Climatic Disruption in 2002: A Scientific Puzzle and Political Dilemma[1]

George M. Woodwell
The Woods Hole Research Center

The issue of climatic disruption by the accumulation of heat-trapping gases in the atmosphere is the most complicated, difficult, and urgent problem the scientific community has ever addressed. Although there are many unanswered questions, and always will be, the core of information required for political action in defense of human interests is abundantly well known and substantially immutable. The scientific community worked over the course of twenty years prior to 1992 to bring the issue to international attention. The Framework Convention on Climate Change, prepared under UN auspices, was signed by the first George Bush for the U.S. at the Rio Environmental Summit Meetings in 1992. This treaty is one of the most successful ever. It was ratified early after the signing by the U.S. and has now been ratified by more than 180 nations. The apostasy of the second George Bush for a new U.S. administration has turned a straightforward scientific issue of great consequence into a transparently venal political argument in which global welfare is sacrificed with enormous, irreversible costs to the world. The U.S. has most recently attempted in the Eighth Conference of the Parties to turn the focus of political response away from the fundamental cause, the use of fossil fuels, to accommodating the climatic disruptions through adaptations. The administration proposes that we extend the fossil fuel binge and the profits of the few by calling on all to adapt their lives to the continuous rise in sea level, the expanding droughts, fires, plagues and diseases of plants and people. In so doing the administration discounts totally the gross unpredictability of global biophysics of the next decades and accepts the untold costs of progressive global climatic disruption. The flat-earth scientific society is in charge.

But first, the scientific background.

The following details about the earth are no longer in question. They are the product of more than a century of research by a steadily expanding scientific community that now reaches to almost every nation and includes thousands of scientists. The earth is warming. The warming has exceeded ½ degree C over the last century for the average temperature of the earth as a whole. There is little change in temperature in the tropics, but changes in the higher latitudes may be 2-3 or more times the global average. The warming in the middle latitudes of the northern hemisphere is now in the range of 0.2 degree C per decade. In higher latitudes, the warming is more rapid.

The cause is the accumulation of heat-trapping gases in the atmosphere. The most abundant and important of these gases, apart from water vapor, is carbon dioxide which accounts for about 50% of the warming from the total suite of trace gases. The carbon dioxide concentration is rising but remains less than 0.04% of an atmosphere that is about

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78% nitrogen and 22% oxygen by volume. Because it is such a small fraction of the total atmosphere and has such a large influence on the heat-trapping potential, a small release from human activities can change its atmospheric concentration enough to produce a large change in global temperature and climate.

Carbon dioxide is a part of the global cycle of carbon and its concentration in the atmosphere is affected in many ways. The total burden in the atmosphere is more than 760 billion metric tons (760 x 10^{15} g) (Fig. 1). This large pool of carbon is in continuous interaction with two other large pools, the upper mixed layer of the oceans and the organic matter in plants and soils on land (Fig. 1). The oceanic mixed layer contains a pool of approximately the same size as the atmosphere. The terrestrial pool is 2-3 times larger and is divided between living plants, largely forests, and the organic matter of peat and soils.

