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Biotic Feedbacks: Will Global Warming Feed Upon Itself?

Bruce E. Johansen

Human-induced warming of the Earth may be working in tandem with several natural feedback mechanisms to accelerate climate change through biotic feedbacks. The possibility that human-induced warming may feed upon itself produces a special sense of urgency in many climate scientists public statements. Along with a sense of urgency, the possibility of biotic "surprises" infuses a high degree of uncertainty into all forecasts of global warming's possible effects.

George M. Woodwell, one of the world's most respected experts on biotic-feedback mechanisms, has written

> A significant body of experience...suggests that there are mechanisms entrained by a change in global climate that tend to increase the trend of temperature change.... [T]here is a possibility that the warming itself may cause a series of further changes in the earth that will speed the warming.... The most serious questions have to do with the potential for...surprises, especially surprises which lead to positive feedbacks. The potential appears significant.... (Woodwell, 393, 406)

Woodwell explains how global warming could feed powerfully upon itself:

> Disruptions of forests globally, especially in the higher latitudes of the northern hemisphere will lead to a significant increase in the release of carbon into the atmosphere. That release can easily be in the range of 1-2 billion tons per year. It means that allowing the warming to progress leads to a potential for surprises. That's only one of the surprises.
>
> If that were to occur it would mean that correcting the problem would be even more difficult than it is at the moment. The releases from the combustion of fossil fuels at the moment (1996) are about 6 billion tons a year. The annual accumulation is 3-4 billion tons a year. Stabilizing the composition of the atmosphere would require removing from current releases something of the order of 3 billion tons, perhaps a little more, immediately. That's a half or more of the current releases of fossil fuels -- a very important challenge.
>
> Warmer temperatures speed the decay of organic matter in soils. Forests...and tundra soils of the Northern Hemisphere contain sufficient carbon to add significantly to the annual emissions, thereby speeding the accumulation of carbon dioxide in the atmosphere. Such a positive feedback has not been incorporated into current estimates of the warming. It is one of several potential surprises lurking in the wings as warming proceeds. (Epstein, Current Effects)

In cold water, for example, methane clathrates form crystal structures which are somewhat similar to water ice. Warming temperatures could destabilize the clathrates, and release some of their stored methane. Roughly 10 trillion tons of methane is trapped under pressure in crystal structures in permafrost or on the edges of the oceans' continental shelves, "the Earth's largest fossil-fuel reservoir", according to Gerald Dickens, a geologist at James Cook University in Townsville, Australia. (Pearce) The greenhouse potential of all the methane stored in clathrates on the continental shelves and in permafrost worldwide is

roughly equal to that of all the world's coal reserves. (Cline, 34) Some of the land masses which host these deposits already have warmed 2 to 4 degrees C. (4 to 7 degrees F.) during the twentieth century. (Lachenbruch)

Atmospheric scientist Roger Revelle has estimated that, with a 3 degree C. rise in global average temperature, methane emissions from clathrates would increase half a gigaton per year. Over a century, this rate could be enough to double the amount of methane in the atmosphere. Add to this another twelve gigatons of methane that could be released by clathrates liberated from ocean bottoms under the Arctic Ocean once the ice cap now covering them melts. "It is possible," writes Jonathan Weiner, "that [this]...feedback effect is already underway and the rise in Earth temperatures in the last hundred years has already sprung many gigatons of methane from their molecular prisons at the bottom of the sea." (Weiner, 118)

Woodwell writes that,

> If, for instance, a sufficient decline in the water table occurs in the boreal and tundra peatlands, subterranean fires could speed oxidation of the peat in the vast, remote peatlands of Canada and Russia, spewing forth smoke, CO2, and CH4 [methane], throughout the northern hemisphere for years.... [I]f water tables remain high, these peatlands might shift toward the production of CH4 at high rates." (Woodwell, 406-407)

Woodwell and colleagues, writing in *Climatic Change*, contend that while terrestrial ecosystems may have absorbed some of the increased carbon generated by human activity during most of the twentieth century, "The recent rate of increase in temperature...leads to concern that we are entering a new phase in climate, one in which the enhanced greenhouse effect is emerging as the dominant influence on the temperature of the Earth." (Woodwell, *et al*., 495)

Biotic feedbacks were discussed in Paris during early December, 1998, at a conference on climate variability organized by the World Meteorological Organization. At this conference, Stephen Schneider warned that the permafrost of Siberia and Arctic North America may already be melting and releasing methane into the air because global warming is occurring as quickly in Siberia as anywhere else on the planet.

