SPECIAL PUBLICATION

GREENING EARTH SOCIETY

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IN DEFENSE OF CARBON DIOXIDE: A Comprehensive Review of Carbon Dioxide's Effects on Human Health, Welfare, and The Environment

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To my good friend & colleague John Passacantando.
Pat Michaels

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EXECUTIVE SUMMARY

A thorough examination of the peer-reviewed scientific literature reveals that the overwhelming weight of scientific evidence does not support the proposition that carbon dioxide can be "reasonably anticipated to cause or contribute to adverse effects on public health, welfare, or the environment." In fact, the balance of evidence is supportive of the opposite notion: Carbon dioxide increases will confer a net benefit on society.

In this report, we document the direct effects of carbon dioxide on human health, agriculture, natural vegetation and climate, as well as the indirect effects of carbon dioxide on living systems that are mitigated through climate change. We conclude that:

1) There is no direct effect of any anticipated level of atmospheric carbon dioxide on human health.

2) There is an overwhelming body of evidence that the direct effect of carbon dioxide on food production is highly positive.

3) The direct effect of carbon dioxide will enhance the growth of plants that use C3 photosynthesis (about 95 percent of all plants), and the indirect effect of climate warming will enhance the growth of plants that use the C4 photosynthetic pathway. The net result is that the current competitive balance is maintained and does not shift in the direction of one type over the other.

4) The direct effect of carbon dioxide protects plants from pollutants, oxidants, moisture stress and low light levels.

5) Carbon dioxide is currently increasing the vegetative biomass of the planet and has increased agricultural production by about 10 percent.

6) Even the most sophisticated climate model cannot adequately simulate today's climate.

7) The planet has warmed several times less than the predictions indicated, based upon models that served as the background for the United Nations Framework Convention on Climate Change.

8) Greenhouse warming is primarily a phenomenon of cold and/or dry airmasses.

9) Forecasts of future warming will have to be adjusted downwards to account for increased carbon dioxide sequestration, an overestimation of the direct heating caused by carbon dioxide, and a cessation of methane increase in the atmosphere.

10) Temperature variability is decreasing.

11) Drought frequency is either not changing or may be in fact decreasing in the United States.

12) Rainfall has increased slightly, but flooding streamflow has not.

13) Temperature extremes are decreasing, primarily by warming the coldest airmasses.

14) The only evidence for a change in hurricanes is a decline in maximum wind in the Atlantic Basin.

15) The magnitude of extratropical storms should not increase.

16) Anticipated sea level rise will be lower than the median estimates of the IPCC and not much different than values observed over some highly populated regions in the current century.

17) There is no consistent evidence linking global warming and an increase in the strength of El Niño.

18) The main cause for the spread of tropical diseases is infrastructural and not related to climate change.

19) Warming will reduce overall weather-related mortality.

In summary, the notion that an increase in atmospheric carbon dioxide will result in a net cost to society as a whole is simply unfounded. Far more compelling evidence exists to show that enhanced carbon dioxide levels result in a net benefit.

INTRODUCTION: CONSIDERING CARBON DIOXIDE

Can carbon dioxide (CO_2) be "reasonably anticipated to cause or contribute to adverse effects on public health, welfare, or the environment"? This question can only be answered by an examination of the individual areas in which carbon dioxide may, directly or indirectly, create a net negative impact on health, welfare, or the environment.

Direct effects of carbon dioxide include the impact on human health and agricultural supply. Indirect effects are those that arise as a result of climate change, such as the way temperature change may influence illness and mortality, and its impact on the incidence of extreme weather events. Ecosystem and agricultural changes, another indirect effect, can also be related to changes in the climate.

DIRECT EFFECTS OF CURRENT AND PREDICTED CARBON DIOXIDE LEVELS

Carbon dioxide is an essential ingredient in the cycle of life on Earth. Plants directly use carbon dioxide in the process of photosynthesis where, combined with water, it is converted into sugars and oxygen. Plants use the sugars to fuel their growth, and animals breathe in the oxygen, consume plant matter, and exhale carbon dioxide. In this way, plants and animals have co-evolved. The more CO_2 available, the better plants grow, and the CO_2 only directly becomes a problem to animal life, including humans, if atmospheric concentrations grow to toxic levels.

HUMAN HEALTH

At high concentrations, those above about 15,000 parts per million (ppm), CO_2 begins to have notable negative effects on the human body. Excessive amounts of blood-borne CO_2 produce acidosis, which can be fatal.[1,2] But it is impossible for this concentration to occur in the earth's atmosphere as a result of the combustion of fossil fuel; the

[1] Luft, U.C., et al., 1974. Respiratory gas exchange, acid-base balance, and electrolytes during and after maximal work breathing 15 mm Hg P_{ICO2}. In Nahas, G. and Shaefer, K.E. (Eds.) *Carbon Dioxide and Metabolic Regulations.* Springer-Verlag, New York, pp. 282–293.

[2] Schaefer, K.E., 1982. Effects of increased ambient CO_2 on human and animal health. *Experientia,* **38**, 1163–1168.

relationship between observed atmospheric concentrations and emissions would require an impossible burn rate to achieve this value.

Ice core measurements indicate that concentrations typical of the last 10,000 years are around 270 to 280 ppm. As a correlate of the rise of technological civilization, concentrations of carbon dioxide have risen by about 25 percent over the last 150 years to the current level of around 360 ppm.

Human beings simply do not have the foreseeable industrial capacity to bring atmospheric concentrations anywhere near the toxic 15,000 ppm level. The United Nations Intergovernmental Panel on Climate Change estimates that, with the maximum possible exponential increase in emissions and deforestation, concentrations still would be 15 times less than the toxic threshold by the year 2100.[3] Of course, even these attempts to predict technological behavior at the 100-year time horizon are highly speculative; the assumption that our energy system will even remain fossil fuel based is an open question, given technological histories of the last three centuries.

CROP YIELDS

There is an overwhelming body of evidence that the rising levels of atmospheric CO_2 are very favorable for the production of food. CO_2 acts as a fertilizer, increasing plant growth rate and biomass by increasing photosynthetic capacity. It increases plant water use efficiency and drought tolerance, as well as performance under low light conditions and high temperature conditions. It also increases plants' abilities to grow in the presence of environmental hazards imposed by soil alkalinity, mineral stress, atmospheric pollutants, and UV-B radiation.[4]

Sylvan Wittwer, chairman emeritus of the National Research Council's Board on Agriculture, has written the definitive review of the effect of carbon dioxide on crops. His book, *Food, Climate and Carbon Dioxide,* in terms of number of refereed scientific citations, is the single most comprehensive review of this subject. In his final section, Wittwer concludes:

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[3] Houghton, J.T., et al. (Eds.), 1996. *Climate Change 1995. The Science of Climate Change.* Cambridge: Cambridge University Press. (Hereafter referred to as IPCC, 1995)

[4] Wittwer, S.H., 1995. *Food, Climate, and Carbon Dioxide.* CRC Press, Boca Raton, p. 63.

> The debates on global warming and its magnitude will likely continue without resolution well into the 21st century...The effects of an enriched CO_2 atmosphere on crop productivity, in large measure, are positive, leaving little doubt as to the benefits for global food security.... Now, after more than a century, and with the confirmation of thousands of scientific reports, CO_2 gives the most remarkable response of all nutrients in plant bulk, is usually in short supply, and is nearly always limiting for photosynthesis...The rising level of atmospheric CO_2 is a universally free premium, gaining in magnitude with time, on which we can all reckon for the foreseeable future.[5]

Wittwer discusses hundreds of experiments that have confirmed that plant growth, total plant output, and the yields of all the major food crops (cereals, legumes, roots and tubers, sugar crops, fruits, and vegetables) have been enhanced by the rising levels of atmospheric CO_2. In his estimation, global agricultural output has increased 8 percent to 12 percent due solely to the rising levels of atmospheric CO_2 in the last 50 years.[6]

Enhanced Photosynthetic Capacity

An enhancement of atmospheric CO_2 levels increases the efficiency of photosynthesis, resulting in a marked reduction of plant respiration.[7] Using less energy in the respiration process means that more energy can be allocated into biomass accumulation. As far as agricultural crops are concerned, this results in increases in total dry weight, root growth, higher root/top ratios, leaf area, weight per unit area, leaf thickness, stem height, branching and seed, and fruit number and weight.[8] This makes for an increase in harvest index and marketable product, as well as an overall shortening of the growing season with earlier maturity—reducing both water and pesticide requirements, and expanding growth range.[9]

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[5] Ibid, p189–190.

[6] Wittwer, S.H., 1997. *State of the Climate Report*, New Hope Environmental Services.

[7] Wittwer, S.H., 1995. op. cit., p. 63.

[8] Ibid, p. 65.

[9] Ibid.

There are three types of plants, C3, C4, and Crassulaceous Acid Metabolism (CAM), categorized by the type of photosynthetic pathway they employ for using CO_2. Each of these plant types responds differently to CO_2 increases; thus it has been hypothesized that a competitive advantage might arise from increased CO_2 levels. Some people believe that as the CO_2 content of the air continues to rise, C3 plants (which comprise about 95 percent of all plant species and include most major crops except corn and sugar cane) will out-compete C4 plants (which comprise about 1 percent of plants, including corn, sugar cane, sorghum, millet, and some grasses), thereby driving many of them to extinction. They base their theory on the fact that C4 plants typically exhibit less of a CO_2-induced growth stimulation than C3 plants. CAM plants are mainly desert succulents that are agriculturally insignificant.

Poorter surveyed the literature in this area.[10] He found that C3 plants, on average, exhibited a 41 percent increase in growth, while C4 plants displayed a 22 percent stimulation, for a doubling of the air's CO_2 content. But conditions in these studies varied widely, and when those conditions are taken into account, the differences between C3 and C4 responses to enhanced carbon dioxide become much smaller.

C3 vs. C4 Competition

Many scientists have predicted that as the atmospheric CO_2 content continues to climb, Earth's mean air temperature will rise by a median value of 2.0°C in the next 100 years.[11] This is a subject of serious scientific contention discussed later in this report. But, given that all scientists believe that enhancing CO_2 will create some warming, how might this phenomenon influence the relative distributions of C3 and C4 plants?

Because they are so diverse, C3 plants can be found in nearly all environments on Earth; whereas C4 plants are typically relegated to hot and/or arid climates, such as those associated with tropical and desert regions, where they thrive as a consequence of unique biochemical and anatomical adaptations they possess.[12] One of these adaptations is their ability to increase the intracellular CO_2 concentration at the site of CO_2 fixation, which greatly reduces carbon

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[10] Poorter, H., 1993. Interspecific variation in the growth response of plants to an elevated and ambient CO2 concentration. *Vegetation*, **104/105**, 77–97.
[11] IPCC, 1995, p. 6.
[12] Ehleringer, J.R., et al., 1991. Climate change and the evolution of C4 photosynthesis. *Trends in Ecological Evolution*, **6**, 95–99.

losses from photorespiration, which can account for the "cannibalization" of up to 50 percent of recently fixed carbon in C3 plants.[13]

Although this CO_2 concentrating mechanism requires additional cellular energy to operate, its costs are more than offset by increased net carbon gains, relative to C3 plants. This provides C4 plants with a competitive advantage in environments with high air temperatures, such as are being predicted for Earth's future. In areas with cooler temperatures, however, C3 photorespiratory carbon losses decline and the additional energy required by C4 photosynthesis no longer provides C4 plants with an advantage over C3 species. Teeri and Stowe documented this temperature-driven phenomenon over two decades ago in a study of C4 grass distribution across North America.[14] They determined that the percentage of C4 grasses in local flora decreased with increasing latitude, actually going to zero for all locations within the Arctic Circle. In addition, they determined that C4 grass distribution in the continental United States was more strongly correlated ($r = 0.972$) with July daily minimum temperature than with any of the other 18 environmental variables they considered. Consequently, Teeri and Stowe concluded that "the warmer the nights, the greater the success of C4 taxa."[15]

Because nighttime temperatures in July have the greatest influence on C4 plant distribution, a little nocturnal warming could well stimulate their poleward expansion; and studies of land-based records have shown most of the 0.5°C warming observed in the last 100 years has occurred at night.[16] Consequently, with CO_2-induced warming, C4 plants should be able to persist in their current locations, and may even expand into regions where they do not now exist due to low night temperatures that occur there.

In summary, experimental data show elevated CO_2 levels favor C3 plants, while ecological studies show elevated temperatures favor C4 plants. Consequently, since the future Earth will experience both higher CO_2 levels and higher temperatures (especially at night, when it is most important for C4 plants), it is difficult to say which of these

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[13] Zelitch, I., 1992. Control of plant productivity by regulation of photorespiration. *Biological Science*, **42**, 510–516.

[14] Teeri, J.A. and Stowe, L.G., 1976. Climatic patterns and the distribution of C4 grasses in North America. *Oecologia* , **23**, 1–12.

[15] Ibid.

[16] Karl, T.R., et al., 1992. Global warming: Evidence for asymmetric diurnal temperature change. *Geophysical Research Letters*, **18**, 2252–2256.

phenomena may have the greater influence on competition between C3 and C4 plants. But, the compensative effects of CO_2 and night warming suggest little relative change.

Photosynthesis and Temperature Interactions

Concern has been expressed that global warming driven by elevated levels of atmospheric CO_2 will be so great that plants will need to migrate toward the poles or up mountainsides in order to remain within the climatic regimes to which they are currently adapted. If climate change is too rapid, they contend, plants will not be able to migrate fast enough to avoid extinction.

Such concerns are largely contradicted by basic plant physiological research. In a comprehensive analysis of 42 different experiments. Idso and Idso found that the percentage growth enhancement resulting from a 300 ppm increase in the air's CO_2 content actually rose with increasing air temperature, going from close to zero at 10°C to 100 percent at 38°C.[17] This increase in relative growth response arises from the fact that the growth-retarding process of photorespiration is most pronounced at high temperatures[18] but is effectively inhibited by atmospheric CO_2 enrichment.[19] So powerful is this effect of elevated CO_2, in fact, that the optimum temperature for plant growth and development has typically been found to rise with increasing levels of atmospheric CO_2.[20,21,22]

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[17] Idso, K.E. and Idso, S.B., 1994. Plant responses to atmospheric CO_2 enrichment in the face of environmental constraints: A review of the past 10 years' research. *Agricultural and Forest Meteorology,* **69**, 153–203.
[18] Hanson, K.R., and Peterson, R.B., 1986. Regulation of photorespiration in leaves: Evidence that the fraction of ribulose bisphosphate oxygenated is conserved and stoichiometry fluctuates. *Archives of Biochemistry and Biophysics,* **246**, 332–346.
[19] Grodzinski, B., et al., 1987. Partitioning and metabolism of photorespiratory intermediates. In: J. Biggins (Ed.), *Progress in Photosynthesis Research.* W. Junk, The Hague, The Netherlands, 645–652.
[20] McMurtric, R.E. and Wang, Y.-P., 1993. Mathematical models of the photosynthetic response of tree stands to rising CO2 concentrations and temperatures. *Plant Cell Environment,* **16**, 1–13.
[21] McMurtrie, R.E., et al., 1992. Modifying existing forest growth models to take account of effects of elevated CO_2. *Australian Journal of Botany,* **40**, 657–677.

This phenomenon was predicted by Long, who calculated from well-established plant physiological principles that the optimum growth temperatures of most C3 plants should rise by approximately 5°C for a 300 ppm increase in the air's CO_2 content.[23] And in a number of scientific studies that have experimentally evaluated this phenomenon,[24,25,26,27,28,29,30] a 300 ppm increase in atmospheric CO_2 has been found to cause the optimum plant growth temperatures of several C3 plants to rise by approximately 6°C.[31] It is also worth noting that the photosynthetic rates of these particular C3 plants were found to be nearly twice as great at their CO_2-enriched optimum temperatures as they were at their optimum temperatures under ambient CO_2 concentrations.[32] Consequently, not only would the predicted increases in atmospheric CO_2 and air temperatures not hurt Earth's vegetation, they would likely work synergistically to promote

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[22] Berry, J., and Bjorkman, O., 1980. Photosynthetic response and adaptation to temperature in higher plants. *Annotated Review of Plant Physiology,* **31**, 491–543.

[23] Long, S.P., 1991. Modification of the response of photosynthetic productivity to rising temperature by atmospheric CO_2 concentrations: Has its importance been underestimated? *Plant Cell Environment,* **14**, 729–739.

[24] McMurtrie, R.E., et al., 1992, op.cit.

[25] Stuhlfauth, T., and Fock, H.P. 1990. Effect of whole season CO_2 enrichment on the cultivation of a medicinal plant, *Digitalis lanata. Journal of Agronomy and Crop Science,* **164**, 168–173.

[26] Harley, P.C., et al., 1986. Use of an analytical model to study the limitations on net photosynthesis in Arbutus unedo under field conditions. *Oecologia,* **70**, 393–401.

[27] Jurik, T.W., et al., 1984. Short-term effects of CO_2 on gas exchange of leaves of bigtooth aspen (*Populus grandidentata*) in the field. *Plant Physiology,* **75**, 1022–1026.

[28] Seeman, J.R., et al., 1984. Photosynthetic response and adaptation to high temperature in desert plants. A comparison of gas exchange and fluorescence methods for studies of thermal tolerance. *Plant Physiology,* **75**, 364–368.

[29] Nilsen, S., et al., 1983. Effect of CO_2 enrichment on photosynthesis, growth and yield of tomato. *Science and Horticulture,* **20**, 1–14.

[30] Bjorkman, O., et al., 1978. Thermal acclimation of photosynthesis: Effect of growth temperature on photosynthetic characteristics and components of the photosynthetic apparatus in *Nerium oleander.* Carnegie Institute: Washington Yearbook, **77**, 262–276.

[31] Idso, K.E. and Idso, S.B. 1994, op. cit.

[32] Ibid.

its growth and development, as ever more investigations continue to demonstrate.[33,34,35,36]

It may be stated with confidence that the experimentally observed rise in optimum C3 plant growth temperature caused by a doubling of the air's CO_2 content is even larger than the air temperature rise predicted to result from co-occurring CO_2-induced global warming.[37] Consequently, it is clear that any such warming would not adversely affect the vast majority of Earth's plants; for fully 95 percent of them are of the C3 variety.[38] In addition, the remainder of the planet's species—which may not experience quite as large a CO_2-induced rise in optimum temperature[39]—are already adapted to Earth's warmer climates,[40,41,42] which are expected to warm much less than other portions of the globe.[43]

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[33] Reddy, K.R., et al., 1998. Interactions of CO_2 enrichment and temperature on cotton growth and leaf characteristics. *Environmental and Experimental Botany,* **39**, 117–129.

[34] Vu, J.C.V., Allen, L.H., Jr., Boote, K.J. and Bowes, G., 1997. Effects of elevated CO_2 and temperature on photosynthesis and Rubisco in rice and soybean. *Plant Cell Environment,* **20**, 68–76.

[35] Nijs, I. and Impens, I., 1996. Effects of elevated CO_2 concentration and climate-warming on photosynthesis during winter in Lolium perenne. *Journal of Experimental Botany,* **47**, 915–924.

[36] Wang, K.-Y., 1996. Canopy CO_2 exchange of Scots pine and its seasonal variation after four-year exposure to elevated CO_2 and temperature. *Agricultural and Forest Meteorology,* **82**, 1–27.

[37] IPCC, 1995.

[38] Bowes, G., 1993. Facing the inevitable: Plants and increasing atmospheric CO_2. *Annotated Review of Plant Physiology and Plant Molecular Biology,* **44**, 309–332.

[39] Chen, D.-X., Coughenour, M.B., Knapp, A.K. and Owensby, C.E., 1994. Mathematical simulation of C4 grass photosynthesis in ambient and elevated CO_2. *Ecological Modeling,* **73**, 63–80.

[40] Johnson, H.B., Polley, H.W. and Mayeux, H.S., 1993. Increasing CO_2 and plant-plant interactions: Effects on natural vegetation. *Vegetation,* **104–105,** 157–170.

[41] Drake, B.G., 1989. Photosynthesis of salt marsh species, *Aquatic Botany,* **34**, 167–180.

[42] De Jong, T.M., Drake, B.G. and Pearcy, R.W., 1982. Gas exchange responses of Chesapeake Bay tidal marsh species under field and laboratory conditions. *Oecologia,* **52**, 5–11.

[43] IPCC, 1995.

Even at the highest air temperatures encountered by plants, in fact, atmospheric CO_2 enrichment is still to be desired; for it can often mean the difference between their living or dying,[44,45] as elevated CO_2 typically enables plants to maintain positive carbon exchange rates in situations (such as very hot environments) where plants growing under ambient CO_2 concentrations exhibit negative growth rates that ultimately lead to their demise.[46,47]

It is abundantly clear from a large body of detailed scientific investigations that a CO_2-induced warming would not produce a massive poleward or up-slope migration of plants seeking cooler weather; for the temperatures at which nearly all plants perform at their optimum would rise even higher than the temperatures of their respective environments under such conditions. Indeed, elevated levels of atmospheric CO_2 will enable most plants to not only cope with predicted air temperature increases, but to thrive in their presence, performing even better than they do today.

