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UNITED STATES DISTRICT COURT
NORTHERN DISTRICT OF CALIFORNIA
SAN FRANCISCO DIVISION

FRIENDS OF THE EARTH, INC., et al.,	) Civ. No. 02-4106 (JSW)
Plaintiffs,	) DECLARATION OF DR. DAVID R. LEGATES IN SUPPORT OF DEFENDANTS' REPLY TO PLAINTIFFS' OPPOSITION TO DEFENDANTS' MOTION FOR SUMMARY JUDGMENT
v.	)
PETER WATSON, et al.,	) Date: April 29, 2005
Defendants.	) Time: 9 A.M.) Courtroom 2, 17th Floor

Attachment C

DECLARATION OF DR. DAVID R. LEGATES

I, Dr. David R. Legates, declare as follows:

1. I received my Bachelor of Arts degree, cum laude, in Mathematics and Geography (double major) from the University of Delaware in 1982. My studies were recognized by my election into the Phi Beta Kappa, Phi Kappa Phi, and Pi Mu Epsilon (mathematics) honor societies. I then received my Master of Science degree in Climatology/Geography and my Ph.D. degree in Climatology from the University of Delaware in 1985 and 1988, respectively. From 1988 to 1994, I was an Assistant Professor in the College of Geosciences at the University of Oklahoma. In 1994, I was tenured and promoted to the rank of Associate Professor and served at that rank at the University of Oklahoma through 1997. From 1998 to 1999, I was an Associate Professor at Louisiana State University and in 1999 I became an Associate Professor at the University of Delaware, where I continue today. As a University professor, I am the author/co-author of 40 refereed journal articles, 18 book chapters, monographs, and reports, and 41 articles in conference proceedings. I have given more than 90 presentations at professional meetings and have been invited to speak at more than 20 universities and national or private research laboratories. I also have been awarded over $5 million in research grants on which I served as either Principal Investigator or co-Principal Investigator. In addition, I currently serve as the Director of the Center for Climatic Research and Associate Director of the Delaware Space Grant Consortium (a NASA Center) at the University of Delaware and I am the Associate State Climatologist for Delaware. I also have served as Visiting Research Scientist at the National Climatic Data Center in Asheville, NC (in 1991), as Visiting Associate Professor at the University of Virginia (from 1995 to 1996), Chief Research Scientist in the Center for Computational Geosciences at the University of Oklahoma (from 1995 to 1997), and Research Scientist in the Southern Regional Climate Center at Louisiana State University (1998 to 1999). I presently serve as Editor or Associate Editor for three journals and monograph series.

2. Much of my research has focused on assessing climate variability and change, particularly with respect to precipitation and the hydrologic cycle. I have extensively studied biases in precipitation gage measurements, problems associated with obtaining large-scale climatic estimates (such as globally-averaged estimates and regional assessments), the use of remote sensing (weather radar and satellite) to assess precipitation variability, analysis and trends in precipitation, floods, and droughts, and evaluating model-derived estimates of precipitation. I also have published research on statistical methods and how they are used to assess climate variability and change. The results from my dissertation research – which developed high-resolution representations of current and recent climatological conditions – are used still today to evaluate General Circulation Model estimates of air temperature and precipitation. In recognition of my work, I was invited to participate in the joint USA/USSR Working Meeting on Development of Data Sets for Detecting Climatic Change in 1989. At this meeting, the first protocol for the exchange of data for climatic change research was signed between the United States and the Soviet Union. I also served as National Expert for the International Organizing Committee for the World Meteorological Organization Solid Precipitation Measurement Intercomparison. From 1992 to 1996, I was elected to the Board of Directors of the Climate Specialty Group of the Association of American Geographers[1], serving as its Chair during the last two years. I also have been invited to participate in a number of NATO and NOAA workshops and have spoken to Congressional groups about climate change on a number of occasions, including being twice invited to provide Congressional testimony before the United States Senate Committee on Environment and Public Works. In 2000, I earned *Certified Consulting Meteorologist* status from the American Meteorological Society[2].

[1] The Climate Specialty Group of the Association of American Geographers is one of the largest organizations of climatologists in the country.

[2] There have only been 628 Certified Consulting Meteorologist certificates awarded since the program was begun in 1958.

SUMMARY

3. The following findings and supporting information are offered as my expert scientific opinion, based on my education, qualifications, experience, and knowledge obtained from my own research and that published in the scientific literature. I have reviewed the MacCracken Declaration as well as the Declarations of Mr. Mark Andre, Mr. Arthur Berndt, Ms. Melanie Duchin, Dr. Phillip Dustan, Ms. Carol Ellinghouse, Mr. Randall L. Hayes, Mr. Brian Johnson, Mr. Jesse Williford, and Ms. Pam Williford. The opinions expressed in my declaration are based on the conclusions drawn in the above-cited Declarations.

4. The MacCracken Declaration refers to two studies – the Intergovernmental Panel on Climate Change (IPCC), including its Third Scientific Assessment Report (TAR)[3] and its Summary for Policymakers (SPM)[4], and the United States National Assessment of the Potential Consequences of Climate Variability and Change (USNA)[5]. The IPCC TAR purports to represent the current scientific understanding of climate change and its projected effects while the IPCC SPM is intended to be a distilled synthesis of the IPCC TAR and inclusion or omission of text is determined by a line-by-line vote of national delegates (although it often provides statements which are at odds with the TAR). The USNA was "produced by the National Assessment Synthesis Team, an advisory committee chartered under the Federal Advisory Committee Act to help the US Global Change Research Program fulfill its mandate under the Global Change Research Act of 1990."

5. In my declaration, I will assess our current understanding regarding climate change and provide an overview of the limitations associated with observational assessments and global climate model prognostications and discuss the direct link that the plaintiff's declaration make between

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[3] IPCC (2001): Climate Change 2001: The Scientific Basis. Edited by J.T. Houghton *et al.* Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press.
[4] IPCC (2001): Summary for Policy Makers. A report of Working Group I of the Intergovernmental Panel on Climate Change. Edited by J.T. Houghton *et al.*, Cambridge University Press.

anthropogenic greenhouse gas emissions and climate change. In general, the climate has been warming since the end of the 'Little Ice Age' in the mid-1800s, well before significant industrial development and substantial increases in greenhouse gases have occurred. However, observations are limited by their proximity to urban centers (the adverse effect of urbanization) and their temporal and spatial extent (the oceans, high altitudes, and high latitudes are underrepresented and the availability of observing sites has varied by more than an order of magnitude over just the 20th Century). Climate models (general circulation models) are not affected by these data-based problems, but additional and fundamental problems are associated with modeling the climate (*e.g.*, model spatial resolutions are far below that required to describe many atmospheric and land-surface processes) and other important processes (including, for example, the representation of surface topography) such that even model simulations of present-day conditions do not represent well the current climate and have not been able to adequately reproduce the climate of the past thirty years. This makes it difficult to attribute changes in flood and drought frequencies, for example, to rising concentrations of greenhouse gases. Most importantly, it is impossible to relate non-climatic impacts directly to increases in atmospheric trace gas concentrations as the climate system is quite complex. Thus, changes in sea ice extent, polar bear extinctions, sea level rise, snow cover, coral reefs, and forest ecology depend on a myriad of factors and their interrelationships; it is extremely difficult to ascribe the rise in greenhouse gas concentrations directly to these changes and the data do not support the plaintiff's definitive statements on these points.

6. Since 1900, globally averaged air temperature has increased approximately 1°F (0.6°C ± 0.2°C) due, in part, to human activities. However, it is my belief, shared by a large number of climatologists, that significant questions still remain as to the extent to which this 1°F (0.6°C) rise in

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[5] The United States National Assessment of the Potential Consequences of Climate Variability and Change is available at http://www.usgcrp.gov/usgcrp/nacc/default.htm. The US National Assessment relies on the two most extreme climate models as discussed below.

air temperature can be attributed to anthropogenic increases in greenhouse gas concentrations, or how future increases will affect other aspects of the climate system. This is because:

a. Global air temperatures have been rising since the mid-1800s, long before significant increases in anthropogenic greenhouse gas concentrations have been documented. The period from about 1500 to the mid-1800s is known as the *Little Ice Age* because global air temperatures were cooler during this period. Part of the explanation for the rise in global air temperatures is natural variability arising from the demise of the *Little Ice Age*. Indeed, it is the only real explanation for rising air temperatures prior to the 1940s – when approximately half of the observed 20th Century warming occurred and significant, anthropogenic increases in greenhouse gases began. Research[6] recently has shown that solar variability may be responsible for a warming of about 0.45°F (0.25°C) between 1900 and 1990 and about a third of the warming since 1500[7]. Of this warming, most is likely to occur in the coldest, driest air masses in the winter – since water vapor has a greater specific heat[8] than dry air and the Stefan-Boltzmann radiation law shows that for the same energy input, cold air will warm more than warm air.

b. Many of our observations are adversely affected by urbanization and the rapid growth of our cities. After World War II, for example, many weather observations in the United States national network were moved from downtown locations to the newly built airports located on the urban fringe. Over the years, the urban sprawl has increased dramatically to the extent that many stations that had little or no urban effect in 1940 are now significantly affected by the *urban heat island* – a term used to describe the fact that a city will be warmer than its surrounding countryside. Studies in numerous urban areas have shown that

[6] Lean, J, and D Rind (1999): Evaluating sun-climate relationships since the Little Ice Age. Journal of Atmospheric and Solar-Terrestrial Physics, 61:25-36.

on warm summer days, temperatures in a city can be as much as 8°F (4.5°C) warmer than the surrounding countryside with annual air temperatures averaging about 4.5°F (2.5°C) warmer. This is because of the increase in impervious surfaces (decreased energy exchange by evaporation of water), an overall decrease in winds (decreased exchange of heat by convection), the use of darker surfaces and the canyon-like structure of cities (increase in absorbed solar energy), and anthropogenic sources of heat.

c. The observations we have often are limited both spatially and temporally. Over time, many stations have either been moved or removed, resulting in a discontinuity in the observed time-series. Moreover, observing stations are biased toward mid-latitudes, coastal areas, and lower elevations – where most people live. Oceanic areas (covering approximately two-thirds of the earth's surface), high latitudes (the Arctic and Antarctic), and high altitude mountains are underrepresented. Overall, the pattern in global air temperature has seen a general rise in air temperature since before 1900 with a marked decrease between the early 1960s and the mid-1970s. Incidentally, this decrease coincides with an increase in the density of observing stations from around the globe while the rise since the mid-1970s is commensurate with a steady decrease in the number of observing stations.