Scientists who study biotic feedbacks sometimes remind themselves that while models are linear, nature can behave in random ways which confound linear analysis. The speed and geographic variability of ozone depletion surprised many scientists who had studied the anticipated effects of chloroflourocarbons (CFCs) in theory. It is believed that the role of biotic feedbacks in global warming could be similarly surprising. In its Second Assessment (1995), the IPCC stated that non-linear systems "when rapidly forced," are particularly subject to unexpected behavior ("surprises"). Examples of such "surprises," according to Schneider, may "include rapid decrease in the thermohaline circulation in the North Atlantic Ocean, excitation of certain dynamical modes of response of the climate system, rapid decarbonization of terrestrial ecosystems (e.g., forest die-back in fires or insect outbreaks), [and] catastrophic deglaciation of ice shelves in the West Antarctic." (Schneider, Talk Abstract)

Atmospheric levels of carbon dioxide, which increased between 1.5 and 2.4 parts per million per year during the later years of the twentieth century, builds like a bank account compounding interest. Every five years, the total from which the range of increase is calculated rises by about 8 per cent. Add to this the fact that soils tend to release more carbon dioxide and methane naturally under warmer conditions. In scientific language, "Any changes that increase temperature or reduce pressure may liberate CH4 from hydrate.... The

major potential dangers include massive emission from Arctic hydrate, especially in western Siberia." (Nisbit, 193, 212) Higher temperatures accelerate the oxidation rates of sulfur dioxide and nitrogen oxide to sulfuric and nitric acids, the precursors of acid rain.

Warming temperatures may change the behavior of the Earth's hydrological cycle. Warmer ocean water removes less carbon dioxide from the atmosphere than cooler water, so warming of the oceans may feed upon itself in coming years. Water vapor is also a potent absorber of heat in the atmosphere. It has been estimated that a doubling of carbon-dioxide in the atmosphere would increase its water content by about 30 per cent, raising temperatures an additional 1.4 degrees C. (Hansen, 957) Many models project a rise in cloudiness, and attendant atmospheric moisture, in a warmer, more humid world. George M. Woodwell raises the possibility of a rapid surge in global warming beyond any possibility of human control:

> The possibility exists that the warming will proceed to the point where biotic releases from the warming will exceed in magnitude those controlled directly by human activity. If so, the warming will be beyond control by any steps now considered reasonable. We don't know how far we are from that point because we do not know sufficient detail about the circulation of carbon dioxide among the pools of the carbon cycle. We are not going to be able to resolve those questions definitely soon. Meanwhile, the concentration of heat-trapping gases in the atmosphere rises..." (Woodwell, 130)

Given Woodwell's expectations, the peoples of the Earth in the year 2000 are rapidly approaching a point of no return with regard to biotic feedbacks. Deforestation is accelerating around the world due to growing populations and levels of material affluence. Use of fossil fuels, which has increased at an annual rate of roughly five per cent during most of this century, shows no signs of stabilizing, much less falling by half in the next thirty years. China, alone, projects burning enough fossil fuel (mainly coal) by 2025 to account for about half the present consumption of fossil fuels by everyone on Earth. (Legget, 27)

The "Methane Burp" Hypothesis

Researchers who have drilled into sediment layers near the east coast of Florida found evidence that melting methane clathrates thawed suddenly (over the course of a few thousand years) about 55 million years ago, initiating a sudden episode of global warming which ended with crocodiles and palm trees in the Arctic. At the peak of this episode, greenhouse-gas levels in the atmosphere were between two and six times as high as at present. Lisa Sloan, a paleoclimatologist at the University of California (Santa Cruz) and Gerald Dickens, a paleoceanographer at James Cook University in Queensland, Australia (two of several scientists who conducted the study) reported the findings at a meeting of the American Geophysical Union late in 1999.

