Climate Science:
Climate Change and Its Impacts

by

David R. Legates, Ph.D., C.C.M.

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Dr. David Legates in *Friends of the Earth v. Peter Watson*

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National Center for Policy Analysis
12770 Coit Rd., Suite 800
Dallas, Texas 75251
(972) 386-6272

Executive Summary

Scientific debate continues regarding the extent to which human activities contribute to global warming and what the potential impact on the environment might be. Importantly, much of the scientific evidence contradicts assertions that substantial global warming is likely to occur soon and that the predicted warming will harm the Earth's biosphere.

The Earth's climate began a warming trend after the "Little Ice Age" ended in the mid-1800s, long before global industrial development led to substantial increases in greenhouse gases beginning in the middle of the 20th century. About half of the warming during the 20th century occurred prior to the 1940s, and natural variability accounts for all or nearly all of the warming.

To assess future climate trends, climatologists rely upon General Circulation Models (GCMs) that attempt to describe Earth's climate. The many climate models in use vary widely with respect to the variables they include and in the assumptions they make about how those variables interact. Yet some official reports, including the U.S. National Assessment published in 2000, report only the most extreme predictions, ignoring others that project only moderate warming in the 21st century.

Global warming alarmists have attributed increases in hurricanes, floods, droughts, tornadoes, hail storms and heat waves to global warming caused by human activities. However, the evidence does not support their claims. In recent months, for instance:

- The unprecedented destruction caused by Hurricanes Katrina and Rita was blamed on climate change — but experts say recent, more powerful storms are part of a natural cycle, and greater hurricane damage in North America is due to increased coastal populations and development rather than more severe storms.

- Similar claims have been made about other weather phenomena in North America; but, in fact, there is no evidence of an increase in the frequency or severity of floods, droughts, tropical cyclones, tornadoes, hail storms or other severe weather events.

Some have attempted to link the present warming trend to secondary effects, such as species extinction. However, the relationship between species extinction and climate change is even more tenuous. For example:

- Recent claims that polar bear populations are threatened by global warming ignore the fact that only two polar bear populations are declining, others are increasing in numbers and the majority have stable populations.

- Recent claims that coral reefs are "bleaching" (losing color and dying off) due to warming oceans ignore the evidence that bleaching appears to be a healthy response in which corals expel one symbiotic species of algae for a better-adapted species that allows corals to thrive in warmer waters.

It has also been claimed that low-lying coastal areas are endangered due to rises in sea level as the Arctic pack ice, glaciers and the mile-thick Greenland Ice Sheet melt in a warming climate. However, the evidence does not show this is occurring:

- The fact that parts of the Arctic Ocean are ice-free in the summer is said to be evidence that sea ice and the pack ice along the Arctic coast are disappearing; but changing wind patterns pushing the ice around, not rising temperatures, are responsible for navigable Arctic waters.

- In Alaska, home to many glaciers, several decades of increasingly colder temperatures in the middle of the 20th century preceded a more recent return to the average temperatures of the early 20th century.

- Temperatures at the peak of the Greenland Ice Sheet show it is actually growing colder.

- Sea levels have been rising — in fact, they have been rising since the end of the last ice age 20,000 years ago — but there is no evidence of an accelerating trend.

The complexity of the climate and the limitations of data and computer models mean projections of future climate change are unreliable at best. In sum, the science does not support claims of drastic increases in global temperatures over the 21st century, nor does it support claims of human influence on weather events and other secondary effects of climate change.

Introduction

In 1988, James Hansen, director of NASA's Goddard Institute of Space Studies, testified before the United States Senate that, based on computer models and temperature measurements, he was "99 percent" certain "... the [human-caused] greenhouse effect has been detected and it is changing our climate now."[1] His statement was widely covered by the media and first brought the term "global warming" to the general public's attention. Many of his colleagues thought his announcement was premature at best and rash at worst, including two scientists who testified at the same hearing.[2] Since then, climate science has improved but debate continues regarding the extent to which human activities contribute to global warming and what the potential impact on the environment might be. Importantly, much of the scientific evidence contradicts assertions that substantial global warming is likely to occur soon and that the predicted warming will harm the Earth's biosphere.

"Global warming began long before industrial development led to increases in greenhouse gases."

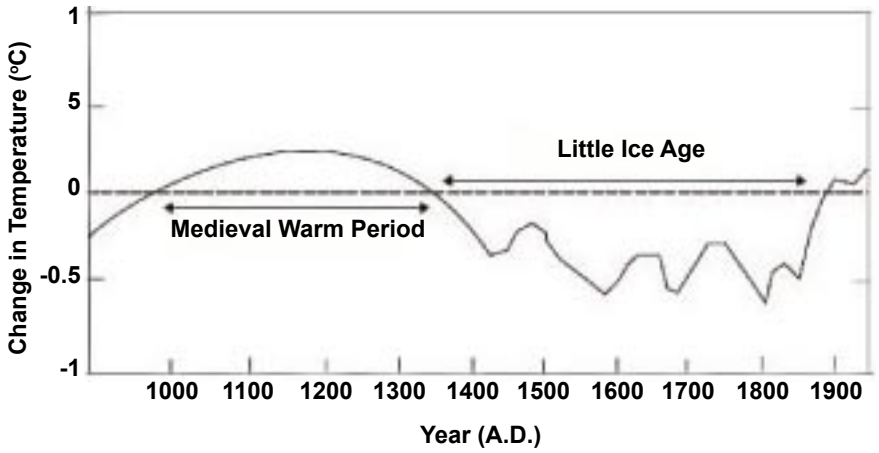
The Earth's climate began a recent general warming trend long before global industrial development led to substantial increases in greenhouse gases beginning in the middle of the 20th century. Indeed, the Earth's climate has been warming since the "Little Ice Age" ended in the mid-1800s. [See Figure I.] The period from about 1500 to the mid-1800s is known as the Little Ice Age because glaciers around the world grew to their greatest extent since the Northern Hemisphere ice age ended about 20,000 years ago. Because the Earth's climate began warming before substantial amounts of greenhouse gases were added to the Earth's atmosphere in the middle of the 20th century, natural variability accounts for all or nearly all of the warming prior to the 1940s — when approximately half of the observed 20th century warming occurred and before significant human-caused increases in greenhouse gases began. Similarly, natural variability must be considered as a possible cause of warming since the 1940s until and unless scientific evidence proves otherwise.

However, based on the assumption that climate change is occurring and that human activities — principally emissions of greenhouse gases, such as carbon dioxide (CO_2) — are major contributors to global warming, the United Nations established its Intergovernmental Panel on Climate Change (IPCC) in 1988. Since then, the IPCC has issued First, Second and Third Assessment Reports (1990, 1996 and 2001, respectively) as well as a number of special reports. Additionally, there have been regional studies, including the United States National Assessment of the Potential Consequences of Climate Variability and Change (USNA or National Assessment). These reports profess to represent the state of climate science. But claims that these reports represent a scientific consensus that human activities are causing or will soon cause significant and generally harmful global warming ignore uncertainties noted in the reports themselves, internal inconsistencies in the supporting data, inconsistencies among the various climate models, and many studies that have reached contrary conclusions.

"The Earth's climate has been warming since the mid-1800s."

FIGURE I

Climate Cycle



Source: Thomas J. Crowley (1996, http://www.gcrio.org/). Compiled by R. S. Bradley and J. A. Eddy (*EarthQuest*, vol. 5, no. 1, 1991) based on J. T. Houghton et al. (1990).

Global warming alarmists assert that greenhouse gas emissions will cause significant changes in global temperature, storm frequency, rainfall and species extinction. However, scientific evidence undermines these assertions. Unfortunately, extreme predictions reported in the popular press adversely affect the public's perception of the real science behind global warming.

This study examines the state of climate science and our understanding of climate change. The underlying theme is that the climate system is complex, resilient and inherently stable. Research from a wide variety of disciplines, published in a number of peer-reviewed journals and spanning a broad spectrum of climate expertise, supports this conclusion. Throughout the millennia, life has survived and thrived despite wide changes in solar output, air temperature and atmospheric gas concentrations.

Computer Models Are Unreliable Due to Faulty Data and Unsound Assumptions

The claim by global warming alarmists that humans are causing dangerous changes in the Earth's climate is based both on several sets of data — temperature measurements, greenhouse gas levels and other phenomena thought to be affected by the climate (such as precipitation) — and General Circulation Models (GCMs) that attempt to predict the Earth's climate**.** Specifically:

- Ground-level temperature measurements show the Earth warmed approximately 1° F over the last century.
- Atmospheric carbon dioxide (CO_2), a primary greenhouse gas, has increased by more than 30 percent in the last century and a half.

However, the link between human activities and current temperature trends and other environmental impacts is very unclear.

"Air temperature measurements do not accurately represent global patterns."