Plant Cooperation and Carbon Dioxide Enhancement

Simard et al. studied nutrient transfer among trees in a temperate forest, discovering that nutrients are passed along a complex network of fungal mycelium from trees that have an abundance of nutrients at their disposal to those that are lacking them, regardless of species.[48] This finding suggests that competition among plants may not play as great a role in natural ecosystems as has been believed in the past, as

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[44] Idso, S.B., 1997. The poor man's biosphere, including simple techniques for conducting CO_2 enrichment and depletion experiments on aquatic and terrestrial plants. *Environmental and Experimental Botany,* **38**, 15–38.
[45] Rowland-Bamford, A.J., et al., 1996. Interactions of CO_2 enrichment and temperature on carbohydrate accumulation and partitioning in rice. *Environmental and Experimental Botany,* **36,** 111–124.
[46] Idso, S.B., Idso, K.E., Garcia, R.L., Kimball, B.A. and Hoober, J.K. 1995. Effects of atmospheric CO2 enrichment and foliar methanol application on net photosynthesis of sour orange tree (*Citrus aurantium; Rutacea*) leaves. *American Journal of Botany*, **82**, 26–30.
[47] Idso, S.B., et al., 1989. Atmospheric CO_2 enrichment enhances survival of Azolla at high temperatures. *Environmental and Experimental Botany,* **29**, 337–341.
[48] Simard, S.W., et al., 1997. Net transfer of carbon between ectomycorrhizal tree species in the field. *Nature,* **388**, 579–582.

this nutrient-sharing phenomenon would appear to promote species coexistence and greater biodiversity. Enhancement of root systems improves this capability.

It is also well documented that elevated levels of atmospheric CO_2 enhance below-ground growth and stimulate the root activities of most plants.[49,50,51,52,53,54] One such CO_2-enhanced process is the exudation of nutrients and carbon compounds,[55] which stimulates microbial and fungal activities in the vicinity of plant roots.[56,57,58,59,60] Consequently, as the air's CO_2 content continues to rise, it should lead to the

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[49] King, J.S., et al., 1996. Growth and carbon accumulation in root systems of *Pinus taeda* and *Pinus ponderosa* seedlings as affected by varying CO_2, temperature and nitrogen. *Tree Physiology*, **16**, 635–642.

[50] Prior, S.A., et al., 1995. Free-air carbon dioxide enrichment of cotton: Root morphological characteristics. *Journal of Environmental Quality*, **24**, 678–683.

[51] Curtis, P.S., et al., 1994. Above- and belowground response of *Populus grandidentata* to elevated atmospheric CO_2 and soil N availability. *Plant Soil*, **165**, 45–51.

[52] Norby, R.J., 1994. Issues and perspectives for investigating root responses to elevated atmospheric carbon dioxide. *Plant Soil*, **165**, 9–20.

[53] Idso, S.B. and Kimball, B.A., 1992. Seasonal fine-root biomass development of sour orange trees grown in atmospheres of ambient and elevated CO_2 concentration. *Plant Cell Environment*, **15**, 337–341.

[54] Curtis, P.S., et al., 1990. Elevated atmospheric CO2 effects on below ground processes in C3 and C4 estuarine marsh communities. *Ecology*, **71**, 2001–2006.

[55] Rogers, H.H., et al., 1992. Response of plant roots to elevated atmospheric carbon dioxide. *Plant Cell Environment*, **15**, 749–752.

[56] Lazarovits, G., and Nowak, J., 1997. Rhizobacteria for improvement of plant growth and establishment. *Horticultural Science*, **32**, 188–192.

[57] Ringelberg, D.B., et al., 1997. Consequences of rising atmospheric carbon dioxide levels for the below-ground microbiota associated with white oak. *Journal of Environmental Quality*, **26**, 495–503.

[58] Tingey, D.T., et al., 1996. Effects of elevated CO_2 and nitrogen on the synchrony of shoot and root growth in ponderosa pine. *Tree Physiology*, **16**, 905–914.

[59] Pregitzer, K.S., et al., 1995. Atmospheric CO_2, soil nitrogen and turnover of fine roots. *New Phytologist*, **129**, 579–585.

[60] Lamborg, M.R., et al., 1983. Microbial effects. In Lemon, E.R. (Ed.) *CO_2 and Plants: The Response of Plants to Rising Levels of Atmospheric Carbon Dioxide*. Westview Press, Boulder, pp. 131–176.

development of ever better mycelial networks for distributing nutrients among plants, enhancing their transfer from the "haves" to the "have-nots," including both C3 and C4 species. Further, this observation calls the whole concept of competition into question, suggesting that cooperation may be the more fitting term to describe interspecies interactions in a future world of higher CO_2.

Considered in their entirety, these observations provide no substantive basis for believing that C3 plants will out-compete C4 plants and drive any portion of them to extinction as the air's CO_2 content continues to rise. If anything, they point to the tantalizing possibility that both types of plants will fare even better in the future than they do now, and that they may actually help each other to some degree as opportunities for cooperation among species increase with increasing root growth and fungal networking in the below-ground environment in response to the rising carbon dioxide content of the atmosphere.

Increased Water Use Efficiency

Another important plant phenomenon associated with the rising levels of atmospheric CO_2 is the increase in plants' water-use efficiency. Water stress is the single greatest factor limiting global food production. Therefore, by increasing plants' ability to make best use of the available moisture supply, CO_2 directly enhances plant growth.[61]

CO_2 improves water use efficiency by closing down the pores (stomates) through which plants lose moisture. Idso and Idso found that when plants received inadequate water, the percent growth enhancement from CO_2 became even greater than for well-watered plants. The relative enhancement for well watered plants was 31 percent, while for moisture stressed plants it was 62 percent, a twofold increase.[62] Plants increase their fine root mass—which increases the ability to ingest water—at higher CO_2 concentrations.[63,64]

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[61] Wittwer, S.H., 1995, op. cit., p. 70.

[62] Idso, K.E., and S.B. Idso, 1994, op. cit.

[63] Idso, S.B., and B.A. Kimball, 1991. Effects of two and a half years of atmospheric CO_2 enrichment on the root density distribution of three year-old sour orange trees. *Agricultural and Forest Meteorology*, **55**, 345–349.

[64] Curtis, P.S., et al., 1990. Elevated atmospheric CO_2 effects on below ground processes in C3 and C4 estuarine marsh communities. *Ecology*, **71**, 2001–2006.

One of the implications of increased water-use efficiency is that plants grown under higher temperatures (which increases moisture stress by increasing evaporation) should also experience a relative enhancement of growth as carbon dioxide increases as we have previously discussed.

Countering the Effects of Other Environmental Stresses

Volin et al. studied the interactive effects of elevated CO_2 and ozone (O_3) on the growth of C3 and C4 species.[65] In general, plants grown at ambient CO_2 manifested lower growth and photosynthetic rates at elevated O_3 than they did at reduced O_3 concentrations. However, the deleterious effects of high ozone concentrations were reduced, and in some cases even eliminated, when plants were exposed to elevated levels of CO_2. This amelioration occurred irrespective of plant photosynthetic pathway or growth form, demonstrating that both C3 and C4 plants should better withstand the deleterious effects of this and other forms of air pollution as the atmospheric CO_2 concentration continues to increase.

Other air pollutants, such as nitrogen and sulfur oxides, have known negative effects on plant growth.[66,67,68] Averaged across a number of studies, Idso found that the percentage increases in plant growth from elevated CO_2 were generally greater in the presence of these species. The mechanism may be similar to the one that increases water efficiency, with closing of the stomates restricting the access of pollutants to sensitive plant tissues.[69]

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[65] Volin, J.C., et al., 1998. Elevated carbon dioxide ameliorates the effects of ozone on photosynthesis and growth: species respond similarly regardless of photosynthetic pathway or plant functional group. *New Phytologist*,**138**, 315–325.

[66] Unsworth, M.H. and D.P. Ormrod (Eds.), 1982. *Effects of Gaseous Air Pollution in Agriculture and Horticulture*. Butterworth, London.

[67] Heck, W.W., Taylor, O.C. and D.T. Tingey (Eds.), 1988. Responses of crops to air pollutants. *Environmental Pollution*, **53**, 1–478.

[68] Darrall, N.M., 1989. The effect of air pollution on physiological processes in plants. *Plant and Cellular Environment*, **12**, 1–30.

[69] Idso, K.E., 1995. Rising CO_2: A breath of new life for the biosphere. *World Climate Review*, **3(3)**, 8–15.

Elevated carbon dioxide also induces enhanced plant growth at low light levels according to Idso and Idso.[70] Doubling the concentration results in more than a doubling of plant growth at low light, compared with concentrations that existed in the atmosphere before the combustion of fossil fuels.

The Historical Record of Crop Yields

It is clear from an overwhelmingly large number of scientific studies that rising atmospheric CO_2 levels are a net benefit to agriculture and crop production. Figure 1 shows the combined global yield on the major foods crops for the last half-century as well as the global temperatures. It indicates that regardless of the temperature, food production has increased steadily.

In the United States, the picture is much the same. Figure 2 shows the historical record of soybean yields in Illinois, a large producer of this crop, as well as the temperature history there during the past three-quarters of a century. Figure 3 shows the same for corn in Iowa and Figure 4 shows wheat yields in Kansas.

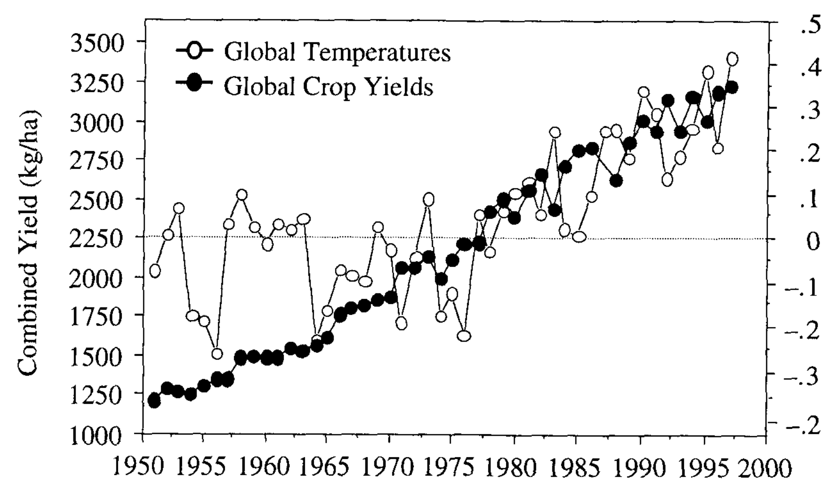

Figure 1. Over the past 50 years, global crop yields have increased steadily, whether it has been warming or not.

[70] Idso, K.E., and S.B. Idso, 1994, op. cit..

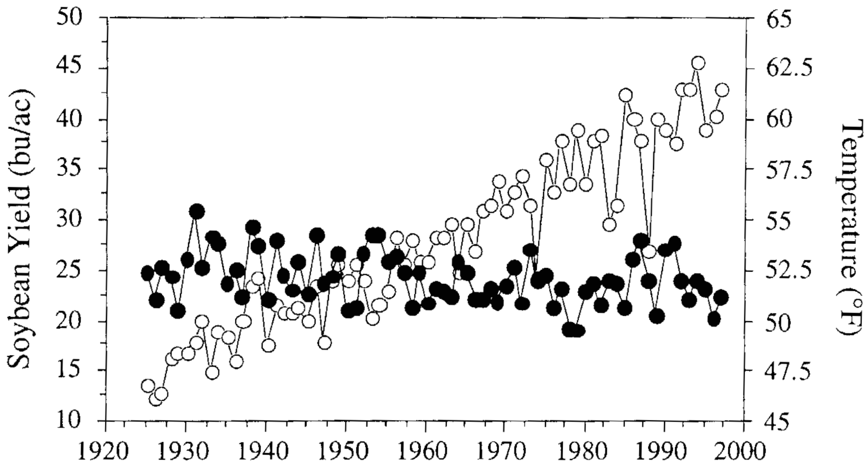

Figure 2. Soybean yields in Illinois (open circles) have been steadily rising over the past 75 years, while temperatures (solid circles) there have declined.

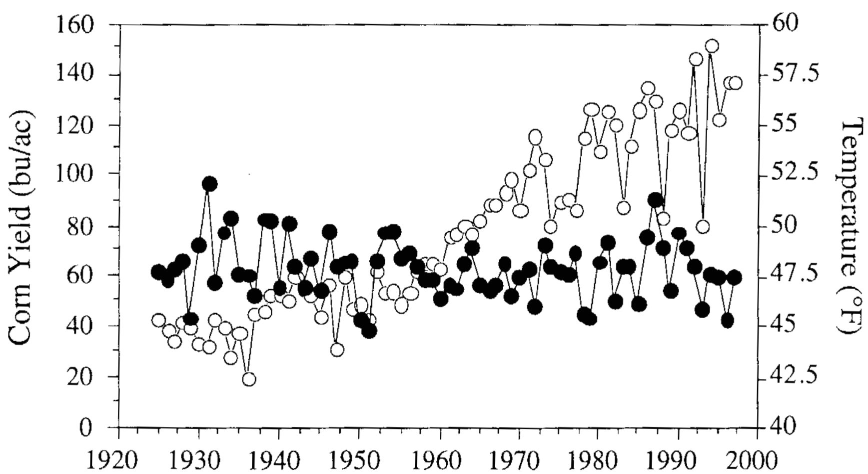

Figure 3. Corn yields in Iowa (open circles) have been steadily rising over the past 75 years, while temperatures (solid circles) exhibit no significant change.

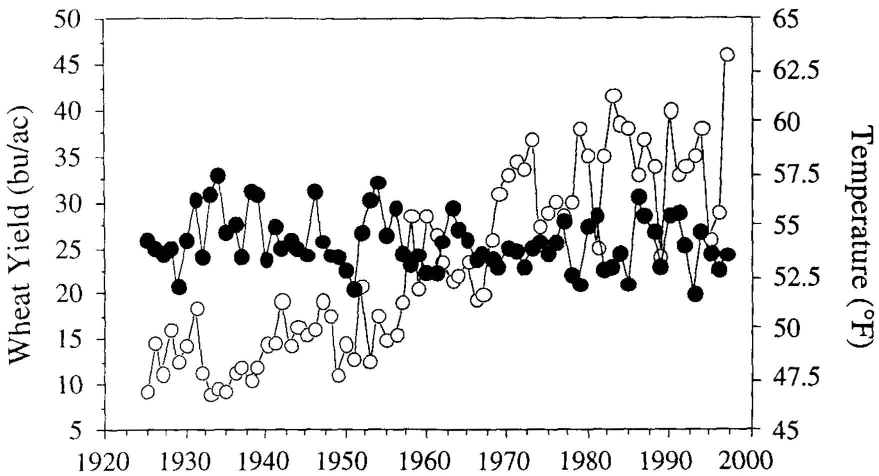

Figure 4. Wheat yields in Kansas (open circles) have been steadily rising over the past 75 years, while temperatures (solid circles) there show no significant change.

Everywhere, the picture is the same. Yields increase primarily as a result of technology but, undoubtedly, elevated atmospheric CO_2 levels have helped as well. Temperatures have not changed (or even declined in Illinois) during this period.

It should be considered good fortune that we are living in a world of gradually increasing levels of atmospheric CO_2. The effects of the increasing atmospheric level of CO_2 on the enhancement of food production are far more important than any putative change in climate. Elevated levels of atmospheric CO_2 also provide a cost-free environment for the conservation of water, which is rapidly becoming another of the world's most limited natural resources, the majority of which is now used for crop irrigation. According to Wittwer: "Unlike other natural resources (land, water, energy) essential for food production, which are costly and progressively in shorter supply, the rising level of atmospheric CO_2 is a universally free premium gaining in magnitude with time on which we can all reckon for the future."[71] And we are enjoying it in the present. Wittwer states that, "Globally it is estimated that overall crop productivity has already been increased by 10 percent because of CO_2."[72]

[71] Wittwer, S., 1997, op cit.

[72] Ibid.

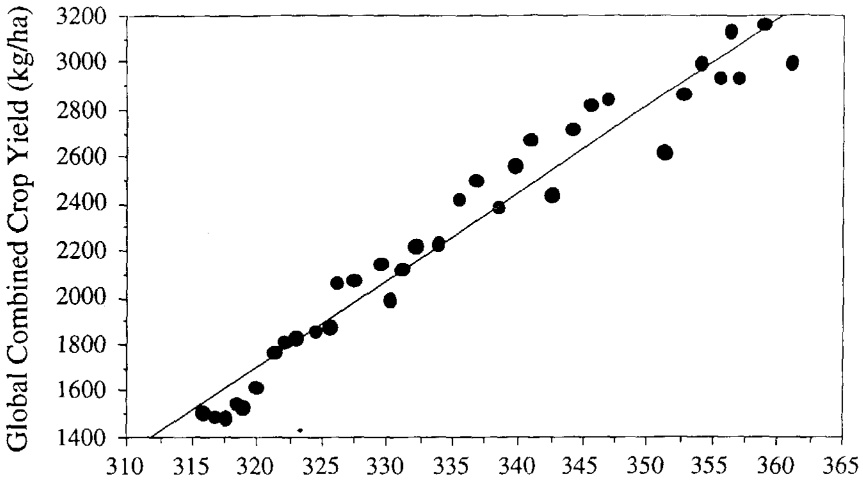

Figure 5. There is a strong statistical relationship between global crop yields and atmospheric carbon dioxide concentration.

Figure 5 shows the extremely strong statistical relationship between atmospheric carbon dioxide and global crop yields. While much of the increase in yields with time has been driven by changes in technology, Wittwer's previous statement that approximately 10 percent of the increase is directly related to CO_2 is undoubtedly true because of the nature of the change in yield. The temporal increases in Figure 1 are due in part to increases in nitrogen fertilizer, genetic and mechanical improvements, and tillage practices. But none of those variables is changing in such a smooth fashion over time. The *only* agricultural input that changes in such a fashion is carbon dioxide.

Further indirect evidence for CO_2 enrichment of agricultural yields is shown in Figure 6, which shows CO_2 concentrations measured at Mauna Loa since record taking began in 1958. The annual cycle in the data is the planetary greening that takes place every year as a result of the dominance of vegetation in the Northern Hemisphere. Inset in Figure 6 is the history of the amplitude of that cycle. Clearly, as CO_2 increases in the atmosphere, an increased greening of the natural vegetation results. Agricultural plants behave no different than others with respect to their uptake of CO_2—they *must* be experiencing the same annual growth enhancement as does the rest of the world's vegetation.

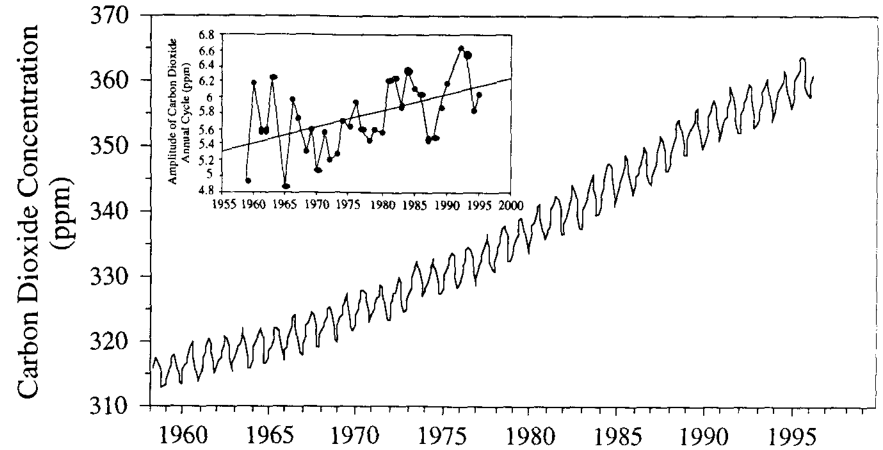

Figure 6. The atmospheric concentration of carbon dioxide shows an annual cycle due to the uptake of carbon dioxide by plants during the Northern Hemisphere summer. Inset: The amplitude of the annual cycle is increasing indicating that plants are taking up more carbon dioxide, i.e., they are growing better.

INDIRECT EFFECTS OF CURRENT AND PREDICTED CARBON DIOXIDE LEVELS

Besides the direct effect on human health and agriculture, carbon dioxide increases in the atmosphere can have an indirect effect through CO_2-induced climate change. In order for this climatic effect to constitute a negative influence on health, welfare, and the environment, the climate has to change in a fashion that significantly increases such a likelihood.

Regional climate changes are what influence people, agriculture and the environment. There is only one way that the future climate, as modified by carbon dioxide, can be projected on a regional basis: through the use of computer models (called General Circulation Models, GCMs). If these GCMs are invalid, so are all their projections, and so are the projected impacts of climate change on health and welfare.

In fact, we do not have climate models that are capable of replicating today's climate. An entire issue of a recent *Journal of Climate* was devoted to the newest ("CCM3") GCM of the U.S. National Center for Atmospheric Research. In Northern Hemisphere summer, the difference between observed temperatures and those calculated by the model is more than two standard deviations from the calculated average for approximately 75 percent of the entire land area.[73] Statistically, this means that the model says *today's* temperatures are either in the lowest 2.5 percent of all observations or in the highest 2.5 percent. In other words, almost everywhere it is *currently* either too hot or too cold to grow our crops. The regions where this error is currently being made are shown in Figure 7. Any scenario of negative impact on world food supply as a result of climate change that is based upon this, the most sophisticated model, is simply unreliable.

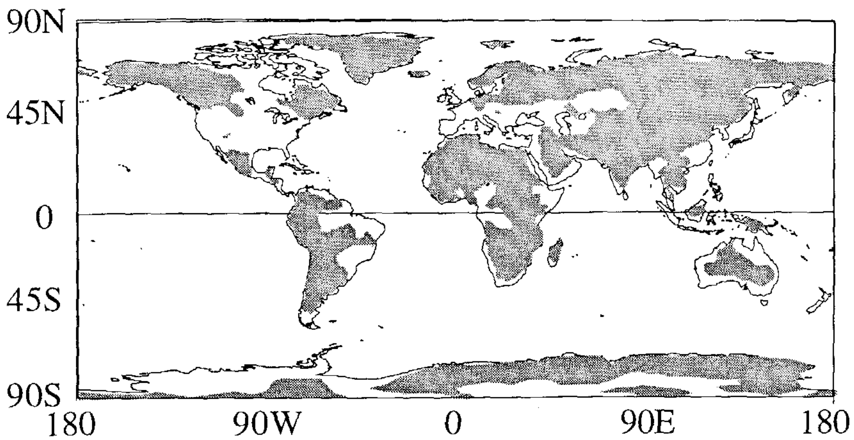

Figure 7. The shaded areas are locations where the current average temperature is more than two standard deviations from the model mean for that location. Note that ocean areas were not included in this analysis.

