a wide variety of simplifications, approximations and assumptions in the models to study climate and climate change. At one extreme is a simple model that severely limits the number of variables to be predicted (forecasting only temperature, for example) or that severely restricts the physical and chemical processes (omitting, for example, heat transport by ocean currents). At the other extreme are large numerical general circulation models that include as many variables and processes as possible. But even the general circulation models are not truly comprehensive.

The simple models play a valuable role in determining which variables and processes are important, thereby allowing scientists to improve the larger models. Originally, the greenhouse global warming scenario was tested on simple climate models. These simple models predicted rapid increases in global temperatures. However, scientists soon realized these outputs were not realistic. Consequently, more sophisticated models were developed, such as the general circulation models in use today.

Modeling climatic change is an inherently difficult task. To begin with, climatologists must attempt to simulate the behavior of oceanic and atmospheric systems that are incredibly complex themselves and, in climate models must be linked together. For example, the constituents of the atmosphere that absorb the most infrared radiation, and therefore contribute most strongly to the greenhouse effect, are water vapor and clouds. But other gases contribute as well, and their concentration in the atmosphere, is growing, as a result of human activities. However, human activity and the amount of a gas that activity will produce is also unpredictable. For example, in the 1980s, chlorofluorocarbons (CFCs) increased by 40 percent, methane by 10 percent, and carbon dioxide by 4 percent. If these rates of increase were to continue, CFCs would replace carbon dioxide as the major contributor to increases in global warming in about 25 years. However, the Montreal Protocol apparently has slowed the rate of increase of CFCs, thus altering forecasts considerably.

Other scientific uncertainties surround the build-up of carbon dioxide, methane and other greenhouse gases. For example, a portion of each gas added to the atmosphere does not remain there but is absorbed by the biosphere and the oceans, or destroyed by chemical reactions. This happens to about half the carbon dioxide now being added to the atmosphere. Moreover, the fraction that is removed may vary as climate changes, thus modifying the climate itself. Currently, no one truly understands all the natural processes that remove these gases, so no general circulation models to date has been able to fully incorporate these processes in its calculations. Models are therefore, incomplete.

Other climate factors also are not well understood. For example, if the reflection of sunlight (albedo) increases, temperatures will fall, all else being equal. However, the albedo is affected by clouds, polar ice caps, glaciers, snow-cover, type of vegetation, surface of the ocean and dust particles in the atmosphere, to name a few. How much solar radiation each component reflects depends on widely varying properties. For example, the water content of a cloud, the composition of the dust particles, the age of the snow, the roughness of the ocean's surface and the health of the vegetation are all important factors in determining the albedo. In principle, all these details must be predicted if one is to model climate change accurately.

It is especially difficult to predict the way climate will change in a particular region. For some regions, climate models do not even agree on whether temperatures will rise or fall. The fundamental problem is that the atmosphere and oceans are fluid and move in response to changes in temperature and pressure. The resulting winds and ocean currents transport heat from one locality to another, thus modifying temperatures. Because of these fluid motions, every point in the Earth's atmosphere/ocean system is coupled to every other point in the system. Climate change at one point cannot be predicted accurately without also predicting changes at other points and changes in the fluid motions that couple them. These fluid motions affect predictions of global average temperatures and rainfall (or its absence) as well.

The fluid motions in the atmosphere are best understood by examining the characteristics of the familiar high and low pressure areas seen on weather maps on television and in newspapers. In the Northern Hemisphere the air moves clockwise around and outward from high-pressure areas into low-pressure systems. The air in the latter rotates counterclockwise. In addition to the horizontal motion of the air, a vertical component also exists which frequently moves upward in the presence of low-pressure systems and downward in high-pressure areas. Unfortunately, these vertical motions are extremely difficult to measure and consequently must be estimated by certain mathematical techniques. Such estimates add more uncertainty not only to long-term climate models but also to short-range computer weather forecasts.

Moreover, the "whirlpools" that spin counter clockwise (low-pressure areas) generally move poleward and to the east in the middle latitudes. Their counterparts (high-pressure areas) generally move toward the equator and also to the east.* It is the movement of these "whirlpools" in the atmosphere (the fluid motion of the atmosphere), that generates most of what we call the weather. Scientists also refer to these systems as "horizontal eddies." Eddies not only produce weather changes but are the major horizontal transporters of heat, water (in its various forms) and momentum throughout the planet. The rate of vertical transport of heat, moisture and momentum of the air is extremely complex, but vital to modeling. Surface character, roughness, atmospheric structure, wind speed, etc., all affect these vital parameters, but can be estimated only for large areas.

