Do Human Activities Threaten to Change the Global Climate?

**YES:** Intergovernmental Panel on Climate Change, from “Climate Change 2001: The Scientific Basis,” A Report of Working Group I of the Intergovernmental Panel on Climate Change (2001)

**NO:** Kevin A. Shapiro, from “Too Darn Hot?” Commentary (June 2001)

**ISSUE SUMMARY**

**YES:** The Intergovernmental Panel on Climate Change states that global warming appears to be real, with strong effects on sea level, ice cover, and rainfall patterns to come, and that human activities—particularly emissions of carbon dioxide—are to blame.

**NO:** Neuroscience researcher Kevin A. Shapiro argues that past global warming predictions have been wrong and that the data do not support calls for immediate action to reduce emissions of carbon dioxide.

Scientists have known for more than a century that carbon dioxide and other “greenhouse gases” (including water vapor, methane, and chlorofluorocarbons) help prevent heat from escaping the earth’s atmosphere. In fact, it is this “greenhouse effect” that keeps the earth warm enough to support life. Yet there can be too much of a good thing. Ever since the dawn of the industrial age, humans have been burning vast quantities of fossil fuels, releasing the carbon they contain as carbon dioxide. Because of this, some estimate that by the year 2050, the amount of carbon dioxide in the air will be double what it was in 1850. By 1982 an increase was apparent. Less than a decade later, many researchers were saying that the climate had already begun to warm. Now there is a strong consensus that the global climate is warming and will continue to warm. There is less agreement on just how much it will warm or what the impact of the warming will be on human (and other) life. See Spencer R. Weart, “The Discovery of the Risk of Global Warming,” Physics Today (January 1997).

The debate has been heated. The June 1992 issue of The Bulletin of the Atomic Scientists carries two articles on the possible consequences of the greenhouse effect. In “Global Warming: The Worst Case,” Jeremy Leggett says that although there are enormous uncertainties, a warmer climate will release more carbon dioxide, which will warm the climate even further. As a result, soil will grow drier, forest fires will occur more frequently, plant pests will thrive, and methane trapped in the world’s seabeds will be released and will increase global warming much further—in effect, there will be a “runaway greenhouse effect.” Leggett also hints at the possibility that polar ice caps will melt and raise sea levels by hundreds of feet.

Taking the opposing view, in “Warming Theories Need Warning Label,” S. Fred Singer emphasizes the uncertainties in the projections of global warming and their dependence on the accuracy of the computer models that generate them, and he argues that improvements in the models have consistently shrunk the size of the predicted change. There will be no catastrophe, he argues, and money spent to ward off the climate warming would be better spent on “so many pressing—and real—problems in need of resources.”

Global warming, says the UN Environment Programme, will do some $300 billion in damage each year to the world economy by 2050. In March 2001 President George W. Bush announced that the United States would not take steps to reduce greenhouse emissions—called for by the international treaty negotiated in 1997 in Kyoto, Japan—because such reductions would harm the American economy (the U.S. Senate has not ratified the Kyoto treaty). Since the Intergovernmental Panel on Climate Change (IPCC) had just released its third report saying that past forecasts were, in essence, too conservative, Bush’s stance provoked immense outcry.

The analysis of data and computer simulations described by the IPCC in the following selection indicates that global warming is a genuine problem. According to the IPCC, climate warming is already apparent and will get worse than previous forecasts had suggested. Sea level will rise, ice cover will shrink, rainfall patterns will change, and human activities—particularly emissions of carbon dioxide—are to blame. The report excerpt reprinted here does not suggest that anything in particular should be done, but other writers, such as Stephen H. Schneider and Kristin Kurz-Dušićeti (“Facing Global Warming,” The World & I [June 2001]), pull no punches: “Nearly all knowledgeable scientists agree that some global warming is inevitable, that major warming is quite possible, and that the bulk of humanity the net effects are more likely to be negative than positive. This will hold true particularly if global warming is allowed to increase beyond a few degrees, which is likely to occur by the middle of this century if no policies are undertaken to mitigate emissions.”

Kevin A. Shapiro is more optimistic. In the second selection, he argues that past global warming predictions have been wrong and that there is too much room for error in the data and computer simulations to support calls for immediate action to reduce emissions of carbon dioxide.

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Summary for Policymakers

The Third Assessment Report of Working Group I of the Intergovernmental Panel on Climate Change (IPCC) builds upon past assessments and incorporates new results from...five years of research on climate change. Many hundreds of scientists from many countries participated in its preparation and renewal.

This Summary for Policymakers (SPM), which was approved by IPCC member governments in Shanghai in January 2001, describes the current state of understanding of the climate system and provides estimates of its projected future evolution and their uncertainties...

An increasing body of observations gives a collective picture of a warming world and other changes in the climate system.

Since the release of the Second Assessment Report (SAR), additional data from new studies of current and palaeoclimates, improved analysis of data sets, more rigorous evaluation of their quality, and comparisons among data from different sources have led to greater understanding of climate change.

The global average surface temperature has increased over the 20th century by about 0.6°C.