Because of this inability to accurately model today's climate, projections for changed temperatures under conditions of enhanced carbon dioxide generated by GCMs represent the *difference between computer models*, not the difference between the projected temperature and what is (or was) observed. The GCM is first run with the pre-industrial concentration of carbon dioxide and then with a changed value, usually a doubling of the background or a gradually increasing value. The projected temperature change is the difference between the background model and the model with changed carbon

[73] Bonan, G.B., 1998. The land surface climatology of the NCAR land surface model coupled to the NCAR community climate model. *Journal of Climate*, **11**, 1307–1326.

dioxide. The background model is producing errors that are larger than most projected climate changes! We must keep this in mind when assessing all future scenarios that are based upon GCMs.

MODELED VS. OBSERVED TEMPERATURE CHANGE

General Circulation Model Projections

A range of GCM model output provides the basis for climate change projections made by the United Nations Intergovernmental Panel on Climate Change (IPCC). In their First (1990) Assessment of climate change, the IPCC stated that "when the latest atmospheric models are run with the present atmospheric concentrations of greenhouse gases, their simulation of climate is generally realistic on large scales."[74] Were these models really "generally realistic?" As Mitchell et al. later showed, the most popular type of climate model to which the IPCC's statement referred predicted that, by now, the earth's temperature should have warmed between 1.3°C and 2.3°C (the larger figure for the Northern Hemisphere), as a result of anthropogenerated greenhouse gas changes.[75]

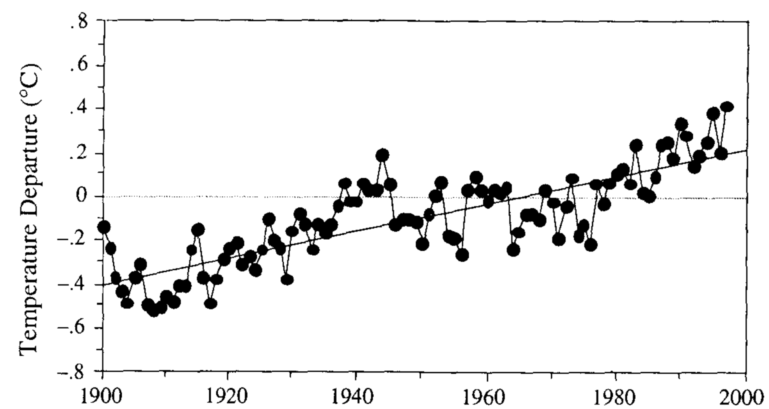

Figure 8. The temperature history of the Northern Hemisphere since 1900 shows a rise of about 0.6°C.

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[74] Houghton, J.T., G.J. Jenkins, and J.J. Ephraums (Editors), 1990. *Climate Change: The IPCC Scientific Assessment.* Cambridge, England, Cambridge University Press. p. xxviii. (Hereafter referred to as IPCC, 1990)

[75] Mitchell, J.F.B., et al., 1995. On surface temperature, greenhouse gases, and aerosols: Models and observations. *Journal of Climate*, **8**, 2364–2385.

Clearly this has not been the case. Figure 8 shows the surface temperature history of the Northern Hemisphere (surface data coverage is very sparse in the Southern Hemisphere), calculated from surface-based thermometers and published by the very same United Nations Panel.[76] The warming in the record is about 0.6°C, or more than three times less than what was predicted. At least half of that warming was prior to major changes in the greenhouse effect, or pre-1940. Everything else being equal, that leads to a maximum contribution of the enhanced greenhouse effect of 0.4°C. This discrepancy alone should be sufficient to disallow GCM-based projections of carbon dioxide-mitigated climate change that is deleterious to health or welfare.

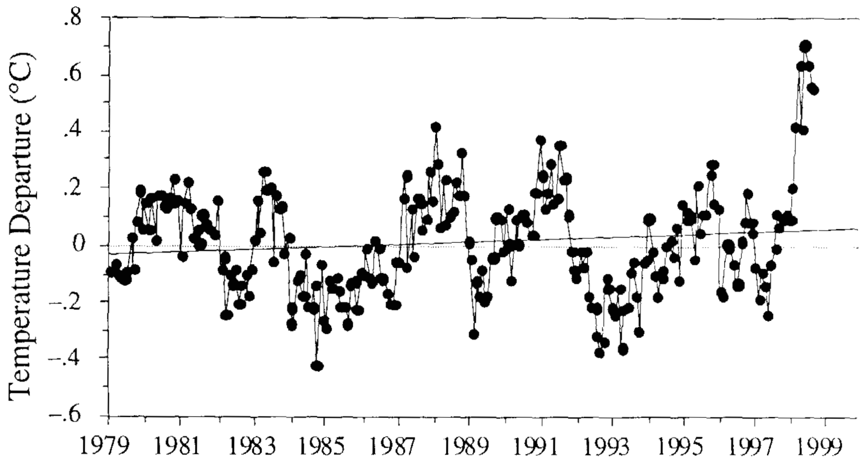

Figure 9. Global satellite temperatures since 1979 show a slight positive trend due to the warmth from El Niño at the end of the record.

Figure 9 shows the satellite temperature history from Spencer and Christy,[77] including their adjustment for the slight orbital decay noted by Wentz and Schabel,[78] and adjustments for other slightly changing

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[76] IPCC, 1995.

[77] Spencer, R.W., and J.R. Christy, 1990. Precise monitoring of global temperature trends from satellites. *Science*, **247**, 1558–1562.

[78] Wentz, F.J., and M. Schabel, 1998. Effects of orbital decay on satellite-derived lower-tropospheric temperature trends. *Nature*, **384**, 661–664.

orbital parameters.[79] The slight warming in this record is due only to the spike at the end of the record, which is a consequence of the strong El Niño conditions that existed in 1997–1998.

These satellite data match nearly perfectly with year-to-year temperature anomalies in the 5,000–30,000-foot layer taken by weather balloons, and the two show a remarkable annual correspondence since they became concurrent in 1979 (Figure 10). Through 1997, both showed no warming trend whatsoever.

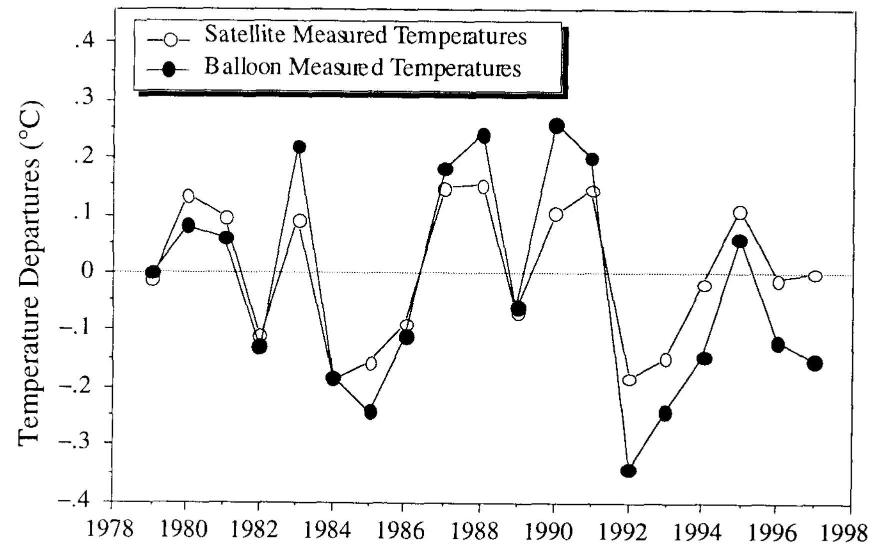

Figure 10. Annual global temperatures from satellites and weather balloons match up nearly perfectly from year to year.

Figure 11 shows the warming predicted for the last decade by a model that was typical of those that IPCC said were "generally" realistic.[80] Global temperatures were projected to rise 0.45°C. During that decade, the IPCC land record has a warming of 0.11°C, the weather

[79] Press release from Roy Spencer entitled "Measuring the temperature of the earth from space." August 13, 1998.

[80] Hansen, J., et al., 1988. Global climate changes as forecast by Goddard Institute for Space Studies three-dimensional model. *Journal of Geophysical Research*, **93**, 9341–9364.

balloon's record a cooling of 0.36°C,[81] and the adjusted satellite data a cooling of 0.03°C.

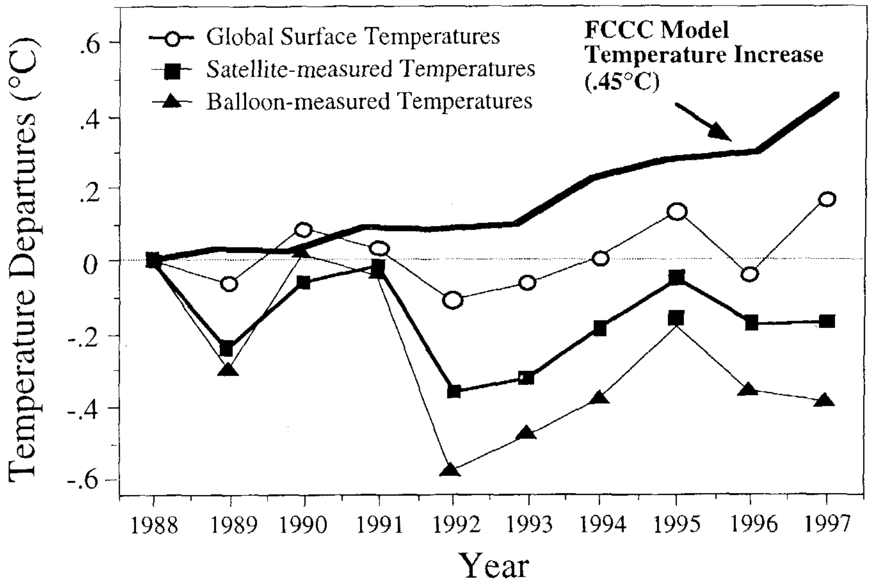

Figure 11. The forecast temperatures from a late 1980s climate model warm much more than any of the actual observations.

If these models serve as the basis for predictions of negative effects of carbon dioxide warming on human health, welfare, and the environment, then they are simply incorrect. On July 29, 1998, Robert Watson, head of the IPCC, testified before the House of Representatives Subcommittee on Small Business that these models were indeed, in his words, "wrong."[82]

While there has been no overall warming in the satellite and balloon records in the last two decades, there is a net warming since 1945 in the IPCC surface record. The principal reason for this is a large

[81] Angell, J.K., 1994. Global, hemispheric, and zonal temperature anomalies derived from radiosonde records. pp. 636–672. In T.A. Boden et al., (eds.), *Trends '93: A compendium of data on global change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn.

[82] Testimony of Robert Watson to the United States House of Representatives Subcommittee on Small Business, July 29, 1998.

warming of the cold winter regions in Siberia and northwestern North America. Mean temperatures in the cold Siberian air have warmed from about –40° to –38°C. Summer warming is approximately one-quarter of what is observed in the winter. The shorter satellite record is quite similar in its distribution of warming, but, again, shows no overall trend in annual global average.

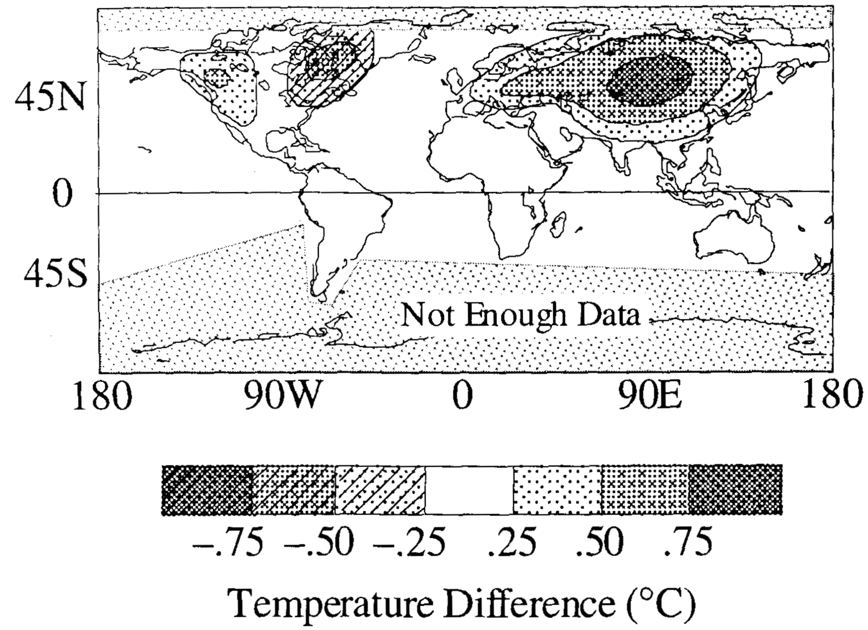

Figure 12. Seasonal difference (winter-summer) in temperature trends (°C decade^{-1}) for the IPCC near-surface data over the period 1946–1995.

Greenhouse theory is consistent with the observation of winter warming, inasmuch as water vapor and carbon dioxide behave similarly over a considerable portion of their absorption spectra and the cold airmasses of winter are virtually devoid of water vapor. Small changes in the absorption in these wavelengths have a logarithmically decreasing effect on temperature as the carbon dioxide concentration increases. In other words, the first increments of either water vapor or carbon dioxide to these very dry airmasses result in substantial warming. In general, warm airmasses contain much more moisture, so they are not as sensitive to carbon dioxide changes.

A relative winter warming and little summer warming has considerable consequences for health and agriculture. In general, a relative winter warming produces longer growing seasons. Evidence that this may already be occurring in high latitudes was recently published by Myneni et al.[83] Weather-related mortality is greater in winter than in summer, so a "de-winterizing" of the atmosphere is a net benefit in terms of human health.[84]

A mere five years after its original report, the IPCC (1995) produced its second overall assessment of climate change. It contains a change from its original statement about models being "generally realistic": "When increases in greenhouse gases only are taken into account...most [GCMs] produce a greater mean warming than has been observed to date, *unless a lower climate sensitivity is used* (emphasis added)...There is growing evidence that increases in sulfate aerosols are partially counteracting the [warming] due to increases in greenhouse gases."[85]

The IPCC is presenting two alternative hypotheses: Either the base warming was simply overestimated, or some other anthropogenerated emission is preventing the warming from being observed. IPCC omitted a third source for the error: Greenhouse gases may not be increasing at the projected rate.

As evidence comes in, the first and third reasons carry the day. The direct warming effect of carbon dioxide was overestimated by 15 percent.[86] Carbon dioxide is not accumulating in the atmosphere at the median rate estimated by IPCC in 1990,[87] and the second most important greenhouse emission, methane, began to slow its rate of increase in 1981.[88]

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[83] Myneni, R.B. et al., 1997. Increased plant growth in the northern high latitudes from 1981 to 1991. *Nature*, **386**, 698–702.

[84] Moore, T.G., 1998. *Climate of Fear: Why we shouldn't worry about global warming*. Cato Institute, pp. 175.

[85] IPCC, 1995, p.295.

[86] Myhre, G., et al., 1998. New estimates of radiative forcing due to well-mixed greenhouse gases. *Geophysical Research Letters*, **25**, 2715–2718.

[87] Hansen, J. et al., 1998. A common-sense climate index: Is climate changing noticeably? *Proceedings of the National Academy of Sciences*, **95**, 4113–4120.

[88] Etheridge, D.M., et al., 1998. Atmospheric methane between 1000 A.D. and present: Evidence of anthropogenic emissions and climate variability. *Journal of Geophysical Research*, **103**, 15,979–15,993.

Was the Climate Sensitivity Overestimated?

The large warmings predicted by the failed models of the late 1980s (which form the basis for the Framework Convention on Climate Change) rely on a roughly threefold amplification of carbon dioxide warming by increased atmospheric moisture. Yet Spencer and Braswell have found that the expected moisture is not there.[89] In another study, using observations as an indicator of climate sensitivity, Idso concludes that the estimates of climate sensitivity used in climate models are nearly five times too high.[90]

Perhaps even more remarkable is that the amount of direct warming by carbon dioxide has been overestimated in the global climate models.[91] This is the basic driving force behind the entire issue.

Was the Increase in Greenhouse Gases Overestimated?

Dlugokencky et al. recently demonstrated that the concentration of methane in the atmosphere—currently 30 percent of the human greenhouse potential—is rapidly stabilizing.[92] Its concentration is coming into chemical equilibrium with other atmospheric reactants. Their calculations strongly suggest that the concentration will remain stable in the future. The IPCC assumed that without any controls, the methane warming effect would double by 2050 and increase by 125 percent by 2100.[93]

Hansen recently calculated that the concentration of carbon dioxide in the atmosphere is increasing at approximately 60 percent of the rate that is normally projected. Notably, he argues that the biosphere is absorbing CO_2 at a rate much faster than anticipated: "Apparently the rate of uptake by CO_2 sinks, either the ocean, or, *more likely the forests*

[89] Spencer, R.W. and W.D. Braswell, 1997. How dry is the tropical free atmosphere? Implications for global warming theory. *Bulletin of the American Meteorology Society*, **78**, 1097–1106.

[90] Idso, S.B., 1998. CO2-induced global warming: A skeptic's view of potential climate change. *Climate Research*, **10**, 69–82.

[91] Myhre, G., et al., 1998, op. cit.

[92] Dlugokencky, E.J., et al., 1998. Continuing decline in the growth rate of the atmospheric methane burden. *Nature*, **393**, 447–450.

[93] IPCC, 1995, p.97.

and soils (emphasis added) has increased."[94] Here Hansen is in perfect agreement with the research of Idso and Idso[95] and Wittwer.[96]

Only the sulfate hypothesis would lend the exaggerated notion of climate change any credibility, but it does not provide a sufficient explanation of the predicted lack of warming.

A Critical Examination of the Sulfate Hypothesis

The sulfate aerosol explanation for the lack of warming is rather simple in principle. These finely divided particles directly reflect away solar radiation and also serve to brighten existing clouds. They do not reside in the atmosphere for long, so their cooling is primarily in the Northern Hemisphere where almost all are produced by the combustion of fossil fuel, which contains small amounts of sulfur.

The sulfate hypothesis is under increasing scientific challenge. Hansen et al. reported that the direct cooling effect of sulfates was too small to account for the lack of observed warming. Further, the magnitude of the indirect cooling (from cloud brightening) is highly speculative, as Hansen et al. argued that a "semi direct" heating of the lower atmosphere by aerosol absorption may minimize the indirect cloud effect.[97] Hobbs reported that air samples from the eastern United States showed a predominance of soot (carbon) that should have created a net warming, rather than sulfates, which should have caused cooling.[98]

The study done by Santer et al.[99] was especially controversial.[100] However, it is often cited as the definitive evidence for the "sulfate plus greenhouse" hypothesis. The controversy grew because the portion of the troposphere that showed the most dramatic warming

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[94] Hansen, J. et al., 1998, op. cit.

[95] Idso, K.E., and S.B. Idso, 1994, op. cit.

[96] Wittwer, S.H., 1995, op. cit., p. 70.

[97] Hansen, J., M. Sato, and R. Reudy, 1997. Radiative forcing and climate response. *Journal of Geophysical Research*, **102**, 6831–6864.

[98] Hobbs, P.V., et al., 1997. Direct radiative forcing by smoke from biomass burning. *Science*, **275**, 1776–1778.

[99] Santer, B.D., et al., 1996. A search for human influences on the thermal structure of the atmosphere, *Nature*, **382**, 39–46.

[100] Michaels, P.J., and P.C. Knappenberger, 1996. Human effect on global climate? *Nature*, **384**, 522–523.

during the study period (1963–1987) was found to show no change whatsoever when the entire available (1958–1995) record was used (Figure 13).

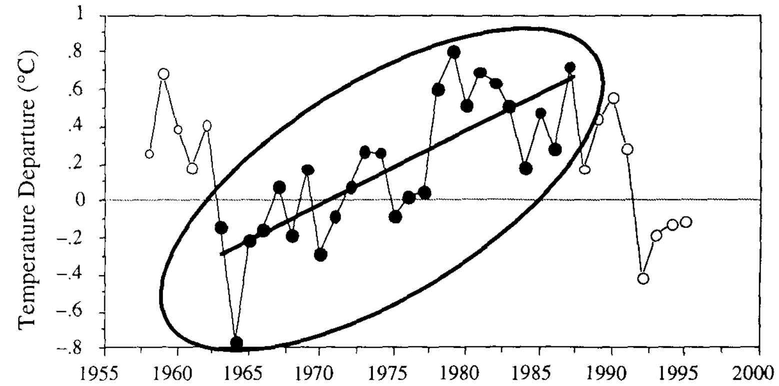

Figure 13. The trend that shows the most warming is in the subset of the record used by Santer et al. (circled). It disappears when the entire record is used.

The overall record of three dimensional atmospheric temperature does not appear consistent with the sulfate hypothesis. The southern half of the planet is virtually devoid of sulfates, and should have warmed at a prodigious and consistent rate for the last two decades. Unfortunately, we have very few long-term weather records from that half of the planet and almost all come from the relatively uncommon landmasses. However, we do have nearly two decades of satellite data (Figure 14). They show no trend whatsoever.

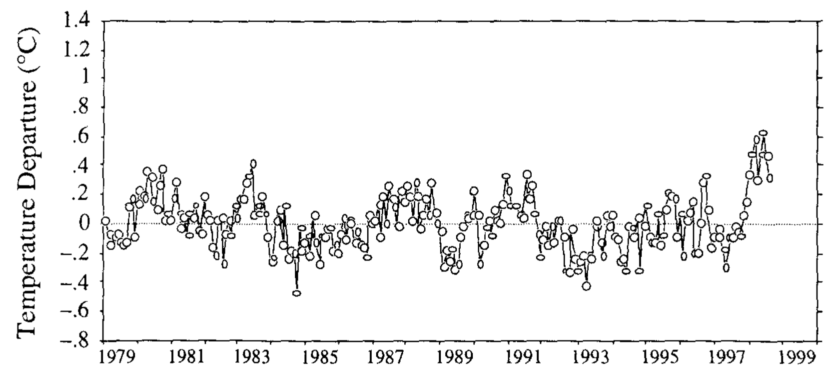

Figure 14. The satellite temperature record of the Southern Hemisphere shows no trend at all since the records began in 1979.