It now is argued[9] that the likely warming over the next fifty years will be about 1.4°F (0.75°C) globally, a much lower estimate than was suggested only fifteen years ago.

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[7] Rind, D, *et al.* (2004): The relative importance of solar and anthropogenic forcing of climate change between the Maunder Minimum and the present. Journal of Climate, 17:906-929.

[8] The amount of heat needed to raise the temperature of one gram of a substance by 1°C.

[9] Allen, M, *et al.* (2000): Quantifying the uncertainty in forecasts of anthropogenic climate change. Nature, 407:617–620 and Hansen, JE, and M Sato (2001): Trends of measured climate forcing agents. Proceedings of the National Academy of Sciences, 98:14,778–14,783.

<u>The Role of Climate Models and Greenhouse Gas Emission Scenarios</u>

7. To assess future trends in global air temperature, as well as other climatic variables, climatologists have relied upon General Circulation Models (GCMs) – mathematical/computer representations of the physical laws and processes that govern our climate system. General circulation models are limited both by our understanding of what drives, shapes, and affects the climate of the earth as well as how the earth's climate responds to a variety of external forces – in addition to the speed and capabilities of modern-day computers. The reliability in GCM prognostications of climate change, however, depends on (1) their ability to simulate present-day conditions and (2) the plausibility of greenhouse gas emission scenarios. It is puzzling why the MacCracken Declaration (citing the models chosen by the USNA[10]) relies only the Hadley Centre (HadCM2) and Canadian Global Coupled (CGCM1) models, particularly when the IPCC report (which compared more than thirty different models in its analysis) demonstrated that these two models present more extreme climate scenarios. In particular, the Canadian Global Coupled (CGCM1) model exhibits more future warming than any other model. Modeling efforts from the United States (including models such as those produced by the National Center for Atmospheric Research, the Goddard Institute for Space Studies, the Geophysical Fluid Dynamics Laboratory, and NASA Goddard's Laboratory for Atmospheres) were not included. A majority of the climate models considered by the IPCC TAR exhibit much less warming as a result of a doubling of atmospheric greenhouse gases – as little as 4.5°F (2.5°C)[11]. Thus, the results of the MacCracken Declaration are biased in that an extreme model (CGCM1) was considered without including one that suggests only modest warming, such as that developed by the National Center for Atmospheric Research (NCAR). For this century, the NCAR

[10] United States National Assessment (2000): Chapter 1 -- Scenarios for Climate Variability and Change. National Assessment Synthesis Team Document, Washington, DC.
[11] Schneider, SH (2001): What is 'dangerous' climate change? Nature, 411:17–19.

model suggests only about 1.8°F (1°C) of warming as a result of increases in greenhouse gases, whereas the CGCM1 produces 14.4°F (8°C) of warming and the HadCM2 produces a warming of 5.4°F (3°C).

8. With respect to the simulation of present-day conditions, a report[12] submitted for the USNA compared important atmospheric and surface variables with observations[13] for the HadCM2 and CGCM1 models. Over North America, both models exhibited significant biases with respect to air temperature and precipitation. In particular, the results demonstrate that model simulations of present-day conditions can differ from the observations by as much as the average precipitation (*i.e.*, errors as large as 100%) and the model prognostications for precipitation and air temperature by 2050 are dwarfed by the large errors in the model representation of present-day conditions. Both models also simulate high-pressure systems and winter storms to be too intense and both exhibit a cold tropospheric bias in upper air temperatures. In short, these models do not adequately represent current climate conditions. This makes it very difficult to place much faith in their prognostications of future climates in a greenhouse gas-enhanced world.

9. A second important limitation in GCM prognostications lies in the plausibility of their anthropogenic emission scenarios – most notably greenhouse gases and atmospheric aerosols[14]. Dr. James Hansen of the Goddard Institute for Space Studies, regarded by many as the 'father of global warming' for his congressional testimony in 1988 where he declared a "99% certainty" of anthropogenic warming, now warns of exaggeration with regard to IPCC greenhouse gas emission scenarios:

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[12] Doherty, R, and LO Mearns (2000): A comparison of simulations of current climate from two coupled atmosphere-ocean global climate models against observations and evaluation of their future climates. Report in Support of the National Assessment, NCAR, Boulder CO. (*http://www.isse.ucar.edu/doherty/*)

[13] Including Legates, DR (1987): A climatology of global precipitation. Publications in Climatology, 40(1), 84pp and Legates, DR, and CJ Willmott (1990): Mean seasonal and spatial variability in gauge-corrected, global precipitation. International Journal of Climatology, 10(2):111-127.

[14] *Atmospheric aerosols* refers to solid and liquid particles suspended in the atmosphere. They originate from both natural (*e.g.*, dust, volcanic eruptions, sea spray) and anthropogenic (*e.g.*, smokestack emission) sources.

> "One problem with IPCC reports is that each report produces new (and more numerous) greenhouse gas scenarios with little attempt to discuss what went wrong with the previous ones. We note that growth rate of CO2 (fossil fuel) emissions has declined from about 4% per year to 1% per year in recent decades. It is noteworthy that the current IPCC (2001) scenarios have a growth rate in the 1990s that is almost double the observed rate of 0.8%/year ... but it is consistent with [the IPCC's] failure to emphasize data."[15]

Such remains the case, as a recent paper that examined the potential for future outbreaks of heatwaves in Europe used an increase of 0.83% per year – the observed rate has averaged 0.42% per year for the last three decades and the yearly trend is decreasing. The greatest warming simulated by GCMs require large changes in per-capita energy use far beyond current levels while lower estimates are commensurate with observed climate changes. Thus, most emission-scenarios fail to account for the observed rate of emissions that are substantially less than what is used by the models.

10. With respect to atmospheric aerosols, IPCC and USNA scenarios both assume that atmospheric aerosols have a slight warming effect. A more recent report[16] (including James Hansen as a co-author), however, concludes that the warming effect from anthropogenically-derived black carbon aerosols is about twice that used in the IPCC report. On the other hand, another report[17] suggests that the net effect of sulfate aerosols is to cool the earth, not warm it. These disparate results must be resolved to assess properly the impact of potential climate change as the latter study concluded:

> "In addressing the critical question of how the climate system will respond... researchers must seek to resolve the present disparity...Until this is achieved, the

[15] Hansen, J (2002): A brighter future. Climatic Change, 52, 435-440.
[16] Sato, M, *et al.* (2003): Global atmospheric black carbon inferred from AERONET. Proceedings of the National Academy of Sciences, 100:6319–6324.
[17] Anderson, TL (2003): Climate forcing by aerosols—a hazy picture. Science, 300, 1103-1104.

> possibility that most of the warming to date is due to natural variability, as well as the possibility of high climate sensitivity [to greenhouse gas forcing], must be kept open."

Indeed, the difficulty in reconciling model simulations of present-day conditions with observations as well as the difficulties associated with specifying anthropogenic emissions, led the American Association of State Climatologists (AASC) – a professional organization of regional and state climatologists who deal with local climate data on a daily basis – to conclude in their policy statement on climate change[18]:

> "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."

Drawing conclusions about the future climate by a sole reliance on climate models is very risky, since they cannot accurately simulate the present climate. Making extrapolations to secondary response variables, such as sea level rise and species extinction is even more tenuous. If 'the past is the key to the future', then a more appropriate strategy (in lieu of climate model prognostications) is to examine what we presently observe and assume that current trends are likely to continue.

Connections to Specific Impacts

11. As I explain below, due to the complexities of the climate system, it is impossible to connect emissions of greenhouse gases from any specific source or group of sources to an increased risk of any particular outcome. Linkages between an anthropogenic increase in greenhouse gas concentrations and climate outcomes are difficult to make (*e.g.*, it is difficult to argue for changes in storminess or flood/drought frequencies since it is affected by many factors other than global air temperatures); attributing a climatic-based cause to non-climate outcomes (such as polar bear

[18] http://www.ncdc.noaa.gov/oa/aasc/aascclimatepolicy.pdf

extinctions or the demise of the maple syrup industry) is even more tenuous. The underlying theme of our understanding of climate science is that the system is both wildly complex and inherently stable – throughout the millennia, life has survived and thrived despite widely changing solar, air temperature, and atmospheric gas concentration conditions.

12. Some of the particular effects that may result from global warming, as alleged by the plaintiffs' declarations, are examined in more detail below in the light of current trends and the plausibility of an adverse effect being created by anthropogenic increases in greenhouse gas concentrations. This is not meant to be an exhaustive compendium of possible effects, but rather, an assessment of the claims pertinent to the plaintiff's allegations of damage.

Increase in Storm Severity and Rainfall Intensity

13. The IPCC Third Assessment Report (IPCC TAR) has made a number of contradictory claims regarding future changes in the hydrologic cycle. These contradictions are largely discrepancies between the Scientific Assessment and the Summary for Policymakers. Since precipitation (along with air temperature) is one of the most widely measured climate variables, it understandably has been the focus of much research. However, precipitation exhibits a significant degree of spatial and temporal variability, which, when coupled with a near complete absence of precipitation over the world's oceans and the potential biases that are associated with its measurement (particularly for snowfall), long-term trends are difficult to discern from the high degree of variability.

14. For the IPCC TAR and the USNA, a study[19] was cited to argue that the frequency of days with precipitation has increased, most notably associated with the heaviest precipitation category (daily rainfall exceeding 2 inches), although this finding contradicted their earlier argument made in an earlier publication for no change in median precipitation. Across the continental United States,

however, moderate precipitation intensities decreased by 1 percent. They concluded "these data suggest that the precipitation regimes in the United States are changing disproportionately across the precipitation distribution...the proportion of total precipitation derived from extreme and heavy events is increasing relative to more moderate events."