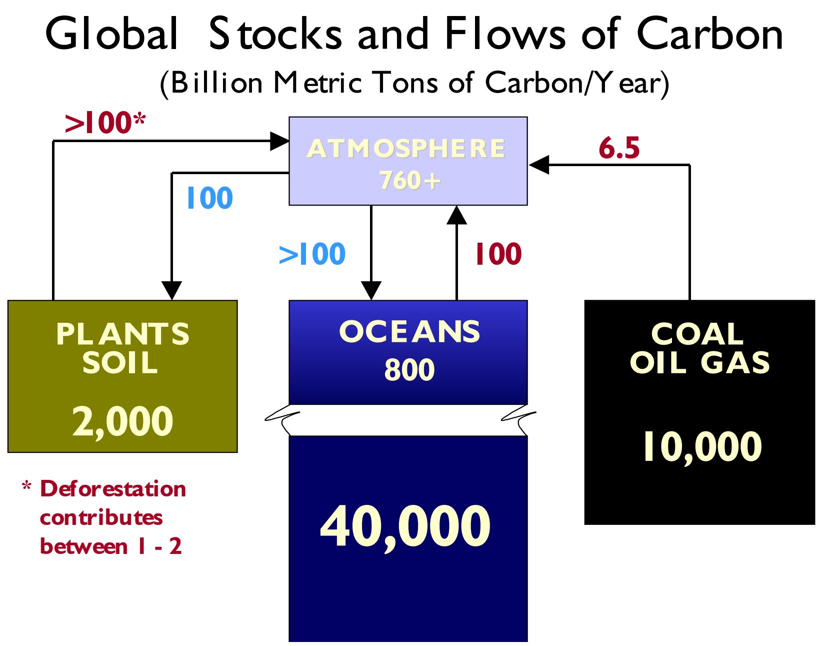


Fig. 1. The global carbon cycle. Before humans began tapping the large pool of fossil carbon for energy from coal, oil and gas, the atmosphere, oceans and terrestrial biota including soils were in a rough equilibrium that resulted in an atmospheric concentration of about 270 ppm (by volume) of carbon dioxide in the late 1800s. As a result of the mining and combustion of fossil carbon for fuels over the last century and more, the current (2002) concentration of carbon dioxide in the atmosphere is 370 ppm and rising at about 1.5 ppm annually. This increase is due to the combination of the release from burning fossil fuels, massive deforestation involving changes in land use from forests to agriculture, and from the inherently long mixing time of the oceans, measured in centuries. The result is the net accumulation of carbon in the atmosphere, now more than 30% above pre-industrial levels. The stocks and flows shown here are approximately correct for the current period (2000-2005). Details are the substance of the first section of this paper.

The atmospheric pool of carbon is increasing annually at about 3 billion tons as the net effect of human activities in interaction with the other pools. The total annual release from burning fossil fuels is about 6.5 billion tons of carbon, released as carbon dioxide through global activities in the mining and burning of coal, oil and gas. There is a further release of 1.6-2.0 billion tons from deforestation globally giving a total release from human activities of about 8 billion tons of carbon into the atmospheric pool. Because less than half this sum remains in the atmosphere there must be a net movement of carbon into the oceans and into the terrestrial vegetation. There is, but the exchanges are somewhat complicated and have been difficult to define clearly.[1]

The oceans have the capacity for storing a large reservoir of carbon in solution as carbon dioxide gas and chemically as a part of the complex oceanic carbonate - bicarbonate system. The oceanic reservoir, however, is divided between the surface layer of a thousand meters more or less, which is warmer and mixed regularly, and the colder abyssal water. The two water masses mix, but slowly, so that carbon dioxide incorporated into the mixed layer is transferred into the deeper water but slowly. The half-time for mixing is measured in hundreds of years. The slowness of the mixing limits the oceanic capacity for absorbing carbon from the atmosphere. There is, however, a continuous annual exchange by diffusion between the surface of the oceans and the atmosphere of about 100 billion tons of carbon in each direction. Because the concentration of carbon dioxide in the atmosphere has risen above the concentration in the oceanic surface, there is a net annual diffusion from the atmosphere into the oceans of about two billion tons of carbon. That flux is gradually transferred to the deep ocean through the sedimentation of organic matter and through the slow mixing of the oceanic waters as discussed below.

The exchanges with the land are even more complicated. The largest pools of carbon on land are in forests and in the organic matter stored in peat in the Arctic and in the organic matter of soils. Deforestation, a change in land use from forest to pasture or agriculture or other uses, results in a large net loss of carbon as carbon dioxide into the atmosphere as a result of the combination of fire and decay of the organic matter in plants and soil over time. The products of fire and organic decay are the same—heat, water and carbon dioxide. Long-term estimates of the magnitude of the releases from deforestation suggest that 1.6-2.0 billion tons of carbon are released annually through this route.[2]

Further details of the global carbon budget have been difficult to resolve over more than twenty years. Of the 8 billion tons released, about two billion tons are absorbed annually in the oceans and about three billion tons accumulate annually in the atmosphere. Roughly three billion tons, a very large quantity, remain to be accounted for. Originally, when we first addressed the complexities of these budgets, it was called “the missing carbon.” The data on the uptake by the oceans seemed pretty well established and the only remaining possibility was absorption into plants on land. Attention focused on forests because of their large area and potential for storage of carbon in plants and soil.

