Sustainable Development: Promoting Progress or Perpetuating Poverty?
edited by Julian Morris
published by Profile Books, London, August 2002

Chapter 9

A Climate of Uncertainty in the Greenhouse Century

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The climate of the Earth has always been in a state of change, ranging from long periods when the planet was nearly covered by ice to warm periods with no ice caps whatsoever. Millions of Years ago, the dinosaurs roamed an Earth nearly devoid of ice and snow, while only a few thousands of years ago, wooly mammoths ranged across a North American continent, half of which was covered by a mile of ice. These natural ebbs and flows in the global climate system are closely tied to variations in the Earth's orbit around the Sun, changes in the output of the Sun, periods of unusually high or low volcanic activity, and/or substantial changes in oceanic circulation.

We know about these natural climate variations from research on ice cores, tree rings, ancient pollen spores, and fossil records, all of which tell us the same story: Climate is highly variable, climate can change rapidly, and we should not expect the climate of our day to persist over long periods of time. They also tell us that climate change *has* occurred many times on a grand scale during the history of the Earth without any interference from human activities.

Despite this rich understanding of the climate history over the past five billion years of Earth's existence, we have recently witnessed the emergence of global climate change as one of the preeminent environmental issues of the day. The April 9, 2001, issue of *Time* magazine contained a cover story about global warming, and the final page of the issue was a letter to United States President Bush signed by Jimmy Carter, John Glenn, George Soros, Jane Goodall, Harrison Ford, Mikhail Gorbachev, Walter Cronkite, J. Craig Venter, Edward O. Wilson, and Stephen Hawking stating in the first sentence "No challenge we face is more momentous than the

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threat of global climate change." Up until September 11, 2001, this viewpoint was shared by many environmentalists and policymakers, and despite the more immediate and serious threat posed by terrorism, the global warming "threat" is still very much on minds of scientists and policymakers around the world.

Invention of the global warming scare

The global warming issue had been smoldering in climatology for nearly a century, but in a matter of a few months in 1988, it went from the stacks in the science library to front-page news throughout the world. During the late spring and early summer of 1988, much of the United States was suffering through an exceptional drought and stifling heat. On June 23rd of that year, Dr. James Hansen, then director of NASA's Goddard Institute for Space Studies, told a United States Senate hearing on climate change that the world was warmer than at anytime in the instrumental period (the past 150 or so years) and that at least some part of the warming was related to the buildup of greenhouse gases. In a much repeated and often misunderstood phrase, Hansen told the committee that he was "99 percent certain" that observed increase in global temperature was related to a global greenhouse effect enhanced by a variety of human activities, most notably the burning of fossil fuels.

Global warming was a leading news story for months to come in 1988, only to be fueled further by September's wildfires in Yellowstone Park (and throughout the western states of the USA) and Hurricane Gilbert's devastation from the Yucatan to Texas. Throw in a few other calamities from other parts of the world, including a record-breaking windstorm in London, and by the end of 1988 the global warming scare had shifted into high gear.

Acting in response to this scare, the United Nations quickly formed An "Intergovernmental Panel on Climate Change" (IPCC). Soon-to-be US Vice-President Al Gore took a leadership role in the global warming crusade (including publishing *Earth in the Balance* in 1992). Practically every environmental group on the planet climbed on board the global warming bandwagon. The media took any unusual weather event as convincing evidence of global warming, and on and on.

Momentum for the global warming scare became so great over such a short period of time that the ongoing debate regarding many key scientific questions and uncertainties was nearly squashed by the calls to "do something" about the problem. This momentum received a boost every January as we would learn that the previous year had been one of the warmest, if not *the* warmest, year on record. That momentum, quite unlike anything seen for any other environmental issue, continues to drive the global warming scare into the 21st century. And while the tragic events of September 11, 2001 may have deflated the importance of the perceived global warming crisis, countries throughout the world continue to push global warming as a centerpiece environmental issue.