The Data Are Flawed. Our knowledge of present and historic temperature trends is limited by the quality of available data and the way in which it is used. For example, there are major problems with data gathered from direct observation of air temperatures. Air temperature measurements do not accurately represent global patterns because of changes in the location, number, distribution and development surrounding observation sites over the 20th century. For example, city temperatures on warm summer days can be as much as 8° F warmer than the surrounding countryside and annually average about 4.5° F warmer. Over the years, cities have grown so dramatically that many temperature stations are now significantly affected by this urban heat island effect. Cities are heat islands because they have:

- more impervious surfaces — less heat is removed from concrete than soil via the evaporation of water,
- less wind — standing structures disrupt and reduce the wind's exchange of heat by convection,
- darker surfaces — asphalt and other materials that absorb and retain heat,
- canyon-like clusters of structures — skyscrapers increase solar energy absorption, and
- heat sources — human activities such as manufacturing, transportation, air conditioning and so forth generate heat.

In addition to urban observation stations being subject to heat island effects, many other observation stations have either been moved or removed, causing discontinuities in the location of measurements over time. Moreover, observation stations are biased toward mid-latitudes, coastal areas and lower elevations — where most people live and where the urban heat island effect is strongest. Oceans (covering approximately two-thirds of the Earth's surface), high latitudes (the Arctic and Antarctic) and high-altitudes (mountains) are underrepresented.

Arguably, the recorded rise in average global temperatures is due in part to inconsistent data collection, rather than actual warming temperatures. The marked fall in global air temperatures between the early 1960s and the mid-1970s coincided with an increase in the density of observing stations around the globe, whereas the rise over the past 30 years has coincided with a steady decline in station numbers.

Because greenhouse gas concentrations and temperatures were not directly measured for most of human history, much of the data input into the models are estimates based on proxy data, such as the concentration of CO_2

molecules trapped in ice cores. But even when data from direct observations is available, global warming predictions are often based on unrealistic estimates regarding real-world conditions. For example, Hansen, regarded by many as the "father of global warming," recently conceded that CO_2 emissions are now rising 1.0 percent per year, yet computer simulations forming the basis of the Third Assessment Report assumed that emissions would be growing almost twice as fast.[3]

Furthermore, GCMs predicting substantial global warming in the near future assume far greater per-capita energy use than is currently the case, and far greater future per-capita energy use than most current estimates. By contrast, when models use more realistic estimates of energy use, they produce far less alarming results.

Climate Models Are Limited. To assess future climate trends, climatologists rely upon GCMs that attempt to describe Earth's climate. They include many variables (such as temperature and CO_2 emissions) and make assumptions about how changes in one variable affect others. The many climate models scientists use to generate climate predictions vary widely in which variables they include and in the assumptions they make about how those variables interact. For example, there is considerable scientific debate concerning the overall impact of atmospheric aerosols on the Earth's climate and how the models simulate these effects.

"Predictions by climate models vary widely."

Aerosols are minute particles suspended in the atmosphere. When these particles are sufficiently large, they scatter and absorb sunlight, which can reduce visibility. The resulting haze reddens sunrises and sunsets. Both IPCC and National Assessment projections assume that all atmospheric aerosols have a slight net warming effect. However, more recent scientific data provide a less certain answer.

One study — of which James Hansen is a coauthor — concluded that the warming effect of carbon black aerosols arising from human activities is about twice that used in the IPCC's Third Assessment Report.[4] But another study suggested that the net effect of sulfate aerosols is to cool the Earth, not warm it.[5] The net effect of different types of aerosols must first be properly resolved before we can assume a general warming impact on the climate. As the latter study concluded:

> "Until [researchers resolve how] the climate system respond[s] [to aerosols], the possibility that most of the warming to date is due to natural variability, as well as the possibility of high climate sensitivity [to the effects of greenhouse gases], must be kept open."

Thus, the extent to which the present warming trend is due to natural factors, human greenhouse gas emissions, and other impacts like the emission of aerosols remains an open question.

Another variable that climate models do not take into account is the effect of changes in solar radiation on the Earth's climate. Over the past 350 years, scientists have discovered cyclical changes in the Earth's climate due to solar activity — such as increases and decreases in solar flares and sun spots. Some researchers have argued that solar variability may be responsible for about 0.45° F of warming between 1900 and 1990 — just under half of the recent warming — and about a third of the total warming since 1500.[6] This is notable since approximately half of the observed 20th century warming occurred before 1940 and cannot be attributed to human causes. Others have shown that the effect of changes in solar radiation can account for 71 percent of the variation in global surface air temperature from 1880 to 1993.[7] When changes in solar output are considered in climate simulations, the models predict this warming.[8] However, it is still not possible to incorporate into a single model all the variables that affect the climate — such as solar variability, changing greenhouse gas concentrations, volcanic eruptions, changes in cloud type and coverage and various pollutants.

Climate Models Do Not Make Accurate Predictions. In addition to problems with the data, computer models are limited by our incomplete understanding of how the Earth's climate responds to a variety of external forces. They are also limited by the speed and capabilities of contemporary computers.[9] As a result, they do not accurately describe the current climate and have not been able to accurately describe the climate of the past 30 years. For instance, computer models consistently project a rise in global temperatures over the past century that is more than twice as high as the measured increase. As the models cannot explain what has happened in the past, it is fair to question their predictions of future warming. This is particularly true of projections regarding regional changes in temperatures and other climate phenomena. [See the side bar on the U.S. National Assessment.]

"Computer models cannot accurately predict the present or future climate."

The difficulty of reconciling GCM simulations of present-day conditions with real-world observations, and the difficulty of formulating appropriate assumptions about human-caused emissions, led the American Association of State Climatologists (AASC) — a professional organization of regional and state climatologists who use local climate data every day — to conclude in their policy statement on climate change:[10]

> "Climate predictions have not demonstrated skill in projecting future variability and changes in such important climate conditions as growing season, drought, flood-producing rainfall, heat waves, tropical cyclones and winter storms."

Therefore, relying on climate model simulations to draw conclusions about the future is very risky, since the simulations do not, and perhaps cannot, accurately simulate the present climate.

U. S. National Assessment Relied on Extreme Models

The numerous climate models in use often produce conflicting projections of trends or results at odds with actual observations. The IPCC's Third Assessment Report compared more than 30 such models. The results from models that predict less warming in the future are generally closer to the observed data.

However, the U.S. National Assessment, published in 2000, used only the HadCM2 (Hadley Centre model) and the CGCM1 (Canadian model) in analyzing the direction and impacts of climate change. It did not include other models from the United States. This is puzzling, since a majority of the models considered in the Third Assessment Report predicts much less warming from a doubling of atmospheric greenhouse gases — as little as 4.5° F. In particular, the Canadian model predicts more future warming under a doubling of atmospheric CO_2 concentrations than any other model. As Figure II shows:

- The National Center for Atmospheric Research (NCAR) model suggests only about 1.8° F of warming globally for the 21st century as a result of increases in greenhouse gases.
- The Hadley Centre model produces a warming of 5.4° F.
- The Canadian model produces 14.4° F of warming.

Thus, the results of the National Assessment are biased in that the extreme Canadian model was considered, but not the numerous models that suggest only modest warming.

A report submitted for the National Assessment added further doubt to the Hadley Center and Canadian model predictions. The report compared real-world observations with important atmospheric and surface variables used in the Hadley Centre and Canadian models to simulate present-day conditions. Over North America, both models tend to show greater changes in air temperature and precipitation than actual observations. In fact, the Canadian model predicts that the United States should have warmed 2.7° F during the 20th century — 10 times more than the observed increase of about 0.25° F.

For precipitation, the Hadley Centre model and the Canadian model produce the two most extreme projections of changes for the United States — twice the estimates of other models. In particular, the models' simulations predict present-day precipitation that differs from actual observations by as much as 100 percent!

Furthermore, both models predict high-pressure systems and winter storms that are much more intense than those we are currently experiencing. They also predict current temperatures for the upper atmosphere (between about 5 km and 20 km in height) that are colder than observed temperatures.

Since these models cannot accurately replicate current climate conditions, it is difficult to place much faith in their projections of future climate in a greenhouse gas-enhanced world. Since the National Assessment relied on these models exclusively, its conclusions are suspect.