The issue has proven awkward. There is an apparently simple question of changes in the area of forests globally. Deforestation is occurring globally, largely to favor the expansion of agriculture, especially in the tropics. At the same time there are areas that have been abandoned from agriculture over more than a century and are reverting to forest. Other areas, impoverished by erosion during agriculture, have simply been abandoned and remain impoverished. An appropriate accounting for land-use changes globally is possible using satellite data but it has never been done despite a clear need and various efforts toward such an inventory. Ground-based analyses that take advantage of thousands of plots that are inventoried regularly suggest a small net storage of carbon in forests, but not as much as 3 billion tons annually. These data have been supplemented by a limited number of short-term measurements of carbon dioxide fluxes within forests from towers. Such appraisals are vulnerable to many errors but commonly have suggested that forests are net accumulators of carbon under most circumstances. Three mechanisms may be at work here: the successional stage of the forest, a potential stimulation of photosynthesis by the increased concentration of carbon dioxide in the atmosphere, and, according to some, a further stimulation of net production by the excess nitrogen flooding the atmosphere from human activities. Confirmation of these latter two mechanisms for forests in general has been difficult and the data remain equivocal. [3]

Finally, there have been several efforts to resolve the global carbon flux by adapting the very large and complex global circulation models developed by climatologists to that purpose. These studies, too, are vulnerable to errors and results have been highly variable. They do agree, however, that there appears to be a sink for atmospheric carbon in the middle latitudes of the northern hemisphere. The mechanism is not clear between forest succession and a stimulation of carbon storage through physiological changes associated with the climatic disruption. Undisturbed tropical forests also seem to be storing carbon. These studies raise many questions and resolve few. The budget is in fact balanced; it is our measurements that are crude and misleading.[4].

While there remain many questions, the fact is that the changes in the earth involve a warming that is greater than any change in more than a thousand years (Fig. 2) and a global disruption of climate. The last century is the period for which the best data