The global warming debate enters the new millennium with many scientists and policymakers worldwide believing that without a substantial slow-down or reduction in the consumption of fossil fuels, we will soon witness a significant increase in planetary temperature, a rise in sea level, melting of icecaps and alpine glaciers, and an increase in droughts, floods, and severe storms.

But while some folks see a global warming apocalypse over the horizon, other scientists do not believe that warming is inevitable or that policy actions would significantly impact variations and trends in the global climate system. Furthermore, literally thousands of experiments have been conducted throughout the world showing that elevated levels of atmospheric carbon dioxide (CO_2) cause virtually all plants to increase their photosynthetic rates, water-use efficiency, and resistance to drought and other stresses. The spectrum of opinions runs from CO_2 as a curse threatening the climate system at one end to an inadvertent blessing from the Industrial Revolution at the other end of the spectrum. The "heated debate" is likely to go on for many years to come and uncovering fact verses fiction in such a complicated scientific, political, economic, and social issue is a major challenge unto itself.

How Reliable are Predictions of Climate Change?

The concentration of atmospheric CO_2 has increased from near 280 ppmv (parts per million by volume) at the beginning of the Industrial Revolution to approximately 370 ppmv in 2001, and the consumption of fossil fuels appears to be the largest contributor to this upward trend. At present, approximately 20 percent of the CO_2 emission comes from the United States leading to a popular observation that a relatively small number of people (approximately 5 percent of the global population) contribute disproportionately to the buildup of CO_2. But in the first few decades of this new century, CO_2 emissions from developing countries are expected to rise substantially, thereby lowering the proportion of global emissions emanating from the US (the US accounted for nearly half of global fossil-fuel CO_2 emissions in the late 1940s). Humans are currently adding over six billion tons of carbon to the atmosphere each year, thereby overwhelming the climate's carbon budgeting system and allowing the atmospheric CO_2 concentration to increase on a global scale.

Other human activities release assorted gases into the atmosphere which also have the ability to trap heat energy that would otherwise escape into space. These other greenhouse gases include methane, nitrous oxide, and various chloroflourocarbons, and each of these gases has its own unique geography of emissions. For example, rice paddy agriculture in southeastern Asia is a leading contributor to the global increase in methane. Humans are engaged in activities throughout the world that slightly alter the composition of the global atmosphere; however, even these relatively small changes to the gaseous mixture we call air can produce substantial changes to the climate.

For more than 100 years, climate scientists have calculated that a doubling of the concentration of these many greenhouse gases (expressed as CO_2 equivalents) would raise the planetary temperature by up to 6°C (10.8°F). The naturally-occurring greenhouse gases (water vapor is by far the most important greenhouse gas) act as a thermal blanket and maintain a mean atmospheric temperature 30°C (86°F) to 35°C (95°F) above the planetary temperature we would experience in the absence of these critical gases. The CO_2 and other greenhouse gases increase in atmospheric concentration and absorb heat energy (infrared radiation) given off by the surface of the Earth. The addition of these greenhouse gases should warm the Earth by themselves, but a water-vapor feedback mechanism nearly triples the overall warming effect. Basically, as the planetary temperature rises in response to higher concentrations of greenhouse gases, more water is evaporated into the atmosphere, and the increased concentration of water vapor drives the global temperature further upward.

Sophisticated global climate models, which are giant computer programs designed to simulate the laws of physics that control the atmosphere, continue to show that a doubling of greenhouse gas concentrations would force the global temperature to rise from between 1°C (1.8°F) to as much as 6°C (10.8°F). Furthermore, these models predict that a warmer world will have an invigorated hydrological cycle leading to an increase in precipitation at most locations across the globe.