15. But in contrast with the IPCC findings, a more recent study[20] has examined precipitation over the United States using a new and extended dataset designed to provide extensive quality control, particularly in the early (data sparse) years. One of the significant effects of this new dataset is that it extends back to the late 19th Century, whereas the earlier report (cited in the IPCC TAR and the USNA) used data only as far back as the 1910s. In this new analysis, the frequency of heavy precipitation was high during the late 19th and early 20th Centuries as well as during the late 20th Century, with a minimum during the 1920s and 1930s (when the records for the IPCC-cited report began). They conclude "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."

16. It is relatively easy to explain the discrepancy between the IPCC-cited study and these newer results. The earlier study based its conclusions on an analysis that extended from 1910 to 1996, which did not capture the high precipitation frequencies occurring during the late 19th and early 20th Centuries. When the time period was carefully extended back to the late 19th Century (these researchers are state and regional climatologists for the Midwestern and western states), the rising precipitation trend since the 1930s can be evaluated in a more appropriate context. For the time period where the two studies overlap (*i.e.*, from 1910 to 1996), there is no disagreement between the two results. Thus, the latter more comprehensive and extended temporal analysis argues strongly that the

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[19] Karl, TR, and RW Knight (1998): Secular trends of precipitation amount, frequency, and intensity in the United States. Bulletin of the American Meteorological Society, 79(2):231-241.

results cited by the IPCC may not be of anthropogenic origin, but simply a result of longer-term natural variability.

17. The IPCC conclusions also rely on a number of GCM simulations of precipitation, although, owing to a number of factors, precipitation is difficult to simulate in a GCM. First, GCMs are limited by our incomplete understanding of the climate system and our limited ability to transform this knowledge into a mathematical representation. Second, GCMs use spatial and temporal resolutions that are far too coarse for precipitation modeling – spatial resolutions, for example, are no finer than one hundred kilometers. A third and important limitation is that GCMs simply cannot reproduce many important phenomena, such as hurricanes and most other forms of severe weather (e.g., thunderstorms, tornadoes, and nor'easters), that are important in shaping the earth's climate. Even weather fronts that are commonplace across the United States are not simulated. Finally, more complex phenomena that result from interactions among the various components of the climate system, such as the El Ninõ and La Ninã phenomena, the Pacific Decadal Oscillation, PNA (Pacific-North American) teleconnection patterns, and other complex interrelationships, are inadequately reproduced or often completely absent in climate model simulations. With respect to this latter issue, climate model simulations of precipitation are unable to replicate the observed spatial and interannual variability. In a study published since the IPCC TAR[21], it was demonstrated that the interannual variability in GCM-simulated precipitation is nearly an order of magnitude less than the observed variability. The study concludes:

> "Not only do the 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,

[20] Kunkel, KE, *et al.* (2003): Temporal variations of extreme precipitation events in the United States: 1895-2000. Geophysical Research Letters, 30(17):1900-1903.

> this deficiency would presumably reflect a more fundamental flaw common to all models."

It is difficult to argue that precipitation frequency and intensity are increasing when climate models cannot simulate correctly the observed interannual variability in precipitation. And in light of new research that demonstrates precipitation intensities today are commensurate with what they were nearly a century ago, it is inappropriate to ascribe recent changes in precipitation to anthropogenic sources.

Increase in Hurricane/Tropical Storm and Extra-Tropical Storm Frequency and Intensity

18. The argument that tropical cyclone (hurricanes, tropical storms, and tropical depressions, in decreasing levels of intensity) and extra-tropical storm (storms not of tropical origin, including thunderstorms and nor'easters) frequency and intensity will dramatically increase seems to be the most overstated consequence of global warming, as virtually no evidence exists to support it. The IPCC TAR states unequivocally,

> "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."

With respect to changes in their frequency and intensity arising from anthropogenic effects, a study[22] cited by both the IPCC and USNA clearly emphasized, "the popular belief that the region of cyclogenesis [tropical cyclone formation] will expand with the 26°C [sea surface temperature] isotherm is a fallacy...the very modest available evidence points to an expectation of little or no change in global frequency." Since tropical cyclone formation is linked to sea surface temperatures exceeding 78.8°F (26°C), it had been speculated that an increase in the area of warmer waters would

[21] Soden, BJ (2000): The sensitivity of the tropical hydrological cycle to ENSO. Journal of Climate, 13(3):538-549.

increase tropical cyclone frequencies and intensities. A more recent study[23] 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."

19. Despite these published results and their inclusion in the IPCC TAR, the MacCracken Declaration erroneously claims a "potential for an increase in the wind speed and peak rate of precipitation of major tropical cyclones (*i.e.*, hurricanes and typhoons)" and "an intensification of peak winds by up to about 6% (which would lead to an increase in the energy of damaging winds by about 18%) and a significant increase (up to 18%) in the amount of peak rainfall within 100km (about 60 miles) of the center (eye) of the hurricane." Despite this assertion, much research strongly argues against making these claims[22,23]. Unfounded statements such as this, despite the overwhelming scientific literature to the contrary, have given rise to the erroneous belief that for large increases in tropical cyclone frequencies and intensities will occur as a direct result of anthropogenic global warming.

20. With respect to changes in extratropical storms (*i.e.*, storms not of tropical origin), a study[24] 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...It is not possible, at this time, to attribute the large regional changes in storm climate to elevated atmospheric carbon dioxide." The study goes on to argue that GCM assessments "of North American storminess shows no sensitivity to elevated carbon dioxide...it would appear that statements about storminess based on [GCM] output statistics are unwarranted at this time" and "it should also be clear that little can or should be said

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[22] Henderson-Sellers, AH, *et al.* (1998): Tropical cyclones and global climate change: A post-IPCC assessment. Bulletin of the American Meteorological Association, 79(1):19-38.
[23] Goldenberg, SB, *et al.* (2001): The recent increase in Atlantic hurricane activity: Causes and implications. Science, 293:474-479.
[24] Hayden, BP, (1999): Climate change and extratropical storminess in the United States: An assessment. Journal of the American Water Resources Association, 35(6):1387-1398.

about change in variability of storminess in future, carbon dioxide enriched years." Another study[25] published in the same year concluded that increased concentrations of atmospheric trace gases, in fact, leads to a significant decrease in extratropical storm frequencies and went on to assert that results from studies "promot[ing] the possibility of enhanced storminess under greenhouse warming are more likely the result of global-scale sea level pressure falls rather than any real increase in cyclone circulation strength." The comment regarding 'global-scale sea level pressure falls' refers to the fact that, due to numerical instabilities, some GCMs fail to follow the Law of Mass Conservation and that lower atmospheric pressures over time were not a sign of intensifying low pressure systems[26], but rather, were simply a result of the model atmosphere losing mass.

21. In general, the Scientific Assessment of the IPCC TAR indicates more uncertainty about the impact of increasing greenhouse gases on tropical and extratropical storms than was presented in the Second Assessment Report. Both reports express doubts about the quality and homogeneity of data used to assess changes in storm frequencies and intensities. Similar analyses that have focused on changes in thunderstorm frequencies[27] and hail occurrences[28] as well as tornado frequencies, including the occurrence of 'significant' tornadoes (*i.e.*, those rated F3 and higher)[29] have concluded that current trends do not show significant increases in any of these events and that the connection of these phenomena with increases in greenhouse gases is inconclusive.

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[25] Sinclair, MR, and IG Watterson (1999): Objective assessment of extratropical weather systems in simulated climates. Journal of Climate, 12:3467-3485.

[26] Storms are centers of lower atmospheric pressure; hence, a decrease in minimum atmospheric pressure may be a sign of more intense low pressure systems.

[27] Dai, A (2001): Global precipitation and thunderstorm frequencies. Parts I and II. Journal of Climate, 14(6):1092-1111 and 1112-1128.

[28] Changnon, SA, and D Changnon (2000): Long-term fluctuations in hail incidences in the United States. Journal of Climate, 13(4): 658-664.

Enhanced Frequency of Flood and Drought Occurrences

22. Among the concerns associated with increasing concentrations of greenhouse gases in the atmosphere is that the hydrologic cycle is likely to become more extreme, with increased frequencies of both floods and droughts. Part of the difficulty in assessing whether this enhancement has been observed lies in the definition and our perception of floods and droughts. A 'flood' is simply streamflow that exceeds a prescribed threshold and is not necessarily caused by increased precipitation. Streamflow strongly depends on the antecedent moisture condition of the soil and the amount of moisture stored in detention areas prior to the onset of rainfall – rain falling on saturated ground or when reservoirs and lakes are near capacity may produce more of an increase in streamflow than if the ground is drier or when detention areas are low. Streamflow in the early spring also can be greatly affected by snowmelt, which, in turn, depends on the timing of springtime warming and the snowpack accumulation. Floods, therefore, depend on the state of the land surface hydrology in addition to the timing and form of precipitation.

23. Changing land use conditions and engineering developments also affect the frequencies by which enhanced streamflows occur. Urbanization increases the amount of impervious surfaces and generates more runoff (which ultimately becomes streamflow). River channelization efforts, such as dredging, levee construction, and stream bank reinforcement, speed water flow and restrict water from entering the natural flood plain. Direct anthropogenic effects on rivers often enhance the occurrence of flood conditions, masking the effect of changes to the earth's climate.

24. The simplest definition of drought is a 'meteorological drought', which occurs when below-normal precipitation falls over a specified time period, although that definition is greatly affected by the time period selected and the period for which 'normal precipitation' is defined. A more useful definition of drought is a 'hydrological drought', which occurs when river, lake, and/or well

[29] Browning, P (2002): Tornado trends. Bulletin of the American Meteorological Society, 83(12):1768-1769.

levels fall below a specified threshold. Increased urbanization, however, is concomitant with an increased demand for water use – industrial, residential, and agricultural – that can increase the frequency of hydrologic droughts and potentially mask the effect of potential changes in the earth's climate. Thus, our *perception* of drought and flood frequencies is greatly affected by anthropogenic influences that do not, in fact, affect the climate. Even with an unchanging but variable climate, urbanization leads to an increase in these hydrological extremes, due simply to an increased demand for water, the presence of more impervious surfaces, and channelization of streams and rivers. Thus, care must be taken to ensure that the causes of changing flood and drought frequencies is, in fact, a changing climate and not simply a result of a changing landscape.