Natural Climate Variables Ignored by Alarmists

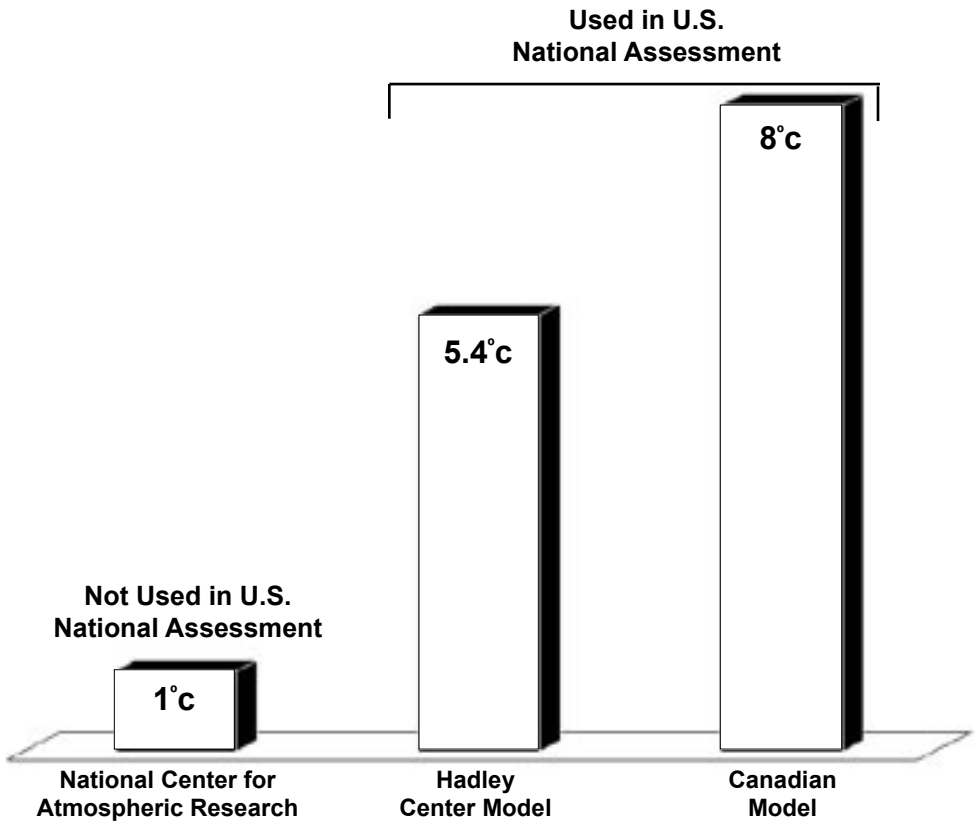
Due to the complexities of the climate system, we currently cannot reliably connect emissions of greenhouse gases from any specific source or group of sources to an increased risk of any particular outcome. For instance, changes in the frequency or intensity of storms, droughts and floods are affected by many factors other than temperature. Yet many of the predicted effects of global warming involve changes in weather patterns and weather-related events, such as floods and hurricanes.

The Link Between Climate Change and Rainfall Is Unsubstantiated. Precipitation (along with air temperature) is one of the most widely measured climate variables, and it has been the focus of much research. However, long-term trends are difficult to discern because precipitation varies significantly over time and from one area to another and is nearly absent over the world's oceans. In addition, it is difficult to accurately measure precipitation, particularly snowfall. For example, when rain and snow blow across the

"The National Assessment was based on models that predict extreme warming."

FIGURE II

Average 21st Century Global Temperature Increase Projected by Selected Models



Source: National Center for Atmospheric Research and the *United States National Assessment of the Potential Consequences of Climate Variability and Change*, 2000.

mouth of a rain gauge, the full amount is not captured. In addition, humidity, temperature and sunlight affect the rate of evaporation from gauges and must be accounted for when measuring precipitation.[11]

"Computer models cannot accurately predict rainfall."

Both the IPCC's Third Assessment Report and the National Assessment cite a study by Thomas R. Karl and Richard W. Knight to argue that the number of days with rainfall exceeding two inches has increased, while the frequency of more moderate rainfalls and other precipitation of less than one inch decreased by one percent across the continental United States.[12] Karl and Knight concluded "these data suggest that…the proportion of total precipitation derived from extreme and heavy events is increasing relative to more moderate events."

However, Karl and Knight used data only as far back as the 1910s. In a more recent study, Kenneth E. Kunkel and other state and regional climatologists for the Midwestern and Western states carefully extended the period studied back to the late 19th century using a newer dataset designed to provide extensive quality control, particularly for the early years for which there is little data.[13] Their analysis found the frequency of heavy precipitation was high during the late 19th and early 20th centuries, fell to a minimum during the 1920s and 1930s (when the records for the IPCC-cited report began), then returned to higher levels during the late 20th century. The new report concluded "the frequencies at the beginning of the 20th century were nearly as high as during the late 20th century…suggesting that natural variability cannot be discounted as an important contributor to the recent high values."

The discrepancy between the two studies can be explained by the earlier study's reliance on an abbreviated dataset, because for the time period where the two studies overlap — from 1910 to 1996 — the results are consistent. Thus, Kunkel's more comprehensive analysis is strong evidence that the results cited by the IPCC may not be of human origin, but simply a result of natural variability.

The IPCC's conclusions concerning the timing and amount of future rainfall also rely on a number of computer simulations. However, precipitation is difficult to simulate because it is affected by so many factors. Computer models simply cannot predict many important phenomena that affect precipitation, such as hurricanes, thunderstorms, tornadoes and nor'easters. Even weather fronts that are common across the United States are not simulated adequately. Finally, climate models inadequately simulate or often completely ignore more complex but relatively regular phenomena involving atmospheric circulation patterns and ocean currents, such as El Ninõ and La Ninã — the periodic warming and cooling of the surface waters off the Pacific Coast of South America that affects weather globally.[14]

Computer models are also unable to replicate rainfall variability. A study published before the 2001 Third Assessment Report demonstrated that rainfall is much more variable than computer simulations indicate.[15] There-

fore, it is difficult to trust models that predict precipitation will increase in frequency and intensity. And since precipitation intensities today are similar to what they were nearly a century ago, it is inappropriate to ascribe recent, short-term changes to human causes.

"Storm patterns show no evidence of global warming."

Tropical Storm Cycles Are Largely Unaffected by Climate Change. Arguably, the most overstated claim about the consequences of global warming is that the frequency and intensity of tropical cyclones (hurricanes, tropical storms and tropical depressions) and extra-tropical storms (including thunderstorms and nor'easters) will dramatically increase. One of the factors linked to tropical cyclone formation is sea surface temperatures exceeding 78.8° F. Tropical sea surface temperatures have risen in recent years, due partly to changes in ocean and wind currents and air temperatures. Some researchers have speculated that an increase in areas of warmer waters will increase tropical cyclone frequencies and intensities, but thus far even the IPCC has found virtually no evidence to support this claim. The "Scientific Assessment" section of the Third Assessment Report states:

> "Changes globally in tropical and extra-tropical storm intensity and frequency are dominated by inter-decadal to multi-decadal variations, with no significant trends evident over the 20th century. Conflicting analyses make it difficult to draw definitive conclusions about changes in storm activity, especially in the extra-tropics."

Thus, there is scant evidence that the recent warming trend has affected the frequency and intensity of tropical storms during the past century. There is also no reason to expect further warming will have much effect, because, as the IPCC concluded, tropical storm patterns are largely driven by factors other than sea surface temperature.

Further support for this conclusion comes from a study examining the links between tropical cyclone formation and sea surface temperatures that was cited by both the Third Assessment Report and the National Assessment.[16] The study states: "…the very modest available evidence points to an expectation of little or no change in global frequency [of hurricanes]."[17]

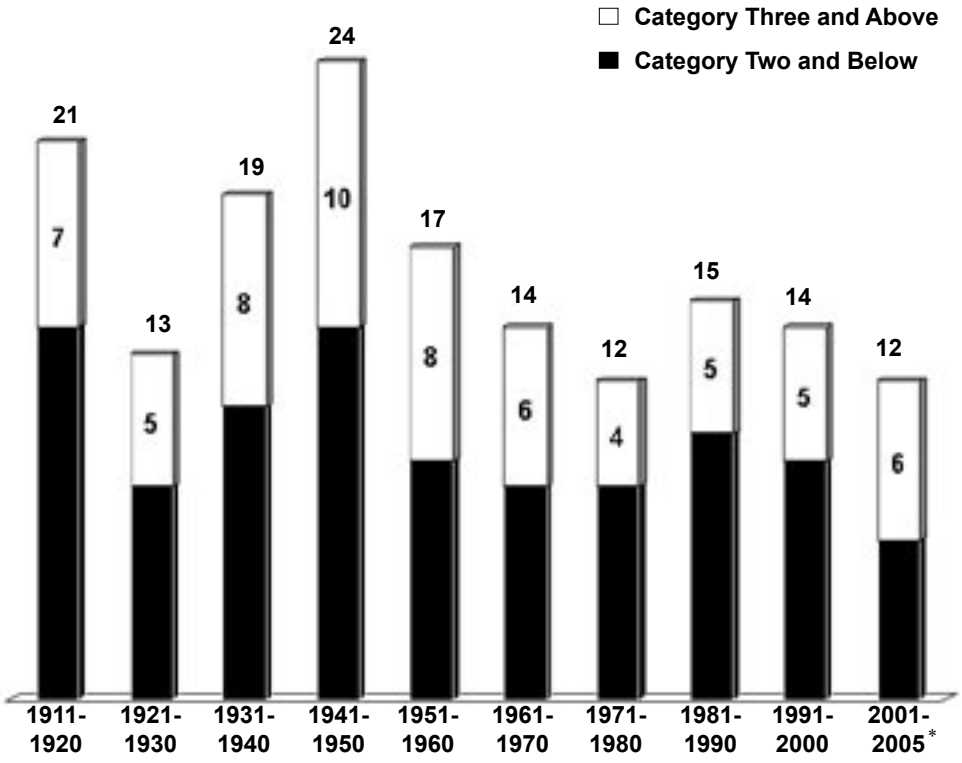
More recently, however, the media have paid particular attention to two studies cited by the popular press as providing compelling evidence that the devastating Atlantic Basin hurricanes of 2004 and 2005 were caused by global warming. They have misinterpreted the significance of these studies; no such conclusion is warranted.