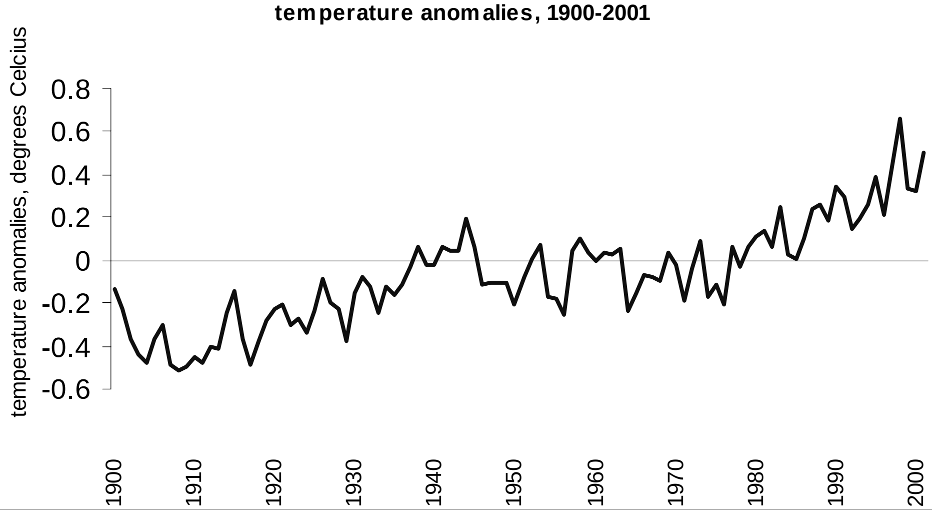
There is no doubt that the prediction for higher global temperatures and precipitation levels, given higher concentrations of greenhouse gases, is solidly grounded in the underlying physics that govern the climate system. These are fairly basic principles in the atmospheric sciences that have been known for over a century. Moreover, the prediction for warming comes from numerical climate models developed in major research laboratories in many nations, employing hundreds of the world's leading atmospheric scientists.

But the prediction is not without significant uncertainties. Climate models poorly represent cloud processes that could be critical in determining the overall energy balance of the Earth-atmosphere system. Additional high cloud cover in response to global warming would create a positive feedback effect, creating even higher temperatures. However, any increase in low cloud cover would act to cool the Earth putting a natural brake on the greenhouse effect. Today's models are not able to resolve critical questions regarding how the global cloud patterns will respond to higher temperatures, and as result of these cloud-related uncertainties, the confidence place on any prediction for future temperature increases remains relatively low.

When the clouds are not well modeled, neither are precipitation patterns, which in turn produce problems with the simulated surface hydrology. And without an adequate representation of soil moisture patterns, the models struggle with the surface energy balance, including the calculation of the near-surface air temperatures A shortcoming of numerical climate models is that they fail to accurately account for the relationship between the ocean and the atmosphere, which is especially critical for a planet on which land cover is less than 30 percent of the total global surface area. The numerical models also poorly simulate snow and ice processes, have poor, if any, biological routines, and many require significant flux adjustments (fudge factors) to keep from drifting into unrealistic climate states. One of the greatest uncertainties in model construction is the representation of water vapor levels in the middle atmosphere in the subtropical latitudes which are known to be critical in maintaining the radiation balance of the planet.

Despite these many uncertainties, the models are fabulous achievements in the atmospheric and computing sciences, and their prediction for global warming given a buildup of greenhouse gases should not be taken lightly. The exact amount of warming that will occur as a result of mankind's emissions of greenhouse gases remains unknown but current models, along with those simpler models used for over a century, universally show some amount of global warming.

Figure 1: Thermometer-based annual global temperature anomalies, 1900-2001



Observed Climate Changes

Given the long-standing prediction for global warming with increasing concentrations of greenhouse gases, it is logical for empirical scientists to examine the temperature record of the Earth to determine if warming has in fact occurred during the period of greenhouse gas buildup. Thermometer-based temperature records from land and sea have been assembled for as much of the Earth as possible[1], and indeed, the record shows a linear warming of 0.68°C (1.22°F) over the period 1900-2001, and the warming has accelerated in recent decades (Figure 1).

Scientists have noted that warming has occurred in most areas of the world, with the greatest warming occurring in high-latitude land areas of the Northern Hemisphere, in winter, and at night[2]. While interpretations vary on how to assemble these records and calculate the global temperature, the inescapable fact emerges that the thermometer-based near-surface air temperature record shows statistically significant warming over the past century, with the warmest years occurring in the most recent decades. At first glance, the warming anticipated from model simulations is similarly reflected by the historical temperature record from thermometers around the world. Analyses of global precipitation patterns are far less certain, although some evidence certainly exists suggesting a slight increase in global precipitation over the past century.