25. The IPCC TAR concludes that from 1900 to 1995:

> "There were relatively small increases in global land areas experiencing severe drought or severe wetness. In many regions, these changes are dominated by inter-decadal and multi-decadal climate variability, such as the shift in [El Niño/La Niña][30] towards more warm events."

Since flood frequencies are affected by changes in land use, urbanization, and stream channelization, it is difficult to attribute trends in streamflow to climatic changes. However, two studies that examined streamflow trends in the United States yielded divergent results. Using streams for which anthropogenic and urbanization effects were minimal, the first study[31] found that increasing streamflow was most prevalent in the low and median flows and least prevalent for the high (*i.e.*, flood) flows. Decreases in streamflow were observed for parts of the Pacific Northwest and the Southeastern United States. They conclude, "hydrologically, these results indicate that the

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[30] 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.

[31] Lins, HF, and JR Slack (1999): Stream flow trends in the United States. Geophysical Research Letters, 26(2):227-230.

conterminous [United States] is getting wetter, but less extreme." The IPCC TAR largely relied on this study in its assessment for trends in the United States.

26. By contrast, a more recent study[32] reexamined streamflow in the United States and concluded that significant increases in streamflow have occurred, particularly for high (flood) flow events, which was consistent with their earlier analysis of trends in precipitation. They argued that increases in streamflow were most significant for the eastern half of the United States, although decreases in winter snow cover (due to rising air temperatures) explained why the western half has exhibited no increases in peak streamflow. While apparently contradictory, the discrepancy between these two studies is easy to explain: the two analyses answered different questions. The earlier study addressed the question 'Are trends occurring in the streamflow frequency distribution?' whereas the more recent study evaluated that 'Of the total volume of streamflow that has changed, how much of it came from a particular part of the frequency distribution?'[33] Since the annual peak flow can be two or three orders of magnitude larger than the annual minimum flow, the conclusions reached by the more recent study appear largely a result of the extreme skew in the streamflow frequency distribution. It is more correct to evaluate flow depth and not flow volume in this case. A recent assessment[34] reexamined the conclusions reached by the two studies and concurred with the earlier results. Analyses such as these underscore the difficulties in attributing streamflow trends to climate changes. Large changes that have occurred in the United States resulting from urban growth and management efforts substantially affect stream flow and undermine the ability to detect climate change signals.

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[32] Groisman, PYa, *et al.* (2001): Heavy precipitation and high stream flow in the contiguous United States: Trends in the twentieth century. Bulletin of the American Meteorological Society, 82:219-246.
[33] Lins, H.F. (2003): Personal communication, USGS, Reston, VA.
[34] McCabe, GJ, and DM Wolock (2002): A step increase in streamflow in the conterminous United States. Geophysical Research Letters, 29:2185–2188.

27. With respect to drought over the globe, a study[35] cited by the IPCC TAR used the Palmer Drought Severity Index (PDSI)[36] and found small increases in drought frequencies over the United States and an increase in moisture surplus as well. But the PDSI uses an extremely simple representation of the surface water balance and it is a relative index, in that drought and moisture surplus are standardized for each location. Streamflow response, for example, is underestimated as a result of an improper treatment of snowfall, frozen soil conditions, and the delay between precipitation and runoff. Thus, its interpretation should be weighed with caution. However, natural variability has produced drought frequencies and durations that are greater than what we experience today. In an assessment of paleoclimate records of drought in the United States that extends back some two millennia[37], the authors concluded, "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." Moreover, the current drought intensity in the western United States was similar to that during the mid-1950s and was actually less than that experienced in the early 1900s, at a time when conditions were cooler than at present and before increases in atmospheric greenhouse gas concentrations. The IPCC SPM, however, argues strongly that the risk of drought will become greater in the future, particularly in the continental interiors. But given the assessments of current trends in floods, droughts, and streamflow that argue against observed increases in extreme events and the lack of accuracy in model projections of present-day precipitation (let alone their questionable prognostications for changes in precipitation), assertions of changes in the frequencies of these variables resulting from climate changes appear erroneous.

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[35] Dai, A, *et al.* (1998): Global variations in droughts and wet spells: 1900-1995. Geophysical Research Letters, 25:3367-3370.

[36] A large value of the PDSI was defined by Palmer as "an interval of time, generally in months or years in duration, during which the actual moisture supply at a given place rather consistently falls short of the climatically expected or climatically appropriate moisture supply".

[37] Woodhouse, CA, and JT Overpeck (1998): 2000 years of drought variability in the central United States. Bulletin of the American Meteorological Society, 79:2693–2714.

28. The notion that increases in atmospheric trace gas concentrations will likely lead to 'an enhanced hydrologic cycle', with increased frequencies of floods and droughts, simply runs counter to our understanding of the climate system. It has been argued that with global warming, the earth's polar regions are likely to warm more than the tropics as a result of a number of factors, including the exposure of darker surfaces with the melting of snow and ice and the fact that cold, dry air warms more than warm, moist air with the same energy input. But global atmospheric circulation is driven by the difference in temperature between the pole and the equator. If that difference were to decrease significantly (as would happen under the global warming hypothesis), the global atmospheric circulation would decrease as a result. With the diminished transport of energy and moisture, this would decrease the frequency of heavy rainfall events and weaken atmospheric steering currents. Thus, I find that the notion of 'an enhanced hydrologic cycle' resulting from global warming – more floods, droughts, storms, and severe weather – to be contrary to the theory of climate. The fact that no significant trends have been observed in flood, tropical cyclone, tornado, and hail frequencies[38], despite an increase in air temperatures over the last century, is consistent with climate theory.

Arctic Warming, Sea Ice Extent, and Polar Bear Extinction

29. One of the most recent pronouncements regarding Arctic warming is the Arctic Climate Impact Assessment (ACIA)[39], which recently proclaimed that Arctic air temperature trends provide early and strong indication of global warming. The resultant melting of polar ice caps and glaciers, it is suggested, will directly lead to a rise in global sea levels. However, estimating the amount of surface warming and its cause relies on a scientific knowledge of natural and anthropogenic effects, including modification of the land surface and urbanization as well as the concentration of greenhouse

[38] See ¶16, ¶18, and ¶19.

[39] Arctic Climate Assessment (2004): Impacts of a warming Arctic. Cambridge University Press, Cambridge, UK.

gases. Moreover, Arctic climate varies dramatically from one region to another, and over time in ways that cannot be accurately reproduced by climate models. The quantitative impacts of natural and anthropogenic factors remain highly uncertain, especially for a region as complex as the Arctic. The ACIA report argues that an unprecedented Arctic warming has occurred. Current research and a detailed evaluation of the ACIA report, however, suggest that such a conclusion is not warranted. For example, it has recently been documented that coastal stations in Greenland are experiencing a cooling trend while average summer air temperatures at the summit of the Greenland Ice Sheet have decreased at the rate of 4°F (2.2°C) per decade since measurements began in 1987[40]. Moreover, this warming has occurred before, as is evidenced by ice corings on Baffin Island[41] and sea core sediments from the Chukchi Sea.[42] For example, in Alaska, the onset of a climatic shift in 1976-1977 ended the multi-decadal trend of cold in the middle of the 20th Century, returning temperatures to the warmth of the early 20th Century. It is unsurprising that Alaskan ecosystems have responded to this recent warmth that has the characteristic step-upward shape of natural variability, rather than the gradual but large warming trend as implied by the models. Such fluctuations typically represent the documented pattern of natural climate fluctuations extending back several centuries.

30. Three relatively recent long-term analyses of air temperature records for the Arctic region contradict the conclusions reached by the ACIA. However, the results of these three studies were not cited in the ACIA report, although they were readily available in the published literature. First, Russian records from coastal stations and both sea-ice extent and fast ice-thickness extending back 125 years show significant variability with significant fluctuations at temporal scales of 60 to 80

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[40] Chylek, P., *et al.* (2004): Global warming and the Greenland ice sheet. Climatic Change, 63:201-221.
[41] Grumet, N.S., *et al.* (2001): Variability of sea-ice extent in Baffin Bay over the last millennium. Climatic Change, 49:129-145.
[42] Darby, D., *et al.* (2001): New record shows pronounced changes in Arctic Ocean circulation and climate. EOS, Transactions, American Geophysical Union 82, 601, 607.

years[43]. Moreover, the air temperature maximum of 1938 was, in fact, warmer by nearly 0.4°F (0.2°C) than the air temperature for 2000. The study further suggests, "the high-latitude temperature increase was stronger in the late 1930s to the early 1940s than in recent decades" and it concludes that observations do "not support amplified warming in Polar Regions predicted by GCMs."

31. An earlier study[44] 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." Similarly, a comprehensive study[45] of Arctic air temperature data concluded that from 1951 to 1990, "no tangible manifestations of the [enhanced] greenhouse effect can be identified" although much inter-annual (year-to-year) variability was observed. The first step in this latter study was to identify properly the 'Arctic' using climatological, rather than astronomical, parameters. Defining 'the Arctic' based simply on a specific latitude band, the article demonstrates, creates a significant bias in that inclusion of data from outside the Arctic region can induce spurious trends. The study then demonstrates that for the Arctic, air temperatures were warmest in the 1930s while they were near the minimum for the observed period of record (since at least 1920) in the late 1980s. When data from mid-latitude stations that border the Arctic are included in the calculation of air temperature trends, the characteristic warming since the mid-1970s becomes evident. Thus, while lower and mid-latitudes of the Northern Hemisphere have warmed during the last thirty years, the Arctic region clearly has not – which runs counter to what GCMs predict should occur (see ¶26). Since the predicted warming of the models is greatest in the high latitudes, this study refutes their suggestions.

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[43] Polyakov, IV, *et al.* (2002): Observationally based assessment of polar amplification of global warming. Geophysical Research Letters, 29:10.1029/2001GL011111.

[44] Kahl, JD, *et al.* (1993): Absence of evidence for greenhouse warming over the Arctic Ocean in the past 40 years. Nature, 361:335-337.

[45] Przybylak, R (2002): Changes in seasonal and annual high-frequency air temperature variability in the Arctic from 1951-1990. International Journal of Climatology, 22:1017-1032.