In the first study, Kerry Emanuel argues that "the record of net hurricane power dissipation is highly correlated with tropical sea surface temperature, reflecting well-documented climate signals [cycles], including multi-decadal oscillations in the North Atlantic and North Pacific, and global warming."[18] Thus, although he attributes some of the rise in tropical sea surface

"Hurricanes vary due to natural cycles, not global warming."

FIGURE III

Number of U.S. Hurricanes by Decade



* For first half of the decade.
Note: The number on top of each bar is the total of all categories of hurricanes.
Source: National Hurricane Center.

temperatures to global warming, Emmanuel recognizes that the historically documented cycle of shifts in ocean currents over several decades is largely responsible for the current upswing in hurricane numbers and intensity.

In the second recent study, looking at data from the last 35 years, Peter Webster and colleagues concluded that there was a large increase "in the number and proportion of hurricanes reaching categories 4 and 5," but "the smallest percentage increase occurred in the North Atlantic Ocean."[19] The latter conclusion appears to undermine claims that rising ocean temperatures due to global warming are responsible for increasing Atlantic hurricane activity. In addition, Webster found that the area undergoing the second largest increase in hurricane activity experienced no appreciable rise in ocean temperature.

Webster and his colleagues also plea for the assessment of a longer data record: "Attribution of the 30-year trends [in hurricane intensity] to global warming would require a longer global data record [than the 35-year record they used] and, especially, a deeper understanding of the role of hurricanes in the general circulation of the atmosphere and ocean, even in the present climate state."

Thus, claims that these two studies provide compelling evidence linking recent hurricanes to global warming are unwarranted. Also, a longer-term assessment of tropical cyclones extending back more than 80 years by two teams of researchers subsequently documented a cycle that shows little influence from global warming.

The first team, Roger Pielke Jr. and colleagues, concluded that since 1995, "there has been an increase in the frequency and in particular the intensity of hurricanes in the Atlantic…but the changes of the past decade are not so large as to clearly indicate that anything is going on other than the multi-decadal variability that has been well documented since at least 1900."[20] [See Figure III.] They went on to argue that claims of a link between global warming and tropical storm frequency and intensity are misguided because 1) no connection has been established between greenhouse gas emissions and the observed behavior of tropical storms, 2) there is a scientific consensus that any future changes in hurricane intensities will be small relative to observed variability, and 3) under the assumptions of the IPCC, increased population and development along coastal areas, rather than changes in hurricane strength and frequency, will be responsible for most future hurricane damage.

A second group of researchers, composed of National Oceanic and Atmospheric Administration (NOAA) scientists with years of experience in tropical storm forecasting, examined the longer-term tropical storm record and concluded "NOAA research shows that the tropical multi-decadal signal [cycle] is causing the increased Atlantic hurricane activity since 1995, and is not related to greenhouse warming."[21] Instead, they relate recent increased hurricane activity "to natural occurring cycles in tropical climate patterns near the equator" that cause long-term fluctuations in vertical wind shear (which has a substantial effect on hurricane formation) and ocean temperatures.

"There has been no significant change in the number or frequency of thunderstorms, hail storms or tornadoes."

Storm Cycles in Extra-Tropical Regions Are Largely Unaffected by Climate Change. With respect to changes in extra-tropical storms, a 1999 study by Bruce Hayden for the National Assessment concluded "there has been no trend in North America-wide storminess or in storm frequency variability found in the record of storm tracks for the period 1885-1996…[I]t is not possible, at this time, to attribute the large regional changes in storm climate to elevated atmospheric carbon dioxide."[22] Hayden goes on to argue that assessments based on computer modeling "of North American storminess shows no sensitivity to elevated carbon dioxide… [I]t would appear that statements about storminess based on output statistics [from the models] are unwarranted at this time." And, "it should also be clear that little can or should be said about change in variability of storminess in future, carbon dioxide enriched years."

In general, IPCC reports express doubts about the quality and homogeneity of data used to assess changes in storm frequencies and intensities. Similar analyses have focused on changes in the frequencies of thunderstorms,[23] hail[24] and tornadoes — including the occurrence of "significant" tornadoes

(that is, those rated F3 and higher on the five-point Fujita scale)[25] — and have concluded that none of them have increased significantly and that there is no conclusive evidence of a connection between these weather phenomena and increases in greenhouse gases.

Climate Change Has Little Impact on Floods and Droughts. Global warming alarmists also claim that increasing concentrations of greenhouse gases in the atmosphere make floods and droughts more likely. Part of the difficulty in assessing whether such a change is already underway lies in how we define floods and droughts.

"Floods have increased due to development, not global warming."

Floods. A flood is simply streamflow that exceeds a prescribed threshold and is not necessarily caused by increased precipitation. Streamflow strongly depends on a number of nonclimate factors, such as how moist the soil is and the amount of moisture stored in detention areas prior to the rainfall; rain falling on saturated ground or when reservoirs and lakes are near capacity may produce more streamflow than if the ground is drier or when water detention levels are low.

Changing land uses and engineering developments also affect streamflows. Urbanization generates more runoff, which ultimately becomes streamflow. River channelization — dredging, levee construction and stream bank reinforcement — speeds water flow and restricts water from entering natural flood plains. These direct human effects on rivers often increase flooding, masking the effects of climate change.

Two studies of streamflow trends in the United States yielded divergent results. In the first study, Harry Lins and James Slack examined streams that have been minimally affected by urbanization and human alterations. They found that low and median streamflows increased the most and that high flows — that is, floods — increased the least.[26] As they explained, this means that "the conterminous [United States] is getting wetter, but less extreme." Their analysis of the data showed streamflow decreases in parts of the Pacific Northwest and the Southeastern United States. The Third Assessment Report largely relied on this study in its analysis of trends for the United States.

By contrast, a more recent study by Pavel Y. Groisman and his colleagues concluded that significant increases in streamflow have occurred, particularly floods.[27] Groisman argued that streamflow increases were most significant in the eastern half of the United States. He claimed decreases in winter snow cover as air temperatures have risen explains why the western half has exhibited no increases in peak streamflow.[28]

The discrepancy between these two studies is easy to explain: The two analyses answered different questions. Lins and Slack focused on whether particular streamflow levels — floods or low water flows — were occurring more or less frequently. Therefore, they emphasized changes in the *depth* of streamflow.[29] By contrast, Groisman and his colleagues calculated the pro-

portion of change in total annual streamflow volume that could be attributed to particular streamflow levels. Streamflow volume is simply the product of the depth of the flow and the width of the stream. Since the channels of most streams in the United States resemble the letter "V" in shape, a change in streamflow depth results in a larger change in flow volume when a river is at or near flood stage. Groisman's conclusions, therefore, are biased by the higher volume of water associated with floods. And since annual peak flows can be several times greater than the minimum flow, it is more correct to evaluate streamflow depth, as Lins and Slack did.[30]

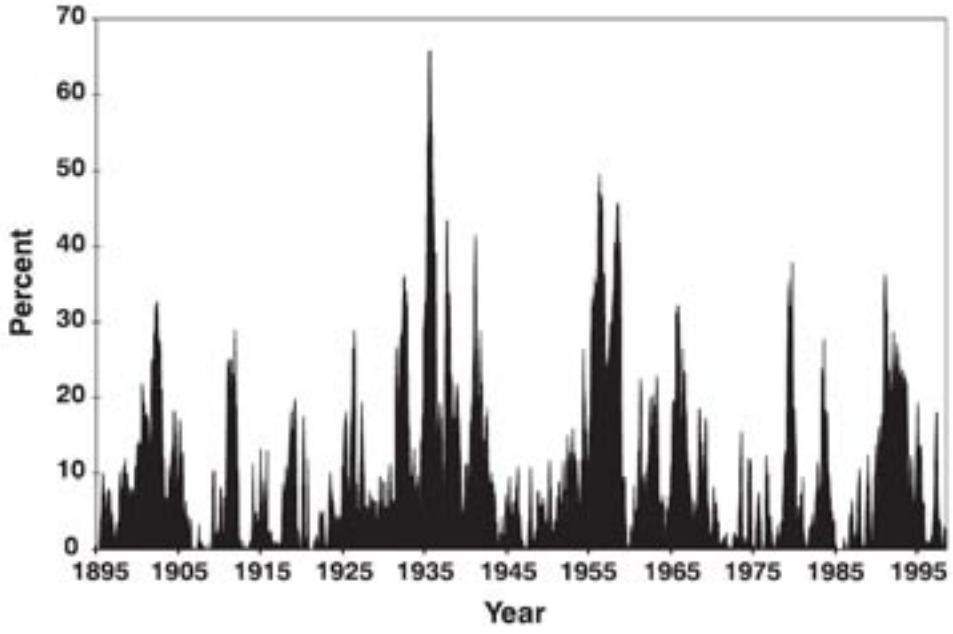
Droughts. The simplest definition of drought is a "meteorological drought," which occurs when precipitation is below normal over a specified period. That definition is greatly affected by the period selected and for which "normal precipitation" is defined. A more useful concept is a "hydrological drought," which occurs when river, lake and/or groundwater levels fall below a specified threshold. However, since urbanization raises demand for water, it can increase the frequency of hydrologic droughts and potentially mask the effect of climate change. The Third Assessment Report concludes that from 1900 to 1995:

> "There were relatively small increases in global land areas experiencing severe drought or severe wetness. In many regions,

"Droughts were more frequent and longer in the past."