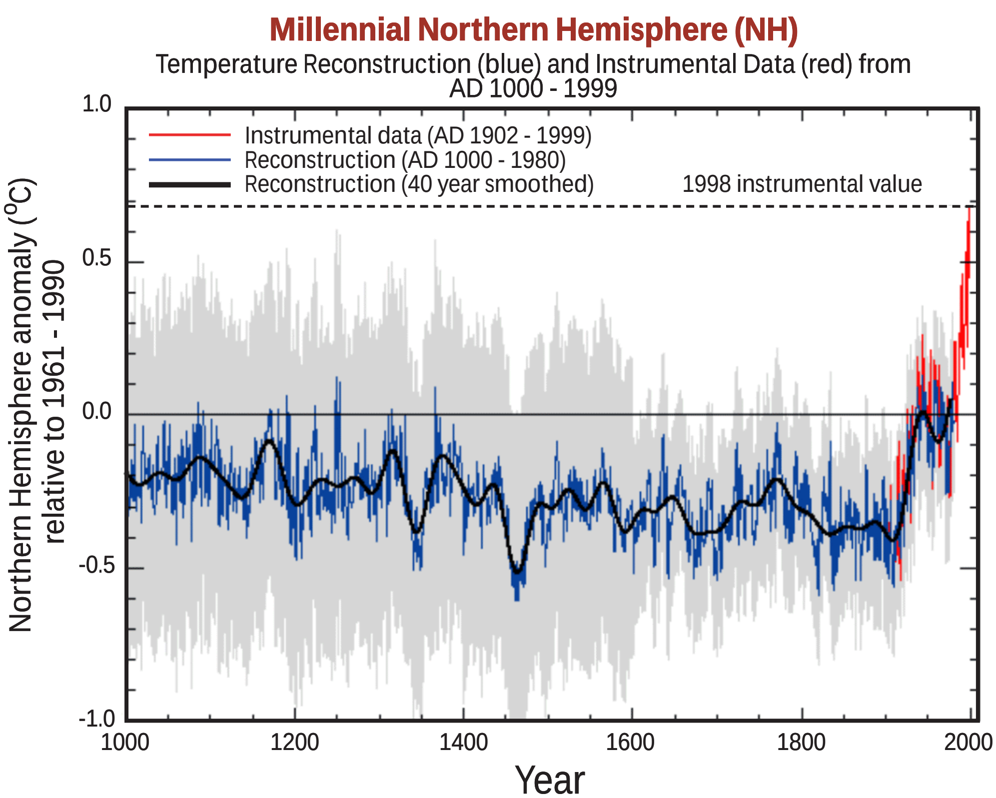
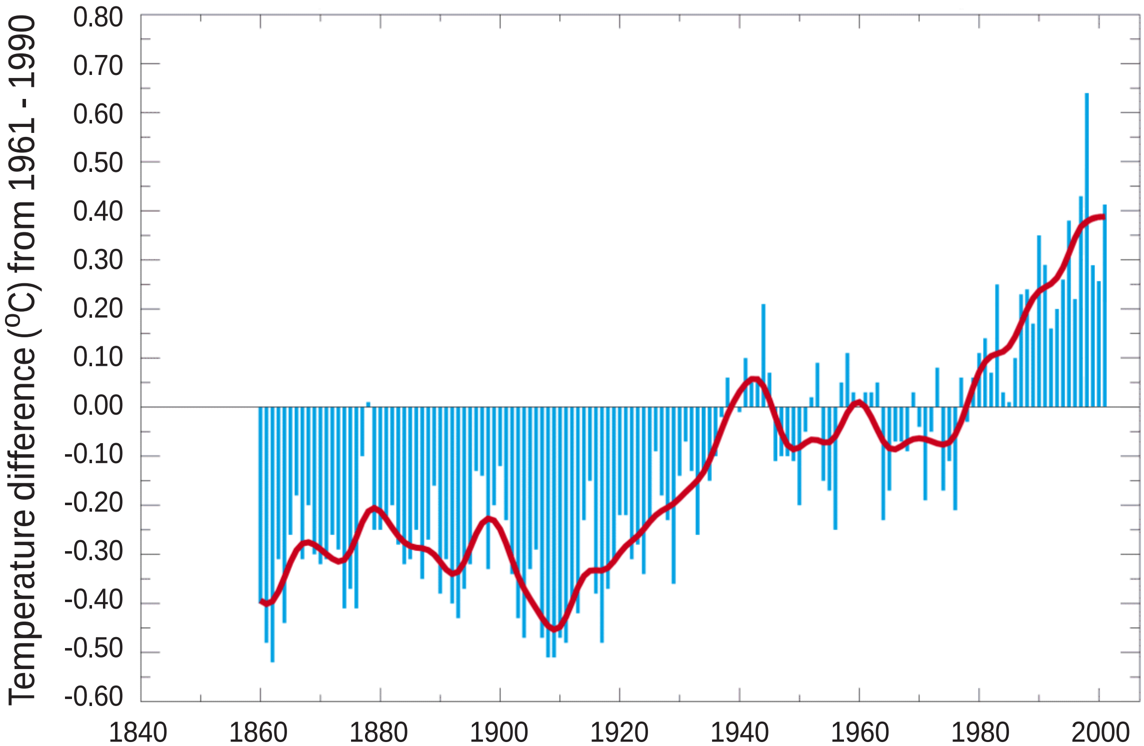


Figure 2. The global temperature record over a millennium. Source: Mann *et al* 1999.

exist both on temperature (Fig.3) and on the changes in climate. Not only has the abrupt change in temperature of the earth become clear from these records, but so have the cooling effects of the releases of debris from volcanic explosions been well demonstrated. The world is already committed not only to a further disruption of climates as the effects of current burdens of heat-trapping gases are felt but also to a further accumulation of those gases as the global commitment to fossil fuels continues for the indefinite future.



Adapted from Mann, M. *et al* 1999

Fig. 3. Global temperature over the last century. 1998 was the warmest year with subsequent years close behind.

The accumulation of heat-trapping gases continues and, as far as governmental policies are concerned, will continue unabated for the immediate future (Fig 4).

How will the world respond? What will the next years bring?