* References to highs and lows refer to the spinning motion in the <u>Northern Hemisphere</u> only.

In short, calculating the predictable part of climate change poses a formidable problem. Not only do we not fully understand the physics of the climate system, today's general circulation models have very low levels of resolution. This means models can not differentiate between the climates of, say, Boston and Washington, D.C. This limitation severely restricts a modeler's ability to predict regional climate, for models cannot accurately calculate the effects of a number of important physical phenomena that take place on scales smaller than the model's resolution.

Clouds, which contribute greatly to the planetary albedo and greenhouse effect, and moist convection, which both cools the surface of the Earth and affects the concentration of water vapor, pose an equally daunting challenge to climate modelers. Nor are hydrological processes that affect the amount of moisture in the soil well understood. Consequently, the possible impact of climate change on agriculture and water resources cannot be anticipated with any accuracy. Indeed, given complex relationships within the climate system, errors are likely to occur during calculation that seriously compromise a model's ability to simulate even larger scale climate patterns. Moreover, a number of scientists, including Richard Lindzen of MIT, have expressed doubts about the ability of models to simulate small scale processes. Lindzen's and others' criticisms of current global atmospheric models will be discussed later.

All climate models must also make tradeoffs between the number of locations they simulate, the number of climatic processes they calculate and the accuracy with which they calculate these processes. For example, some climate general circulation models specify the state of the atmosphere as the intersection of a three-dimensional grid. The grid is frequently divided into sections that are only about two to three degrees on a side in the horizontal direction (on average 150 miles) and about a mile in the vertical direction. Since these models often incorporate as many as five or six variables at each individual intersection of the grid, they must predict hundreds of thousands of numbers to describe the state of the atmosphere over the entire Earth at any given time.

However, small scale phenomena cannot be completely left out of general circulation models or these models would never even come close to simulating the Earth's climate, much less changes that might occur. However, since these modelers cannot capture every facet of these small-scale systems they must resort to simplified equations or parameters, that partially reflect current climate conditions. Computers can solve simplified equations far more efficiently than exact equations, but they do so at the expense of accuracy. Indeed, the simplified equations are often quite crude and must be adjusted considerably.

Lindzen (1990) has pointed out in a number of articles that models inaccurately portray the role of clouds and water vapor in climate models. For example, Lindzen argues that positive feedback from clouds and water vapor is needed to increase temperatures 2^{O} C or more, even with a doubling of carbon dioxide concentrations. However, most models simply assume that atmospheric water vapor will rise as temperature increases. Moreover, modelers assume that water vapor will be confined to those levels of the atmosphere where the absorption of the infrared radiation from the Earth will be most effective in raising the temperature. In these models, temperature and water vapor increase simultaneously, thus trapping more and more radiation. This is an example of a positive feedback mechanism. However, to admit only positive feedback is to ignore the way the climate really works.

Lindzen is also critical of the tendency among modelers to treat clouds as sources of only positive feedback. Broccoli (1994) and Arking (1990) have also criticized modelers for
including only positive increases in temperatures into their models. For example, Arking notes that in 19 general circulation models he investigated, most considered clouds as producing positive feedback, even though most meteorologists are convinced that clouds, on the average, produce a net cooling effect.

This is especially true of low strato cumulus clouds, which reflect more energy than they absorb (Arking, 1991; Hosler, C., 1994).

There is also evidence that glaciation in geophysical time scales is associated with large concentrations of carbon dioxide. Interglacial warming by contrast has been associated on occasion with low levels of atmospheric carbon dioxide. This pattern casts doubt on the argument that high carbon dioxide levels force global warming. In addition, the time resolution of the models is so course that the modelers cannot really determine which came first in any particular cycle, warming/cooling or increased/decreased carbon dioxide.

Moreover, while different general circulation models often yield similar temperature predictions based on a doubling of carbon dioxide, these models often disagree sharply in detail. Figure 21, (taken from Stone, 1992) provides one example of these disparities. Note that two of the models, the NCAR and GFDL models, predict that a doubling of carbon dioxide would make southern California winters drier, while the GISS and United Kingdom meteorological office models indicate winters would be wetter.

These differences may well be due to the selection of different mathematical equations embedded in each model. To obtain more accurate results, modelers would need to be able to replicate variations, say, in moist convection, on a scale of 100 yards to three miles. A grid with horizontal spacing hundreds of times smaller than today's general circulation models in both latitude and longitude would be needed to capture the important small scale features of moist convection. Some increase in vertical resolution would also be required. However, computers would have to run at least a billion times faster than today in order to accurately calculate small-scale moist convection. Moreover, no one is confident they truly understand the physics of the general circulation.