- The global average surface temperature (the average of near surface air temperature over land, and sea surface temperature) has increased since 1861. Over the 20th century the increase has been 0.6 ± 0.2°C. This value is about 0.15°C larger than that estimated by the SAR for the period up to 1994, owing to the relatively high temperatures of the additional years (1995 to 2000) and improved methods of processing the data. These numbers take into account various adjustments, including urban heat island effects. The record shows a great deal of variability; for example, most of the warming occurred during the 20th century, during two periods, 1910 to 1945 and 1976 to 2000.
- Globally, it is very likely that the 1990s was the warmest decade and 1998 the warmest year in the instrumental record, since 1861.

- New analyses of proxy data for the Northern Hemisphere indicate that the increase in temperature in the 20th century is likely to have been the largest of any century during the past 1,000 years. It is also likely that, in the Northern Hemisphere, the 1990s was the warmest decade and 1998 the warmest year. Because less data are available, less is known about annual averages prior to 1,000 years before present and for conditions prevailing in most of the Southern Hemisphere prior to 1861.
- On average, between 1950 and 1993, night-time daily minimum air temperatures over land increased by about 0.2°C per decade. This is about twice the rate of increase in daytime daily maximum air temperatures (0.1°C per decade). This has lengthened the freeze-free season in many mid- and high latitude regions. The increase in sea surface temperature over this period is about half that of the mean land surface air temperature.

Temperature have risen during the past four decades in the lowest 8 kilometres of the atmosphere.

- Since the late 1950s (the period of adequate observations from weather balloons), the overall global temperature increases in the lowest 8 kilometres of the atmosphere and in surface temperature have been similar at 0.1°C per decade.
- Since the start of the satellite record in 1979, both satellite and weather balloon measurements show that the global average temperature of the lowest 8 kilometres of the atmosphere has changed by +0.05 ± 0.10°C per decade, but the global average surface temperature has increased significantly by +0.15 ± 0.05°C per decade. The difference in the warming rates is statistically significant. This difference occurs primarily over the tropical and sub-tropical regions.
- The lowest 8 kilometres of the atmosphere and the surface are influenced differently by factors such as stratospheric ozone depletion, atmospheric aerosols, and the El Niño phenomenon. Hence, it is physically plausible to expect that over a short time period (e.g., 20 years) there may be differences in temperature trends. In addition, spatial sampling techniques can also explain some of the differences in trends, but these differences are not fully resolved.

Snow cover and ice extent have decreased.

- Satellite data show that there are very likely to have been decreases of about 10% in the extent of snow cover since the late 1960s, and ground-based observations show that there is very likely to have been a reduction of about two weeks in the annual duration of lake and river ice cover in the mid- and high latitudes of the Northern Hemisphere, over the 20th century.
- There has been a widespread retreat of mountain glaciers in non-polar regions during the 20th century.
Global average sea level has risen and ocean heat content has increased,

- Tide gauge data show that global average sea level rose between 0.1 and 0.2 metres during the 20th century.
- Global ocean heat content has increased since the late 1950s, the period for which adequate observations of sub-surface ocean temperatures have been available.

Changes have also occurred in other important aspects of climate,

- It is very likely that precipitation has increased by 0.5 to 1% per decade in the 20th century over most mid- and high latitudes of the Northern Hemisphere continents, and it is likely that rainfall has increased by 0.2 to 0.3% per decade over the tropical (10°N to 10°S) land areas. Increases in the tropics are not evident over the past few decades. It is also likely that rainfall has decreased over much of the Northern Hemisphere sub-tropical (10°N to 30°N) land areas during the 20th century by about 0.3% per decade. In contrast to the Northern Hemisphere, no comparable systematic changes have been detected in broad latitudinal averages over the Southern Hemisphere. There are insufficient data to establish trends in precipitation over the oceans.
- In the mid- and high latitudes of the Northern Hemisphere over the latter half of the 20th century, it is likely that there has been a 2 to 4% increase in the frequency of heavy precipitation events. Increases in heavy precipitation events can arise from a number of causes, e.g., changes in atmospheric moisture, thunderstorm activity and large-scale storm activity.
- It is likely that there has been a 2% increase in cloud cover over mid- to high latitude land areas during the 20th century. In most areas the trends relate well to the observed decrease in daily temperature range.
- Since 1950 it is very likely that there has been a reduction in the frequency of extreme low temperatures, with a smaller increase in the frequency of extreme high temperatures.
- Warm episodes of the El Niño-Southern Oscillation (ENSO) phenomenon (which consistently affects regional variations of precipitation and temperature over much of the tropics, sub-tropics and some mid-latitude areas) have been more frequent, persistent and intense since the mid-1970s, compared with the previous 100 years.
- Northern Hemisphere spring and summer sea-ice extent has decreased by about 10 to 15% since the 1950s. It is likely that there has been about a 40% decline in Arctic sea-ice thickness during late summer to early autumn in recent decades and a considerably slower decline in winter sea-ice thickness.

Over the 20th century (1900 to 1995), there were relatively small increases in global land areas experiencing severe drought or severe wetness. In many regions, these changes are dominated by inter-decadal and multi-decadal climate variability, such as the shift in ENSO towards more warm events.

Some important aspects of climate appear not to have changed.

- A few areas of the globe have not warmed in recent decades, mainly over the Arctic, parts of the Southern Hemisphere oceans and parts of Antarctica.
- No significant trends of Antarctic sea-ice extent are apparent since 1978, the period of reliable satellite measurements.
- Changes globally in tropical and extra-tropical storm intensity and frequency are dominated by inter-decadal to multi-decadal variations, with no significant trends evident over the 20th century. Conflicting analyses make it difficult to draw definitive conclusions about changes in storm activity, especially in the extra-tropics.
- No systematic changes in the frequency of tornadoes, thunder days, or hail events are evident in the limited areas analysed.