Attributing the observed surface warming to changes in atmospheric chemistry is compounded by many factors. First, as noted in the introduction, the climate system fluctuates naturally even without any external forcing, and the observed warming is not outside the bounds of natural fluctuations seen repeatedly in the long-term reconstructions of the global temperature. Also, much of the Earth experienced a “Little Ice Age” from approximately 1450 AD to 1850 AD, and the recent warming may be nothing more than a natural recovery from this unusually cool period.

Second, the irradiance from the Sun has varied through the past century with a distinctive upward trend (Figure 2) from 1900 to 1960. Many scientists believe that much of the observed warming prior to the 1970s can be ascribed to increasing output from the Sun and not to the buildup of greenhouse gases[3]. A more careful inspection of the near-surface global air temperatures (Figure 1) reveals substantial warming from 1910 to 1940, and that warming coincides nicely with the increasing output of the Sun.

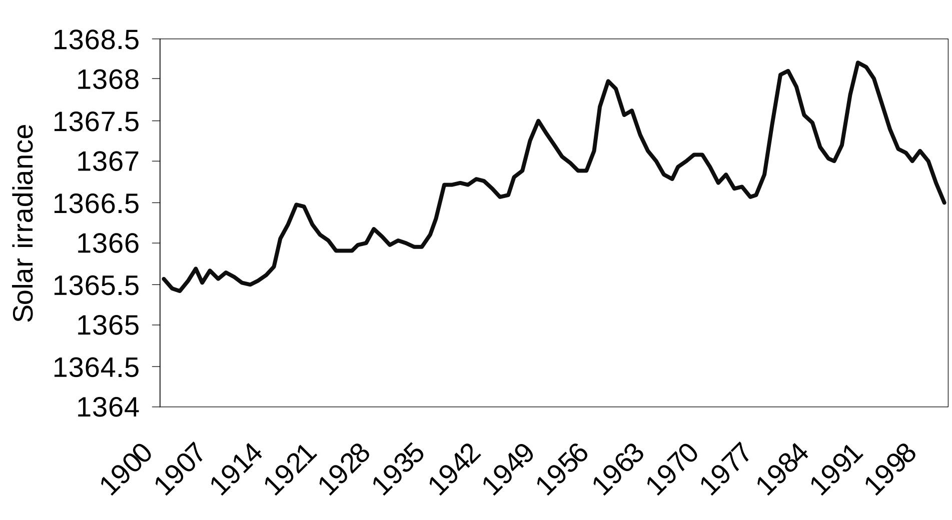


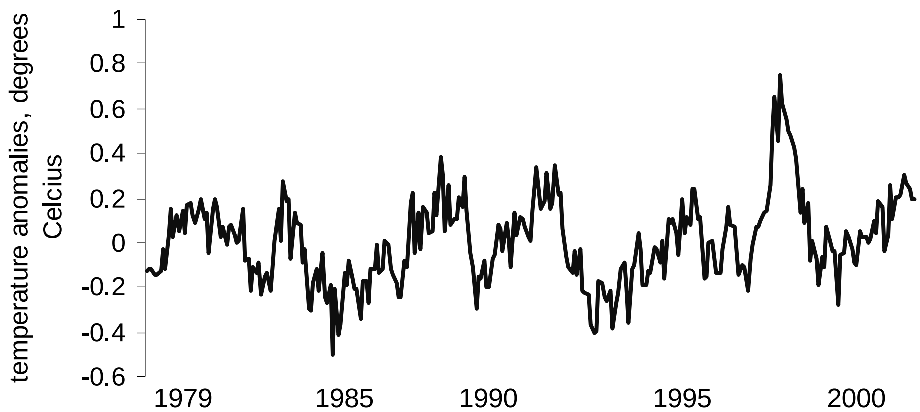
Figure 2: Solar irradiance (in watts per square meter), 1900-2001

Third, volcanic eruptions and the El Niño/Southern Oscillation (ENSO) patterns exert significant influence on the climate system producing a non-greenhouse forcing on planetary temperature. The periodic disruption to global temperature caused by volcanoes and ENSO complicates any search for the greenhouse "fingerprint" in the records.

