CLIMATE CHANGE

State of Knowledge

CLIMATE CHANGE

State of Knowledge

October 1997

Background

During the 1980s, scientific evidence about global climate change and its consequences led to growing concern among scientists, policy makers, and the public. In 1988, the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) jointly established the Intergovernmental Panel on Climate Change (IPCC). Through the IPCC process, scientists representing more than 150 countries have assessed the available information on climate change and its environmental and economic effects and have provided the scientific understanding needed to help formulate appropriate responses. A series of IPCC reports, incorporating extensive peer review and a commitment to scientific excellence, have provided the most authoritative and comprehensive information available on the science of climate change. In 1996, the IPCC published its Second Assessment Report, which summarizes the most recent information on climate change science and the vulnerability of natural and socioeconomic systems.

IPCC Website: http://www.ipcc.ch/

In 1990, the United Nations (UN) General Assembly established the Intergovernmental Negotiating Committee for a Framework Convention on Climate Change (FCCC). The FCCC was adopted in 1992, and over 160 signatories have now become parties to the agreement. The agreement was signed by the President of the U.S. and ratified by the U.S. Senate in 1992. The ultimate aim of the FCCC is to stabilize greenhouse gas concentrations "at a level that would prevent dangerous anthropogenic interference with the climate system." This stabilization should be achieved within a time frame that (1) allows ecosystems to adapt naturally to climate change, (2) ensures that food production is not threatened, and (3) enables sustainable economic development to proceed.

Framework Convention Website:
http://www.unep.ch/iucc.html

In the United States, climate change research is overseen by the U.S. Global Change Research Program (USGCRP), which was established in 1989. Since its inception, the USGCRP has strengthened research on key scientific issues and has fostered improved understanding of Earth processes. New directions for the USGCRP include identifying and analyzing regional vulnerabilities to climate variability and climate change. The results of the research it supports have played an important role in the work of the IPCC and other national and international bodies.

GCRP Website: http://www.usgcrp.gov/

Introduction

Burning coal, oil and natural gas to heat our homes, power our cars, and illuminate our cities produces carbon dioxide (CO_2) and other greenhouse gases as by-products. Deforestation and clearing of land for agriculture also release significant quantities of such gases. Over the last century, we have been emitting greenhouse gases to the atmosphere faster than natural processes can remove them. During this time, atmospheric levels of these gases have climbed steadily and are projected to continue their steep ascent as global economies grow.

Records of past climate going as far back as 160,000 years indicate a close correlation between the concentration of greenhouse gases in the atmosphere and global temperatures. Computer simulations of the climate indicate that global temperatures will rise as atmospheric concentrations of CO_2 increase. The 1995 report of the Intergovernmental Panel on Climate Change (IPCC), which is the most comprehensive and thoroughly reviewed assessment of climate change science ever produced, concluded that change is already underway. The IPCC, which represents the work of more than 2,000 of the world's leading climate scientists, concluded that Earth has already warmed about 1° F over the last century, and that "the balance of evidence suggests that there is a discernible human influence on global climate."

The IPCC estimates that global surface air temperature will increase another 2 - 6.5° F in the next 100 years. The difference in temperature from the last ice age to now is about 9° F. Their "best guess" is that we will experience warming of about 3.5° F by 2100, which would be a faster rate of climate change than any experienced during the last 10,000 years, the period in which modern civilization developed.

Warming of this magnitude will affect many aspects of our lives as it changes temperature and precipitation patterns, induces sea level rise, and alters the distribution of fresh water supplies. The impacts on our health, the vitality of forests and other natural areas, and the productivity of agriculture are all likely to be significant. As the risks of global climate change become increasingly apparent, there is a genuine need to focus on actions to reduce our greenhouse gas emissions and minimize the adverse impacts of a changing climate.

The Greenhouse Effect and Historical Emissions

Life as we know it is possible on Earth because of a natural greenhouse effect that keeps our planet about 60° F warmer than it otherwise would be (Figure 1). Water vapor, carbon dioxide (CO_2), and other trace gases, such as methane and nitrous oxide, trap solar heat and slow its loss by re-radiation back to space. With industrialization and population growth, greenhouse gas emissions from human activities have consistently increased. These steady additions have begun to tip a delicate balance, significantly increasing the amount of greenhouse gases in the atmosphere, and enhancing their insulating effect.