FIGURE IV

Severe and Extreme Drought, 1895-1995
(percentage of U.S. land area affected)



Source: National Drought Mitigation Center.

these changes are dominated by inter-decadal and multi-decadal climate variability, such as the shift in [El Niño/La Niña][31] towards more warm events."

With respect to drought worldwide, the Third Assessment Report relies on a study[32] by Aigu Dai and others that uses the Palmer Drought Severity Index (PDSI)[33] to examine the relation among human activities, climate and drought. The study found small increases in drought frequencies over the United States and an increase in moisture surplus as well. But the PDSI over-simplifies the surface water balance, *and* the values of the index are relative to each location — making comparisons between different locations difficult.[34] Thus, the Dai study should be interpreted with caution.

Historical records show that natural variability has produced more frequent and longer droughts in the past than we experience today. An assessment of physical evidence of drought in the United States over two millennia concluded that "the droughts of the 20th century have been characterized by moderate severity and comparatively short duration, relative to the full range of past drought variability."[35] Moreover, the authors said current drought intensity in the western United States is similar to that during the mid-1950s and actually less than that of the early 1900s, when conditions were cooler than at present and before increases in atmospheric greenhouse gas concentrations. [See Figure IV.]

The Difficulty of Linking Floods and Droughts to Climate Change. As the foregoing discussion suggests, our *perception* of drought and flood frequencies is greatly affected by human activities that are not climate-related. Thus, we must carefully determine whether the cause of changing flood and drought frequencies is, in fact, due to climate change or simply a result of a changing landscape.

More importantly, the notion that increases in greenhouse gas concentrations will increase flood and drought frequencies runs counter to our understanding of the climate system. It has been argued that global warming could cause the Earth's polar regions to warm more than the tropics due to a number of factors, including the exposure of darker land surfaces as snow and ice melt, and the fact that the same energy input will warm cold, dry air more than warm, moist air. But global atmospheric circulation is driven by the temperature difference between the poles and the equator. A significant decrease in that temperature difference is consistent with global warming, but it would reduce global atmospheric circulation rather than increase it. The diminished transport of energy and moisture would decrease the frequency of heavy rainfall and weaken atmospheric currents that steer storms. Indeed, during warmer periods in the past, the number and severity of storms has declined. The fact that no significant deviations from long-term trends have been observed in flood, tropical cyclone, tornado and hail frequencies (despite an increase in

"During past warming periods, the number and severity of storms declined."

air temperatures over the last century) is consistent with a decrease in global atmospheric circulation. What is inconsistent is the claim that severe weather is increasing due to global warming when the atmospheric currents that contribute to these phenomena are decreasing.

Links Between Climate Change and Nonclimate Effects Are Tenuous. Knowing the limits and difficulties of linking human activities to global warming, and of linking global warming to other climate changes, we should use even greater caution in linking human-caused climate change to nonclimate changes, such as sea level rise and species extinction.

Arctic Temperatures. The Arctic Climate Impact Assessment (hereafter, the Arctic Assessment) recently proclaimed that Arctic air temperature trends provide early and strong indication that global warming is causing polar ice caps and glaciers to melt, which will lead directly to a rising global sea level.[36] However, estimating the amount of surface warming and its causes requires knowledge of both natural factors and the effects of human actions — many completely unrelated to greenhouse gas emissions — including land use changes and urbanization. Moreover, the Arctic climate varies dramatically over time from one area to another, with both warming and cooling presently occurring in different polar regions.

"Greenland Ice Sheet summer temperatures have declined."

Though the Arctic Assessment argues that unprecedented Arctic warming has occurred, the evidence suggests that this conclusion is unwarranted. For example, coastal stations in Greenland are experiencing a cooling trend, and average summer air temperatures at the summit of the Greenland Ice Sheet, have decreased at the rate of 4° F per decade since measurements began in 1987.[37] Moreover, even if such warming is happening, it has occurred before as shown by ice cores from Baffin Island[38] and sea core sediments from the Chukchi Sea.[39] For example, in Alaska, the onset of warming in 1976-1977 ended a multi-decade trend of cold in the middle of the 20th century. The warming since 1976 has simply returned temperatures to those of the early 20th century. And as would be expected in response to natural variability, Alaskan ecosystems have merely adjusted in a manner consistent with temperatures in the early 20th century.

Indeed, the Arctic Assessment ignored three relatively recent long-term analyses that contradict its conclusions, although they were readily available in published literature. Those analyses are based on: 1) Russian coastal observations, 2) Arctic Ocean temperatures, and 3) the definition of the Arctic region climatologically, rather than by latitude.

First, Russian coastal-station records of both the extent of sea ice and the thickness of fast ice (ice fixed to the shoreline or seafloor) extending back 125 years show significant variability over 60- to 80-year periods.[40] Moreover, the maximum average air temperature they report for the 20th century was in 1938, before humans released significant greenhouse gas emissions and when it was nearly 0.4° F warmer than the average air temperature for 2000. The

Russian study further suggested, "the high-latitude temperature increase was stronger in the late 1930s to the early 1940s than in recent decades," and it concluded that observations do "not support amplified warming in polar regions predicted by GCMs."

Second, an earlier study evaluating data for the Arctic Ocean also reported an overall decline in Arctic air temperatures and "[an] absence of evidence for greenhouse warming over the Arctic Ocean in the past 40 years."[41]

Third, a comprehensive study of Arctic air temperature data concluded that from 1951 to 1990, "no tangible manifestations of the [enhanced] greenhouse effect can be identified" although much year-to-year variability was observed.[42] The first step in this latter study was to properly identify the Arctic using climate parameters, not latitudes. Defining the study area based simply on a specific latitude band biases temperature readings because it includes data from outside the Arctic region. The study then demonstrated that Arctic air temperatures were warmest in the 1930s and near the coolest for the period of recorded observations (since at least 1920) in the late 1980s. When data from mid-latitude stations that border the Arctic are included, the characteristic warming since the mid-1970s is evident. Thus, while lower and mid-latitudes of the Northern Hemisphere have warmed during the last 30 years, the Arctic region clearly has not. This study refutes the GCMs' predictions that the greatest warming will occur in the high latitudes.

"Arctic air temperatures were warmest in the 1930s and coolest in the late 1980s."

Furthermore, the study compared observed data with gridded data used by the IPCC for the same region. ("Gridded data" are spatial averages computed at the nodes, or intersecting points, of lines of latitude and longitude forming a lattice, in this case 5° of latitude by 5° of longitude.) While the IPCC gridded data exhibits warming during the 1990s, weather station measurements contradict this warming claim and show significant cooling since the mid-1980s. Thus the study raises concern that the IPCC gridded data for the Arctic is contaminated with data from outside the Arctic. Since the gridded data presumably represent spatial averages based on observations (rather than the recorded data itself), the study cautions that "the quality of [gridded] data in its present state is significantly lower than the station data."

There are a number of other reasons that observed global warming is not greatest in the Arctic during winter. Arctic snow and ice is highly reflective and has high thermal inertia — in other words, it naturally resists temperature changes; as a result, more energy is required to warm an Arctic area than a tropical area of similar size. In addition, such natural factors as the variability of atmospheric circulation and changes in solar output have just as great (and perhaps a greater) effect on Arctic temperatures as increasing greenhouse gas concentrations.[43] For instance, since 1970, seasonal (particularly autumnal) and annual air temperatures in the Canadian Arctic have followed a distinct pattern, varying over a period of about 4 to 6 years, with a slightly longer period before 1970. This pattern may be directly related to the El Ninõ and La

Ninã phenomena but, like El Ninõ and La Ninã, the pattern is not one of the variables GCMs consider.[44]

Sea Ice. Global warming alarmists also claim that Arctic warming will necessarily lead to a decrease in the thickness and extent of sea ice, and that sea levels will rise significantly due to the melting ice. However, researchers who evaluated air temperature trends from coastal Greenland also looked at changes in Arctic sea ice using long-term data on fast-ice thickness and ice extent.[45] They concluded: "The analysis indicates that long-term trends are small and generally statistically insignificant." The Third Assessment Report also recognized that the rate of sea level rise has not accelerated during the last century.

It is critical to note that air temperature is only one factor that dictates sea ice coverage and thickness. Another factor in the formation of sea ice is the frequency and intensity of wind. When the Arctic is relatively calm, it is easier for sea ice to form. During stormy periods, churning water makes sea ice formation more difficult. This is one of the main reasons for a distinct lack of correlation between computer projections and the observed response of the Arctic region. A study by Canada's Department of Fisheries and Oceans examining the relationship between air temperature and sea ice coverage concluded "global warming appears to play a minor role in changes to Arctic sea ice."[46] Indeed, the Canadian study determined that changing wind patterns are the primary cause of changing sea ice distributions. Moreover, while sea ice has decreased in the Arctic (due largely to other causes, as shown above), NASA scientists have determined that it has remained relatively constant (or even increased slightly) in the Antarctic since 1978.[47]

Polar Bear Populations. Warming theory proponents also argue that a warmer Arctic with less sea ice poses a significant risk to polar bear populations (and other indigenous species).[48] Indeed, the Arctic Assessment concluded "global warming could cause polar bears to go extinct by the end of the century by eroding the sea ice that sustains them." This is misleading because, as discussed above, Arctic air temperatures in the 1930s were as high as present temperatures and Arctic air temperatures prior to the Little Ice Age were higher than present temperatures, yet polar bears survived.