32. The study goes further to compare observed data with gridded data (5° of latitude by 5° of longitude spatial averages) used by the IPCC for the same region. While the gridded data exhibits warming during the 1990s, the station data shows significant cooling has occurred since the mid-1980s. The study raises a concern in that the gridded data for the Arctic is contaminated with data from outside the Arctic, thus leading earlier research to obtain erroneous conclusions. This is troublesome as the gridded data presumably represent a spatial average obtained from observations. The caution is raised that "the quality of [gridded] data in its present state is significantly lower than the station data."

33. The study also lists several reasons why the observed warming for the globe is not greatest in the Arctic during the winter, contrary to what theory and climate models suggest. With the high reflectivity of Arctic snow and ice and its high thermal inertia, the study suggests more energy is required to warm an area in the Arctic by 1°F (0.6°C) than a similarly sized area in the tropics. But natural factors, such as atmospheric circulation variability or changes in solar output, may be far more important than the warming due to increasing greenhouse gas concentrations. The study notes that Arctic circulation was observed to shift during the mid-1970s, which corresponds with a lack of warming in the Arctic.

34. The global warming argument continues that warming in the Arctic will necessarily lead to decreased sea ice thickness and extent. In evaluating air temperature trends, however, the article discussed earlier also evaluated changes in Arctic sea ice using long-term data of fast-ice thickness and ice extent. The article concluded, "The analysis indicates that long-term trends are small and generally statistically insignificant." The IPCC TAR also indicates that the rate of sea level rise has not accelerated during the last century. Note that air temperature is not the only factor that dictates sea ice coverage and thickness. Sea ice is moved around the Arctic by the force of the wind; the phrase 'the wind sets the ocean in motion' applies to sea ice as well. When the Arctic is relatively

calm, it is easier for sea ice to form. During stormy periods, surface winds churn the water and move existing ice, making it more difficult for sea ice formation. This is one of the main reasons the article sites for a distinct lack of correlation between model prognostications and the observed response of the Arctic region. Moreover, the response of sea ice in the Antarctic has been quite different – while it has decreased in the Arctic, it has remained relatively constant (increasing slightly) in the Antarctic since 1978[46].

35. As a result of the apparent warming of the Arctic and the concomitant disappearance of sea ice, it often is concluded that polar bear populations (as well as other indigenous species) will be placed at significant risk.[47] Indeed, the ACIA report concludes, "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 was discussed above in ¶29, Arctic air temperatures were as high at present in the 1930s and polar bears survived. The data also run contrary to claims that anthropogenic increases in greenhouse gases are indirectly leading to decreasing bear populations. At present, the World Wildlife Fund (WWF) states that of about 20 distinct polar bear populations, only 17% are currently decreasing, whereas 46% are stable and 14% are increasing. A study commissioned by Canada's Department of Fisheries and Oceans[48] also examined the relationship between air temperature and sea ice coverage and concluded, "the possible impact of global warming appears to play a minor role in changes to Arctic sea ice." Rather, the study concluded it is the changing wind patterns that are the primary cause of changing sea ice distributions. Moreover, when the WWF report is compared with the Arctic air temperature trend study discussed earlier, a strong direct correlation exists between air temperature and polar bear populations; that is, areas for which polar bear populations are declining

[46] Cavalieri, DJ, *et al.*, Laboratory for Hydrospheric Processes, NASA Goddard Space Flight Center. (http://polynya.gsfc.nasa.gov/seaice_projects.html#image10).
[47] Norris, S, *et al.* (2002): Polar Bears at Risk. WWF International Arctic Programme. (http://www.worldwildlife.org/climate/polar_bears.pdf)
[48] Is Arctic sea ice rapidly vanishing? Fisheries and Oceans Canada - Pacific Region (http://www-sci.pac.dfo-mpo.gc.ca/osap/projects/jpod/projects/arc_thin/thin1.htm)

(*e.g.*, the Baffin Bay region) have experienced a decrease in air temperature while areas for which polar bear populations are increasing (*e.g.*, near the Bering Strait and the Chukchi Sea), are associated with increasing air temperatures. Thus it is difficult to argue that rising air temperatures will lead to a decrease in polar bear populations.

Sea Level Rise

36. Another often-cited impact of global warming is the rise in global levels of seawater. About half of the projected increase 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), while the remainder of the rise is attributed to melting of polar ice caps and glaciers.[49] In fact, sea levels experience a seasonal fluctuation – reaching a maximum in the early autumn and a minimum in early spring. This is because almost 90% of precipitation falling over land originated from water that evaporated from the oceans. During winter, this precipitation is stored on the land as snow, which only returns 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 they are in early autumn (little seasonal snow cover exists in the Southern Hemisphere).

37. However, with warmer temperatures in high latitudes comes the possibility for more snow since the amount of water vapor in saturated air increases with increasing air temperature. Antarctica is called a 'polar desert' because snowfall is extremely low (average annual precipitation at the South Pole Station is only 8mm per year), although since the temperature remains below freezing, the snow accumulates year after year. However, there exists a strong positive relationship between air temperature and snowfall such that there is more snowfall at coastal stations owing to the warmer temperatures and a proximity to the source of water (greater potential for moisture in the air and less

distance to transport it). Thus, it has been argued that a doubling of carbon dioxide in the atmosphere would remove 9.0 x 10^{14} liters of water from the world's oceans,[50] thereby mitigating some of the rise in sea levels. In the Northern Hemisphere, increased snowfall at cold, high latitudes could have a similar effect, particularly over the Greenland Ice Sheet where air temperatures are extremely cold. On the other hand, some areas on the snow cover margins might experience a decrease in snowfall as some snowfall occurrences become a rain event. Taking this into account and using GCM model prognostications of warming, the study estimated that there would be a small net snowfall increase in the Northern Hemisphere, thereby slightly offsetting the forecast sea-level rise. Thus, prognostications of future global sea levels depend on correctly simulating precipitation and snowfall patterns – something that climate models do not do well.

38. In the United States, concerns have been raised about sea-level rises along the California and Carolina coasts. A recent study[51] provided an evaluation of global sea level trends obtained from the Topex/Posidon satellite (1993 to 1998) and station observations (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). These 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 was estimated from –0.6 to –0.3 mm per year (satellite) and 2.1 to +2.8 mm per year (observations). When compared for the last six years of the record, the satellite and observational data are commensurate. This implies that although there has been a significant rise in sea level along the Carolina coast over the last 40 years, the rate has decreased dramatically during recent years – a pattern

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[49] Note that changes in sea ice will *not* affect sea levels because Archimedes principle states that 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.
[50] Ye, H, and JR Mather (1997): Polar Snow Cover Changes and Global Warming. International Journal of Climatology, 17:155–162.
[51] Cabanes, C., *et al.* (2001): Sea level rise during the past 40 years determined from satellite and in situ observations. Science, 294:840-842.

that runs counter to the global warming signal and suggests that factors other than global warming may contribute to rising sea levels in this region. Our knowledge of sea level fluctuations is relatively recent and certainly it cannot be inferred that sea levels have remained unchanged for nearly 6000 years (as suggested by the MacCracken Declaration). If true, this would assert that global air temperatures have no effect on sea level rise as the climate of the last millennium is charactized by significant warming (*i.e.*, the Medieval Warm Period) and cooling (*i.e.*, the Little Ice Age). It also is widely agreed that the climate warming of the altithermal (approximately 4000 years ago) contributed greatly to the rise of civilization. Noting that a single observation (*i.e.*, the roman baths in the MacCracken Declaration) is near its original level from 2000 years ago is not sufficient evidence, as it has been clearly evidenced that coastal sea level rise has exhibited considerable spatial variability in just the last fifty years; global sea level rise is not uniform.

Decreased Snow Cover

39. As discussed above, snowfall and air temperature tend to exhibit a direct relationship when temperatures are cold and an inverse relationship when temperatures are relatively warm.[52] Snow formation in the northern United States and in the high mountains requires cold air (below freezing), a supply of moisture, and a mechanism (rising air) to condense that moisture. It cannot be assumed that rising air temperatures will necessarily lead to decreased snow cover, as several recent studies focusing on temporal trends in snow cover have demonstrated. In an evaluation of several hundred stations in the United States Great Plains from 1910 to 1993, a generally increasing trend was found[53] in the number of days with snow cover, despite the increasing air temperature. More recently,

[52] Davis, RE, *et al.* (1999): A Climatology of Snowfall- Temperature Relationships in Canada. Journal of Geophysical Research, 104:11,985-11,994.
[53] Hughes, MG, and DA Robinson (1996): Historical snow cover variability in the Great Plains region of the USA: 1910 through to 1993. International Journal of Climatology, 16:1005-1018.

an assessment of satellite-derived snow cover extent for the Northern Hemisphere[54] shows no significant trend from 1978 to 2003. An assessment of North American snow cover extent from 1967 to 2004[55] shows no significant trend in snow cover for the winter (December to February) with a slight decrease in snow cover in spring (March to May). Given the mixed relationship between air temperature and snowfall, it is difficult to assess what might happen in the future. However, spring snow extent may decrease slightly but snowpack depth in the high mountains may actually increase due to the added moisture in warmer saturated air that is still below freezing.

<u>Adverse Effects on Coral Reefs</u>

40. 'Bleaching' of coral is often cited as evidence of damage caused by global warming. Indeed, coral has often been called a 'barometer of global warming'. Coral bleaching is a misnomer in that the coral do not change color because they are 'bleached' by solar radiation, but they lose their color because of the loss of a symbiotic relationship between algal species (which provides the color) and the coral. This can occur when water temperatures, pollutants, or sediments become too high. Without an algal symbiont, the coral will die in a few years. However, a recent study[56] argues that coral bleaching may simply be a mechanism to help corals survive environmental stress. In this study, several varieties of coral were subjected to changes in water temperature. Most of those that were moved to warmer waters bleached immediately whereas those that were moved to cooler waters did not. However, a year later it was discovered that those corals that had bleached were developing better than those that did not. Bleaching is a process that expels algae and the corals that bleached took up a symbiotic relationship with a new species of algae that were better suited to the new environment. The

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[54] Armstrong, RL, and MJ Brodzik (2001): Recent Northern Hemisphere snow extent: a comparison of data derived from visible and microwave sensors. Geophysical Research Letters, 28:3673-3676.
[55] Robinson, DA. Global Snow Lab, Rutgers University. http://climate.rutgers.edu/snowcover/
[56] Baker, AC, (2001): Reef corals bleach to survive change. Nature, 411, 765-766.

study concluded, "this counters conventional wisdom that bleaching is detrimental from all perspectives, and supports the role of symbionts as adaptive agents."