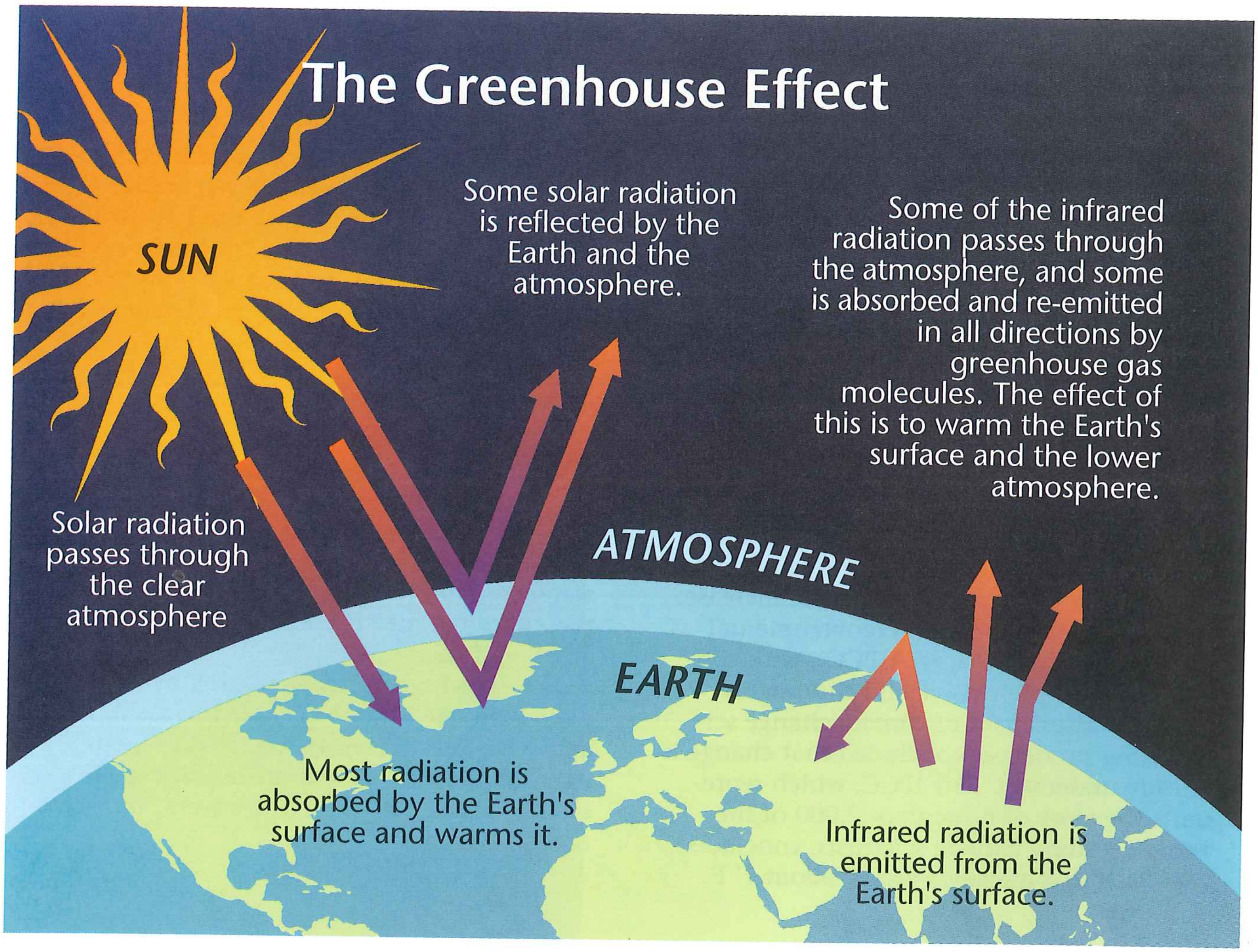


Figure 1. The greenhouse effect naturally warms the Earth's surface. Without it, Earth would be 60° F cooler than it is today – uninhabitable for life as we know it.