Emissions of greenhouse gases and aerosols due to human activities continue to alter the atmosphere in ways that are expected to affect the climate.

Changes in climate occur as a result of both internal variability within the climate system and external factors (both natural and anthropogenic). The influence of external factors on climate can be broadly compared using the concept of radiative forcing. A positive radiative forcing, such as that produced by increasing concentrations of greenhouse gases, tends to warm the surface. A negative radiative forcing, which can arise from an increase in some types of aerosols (microscopic airborne particles) tends to cool the surface. Natural factors, such as changes in solar output or explosive volcanic activity, can also cause radiative forcing. Characterisation of these climate forcing agents and their changes over time is required to understand past climate changes in the context of natural variations and to project what climate changes could lie ahead.

Concentrations of atmospheric greenhouse gases and their radiative forcing have continued to increase as a result of human activities.

- The atmospheric concentration of carbon dioxide (CO₂) has increased by 31% since 1750. The present CO₂ concentration has not been exceeded during the past 420,000 years and likely not during the past 20 million years. The current rate of increase is unprecedented during at least the past 20,000 years.
- About three-quarters of the anthropogenic emissions of CO₂ to the atmosphere during the past 20 years is due to fossil fuel burning. The rest is predominantly due to land-use change, especially deforestation.
- Currently the ocean and the land together are taking up about half of the anthropogenic CO₂ emissions. On land, the uptake of anthropogenic CO₂ very likely exceeded the release of CO₂ by deforestation during the 1990s.
- The rate of increase of atmospheric CO₂ concentration has been about 1.5 ppm (0.4%) per year over the past two decades. During the 1990s the year to year increase varied from 0.9 ppm (0.2%) to 2.8 ppm (0.8%). A large part of this variability is due to the effect of climate variability (e.g., El Niño events) on CO₂ uptake and release by land and oceans.
- The atmospheric concentration of methane (CH₄) has increased by 1060 ppb (151%) since 1750 and continues to increase. The present CH₄ concentration has not been exceeded during the past 420,000 years. The annual growth in CH₄ concentration slowed and became more variable in the 1990s, compared with the 1980s. Slightly more than half of current CH₄ emissions are anthropogenic (e.g., use of fossil fuels, cattle, rice agriculture and landfills). In addition, carbon monoxide (CO) emissions have recently been identified as a cause of increasing CH₄ concentration.
- The atmospheric concentration of nitrous oxide (N₂O) has increased by 46 ppb (17%) since 1750 and continues to increase. The present N₂O concentration has not been exceeded during at least the past thousand years. About a third of current N₂O emissions are anthropogenic (e.g., agricultural soils, cattle feedlots and chemical industry).
- Since 1995, the atmospheric concentrations of many of those halocarbon gases that are both ozone-depleting and greenhouse gases (e.g., CFC₃ and CF₂Cl₂) are either increasing more slowly or decreasing, both in response to reduced emissions under the regulations of the Montreal Protocol and its Amendments. Their substitute compounds (e.g., CHF₃Cl and CF₃CH₂F) and some other synthetic compounds (e.g., perfluorocarbons (PFCs) and sulphur hexafluoride (SF₆)) are also greenhouse gases, and their concentrations are currently increasing...

Confidence in the ability of models to project future climate has increased.

Complex physically-based climate models are required to provide detailed estimates of feedbacks and of regional features. Such models cannot yet simulate all aspects of climate (e.g., they still cannot account fully for the observed trend in the surface-troposphere temperature difference since 1979) and there are particular uncertainties associated with clouds and their interaction with radiation and aerosols. Nevertheless, confidence in the ability of these models to provide useful projections of future climate has improved due to their demonstrated performance on a range of space and time-scales.

- Understanding of climate processes and their incorporation in climate models have improved, including water vapour, sea-ice dynamics, and ocean heat transport.
- Some recent models produce satisfactory simulations of current climate without the need for non-physical adjustments of heat and water fluxes at the ocean-atmosphere interface used in earlier models.
- Simulations that include estimates of natural and anthropogenic forcing reproduce the observed large-scale changes in surface temperature over the 20th century. However, contributions from some additional processes and forcings may not have been included in the models. Nevertheless, the large-scale consistency between models and observations can be used to provide an independent check on projected warming rates over the next few decades under a given emissions scenario.
- Some aspects of model simulations of ENSO, monsoons and the North Atlantic Oscillation, as well as selected periods of past climate, have improved.

There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities.

The SAR concluded: “The balance of evidence suggests a discernible human influence on global climate”. That report also noted that the anthropogenic signal was still emerging from the background of natural climate variability. Since the SAR, progress has been made in reducing uncertainty, particularly with respect to distinguishing and quantifying the magnitude of responses to different external influences. Although many of the sources of uncertainty identified in the SAR still remain to some degree, new evidence and improved understanding support an updated conclusion.