The study of methane clathrates has become more popular in recent years, as evidence accumulates that their release, especially from oceans, may be a major driving force in Earth's climate cycles. James P. Kennett, *et al*. studied climate records for the last 60,000 years off Santa Barbara, California, and parts of Greenland, finding that "surface and bottom temperatures change in concert." (Kennett, *et al*.; Blunier, 68) This findings support assertions by E.G. Nisbet [*Canadian Journal of Earth Sciences* 27(1990):148] that massive release of oceanic methane from clathrates have played a significant role in rapid warmings during the past, even without added forcings by human industry.

Scientists have yet to reach any sort of consensus on causes of the Earth's "methane burps." No one yet knows why a trillion tons of methane may be released so suddenly from solid methane hydrates around the world. This chemical reaction provoked a sudden (in geologic time) global warming of 4 to 8 degrees C. James Cook and Gerald Dickens theorize that "The methane probably oxidized to form carbon dioxide. which eventually reached the atmosphere, driving greenhouse warming." (Kerr, 1999, 1465)

The sediment cores drilled by Katz, *et al*. contained remnants of small marine organisms called foraminifera, which preserve a record in their shells of carbon levels in the ocean. The shells tell a story of an extreme warming (possibly more than 10 degrees F.) in the ocean over a short time, which killed more than half of the foraminifera. The sediment core also contains evidence of an underwater landslide which scientists believe took place as melting methane clathrates "warmed dramatically, breaking apart into water and methane gas, and bubbl[ed] ferociously out of the sea floor." (Witze, 4)

This line of reasoning was supported by Richard Norris of the Woods Hole Research Center, and Ursula Rohl of Germany's University of Bremen, who wrote in *Nature* that the "methane burp" occurred when an as-yet-unknown natural provocation pumped greenhouse gases into the atmosphere, causing a sudden bout of global warming. "Our results suggest that large natural perturbations to the global carbon cycle have occurred in the past...at rates that are similar to those induced today by human activity," Norris and Rohl wrote. (p. 775) Miriam E. Katz, Dorothy K. Pak, Gerald R. Dickens, and Kenneth G. Miller assert that this surge in global temperatures may have played a crucial role in the evolution of warm-blooded mammals as the Earth's dominant species 10 million years after a cataclysmic event (probably the impact, on the Earth, of a very large asteroid) ended dominance by the dinosaurs. Katz, *et al*. contend that "elevated temperatures quickly opened high latitude migration routes for the widespread dispersal of mammals." (Katz, 1531)

Stephen P. Hesselbo and colleagues reported in *Nature* (July 27, 2000) that roughly 200-140 million years ago large quantities of methane were liberated from ocean floors, possibly because of warming global temperatures. This "methane pulse" -- a "voluminous and extremely rapid release of methane from gas hydrate contained in marine continental-margin sediments" (Hesselbo, *et al*., 392) -- combined with oxygen in the oceans to form carbon dioxide, accelerating the worldwide warming. Along the way, a large proportion of oceanic animal life (perhaps 80 per cent) died for lack of oxygen. "One of the important questions that is debated a lot today is the stability of this methane hydrate reservoir, and how easy it is to release the methane," said Stephen P. Hesselbo, lead author of the paper. "The extinction and the association with lack of oxygen has been fairly well established, but the association with methane release is something that hadn't been realized before," he said. (Prehistoric, 9)

New Forecasts of Temperature Rise

A report on global warming issued by the Pew Center on Global Climate Change in 1999 asserts that temperatures will rise somewhat more by the year 2100 than forecast in 1995 by the Intergovernmental Panel on Climate Change's Second Assessment. The study, titled *The Science of Climate Change: Global and U.S. Perspectives*, was researched and written by Tom Wigley of the National Center for Atmospheric Research for the Pew Center.

The Pew Center study projects global-mean temperature increases ranging from 1.3 to 4.0 degrees C (2.3 to 7.2 degrees F), as compared with the IPCC's projections of 0.8 to 3.5

degrees C (1.4 to 6.3 degrees F). The Pew Center study also forecasts a sea-level rise of 17 to 99 centimeters (7 to 39 inches) by the year 2100, compared to a previous IPCC projection of 13 to 94 centimeters (5 to 37 inches).

The study suggests that the rate of warming in the United States may be "noticeably faster than the global-mean rate." (Pew) The study expects temperatures in the southeastern and southwestern sections of the United States to warm slightly less than the global mean. The northernmost states, from North Dakota eastward to Maine, are expected to warm as much as twice the global mean during winter months, according to Wigley's projections. The study also forecasts that "The frequency of high-precipitation events is likely to increase, bringing increased chances of flooding." (Pew) The Pew Center study also estimates that about one-third of the expected global warming during the next century may be attributed to changes in the sun's radiative output.