In conclusion, the GCMs used to determine the indirect (climate) effect of CO_2 are wrong. Sulfate cooling does not explain the error. CO_2 is being increasingly sequestered in living matter. Methane is not likely to increase. And, finally, observed climate changes are much smaller than anticipated and are largely confined to the cold airmasses of winter.

Nevertheless, even though the model output can be shown to be wrong, predictions about the future climate and its negative impacts on human welfare continue to be made. In the following sections, we address each of these associations, and show how observations do not support them.

OVERALL CLIMATE VARIABILITY

Popular reports would have us believe that the increase in the concentration of atmospheric carbon dioxide will produce an increase in the overall variability of climate, thus exposing us to more climate extremes. Though it is true that a few modeling studies suggest that an increase in variability is possible given a buildup of CO_2, others suggest a decrease. More important, the observed evidence generally shows a decrease in variability.

One of the most important papers on this subject was published by Gregory and Mitchell.[101] They concluded that changes in variability could differ greatly from season to season and were highly dependent upon local physical processes. Under doubled conditions, their numerical experiments revealed decreases in temperature variability in Europe in winter due to reduced land/sea thermal contrast, but variability increased in summer due to the surface heat balance. Complex temperature variability results, like those found in Europe, could be expected in other parts of the world. Basically, it is difficult to look at the various model results on this issue and conclude that temperature variability will increase in the future.

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[101] Gregory, J.M., and J.F.B. Mitchell, 1995. Simulation of daily variability of surface temperature and precipitation over Europe in the current and 2 x CO_2 climates using the UKMO climate model. *Quarterly Journal of the Royal Meteorological Society*, **121**, 1451–1476.

When models produce mutually inconsistent projections, it is instructive to look at real data. Parker et al. [102] examined the long temperature record from central England[103] and found no evidence of increased variance in recent decades. Parker et al.[104] compared interannual seasonal temperature anomalies from the 1954–1973 period to the 1974–1993 period for most of the globe. They found a small increase in variability overall, with an especially large increase in central North America. However, Karl et al.[105] concluded that an increase in CO_2 should decrease high frequency temperature variance. They also found that day-to-day variability during the 20th century is down in the Northern Hemisphere, particularly in the United States and China. Karl et al.[106] later stated, "Projections of the day-to-day changes in temperature are less certain than those of the mean, but observations have suggested that this variability in much of the Northern Hemisphere's mid-latitudes has decreased as the climate has become warmer. Some computer models also project decreases in variability."

It is difficult to review the literature, read that statement from the IPCC and continue to believe that scientists are predicting an increase in variability for a rise in CO_2. Michaels et al. [107] analyzed trends in the variability of daily and monthly near-surface air temperatures in the 5° latitude by 5° longitude IPCC temperature record. They found that the trend in temperature variance within each year is toward reduced variability and is highly significant over the past 50 and 100 years (Figure 15). Furthermore, they found that temperature variance and global temperature are negatively related (Figure 16), with a tendency for lower variance in warmer years.

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[102] Parker, D.E., T.P. Legg, and C.K. Folland, 1992. A new daily central England temperature series, 1772–1991. *International Journal of Climatology*, **12**, 317–342.

[103] Manley, G., 1974. Central England temperatures: Monthly means 1659 to 1973. *Quarterly Journal of the Royal Meteorological Society*, **100**, 389–405.

[104] Parker, D.E., P.D. Jones, C.K. Folland, and A. Bevan, 1994. Interdecadal changes of surface temperature since the late nineteenth century. *Journal of Geophysical Research*, **99**, 14,373–14,399.

[105] Karl, T.R., R.W. Knight, and N. Plummer, 1995. Trends in high-frequency climate variability in the twentieth century. *Nature*, **377**, 217–220.

[106] Karl, T.R., N. Nicholls, and J. Gregory, 1997. The coming climate. *Scientific American*, **276**, 79–83.

[107] Michaels, P.J., et al., 1998. Analysis of trends in the variability of daily and monthly historical temperature measurements. *Climate Research*, **10**, 27–33.

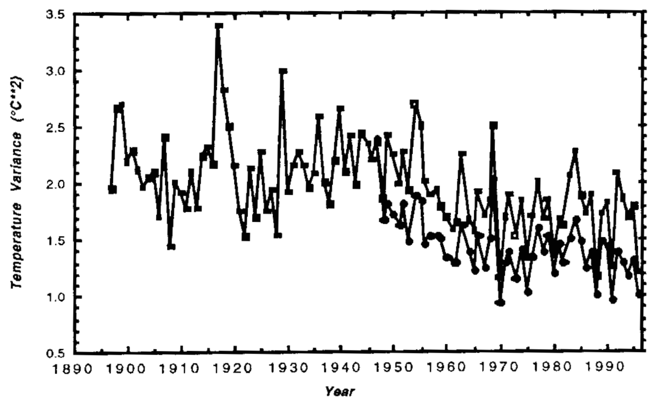

Figure 15. Plot of intra-annual temperature variance for 393 valid 5° latitude by 5° longitude cells in the 1897–1996 time series (open squares) and 1041 cells for the 1947–1996 time series (filled diamonds).

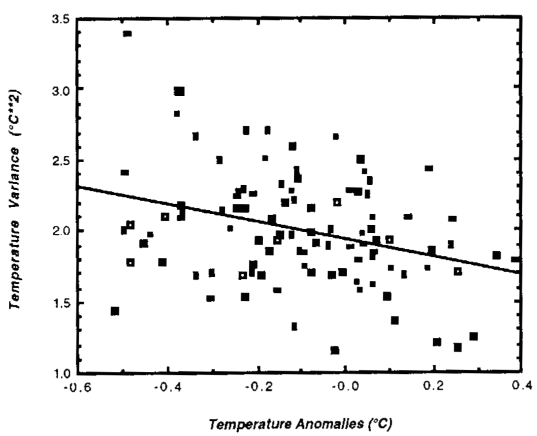

Figure 16. Intra-annual temperature variance versus global temperature anomalies for the 1897-1996 time series.

They then examined daily maximum and minimum temperatures from the United States, China, and the former Soviet Union for day-to-day variability in January and July. Most of the trends also indicated declining variability (Table 1). A final approach examined the occurrence of record-setting daily maximum and minimum temperatures from the same countries. They found no evidence for an increase in record temperatures.

Table 1

Mean Linear Trend (°C^2 dec^{-1}) in Daily Temperature Variance Values

Temperature	USA	China	fUSSR
Maximum:			
January	-0.19	-1.13	0.07
July	-0.13	0.06	-0.02
Minimum:			
January	-0.26	-1.32	-0.37
July	-0.19	0.06	-0.08

Balling[108] examined changes in the spatial variance of mean monthly and daily temperatures that may have occurred during the period of historical records. The Northern Hemispheric lower-tropospheric satellite-based temperature records from 1979-1996, and the near-surface air temperature records from either 1947-1996 or 1897-1996 show relatively consistent temporal patterns with respect to spatial variance. Overall, the spatial variance in temperature anomalies has declined during the period of historical records, and the interannual spatial variance levels in temperature anomalies are negatively related to mean hemispheric temperature. As Figure 17 shows, a high correlation of 0.92 exists between the interannual patterns of spatial and temporal variance.

[108] Balling, R.C., Jr., 1998. Analysis of daily and monthly spatial variance components in historical temperature records. *Physical Geography*, in press.

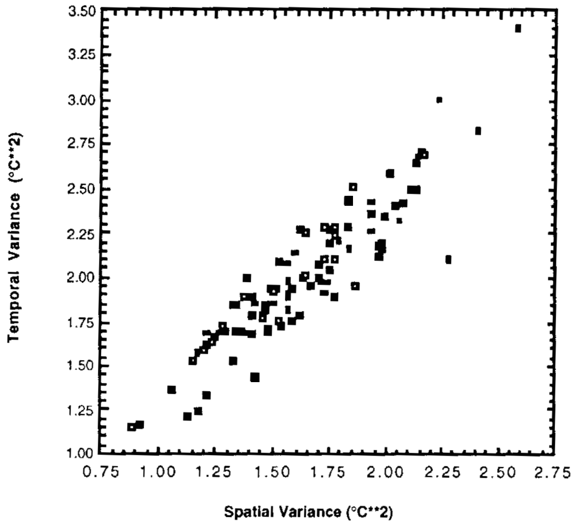

Figure 17. Scatter diagram showing the relationship between annual spatial variance patterns verses the intermonthly temperature variance from 1897 to 1996.

Clearly, there is little support for the popular perception that temperatures have become more variable. In fact, the bulk of the evidence points to lower variability in temperature, both over time and across space. The latest assessment by the IPCC summarizes this debate in this way: "Overall, there is no evidence that extreme weather events, or climate variability, has increased in a global sense, through the 20th century, although data and analyses are poor and not comprehensive."[109]

EXTREME WEATHER EVENTS

Precipitation Patterns

Changes in the patterns of precipitation across the globe have long been proposed as one of the major consequences of global warming.

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[109] IPCC, 1995, p173.

In the 1995 IPCC report, the outlook for the future was summed up as follows: "Warmer temperatures will lead to a more vigorous hydrological cycle: this translates into prospects for more severe droughts and/or floods in some places and less severe droughts and/or floods in other places."[110]

Although it seems as if this just about covers all possible future scenarios, the one that draws the most attention is the prospect for more severe droughts and/or floods.

Severe Droughts

Forecasts of increased droughts were first brought to the public's attention during the early summer of 1988. The United States corn belt was gripped by a severe spring drought that left many fields barren because there was not enough moisture even to germinate the seeds. Testifying before the U.S. Senate Committee on Energy and Natural Resources, NASA scientist James Hansen stated with a "high degree of confidence" that the current climate was related to changes in the greenhouse effect. This pronouncement, which made headlines across the country, was really the beginning of the current greenhouse concern. Hansen would later go on to predict that increased drought frequency would become evident during the early or mid-1990s.[111]

But what Hansen characterized as inevitable simply has not happened. Figure 18 shows the percentage of the United States that has experienced severe to extreme drought conditions each month since January 1895. There is no long-term trend in this record.

In other parts of the world the results are similar. In some places, such as the African Sahel, there has been a tendency toward more dry conditions; but overall, according to the IPCC 1995, there is little evidence for changes in drought frequency or intensity.[112]

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[110] IPCC, 1995, p7.

[111] Testimony of James E. Hansen before the U.S. Senate Committee on Energy and Natural Resources on June 23, 1988.

[112] IPCC, 1995, p 138.

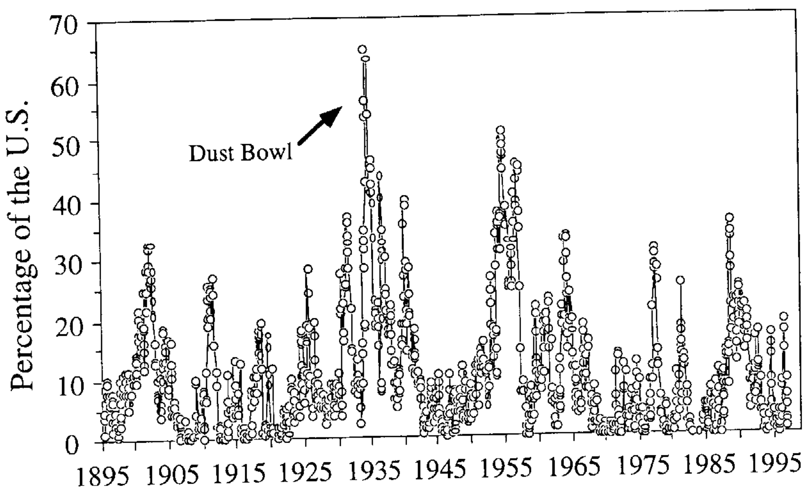

Figure 18. The percentage of the United States experiencing severe or extreme drought conditions fluctuates from year to year, but shows no long-term trend.

Severe Floods

The idea that more intense and extreme rainfall will produce greater and more frequent flood events entered the popular mind with the publication of a paper by Karl et al.[113] In this work, Karl reported an increase in the percentage of rainfall in the United States that fell from storms producing between two and three inches of rain per day. Vice President Al Gore has subsequently referred to such events as "torrential rains." The notion that global warming will produce more heavy rainfall derives from the fact that as the atmosphere warms, evaporation of surface water increases the amount of water vapor in the air. The warmer air, coupled with a more moist atmosphere, will produce conditions conducive for the development of heavy precipitation.

Missing from disaster scenarios, however, is another fact: In most parts of the United States (and the world), more precipitation is beneficial. In most of the United States, during the summer, total evaporation greatly exceeds total precipitation. Hence, a moisture deficit exists. This lack of moisture stresses plants, including crops. Most farmers,

[113] Karl, T.R., R.W. Knight, and N. Plummer, 1995, op. cit.

therefore, welcome more summertime rainfall. Additionally, increasing population density puts increased pressure on water supplies as the need for water in the industrial, commercial, and private sectors rapidly rises. Any increase in the amount of precipitation would help to meet this growing demand.

In Karl's study, the majority of the increase in rainfall occurred during the summer. About 70 percent of the rainfall from storms producing more than 2 inches was, in actuality, less than 3 inches—hardly a "torrential rain." Karl found no trend in the amount of rain falling from storms producing more than 3 inches. A 2-to-3-inch daily rainfall during the summer will not cause problems unless the ground is already saturated, a condition that is rare during most times across the United States.

A U.S. Department of Commerce Press Release[114] claimed, based upon Karl's results, that there had been a 20 percent increase in the amount of "flooding rain." What Karl had found is shown in Figure 19—a change of 2 percent, not 20 percent. The Department of Commerce's press release claimed 20 percent because, at the beginning of the record, 9 percent of all rain came from such storms, and by the current decade it is 11 percent; 2 percent divided by 10 percent (the average of 9 and 11) equals 20 percent. This mathematical trick clearly distorted the facts.

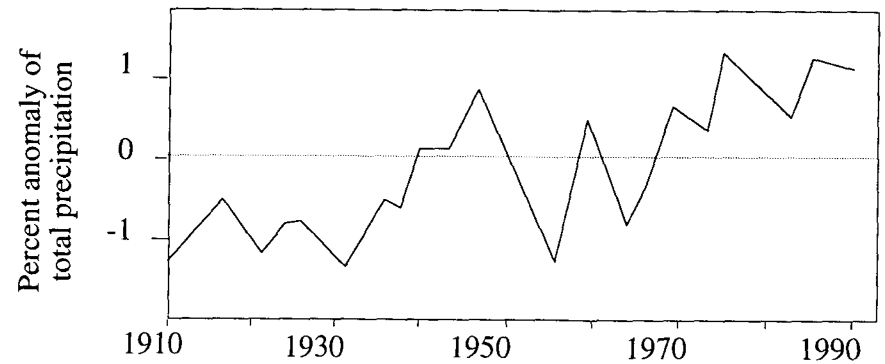

Figure 19. Change in the percentage of total precipitation falling from rainstorms of two inches or more in 24 hours. The biggest rise occurred before the greenhouse effect changed very much.

[114] January, 1997, National Climatic Data Center, Asheville, North Carolina

The amount of rain that has changed is truly minuscule. It works out to a total annual change of 0.7 inches in the two-to-three inch category, averaged across the United States. Also, as is apparent from Figure 19, the value reached around 1950—before the greenhouse changes would be thought to have much effect on climate—was nearly the same as the value in recent decades. Ascribing greenhouse causation to this phenomenon is very risky.

In related work, Lins and Slack[115] looked directly at streamflow data from hundreds of U.S. streams and rivers. After a thorough analysis of data collected from streamflow gauges, they found no overall trends in peak discharges or peak flow rates—the events associated with floods. Of 206 gauging stations with adequate records from 1946 to 1995, only 26 reported statistically significant trends. Of these, 13 showed increasing peak flow rates, and 13 showed decreasing peak flow rates.

Lins and Slack only used those stream gauges where the upstream waterflow was undisturbed. This ensured the data they were using was not influenced by alterations of the watershed or the stream channel. In fact, it is these types of alterations that are undoubtedly giving rise to the public's perception of increasing floods. As land use increasingly becomes more urban, the surface becomes more and more impervious and run-off increases. Also, as streams and rivers are channeled and diked, the natural system of checking floods—flood plains—is eliminated and all of the water is forced to flow in narrow stream channels. This has the effect of increasing downstream water levels, often to heights that have never been seen before. The result? Seemingly record floods, despite the current waterway's bearing no resemblance to the one of the past with which the records are being compared.

On a larger scale, the IPCC reports that there has been a slight (1 percent) upward trend in precipitation over the earth's land areas during the 20th century; though they note that since about 1980, precipitation has been relatively low. On regional scales, there has, of course, been variability in this trend. As for a tendency toward increased flooding, the IPCC reports that no clear, large-scale pattern has emerged.[116]

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[115] Lins, H.F. and J.R. Slack, 1997. A flood of perception, U.S. Geological Survey, presented to the American Geophysical Union, San Francisco, Calif., December 8, 1997.
[116] IPCC, 1995, p. 137–138.

Temperature Extremes

Changes in the frequency of extreme temperatures are pointed to as another likely consequence of global warming. They would have direct consequences on human health and mortality, as well as on energy usage and agriculture. Therefore, a careful understanding of how future climate change may impact the magnitude and frequency of extreme temperature outbreaks is necessary in order to assess any potential adverse consequences.

High Temperatures

10 years ago, Hansen predicted that the number of days in Washington, D.C., with high temperatures over 95 degrees would increase from a normal of six to nearly 50 by the decade of the 2050s. Similar statistics were calculated for other cities across the country.[117] These forecasts served as the basis for a 1990 Sierra Club television advertising campaign featuring Meryl Streep and William Shatner.

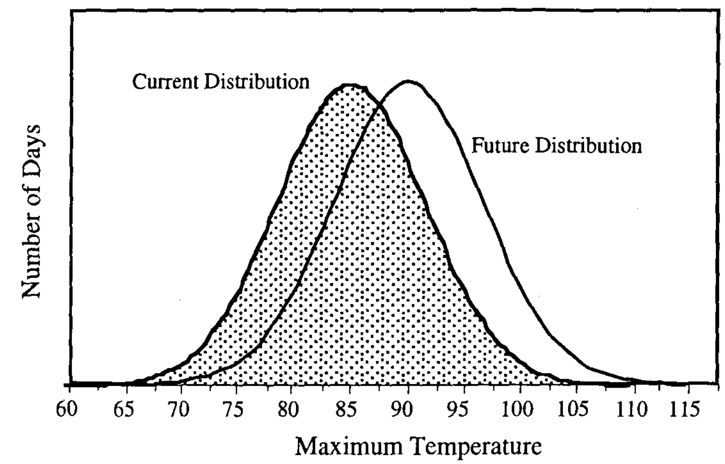

Figure 20. If the forecasts of future temperature increases are simply added to the current temperature distribution, the number of extremely high temperatures greatly increases.

[117] Hansen, J., et al., 1988, op. cit.

A closer look at the numbers, however, proves these statistics to be based upon "facts" that are demonstrably wrong. The value for the number of extremely hot days was arrived at by simply adding the amount of GCM-projected warming to the normal distribution of maximum temperature values occurring during the summer (Figure 20). This practice is flawed in that it does not consider the nature of the temperature changes both as observed, and as projected by the climate models.

Several recent papers point out this problem. Karl states that GCMs predict that the variance of temperatures will decline in the future—that is, temperatures will be confined to a tighter range. [118] Indeed, this effect can be found in the observations (previously discussed here; see section on temperature variability). Therefore, a simple addition of the forecast warming to the currently existing temperatures is not correct; it is necessary to adjust the temperature forecasts for changes in the diurnal cycle. When this is done, the number of extreme events shows little change, and, in some cases, may in fact actually decrease in number (Figure 21).

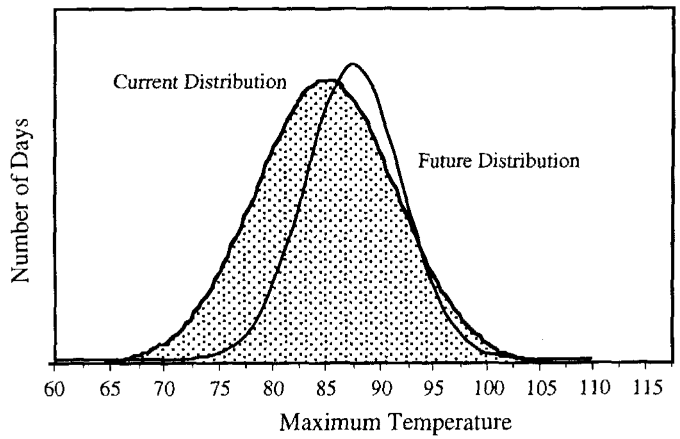

Figure 21. If the forecasts (and observations) of decreases temperature variance are included, a future warming does not significantly effect the number of extremely high temperatures.

Karl also examined the long-term trends of maximum apparent temperatures (temperatures plus humidity), in order to assess any trends that might have contributed to the deaths in Chicago and across

[118] Karl, T.R., N. Nicholls, and J. Gregory, 1997., op. cit.

the Midwest during the summer of 1995. He found that the greatest influence was caused by instrument changes and urbanization. When he corrected for these effects, he found no discernible trend.[119] In other research, Easterling et al. found that most of the increase in global temperatures has been occurring during the winter and at night. Summer maximum temperatures in the Northern Hemisphere showed no significant trend.[120] This is another fact that is overlooked when simply adding the forecast temperature change to the currently observed maximum temperatures.