- There is a longer and more closely scrutinised temperature record and new model estimates of variability. The warming over the past 100 years is very unlikely to be due to internal variability alone, as estimated by current models. Reconstructions of climate data for the past 1,000 years also indicate that this warming was unusual and is unlikely to be entirely natural in origin.
- There are new estimates of the climate response to natural and anthropogenic forcing, and new detection techniques have been applied. Detection and attribution studies consistently find evidence for an anthropogenic signal in the climate record of the last 35 to 50 years.
- Simulations of the response to natural forcings alone (i.e., the response to variability in solar irradiance and volcanic eruptions) do not explain the warming in the second half of the 20th century. However, they indicate that natural forcings may have contributed to the observed warming in the first half of the 20th century.
The warming over the last 50 years due to anthropogenic greenhouse gases can be identified despite uncertainties in forcing due to anthropogenic sulphate aerosol and natural factors (volcanoes and solar irradiance). The anthropogenic sulphate aerosol forcing, while uncertain, is negative over this period and therefore cannot explain the warming. Changes in natural forcing during most of this period are also estimated to be negative and are unlikely to explain the warming.

Detection and attribution studies comparing model simulated changes with the observed record can now take into account uncertainty in the magnitude of modelled response to external forcing, in particular that due to uncertainty in climate sensitivity.

Most of these studies find that, over the last 50 years, the estimated rate and magnitude of warming due to increasing concentrations of greenhouse gases alone are comparable with, or larger than, the observed warming. Furthermore, most model estimates that take into account both greenhouse gases and sulphate aerosols are consistent with observations over this period.

The best agreement between model simulations and observations over the last 140 years has been found when all the above anthropogenic and natural forcing factors are combined. These results show that the forcings included are sufficient to explain the observed changes, but do not exclude the possibility that other forcings may also have contributed.

In the light of new evidence and taking into account the remaining uncertainties, most of the observed warming over the last 50 years is likely to have been due to the increase in greenhouse gas concentrations.

Furthermore, it is very likely that the 20th century warming has contributed significantly to the observed sea level rise, through thermal expansion of sea water and widespread loss of land ice. Within present uncertainties, observations and models are both consistent with a lack of significant acceleration of sea level rise during the 20th century.

Human influences will continue to change atmospheric composition throughout the 21st century.

Models have been used to make projections of atmospheric concentrations of greenhouse gases and aerosols, and hence of future climate, based upon emissions scenarios from the IPCC Special Report on Emission Scenarios (SRES). These scenarios were developed to update the IS92 series, which were used in the SAR and are shown for comparison here in some cases.

**Greenhouse Gases**

- Emissions of CO₂ due to fossil fuel burning are virtually certain to be the dominant influence on the trends in atmospheric CO₂ concentration during the 21st century.

- As the CO₂ concentration of the atmosphere increases, ocean and land will take up a decreasing fraction of anthropogenic CO₂ emissions. The net effect of land and ocean climate feedbacks as indicated by models is to further increase projected atmospheric CO₂ concentrations, by reducing both the ocean and land uptake of CO₂.

- By 2100, carbon cycle models project atmospheric CO₂ concentrations of 540 to 970 ppm for the illustrative SRES scenarios (90 to 250% above the concentration of 280 ppm in the year 1750). These projections include the land and ocean climate feedbacks. Uncertainties, especially about the magnitude of the climate feedback from the terrestrial biosphere, cause a variation of about -10 to +30% around each scenario. The total range is 490 to 1260 ppm (75 to 350% above the 1750 concentration).

- Changing land use could influence atmospheric CO₂ concentration. Hypothetically, if all of the carbon released by historical land-use changes could be restored to the terrestrial biosphere over the course of the century (e.g., by reforestation), CO₂ concentration would be reduced by 40 to 70 ppm.

- Model calculations of the concentrations of the non-CO₂ greenhouse gases by 2100 vary considerably across the SRES illustrative scenarios, with CH₄ changing by -190 to +1,970 ppb (present concentration 1.760 ppb), N₂O changing by +38 to +144 ppb (present concentration 316 ppb), total tropospheric O₃ changing by -12 to +62%, and a wide range of changes in concentrations of HFCs, PFCs and SF₆, all relative to the year 2000. In some scenarios, total tropospheric O₃ would become as important a radiative forcing agent as CH₄ and, over much of the Northern Hemisphere, would threaten the attainment of current air quality targets.

- Reductions in greenhouse gas emissions and the gases that control their concentration would be necessary to stabilise radiative forcing. For example, for the most important anthropogenic greenhouse gas, carbon cycle models indicate that stabilisation of atmospheric CO₂ concentrations at 450, 650 or 1,000 ppm would require global anthropogenic CO₂ emissions to drop below 1990 levels, within a few decades, about a century, or about two centuries, respectively, and continue to decrease steadily thereafter. Eventually CO₂ emissions would need to decline to a very small fraction of current emissions.

Aerosols

The SRES scenarios include the possibility of either increases or decreases in anthropogenic aerosols (e.g., sulphate aerosols, biomass aerosols, black and organic carbon aerosols) depending on the extent of fossil fuel use and policies to abate polluting emissions. In addition, natural aerosols (e.g., sea salt, dust and emissions leading to the production of sulphate and carbon aerosols) are projected to increase as a result of changes in climate.
Radiative Forcing Over the 21st Century

For the SRES illustrative scenarios, relative to the year 2000, the global mean radiative forcing due to greenhouse gases continues to increase through the 21st century, with the fraction due to CO₂ projected to increase from slightly more than half to about three quarters. The change in the direct plus indirect aerosol radiative forcing is projected to be smaller in magnitude than that of CO₂.