"Polar bear populations do not show a temperature-linked decline."

The data on polar bear populations also contradict claims that rising air temperatures will cause a decline in polar bear populations. According to the World Wildlife Fund (WWF), there are about 20 distinct polar bear populations accounting for approximately 22,000 polar bears worldwide. Population patterns, according to the WWF data, do not show a temperature-linked decline:

- Only two of the distinct bear populations — accounting for about 16.4 percent of the total number of bears — are decreasing, and they are in areas where air temperatures have actually fallen, such as the Baffin Bay region.

- Ten populations — comprising about 45.4 percent of the total number of bears — are stable.
- Another two populations — about 13.6 percent of the total number — are growing, and they live in areas were air temperatures have risen, such as near the Bering Strait and the Chukchi Sea.[49]

Thus, the evidence does not support claims that rising air temperatures will lead to polar bear decline or that global warming will cause their extinction.

Sea Levels Show No Signs of Dramatic Change. Our knowledge of sea level fluctuations is relatively recent, but there is evidence that sea levels have risen (although not steadily) since we emerged from the last ice age about 20,000 years ago. Global air temperatures do affect sea levels, which changed over the last millennium as temperatures rose and fell from the Medieval Warm Period to the Little Ice Age. The rate of change in coastal sea levels has varied in just the last 50 years and much more over the millennia. The evidence shows that this sea-level rise is not uniform.

"The rate of change in coastal sea levels varies widely."

About half of the projected rise in sea level due to global warming will occur simply because water expands as it warms — which explains why, during this century, global sea levels have risen along with air temperatures. The remainder of the rise is attributed to melting polar ice caps and glaciers.[50] In fact, sea levels fluctuate seasonally — reaching a maximum in each respective hemisphere in early autumn and a minimum in early spring. This is because almost 90 percent of precipitation falling over land originates from water that evaporated from oceans. During winter, this precipitation is stored on land as snow, returning to the oceans as streamflow during the spring and summer melt. Globally, sea levels are about 0.55 inches (1.4 cm) lower in early spring than in early autumn.

However, with warmer temperatures in high latitudes comes the likelihood of more snow, rather than less, since the amount of water vapor in saturated air increases with rising temperature. Indeed, Arctic coastal stations receive more snowfall than inland stations due to warmer air temperatures along the coast. Thus, Hengchun Ye and John R. Mather argued that a doubling of CO_2 in the atmosphere would remove 9.0×10^{14} liters of water from the world's oceans, thereby mitigating some of the rise in sea levels.[51]

By contrast, Antarctica is called a "polar desert" because snowfall is extremely low. The average annual precipitation at the South Pole Station is only 8mm per year, but since the temperature remains below freezing the snow accumulates year after year. In the Northern Hemisphere, increased snowfall at cold, high latitudes could also accumulate, particularly over the Greenland Ice Sheet where air temperatures are extremely cold. On the other hand, snowfall might decrease in some areas on the margins, as water falls as

rain rather than snow. Taking this into account and using GCM projections, Ye and Mather estimated there would be a small net snowfall increase in the Northern Hemisphere, thereby slightly offsetting the forecast sea-level rise. Thus, predictions of future global sea levels depend on correctly simulating precipitation and snowfall patterns — something that climate models do not do well.

In the United States, global warming alarmists have raised concerns about the rise in sea level along the California and Carolina coasts. However, scientific measurements counter these claims. One recent study evaluated global sea level trends obtained from the Topex/Posidon satellite and station observations.[52] The satellite data run from 1993 to 1998 while station observations extend from 1955 to 1996. For northern California, the rate of sea level rise has been 0.0 to +6.0 mm per year (satellite) and 0.0 to +7.0 mm per year (observations). In southern California, the rate was estimated from -0.3 to +0.3 mm per year (satellite) and 0.0 to +7.0 mm per year (observations). The rates for both regions are among the lowest trends for coastal regions seen anywhere in the world.

For the North and South Carolina coasts, the rate of sea level rise was estimated from -0.6 to -0.3 mm per year (satellite) and 2.1 to 2.8 mm per year (observations). For the last six years of the record, satellite and observational data are similar. Though the sea level along the Carolina coast has risen significantly over the last 40 years, the *rate* of sea level rise has actually *decreased* dramatically in recent years — countering the assertion that global warming is causing an increasing rate of sea level rise and suggesting that other factors contribute to rising sea levels in this region.

Snow Cover Is Stable. Outside of extremely and consistently cold areas, like Antarctica, snowfall and air temperature tend to rise and fall together when temperatures are cold. Conversely, snowfall and air temperature tend to move in opposite directions when temperatures are relatively warm.[53] Because of these complexities we cannot automatically assume that rising air temperatures will necessarily lead to decreased snow cover. Several recent studies that focused on snow cover trends over time have demonstrated this.

"Warmer temperatures could increase snowfall."

An evaluation of data from several hundred stations in the United States Great Plains for the period 1910 to 1993 found a generally increasing trend in the number of days with snow cover, despite the increasing air temperature.[54] More recently, a satellite-derived assessment of snow cover extent for the Northern Hemisphere showed no significant trend from 1978 to 1999.[55] An assessment of the extent of snow cover in North America from 1967 to 2004 showed no significant trend for the winter (December to February) with a slight decrease in snow cover in spring (March to May).[56] While the extent of spring snow may decrease slightly, snowpack depth in the high mountains may actually increase due to the added moisture in warmer saturated air that is still below freezing.

Coral Reefs Are Adapting. Global warming alarmists often claim that human-induced global warming is causing the "bleaching" of coral reefs. Indeed, alarmists often refer to coral as a "barometer of global warming." However, there is little scientific support for such claims.

"Bleaching helps corals survive environmental stress."

Coral bleaching is a misnomer in that coral do not change color because they are "bleached" by solar radiation; rather they lose color because the symbiotic relationship between algal species (which provide the color) and the coral breaks down. This can occur when water temperatures, pollution levels or water sediments become too high. Without an algal symbiont, the coral will die in a few years.

However, a recent study argued that coral bleaching may simply be a mechanism to help corals survive environmental stress.[57] In this study, several varieties of coral were subjected to changes in water temperature. Most of those that were moved to warmer water bleached immediately whereas those that were moved to cooler water did not. However, a year later it was discovered that the corals that had bleached were developing better than those that had not. Bleaching is a process that expels algae, and the corals that bleached formed a symbiotic relationship with new species of algae that were better suited to the new environment. The study concluded, "this counters conventional wisdom that bleaching is detrimental from all perspectives, and supports the role of symbionts as adaptive agents."

Two more recent studies have examined coral bleaching and have also concluded that it may be a beneficial response to stress. In one study, Caribbean corals were bleached and exposed to a number of algal species.[58] Not only did the coral and algae reestablish a symbiotic relationship, but in some cases it was with a different algal species that was better suited to the current environmental conditions. In the second study, it was found that reestablished symbiotic relationships vary depending upon whether the coral is an adult or a juvenile.[59] The authors concluded that this "suggests that there may be 'active' selection by the host to maximize symbiont effectiveness that varies with differences in physiological requirements between juvenile and adult corals." Such a response may explain why corals have survived for millions of years despite a widely varying climate that has fluctuated between cold glacial epochs and warm interglacial periods. Indeed, coral bleaching appears to be a mechanism to guarantee survival and development of the species, not a harbinger of death.

Conclusion: Links between Greenhouse Gas Emissions and Severe Climate Impacts Are Tenuous

Despite pronouncements of "scientific consensus," climatologists are still uncertain concerning the likely impact of increased atmospheric green-

house gas concentrations. Trace gas concentrations, such as CO_2, have been increasing, largely as a result of fossil fuel emissions. However, concentrations of methane and chlorofluorocarbons (which are also important atmospheric trace gases) have leveled off in recent years. The extent to which fossil fuel emissions have contributed to the rise in global atmospheric air temperatures since about the mid-1800s is still debatable, since much of the warming occurred before significant increases in atmospheric trace gas concentrations, and because there was a dramatic downward trend in air temperatures between the early 1960s and the mid-1970s — after significant increases in atmospheric CO_2 — which led to the short-lived "global cooling" scare. Connections between this recent moderate rise in air temperature and changes in other parts of the climate system are far more tenuous.

"Global warming due to human greenhouse gas emissions is still debatable."

In fact, even among global warming alarmists, projections of global warming for 2100 have decreased significantly since early modeling efforts. The response to a doubling of CO_2 exhibited by the many models used for the Third Assessment Report range between 2.7° and 5.4° F. If such trends continue — and all models except one (the Canadian model) exhibit a gradual, consistent rise over time — global air temperatures should increase by 2.5° F and air temperatures in the United States by about 1° F during the 21st century. Most of this warming should occur in the coldest winter air masses, while summer rainfall should increase slightly. Such a warming could hardly be called unprecedented or catastrophic. In general, our climate has and will continue to exhibit intricate patterns not reliably reproduced by global climate simulations, thus underscoring their scientific incompleteness — and lack of reliability for prediction of future climate scenarios.