41. More recently, two additional studies have examined coral bleaching and concluded that it may be a beneficial response to stress. In one study[57], Caribbean corals were bleached and exposed to a number of algal species. Not only was a symbiotic relationship between the coral and algae reestablished, but also in some cases, the reestablished relationship was made with a new algal species that was better suited to the current environmental conditions. In the second study[58], it was found that reestablished symbiotic relationships vary depending upon whether the coral is an adult or a juvenile. They conclude 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. Thus, coral bleaching appears to be a mechanism to guarantee the survival and development of the species and not a harbinger of coral death.

Changes to Northeastern Forests

42. The Declaration of Mr. Arthur Berndt expresses concern about the loss of maple syrup production. Presumably, this is based on claims that by 2050, there will be an increase in the air temperature in New England from 6° to 10°F (3.3° to 5.6°C). However, using even one of the models cited by the MacCracken Declaration, the HadCM2, the March-May air temperature prognostication is for only a 3.5° to 5.5°F (2° to 3°C) temperature rise to occur by 2090, with a rise only about half that

[57] Lewis, CL, and MA Coffroth (2004): The acquisition of exogenous algal symbionts by an octocoral after bleaching. Science, 304:1490–1492.

[58] Little, AF, *et al.* (2004): Flexibility in algal endosymbioses shapes growth in reef corals. Science, 304:1492–1494.

by 2060. Based on the observations, the present increase in air temperature since the end of the Little Ice Age has resulted only in an earlier harvest – rates of production have not been affected.

43. Trends in maple syrup production do not support the conclusion that production has been decreasing and, in fact, the production appears linked to factors other than air temperature. It is assumed that maple syrup production is related to the January-to-April air temperature, with warmer temperatures resulting in diminished production. In a graph produced by the New England Regional Assessment, maple syrup production for the United States as a whole and Vermont in particular decreased from 1916 to the early 1980s and has remained relatively constant ever since. By contrast, maple syrup production in Canada increased nearly threefold since 1977. Plotted on the same graph is the regional trend in air temperature, which shows no trend at all from 1915 to 1998 and is virtually devoid of even decadal trends. The figure cites a correlation between air temperature and maple syrup production of –0.33, which means that air temperature accounts for only about 11% of the variability[59] in maple syrup production. Clearly, the demise in maple syrup production in the United States and Vermont, as well as the increase in Canadian production, must be linked to something other than air temperature changes.

<u>Links Between Greenhouse Gas Emissions and Severe Climatic Impacts are Tenuous</u>

44. Despite pronouncements of a 'scientific consensus', climatologists are still uncertain as to the likely impacts of increased atmospheric greenhouse gas concentrations. It has been well documented that trace gas concentrations, such as carbon dioxide, have been increasing, largely as a result of fossil fuel emissions. However, concentrations of methane and chlorofluorocarbons, other important atmospheric trace gases, have leveled off in recent years. Global atmospheric air temperatures have risen since about the mid-1800s, but the contribution of that rise from fossil fuel

emissions is still debatable – much of the warming occurred before significant increases in atmospheric trace gas concentrations and a dramatic downward trend in air temperatures was observed between the early 1960s and the mid-1970s (which led to the short-lived 'global cooling' scare). Attempts to connect this rise in air temperature to changes in other parts of the climate system are far more tenuous and conflicting scientific evidence often exists.

45. To support my conclusions of an uncertain or possible non-response of various components of the climate system to rising air temperatures, I have cited from a number of sources, including the IPCC TAR. These sources include a wide variety of researchers publishing in a number of peer-reviewed journals and spanning an array of climatic expertise. On the other hand, the IPCC SPM and the USNA, and particularly the latter because of its reliance on the most extreme models, largely are documents that favor dramatic scenarios. Unfortunately, they adversely affect the public's perception of the real science behind global warming. In the MacCracken Declaration, for example, it is argued that without controls, "atmospheric concentrations of greenhouse gases will continue to rise relatively rapidly throughout the 21st century, very likely exceeding concentrations seen over at least the last 10 million years." Such proclamations are overstated since they over-predict trends and may not account for the observed slowing in the rate of population growth. This leads to an overestimates of the future climatic response, particularly for North America, and, consequently, a more pessimistic view of the future.

46. Despite the overstated increases in greenhouse gas concentrations, the overarching problem associated with the MacCracken Declaration is its reliance on the most extreme climate model – the CGCM1 model. Of the more than two-dozen climate models that have been extensively evaluated and tested, the CGCM1 model produces the most extreme climate prognostication for the future and, more importantly, it is the only model that produces a warming that is exponentially

[59] The variance explained by the regression equals the square of the correlation coefficient; the New England Regional

increasing – all other models exhibit a warming trend to 2100 that is essentially linear. This is problematic because the regional assessments were charged with defining climate change impacts resulting from scenarios derived from this climate model. Prognostications of global warming for 2100 have decreased significantly since early modeling efforts – the myriad of models used for the IPCC TAR exhibit a range of warming between 2.7° and 5.4°F (1.5° and 3°C) for the equilibrium response to a doubling of CO_2. But the CGCM1 provides the most extreme scenario – with warming for the United States between 5.4° and 10°F (3° and 5.5°C) and an average of 8.1°F (4.5°C) by 2100 – which is more than twice the rise of 3.6°F (2.0°C) based on the HadCM2. Overall, the CGCM1 model showed that the United States should have warmed by 2.7°F (1.5°C) during the 20th Century, although the observed increase was only about 0.25°F (0.14°C)[60]. For precipitation, the HadCM2 and the CGCM1 produce two most extreme prognostications of changes for the United States, both of which are twice the prognostications of any other model and which are comparatively inconsistent.

47. Setting aside the question of whether current trends can be determined to be influenced by anthropogenic emissions of greenhouse gases, if we agree that such trends should continue – and all models except the CGCM1 exhibit a linear temporal response – global air temperatures should increase by 2.5°F (1.4°C) and air temperatures in the United States by about 1°F (0.6°C) during the 21st Century. Most of this warming should occur in the coldest winter air masses, while summer rainfall should increase slightly. In general, our climate has and will continue to exhibit intricate patterns not reliably reproduced by global climate simulations, thus underscoring their scientific incompleteness. Thus, a reliance on climate model projections of the future that are inherently flawed is unwise.

Assessment erroneously failed to square the correlation before reporting the explained variance.

60 Hansen, JE, *et al.* (1999): GISS analysis of surface temperature change. Journal of Geophysical Research, 104:30,997-31,022.

I declare under the penalty of perjury that the foregoing is true and correct to the best of my knowledge.

Executed on February 11, 2005, in Middletown, Delaware.

David R Legates

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

DAVID R. LEGATES, Ph.D, C.C.M — January 2005

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Research Interests

Climatology	*Computational Methods*
Hydroclimatology/Surface Water Hydrology	Statistical/Numerical Methods
Precipitation and Climate Change	Spatial Analysis and Spatial Statistics
Global and Regional Climatology	Digital/Numerical Cartography

Education

Ph.D. Climatology, University of Delaware, Newark, Delaware. Received: August 1988.
Dissertation: *A Climatology of Global Precipitation.*

M.S. Climatology/Geography, University of Delaware, Newark, Delaware. Received: June 1985.
Thesis: *Interpolation of Point Values from Isarithms*

B.A. Mathematics and Geography (Double Major), University of Delaware, Newark, Delaware.
Received: June 1982. Graduated: *Cum Laude.*

Professional Experience

1999–	Associate Professor, University of Delaware, Newark, DE. (2000–present: Associate Director, Delaware Space Grant Consortium) (2001–present: Director, Center for Climatic Research) (2001–present: Associate State Climatologist)
1998–1999	Associate Professor, Louisiana State University, Baton Rouge, LA.
1998–1999	Research Scientist, Southern Regional Climate Center, Baton Rouge, LA.
1994–1997	Associate Professor, University of Oklahoma, Norman, OK.
1995–1997	Chief Research Scientist, Center for Computational Geosciences, Norman, OK.
1995–	Vice President for Research, Computational Geosciences Inc., Norman, OK.
1995–1996	Visiting Associate Professor, University of Virginia, Charlottesville, VA.
1988–1994	Assistant Professor, University of Oklahoma, Norman, OK.
1991	Visiting Research Scientist, National Climatic Data Center, Asheville, NC.
1982–1988	Graduate Research Assistant, University of Delaware, Newark, DE.
1986–1987	University of Delaware Graduate Fellowship, University of Delaware, Newark, DE.
1984	Instructor, University of Delaware, Newark, DE.
1981–1982	Undergraduate Research Assistant, University of Delaware, Newark, DE.

Selected Awards, Grants, and Projects

2004	"Year Two State Funding for the Delaware Environmental Observing System", Delaware Emergency Management Agency, Principal Investigator (D.J. Leathers), $165,000.
2004–2005	"The Virginia Rainfall Monitoring and Analysis System", Virginia Office of Environmental Quality, co-Principal Investigator (P.J. Michaels, PI), $100,000.
2003–2004	"Development of a Real-Time System for Monitoring Weather Conditions in Kentucky", Kentucky Climate Center, Principal Investigator, $25,000.