Fourth, the thermometer measurements themselves are compromised by local influences (e.g., urban effects), the uneven distribution of the thermometer network, and changes through time in instrumentation and recording practices. We have few if any actual temperature records from huge parts of the planet including much of the South Pacific. Nonetheless, and despite an endless number of criticisms of the thermometer-based near-surface air temperature record, there is compelling evidence that the global temperature has increased on a planetary scale over the past century, and the warming near the surface has accelerated in recent decades.

With the models predicting warming, consequent on a buildup of greenhouse gases, and thermometer-based records of the world showing warming, it would seem that any debate on the global warming subject would be one-sided. However, global temperature measurements made from space call into question the recent planetary warming seen in the thermometer records[4]. Sounding units aboard polar-orbiting satellites measure microwave emissions from the low atmosphere that are directly related to the temperature of the atmosphere from approximately 1,500 m (4,947 ft) to 8,500 m (28,024 ft). The polar orbits provide true global coverage as the Earth rotates underneath the satellites that carry the measuring devices. Unlike the near-surface air temperature record that shows warming over the past few decades (Figure 1), the satellite-based observations show no warming whatsoever from 1979 to 2001 (Figure 3) in spite of the very warm El Niño year of 1998. The thermometer-based record and the satellite-based record are well correlated, showing that their annual measurements are similar, but over time the surface record has a significant upward trend while the satellite record has no trend whatsoever.

Figure 3: satellite based monthly temperature anomalies, January 1979-November 2001



Obviously, scientists and policymakers want to know which of these two trends is correct, and they search for other means for estimating global temperature. Twice each day at hundreds of locations around the world, balloons are launched through the atmosphere to measure vertical profiles of temperature, wind, and moisture. When the balloon-based measurements are averaged globally for the same 1,500 m to 8,500 m layer measured by the satellites, the two records are nearly identical in terms of variations and overall linear trend (both show no warming from 1979-near present). This finding leads to an argument that the Earth is simply not warming, despite the trend seen in the near-surface thermometer record. However, measurements from these same balloons made close to the ground are similar to the thermometer-based temperatures showing approximately the same upward trend. This dilemma has been the focus of many scientific articles and reviews, and most scientists now agree that the surface has been warming over the past few decades while the low atmosphere is not warming at all[5].

These differently-derived temperature trends represent anything but a "draw" in the greenhouse debate. The numerical models of climate used to simulate the response to higher concentrations of greenhouse gases suggest that the low atmosphere should be warming faster than the surface, and that is clearly not the case. The observed temperature trends, warming at the surface and no warming in the low atmosphere, are simply not consistent with model expectations given the buildup of greenhouse gases! Volcanic activity, El Niño events, and even instrumentation changes have all been suggested as causes for the differential warming between the surface and the lower atmosphere, but the answer to this critical matter remains elusive and a major focus of scientific inquiry.

While climatologists have struggled in their attempts directly TO link any trends in global temperatures with the buildup of greenhouse gases, other patterns in the climate system have been even more difficult to reconcile.

Precipitation levels are generally increasing in most parts of the world, and the pattern is broadly consistent with the predictions from the numerical models[6]. In the United States and Australia, there is some evidence that heavy precipitation has increased slightly, but the pattern has not been verified in other areas studied to date. Droughts continue to plague different parts of the Earth each year, but most scientists are unwilling to attribute drought patterns to changes in greenhouse gas concentration.

Analyses of tropical cyclones, mid-latitude cyclones, and/or tornado activity have generally led to the conclusion that no discernible trends in these events are apparent in the historical records. The most recent United Nations Intergovernmental Panel on Climate Change report concludes that "No systematic changes in the frequency of tornadoes, thunder days, or hail events are evident in the limited areas analysed"[7] and that "Changes globally in tropical and extra-tropical storm intensity and frequency are dominated by inter-decadal and multi-decadal variations, with no significant trends evident over the 20th century." [8]

These conclusions from the scientific community fly in the face of the popularized visions of the greenhouse world that inevitably include images of more severe storms and increased climate variability in the coming decades.