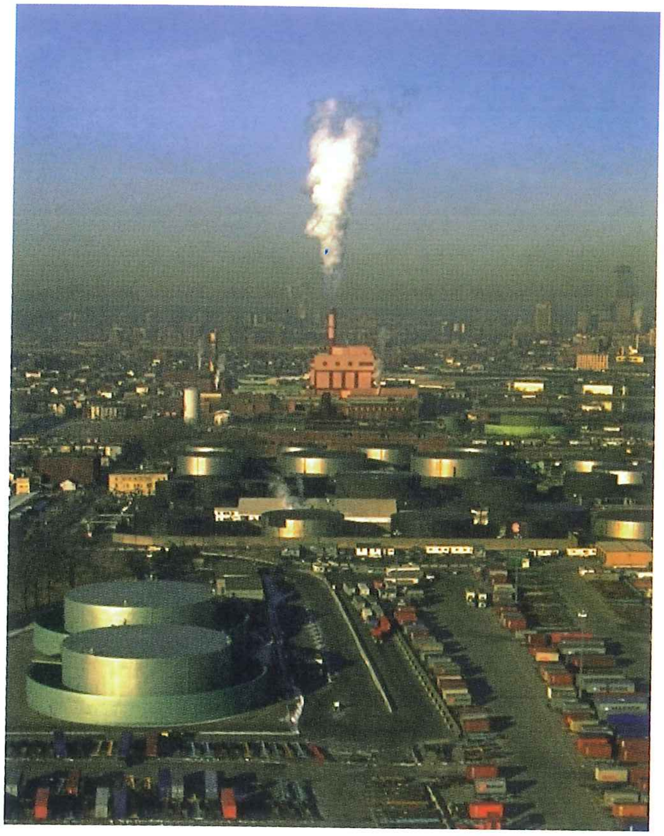


Figure 2. Burning fossil fuels such as coal, oil, and gas, add 6 billion metric tons of carbon each year to the atmosphere.

A wide variety of activities contribute to greenhouse gas emissions. Burning of coal, oil, and natural gas releases about 6 billion tons of carbon into the atmosphere each year worldwide. Burning and logging of forests contributes another 1-2 billion tons annually by reducing the storage of carbon by trees (Figures 2 and 3).

Figure 3. Deforestation worldwide adds 1 to 2 billion metric tons of carbon to the atmosphere each year.

The result is that the atmospheric level of CO_2, the most important human-derived greenhouse gas, has increased 30 percent, from 280 to 360 parts per million (ppm) since 1860 (Figure 4). Over the same time period, agricultural and industrial practices have also substantially increased the levels of other potent greenhouse gases -- methane concentrations have doubled and nitrous oxide levels have risen by about 15 percent. These gases have atmospheric lifetimes ranging from decades to centuries; today's emissions will be affecting the climate well into the 21st century.

The overall emissions of greenhouse gases are growing at about 1 percent per year. For millennia, there has been a clear correlation between CO_2 levels and the global temperature record. Fluctuations of CO_2 and temperature have roughly mirrored each other over the last 160,000 years (Figure 5). The current level of CO_2 is already far higher than it has been at any point during this period. If current emissions trends continue over the next century, concentrations will rise to levels not seen on the planet for 50 million years.