A report by the United Kingdom's Hadley Center for Climate Change, incorporating improved representations of ocean currents into models of the climate system, suggests that a "runaway" greenhouse effect is possible by the end of the twenty-first century. (Brown, 1998) The study contends that as lack of rainfall turns large swaths of the Amazon, the Eastern United States, Southern Europe and other areas into near-deserts, the ability of plants and trees to absorb greater amounts of carbon dioxide will be reduced, resulting in higher atmospheric concentrations and rapid global temperature increases.

By 2050, this report projects that agricultural output in central and southern Africa will be severely reduced, and North America's agricultural heartland could see wheat and corn yields fall by as much as 10 per cent. Extreme water shortages will affect 170 million people, according to this study, which was presented at the Buenos Aires climate conference in 1998. The study forecasts that temperatures on land will rise an average of 6 degrees C. by the year 2100, subjecting about 100 million people to annual hazards of coastal flooding from rising sea levels.

The Hadley Center study also projects that the Gulf Stream, which is an important warming influence on much of Europe during the winter, will be 20 per cent less strong in the future, but that Europe still will warm considerably. This study, unlike some others (See also: Chapter Four, Icemelt), does not foresee a weakening of the Gulf Stream as portending colder winters for Europe while most of the rest of the world warms. Instead, the Hadley Center model forecasts that Western Europe, including Scotland, will gain the ability to grow extra grain, and that European storms will become more severe, especially during the winter.

The Hadley Center study anticipates that the benefits for plants of a carbon-enhanced atmosphere will be outweighed by lack of rainfall in many important agricultural areas. The study also asserts that many tropical grasslands will be transformed into deserts, leading to widespread extinction of wildlife. Michael Meacher, British environment minister, told The Guardian that "These are sobering findings. Millions of people will have life made miserable by climate change, with increased risk of hunger, water shortages and extreme events like flooding. Combating climate change is the greatest challenge of human history." (Brown, 1998) The Hadley Center study also anticipates that much of central and southern Africa will experience a reduced ability to grow staple crops. While the agricultural heartland of the United States will suffer production reductions (as previously noted) because of drought and heat, the study projects that Canada will experience a wheat-production increase of about 2.5 per cent.

Temperature readings during the late 1990s indicated that a steep rise in temperatures seemed to be underway. On March 9, 2000 the National Oceanic and Atmospheric Administration (NOAA) said the winter of 1999-2000 was the warmest such season in the

United States since the government began keeping records 105 years earlier. This marked the third year in a row that record warmth was recorded in the United States during the winter months. Since 1980, more than two-thirds of U.S. winters have been warmer than average, NOAA said.

The average temperature in the United States between December, 1999 and February, 2000 was 38.4 degrees F., six-tenths of a degree warmer than the record set the previous year. Scientists at NOAA reported that every state in the continental United States was warmer than its long-term average, with 21 states from California to the Midwest ranked as much above average. As the report was being released, a winter carnival was being canceled near Wausau, Wisconsin, for lack of snow. Other casualties of the warmth included North America's largest cross-county ski race and an ice fishing derby in International Falls, Minn.

A week later, the Great Lakes, the world's largest body of fresh water, were measured at their lowest level in recorded history, because of scant snowfall during the winter, after several years of declining water levels. Consequences have included dry wells, landlocked docks, obstacle courses for commercial shipping and pleasure boaters, and smelly drinking water in some areas. Many docks have become useless, while emergency dredging has been required for others. At the same time, the temperature of lakes water has been climbing. During 2000, Buffalo, New York reported that its harbor's water temperature at the end of March had equaled the record warmest (39 degrees F.) set in 1998.