2003	"Initial Deployment of the Delaware Environmental Observing System", Delaware Emergency Management Agency, Principal Investigator (D.J. Leathers), $165,000.
2003	"K-12 Educational Outreach Activities for DEOS", Delaware Space Grant Consortium, National Aeronautics and Space Administration, Principal Investigator, $7,600.
2002–2006	"Development of Bias-Corrected Precipitation Database and Climatology for the Arctic Regions", National Science Foundation, co-Principal Investigator (D. Yang, PI, and D.L. Kane), $300,000.
2002–2003	"Assessment of Road Surface Sensors for Use with DEOS", Delaware State Department of Transportation, Principal Investigator (D.J. Leathers), $13,000.
2002–2003	"Use of Calibrated WSR-88D Radar Estimates of Precipitation in Assessment of Nutrient Discharge on the Inland Bays of Delaware," Center for Inland Bays, co-Principal Investigator (T. DeLiberty, PI), $15,000.
2002	Awarded the *2002 Boeing Autometric Award for the Best Paper in Image Analysis and Interpretation* by the American Society of Photogrammetry and Remote Sensing.
2000	"WSR-88D Radar Precipitation Interface Client-Server", Duke Energy Corporation, Charlotte, North Carolina, co-Principal Investigator (K.R. Nixon, PI), $150,000.
2000	Awarded *Certified Consulting Meteorologist* status by the American Meteorological Society.
1999–2000	"Doppler Radar Irrigation Scheduling System: DRISS – Phase II", USDA Small Business Innovation Research Grant, United States Department of Agriculture, co-Principal Investigator (K.R. Nixon, PI), $230,000.
1999–2001	"Searching for Anthropogenic Climate Change Signals Using Non-Correlation-Based Approaches", National Oceanic and Atmospheric Administration and Department of Energy's Climate and Global Change Program, Principal Investigator (R.E. Davis and S.M. Robeson), $50,001.
1999–2002	"The Great Plains Regional Earth Science Applications Center (GP-RESAC): A Consortium to Transfer Remote Sensing Products and Technology to Support the Great Plains Agroecosystem", Regional Earth Science Applications Center, National Aeronautics and Space Administration, co-Principal Investigator (E. Martinko, PI, K. Price, and M.E. Jakubauskas), $75,000.
1999	"Monitoring Precipitation for the St. Johns River Watershed During June 1999", St. Johns River Water Management District, co-Principal Investigator (K.R. Nixon, PI), $5,000.
1998–1999	"Doppler Radar Irrigation Scheduling System: DRISS – Phase I", USDA Small Business Innovation Research Grant, United States Department of Agriculture, co-Principal Investigator (K.R. Nixon, PI), $65,000.
1998	Awarded the Alpha Lambda Delta Freshman Honor Society Award for Superior Instruction of Freshman Students -- Fall 1998. Louisiana State University.
1997–1998	"Development of an Intelligent Geographic Information System to Support Spatiotemporal Queries, Analysis, and Modeling in Hydrology", United States Department of Defense, National Imagery and Mapping Agency, University Research Initiatives (NURI), co-Principal Investigator (M. Yuan, PI, J. Canning), $596,919.
1997–2001	"Interaction Between Land Cover/Land Use Dynamics and Climatological Variability in the Western Oklahoma/Kansas/Texas Indicator Region", National Institute for Global Environmental Change, co-Principal Investigator (M.E. Jakubauskas, PI), $301,081.
1997–1998	"Expansion and Analysis of the Comprehensive Pacific Rainfall Data Base", National Oceanic and Atmospheric Administration's Climate and Global Change Program, co-Principal Investigator (M. Morrissey, PI), $163,740.

1997–1998	"Rapid Tornado Damage Assessment". Natural Hazards Research Applications and Information Center's Quick Response Research Program, Principal Investigator (with M.D. Biddle), $3000.
1995–1998	"Accuracy Assessment of the 4km x 4km Hourly WSR-88D GCIP Precipitation Data Using Raingage Measurements as Baseline Data", NOAA Climate and Global Change Program, co-Principal Investigator (M.L. Morrissey, PI, and C.E. Duchon), $244,000.
1995–1997	"Water Resource Decision Support System – Phase II". USDA Small Business Innovation Research Grant, United States Department of Agriculture, Consulting Hydroclimatologist (K.R. Nixon, PI), $208,000.
1995–1999	"Acquisition of Equipment to Create the Environmental Computing Applications System", National Science Foundation's Academic Research Infrastructure Program, co-Principal Investigator (with thirteen researchers at the University of Oklahoma, K.K. Droegemeier, PI), $580,000.
1995	University of Oklahoma nominee for an International Affairs Fellowship from the Council on Foreign Relations.
1994–1997	"WSR-88D Radar Precipitation Interface", Duke Power Company, Charlotte, North Carolina, co-Principal Investigator (K.R. Nixon, PI), $504,016.
1994	"Water Resource Decision Support System – Phase I", USDA Small Business Innovation Research Grant, United States Department of Agriculture, Consulting Hydroclimatologist (K.R. Nixon, PI), $50,000.
1993–1994	"Development of an Interdisciplinary GIS Teaching Laboratory", Instrumentation and Laboratory Improvement Program, National Science Foundation, co-Principal Investigator (G.L. Thompson, PI), $15,700.
1992–1994	"The Impact of Doubling Atmospheric Carbon Dioxide on Precipitation Frequency and Intensity in the Southern Great Plains Region", Bureau of Reclamation, United States Department of the Interior, Principal Investigator, $122,020.
1992–1995	"Surface Hydrology Research Cluster", EPSCoR program, National Science Foundation and the State of Oklahoma EPSCoR Program, co-Principal Investigator (with seven researchers at the University of Oklahoma and Oklahoma State University, T.H.L. Williams, PI), $871,335.
1992	University of Oklahoma nominee for the National Science Foundation's Presidential Faculty Fellow and Young Investigator Awards.
1991–1993	"Compilation of an Unbiased Precipitation Data Set and Its Use in the Evaluation of the Natural Variability and GCM-Simulated Climates for the United States", Climate Dynamics Division, National Science Foundation, Principal Investigator, $25,839.
1990–1991	Consultant to the Global Precipitation Climatology Project sponsored by the World Meteorological Organization at Deutscher Wetterdienst (German Weather Service).
1989	"An Objective Approach to the Selection of a Precipitation Frequency Distribution", Research Fellowship, University of Oklahoma, Principal Investigator, $5000.

Service on National and International Committees and Boards

Editor for Climatology, *Physical Geography*, 2002 – present.
Associate Editor, *Climate Research*, 2002 – present.
Senior Editor and Publisher, *Publications in Climatology*, 2004 – present.
Editorial Board, *Publications in Climatology*, 1999–2003.
Editorial Board, *The Professional Geographer*, 1998–2000.
Adjunct Scholar, National Center for Policy Analysis, 2001–present.
Research Fellow, The Independent Institute, 2003–present.

Treasurer, Delaware/Philadelphia Area Chapter of the American Meteorological Society, 2001–2004.
Panel Member, National Science Foundation, 2000–2002.
Vice President, Central Louisiana Joint Chapters of the American Meteorological Society and the National Weather Association, 1998–1999.
Member, Annual Meetings Program Committee, Association of American Geographers, 1996.
Chair, Climate Specialty Group, Association of American Geographers, 1994–1996.
Board of Directors, Climate Specialty Group, Association of American Geographers, 1992–1994.
National Expert, International Organizing Committee (OC) for the WMO Solid Precipitation Measurement Intercomparison Project, 1989–1993.

Membership in Professional Organizations and Honorary Societies

American Geophysical Union
American Meteorological Society
American Water Resources Association
Phi Beta Kappa
Phi Kappa Phi
Pi Mu Epsilon (Mathematics)

Refereed Publications

Legates, D.R., H.F. Lins, and G.J. McCabe (2005): Comments on "Evidence for Global Runoff Increase Related to Climate Warming" by Labat *et al. Advances in Water Resources*, forthcoming.

Mahmood, R., M. Meo, and D.R. Legates (2004): The Role of Soil Water Availability in Potential Rainfed Rice Productivity in Bangladesh: Applications of the CERES-Rice Model. *Applied Geography*, 24(2):139–159.

Soon, W.-H., D.R. Legates, and S.L. Baliunas (2004): Estimation and Representation of Long-Term (>40 year) trends of Northern-Hemisphere-gridded Surface Temperature: A Note of Caution. *Geophysical Research Letters,* **31**(3).

DeLiberty, T.L., and Legates, D.R. (2003). Interannual and Seasonal Variability of Modelled Soil Moisture in Oklahoma. *International Journal of Climatology,* **23**(9):1057–1086.

Mahmood, R., M. Meo, D.R. Legates, and M.L. Morrissey (2003). The CERES-Rice Model-Based Estimates of Potential Monsoon Season Rainfed Rice Productivity in Bangladesh. *The Professional Geographer*, **55**(2):259–273.

Soon, W.-H., S.L. Baliunas, C. Idso, S. Idso, and D.R. Legates (2003): Reconstructing Climatic and Environmental Changes of the Past 1000 Years: A Reappraisal. *Energy and Environment,* **14**:233–296.

Jakubauskas, M.E., D.R. Legates, and J.H. Kastens (2002). Crop Identification Using Harmonic Analysis of Time-Series AVHRR NDVI Data. *Computers and Electronics in Agriculture,* **37**(1–3):127–139.

Jakubauskas, M.E., D.L. Peterson, J.H. Kastens, and D.R. Legates (2002). Time Series Remote Sensing of Landscape-Vegetation Interactions in the Southern Great Plains. *Photogrammetric Engineering and Remote Sensing*, **68**(10):1021–1030.

Jakubauskas, M.E., D.R. Legates, and J.H. Kastens (2001). Harmonic Analysis of Time-Series AVHRR NDVI Data. *Photogrammetric Engineering and Remote Sensing*, **67**(4):461–470.

Legates, D.R. (2000). Real-Time Calibration of Radar Precipitation Estimates. *The Professional Geographer*, **52**(2):235–246.

Legates, D.R. (2000). Remote Sensing in Hydroclimatology: An Introduction to a Focus Section of *The Professional Geographer. The Professional Geographer*, **52**(2):233–234.

Jakubauskas, M.E., D.R. Legates, and J.H. Kastens (2000). Harmonic Analysis of Time-Series AVHRR NDVI Data for Characterizing US Great Plains Land Use/Land Cover. *International Archives of Photogrammetry and Remote Sensing*, **33**(B4):384–389.

Legates, D.R., and G.J. McCabe, Jr. (1999). Evaluating the Use of "Goodness of Fit" Measures in Hydrologic and Hydroclimatic Model Validation. *Water Resources Research*, **35**(1):233–241.

Davis, R.E., M.B. Lowit, P.C. Knappenberger, and D.R. Legates (1999). A Climatology of Snowfall-Temperature Relationships in Canada. *Journal of Geophysical Research*, **104**(D10): 11,985–11,994.