A study that looked at the occurrence of record-setting daily high temperatures across the United States, China, and the former Soviet Union found that there was an overall tendency for daily record high temperatures to be set *earlier* in the record. Although these results were not statistically significant, they do indicate that there is no observed trend toward more frequent record maximum temperatures.[121] This conclusion was also drawn by the IPCC which states that "widespread significant changes in extremely high temperature events have not been observed."[122]

Low Temperatures

In the United States, more than twice as many people die due to exposure to extreme cold weather than to exposure to extreme heat.[123] During an Arctic outbreak that reached into the deep South during the Christmas of 1983, more than 150 people died. The low temperature in Orlando, Florida was 20°F with a wind-chill of –6°F. Many of the victims died of hypothermia in their unheated homes.

This killer air mass formed over Siberia—a dark, dry frozen expanse of land where there is little to brake the escape of radiation into space, and where temperatures routinely drop to 40 or 50 degrees below zero. These Siberian air masses travel over the pole, and when conditions are right, they can drop deep into the southern United States, often with dire consequences. However, as the carbon dioxide

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119 Karl, T.R., and R.W. Knight, 1997. The 1995 Chicago heat wave: How likely is a recurrence? *Bulletin of the American Meteorological Society*, **78**, 1107–1119.

120 Easterling, D.R., et al., 1997. Maximum and minimum temperature trends for the globe. *Science*, **277**, 364–367.

121 Michaels, P.J. et al., 1998, op cit.

122 IPCC, 1995, p138.

123 Vital Statistics of the United States, 1983 through 1992.

concentration in the atmosphere increases, these are the air masses that should warm the most.

As noted in our previous section on climate models, greenhouse warming tends to take place in the coldest, driest airmasses. Also, as noted earlier, observations show that the largest temperature increases have been occurring during the winter over Siberia and northwestern North America.[124] The warming of these cold polar air masses should lessen occurrences of extremely cold temperatures. This would reduce the severity of cold air outbreaks and reduce the number of deaths resulting from these excursions into the lower latitudes.

Hurricanes

Newsweek magazine, January 22, 1996: Above a photograph of a man walking through the whiteout of a snowstorm, the cover headline proclaims, "The Hot Zone: Blizzards, Floods & Hurricanes: Blame Global Warming."[125] Yet the Technical Summary of the Intergovernmental Panel on Climate Change's latest assessment states, "Although some models now represent tropical storms with some realism for present day climate, the state of the science does not allow assessment of future changes."[126] In the body of the text, IPCC says, "In conclusion, it is not possible to say whether the frequency, area of occurrence, time of occurrence, mean intensity or maximum intensity of tropical cyclones will change."[127]

Will an increased concentration of atmospheric carbon dioxide result in more frequent and more intense hurricanes? In 1986, Emanuel published an important paper dealing with air-sea interactions and hurricane activity.[128] He showed that if the sea-surface temperature falls below approximately 26°C, intense hurricanes would become a physical impossibility. Further, the intensity of a hurricane has a well-defined upper limit that is governed, in part, by sea surface temperatures. In simple terms, a warmer sea surface could

[124] Balling, R.C., P.J. Michaels, and P.C. Knappenberger, 1998. Analysis of winter and summer warming rates in gridded temperature time series. *Climate Research*, **9**, 175–181.
[125] *Newsweek*, January 22, 1996, cover.
[126] IPCC, 1995, p44.
[127] IPCC, 1995, p334.
[128] Emanuel, K.A., 1986: An air-sea interaction theory for tropical cyclones. Part I: Steady-state maintenance. *Journal of the Atmospheric Sciences*, **43**, 585–604.

theoretically increase the upper limit of a storm's intensity. Only a few storms actually approach this theoretical upper limit, but those storms turn out to be the most destructive and dangerous.

The following year, Emanuel published another article on the dependence of hurricane activity on climate.[129] He showed that a numerical model perturbed by an increase in greenhouse gases could increase the sea surface temperature thereby increasing the theoretical upper limit of storm intensity. This is not to say that the world would see more hurricanes or even more intense hurricanes, but only that the theoretical upper limit of intensity could increase. For a 3°C increase in sea surface temperatures, the potential destructive power of storms approaching this theoretical limit, as measured by the square of the wind speed, could increase by 40 percent to 50 percent.

A third paper by Emanuel further developed the linkage between the upper limit of storm intensity and warming in the lower atmosphere.[130] He wrote that with a warming of the sea surface of 6°C to 10°C (and with conditions in the lower stratosphere held constant), a supersized, ultra-powerful "hypercane" becomes a theoretical possibility. These ideas were presented to a more popular audience in a paper he prepared for *American Scientist*.[131] There, people learned about the hypercane and its link to warmer conditions.

Other theoretical results are in agreement with the notion that hurricane activity will increase due to the buildup of carbon dioxide. Ryan et al. concluded that the area affected by hurricanes would increase.[132] Haarsma et al. found that both the frequency and intensity of tropical cyclones would increase in a warmer climate.[133] Evans et al. concluded that future increased sea surface temperatures would decrease the central pressure of the storms (and therefore increase their intensity) and increase the total rainfall generated by the tropical

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[129] Emanuel, K.A., 1987: The dependence of hurricane intensity on climate. *Nature,* **326**, 483–485.

[130] Emanuel, K.A., 1988a: The maximum intensity of hurricanes. *Journal of the Atmospheric Sciences,* **45**, 1143–1156.

[131] Emanuel, K.A., 1988b: Toward a general theory of hurricanes. *American Scientist,* **76**, 370–379.

[132] Ryan, B.F., I.G. Watterson, and J.L. Evans, 1992. Tropical cyclone frequencies inferred from Gray's yearly genesis parameter: Validation of GCM tropical climates. *Geophysical Research Letters,* **19**, 1831–1834.

[133] Haarsma, R.J., J.F.B. Mitchell, and C.A. Senior, 1993: Tropical disturbances in a GCM. *Climate Dynamics,* **8**, 247–257.

cyclones.[134] Knutson et al.'s numerical simulations for a CO_2-warmed world showed hurricanes with lower pressures and increased winds.[135] Royer et al. examined the effect of increased greenhouse gas concentrations on climate and found an increase in the number of tropical cyclones in the Northern Hemisphere and a decrease in the Southern Hemisphere.[136]

Other scientists are producing calculations that lead to a different conclusion—that elevated carbon dioxide levels might even decrease tropical cyclone activity. In 1995, Bengtsson et al. used a global climate model and found a reduction in hurricanes, particularly in the Southern Hemisphere, for a warming climate.[137] One year later, Bengtsson et al. published another paper entitled, "Will greenhouse gas-induced warming over the next 50 years lead to a higher frequency and greater intensity of hurricanes?"[138] Their high-resolution numerical simulations with a coupled ocean-atmosphere model showed that greenhouse-induced changes would weaken the Hadley circulation that dominates the tropics. Reducing the Hadley circulation would weaken hurricanes. Additionally, it would strengthen the upper-level westerlies in the vicinity of hurricane development, which further weakens hurricanes. When compared with present day global distribution and seasonality of hurricanes, they found no changes for a doubling of greenhouse gases. However, the number of hurricanes in the Northern Hemisphere fell from 56.2 storms per year in the present-day climate simulation (the observed value from 1958–1977 is 54.6) to 42.0 storms per year in the doubled CO_2 case. In the Southern Hemisphere, the number of hurricanes dropped from 26.8 in the present-day model run (24.5 is the observed value) to only 11.6 storms per year. Their results on

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[134] Evans, J.L., B.F. Ryan, and J.L. McGregor, 1994. A numerical exploration of the sensitivity of tropical cyclone rainfall intensity to sea surface temperatures. *Journal of Climate,* **7**, 616–623.

[135] Knutson, T.R., R.E. Tuleya, and Y. Kurihara, 1998. Simulated increase of hurricane intensities in a CO_2-warmed climate. *Science,* **279**, 1018–1020.

[136] Royer, J.-F., et al., 1998. A GCM study of the impact of greenhouse gas increase on the frequency of occurrence of tropical cyclones. *Climatic Change,* **38**, 307–343.

[137] Bengtsson, L., M. Botzet, and M. Esch, 1995. Hurricane type vortices in a general circulation model. *Tellus,* **47A**, 175–196.

[138] Bengtsson, L., M. Botzet, and M. Esch, 1996. Will greenhouse gas-induced warming over the next 50 years lead to a higher frequency and greater intensity of hurricanes? *Tellus,* **48A**, 57–73.

intensity were less conclusive, but they did find a tendency for reduced wind speeds in the doubled CO_2 model simulations.

While the numerical modelers have been busy conducting theoretical experiments on the linkage between hurricanes and warmer conditions, atmospheric scientists have been examining the historical record to determine the relationship between observed temperatures and observed hurricane activity as well as trends in hurricane activity. In 1990, noted hurricane scientist William Gray published an important article dealing with landfall of intense hurricanes in the United States and its relation to rainfall in West Africa, showing that hurricane activity over the period 1970 to 1987 was less than half of that observed for the period 1947 to 1969.[139] Even though the largest greenhouse gas increases are in the latter period, hurricanes were decreasing in overall activity.

Idso et al. analyzed hurricane data for the central Atlantic, U.S. East Coast, the Gulf of Mexico, and the Caribbean Sea for the period 1947 to 1987.[140] They found that "there is basically no trend of any sort in the number of hurricanes experienced in any of the four regions with respect to variations in temperature." The number of hurricane-days was negatively related to the Northern Hemispheric temperatures; warmer years produced the lowest number of hurricane-days while the cooler years had more than the average number of hurricane-days. The number of storms within the various intensity classes was also inversely correlated with the hemispheric temperature values (Figure 22). Idso et al. examined the trends with different intensity classes and concluded "For global warming on the order of one-half to one degree Centigrade, then, our analyses suggest that there would be no change in the frequency of occurrence of Atlantic/Caribbean hurricanes, but that there would be a significant decrease in the intensities of such storms."[141]

[139] Gray, W.M., 1990. Strong association between West African rainfall and U.S. landfall of intense hurricanes. *Science,* **249**, 1251–1256.
[140] Idso, S.B., R.C. Balling Jr., and R.S. Cerveny, 1990. Carbon dioxide and hurricanes: Implications of Northern Hemispheric warming for Atlantic/Caribbean storms. *Meteorology and Atmospheric Physics,* **42**, 259–263.
[141] Ibid, p. 262.

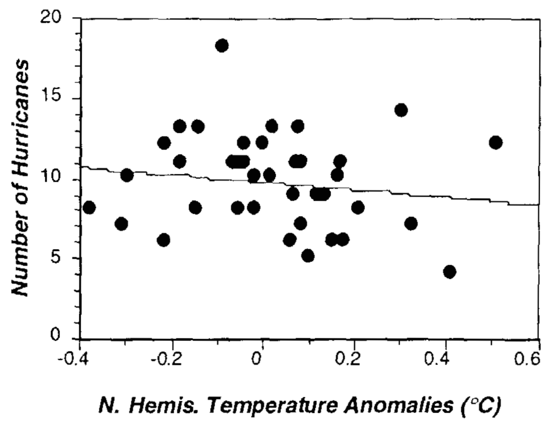

Figure 22. Number of Atlantic/Caribbean hurricanes versus Northern Hemispheric near-surface air temperature anomalies.

Later, Landsea reported that the intensity of Atlantic hurricanes has been decreasing since the middle of this century.[142] He carefully screened his data to remove known biases, and the decreasing trend remained an identifiable pattern in the intensity estimates. Another article by Landsea et al. reconfirmed that hurricane frequency and intensity were not increasing over the past five decades.[143] They examined Atlantic hurricanes from 1944, when aircraft reconnaissance began in the Atlantic, to the near-present. They found that "a long-term (five decade) downward trend continues to be evident primarily in the frequency of intense hurricanes. In addition, the mean maximum intensity (i.e., averaged over all cyclones in a season) has decreased." A plot of the mean intensity (Figure 23) clearly shows this downward trend during a time of greatest buildup of greenhouse gases.

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[142] Landsea, C.W., 1993. A climatology of intense (or major) Atlantic hurricanes. *Monthly Weather Review,* **121**, 1703–1713.

[143] Landsea, C.W., et al., 1996. Downward trends in the frequency of intense Atlantic hurricanes during the past five decades. *Geophysical Research Letters,* **23**, 1697–1700.

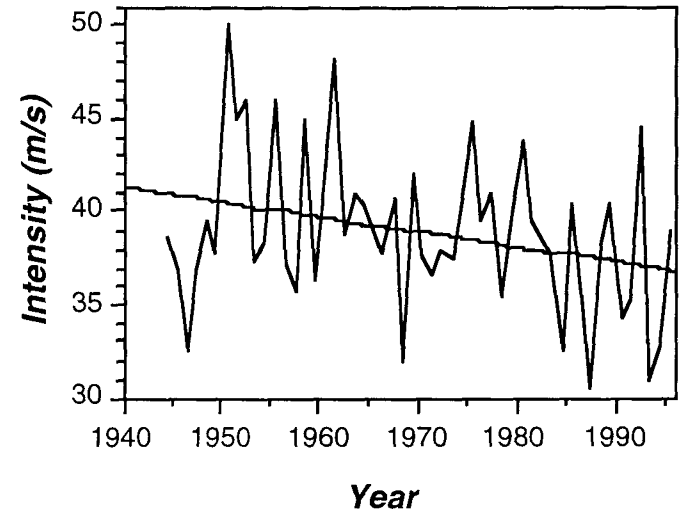

Figure 23. Time series of Atlantic basin mean intensity (m/s) as determined from maximum sustained wind speeds of all hurricanes.

This downward trend in intensity of Atlantic hurricanes over the past five decades raises a question about trends prior to the 1940s, when data are less reliable. Karl et al. examined records of the number and intensity of hurricanes that reached the continental United States over the past century, and found that the number of hurricanes making landfall in the United States decreased from the 1940s through the 1980s (Figure 24), but over the entire twentieth century, there was no overall trend.[144,145] Elsner et al. looked at Atlantic hurricanes in the tropics from 1896 to 1990, and they noted a drop in these tropical hurricanes, which tend to be more severe, during the 1960s.[146] Chan and Shi examined the record of typhoons and tropical cyclones from 1959 to 1994 in the western North Pacific and found a decrease in storms from 1959 to the late 1980s and a trend upward since (the late

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[144] Karl, T.R., et al., 1995. Trends in U.S. climate during the twentieth century. *Consequences,* **1**, 3–12.

[145] Karl, T.R., et al., 1996. Indices of climate change for the United States. *Bulletin of the American Meteorological Society,* **77**, 279–292.

[146] Elsner, J.B., G.S. Lehmiller, and T.B. Kimberlain, 1996. Objective classification of Atlantic hurricanes. *Journal of Climate,* **9**, 2880–2888.

1980s to 1994).[147] But when the most recent years were included, there was no significant change at all. Nicholls et al. analyzed satellite records of tropical cyclone activity in the Australian region and found a decline over the past three decades.[148] Finally, Bove et al. have examined Gulf of Mexico hurricane landfalls from Florida to Texas for the period 1886 to 1995, and they concluded that "there is no sign of an increase of hurricane frequency or intensity in the Gulf of Mexico at this time."[149] Their final sentence states. "Fears of increased hurricane activity in the Gulf of Mexico are premature."[150]

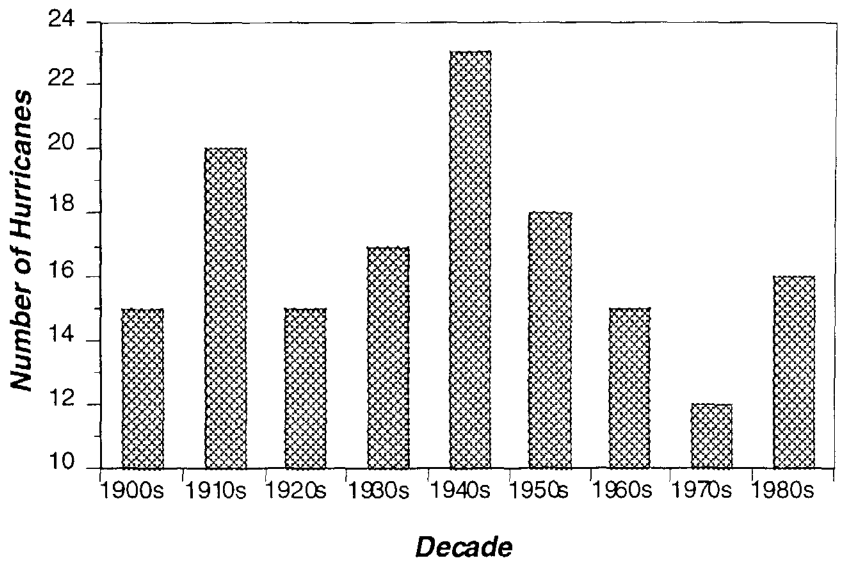

Figure 24. Number of hurricanes making landfall in the conterminous United States.

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[147] Chan, J.C.L., and J. Shi, 1996. Long-term trends and interannual variability in tropical cyclone activity over the western North Pacific. *Geophysical Research Letters,* **23**, 2765–2767.

[148] Nicholls, N., C. Landsea, and J. Gill, 1998. Recent trends in Australian region tropical cyclone activity. *Meteorology and Atmospheric Physics,* **65**, 197–205.

[149] Bove, M.C., D.F. Zierden, and J.J. O'Brien, 1998. Are Gulf landfalling hurricanes getting stronger? *Bulletin of the American Meteorological Society,* **79**, 1327–1329. p. 1327

[150] Ibid. p. 1328

In addition to studies examining precise aspects of a certain scientific question, there are "overview" studies that review the available science to draw broad conclusions In the first scientific assessment from the IPCC in 1990, the "Policymakers Summary" states, "Climate models give no consistent indication whether tropical storms will increase or decrease in frequency or intensity as climate changes; neither is there any evidence that this has occurred over the past few decades."[151] Four years later, Lighthill et al. published a major paper using two different basic approaches, but both led to the conclusion that "even though the possibility of some minor effects of global warming on tropical cyclone frequency and intensity cannot be excluded, they must effectively be 'swamped' by large natural variability."[152]

Lighthill et al. examined a widely accepted list of conditions permitting hurricane formation and development, such as a sea-surface temperature above 26°C, distance from the equator of at least 5° of latitude, and fairly high relative humidity levels surrounding the storm. Other entries on the list dealt with more complex conditions such as the vertical temperature structure of the atmosphere and horizontal rotation of the system. Their analyses led to the conclusion that we should not expect any direct effects of changing sea surface conditions on hurricane frequency and intensity. Lighthill et al. also examined the empirical records of hurricane activity since 1944 in the Atlantic and since 1970 in the Pacific. The authors noted great year-to-year variability in the hurricane data, but they could not find evidence linking hemispheric temperatures to variations in hurricane activity.

The second scientific assessment of the IPCC, stated, "Although some models now represent tropical storms with some realism for present day climate, the state of the science does not allow assessment of future changes."[153] It went on to summarize, "[I]t it is not possible to say whether the frequency, area of occurrence, time of occurrence, mean intensity or maximum intensity of tropical cyclones will change."[154] Similarly, Karl et al. reported that "Overall, it seems unlikely that tropical cyclones will increase significantly on a global scale. In some regions, activity may escalate; in others, it will

[151] IPCC, 1990, p. xxv.

[152] Lighthill, J., et al., 1994. Global climate change and tropical cyclones. *Bulletin of the American Meteorological Society,* **75**, 2147–2157.

[153] IPCC, 1995, p44.

[154] IPCC, 1995, p334.

lessen."[155] The most recent review article was published by Henderson-Sellers et al. and concluded, "There are no discernible global trends in tropical cyclone number, intensity, or location from historical data analyses."[156] They also stated that the bulk of the evidence suggests little change will occur in hurricane activity over the next century, given the expected changes to atmospheric composition.

Extra-Tropical Storms

Extra-tropical storms, or cyclones (areas of low surface air pressure), draw their energy from a different source than do tropical systems (e.g., hurricanes). They are a key component of the climate systems, and critical to any discussion of climate change. While the general term "cyclone" applies to almost any weather feature with cyclonic (in the Northern Hemisphere, counter-clockwise) winds, this discussion focuses on large-scale middle and high latitude cyclonic storms like those represented on surface weather maps.

Cyclonic storms are responsible for most of the significant weather events outside the tropics. Low pressure systems and their related fronts produce most of the precipitation, especially in the autumn, winter, and spring. Severe summer thunderstorm complexes, including tornadoes, are almost always linked to cyclones. All major (and most minor) snowstorms are cyclone-related. Thus, cyclones include almost all major non-tropical weather systems. It has been suggested by some that global warming will increase the frequency and violence of these types of storms.

The popular vision of the warmed world of the future is one with stronger blizzards, more forceful winds, and more intense tornadoes.[157] But this notion is based on an incomplete understanding of the atmospheric dynamics that are involved in the creation and evolution of midlatitude cyclones. Midlatitude storms derive their energy and sustenance from changes in atmospheric circulation (large-scale wind systems) at all levels of the atmosphere up to and including the jet stream (about 35,000 feet). Surface cyclones are regions with converging surface winds. As the air spirals into a storm at the surface and rises (producing clouds and precipitation), in order for the

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[155] Karl, T.R., N. Nicholls, and J. Gregory, 1997, op. cit.

[156] Henderson-Sellers, A., et al., 1998. Tropical cyclones and global climate change: A post-IPCC assessment. *Bulletin of the American Meteorological Society,* **79**, 19–38.

[157] *Newsweek*, January 22, 1996

cyclone to maintain its low pressure, there must be a mechanism aloft that removes the air being added from below. This occurs in the upper atmosphere near the level of the jet stream. A strong jet is needed above a strong cyclone to generate divergence aloft that at least compensates for the convergence at the surface.[158] Therefore, any discussion of future changes in cyclonic systems and their consequences requires an analysis of future upper atmosphere circulation changes.