During 1990, Congress commissioned a study of how global warming would affect various regions by the year 2100. The report ("Climate Change Impacts on the United States;" [www.nacc.usgcrp.gov] was issued in draft for public comment during the summer of 2000. The report, which involved 5,000 people in nine federal agencies, projected that average temperatures will rise 5 to 10 degrees F. by the end of the century. This report analyzed possible climate changes in eight regions of the United States, "based on a pair of state-of-the-art climate models -- one from the Canadian Climate Center and one from the United Kingdom Hadley Centre for Climate Research and Prediction" (Kerr, June 23, 2000, 2113). The entire study was coordinated by Thomas Karl, director of the NOAA National Climate Center in Asheville, North Carolina, who said that the report illustrated a "range of our uncertainties." To Karl, the report also indicated that "The past isn't going to be a very good guide to future climate." (Kerr, June 23, 2000, 2113)

The two climate models used in the study sometimes contrast vividly. The Canadian model, for example, indicates frequent severe drought in the United States' agricultural heartland, while the Hadley model suggests plentiful rainfall in the same area. Generally, however, the report supports a 5 to 10 degree F. rise in temperatures during the century, in line with the models of the Intergovernmental Panel on Climate Change. The report was largely a compilation of data from existing sources because when Congress mandated the study no funds were provided to pay for it.

According to this report, water levels in the Great Lakes are expected to drop five feet by century's end. By the year 2000, Lakes Eire, Michigan, Huron had dropped three feet in three years, while Lakes Superior and Ontario were down about eighteen inches during the same period. Todd Thompson of the Indiana Geological Survey was quoted (Flesher, B-1) as saying that the levels of the Great Lakes ebb and flow in thirty-year cycles. The lakes receded during the drought years of the 1930s, then again in the 1960s. Coming years will reveal whether present lake-level declines are merely cyclical, or part of a new trend related to global warming. In the meantime, the Toledo Beach Marina was spending $1 million during the year 2000 to add three and a half feet of draft to its docking facilities. (Flesher, B-3) Lake Eire averages only 70 feet deep, and in some places even a few inches make a big

difference for cargo shipping. At about the same time, the National Environmental Trust released a report describing global warming's anticipated effects on the Great Lakes. Philip Clapp, president of the organization, said dredging of shipping lanes caused by declining lake levels could cost billions of dollars. (Fauber, 1-A)

The same federal report also anticipates some beneficial effects, such as reduced costs for snow removal in many Midwestern cities, and an opportunity for farmers to profit by planting more than one crop a year. (Fialka, A-24) This 700-page report contains regional summaries of global warming's possible effects, many of which cite previous research cited in this volume.

As news of recent temperature rises arrived during the year 2000, the IPCC strengthened its previous statement affirming human modification of the Earth's climate. In 1995 the IPCC had concluded that "the balance of evidence suggests a discernible human influence." In its 2000 assessment, this language reads: "There has been a discernible human influence on global climate." (Kerr, 2000, 590, emphasis added) The temperature records of the last 1,000 years now leave very little doubt that the upward spike in temperatures since 1980 has been influenced in large part by human greenhouse-gas emissions. The IPCC's new forecasts for global temperatures in 2100 changed little in 2000 from the 1990 or 1995 assessments -- 1 degree C. to 5 degrees C., according to several sets of assumptions about how human numbers, societies, economies, and technologies may change during that time.

The Possible Speed of Climate Change

During May of 1997, twenty-one nationally prominent ecologists warned President Clinton that rapid climate change due to global warming could ruin ecosystems on which human societies depend. The signers, including Stephen H. Schneider and three colleagues from Stanford University, urged Clinton to take a "prudent course" in the then-upcoming global climate-change negotiations in Kyoto, Japan. (Basu) The scientists warned that the warming would happen so quickly that many plant and animal species will not be able to adapt. The resulting breakdown of ecosystems could lead to disturbances with major effects on human populations, the scientists warned. These may include increasing numbers of fires, floods, droughts, and storms, as well as erosion and outbreaks of pests and pathogens. The letter says that if present (1997) levels of greenhouse-gas emissions continue to rise, the climate will change more quickly during the coming century than at any time during the past 10,000 years.

"The signers include the leading international experts on many particular dimensions of this problem," said Harold Mooney, Stanford professor of biological sciences and the organizer of the effort. "As you will read in the letter, they all have deep concerns about the ecological consequences of rapid climatic change." (Basu) Among the signers are Mooney, as well as Paul Ehrlich of Stanford (who is considered to be an international leader in ecological research), and Jane Lubchenco of Oregon State University, a past president of the American Association for the Advancement of Science. Seven of the signers are members of the National Academy of Sciences and five are past presidents of the Ecological Society of America.