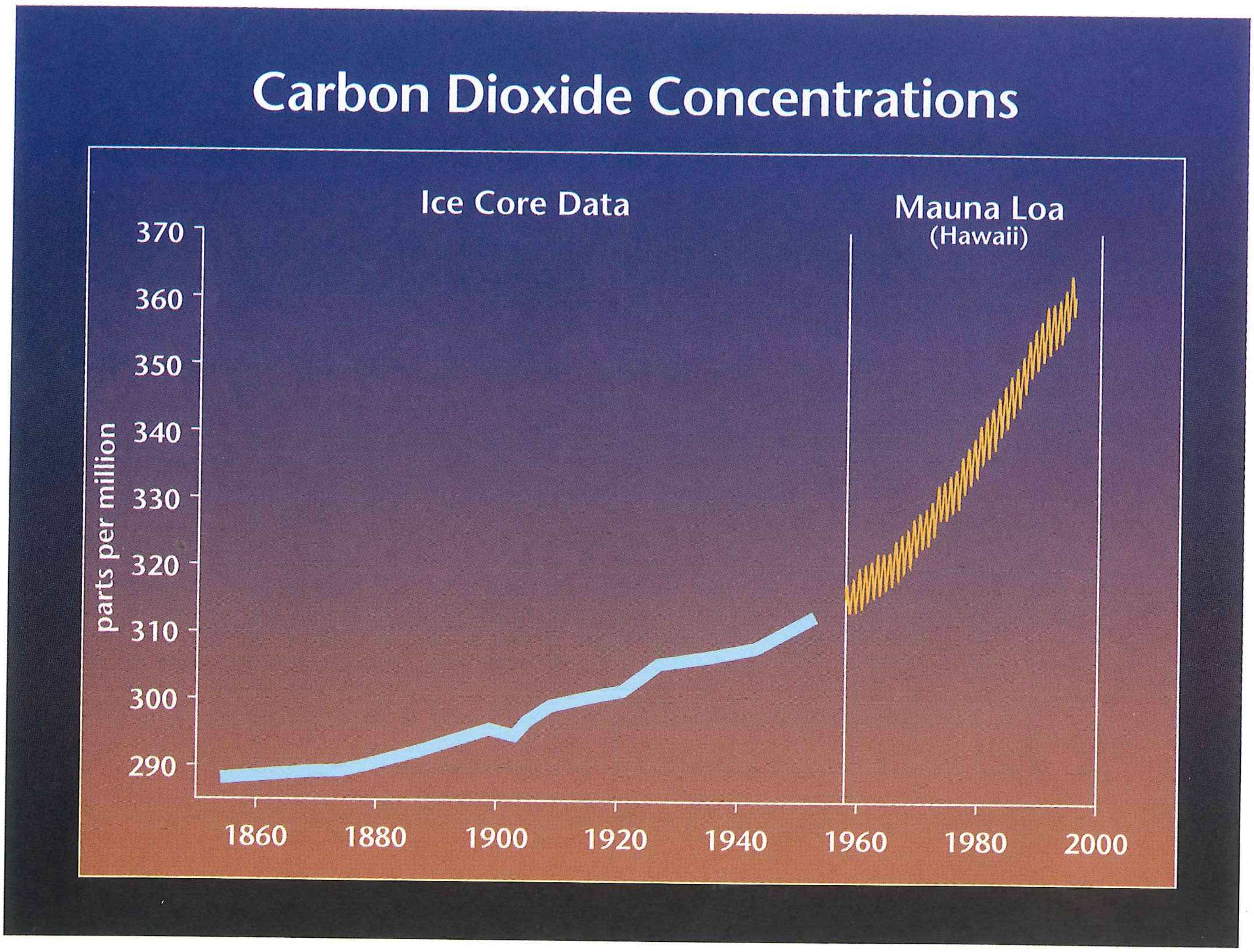


Figure 4. Since the beginning of the Industrial Revolution in the middle of the 19th century, the concentration of carbon dioxide (CO_2) in the atmosphere has steadily increased. Beginning in 1957, continual measurements of atmospheric CO_2 concentrations have been made by scientists at an observatory in Mauna Loa, Hawaii. The seasonal cycle of vegetation in Northern latitudes can be seen in this record: each spring the vegetation "inhales" and absorbs CO_2, and each autumn most of that CO_2 is released back to the atmosphere.