Notes

[1] James Hansen, Testimony before the U.S. Congress, June 23, 1988. See James Hansen, I. Fung, A. Lacis, D. Rind, S. Lebedeff, R. Ruedy, G. Russell and P. Stone, "Global climate changes as forecast by Goddard Institute for Space Studies three-dimensional model," *Journal of Geophysical Research,* Vol. 93, 1988, pages 9,341-9,364.

[2] Syukuro Manabe, then at the Geophysical Fluid Dynamics Laboratory of the National Oceanic and Atmospheric Administration, and Patrick Michaels, state climatologist and professor of environmental sciences at the University of Virginia.

[3] James E. Hansen, "A Brighter Future," *Climatic Change*, Vol. 52, No. 4, March 2002, pp. 435-40.

[4] Makiko Sato et al., "Global Atmospheric Black Carbon Inferred from AERONET," *Proceedings of the National Academy of Sciences,* Vol. 100, No. 11, May 2003, pages 6,319-6,324.

[5] Theodore L. Anderson, "Climate Forcing by Aerosols — A Hazy Picture," *Science*, Vol. 300, No. 5622, May 2003, pages 1,103-1,104.

[6] See Judith Lean and David Rind, "Evaluating Sun-Climate Relationships Since the Little Ice Age," *Journal of Atmospheric and Solar-Terrestrial Physics*, Vol. 61, No. 1-2, January 1999, pages 25-36; and David Rind et al., "The Relative Importance of Solar and Anthropogenic Forcing of Climate Change Between the Maunder Minimum and the Present," *Journal of Climate*, Vol. 17, No. 5, March 2004, pages 906-929.

[7] Willie Soon et al., "Inference of Solar Radiance Variability from Terrestrial Temperature Changes, 1880-1993: An Astrophysical Application of the Sun-Climate Connection." *The Astrophysical Journal*, Vol, 472, pages 891-902.

[8] Judith Lean and David Rind, "Evaluating Sun-Climate Relationships Since the Little Ice Age,"

[9] For a more detailed discussion of these issues, see David R. Legates, "Limitations of Climate Models as Predictors of Climate Change," National Center for Policy Analysis, Brief Analysis No. 396, May 17, 2002.

[10] American Association of State Climatologists. Available at http://www.ncdc.noaa.gov/oa/aasc/aascclimatepolicy.pdf.

[11] Such biases include the effect of the wind (where rain and, particularly, snow is blown across the mouth of the raingage), evaporation from the gage, and problems associated with automatic recording techniques.

[12] Thomas R. Karl and Richard W. Knight, "Secular Trends of Precipitation Amount, Frequency, and Intensity in the United States," *Bulletin of the American Meteorological Society*, Vol. 79, No. 2, February 1998, pages 231-241.

[13] Kenneth E. Kunkel et al., "Temporal Variations of Extreme Precipitation Events in the United States: 1895-2000," *Geophysical Research Letters*, Vol. 30, No. 17, September 2003, pages 1,900-1,903.

[14] Another phenomenon the IPCC is unable to reproduce is the Pacific Decadal Oscillation, which arises from the interaction of ocean and wind currents, and other factors.

[15] The study concludes: "Not only do the [30] GCMs differ with respect to the observations, but the models also lack coherence among themselves. It is noted, however, [t]hat even the extreme models exhibit markedly less precipitation variability than observed … If the GCMs are in error, this deficiency would presumably reflect a more fundamental flaw common to all models." See Brian J. Soden, "The Sensitivity of the Tropical Hydrological Cycle to ENSO," *Journal of Climate*, Vol. 13, No. 3, February 2000, pages 538-549.

[16] Ann H. Henderson-Sellers et al., "Tropical Cyclones and Global Climate Change: A Post-IPCC Assessment," *Bulletin of the American Meteorological Association*, Vol. 79, No. 1, January 1998, pages 19-38.

[17] A more recent study concurs, "There have been various studies investigating the potential effect of long-term global warming on the number and strength of Atlantic-basin hurricanes … the results are inconclusive." See Stanley B. Goldenberg et al., "The Recent Increase in Atlantic Hurricane Activity: Causes and Implications," *Science*, Vol. 293, No. 5529, July 2001, pages 474-479.

[18] Kerry Emanuel, "Increasing Destructiveness of Tropical Cyclones over the Past 30 Years," *Nature*, Vol. 436, August 4, 2005, pages 686-688.

[19] Peter J. Webster et al., "Changes in Tropical Cyclone Number, Duration, and Intensity in a Warming Environment," *Science*, Vol. 309, September 16, 2005, pages 1,844-1,846.

[20] Roger A. Pielke Jr. et al., "Hurricanes and Global Warming," *Bulletin of the American Meteorological Society*, Vol. 86, No.

11, November 2005, pages 1,571-1,575.

[21] "NOAA Attributes Recent Increase in Hurricane Activity to Naturally Occurring Multi-Decadal Climate Variability," National Oceanic and Atmospheric Administration, NOAA News Online, November 29, 2005. Available at http://www.magazine.noaa.gov/stories/mag184.htm.

[22] Bruce P. Hayden, "Climate Change and Extratropical Storminess in the United States: An Assessment," *Journal of the American Water Resources Association*, Vol. 35, No. 6, December 1999, pages 1,387-1,398.

[23] Aiguo Dai, "Global Precipitation and Thunderstorm Frequencies, Parts I and II," *Journal of Climate*, Vol. 14, No. 6, March 2001, pages 1,092-1,128.

[24] Stanley A. Changnon and David Changnon, "Long-Term Fluctuations in Hail Incidences in the United States," *Journal of Climate*, Vol. 13, No. 4, February 2000, pages 658-664.

[25] P. Browning, "Tornado Trends," *Bulletin of the American Meteorological Society*, Vol. 83, No. 12, December 2002, pages 1,768-1,769.

[26] Harry F. Lins and James R. Slack, "Stream Flow Trends in the United States," *Geophysical Research Letters*, Vol. 26, No. 2, January 1999, pages 227-230.

[27] Pavel Y. Groisman et al., "Heavy Precipitation and High Stream Flow in the Contiguous United States: Trends in the Twentieth Century," *Bulletin of the American Meteorological Society*, Vol. 82, No. 2, February 2001, pages 219-246.

[28] Groisman's results are consistent with the earlier analysis of precipitation trends by Karl and Knight.

[29] Harry F. Lins, "Personal Communication," *United States Geographical Survey*, 2003.

[30] A recent assessment reexamined the conclusions reached by the two studies and concurred with the results of Lins and Slack. See Gregory J. McCabe and David M. Wolock, "A Step Increase in Streamflow in the Conterminous United States," *Geophysical Research Letters*, Vol. 29, No. 24, December 2002, pages 2,185-2,188.

[31] El Niño and La Niña are defined as a warming or cooling, respectively, of the ocean sea surface temperatures in the western equatorial Pacific Ocean and the associated changes in global weather patterns that result.

[32] Aigu Dai et al., "Global Variations in Droughts and Wet Spells: 1900-1995," *Geophysical Research Letters*, Vol. 25, No. 17, September 1998, pages 3,367-3,370.

[33] A large value of the Palmer Drought Severity Index was defined by Palmer as "an interval of time, generally in months or

expected or climatically appropriate moisture supply."

[34] Nathan Wells et al, "A Self-Calibrating Palmer Drought Severity Index," *Journal of Climate*, Vol. 17, No. 12, June 15, 2004, pages 2,335-2,351.

[35] Connie A. Woodhouse and Jonathan T. Overpeck, "2000 Years of Drought Variability in the Central United States," *Bulletin of the American Meteorological Society*, Vol. 79, No. 12, December 1998, pages 2,693-2,714.

[36] "Impacts of a Warming Arctic," *Arctic Climate Assessment* (Cambridge University Press, 2004).

[37] Petr Chylek et al., "Global Warming and the Greenland Ice Sheet," *Climatic Change*, Vol. 63, Nos. 1-2, March 2004, pages 201-221.

[38] Nancy S. Grumet et al., "Variability of Sea-Ice Extent in Baffin Bay over the Last Millennium," *Climatic Change*, Vol. 49, 2001, pages 129-145.

[39] Dennis Darby et al., "New Record Shows Pronounced Changes in Arctic Ocean Circulation and Climate," *EOS, Transactions, American Geophysical Union,* Vol. 82, No. 29, 2001, pages 601 and 607.

[40] Igor V. Polyakov et al., "Observationally Based Assessment of Polar Amplification of Global Warming," *Geophysical Research Letters*, Vol. 29, No. 18, September 2002, 10.1029/2001GL011111.

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[42] Rajmund Przybylak, "Changes in Seasonal and Annual High-Frequency Air Temperature Variability in the Arctic from 1951-1990," *International Journal of Climatology*, Vol. 22, No. 9, July 2002, pages 1,017-1,032.