Circulation Changes

Global wind patterns in the upper atmosphere change on a daily, seasonal, and annual basis. Westerly winds surround the poles of each hemisphere, producing a circumpolar vortex that effectively isolates the cold, poleward air from the warmer, tropical air. The area of the strongest temperature contrast as one moves south to north over the hemisphere is where the jet stream, or the region of maximum winds, is located. Whereas tropical temperatures remain roughly constant throughout the year, high latitude temperatures change significantly from summer to winter. As the polar latitudes warm, the north-south temperature contrast weakens, the circumpolar vortex (and the pool of cold air) contracts poleward, and the jet stream slackens. These seasonal changes correspond closely with changes in the frequency, intensity, and tracks of surface cyclones. In winter and spring, when intra-hemispheric temperature contrasts are strongest, cyclones track farther south throughout the hemisphere and are more intense. Summer sees fewer, weaker cyclonic storms with tracks displaced to the north.

Modeling Studies

How will increasing trace gas levels change the atmospheric circulation? Most GCMs predict that the greatest warming will occur over the high latitudes in winter with comparatively little warming in the tropics. The future hemispheric temperature gradient should be weak compared with that of today, particularly in winter, producing a weaker jet stream, a more contracted vortex, and fewer, weaker cyclones. In short, the future atmospheric circulation should be more summerlike, with fewer intense winter cyclones. In fact, these are the kinds of conditions that most GCMs project to occur in a world with an enhanced greenhouse effect.

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[158] Davis, R.E, Michaels, P.J., and B.P. Hayden. Cyclone Climatology. In *Cyclones* , R.A. Pielke ed. in press.

Interestingly, atmospheric GCMs, including the generation of GCMs that served as the basis for the 1992 Framework Convention on Climate Change and the 1995 report of the IPCC, do not explicitly incorporate cyclones. Typical midlatitude storm systems span hundreds of miles but are nevertheless smaller than the grid scale of most global GCMs. However, it is possible to run higher resolution models over limited spatial areas and produce more regional experiments that explicitly include cyclones. For example, Beersma examined changes in North Atlantic cyclones between atmospheres with current and doubled carbon dioxide levels. He noted "There is a shift in the distribution of depression [cyclone] strength towards weaker depressions. As a result, the number of storm events...decreases in most areas." He further added it was "impossible to conclude that the modeled differences were the result of the CO_2 doubling because they were small compared with the background natural variability."[159] In another study of cyclones, Zhang and Wang ran the NCAR model for trace gas conditions of 1990 vs. projections for 2050 for the Northern Hemisphere. They detected a decline in the number of cyclones, a weakening of cyclones in their formation regions, and fewer coastal cyclones forming, particularly in winter.[160] However, using the United Kingdom Meteorological Office (UKMO) GCM, Murphy and Mitchell noted "The increased westerlies which coincide with an increase in the strength of the Atlantic storm track are associated with an increase in the south-to-north temperature gradient between 30°N and 60°N."[161]

Their model forecasts more North Atlantic cyclone activity in accord with stronger circulation arising from a stronger north-south temperature gradient, but in doing so it contradicts both theory and most other GCMs that call for a weaker temperature gradient and a decrease in the strength of the cyclonic storm track. The UKMO results are also not supported by observations. Serreze et al. identified a significant decrease in the number of cyclones in the North

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[159] Beersma, J.J. et al., 1997. An analysis of extra-tropical storms in the North Atlantic region as simulated in a control and 2 x CO2 time-slice experiment with a high-resolution atmospheric model. *Tellus*, **49A**, 347–361.
[160] Zhang, Y. and W.C. Wang, 1995. Model-simulated Northern winter cyclone and anticyclone activity under a greenhouse warming scenario. *Journal of Climate*, **10**, 1616–1634.
[161] Murphy, J.M. and Mitchell, J.F.B., 1995. Transient response of the Hadley Centre coupled ocean-atmosphere model to increasing carbon dioxide, Part II: Spatial and temporal structure of response. *Journal of Climate*, **8**, 57–80.

Atlantic.[162] Thus, with the exception of the UKMO model, which runs counter to other forecasts, projections say that the number and intensity of storms will decrease as atmospheric trace gas levels rise. There is therefore no basis, in theory or in fact, to point to a rise in the frequency or intensity of midlatitude storms as symptomatic of a global warming response. In fact, it may very well signal the exact opposite.

Circumpolar Vortex Changes

Few studies have explicitly examined changes in upper atmospheric hemispheric circulation patterns over climatic time scales. Davis and Benkovic[163,164] and Burnett[165] plotted changes in the January circumpolar vortex in the mid-troposphere (500 mb pressure level, or approximately 18,500 feet). These studies have found that, from 1947–1990, the January vortex expanded significantly. This is the opposite of what we would expect in a global warming scenario. Later analysis uncovered no statistically significant contraction of the vortex in any month, but significant expansion in four of the twelve months from 1947–1995. [166] Conversely, recent research by Angell notes a significant 1.4 percent per decade contraction of the circumpolar vortex at the jet stream level (300mb) over the period 1963-1997. This difference between atmospheric behavior at different upper altitude levels may be real, or it could be a function of different time periods used in the analyses.[167]

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[162] Serreze, M.C. et al., 1997. Icelandic Low cyclone activity: Climatological features, linkages with the NAO, and relationships with recent changes in the Northern Hemisphere circulation, *Journal of Climate*, **20**, 453–464.

[163] Davis, R.E. and S.R. Benkovic, 1992. Climatological variations in the Northern Hemisphere circumpolar vortex in January. *Theoretical and Applied Climatology*, **46**, 63–73.

[164] Davis, R.E. and S.R. Benkovic, 1994. Spatial and temporal variations of the January circumpolar vortex over the Northern Hemisphere. *International Journal of Climatology*, **14**, 415–428.

[165] Burnett, A.W., 1993. Size variations and long-wave circulation within the January Northern Hemisphere circumpolar vortex: 1946–89. *Journal of Climate*, **6**, 1914–1920.

[166] Davis, R.E., P.C. Knappenberger, and A. Burnett, 1997. Relationships between surface temperatures and the 500 hPa circumpolar vortex in the Northern Hemisphere. *Proceedings 10th Conference of Applied Climatology,* 253–257.

[167] Angell, J.K., 1998, Contraction of the 300 mb North Circumpolar Vortex during 1963–1997, and its movement into the Eastern Hemisphere, *Journal of Geophysical Research*, forthcoming.

Cyclone Frequency

Observational cyclone climatologies typically rely on cyclone counts and tracking of closed surface lows (cyclones encircled by at least a single isobar on a surface weather map). Earlier research by Hosler and Gamage,[168] Reitan,[169,170] and Whittaker and Horn[171] documented significant changes in the year-to-year variability in cyclone counts, intensity, and tracks. In a recent study, Lambert analyzed the yearly counts of intense cyclones in the Northern Hemisphere.[172] He detected no trend from 1899 to 1970 but noted a statistically significant increase from 1970 to 1991 over the Atlantic and Pacific Oceans. Lambert then argued that the stronger Pacific storms are related to lower water temperatures in the basin. In a more regional-scale study, Angel and Isard detected a significant increase in the number of strong storms in the Great Lakes region.[173] They also detected more storms in cold years than in warm.

So observations show that more frequent cyclones are associated with lower temperatures. These observations, therefore, support the theory that global warming should produce fewer storms, and fewer intense storms, owing to a decline in the hemispheric temperature gradient that provides the energy needed to generate cyclones.

High Winds

In Switzerland, Schiesser et al. examined 100 years of wind data in which they detected trends toward less windy conditions and fewer

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[168] Hosler, C.L. and L.A. Gamage, 1956. Cyclone frequencies in the United States for the period 1905 to 1954. *Monthly Weather Review*, **84**, 388–390.
[169] Reitan, C.H., 1974. Frequencies of cyclones and cyclogenesis for North America, 1951–1970. *Monthly Weather Review*, **102**, 861–868.
[170] Reitan, C.H., 1979. Trends in the frequencies of cyclone activity over North America. *Monthly Weather Review*, **107**, 1684–1688.
[171] Whittaker, L.M. and L.H. Horn, 1984. Northern Hemisphere extratropical cyclone activity for four mid-season months. *Journal of Climatology*, **4**, 297–310.
[172] Lambert, S.J., 1996. Intense extratropical Northern Hemisphere winter cyclone events: 1899–1991. *Journal of Geophysical Research*, **101**, 21,319–21,325.
[173] Angel, J.R. and S.A. Isard, 1998. The frequency and intensity of Great Lake cyclones, *Journal of Climate*, **11**, 1861–1871.

storms.[174] They suggested that this response could in fact be evidence of a global warming signal.

Blizzards

In the winter of 1996, after a spate of strong snowstorms and cold outbreaks, several government officials, with the support of a handful of climate scientists, contended that these events could be related to global warming. This argument is especially surprising since most of the GCMs indicate that the formation regions of coldest air masses (as these air masses are responsible for the severe winter cold air outbreaks) are projected to warm more than any other place on the planet. Neither at that time, nor since, has any scientist made a logical defense of a hypothesis that warming implies cooling.

The blizzard contention is similarly ill-founded. Along the East Coast of the United States (and Asia), strong snowstorms require three conditions to form: a deep wedge of cold air in place, a strong coastal cyclone, and sufficient moisture. Lack of any one ingredient, or a slight change in the timing of the storm's arrival, has changed many forecast major snowstorms into sleet or rain events.

For a blizzard to occur, a deep layer of cold air typically must be in place upon the arrival of the cyclone. Winds associated with strong coastal lows mix in warmer, oceanic air and moisture, which often raise air temperatures above freezing. But a sufficiently deep layer of very cold air is not easily eroded by coastal storm winds, and the resulting precipitation falls as snow. Any warming of these cold air masses would logically reduce the likelihood of blizzards in the future. Furthermore, the relationship between temperatures and total snowfall over most of the East Coast is negative, so warm winters have significantly less snow than do cold winters.[175]

The second key ingredient for snowstorms, strong coastal cyclones, is slightly more complex. A 50-year record of coastal cyclones by Davis and Dolan reveals that, for the mid-Atlantic Bight, total storms are declining in frequency but strong storms are becoming more common.[176] Could this be a global warming signal? Major snowstorms require the presence of a strong trough in the jet stream over the

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[174] Schiesser, H.H. et al.,1997. Winter storms in Switzerland north of the Alps, 1864/1865–1993/1994. *Theoretical and Applied Climatology*, **58**, 1–19.

[175] Davis, R.E. et al., in review. *Journal of Geophysical Research*

[176] Davis, R.E. and R. Dolan, 1993. Nor'easters, *American Scientist*, **81**, 428–439.

eastern seaboard to track the storms up the coast. Deeper East Coast troughing could be a signal for more strong storms. However, analysis of the circumpolar vortex in warm vs. cold winters shows no changes in the vortex over the eastern United States.[177] Furthermore, a decline in the coastal land-ocean temperature gradient with a warming of the coldest air masses reduces the likelihood of more future storminess.[178]

The third and final ingredient in snowstorm formation is the presence of adequate moisture. Since GCMs project a moister atmosphere, this is the primary feature that fuels speculation about more intense future blizzards. However, sufficient moisture is almost never a limiting factor in snowstorm formation. Cyclones traveling along the coast have plenty of Atlantic moisture to tap into given the proper storm track. An already wet atmosphere has little room for additional moisture.

In short, a weakened jet steam supporting fewer cyclones, warming of the coldest air masses, and the general negative relationship between snow and temperatures, all point to a decrease in these events in a greenhouse warmed future.

Tornadoes

The great majority of tornadoes form in the United States, owing primarily to a coincidence of geography. The lack of analyses of long-term time series on tornado frequencies or strength is related to substantial biases in the available data. Observed tornado frequencies have been increasing over time in the United States, but most of this trend is driven by improvements in our ability to detect tornadoes through technological advances and a larger and widely scattered populace with simple means to report tornado sightings to authorities. That the upward frequency count coincides with equally significant declines in the number of tornado-related fatalities leads one to suspect that the frequency counts are biased. There is also little doubt that innumerable lives have been saved by better tornado detection and public warming systems.

Most tornadoes require the presence of a strong cyclone. A strong jet stream also helps support the development of strong thunderstorms by enhancing the horizontal wind shear that is required for the formation

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[177] Davis, R.E., P.C. Knappenberger, and A. Burnett, 1997, op. cit.

[178] Dickson, R.R. and Namias, J., 1976. North American influences on the circulation and climate of the North Atlantic sector, *Monthly Weather Review*, **104**, 1255–1265.

of severe thunderstorm complexes. A weaker jet stream, as should occur with increasing levels of carbon dioxide, therefore would decrease the likelihood of tornadic activity, although this effect may be somewhat balanced by increases in atmospheric moisture levels. All in all, an enhanced greenhouse effect should have little effect on the intensity or frequency of tornadoes.

The notion of a future with more intense midlatitude storms caused by greenhouse gas increases is not supported by most models, by observations, or by theory.

SEA LEVEL RISE

Forecasts of disastrous flooding and coastal inundation from rising seas have also be included in scenarios of global warming caused by an increasing greenhouse effect. The earliest forecasts, made almost 20 years ago, showed sea levels rising tens of feet and included maps showing historic parts of Washington, D.C., awash in the waters of the tidal Potomac River.[179] These predictions were based upon early model scenarios that forecast an unrealistically large amount of warming to take place in the high latitudes, thereby melting vast volumes of ice stored there. Since that time, forecasts of sea level rise have been sharply reduced, as have high latitude temperature forecasts and the resulting ice melt; and now, sea level rise forecasts by the IPCC for the next hundred years are only in the range one to three feet.[180]

There are two primary reasons that sea levels rise: addition of more water and thermal expansion. The effect of each needs to be examined independently in order to assess the future importance and impact of climate change. Each would be affected by a rise in global temperatures, with the regionality, as well as the seasonality of the temperature change being important in addressing the overall impact on total global sea level rise.

Additional Water Inputs

Water sources that could potentially contribute to sea level rise include surface and ground water, glaciers and ice caps, and the ice sheets of

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[179] Schneider, S.H., and R. Chen, 1980. Carbon dioxide warming and coastal flooding: Physical factors and climate impact. *Annual Review of Energy*, **5**, 107–135.
[180] IPCC, 1995.

Antarctica and Greenland. Of these three, the one that is most directly impacted by humans is the alteration of surface and ground water storage. Human activity affects the terrestrial hydrologic cycle through water diversions, changes in stream networks, changes in watershed characteristics and irrigation practices. The sum of these changes has not been fully analyzed and therefore the effects on sea levels are not well quantified. Rough forecasts of the contribution to sea level rise from changing land and water use practices are rather low, with the IPCC estimate of about 1.1 inches over the next 50 years.[181] These changes, however, are not at all related to the amount of carbon dioxide in the atmosphere, and have occurred, and will continue to occur, regardless of atmospheric CO_2 concentrations. Therefore, sea level rise due to direct alteration of the hydrologic cycle due to these types of activities should not be included in discussions of the climate change aspects of sea level rise.

In any case, far more important are the possible contributions from the vast stores of ice on the planet. Glaciers around the world have been melting during the past 150 years or so. The primary cause of this melting has been the rebound of global temperatures from the multicentury period of lower global temperatures known as the "Little Ice Age," which ended in the mid-19th century. During this period, mountain glaciers experienced rapid accumulation and growth of ice. Since then, temperatures have been rising, and glaciers have been melting. The IPCC estimates that the additional melting of glaciers will contribute about 6.3 inches of sea level rise by 2100.[182] Considering that estimates of the total amount of water contained in this ice are in the range of 5.9 to 10.6 inches,[183] the IPCC estimate seems much too high, in that it would require a melting of between 60 percent and 100 percent of all the world's ice outside of Greenland and Antarctica. Additionally, the largest cause of glacial melting is a prolonged warming of summer daytime temperatures. It is primarily during this time that temperatures on the glaciers reach above freezing. The warming that is most likely to occur in the future is one that is mostly confined to night, and thus has its largest effects in winter. This type of climate change does not significantly melt glaciers.

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[181] IPCC, 1995, p380.

[182] IPCC, 1995, p381.

[183] Ohmura, A., M. Wild, and L. Bengtsson, 1996. A possible change in mass balance of Greenland and Antarctic ice sheets in the coming century. *Journal of Climate*, **9**, 2124–2135.

By far, most of the world's ice is contained in the ice sheets of Antarctica and Greenland. If these regions were to release large volumes of water, drastic sea level rise would occur. However, temperatures in these places are very low, with only the margins and southern portions of Greenland subject to any melting at all during the course of a year. Even future warming scenarios do not change this fact. With higher temperatures, though, more moisture is available in the atmosphere, and more snowfall occurs in this region. This results in net snow and ice accumulation in the cold areas, which include nearly all of Antarctica and the interior portions of central and northern Greenland. A recent comprehensive study found that, over the course of the next hundred years, the amount of water contained in the ice on Antarctica is supposed to increase, producing a sea level drop of 3.54 inches, while the ice sheets on Greenland experience a net reduction, adding about 4.33 inches of sea level rise.[184] The numbers from IPCC are in a similar range.[185]

Therefore, using the future warming scenarios from current climate models, and including sea level rise from the addition of new water to the oceans that is not due to land and water-use changes, ocean level rises are forecast to be between 6 to 8 inches (6 inches from midlatitude ice and 1 inch from Greenland/Antarctica).

Thermal Expansion

An additional source of sea level rise is thermal expansion. As the temperature of water increases, its density decreases, so that a constant mass of water occupies a larger volume at higher temperatures. In other words, water expands when it warms. Global warming during the past 100 years is thought to be responsible for about 1.5 inches of sea level rise.[186] IPCC forecasts for the next 100 years are for an additional 11 inches.[187] Considering that global temperatures have risen about 0.6 degrees in the last hundred years, and are forecast by the IPCC to rise another 2.0 in the next hundred years, the IPCC estimate of sea level rise due to thermal expansion is too high. Based upon observations alone, the sea levels should only rise 5 inches by 2100 (2.0 / 0.6 * 1.5 = 5) due to expanding sea water.

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[184] Ibid.

[185] IPCC, 1995, p381.

[186] IPCC, 1995, p380.

[187] IPCC, 1995, p381

In the most recent IPCC report, the "best guess" forecast for the total sea level rise by 2100 is 19.3 inches (which includes land and water-use changes).[188] Another scenario included in the same IPCC report and described as "internally consistent, plausible, and 'state-of-the-art,'" shows only 10.2 inches of rise.[189] Our argument here leads to an expected value of 10 inches, based upon the notion that IPCC must be overestimating the amount of midlatitude melting and thermal expansion. Even so, IPCC's own forecasts have been lowered significantly from its original 1990 report, in which the median sea level rise estimate to 2100 was 26 inches. The primary reason for this reduction was that the forecasts of global temperature rise were reduced from 3.2°C to 2.0°C.[190] But the new scenarios are based upon GCMs which increase the future concentration of atmospheric carbon dioxide faster than is currently forecast, and much faster than it has been observed,[191] include too much forcing from methane,[192] and overestimate the direct warming effects of carbon dioxide.[193] Taking into account these errors, total temperature rise by 2100 should be further reduced to between 1°C and 1.5°C. Roughly applying this reduction in temperature to the forecasts of sea level rise results in sea level rises that are between 50 percent and 75 percent of the current forecast values. Even using the IPCC numbers, the best guess range of sea level rise during the next century would then be about 5 to 15 inches. This is a rise that may not be noticeable, and to which adaptations could easily occur. Currently much of the city of New Orleans and The Netherlands is *below* sea level.

We can and do adapt to changes that are this slow. Because of geological considerations, relative sea level rise in Tidewater Virginia has been one foot during this century. There has been no known economic impact.

Sea level rise doesn't make for a disaster unless it occurs in very large amounts over a short time period. The only way this could happen is with a collapse of the West Antarctic ice sheet. While some scientists have proposed that the likelihood that this will happen is greatly increased in a warmer world, recent research has shown the chance of this occurring is about 1 in 100,000 in any given year. In fact, the current conformation of this ice sheet is very stable, and there is no

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188 IPCC, 1995, p384.

189 IPCC, 1995, p385.

190 IPCC, 1995, p384.

191 Hansen, J. et al., 1998, op. cit.

192 Dlugokencky, E.J., et al., 1998, op. cit.

193 Myhre, G., et al., 1998, op. cit.

evidence of any stress that might indicate a sudden shift. Further, it takes thousands of years for the ice sheet to respond to changes in surface air temperatures because a major instability requires shifts in the flow of the ice streams at the bottom of the sheet which are grounded on the sea bed and thus very insensitive to surface temperatures.[194]

Therefore, all indications are that few humans will be directly impacted by rising sea levels. The exception may be residents of low-lying island nations, but they are already dealing with observed sea levels. In the Maldives, for example, where nearly 80 percent of the land has an elevation of less than three feet, residents are now taking steps to better protect the most important shorelines from the effect of storms and waves, regardless of global warming.

Sea level rise has been characterized by the IPCC "in terms of environmental and social consequences...[as] arguably one of the most important impacts of global climate change."[195] But this is off base. The most likely scenario during the next century is one of a slow rise in sea level, not much different than the one that has occurred over the last 100 years. To this we have adapted, and we will continue to do so into the future.

EL NIÑO

The strong 1997–1998 El Niño generated historic levels of media coverage, making it arguably the most discussed climate story in human history. This El Niño was repeatedly linked to nearly every severe weather event that occurred over that time period, including California flooding, strong Atlantic coastal storms, tornadoes and wildfires in Florida, and drought in Texas, to name a few. And for the first time, El Niño was connected by some to global warming.

Many of these proclamations do not survive careful scientific scrutiny. While our understanding of El Niño and its impacts improves with each El Niño event, it is clear that we know very little about direct causes and effects from this recurring climatological feature.