The answer is uncertainty itself. We may be able to narrow the uncertainty somewhat, but, unfortunately, most of the effects of the warming appear to favor more warming. Let me explain with a prime example from the array of biological effects now underway.

The warming of the earth is not uniformly distributed. The highest intensity of solar radiation is received in the tropics. Most of the energy that is not reflected directly back into space is absorbed through the evaporation of water and stored in the energy of vaporization. That water vapor circulates of course in the global circulation of air. The air is warmed in the tropics and rises in the atmosphere and carried poleward in the normal

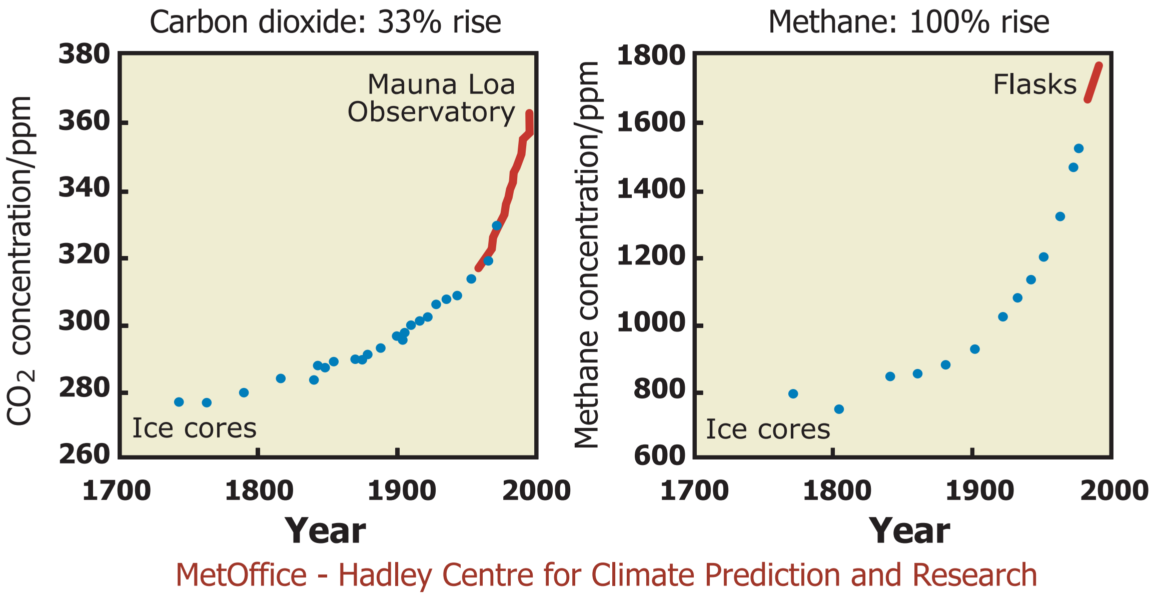


Figure 4. Atmospheric carbon dioxide and methane concentrations over more than a century.

atmospheric circulation of both hemispheres. Cooled at higher latitudes, the water vapor condenses, giving up its heat and warming those latitudes differentially. So the warming of the earth proceeds predictably to warm the higher latitudes at rates that are two to three times the average for the earth as a whole.[5] In the last century while the earth warmed an average of about 0.5 degree C, Canada warmed by more than one degree, and the Mackenzie District of northwestern Canada warmed by more than 1.7 degrees, more than 3 times the average for the earth as a whole. Interestingly, areas in the Davis Strait region of eastern Canada cooled in that period.[6]