Global average temperature and sea level are projected to rise under all IPCC SRES scenarios.

In order to make projections of future climate, models incorporate past, as well as future emissions of greenhouse gases and aerosols. Hence, they include estimates of warming to date and the commitment to future warming from past emissions.

Temperature

- The globally averaged surface temperature is projected to increase by 1.4 to 5.8°C over the period 1990 to 2100. These results are for the full range of 35 SRES scenarios, based on a number of climate models.
- Temperature increases are projected to be greater than those in the SAR, which were about 1.0 to 3.5°C based on the six IS92 scenarios. The higher projected temperatures and the wider range are due primarily to the lower projected sulphur dioxide emissions in the SRES scenarios relative to the IS92 scenarios.
- The projected rate of warming is much larger than the observed changes during the 20th century and is very likely to be without precedent during at least the last 10,000 years, based on palaeoclimate data.
- By 2100, the range in the surface temperature response across the group of climate models run with a given scenario is comparable to the range obtained from a single model run with the different SRES scenarios.
- On timescales of a few decades, the current observed rate of warming can be used to constrain the projected response to a given emissions scenario despite uncertainty in climate sensitivity. This approach suggests that anthropogenic warming is likely to lie in the range of 0.1 to 0.2°C per decade over the next few decades under the IS92a scenario. . .
- Based on recent global model simulations, it is very likely that nearly all land areas will warm more rapidly than the global average, particularly those at northern high latitudes in the cold season. Most notable of these is the warming in the northern regions of North America, and northern and central Asia, which exceeds global mean warming in each model by more than 40%. In contrast, the warming is less than the global mean change in south and southeast Asia in summer and in southern South America in winter.

Precipitation

Based on global model simulations and for a wide range of scenarios, global average water vapour concentration and precipitation are projected to increase during the 21st century. By the second half of the 21st century, it is likely that precipitation will have increased over northern mid- to high latitudes and Antarctica in winter. At low latitudes there are both regional increases and decreases over land areas. Larger year to year variations in precipitation are very likely over most areas where an increase in mean precipitation is projected. . .

El Niño

- Confidence in projections of changes in future frequency, amplitude, and spatial pattern of El Niño events in the tropical Pacific is tempered by some shortcomings in how well El Niño is simulated in complex models. Current projections show little change or a small increase in amplitude for El Niño events over the next 100 years.
- Even with little or no change in El Niño amplitude, global warming is likely to lead to greater extremes of drying and heavy rainfall and increase the risk of droughts and floods that occur with El Niño events in many different regions.

Monsoons

It is likely that warming associated with increasing greenhouse gas concentrations will cause an increase of Asian summer monsoon precipitation variability. Changes in monsoon mean duration and strength depend on the details of the emission scenario. The confidence in such projections is also limited by how well the climate models simulate the detailed seasonal evolution of the monsoons.

Thermohaline Circulation

Most models show weakening of the ocean thermohaline circulation which leads to a reduction of the heat transport into high latitudes of the Northern Hemisphere. However, even in models where the thermohaline circulation weakens, there is still a warming over Europe due to increased greenhouse gases. The current projections using climate models do not exhibit a complete shut-down of the thermohaline circulation by 2100. Beyond 2100, the thermohaline circulation could completely, and possibly irreversibly, shut-down in either hemisphere if the change in radiative forcing is large enough and applied long enough.
Snow and Ice

- Northern Hemisphere snow cover and sea-ice extent are projected to decrease further.
- Glaciers and ice caps are projected to continue their widespread retreat during the 21st century.
- The Antarctic ice sheet is likely to gain mass because of greater precipitation, while the Greenland ice sheet is likely to lose mass because the increase in runoff will exceed the precipitation increase.
- Concerns have been expressed about the stability of the West Antarctic ice sheet because it is grounded below sea level. However, loss of grounded ice leading to substantial sea level rise from this source is now widely agreed to be very unlikely during the 21st century, although its dynamics are still inadequately understood, especially for projections on longer time-scales.

Sea Level

Global mean sea level is projected to rise by 0.09 to 0.88 metres between 1990 and 2100, for the full range of SRES scenarios. This is due primarily to thermal expansion and loss of mass from glaciers and ice caps. The range of sea level rise presented in the SAR was 0.13 to 0.94 metres based on the IS92 scenarios. Despite the higher temperature change projections in this assessment, the sea level projections are slightly lower, primarily due to the use of improved models, which give a smaller contribution from glaciers and ice sheets.

Anthropogenic climate change will persist for many centuries.

- Emissions of long-lived greenhouse gases (i.e., CO₂, N₂O, PFCs, SF₆) have a lasting effect on atmospheric composition, radiative forcing and climate. For example, several centuries after CO₂ emissions occur, about a quarter of the increase in CO₂ concentration caused by these emissions is still present in the atmosphere.
- After greenhouse gas concentrations have stabilised, global average surface temperatures would rise at a rate of only a few tenths of a degree per century rather than several degrees per century as projected for the 21st century without stabilisation. The lower the level at which concentrations are stabilised, the smaller the total temperature change.
- Global mean surface temperature increases and rising sea level from thermal expansion of the ocean are projected to continue for hundreds of years after stabilization of greenhouse gas concentrations (even at present levels), owing to the long timescales on which the deep ocean adjusts to climate change.