El Niño is the term for an oceanic warming that occurs in winter off the coast of Peru. Periodically, the warm period extends well beyond a

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[194] Bentley, C.R., Rapid sea-level rise soon from West Antarctic ice sheet collapse. *Nature*, **275**, 1077–1078.
[195] IPCC, 1995, p365.

few winter months, lasting for one year or more, and the warm pool expands across the equatorial Pacific. During these prolonged El Niño events, the tropical trade winds slacken, significantly altering the typical locations of wet and dry regions throughout the tropics. Because tropical weather is linked in a complex and poorly understood manner with weather outside of the tropics, many scientists believe that El Niño events are global climate phenomena.

The most common method of assessing El Niño's status is to compare standardized surface pressure readings between Tahiti and Darwin, Australia. The pressure difference, called the Southern Oscillation Index (SOI), provides a substantial time series for evaluation of past El Niño events (negative SOI values). Positive SOI readings, or La Niña, represent an abnormal strengthening of the tropical trade winds. La Niña events are likewise believed to produce global climate impacts.

In 1996, Trenberth and Hoar examined a data set somewhat comparable to the typical SOI record.[196] They noted the pronounced intensity and length of the then-recent El Niño event and a relatively greater number of El Niño events in the last two decades. Using these observations, they claimed that, based on statistical probabilities, such a combination could only occur statistically once every 2000 years. Trenberth therefore claimed that global warming should produce more and stronger El Niños, and that this event was evidence of his hypothesis. In a rebuttal, Harrison and Larkin challenged his conclusion. Noting that Trenberth's data set was significantly smoothed and filtered, their statistical analysis suggested "it is plausible...that the unusual behavior in the early 1990s is the result of natural variability."[197]

Also, in a modeling study using the NCAR GCM, Liang and Wang found that, without any increases in greenhouse gases, prolonged and frequent El Niño events are not rare at all in portions of the record.[198] This is an indication that the recent increase in El Niños is likely part of a naturally occurring cycle.

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[196] Trenberth, K.E. and T.J. Hoar, 1996. The 1990–1995 El Niño-Southern Oscillation event: Longest on record. *Geophysical Research Letters*, **23**, 57–60.
[197] Harrison, D.E. and N.K. Larkin, 1997. Darwin sea level pressure, 1876–1996. Evidence for climate change? *Geophysical Research Letters*, **24**, 1779–1782.
[198] Liang, X. -Z. and W.-C. Wang, 1998. The observed fingerprint of 1980–1997 ENSO evolution in the NCAR CSM equilibrium simulation. *Geophysical Research Letters*, **25**, 1027–1030.

Later, during the height of the 1997-98 El Niño event, Trenberth was quizzed about the global warming/El Niño connection. After first noting that the models we have are not really good enough to convincingly make this connection, he nevertheless wrote "There's got to be a connection."[199] This general line of thinking was used repeatedly by Administration officials, including the Vice President, in stating that the weather events to which they linked El Niño are typical of what we would expect as global warming becomes more pronounced. Because prolonged El Niño events generally warm the planet, Gore proclaimed "We know that as a result of global warming, there is more heat in the climate system, and it is heat that drives El Niño."[200]

Several additional modeling studies specifically examining El Niño events contradict Gore and Trenberth. Knutson and Manabe predicted a reduction in El Niño activity in a future atmosphere with elevated carbon dioxide concentrations.[201] Sun, using a different modeling approach, likewise demonstrated an El Niño reduction as the planet warms.[202]

Because El Niños have been occurring for thousands of years, it is possible to extract information on them from the geologic record. Sandweiss et al. detected almost no evidence of El Niño activity 4,000 to 7,000 years ago during a period when the planet was 1°C to 2°C warmer than today.[203] Grove, using historical texts, noted that the earth has a long history of severe El Niños, and proclaimed, "There have been colossal El Niños [over many centuries and] there was no global warming then."[204] Based on an oxygen isotopic analysis of corals, Fairbanks developed a several-hundred-year record of El Niño

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[199] Trenberth, K.E., 1998. El Niño and global warming: What's the connection? *UCAR Quarterly*, **24**, Winter, 1997.
[200] White House press release, June 8, 1998
[201] Knutson, T.R. and S. Manabe, 1994. Impact of increases in CO2 on simulated ENSO-like phenomena. *Geophysical Research Letters*, **21**, 2295–2298.
[202] Sun, de-Zheng, 1997. El Niño: A coupled response to radiative heating. *Geophysical Research Letters*, **24**, 2031–2034.
[203] Sandweiss, D.H. et al., 1996. Geoarchaeological evidence from Peru for a 5,000-year b.p. onset of El Niño. *Science*, **273**, 1531–1533.
[204] Grove, R.H., 1998. Global impact of the 1789–93 El Niño, *Nature*, **393**, 318–319.

occurrence.[205] His analysis showed that current El Niño levels are similar to those of 1783, in the midst of the Little Ice Age. In the nineteenth century, when the earth was warming as the Little Ice Age waned, El Niño occurrence declined.

Somewhat contradictory results were recently reported by Tsonis, who poses the possibility that El Niño/La Niña events have a role in *balancing* global temperature trends.[206] Tsonis hypothesizes that during warming trends, El Niños become more frequent and serve as a method of heat dissipation. Conversely, during cooling episodes, La Niñas become more frequent. In short, El Niños and La Niñas may be responsible for regulating the planet's temperature, making sure the planet neither gets significantly warmer nor colder.

Despite numerous proclamations to the contrary, established, predictable linkages between El Niño events and weather occurrences outside of the tropics are rare. This is partly because each El Niño event is unique, and the resulting atmospheric circulation in the middle latitudes is highly variable. Hoerling and Kumar compared upper air circulation for some recent major El Niños and found that "...most of the observed differences in large-scale circulation anomalies among the [El Niño] events may not [be] predictable from knowledge of [El Niño]." The variability between El Niños is so great that some regions experience flooding during one event and drought during the next.[207]

The winter of 1997–1998 was noteworthy for the impact from a number of strong Atlantic coastal storms, or nor'easters, which were claimed by some to be a response to the contemporaneous El Niño event. Historic records of strong nor'easter occurrence along the mid-Atlantic, however, indicate that there is no statistically significant relationship. There is also no relationship between total nor'easter counts and El Niño.

The spate of wildfires along the central Florida coast in early summer of 1998, driven by severe drought conditions, was frequently

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[205] Fairbanks, R.G. et al., 1997. Evaluating climate indices and their geochemical proxies measured in corals. *Coral Reefs*, **16**, S93–S100.

[206] Tsonis, A.A., Roebber, P.J. and J.B. Elsner, 1998. A characteristic time scale in the global temperature record, *Geophysical Research Letters*, **25**, 2821–2823.

[207] Hoerling, M.P. and A. Kumar, 1997. Why do North American climate anomalies differ from one El Niño event to another? *Geophysical Research Letters*, **24**, 1059–1062.

connected with El Niño. There is, however, no relationship between drought in this region and El Niño events. Figure 25 shows annual values in Florida of the Palmer Drought Severity Index (PDSI), a commonly used indicator of precipitation/soil moisture status with El Niño events highlighted. El Niños are as frequently related to wet years in central Florida (positive PDSI) as to dry years.

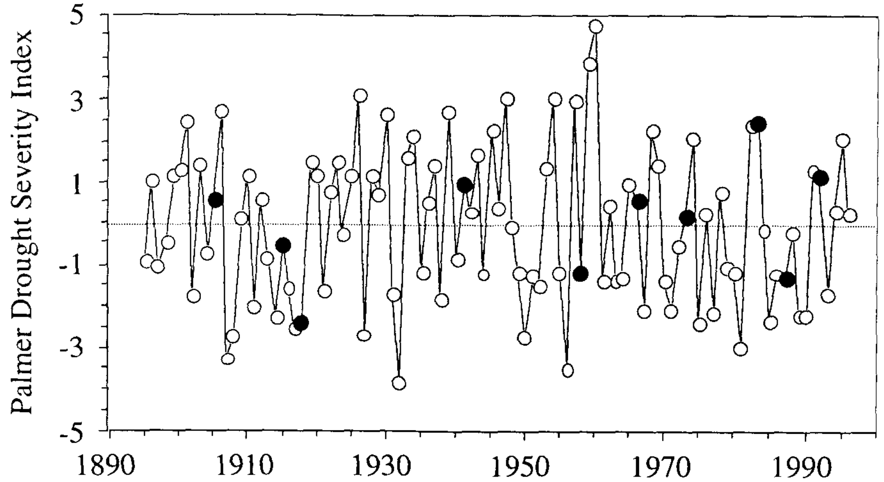

Figure 25. Annual values in Florida of the Palmer Drought Severity Index (PDSI), a commonly used indicator of precipitation/soil moisture status, with El Niño events highlighted.

One of the few demonstrable linkages is that El Niño suppresses Atlantic hurricane activity. Because tropical cyclones are one of the major causes of weather-related damage, it has been argued that El Niños might actually provide a net economic benefit to the United States.[208]

In summary, while El Niño events are frequently linked to specific weather phenomena outside of the tropics, these relationships are not borne out by analysis of historical climate records. There is no evidence that global warming will make future El Niños more common or severe. But there is evidence from geological records that El Niños may in fact be more common during cold periods.

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[208] *World Climate Report*, 1998. El Niño blows $6,000,000,000 into the economy. Volume 3, Number 12.

HUMAN ILLNESS AND MORTALITY

A number of environmentalists and health experts have warned that the climatic effects resulting from global warming might create health problems.[209,210,211,212,213,214,215,216,217,218,219,220] Other studies have found less cause for alarm.[221,222,223,224,225,226,227,228,229] Notably, the World Health

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209 Danzig, D., 1995. Global Warming = Health Hazard, Sierra Club, http://www.sierraclub/org.
210 IPCC, 1995.
211 Jackson, E., 1995. Climate Change and Emerging Infectious Diseases, *Medical Journal of Australia*, **163**, 570–574.
212 Epstein, P., and R. Gelbspan, 1995. Should We Fear a Global Plague? Yes — Disease is the Deadliest Threat of Rising Temperatures, *The Washington Post*, (March 21): C1, C4.
213 Cromie, W., 1995. Global Warming May be Hazardous to Your Health, *Harvard University Gazette*, 91(3), (September 2): 1 & 8.
214 Stone, R., 1995. If the Mercury Soars, so May the Health Hazards, *Science*, **267**, 957–958.
215 Monastersky, R., 1994. Viking Teeth Recount Sad Greenland Tale, *Science News*, **146**, 310.
216 Patz, J., et al., 1996. Global Climate Change and Emerging Infectious Diseases, *JAMA*, **275**, 217–223.
217 Kalkstein, L.S., and R.E. Davis, 1989. Weather and Human Mortality: An Evaluation of Demographic and Interregnal Responses in the United States. *Annals of the Association of American Geographers*, **79**, 44–64.
218 Kalkstein, L.S., 1991. A New Approach to Evaluate the Impact of Climate on Human Mortality, *Environmental Health Perspectives*, **96**, 145–150.
219 Kalkstein, L. S., 1992. Impact of Global Warming on Human Health: Heat Stress-Related Mortality. *Global Climate Change: Implications, Challenges and Mitigation Measures*, Chapter 26, edited by S. K. Majumdar, L. S. Kalkstein, B. Yarnal, E. W. Miller, and L. M. Rosenfeld. Easton, PA: The Pennsylvania Academy of Science, 371–83.
220 Epstein, P., et al., 1998. Biological and Physical Signs of Climate Change: Focus on Mosquito-borne Diseases, *Bulletin of the American Meteorological Society*, 409–417.
221 World Health Organization, 1990. *Potential Health Effects of Climate Change: Report of a WHO Task Group*. World Health Organization, Geneva, Switzerland.
222 Committee on Science, Engineering, and Public Policy, 1991. *Policy Implications of Greenhouse Warming*, National Academy of Sciences, National

Organization in its annual *World Health Reports* has largely ignored the subject, suggesting that it is unimportant.

Most causes of premature death have nothing to do with climate. Worldwide, the leading causes are chronic diseases—accounting for 24 million deaths in 1996—such as maladies of the circulatory system, cancers, mental disorders, chronic respiratory conditions, and musculoskeletal disorders, none of which has anything to do with climate but everything to do with aging.[230] Another 17 million deaths in the same year, most of them in poor countries, are traceable to disorders caused by infections or parasites, such as diarrhea, tuberculosis, measles, and malaria. Many of those diseases are unrelated to climate; most have to do with poverty.

The scientific community and the medical establishment both assert that the frightful forecasts of an upsurge in disease and early mortality stemming from climate change are unfounded, exaggerated, or misleading and do not require action to reduce greenhouse gas emissions. *Science* magazine reports: "Predictions that global warming will spark epidemics have little basis, say infectious-disease specialists, who argue that public health measures will inevitably outweigh effects of climate."[231] The article adds: "Many of the researchers behind the dire predictions concede that the scenarios are

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Academy of Engineering, Institute of Medicine, Washington DC: National Academy Press.

[223] Taubes, G., 1997. Apocalypse Not, *Nature,* **278**, 1004–1006.

[224] White, M.R. and I. Hertz-Picciotto, 1995. Human Health: Analysis of Climate Related to Health, chapter seven in *Characterization of Information Requirements for Studies of CO_2 Effects: Water Resources, Agriculture, Fisheries, Forests and Human Health*, edited by Margaret R. White. Washington, DC: U.S. Department of Energy, Office of Energy Research, 172–206.

[225] Shindell, S. and J. Raso, 1997. *Global Climate Change and Human Health*, American Council on Science and Health, New York, NY.

[226] Cross, F.B., 1995. When Environmental Regulations Kill, *Ecology L. Q.*

[227] Moore, T.G., 1998a. *Climate of Fear: Why We Shouldn't Worry about Global Warming*, Washington, D.C., Cato Institute.

[228] Moore, T.G., 1998b. Health and Amenity Effects of Global Warming, *Economic Inquiry*, **36**, 471–488.

[229] Murray, David., 1996. *Emerging Infectious Diseases: A Stats Report*, Washington D.C., Statistical Assessment Service Report.

[230] World Health Organization, 1997. *The World Health Report*, Geneva.

[231] Taubes, G., 1997, op. cit.

speculative." The American Council on Science and Health has concluded:

> The optimal approach to dealing with prospect of climate change would a) include improvement of health infrastructures (especially in developing countries) and b) exclude any measures that would impair economies and limit public health resources.[232]

Concern about tropical and insect-spread diseases seems overblown. Inhabitants of Singapore, which lies almost on the equator—and of Hong Kong and Hawaii, which are also in the tropics—enjoy life spans as long as or longer than those of people living in Western Europe, Japan, and North America. Both Singapore and Hong Kong are free of malaria, but that mosquito-spread disease ravages nearby regions. Modern sanitation in advanced countries prevents the spread of many scourges found in hot climates. Such low-tech and relatively cheap devices as window screens can slow the spread of insect vectors. The World Health Organization notes:

> Until recent times, endemic malaria was widespread in Europe and parts of North America and ... yellow fever occasionally caused epidemics in Portugal, Spain and the U.S.A. Stringent control measures... and certain changes in life-style following economic progress, have led to the eradication of malaria and yellow fever in these areas.[233]

Diseases such as Lyme disease, yellow fever, malaria, and cholera, can usually be controlled through technology, good sanitary practices, and education of the public. On the other hand, if public health practices are cut back, it is certainly possible that, even without warming, dengue fever or malaria could invade North America.

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[232] Shindell, S. and J. Raso, 1997, op. cit.

[233] World Health Organization, 1990. *Potential Health Effects of Climate Change: Report of a WHO Task Group.* World Health Organization. Geneva, Switzerland. p21.

Diseases

Mosquito-Borne Diseases

Before World War II, malaria was widespread in the United States. The government recorded over 120,000 cases in 1934; as late as 1940, the number of new sufferers totaled 78,000.[234] After the war, reported malaria cases in the United States plunged from 63,000 in 1945 to a little over 2,000 in 1950 to only 522 in 1955. By 1960, DDT had almost eliminated the disease. Only 72 cases were recorded in the whole country. In 1969 and 1970, the Centers for Disease Control reported a resurgence to around 3,000 cases annually, brought in by service personnel returning from Vietnam. Subsequently, immigrants from tropical areas have spawned small upticks in new cases.

In the 1980s and 1990s, as Figure 26 shows, the number of reported cases has averaged around 1200 to 1300 annually. The CDC reports that, since 1985, approximately 1,000 of those cases have been imported every year, with visitors and recent immigrants accounting for about half. The rest come from travelers arriving from tropical countries, service personnel returning from infested areas, and a handful of individuals, typically those living near international airports, bitten by a mosquito that hitched a ride from another country.

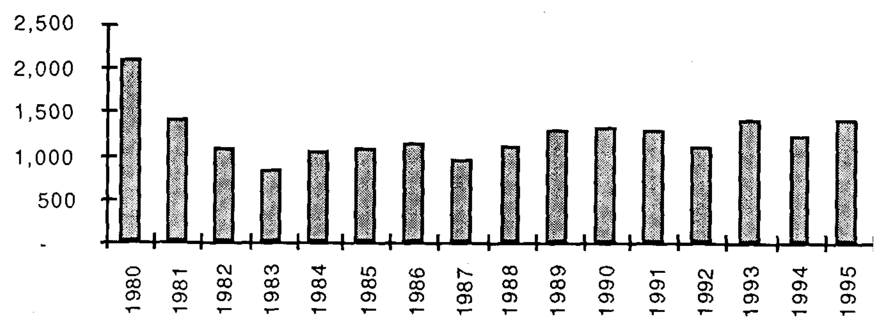

Figure 26. Reports of Malaria cases in the United States have remained relatively constant. Source: CDC and the *Statistical Abstract of the United States.*

[234] Centers for Disease Control and various editions of the Statistical Abstract of the United States.

Yellow and dengue fevers were both common in the United States from the seventeenth century onward. Epidemics of yellow fever ravaged New Yorkers and killed tens of thousands of people. In 1878, of 100,000 cases reported along the East Coast, 20,000 people died. Between 1827 and 1946, eight major pandemics of dengue fever overran the United States. In 1922, the disease spread from Texas, with half a million cases, through Louisiana, Georgia, and Florida. Savannah suffered with 30,000 cases, of which nearly 10,000 had hemorrhagic symptoms, a very serious form of the disease. In contrast, last year the CDC listed 86 imported cases of dengue and dengue hemorrhagic fever and eight local transmissions, all in Texas. There were *no* reported cases of yellow fever.

As a public health issue, those diseases, which did plague the United States in the colder nineteenth and early twentieth centuries, have been largely eradicated. There is no evidence that a resurgence is imminent. Certainly the climate is not keeping the spread of these diseases in check. If it was warm enough in the cold nineteenth century for the mosquitoes to thrive, it is warm enough now.

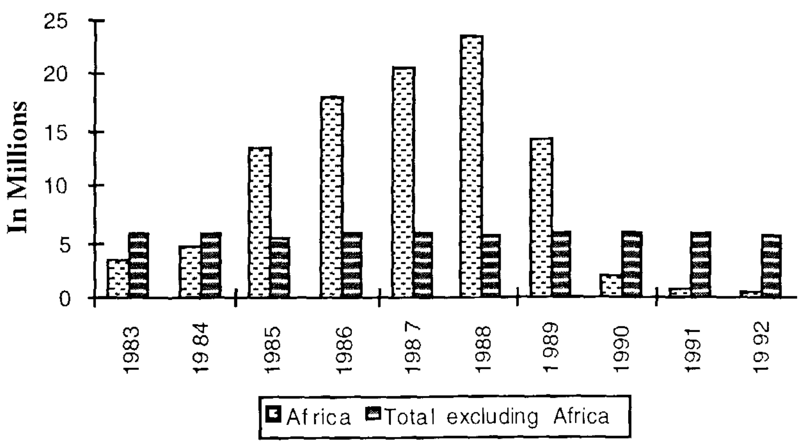

Figure 27. Reported cases of malaria in Africa and the rest of the world. Source: WHO, Malaria Control Program, Geneva, Switzerland.

Is there any basis at all for these scaremongering prophecies? Is malaria rising worldwide? Not according to the World Health

Organization. As Figure 27 shows, from 1983 to the latest year for which data exist, 1992, the number of cases of malaria reported in Africa, the most heavily infested section of the world, has fallen sharply, especially in the most recent years. For the rest of the world, reports are somewhat less encouraging. Malaria continues to be a problem, but there has been no increase in cases reported even though the world's population has climbed. The good news is that the rate of malaria per 100,000 people has fallen for the whole world.

What brought an end to these scourges? The introduction of DDT clearly played a major role. From the end of World War II until it was banned in 1972, that pesticide worked wonders in eliminating harmful insects, especially mosquitoes. But it wasn't just insecticides that did the trick. Screens on windows, the elimination of standing water, and population movement to the suburbs (which reduced population density and thus the risk of transmission) have played a critical role in eliminating mosquito-borne diseases.

In 1995, however, a dengue pandemic afflicted the Caribbean, Central America, and Mexico, generating around 74,000 cases. More than 4,000 Mexicans living in the Tamaulipas state, which borders Texas, came down with the disease. Yet Americans living a short distance away remained unaffected. The contrast between the twin cities of Reynosa, Mexico, which suffered 2,361 cases, and Hidalgo, Texas, just across the border, is striking. Including the border towns, Texas reported only 8 non-imported cases for the whole state.

The only reasonable explanation for the difference between the spread of dengue in Tamaulipas and its absence in Texas is living standards. Where people enjoy good sanitation and public education, have the knowledge and willingness to manage standing water around households, implement programs to control mosquitoes, and employ screens and air conditioning, these mosquito-borne diseases do spread. If the climate does warm, those factors will remain. In short, Americans need not fear an epidemic of tropical diseases.