The warming of the high latitudes sounds benign, even advantageous. Canadians might at first blush think that it would be fine to have shorter, warmer winters with less snow. But large segments of Canada lie in the boreal forest zone and in the tundra. The boreal forest is the largest forested zone on earth and carries on about 1/3 of the total metabolism of the terrestrial vegetation. The total metabolism on land involves a flux of about 100 billion tons of carbon annually. That much carbon is absorbed annually from the atmosphere into the trees and other plants through photosynthesis, and released through respiration. If 1/3 of the total occurs in the boreal forest and tundra, there is a two-way annual exchange with the atmosphere of more than 30 billion tons in those high latitude regions. A fractional change in either photosynthesis or respiration of the region could easily involve one or more billion tons of carbon in the exchange and have a large influence on the atmospheric burden. If we simply resort to first principles based on broad experience in physiology and ecology we can anticipate the problem. First, it is clear that photosynthesis is driven by light and is not especially sensitive to temperature. Respiration, on the other hand, is quite sensitive to temperature and not affected directly by light. The large pools of carbon in forests and soils, including the peat deposits of the tundra as well as the organic matter in dead and dying trees and in soils, are vulnerable to decay when they are not frozen. As the temperature moderates, the respiration of decay is accelerated. A 10% stimulation of decay, common in other circumstances for a 1-degree increase in temperature, might reasonably be expected to increase the rate of the respiration of decay in the heavily organic deposits of the boreal forest and tundra. An increase of 10% would release an additional flow of carbon into the atmosphere of as much as 3 billion tons annually, possibly more. There is abundant evidence now of the thawing of soils frozen since the glacial time, the erosion and decay of peat, and the enhanced respiration of soils in the tundra.[6] The problem is real enough. But it is not the only positive feedback involving forests.

One of the effects of warming the whole earth has long been anticipated as the warming and drying of the continental centers. The process is not surprising as the climatic zones migrate poleward and the existing arid zones expand over the larger areas of land at middle latitudes in the northern hemisphere. While it is always awkward to assign any climatic anomaly uniquely to a single cause, the current droughts afflicting North America and central Asia are completely consistent with the effects long anticipated from the warming. The effects include the unprecedented forest fires of the past summer in the U.S. and Canada and in Siberia and the Russian Far East. The summer was not unique. There has been an increasing frequency of forest fires across Asia and North America for more than a decade as the warming and drying has progressed. Dr. David Schindler, a distinguished ecologist, member of the U.S. National Academy of Sciences and faculty member at the University of Alberta, has recently written in a letter signed by scores of Canadian scientists to the Premier of Alberta as follows:

> *... In the 1980s and 1990s, the incidence of forest fire doubled in Canada compared to the 1960s and 1970s, burning an area equal to 80% of the province of Alberta during this 20-year period. In the worst fire years of the 1990s, the CO_2 emitted by forest fires almost equaled that from burning fossil fuels in Canada. The area burned was enough to turn our boreal forests from a "sink" for atmospheric CO_2 before 1980 to a "source" of carbon to the atmosphere in the 1990s. There are still huge amounts of carbon in the trees and forests of the Canadian boreal forest that would be released by increased forest fire. If climate continues to warm, there is a great potential for forest fire to amplify the effects of fossil fuel burning, resulting in warming that is beyond the predictions of climate models…*

Forests and their soils are large in area and large in carbon content. Globally they contain with their soils about 50% of the total carbon on land, about 1.5 times as much as is in the atmosphere now or about 1000 billion tons with half of that in plants, most in fact in trees. What happens to forests affects the global carbon budget and the composition of the atmosphere significantly. There is no chance of resolving the climatic crisis without addressing forest management globally.

But the challenge is even larger. A middle latitude climate that is warming at 0.2 or more degree C per decade is marching across the landscape at kilometers per year. This change is not a benign change from one climatic regime to another, milder regime. It is a change from comparatively stable climates to continuously changing climates with rates of change that exceed by far the ecologic amplitude of trees and forests. The result is that trees over very large areas are suddenly in a new climate foreign to them; they are suddenly progressively maladapted to their place and vulnerable to diseases and to pests. I had a chance recently to view the forests outside Flagstaff, Arizona, that escaped this summer's fires. It was common on slopes to see 25–50% of the trees dead or dying, not from fire, but from the drought, which weakened the trees and made them vulnerable to bark borers. The result, again, is morbidity and mortality of trees, the accelerated decay of soil organic matter and the release of additional carbon to the atmosphere. The climate change makes the problem worse…and the amounts of carbon released can be significant. These changes have long been anticipated.[7]

There are still other considerations. The oceans, strangely, offer a similar problem. As the oceanic surface water warms, its capacity for holding carbon dioxide in gaseous form declines. That relationship means once again that as the earth warms the net uptake by the oceanic surface water declines and the accumulation in the atmosphere must increase unless the fossil fuel inputs are reduced.