Komuscu, A.U., and D.R. Legates (1999). Effects of Rainfall Variability on Spatial Accumulation of Peak Runoff and Excess Runoff Depth: Little Washita River Basin, Oklahoma, USA. *Journal of Environmental Hydrology*, **7**, Paper 18, November.

Legates, D.R., K.R. Nixon, T.D. Stockdale, and G.E. Quelch (1998). Use of the WSR-88D Weather Radars in Rangeland Management. *Specialty Conference on Rangeland Management and Water Resources*, American Water Resources Association, 55–64.

Legates, D.R., and R.E. Davis (1997). The Continuing Search for an Anthropogenic Climate Change Signal: Limitations of Correlation-based Approaches. *Geophysical Research Letters*, **24**(18):2319–2322.

Legates, D.R. (1997). Comments on "Global and Terrestrial Precipitation: A Comparative Assessment of Existing Climatologies" — A Reply. *International Journal of Climatology*, **17**:779–783.

Legates, D.R., K.R. Nixon, T.D. Stockdale, and G.E. Quelch (1996). Soil Water Management Using a Water Resource Decision Support System and Calibrated WSR-88D Precipitation Estimates. *Symposium on GIS and Water Resources*, American Water Resources Association, 427–435.

Janowiak, J.E., P.A. Arkin, P. Xie, M.L. Morrissey, and D.R. Legates (1995). An Examination of the East Pacific ITCZ Rainfall Distribution. *Journal of Climate*, **8**(11):2810–2823.

Legates, D.R. (1995). Global and Terrestrial Precipitation: A Comparative Assessment of Existing Climatologies. *International Journal of Climatology,* **15**:237–258.

Groisman, P.Ya., and D.R. Legates (1995). Documenting and Detecting Long-Term Precipitation Trends: Where We Are and What Should be Done. *Climatic Change*, **31**:601–622.

McCabe, G.J., Jr., and D.R. Legates (1995). Relationships Between 700 hPa Height Anomalies and 1 April Snowpack Accumulations in the Western USA. *International Journal of Climatology*, **15**:517–530.

Legates, D.R., T.L. DeLiberty, and J.M. Salisbury (1994). Implications of Doubled Trace Gas Concentrations on Summer Precipitation Variability in the Southern Great Plains. *Symposium on the Effects of Human-Induced Changes on Hydrologic Systems*, American Water Resources Association, 755–762.

Groisman, P.Ya., and D.R. Legates (1994). Accuracy of Historical United States Precipitation Data. *Bulletin of the American Meteorological Society*, **75**(2):215–227.

Legates, D.R. (1993). The Effect of Domain Shape on Principal Components Analyses: A Reply. *International Journal of Climatology*, **13**:219–228.

Legates, D.R., and T.L. DeLiberty (1993). Measurement Biases in the United States Raingage Network. *Symposium on Geographic Information Systems and Water Resources*, American Water Resources Association, 547–557.

Legates, D.R., and T.L. DeLiberty (1993). Precipitation Measurement Biases in the United States. *Water Resources Bulletin*, **29**(5), 855–861.

Willmott, C.J., and D.R. Legates (1993). A Comparison of GCM-Simulated and Observed Mean January and July Global Surface Air Temperature. *Journal of Climate,* **6**:274–291.

Legates, D.R., and J.R. Mather (1992). An Evaluation of the Average Annual Global Water Balance. *Geographical Review*, **82**:253–267.

Legates, D.R., and C.J. Willmott (1992). A Comparison of GCM-Simulated and Observed Mean January and July Precipitation. *Global and Planetary Change*, **97**:345–363.

McCabe, G.J., Jr., and D.R. Legates (1992). General Circulation Model Simulations of Winter and Summer Sea-Level Pressures Over North America. *International Journal of Climatology*, **12**:815–827.

Legates, D.R. (1991). The Effect of Domain Shape on Principal Components Analyses. *International Journal of Climatology*, **11**:135–146.

Legates, D.R. (1991). An Evaluation of Procedures to Estimate Monthly Precipitation Probabilities. *Journal of Hydrology*, **122**:129–140.

Willmott, C.J., and D.R. Legates (1991). Rising Estimates of Terrestrial and Global Precipitation. *Climate Research*, **1**:179–186.

Legates, D.R., and C.J. Willmott (1990). Mean Seasonal and Spatial Variability in Gauge-Corrected, Global Precipitation. *International Journal of Climatology*, **10**(2):111–127.

Legates, D.R., and C.J. Willmott (1990). Mean Seasonal and Spatial Variability in Global Surface Air Temperature. *Theoretical and Applied Climatology*, **41**(1):11–21.

Legates, D.R., and C.J. Willmott (1986). Interpolation of Point Values from Isoline Maps. *The American Cartographer*, **13**(4):308–323.

Willmott, C.J., S.G. Ackleson, R.E. Davis, J.J. Feddema, K.M. Klink, D.R. Legates, J. O'Donnell, and C.M. Rowe (1985). Statistics for the Evaluation and Comparison of Models. *Journal of Geophysical Research*, **90**(C5):8995–9005.

Legates, D.R., and C.J. Willmott (1983). A Comparative Evaluation of Principal Components-Based and Information Theory Methods of Precipitation Regionalization. *Archives for Meteorology, Geophysics, and Bioclimatology, Series B*, **32**:381–394.

Book Chapters, Monographs, and Reports

Legates, D.R. (2005). Chapter 12–Climate and Water: Precipitation, Evapotranspiration, and Hydroclimatological Aspects. *Water for Texas*, Texas A&M University Press, 149–152.

Legates, D.R., S. Gopal, and P. Rogerson (2003). Mathematical Models and Quantitative Methods. *Geography in America at the Dawn of the 21st Century*. Oxford University Press, 442–457.

Rogers, J.C., J.A. Winkler, D.R. Legates, L.O. Mearns (2003). Climate. *Geography in America at the Dawn of the 21st Century*. Oxford University Press, 32–46.

Legates, D.R. (2000). A Brief Guide to the Global Climate Models Used in the National Assessment. The George C. Marshall Institute, 16pp.

Legates, D.R., and M.D. Biddle (1999). Warning Response and Risk Behavior in the Oak Grove – Birmingham, Alabama Tornado of 08 April 1998. Natural Hazards Research Application and Information Center, Final Report.

Legates, D.R. (1998). Applications of the Wind-Bias Assessments to Precipitation Data in USA and Global Archives. *WMO Solid Precipitation Measurement Intercomparison: Final Report*, B.E. Goodison *et al., eds.*, WMO Instruments and Observing Methods Report No. 67, WMO/TD-No.872, 73–75.

Legates, D.R. (1998). *Lab Exercises for Physical Geography: The Atmosphere.* Louisiana State University, Baton Rouge, Louisiana, 130pp. (Revised in 2000)

Legates, D.R., and D.C. Goodrich (1997). The Challenges We Face: Panel Discussion on Precipitation (edited by H.V. Gupta and S. Sorooshian). *Global Environmental Change and Land Surface Processes in Hydrology: The Trials and Tribulations of Modeling and Measuring*, S. Sorooshian, H.V. Gupta, and S.C. Rodda, *eds.*, NATO Advanced Science Institute on Global Environmental Change, Springer-Verlag, Berlin, 169–180.

Legates, D.R., and T.L. DeLiberty (1996). Precipitation in the Southern Great Plains: Observations and Model Simulations of Present-Day and Doubled Atmospheric CO_2 Concentrations. *Global*

Climate Change Response Program, United States Department of the Interior, Bureau of Reclamation, Denver, Colorado, 80pp.

Groisman, P.Ya., and D.R. Legates (1996). Documenting and Detecting Long-Term Precipitation Trends: Where We Are and What Should Be Done. *Long-Term Climate Monitoring by the Global Climate Observing System*, T.R. Karl, *ed.*, Kluwer Academic Publishers, The Netherlands, 471–492.

Legates, D.R., and C.J. Willmott (1995). Evaluating the Terrestrial Water Balance from the Historical Climate Record. *The Role of Water and the Hydrological Cycle in Global Change*, NATO ASI Series, Springer-Verlag, The Netherlands, 23–58.

Legates, D.R. (1994). Issues in the Interpolation of Spatially-Continuous Data. *Opportunities for Hydrological Data in Support of Climate Change Studies*, Internationales Hydrologisches Programm der UNESCO Operationelles Hydrologisches Programm der WMO in der Bundesrepublik Deutschland, Sonderheft 7, Koblenz, 199–206.

Legates, D.R. (1994). The Use of Precipitation Time-series in Hydrologic Analyses. *Opportunities for Hydrological Data in Support of Climate Change Studies*, Internationales Hydrologisches Programm der UNESCO Operationelles Hydrologisches Programm der WMO in der Bundesrepublik Deutschland, Sonderheft 7, Koblenz, 95–102.

Legates, D.R. (1993). *Lab Exercises for an Introduction to Physical Geography.* Custom Academic Publishing, Norman, Oklahoma, 130pp.

Legates, D.R., and G.J. McCabe, Jr. (1992). General Circulation Model Estimates of Regional Precipitation, in *Global Climate Change: Implications, Challenges and Mitigation Measures*, S.K. Majumdar *et al.*, eds., The Pennsylvania Academy of Science, 302–314.

Legates, D.R. (1989). A High-Resolution Climatology of Gage-Corrected, Global Precipitation, in *Precipitation Measurement,* B. Sevruk (ed.), Swiss Federal Institute of Technology and the World Meteorological Organization, 519–526.

Legates, D.R. (1987). A Climatology of Global Precipitation. *Publications in Climatology*, **40**(1), 84pp.

Legates, D.R. (1984). Interpolation of Point Values from Isarithms. *Publications in Climatology,* **37**(1), 66pp.

Invited Presentations

Boston University	Princeton University/GFDL	University of Alaska – Fairbanks
Deutscher Wetterdienst	Rutgers University	University of Arizona
Duke Energy Corporation	SUNY – Buffalo	University of Delaware
Gettysburg College	Tennessee Valley Authority (TVA)	University of Georgia
Indiana University	Texas A&M University	University of North Carolina
Louisiana State University	Towson University	University of Oklahoma
National Climatic Data Center		University of Virginia
Oklahoma State University		Virginia Tech University