Observed changes in climate over the past few decades likely include (a) warming at the surface particularly at night, in mid-to-high latitudes over land, and during the winter, (b) no warming in the lower troposphere on a global scale, (c) a general increase in precipitation, and (d) no change in extreme events or climate variability. Whatever changes have occurred fall well within the natural variability of the climate system and are difficult to ascribe to the increase in greenhouse gas concentrations.

Some of the changes are broadly consistent with numerical climate model predictions for a buildup of greenhouse gases, others are not. The lack of warming in the lower-troposphere, as measured by satellites and balloons, remains as a major contradiction to expectations from the model simulations, and will likely be the focus of intense research over the next decade.

Complicating Effects

The inability clearly TO isolate global or regional climate signals related to the buildup of greenhouse gases is further compounded by other anthropogenic forcing of the climate system. Burning fossil fuel undoubtedly produces CO_2 that collects in the global atmosphere, but it produces sulfur dioxide (SO_2) as well. The SO_2 enters the atmosphere and quickly transforms to sulfate aerosols that have a widespread cooling effect by (a) reflecting incoming sunlight back to space, (b) brightening clouds, and (c) making clouds last longer. Unlike CO_2, which mixes fairly evenly throughout the entire atmosphere, the sulfur aerosols are short-lived in the atmosphere, thereby producing a regional pattern of high concentrations near major industrial emission sources and low concentrations throughout the rest of the world. This regional structure complicates the ability to model correctly the thermal effects of the sulfur load in the atmosphere. But to date all models show a cooling for elevated sulfur concentrations, though they differ in terms of the magnitude of the cooling.

Humans have degraded drylands throughout the arid and semi-arid portions of all major landmasses, and this degradation has resulted in an increase in mineral aerosols in many parts of the world. The increased load of mineral aerosols appears to have a cooling effect that may be important at the global scale, although significant uncertainties remain as the magnitude of the cooling.

Also, various chloroflourocarbons deplete ozone in the high atmosphere which results in a significant cooling at the surface, but uncertainties abound in terms of the magnitude of the cooling.

Fossil fuel soot, biomass burning, changes in surface reflectivity caused by land-use patterns, and contrails from high-flying aircraft are all considerations in “predicting” future climate, and yet to date the magnitude of these effects on the climate system remain unknown and highly variable from model to model.

Noted climate modeler James Hansen (the same fellow who was “99 certain” in 1988) and colleagues concluded that “The forcings that drive long-term climate change are not known with an accuracy sufficient to define future climate change."[9] Hansen suggests that even with perfect models and perfect data, climatologists would continue to struggle in an attempt to "predict" climate changes for the next century given the uncertainties regarding the forcings of climate that will be operating 50 to 100 years from present. Overall, the models definitely predict warming in the years to come, but one must appreciate the many uncertainties associated with the prediction.

Hopeless Policy

Uncertainties regarding the Earth's climate future will remain for many decades to come. Given these uncertainties, many scientists and policymakers believe that we should cut back on greenhouse gas emissions and avoid conducting an unknown and largely irreversible experiment on the global atmosphere.

The argument that we have only one atmosphere and should therefore avoid making substantial changes to its composition that may significantly alter the "normal" climate system is certainly a compelling one. To that end, the governments of many nations have expressed their grave concern over the threat of global warming and have signed (but not necessarily ratified) the Kyoto Protocol. That Protocol in essence requires that the world return to a level of anthropogenic emission of greenhouse gases equivalent to such emissions in 1990, with the bulk of the reduction coming from the developed nations that have been large emitters for many decades.