There is little question about the direction and reality of these transitions. There is question about the magnitude and the timing. Once entrained and conspicuous, they are substantially irreversible. They can, in fact, push the process of warming to the point where it runs beyond the limits of human control. We are on the threshold of that tragedy at the moment, expecting almost any year to discover that the atmospheric burden of carbon dioxide is rising suddenly more rapidly as biotic pools of carbon in forests and soils are dumped.

But there are still greater uncertainties. Robert Gagosian, Director of the Woods Hole Oceanographic Institution, has recently circulated a paper summarizing the conclusions of physical oceanographers at the institution that the continued circulation of the Gulf Stream is in question.[8] A major factor in the normal circulation of the North Atlantic Ocean is the sinking of denser high salinity surface water to form bottom water off Iceland in the Norwegian Sea. The water flows as cold, deep water southward through the North and South Atlantic and Indian Oceans ultimately to return as warm surface water through the Straits of Florida as the Gulf Stream, a massive transfer of energy from the tropical Caribbean to northern, western Europe. That flow warms Scandinavia and western Europe and keeps the northern coast of Russia ice-free in winter all the way to Novaya Zemlya, almost a third of the way across the Eurasian continent. That flow depends heavily on the small differences in density that make the cooler, denser water sink and maintain the flow. If the warming floods the region with freshwater from the melting of glaciers in Greenland and elsewhere, the lighter freshwater will float on the surface and stop or check the sinking and renewal of the deep water current. If that occurs the Gulf Stream will also stop or be much diminished. The global effects are profound and difficult to predict in their totality. There would in any case be a very large reduction in the heat being transferred to Scandinavia and northern Europe. The full ramifications of such a change are highly speculative. They range from minor to the possibility of starting a new ice age in just a few years.

The earth is obviously being pushed rapidly toward major environmental instability by human activities. There is entrained at this moment without further additions to the burden of heat-trapping gases a series of environmental changes that extend well beyond confident prediction into the realm of unpleasant surprises. The surprises include a series of positive feedbacks that make any correction of the trends ever more difficult. The scientific community sees this circumstance as an emergency that requires an abrupt turn away from the fossil fueled age and into the renewable energy age, a new world. But there is no possibility of making the transition to a stable atmosphere as stipulated by the nations of the world under the Framework Convention on Climate Change[9] without addressing forests globally. The first step is obviously to stop the further harvest of primary forests. There can be no equivocation. The earth needs its remaining primary forests kept intact. They are, of course, one of the wonders of the world, the major reservoir of the earth's biota, and a major factor in stabilizing global energy budgets, water flows, air and water quality. But they are also a large reservoir of carbon that must be contained and not released into the atmosphere.

At the same time, every effort is to be made to reforest and thereby remove carbon from the atmosphere and store it for the next century or more until the danger is past. There are many ancillary advantages of course in reforestation including the stabilization of landscapes and the purification of surface and ground water as well as the protection of streams, lakes and coastal waters from various forms of pollution.

The United States exerts leadership on such issues. That leadership can be for good or ill. We took leadership in preparing, advancing, and signing and quickly ratifying the Framework Convention on Climate Change. More than 180 other nations have followed and made that treaty law in those nations as it is in the U.S. It provides that the nations will act to protect the interests of people and nature from disruption by climatic change. It does not, however, define those interests and what protecting them might entail. Those definitions were left to later negotiations which took form in 1997 as the Kyoto Protocol to the Convention. The Protocol was complicated in that it acknowledged the necessity for leadership by the developed world and a perceived need for the freedom to use fossil fuels to aid the economic development of the less developed world.