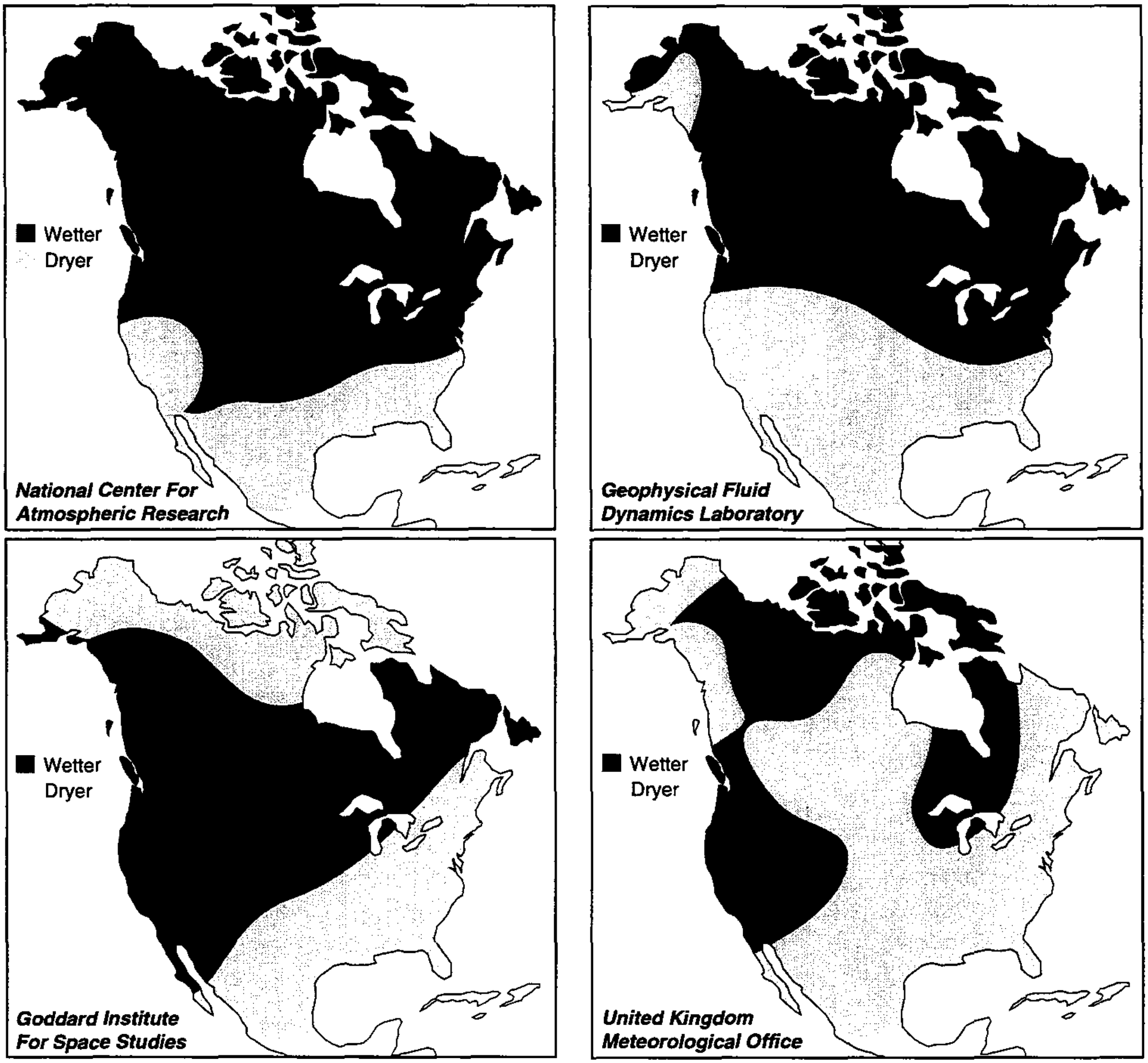


Figure 21: Example of Disagreement Between Climate Model Forecasts
(From Stone 1990)

Other uncertain processes also impair efforts to construct accurate long-range forecasts. For example, the oceans, which have a great capacity to absorb heat, may play an important role in determining the rate of warming, were warming to occur. For example, if atmospheric warming seeped slowly into the ocean's deeper layers, the ocean's surface and the Earth's atmosphere would heat rapidly. Conversely, if the deeper layers absorb heat quickly from the surface layers, the atmosphere will take a long time to warm-up. How fast global warming actually spreads to the ocean's deeper layers would depend on circulation patterns and how closely the ocean and atmosphere were coupled. Forced with today's computer limitations, general circulation models that attempt to calculate this process have had only limited success.