[43] Willie Soon, "Variable Solar Irradiance as a Plausible Agent for Multidecadal Variations in the Arctic-wide Surface Air Tem-

perature Record of the Past 130 Years," *Geophysical Research Letters*, Vol. 32,doi:10.1029/2005GL023429.

[44] Rajmund Przybylak, "Temporal and Spatial Variation of Air Temperature over the Period of Instrumental Observations in the Arctic," *International Journal of Climatology,* Vol. 20, No. 6, May 2000, pages 587-614.

[45] Petr Chylek et al., "Global Warming and the Greenland Ice Sheet."

[46] Greg Holloway, "Is Arctic Sea Ice Rapidly Vanishing? Fisheries and Oceans Canada-Pacific Region,"available at http://www — sci.pac.dfo — mpo.gc.ca/osap/projects/jpod/projects/arc_thin/thin1.htm.

[47] Donald J. Cavalieri et al., Laboratory for Hydrospheric Processes, NASA Goddard Space Flight Center. Available at http://polynya.gsfc.nasa.gov/seaice_projects.html#image10.

[48] Stefan Norris et al., "Polar Bears at Risk," WWF International Arctic Programme, May 2002. Available at http://www.worldwildlife.org/climate/publications/polar_bears_risk_2002.pdf.

[49] It is unknown whether remaining distinct polar bear populations are stable, growing or declining.

[50] Note that changes in sea ice will not affect sea levels because, as the Archimedes principle states, an object floating in water will displace an amount of water equal to its weight — the melted sea ice will equal the amount of water it already displaced.

[51] Hengchun Ye and John R. Mather, "Polar Snow Cover Changes and Global Warming," *International Journal of Climatology*, Vol. 17, No. 2, February 1997, pages 155-162.

[52] Cecile Cabanes et al., "Sea Level Rise During the Past 40 years Determined from Satellite and in Situ Observations," *Science*, Vol. 294, No. 5543, October 2001, pages 840-842.

[53] Robert E. Davis et al., "A Climatology of Snowfall-Temperature Relationships in Canada," *Journal of Geophysical Research*, Vol. 104, No. D10, May 1999, pages 11,985-11,994.

[54] Marilyn G. Hughes and David A. Robinson, "Historical Snow Cover Variability in the Great Plains Region of the USA: 1910 through to 1993," *International Journal of Climatology*, Vol. 16, No. 9, September 1996, pages 1,005-1,018.

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[57] Andrew C. Baker, "Reef Corals Bleach to Survive Change," *Nature*, Vol. 411, June 2001, pages 765-766.

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[59] Angela F. Little et al., "Flexibility in Algal Endosymbioses Shapes Growth in Reef Corals," *Science*, Vol. 304, No. 5676, June 2004, pages 1,492-1,494.

About the Author

David R. Legates is an associate professor of geography and director of the Center for Climatic Research at the University of Delaware. Dr. Legates is also the Delaware State Climatologist, Coordinator of the Delaware Geographic Alliance (sponsored by National Geographic), and Associate Director of the Delaware Space Grant Consortium (sponsored by NASA).

Prior to assuming his current academic position in 1999, Dr. Legates was an Associate Professor at Louisiana State University from 1998 to 1999 and both an Associate Professor (from 1994 through 1997) and an Assistant Professor (from 1998 to 1994) in the College of Geosciences at the University of Oklahoma. He also served as Visiting Research Scientist at the National Climatic Data Center in Asheville, N.C., in 1991, as Visiting Associate Professor at the University of Virginia from 1995 to 1996, as Chief Research Scientist in the Center for Computational Geosciences at the University of Oklahoma from 1995 to 1997, and as Research Scientist in the Southern Regional Climate Center at Louisiana State University from 1998 to 1999. He serves as editor or associate editor for four journals and monograph series.

Dr. Legates is the author or coauthor of 45 refereed journal articles; 19 book chapters, monographs and reports; and 41 articles in conference proceedings. He has given more than 100 presentations at professional meetings and has been invited to speak at more than 20 universities and national or private research laboratories. He has also been awarded more than $5 million in research grants on which he served as either principal investigator or co-principal investigator.

Legates received a Bachelor of Science degree in Mathematics and Geography, a Master of Science degree in Geography-Climatology and a Doctor of Philosophy degree in Climatology - all from the University of Delaware.

About the NCPA

The NCPA was established in 1983 as a nonprofit, nonpartisan public policy research institute. Its mission is to seek innovative private sector solutions to public policy problems.

The center is probably best known for developing the concept of Medical Savings Accounts (MSAs), now known as Health Savings Accounts (HSAs). The *Wall Street Journal* and *National Journal* called NCPA President John C. Goodman "the father of Medical Savings Accounts." Sen. Phil Gramm said MSAs are "the only original idea in health policy in more than a decade." Congress approved a pilot MSA program for small businesses and the self-employed in 1996 and voted in 1997 to allow Medicare beneficiaries to have MSAs. A June 2002 IRS ruling frees the private sector to have flexible MSAs and even personal and portable insurance. A series of NCPA publications and briefings for members of Congress and the White House staff helped lead to this important ruling. In 2003, as part of Medicare reform, Congress and the president made HSAs available to all non-seniors, potentially revolutionizing the entire health care industry.

The NCPA also outlined the concept of using tax credits to encourage private health insurance. The NCPA helped formulate a bipartisan proposal in both the Senate and the House, and Dr. Goodman testified before the House Ways and Means Committee on its benefits. Dr. Goodman also helped develop a similar plan for then presidential candidate George W. Bush.

The NCPA shaped the pro-growth approach to tax policy during the 1990s. A package of tax cuts, designed by the NCPA and the U.S. Chamber of Commerce in 1991, became the core of the Contract With America in 1994. Three of the five proposals (capital gains tax cut, Roth IRA and eliminating the Social Security earnings penalty) became law. A fourth proposal — rolling back the tax on Social Security benefits — passed the House of Representatives in summer 2002.

The NCPA's proposal for an across-the-board tax cut became the focal point of the pro-growth approach to tax cuts and the centerpiece of President George W. Bush's tax cut proposal. The repeal by Congress of the death tax and marriage penalty in the 2001 tax cut bill reflects the continued work of the NCPA.

Entitlement reform is another important area. With a grant from the NCPA, economists at Texas A&M University developed a model to evaluate the future of Social Security and Medicare. This work is under the direction of Texas A&M Professor Thomas R. Saving, who was appointed a Social Security and Medicare Trustee. Our online Social Security calculator, found on the NCPA's Social Security reform Internet site (www.TeamNCPA.org), allows visitors to discover their expected taxes and benefits and how much they would have accumulated had their taxes been invested privately.

Team NCPA is an innovative national volunteer network to educate average Americans about the problems with the current Social Security system and the benefits of personal retirement accounts.

In the 1980s, the NCPA was the first public policy institute to publish a report card on public schools, based on results of student achievement exams. We also measured the efficiency of Texas school districts. Subsequently, the NCPA pioneered the concept of education tax credits to promote competition and choice through the tax system. To bring the best ideas on school choice to the forefront, the NCPA

and Children First America published an *Education Agenda* for the George W. Bush administration, policymakers, congressional staffs and the media. This book provides policymakers with a road map for comprehensive reform. And a June 2002 Supreme Court ruling upheld a school voucher program in Cleveland, an idea the NCPA has endorsed and promoted for years.

The NCPA's E-Team program on energy and environmental issues works closely with other think tanks to respond to misinformation and promote common-sense alternatives that promote sound science, sound economics and private property rights. A pathbreaking 2001 NCPA study showed that the costs of the Kyoto agreement to halt global warming would far exceed any benefits. The NCPA's work helped the administration realize that the treaty would be bad for America, and the United States has withdrawn from the treaty.

NCPA studies, ideas and experts are quoted frequently in news stories nationwide. Columns written by NCPA scholars appear regularly in national publications such as the *Wall Street Journal*, the *Washington Times*, *USA Today* and many other major-market daily newspapers. NCPA scholars also appear on radio talk shows and television public affairs programs. According to media figures from Burrelle's, nearly 3 million people daily read or hear about NCPA ideas and activities somewhere in the United States.

The NCPA home page (www.ncpa.org) links visitors to the best available information, including studies produced by think tanks all over the world. Britannica.com named the ncpa.org Web site one of the best on the Internet when reviewed for quality, accuracy of content, presentation and usability.

What Others Say about the NCPA

"...influencing the national debate with studies, reports and seminars."

- TIME

"Oftentimes during policy debates among staff, a smart young staffer will step up and say, 'I got this piece of evidence from the NCPA.' It adds intellectual thought to help shape public policy in the state of Texas."

- Then-GOV. GEORGE W. BUSH

"The [NCPA's] leadership has been instrumental in some of the fundamental changes we have had in our country."

- SEN. KAY BAILEY HUTCHISON

"The NCPA has a reputation for economic logic and common sense."

- ASSOCIATED PRESS

The NCPA is a 501(c)(3) nonprofit public policy organization. We depend entirely on the financial support of individuals, corporations and foundations that believe in private sector solutions to public policy problems. You can contribute to our effort by mailing your donation to our Dallas headquarters or logging on to our Web site at www.ncpa.org and clicking "An Invitation to Support Us."