Even without warming, it is certainly possible that dengue fever or malaria could invade North America. Unfortunately, some of the government's environmental policies may make the vector more likely. The preservation of wetlands, although useful in conserving species diversity, also provides prime breeding ground for mosquitoes that can carry these diseases. If the United States does in the future suffer from such insect-borne scourges, the infestation may have less to do with global warming than with the preservation of swampy areas.

Cholera

One recent manifestation of fearmongering about the health effects of global warming is a curious article in *Science*, taken from a modified text of Rita Colwell's presidential address to the American Association for the Advancement of Science's (AAAS's) 1996 annual meeting.[235] This address presents a studious analysis of cholera and its recent resurgence in the Americas. What is most singular is not what is in Colwell's report but what she fails to mention.

Despite the title of the address, "Global Climate and Infectious Disease: the Cholera Paradigm," climate change is scarcely broached; the one reference to it comes in connection with malaria, not cholera. Certainly Colwell makes no effort to tie global warming to the spread of cholera. Moreover, in a section strangely entitled "Global Climate, Global Change, and Human Health," the word "climate" never appears; nor do the words "warmer," "temperature," or "global." Also puzzling for such a careful exposition is the absence of any reference to the role that the U.S. Environmental Protection Agency recommendations may have played in creating the conditions leading to the explosion of cholera in Peru in 1991.

In 1817, the British first identified this dreaded disease in Calcutta, from whence it spread throughout India, Nepal, and Afghanistan. Ships carried it into Asia and Arabia, and to the ports of Africa. Cholera reached Moscow, its first port of call in Europe, in 1830, creating panic as locals fled the city. From there it traveled to Poland, Germany, and England. In the decade after it first appeared in Europe, it killed tens of thousands in Paris, London, and Stockholm. It reached North America in 1832, appearing first in New York and Philadelphia, then spreading along the coast to New Orleans. In that same year, the disease killed more than 2,200 people in Quebec. Apparently cholera is not a tropical disease; it can kill and sicken in any climate, although in high latitudes it may do so only in the summer.

Prior to the most recent outbreak, the world suffered six cholera pandemics. By the end of the nineteenth century, however, Europe and North America were free of the disease. The solution was simple: filtration and chlorination of the water supply. Filtering alone reduces not only the spread of cholera but cuts typhoid significantly. Combining filtration with chlorination eliminates waterborne diseases.

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[235] Colwell, R.R., 1996. Global Climate and Infectious Disease: The Cholera Paradigm, *Science*, **274**, 2025–2031.

A warmer climate, if it were to occur, would in no way reduce the effectiveness of these water purification measures.

In January 1991, after many disease-free decades, cholera began sickening villagers in Chancay, Peru, a port fewer than 40 miles north of Lima. It then spread rapidly up and down the coast. From that outbreak to the end of 1995, Latin America reported over 1 million cases—many went unreported—and 11,000 deaths. The illness traveled from Peru to Ecuador, Colombia, then to Brazil. Eight months after appearing in Peru, it reached Bolivia. By the end of 1992, virtually all of South and Central America, from Mexico to Argentina, had confirmed cases. In the early 1990s, cholera also entered the United States; however, with the exception of a few cases brought on by eating raw tainted shellfish, virtually all cases were contracted abroad. Seventy-five cases, nearly half of the total 160 reported to the CDC between 1992 and 1994, originated on a single flight from Lima in 1992!

What brought an end to Latin America's 100 years of freedom from cholera? Rita Colwell theorizes that an El Niño led to a plankton bloom that multiplied the hosts of *V. cholerae*. But El Niños have been occurring with some regularity for many years without producing a cholera epidemic. As Figure 28 shows, the coast of Peru in 1991 was not even particularly warm compared with a number of other years. Even if El Niño were in part the culprit, the basic cause lies elsewhere: Sanitation.

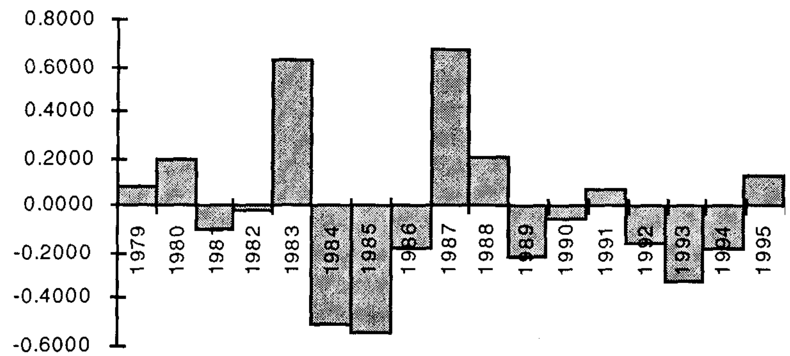

Figure 28. Temperature variation from normal off the Peruvian coast (from IPCC surface temperature data).

Based on U.S. Environmental Protection Agency studies showing that chlorine might create a slight cancer risk, authorities in Peru decided not to chlorinate their country's drinking water.[236] Perhaps they also thought they would save money. Chlorination, however, is the single most effective preventive of cholera and other waterborne diseases. In 1992 after the fiasco in Peru, the E.P.A. determined that there was no demonstrable link between chlorinated drinking water and cancer. It was too late; the harm had been done. Peru's misplaced environmentalism had led to more than 300,000 victims in that country alone.

Cholera is a disease of poverty, crowding, and unsanitary conditions. A warmer climate will not carry this disease to affluent countries; but in the Third World, economic growth can bring freedom from this and many other diseases. We should not impose costs on ourselves or on others that would reduce the resources needed to bring clean water and good public sanitation to Latin America, Africa, and Asia.

Extreme Temperatures

Will mortality rise with rising temperatures? Death rates during periods of very hot weather have jumped in certain cities, but above-normal mortality has not been recorded during all hot spells or in all cities. Moreover, research concerned with "killer" heat waves has generally ignored or downplayed the reduction in fatalities that warmer winter months would bring.

The United States is one of few populous countries that maintains a long-term, high quality database on mortality. For the latter half of this century, everyone who dies is entered into a master database that includes their age, race, sex, county of residence and death, date of death, and cause of death (from the death certificate). This database provides a potentially excellent source for evaluating environmental relationships to human mortality.

To address possible future weather–mortality relationships, current linkages must first be established. Kalkstein and Davis[237] prepared one of the most comprehensive studies based on daily mortality and weather data for all of the major metropolitan areas in the United States. Their results highlight the importance of local factors in

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[236] Anderson, C., 1991. Cholera Epidemic Traced to Risk Miscalculation, *Nature*, **354,** 255.
[237] Kalkstein, L.S. and R.E. Davis, 1989, op. cit.

mortality, making the development of a generally applicable national or global model very difficult if not impossible. For example, Kalkstein and Davis determined that each city has a specific threshold temperature, the temperature beyond which mortality increases abruptly. There is certainly no straightforward, linear relationship between temperature and mortality counts. In Chicago, for instance, when 3 p.m. temperatures are below about 87°F, daily death totals can be high or low (Figure 29). However, as temperatures reach the upper 80s and beyond, the likelihood of higher death totals increases.

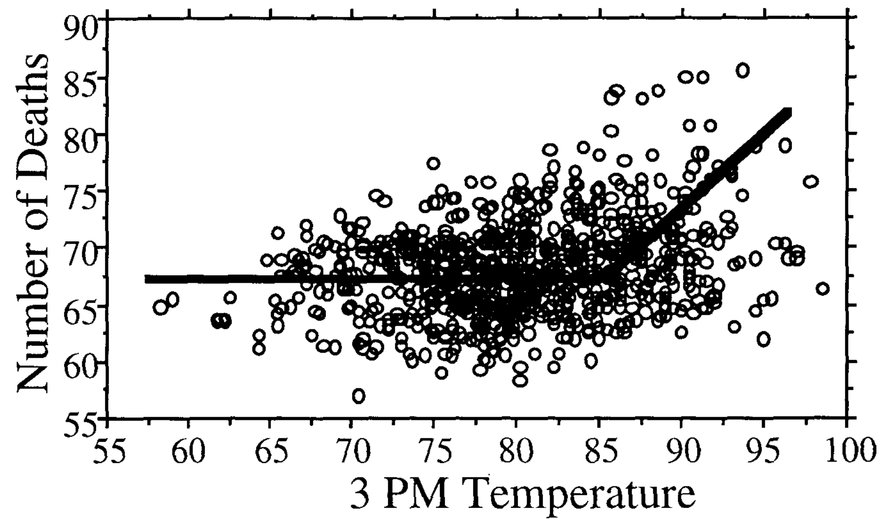

Figure 29. Chicago total daily mortality in summer versus 3 p.m. temperature. Note that that deaths increase sharply above 87°F.

Not all cities have threshold temperatures—hence the importance of intercity differences and acclimatization. For example, there is no summer threshold temperature in Phoenix or Jacksonville. In these cities, there is no increase in mortality whatever the maximum temperature. Populations there acclimatize to hot conditions with the help of better building design, the prevalence of air-conditioners, physiological adaptation, and other factors. Similarly, there is no low threshold temperature in Minneapolis in winter. Most northern cities have summer threshold temperatures, and most southern cities have winter threshold temperatures, since the people in these regions have not adapted to extreme conditions. Thus, whereas 94°F highs in Jacksonville would have no mortality impact, similar conditions in Boston may produce high death totals.

So how will mortality rates in a city like Dallas change in response to global warming? Simply for the sake of argument, let's assume that there will be more warm days in Dallas in the future. Will more people die because of more days above the threshold temperature? Or will the threshold temperature become higher through adaptation? Or, will the relationship change so that Dallas has a mortality–temperature situation more like what Phoenix has now, with no threshold temperature? Those promoting worst-case scenarios would simply assume that current relationship would carry into the future and that mortality would increase dramatically. But is this realistic?

To correctly forecast future mortality changes, one must consider changes in our infrastructure. In the United States, for example, one-half of all homes were built within the last 25 years. No doubt the lion's share of these were fitted with central air-conditioning, which is known to reduce summer mortality. Many more old buildings with poor ventilation will be destroyed, and many others will be retrofitted with current technology. Numerous lives will be saved or prolonged in the process of making these upgrades, and these changes should be factored into future mortality scenarios.

Despite the high-quality mortality data available in the United States, city-specific research is still severely limited by the small sample size. Proper analyses can only be conducted for the largest metropolitan areas, and even these data sets may not be large enough. Daily mortality data have high variances, even in the largest cities. In Chicago, note (Figure 29) that there are numerous low mortality counts on some of the hottest days, and that the variance increases with increasing temperature. This kind of problem is magnified in cities with smaller populations.

Furthermore, most of the analyses focus on total mortality to provide the largest possible samples. In some cities, there are significant relationships for total mortality that do not hold for the elderly, non-elderly, ethnic minority, or nonminority subsets. Relationships are often inconsistent across cities. In some cities, women are most susceptible to high temperatures; in others, men are.[238] There is a significant impact of hot weather on African-Americans in St. Louis but not in New York City, where Caucasians are disproportionately impacted.[239] All of these relationships may be real and explainable, but they could also be statistical artifacts. Information on death causes in

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[238] Moore, T.G.,1996. Health and amenity effects of global warming. *Working Papers in Economics*, E-96-1, The Hoover Institution, 27 pp.
[239] Kalkstein, L.S., 1991, op. cit.

the mortality data set provides little insight. Very few Americans die specifically from heat or cold exposure; rather, heart attacks and strokes, two of the most common causes of death, occur slightly earlier than otherwise during adverse weather conditions. For example, in the major Chicago heat wave in July 1995, Cook County Medical Examiner Edmund Donoghue proclaimed these people were probably very near death, and their date of death was moved up by the heat. "How long they would have lived, I can't tell you." Lake County Coroner Barbara Richardson told the *Chicago Tribune*. "There's no way you're going to get me to say that definitely these were heat deaths. If it's 20 degrees below zero and someone dies of a heart attack, is that a cold death or a heart attack death?"

These officials' comments highlight two additional problems with mortality statistics. First, after a major heat wave, subsequent days typically have total deaths well below the average. This suggests that the heat may only be advancing death in the susceptible populace by a few days. Second, it's difficult even for a professional medical examiner to determine if heat or cold was actually a significant factor in a given death. Forecasts of increased future mortality from global warming must consider differences between winter and summer mortality, and how the future climate will change. In the United States, more people die in winter than in summer. Based on a 10-year record, there are an average of 132 heat deaths and 385 cold deaths annually (Figure 30).[240]

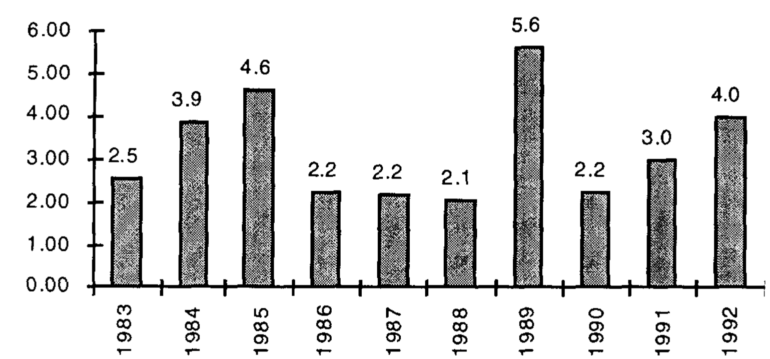

Figure 30. Proportion of weather-related cold deaths to heat-stress mortality. Source: Vital Statistics of the United States, 1983 through 1992.

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[240] Moore, T.G., 1996, op. cit.

For almost all death categories, winter mortality exceeds summer. Overall winter mortality is 16 percent higher than summer.[241] This is partially attributable to communicable diseases, such as influenza and pneumonia, flourishing during cold weather.

Almost all global warming theory and climate models predict that most of the warming will occur in the high latitudes and in winter. Furthermore, most of the warming will occur in the coldest air masses—the ones responsible for all of the winter cold air outbreaks. Warming of these air masses would presumably reduce future winter mortality rates. By comparison, little warming is expected in summer. When the additional future use of air conditioning is considered, summer mortality rates could very well decline even with a modest warming. One counterbalance could be that if an energy tax is imposed (presumably to mitigate global warming and reduce death rates), individuals may opt to reduce their air-conditioning usage to reduce costs. This may very well ultimately increase mortality.

Overall Health Effects

A number of researchers have found a negative relationship between temperature and mortality and/or a correlation between season and death rates.[242,243,244,245,246] For example, G. M. Bull and Joan Morton, British researchers, reported that deaths from myocardial infarction, strokes, and pneumonia fell with higher temperatures in England and Wales. In New York, however, they fell only until the temperature reached 68°F and then rose with the heat.[247] Momiyama et al. found that deaths followed a seasonal path but that, in the United States, this seasonal pattern had been reduced in the period from the 1920s to the

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[241] Ibid.

[242] Momiyama, M., 1963. A Geographical Study of Seasonal Disease Calendar Model by Period and Country. *Papers in Meteorology and Geophysics*, **14**, 1–11.

[243] Momiyama, M. and K. Katayama, 1967. A Medico-Climatological Study in the Seasonal Variation of Mortality in the United States of America (II). *Papers in Meteorology and Geophysics*, (September): 209–232.

[244] Momiyama, M. and K. Katayama., 1972. Deseasonalization of Mortality in the World. *International Journal of Biometeorology* , **16**, 329–342.

[245] Momiyama, M., 1963, op. cit.

[246] Bull, G. M. and J. Morton, 1978. Environment, Temperature and Death Rates. *Age and Aging* , **7**, 210–224.

[247] Ibid.

1960s. Even though a regimen of increased deaths in the winter is apparent for all portions of the United States, England, Wales, and Japan, many subsequent researchers have emphasized summer deaths attributed to high temperatures.

Seasonal Effects

If climate change were to manifest itself as warmer winters without much of an increase in temperature during the hot months, the change in weather could be especially beneficial to human health.[248] The IPCC reports that, over this century, the weather in much of the world has been consistent with such a pattern: Winter and night temperatures have risen much more than summer.[249]

A sample of 45 metropolitan areas in the United States shows that for each increase of a degree in the average annual temperature, July's average temperature goes up by only 0.5°, while January's average temperature climbs by 1.5°.[250] Since warming will likely exert the maximum effect during the coldest periods but have much less effect during the hottest months, the climate change should reduce deaths even more than any summer increase might boost them.

Deaths in the United States and most other advanced countries in the middle latitudes are higher in the winter than in the summer. Except for accidents, suicides, and homicides, which are slightly higher in the summer, death rates from virtually all other major causes rise in winter months; overall mortality from 1985 to 1990 was 16 percent greater when it was cold than during the warm season.[251] These data suggest that, rather than increasing mortality, warmer weather should reduce it. But this possibility is rarely discussed.

Earlier studies have also reported the relationship between season and death rates. Yale University School of Medicine's F.P. Ellis noted that deaths in the United States between 1952 and 1967 were 13 percent

[248] Gates, W.L., et al., 1992. Climate Modeling, Climate Prediction and Model Validation. In *Climate Change 1992. The Supplementary Report to the IPCC Scientific Assessment*, edited by J.T.Houghton, B.A. Callander and S.K. Varney. Cambridge: Cambridge University Press.
[249] IPCC, 1995.
[250] The data were collected from the Department of Cpmmerce, National Climatic Data Center, 1979.
[251] Moore, T.G., 1998b, op. cit.

higher on a daily basis in the winter than in the summer.[252] This difference is smaller than experienced during the 1985–1990 years, a period that included some of the hottest summers on record. Ellis's study covered a time during which recorded average temperatures in the United States were somewhat lower than during the 1985–1990 period. If hot weather were detrimental to life, the differential between summer and winter death rates during the latter period should have been smaller, not larger.

The increase in average temperatures during this century has apparently been accompanied by a decline in hot weather deaths relative to winter mortality. Before the early or middle part of this century, however, deaths during the summer months were much higher relative to winter than is currently the case.[253] Perhaps the decline in physical labor, which is afflicted with a much higher rate of fatal accidents than office work, helps to explain the change. One Japanese scholar, Masako Momiyama, reports that for most advanced countries, such as the United States, Japan, United Kingdom, France, and Germany, mortality is now concentrated in the winter.[254]

A number of studies, as indicated above, have examined death rates on a daily basis.[255,256,257] This allows the authors to compare extreme temperatures with mortality. Although the research has shown that it is typically the elderly or the very sick that are affected by temperature extremes, the analyses ignore the degree to which this shortens life. Might it be only a few days or a few weeks? That cities in the South fail to show any relationship between deaths and high temperatures suggests that the correlation in the North may stem from deaths of the most vulnerable when the weather turns warm. One way to parse whether climate extremes shorten lives by only a few days or whether they lead to more serious reductions in the life span is to consider longer periods.

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[252] Ellis, F.P., 1972. Mortality from Heat Illness and Heat-Aggravated Illness in the United States. *Environmental Research*, **5**, 1–58. This result is based on Table II, p15.
[253] Momiyama, M., 1977. *Seasonality in Human Mortality*, Tokyo: University of Tokyo.
[254] Ibid.
[255] Bull, G. M. and J. Morton, 1978, op. cit.
[256] Kalkstein, L.S. and R.E. Davis, 1989, op. cit.
[257] Kalkstein, L.S., 1991. op. cit.

Monthly data on deaths and temperatures, for example, show that deaths peak in the cold period. Moore's research finds that monthly figures on various measures of warmth are correlated with monthly deaths in Washington, D.C.[258] The results support the proposition that climate influences mortality.

Although deaths peak in the winter, factors other than cold, such as less sunlight, could induce the higher mortality. The peaking itself does not prove that warming would lengthen lives; it could be that the length of the day affects mortality. The day's length is closely correlated with temperature, of course, but unlike the amount of sunlight which remains constant each year, the latter variable fluctuates from year to year. Moore's research indicates that the length of the day is correlated with the death rate but is less statistically significant than temperature.[259] Moreover, if measures of temperature are combined with the length of the day, the amount of sunlight loses its statistical significance. Temperature remains the most important variable.

Climatic Effects

Comparing death rates in various parts of the United States provides evidence about how humans are affected by different climates. Within the continental United States, people live in locales that are subtropical, such as Miami, and cities that are subject to brutally cold weather, such as Minneapolis. The contrast between American cities makes the climate variables stand out. Within the United States, most people residing in big cities eat a more or less similar diet, live roughly the same way, and employ the same currency. Differences between the population of various parts of the United States are largely confined to the age distribution, ethnic concentrations, income, and, of course, weather.

In a recent study, Moore expanded the research from a single city to the effect of climate on death rates around the country. Clearly many factors affect mortality. Within any population the proportion that is old influences death rates. Since African-Americans have lower life expectancies than Caucasians, the proportion that is African-American affects mortality rates. Income and education are also closely related to life expectancy. As is well known, smoking shortens lives. Severe air pollution has pushed up mortality, at least for short periods.

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[258] Moore, T.G. 1998b, op. cit.

[259] Ibid.

As expected, age had the largest effect on death rates. The proportion of African-Americans is also highly significant in explaining death rates across counties. The higher the median income, the lower the death rate. Holding demographic and economic variables constant, Moore found lower death rates in warm climates. Various measures of climate demonstrate that warmer is healthier or at least extends life expectancies. Once the age structure is held constant, there is a well-established direct relationship between death rates and life expectancy. The analysis implies that if the United States were enjoying temperatures 4.5° warmer than today, 41,000 fewer people would die each year.[260] This saving in lives is quite close to the number Moore estimated based on monthly Washington, D.C., data for the period 1987 through 1989.

In summary, the monthly figures for the city of Washington, between 1987 and 1989, indicate that a 4.5° warmer climate would cut deaths nationwide by about 37,000; the analysis of climate in counties around the United States points toward a saving in lives of about 41,000. These data sets produce roughly the same conclusion: a warmer climate would reduce mortality by about the magnitude of highway deaths, although the latter deaths are more costly in that they involve a much higher proportion of young men and women.

A warmer climate should improve health and extend life for residents of the developed world. In the tropics, high death rates appear to be more a function of poverty than of climate.

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[260] Ibid.