Ice sheets will continue to react to climate warming and contribute to sea level rise for thousands of years after climate has been stabilised. Climate models indicate that the local warming over Greenland is likely to be one to three times the global average. Ice sheet models project that a local warming of larger than 3°C, if sustained for millennia, would lead to virtually a complete melting of the Greenland ice sheet with a resulting sea level rise of about 7 metres. A local warming of 5.5°C, if sustained for 1,000 years, would be likely to result in a contribution from Greenland of about 3 metres to sea level rise.

- Current ice dynamic models suggest that the West Antarctic ice sheet could contribute up to 3 metres to sea level rise over the next 1,000 years, but such results are strongly dependent on model assumptions regarding climate change scenarios, ice dynamics and other factors.

Further action is required to address remaining gaps in information and understanding.

Further research is required to improve the ability to detect, attribute and understand climate change, to reduce uncertainties and to project future climate changes. In particular, there is a need for additional systematic and sustained observations, modelling and process studies. A serious concern is the decline of observational networks. The following are high priority areas for action.

- Systematic observations and reconstructions:
  - Reverse the decline of observational networks in many parts of the world.
  - Sustain and expand the observational foundation for climate studies by providing accurate, long-term, consistent data including implementation of a strategy for integrated global observations.
  - Enhance the development of reconstructions of past climate periods.
  - Improve the observations of the spatial distribution of greenhouse gases and aerosols.

- Modelling and process studies:
  - Improve understanding of the mechanisms and factors leading to changes in radiative forcing.
  - Understand and characterise the important unresolved processes and feedbacks, both physical and biogeochemical, in the climate system.
  - Improve methods to quantify uncertainties of climate projections and scenarios, including long-term ensemble simulations using complex models.
- Improve the integrated hierarchy of global and regional climate models with a focus on the simulation of climate variability, regional climate changes and extreme events.
- Link more effectively models of the physical climate and the biogeochemical system, and in turn improve coupling with descriptions of human activities.
- Cutting across these foci are crucial needs associated with strengthening international co-operation and co-ordination in order to better utilise scientific, computational and observational resources. This should also promote the free exchange of data among scientists. A special need is to increase the observational and research capacities in many regions, particularly in developing countries. Finally, as is the goal of this assessment, there is a continuing imperative to communicate research advances in terms that are relevant to decision making.

Kevin A. Shapiro

Too Darn Hot?

Natives of Hawaii, inured by more than a thousand years of island life to the vagaries of the weather and the seas, have a somewhat elliptical saying: "the mists are those that know of a storm upon the water." It can be taken to mean that those nearest to something are the first to become aware of what is happening to it. Using similar reasoning, perhaps, many environmentalists today regard the small islands that dot the Pacific as a sort of planetary weathervane, outcrops of flora and fauna that are sensitive indicators of large-scale shifts in the ecological balance of the earth. If these islands are already beginning to buckle under the stresses imposed on the planet by human activity, it is a sign that we must act quickly lest catastrophe result.

An alarming presentation of this argument can be found in Rising Waters: Global Warming and the Fate of the Pacific Islands, an hour-long documentary that aired on PBS [in] April [2001] on Earth Day. Rising Waters paints a picture of island nations on the veritable brink of ruin: homes destroyed in the wake of storms or threatened by eroding shorelines, churchyards and crop-fields inundated by the rising sea, and shoals of once-vivid coral bleached by overheated waters. On camera, fishermen complain of poor hauls; a Samoan environmentalist laments the looming disappearance of his cultural heritage; Teburoro Tito, the president of tiny Kiribati, speaks glumly of the possibility that the entire populace of his cluster of atolls will have to be relocated.

What is causing this potentially immense disruption? Rising Waters mentions several factors, including seasonal weather fluctuations and overdevelopment, but ultimately it places most of the blame on a long chain of processes at the end of which is: global warming. The nature of this menace is well known and has been widely discussed. Increases in the industrial emission of gases like carbon dioxide ($CO_2$), it is said, have caused the atmosphere to absorb infrared radiation that would otherwise be reflected back into outer space. The resulting "greenhouse effect" lifts the average temperature of the earth's surface. Among the many consequences are rising sea levels caused by the melting of the polar ice caps and increases in the frequency and intensity of storm activity.

Though Rising Waters offers the disclaimer that the earth's climate is a complex and somewhat unpredictable system—"we don't know how it behaves..."—
completely,” says Fred MacKenzie, a professor of oceanography at the University of Hawaii—its overarching message is that unregulated CO₂ emissions have already begun to heat the planet to dangerous levels. To forestall further warming, we must cut those emissions globally by as much as 80 percent over the next several decades. Alas, as Rising Waters notes with a hint of impending doom, the prospects for such a cut are not auspicious.

On this last point, the documentary is certainly correct. Talks in the Hague on implementing the 1997 Kyoto Protocol, an international agreement aimed at reducing the CO₂ emissions of industrial nations to pre-1990 levels by the year 2012, collapsed in December, in the last month of Bill Clinton’s presidency. By mid-March, the Bush administration had announced it would not seek to regulate the CO₂ emissions of power plants, provoking an outcry from environmentalists and angering European leaders who maintain (in the words of Dutch prime minister Wim Kok) that the United States is acting “irresponsibly.” Two weeks later, President Bush declared that it made “no sense” for the United States to pursue implementation of the Kyoto Protocol. European governments, positively livid, dispatched an emergency delegation to Washington, but to no avail; they now plan to assemble an international coalition aimed at “shaming” the United States into reconsidering its stance. Another round of talks on Kyoto will be held in Bonn [in July 2001], and the conflict over global warming is certain to deepen in the months and years ahead.