In the United States, the scientists said,

> [R]apid climate change could mean the widespread death of trees, followed by wildfires and...replacement of forests by grasslands. National parks and forests could become inhospitable to the rare plants and animals that are preserved there -- and where the parks are close to developed or agricultural land, the species themselves may disappear for lack of another safe

> haven. Worldwide, fast-rising sea levels could inundate the marshes and mangrove forests that protect coastlines from erosion and serve as filters for pollutants and nurseries for ocean fisheries. "The more rapid the rate [of change] the more vulnerable to damage ecosystems will be," the scientists told the president. "We are performing a global experiment [with] little information to guide us. (Basu)

The ecologists warned that in some United States temperate-zone forests, rapid climate change could lead to "widespread tree mortality, wildfires and replacement of the forests by grasslands. Species that are long-lived, rare, or endangered will be severely disadvantaged." (Basu) "It would be difficult to imagine, for example," the scientists wrote, "how the imperiled species of Everglades National Park, such as the Cape Sable Sparrow and American Crocodile, could migrate north into the urban and agricultural landscapes of coastal and central Florida and successfully re-establish themselves." (Basu)

The scientists' letter seemed to have an impact at the White House, judging from presidential rhetoric. In his 1999 State of the Union speech, President Clinton called global warming "our most fateful new challenge," as he recalled 1998 as the warmest year ever recorded, with heat waves, floods and storms which "are but a hint of what future generations may endure if we do not act now." Clinton proposed creation of a new "clean air fund to help communities reduce greenhouse and other pollutions." Clinton also said he "want[ed] to work with members of Congress in both parties to reward companies that take early, voluntary action to reduce greenhouse gases. (President Clinton) Many of Clinton's proposals were repeated a year later in his 2000 (and last) State of the Union speech. (Clinton)

"We know from ice-core records and deep-sea sediment records that the earth's climate is capable of changing much more quickly than we had previously thought," said Jeff Severinghaus of the University of California. (Webb, 1998c) "In some cases," said Severinghaus, "The climate warmed abruptly in less than 10 years...up to possibly 10 degrees centigrade." (Webb, 1998c) Severinghaus' findings were presented at the 1998 climate-change conference in Buenos Aires.

Severinghaus continued:

> It is possible that by increasing greenhouse gases, we will induce such a change and that, instead of the smooth warming that's being anticipated over the next 50 years, that we'll instead go along for a while with very little warming and then all of a sudden in a matter of three or five or ten years we'll have a very large catastrophic warming. (Webb. 1998c)

At the National Ice Core Laboratory in Denver, thousands of meter-long tubes are arrayed on shelves, holing ice cores from the Arctic and Antarctic at minus 36 degrees C. These ice cores contain records of the Earth's changing climate for the last 420,000 years. From studies of ice cores taken in Greenland, scientists have assembled a climatic record which indicates that during the last 8,000 years the earth's climate has been relatively warm and stable. At the end of ice ages (the most recent one, which ended about 12,000 years ago is an example), temperatures tend to swing wildly in cycles of five to twenty years. According to Gale E. Christianson, "Temperatures rose by an astonishing 10 degrees C. within the lifespan of a Paleolithic hunter, and some scientists now think that even that figure is too low by half." (Christianson, 128)

Richard B. Alley, also writing in the Proceedings of the National Academy of Sciences, reviews ice-core evidence from the last 110,000 years which indicates that climate may vary very little over long periods, then undergo changes as large as those between glacial and interglacial conditions, sometimes within a few years or decades. Alley points out

that the development of complex human civilization has taken place during a period without such rapid changes. (Alley, 1331)

Thomas V. Lowell of the University of Cincinnati's Geology Department, writing in the Proceedings of the National Academy of Sciences, used changes in glacial mass to track of climatic change. Using such measures, Lowell provides graphic evidence (from glacial samples near coastal Alaska's Prince William Sound and Western Greenland) that average temperatures declined slowly from about 1450 A.D. to almost 1900 A.D. (the so-called "Little Ice Age"). At that time, temperatures began to climb rapidly, at a pace of about 0.8 degrees C. per century, four times the rate of change during the previous 900 years. The temperature curve rises at an increasingly steep angle toward the end of the century. (Lowell, 1351)

Jonathan Overpeck, director of the paleoclimatology program for the National Oceanic and Atmospheric Administration (NOAA), said at the end of 1998 that "There is no period that we can recognize in the last 1,200 years that was as warm on a global basis [as the present]." Overpeck presented his findings at a meeting of the American Geophysical Union in San Francisco. "That makes what we're now seeing more unusual, and more difficult to explain without turning to a 'greenhouse gas' mechanism," said Overpeck. (Warrick) By the 1990s, according to the IPCC's Second Assessment (1995) the temperature was rising at the most rapid rate in at least 10,000 years.