Under Kyoto, the United States is required to reduce emissions to seven percent below 1990 levels. However, US emissions of greenhouse gases are currently 13 percent above 1990 levels; emissions of CO_2 are rising quickly (due in no small part to the electrical demand of the Internet), and US President Bush has largely withdrawn from the Kyoto process. The concerns of the Bush administration include uncertainties regarding global warming science and the near-certain negative impact the Kyoto Protocol would have on the United States economy. While greenhouse advocates cry out that we cannot chance our only atmosphere to some global experiment on the effect of elevated greenhouse gas concentrations, opponents in the United States are unwilling to risk their only economy on the outcome of implementing the Kyoto Protocol.

One of the startling facts regarding the Kyoto Protocol is that its implementation with full participation would have a trivial impact on the climate system. The goal of the Protocol is to stabilize *emissions* of CO_2, not the atmospheric *concentration* of CO_2 (and of course the other greenhouse gases). Even if emissions could be stabilized at 1990 levels, six billion tons of carbon would be added to the atmosphere annually by human activities. That carbon would buildup in the atmosphere and a doubling of CO_2 would still occur near the middle of this century. If the Protocol went into effect today, greenhouse gas emissions suddenly returned to the 1990 level and remained at that level every year from now until 2050, the entire exercise would "spare" the Earth only a few hundredths of a degree of warming. Similar observations have been made by no less a figure than global warming protagonist Tom Wigley. Wigley, a major figure in greenhouse policy circles, is a Senior Scientist at the National Center for Atmospheric Research (NCAR) in Boulder, Colorado, Director of NCAR's Consortium for the Application of Climate Impact Assessments, and was for a long time head of the Climate Research Unit in Norwich, England, which is responsible for assembling and analyzing thermometer-based temperature records from throughout the world. Wigley carefully analyzed the climate impact of the Kyoto Protocol and concluded that "The influence of the Protocol would, therefore, be undetectable for many decades".[10]

The fact that the Kyoto Protocol would have such a small climate impact is not altogether bad news in many circles. Leaders of the IPCC remind us that the Kyoto Protocol is a framework convention that will lead the way to future international agreements aimed at stabilizing concentrations of greenhouse gases below "dangerous" levels. Defining and defending a "dangerous" concentration in this context may be the biggest fight in the greenhouse in the years to come!

Others, particularly those involved in the fossil fuel industry (especially those in the coal industries), may argue that the Kyoto Protocol will not impact climate, and that there is therefore no need to rush into any implementation that would hurt their enterprise or the economies that depend on their products. These same leaders might be quick to point out that James Hansen (again, of "99% certain" fame) recently wrote in the *Proceedings of the National Academy of Sciences* "But we argue that rapid warming in recent decades has been driven mainly by non-CO_2 greenhouse gases (GHGs), such as chlorofluorocarbons, CH_4, and N_2O, not by the products of fossil fuel burning". [11] Not only will the Kyoto Protocol have little climatic effect, but it may be firing at the wrong target!

Environmentalists are naturally drawn into the seductiveness of a potential global disaster brought about by the buildup of greenhouse gases emanating largely – at present – from the world's most developed nations. However, they also realize that policies aimed at substantially reducing greenhouse gas emissions are expensive and these same policies will likely have a trivial impact on climate. We have only limited funds for environmental issues, and relatively simple cost/benefit analyses reveal that spending money on the global warming issue produces few if any benefits. Money targeted at global warming is not available for other environmental issues (often local issues) where real return on investment is far more certain.

The global warming "crisis" dropped quickly from the radar screen of public concern during a few short minutes on the morning of September 11, 2001. But as time goes onward, the global warming issue will again find a place in the public consciousness; the greenhouse momentum built up during the 1990s is simply too great for this environmental issue to suddenly vanish for good. Hopefully, cooler heads will prevail in the future, policymakers will base their decisions on climatic and economic facts, not hype and hysteria, and the complexities of the issue will replace the simplistic presentations suggesting that the planet is warming, greenhouse gases are increasing in concentration, and the two must be linked. As we have seen in this chapter, there is much more to the story, and what might appear to be promising policy options may in fact be useless in impacting the global climate system. Stay tuned...the greenhouse debate has taken some time off, but it will certainly be with us all in the years to come.

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