Against this backdrop, Rising Waters can only serve to underscore the now almost incessant warnings about the disaster that awaits us if we fail to change our profligate energy habits. Global warming has already been blamed for ecological hazards ranging in scale from disruptions in the migration patterns of butterflies and declining amphibian populations to extreme weather events, droughts, and food shortages in farflung portions of the globe. And the dangers that lie ahead are said to be far worse, if not horrific: famine brought on by widespread agricultural failure, an increase in epidemics of infectious disease, even mass extinctions of animal and human populations.

If anything remotely resembling this scenario is likely, it is not hard to see why so many Europeans, and with them many Americans, are apoplectic over President Bush’s determination to scrap the Kyoto deal, the fruit of years of intense multinational discussions among lawmakers, economists, scientists, and environmentalists. Senator Joseph Lieberman has even promised a congressional investigation of the President’s environmental decisions, declaring that they “ignore the public interest and defy common sense.”

Is Lieberman right? There are indeed many things about the global-warming debate that “ignore the public interest and defy common sense.” But the decision to abandon the Kyoto Protocol is not one of them.

In a sense, the decision was hardly even newsworthy. The agreement has been effectively dead—at least as far as the United States is concerned—since shortly after it was negotiated in 1997. For no sooner did Clinton’s negotiators return from Japan than the Senate voted 95-0 to oppose ratification of any treaty that would impose significant burdens on our national economy and that lacked “specificscheduled commitments” for emissions reductions in what are now known as “developing” countries. As Kyoto has never been amended to address these concerns, it is perplexing that any policymaker could have continued to regard the accord as viable.

Indeed, far more inscrutable than President Bush’s final rejection of Kyoto is the vast amount of rhetorical and diplomatic effort that has been and continues to be expended on the agreement’s behalf. Even apart from the unanimous vote in the Senate, there are serious questions about whether the provisions of the treaty could ever have been implemented and enforced, and therefore about whether it really represents a workable mechanism for managing climate change.

From its very inception, as the analyst David G. Victor shows in a new monograph, the Kyoto Protocol was a product of diplomatic wishful thinking. For one thing, the limits it called for on greenhouse gas emissions were draconian. Thus, by 2012 the United States would have been required to reduce CO₂ emissions to 7 percent below 1990 levels—a modest-sounding target until one considers that by the end of 1999, emissions were already 12 percent above 1990 levels and were continuing to rise. Compliance with Kyoto would therefore have required a likely cut of as much as 30 percent by the time the treaty took effect in 2008. Not only would this cost hundreds of billions of dollars in GDP [gross domestic product] but, because most greenhouse gases are released in the course of burning fossil fuels for energy, cutbacks on such a scale would deal a major blow to significant sectors of the U.S. economy—particularly electricity generation, which is already struggling mightily to keep pace with demand.

The agreement was also exceedingly inequitable. Russia, for example, would have been required only to freeze its emissions at 1990 levels; but because the Russian economy has contracted sharply since the collapse of the Soviet Union, its emissions are already far below target, and are unlikely to recover by 2008. Though it remains a significant industrial polluter, Moscow would thus be required to do absolutely nothing. South Korea and Mexico, now formally considered “developed” countries (as defined by membership in the Organization for Economic Cooperation and Development), have for their part also not agreed to curtail emissions.

At the same time, Kyoto sets no targets at all for the developing nations, though these countries will account for half the world’s greenhouse gases by 2020. The two largest such nations, India and China, have refused outright to accept any limits on their emissions output.
In short, the Kyoto Protocol demands that the United States hobble its economy with drastic cuts in energy production, while Russia, India, China, and other nations enjoy the freedom to grow untrammeled. To deal with this gross imbalance, a number of observers have proposed amending the agreement. One proposal involves altering the way emissions are accounted for—for example, by permitting industrialized countries to earn “credits” if they maintain or create carbon sinks, i.e., forest and soil zones that absorb CO₂. Another alternative would be to allow trading, whereby industrialized countries could buy the right to emit carbon dioxide from those nations whose emissions are below targeted levels.

Both of these ideas have their attractions for the United States, but they also entail immense practical and political difficulties. On the positive side, the US. might offset its Kyoto obligations by counting carbon sinks that resulted from intentional changes in land-use policy. If, in addition, it were permissible to count those resulting from unintentional changes (like the spontaneous reforestation of abandoned agricultural lands), we might no longer have a net emitter. But an amendment of this sort would almost certainly prove unacceptable to Europe and Japan, which, unlike the US., have limited capacity to plant new forests. A more fundamental problem is that the Kyoto Protocol provides no standard definitions, methods, or data for quantifying the absorption of CO₂ by trees and soils, making it easy for nations to cheat by claiming credit for carbon sinks that are short-lived or even nonexistent.