Until the 1990s, many climate scientists believed that the Earth had warmed dramatically during the period of time which Europe called the Middle Ages, roughly 900 to 1400 A.D. New research, based on tree rings, glaciers and other "proxy" measurements of past climate around the world, indicates that this warming was limited mainly to northern latitudes in Europe and North America. Evidence of a rapid warm-up during the Middle Ages has been used as "proof" by some global-warming skeptics that natural variations may explain rapid temperature increases worldwide during the last quarter of the twentieth century. "Our study of the Medieval Warm Period supports the likelihood that no known natural phenomenon can explain the record twentieth-century warmth," Overpeck said. "Twentieth century global warming is a reality and should be taken seriously." (Warrick)

Dean Edwin Abrahamson confirms Overpeck's analysis:

> One must go back in time 5 to 15 million years to the late Tertiary to find a time that was 3 or 4 degrees C. warmer than now. During periods when there was no permanent pack ice in the Arctic, climatic and vegetational region and boundaries were displaced as much as 1,000 to 2,000 kilometers north of their present position (a displacement which we may replicate during the next 100 years). (Abrahamson, 15)

During the period Abrahamson describes, intense aridity was the norm from present-day North and South Dakota to Missouri and Alabama, as well as throughout Central and Southern Africa. These changes may be similar to those which will be experienced by generations to come. As Abrahamson comments,

> Beyond the year 2050...we could be committed to a far larger warming -- probably on the order of 6 to 10 degrees C. The climatic conditions that might be associated with such a warming are, with few exceptions, pure mystery.... Today's climate models have little, if any, validity for such extreme warming.... There can be no planned adaptation under these conditions." (Abrahamson, 21)

By early in the year 2000, scientists working for National Atmospheric and Oceanic Administration (NOAA) released compilations of global temperatures for the last half of the

twentieth century which reveal a speed of warming that most climatologists had not expected until late in the twenty-first century. The rate of warming (1 degree F. over the entire century) increased to a rate of 4 degrees F. during the century's last quarter, according to calculations of Tom Karl and associates, published in the March 1, 2000 edition of Geophysical Research Letters. This is roughly the rate of increase which several climate models had forecast for the second half of the twenty-first century. "The next few years could be very interesting," Karl told the *Los Angeles Times*. "It could be the beginning of a new increase in temperatures." (Analysis, 12) Tom Wigley, a senior scientist at the National Center for Atmospheric Research in Boulder, Colorado, said that warming was strengthened frequent El Niño events, which he said are not human-induced. "Those months were unusual," he said, "but they weren't unusual due to human influences." (Analysis, 12)

Karl and colleagues begin a statistical analysis of recent global temperature trends with the observation that between May of 1997 and September of 1998, sixteen months in a row, global temperatures set observational (e.g. century-scale) monthly records. Their analysis of a century-plus of records (roughly 1880 to 2000) indicates that the rate of warming tends to surge upward, then relent a little, and then surge anew. "The increase in global mean temperatures is by no means constant." (Karl, *et al*., 719) Karl and colleagues conclude that "The warming rate over the past few decades [since the mid-1970s] is already comparable to that projected during the twenty-first century based on IPCC business-as-usual scenarios of anthropogenic climate change." (Karl, *et al*., 719)

> We interpret the results to indicate that the mean rate of warming since 1976 is clearly greater than the mean rate of warming averaged over the late nineteenth and twentieth centuries. It is less certain whether the rate of temperature change has been constant since 1976 or whether the recent string of record-breaking temperatures represents yet another increase in the rate of temperature change.... Moreover, these results imply that if the climate continues to warm at present rates of change, more events like the 1997 and 1998 record warmth can be expected. (Karl, *et al*., 720,721)

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