Some modelers recognize the concerns raised by Stone and others and they have begun to develop better climate models. For example, one recent model reduces the atmospheric spacing between geographical grids to two degrees by three degrees while shortening the time between each calculation to 30 minutes. Also, the time steps in the ocean are set at 24-hour intervals. These changes produce more realistic atmospheric-ocean coupling, but the resolution is still not sufficiently high to produce much confidence in the results of this model. Nevertheless, it is interesting to note that this model does not duplicate rapid warming rates predicted by the simpler models (Broccoli - personal communication). The newer models may also be amenable to experiments using past climatic data to predict the present observed state of the climate.

Future climate models may be capable of producing realistic predictions of climate conditions, and they may be useful in evaluating the relative importance of internal and external forcing functions, but to date, computer models cannot reliably predict local or global climate changes several decades into the future.

F. SUMMARY AND CONCLUSIONS

What does the future hold?

No one knows for certain. However, one can expect hurricanes, tornadoes, floods and droughts to be similar in intensity and frequency to those that have occurred in the past. Also, because world population is growing and people are building in previously uninhabited areas, world governments, the insurance industry and others need to prepare to handle extreme weather events. Additionally, research is needed to improve climate models as well as our understanding of the factors that influence climate. Observational studies also are needed in order to better document the Earth's variable climate.

Even if the Earth has warmed slightly during recent decades a modest increase in the Earth's temperature has not caused more intense tropical storms, hurricanes or tornadoes. And although Hurricanes Andrew and Hugo caused extensive property damage, these storms were no more catastrophic than past storms. In fact, the hurricane that struck the Florida Keys in 1935 was more intense than Andrew or Hugo. However, it struck a sparsely populated area and so caused considerably less property damage and claimed fewer lives than either Andrew or Hugo.

Science and technology cannot prevent all loss of life and property from severe storms, but society can track its vulnerability, forecast extreme events, communicate warnings, improve land use and design safer structures. A number of organizations are doing just that including the National Hurricane Center in Coral Gables, Florida; the Natural Hazards Research and Applications Center at the University of Colorado; The World Meteorological Organization (WMO) in Geneva, Switzerland, and the United Nations Technical Committee in New York City. Recent articles by G.F. White (1994) and G.O.P. Obasi (1994) in the Bulletin of the American Meteorological Society also present important information on research efforts aimed at reducing natural disasters.

Interestingly, the number of United States deaths caused by natural weather disasters has declined during the latter part of this century while the dollar value of property damaged has increased dramatically. The reason this is so, seems to be fairly obvious. Weather forecasters are constantly improving their ability to alert people about impending severe storms, such as tropical storms and hurricanes. Moreover, evacuation procedures have been developed to move people from threatened areas. These changes have resulted in fewer injuries and deaths.

However, people do continue to live in or move to areas prone to floods and tropical storms. Because many people want to live or vacation at the shore, new construction occurs along many vulnerable coastal areas. When a powerful storm eventually strikes these densely populated areas, catastrophic damage is going to occur, regardless of whether global warming has occurred or not.

To date, despite increase concentrations of carbon dioxide and other greenhouse gases in the atmosphere, the Earth's climate has not warmed significantly. Moreover, the number and intensity of extreme weather events has not increased in recent years. Indeed, were global warming to take place, it is unlikely that hurricanes or middle latitude cyclones would increase in number or intensity.

This said, it would be prudent for the scientific community to carefully monitor atmospheric temperatures, especially by using satellite measurement systems. Scientists should also under take more detailed observational studies of the temporal and spatial distribution of historically anomalous weather events*. Such studies might refute those who claim that extreme weather events (showing greater variance) are on the rise, even though the global temperature increase has been minimal.

* Droughts, floods, intense short period temperature changes, etc.

Observational programs for other real and potential forcing functions such as sea surface temperature, ocean circulations,
aerosols, and external sources should also be implemented on a much broader scale and in more detail than they are at present. Those observations can be useful not only in detecting any global warming signals but in helping to improve the quality of the mathematical climate models, and to possibly settle

the debate about positive and negative feedback mechanisms.

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