Emissions trading is beset with its own difficulties. The present terms of the Kyoto Protocol would seem to award countries with low baselines-like Russian—a windfall in fictitious credits, the sale of which would result in no reduction in global emissions whatsoever. David Victor has correctly spelled out another hope that Kyoto is funk science, too. The operative assumption here, of course, is that man-made climate change is a real phenomenon, and that averting catastrophe requires doing something about it, and soon. As this assumption has increasingly come to be taken for granted, disputing it has become commensurately pernicious, especially for politicians. According to a 1997 poll taken for the World Wildlife Federation, two-thirds of American voters regard global warming as a “serious threat” and support an international agreement to cut greenhouse-gas emissions, even if this comes at some economic cost. A full three-quarters endorse the view that “the only scientists who do not believe global warming is happening are paid by big oil, coal, and gas companies to find the results that will protect business interests.” Only 15 percent accept the statement that “scientists disagree among themselves” about the extent of the coming danger.

Clearly, climate change is no longer an issue up for grabs. Even if the public could be persuaded that the Kyoto Protocol would be disastrous for the U.S. economy and is the result of funk diplomacy, it would be far harder for a politician to make the case that the research behind Kyoto is funk science, too. But much of it is.

Let us return for a moment to those Pacific islands. It is undeniable that they have been buffeted by a series of severe storms in the past decade, accompanied by unusually intense episodes of the ENSO (El Niño-Southern Oscillation) phenomenon, a periodic fluctuation in sea temperature in the tropical Pacific that has been observed since the last century. What is not clear is whether these have anything to do with global warming.

Storm activity in the Pacific varies from year to year; 1998 saw an above-average incidence of tropical storms, while 1997 was comparatively quiet. The cause of this variation remains unknown. The ENSO phenomenon is not well understood, and it is not predicted by any model of climate change. A United Nations body called the Intergovernmental Panel on Climate Change (IPCC) has rightly observed that while many small island states fear that “global warming will lead to changes in the character and pattern of tropical cyclones (i.e., hurricanes and typhoons),” this fear is not confirmed by the most recent research. Rather, “model projections suggest no clear trend, so it is not possible to state whether the frequency, intensity, or distribution of tropical storms and cyclones will change.”

And what of rising waters? In 1980, climatologists predicted that global warming would melt the polar icecaps, causing sea levels to rise more than 25 feet over the course of the next century. Such an event would undoubtedly be disastrous not only for the Pacific islands but also for densely populated coastal regions in all parts of the world.

Fortunately for those of us in Boston, Miami, New York, and Los Angeles, the deluge failed even to begin to materialize. According to the latest data, the polar icecaps do not appear to be melting at all. The 2001 IPCC report discerns “no significant trends” in the extent of Antarctic sea-ice since 1978, when reliable satellite measurements began to be taken; nor, at the other pole, is there evidence from satellite records that the air above the Arctic has warmed substantially.

With the polar caps essentially intact, it does not come as a surprise that sea levels have risen only a paltry 2 millimeters per year in the mid-1590’s—roughly the same rate observed over the past 100 years. Even the gloomiest doomsayers have been compelled to jettison the dire forecasts put forward in 1980. Under the worst-case scenario now envisioned by the IPCC, the oceans should rise no more than a foot over the next century, not nearly enough to
pose a major threat. And this forecast is in turn based on the assumption that sea levels will increase by approximately 5 millimeters per year, give or take 3 millimeters—in other words, the rate of rise may not change at all.

As for the climate itself, despite the alarmed rhetoric from so many quarters, we do not know for certain that it is even changing in significant ways. It is an established fact that the earth's climate has warmed slightly over the past century. Average temperatures near the surface have risen since 1900 and are now probably higher than they have been at any time in the past 600 to 1,000 years. But that statement more or less exhausts the scientific consensus. On every other important question—what the major causes of global warming are, what its effects will be, whether we should try to prevent it and, if so, how—there is considerable uncertainty.

Most of what we "know" about the earth's future is derived from enormously sophisticated computer models that utilize millions of parameters to simulate the earth's climate. These models are still far from reliable. The editors of Nature, arguably the world's most prestigious scientific journal, pointed out on March 15 that "the accuracy of any model depends significantly on the quality of the underlying raw data." But the quality of the data being used for climate prediction, they go on to state, is "patchy." For example, it is not at all easy to measure the amount of sunlight absorbed by the atmosphere or reflected by its surface back into space—and yet this one key parameter alone might (or might not) account for six times the amount of energy that would be added to the climate system by the doubling of atmospheric CO₂. Similar uncertainties attend other crucial variables like the impact of differing degrees of cloud cover and water vapor.

Given the room for error, it should come as no surprise that climate-prediction models have racked up an exceedingly poor track record over the years. According to those models, the average global temperature should have increased by at least 1 degree centigrade since the beginning of the 20th century, when industrial emissions of greenhouse gases first began to rise. But the best available measurements indicate that the average global temperature has increased by only 0.5 degrees in 100 years, and much of that increase occurred before 1940—early in the century, in other words, to have been caused by a growth in CO₂ levels.

Contrary to the simulations, moreover, the marginal uptick in surface temperatures in the years since 1970 has not been accompanied by warming of the lower atmosphere (as we know from satellite data). A pair of recent papers in the journal Science attempts to account for this discrepancy by locating the missing heat in the oceans, a "discovery" trumpeted by the media as yet another blow to those who remain skeptical of global warming. But this was not a discovery at all, and was not based on any finding that whatever warming may have occurred has been caused by human activity. Rather, it was merely the product of "improved" models, which have their own "improved" assumptions and their own set of poorly understood parameters.