The product was a modest agreement among the nations that the industrialized world would reduce its use of fossil fuels to an average of 5% below the 1990 level by the period from 2008-2012. It is trifling objective. And it does not include any assured contribution from the less developed world. Although the Protocol was negotiated to satisfy the

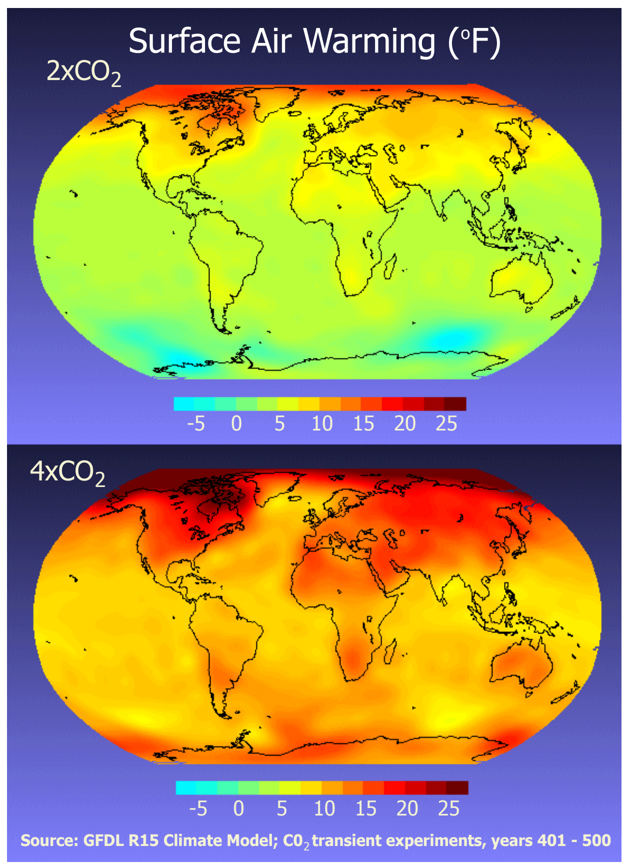


Figure 5. Changes in surface air temperatures anticipated for a doubling and quadrupling of carbon dioxide concentrations above levels at the end of the 19th century.

then demands of the U.S., it has been totally rejected by the new Bush administration which is, in effect, taking a course designed to continue expanding the use of oil in particular and ignoring, even scorning, renewables.

What should be done now? The global challenge of biophysics is clear enough: stabilize the heat-trapping gas content of the atmosphere immediately. One might be inclined to suggest that "immediately" be modified to "as soon as possible." The problem is that "as soon as possible" has not worked and we are out of time (Fig. 5). No longer is it acceptable to equivocate and delay. Time has run out. What is required now is a global reduction in emissions of 3-4 billion tons of carbon annually. A cessation of harvest of primary forests globally and a massive effort at reforestation of abandoned lands globally would reduce the increment by 1.6-2.0 billion tons. Finding an additional 1.6-2.0 billion tons in improvements in the efficiency of use of oil and coal and gas plus a vigorous effort at shifting heating burdens to solar energy makes the transition, if addressed immediately, possible, even attractive.

The Kyoto Protocol will come into effect when 55 of the countries representing 55% of the emissions of 1990 have ratified it. Assuming that Russia will do so, it will be in effect this winter. Its requirements are modest and we should be able to exceed them almost immediately, if we have the will. Taxes and subsidies will be required and are far from novel in such circumstances.

The U.S. apostasy is a problem that is being overridden, at least in part, by public action in acknowledging the challenge and taking it up. A building under construction for The Woods Hole Research Center will have no combustion on site, will provide 30% of its total energy from solar panels at the time of completion, and will ultimately produce more than 100% when a wind turbine has been installed. A proposal for an array of wind turbines in Horseshoe Shoal in Nantucket Sound will produce about 50% of Cape Cod's baseload of electricity within a few years, more than 40% of the output of a 1,000-megawatt power plant. Other wind energy projects are emerging around the country emulating similar installations in Europe.

These transitions are necessary, are economically attractive now, and can be encouraged with subsidies with the express purpose of relaxing demands for fossil fuels. Ultimately, automobiles can be run on hydrogen produced from water with solar electricity. It will not be a world in which fossil fuels have been simply replaced by renewable sources of energy. It will be a new world in which we pay special attention to climate and the role of the biota in maintaining a wholesome human habitat. Energy will be produced locally from renewable sources, used locally, and used with much greater efficiency and greater restraint than currently.

The cost of not making this transition now could easily be this civilization itself.

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Notes and References (incomplete)

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