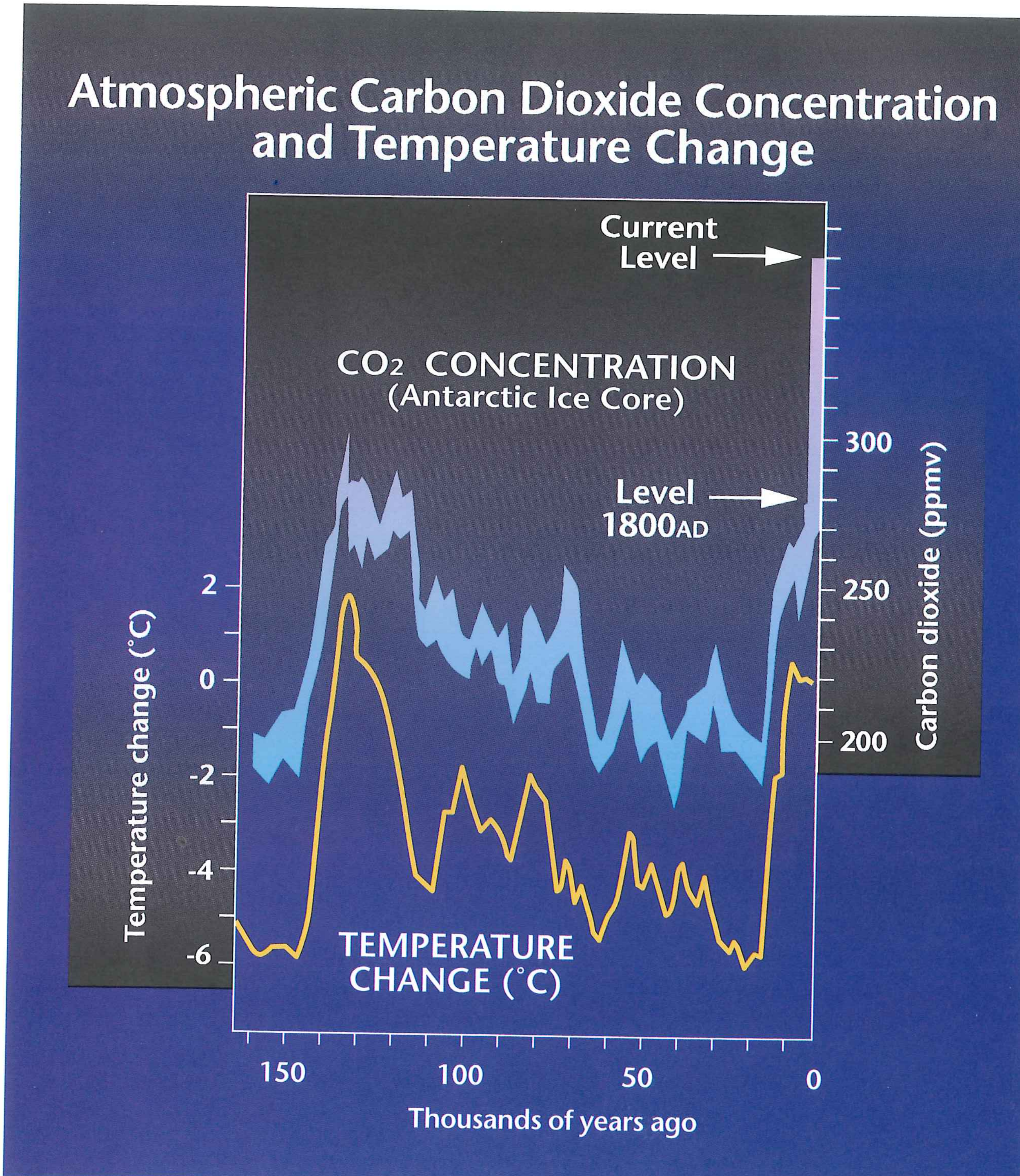


Figure 5. Data from tiny air bubbles trapped in an Antarctic ice core show that atmospheric CO_2 concentrations and temperatures from 160,000 years ago to pre-industrial times are closely correlated. Direct measurement of CO_2 concentration and temperature in recent decades extend this record to the present day, and confirm that CO_2 concentrations have risen to 360 ppm and temperatures have increased 0.5 degree C (1 degree F) over the last 100 years.

Which countries account for the largest proportions of CO_2 emissions? In 1995, 73 percent of the total CO_2 emissions from human activities came from the developed countries (Figure 6). The United States is the largest single source, accounting for 22 percent of the total, with carbon emissions per person now exceeding 5 tons per year. Over the next few decades, 90 percent of the world's population growth will take place in the developing countries, some of which are also undergoing rapid economic development. Per capita energy use in the developing countries, which is currently only 1/10 to 1/20 of the U.S. level, will also increase. If current trends continue, the developing countries will account for more than half of total global CO_2 emissions by 2035. China, which is currently the second largest source, is expected to have displaced the United States as the largest emitter by 2015.

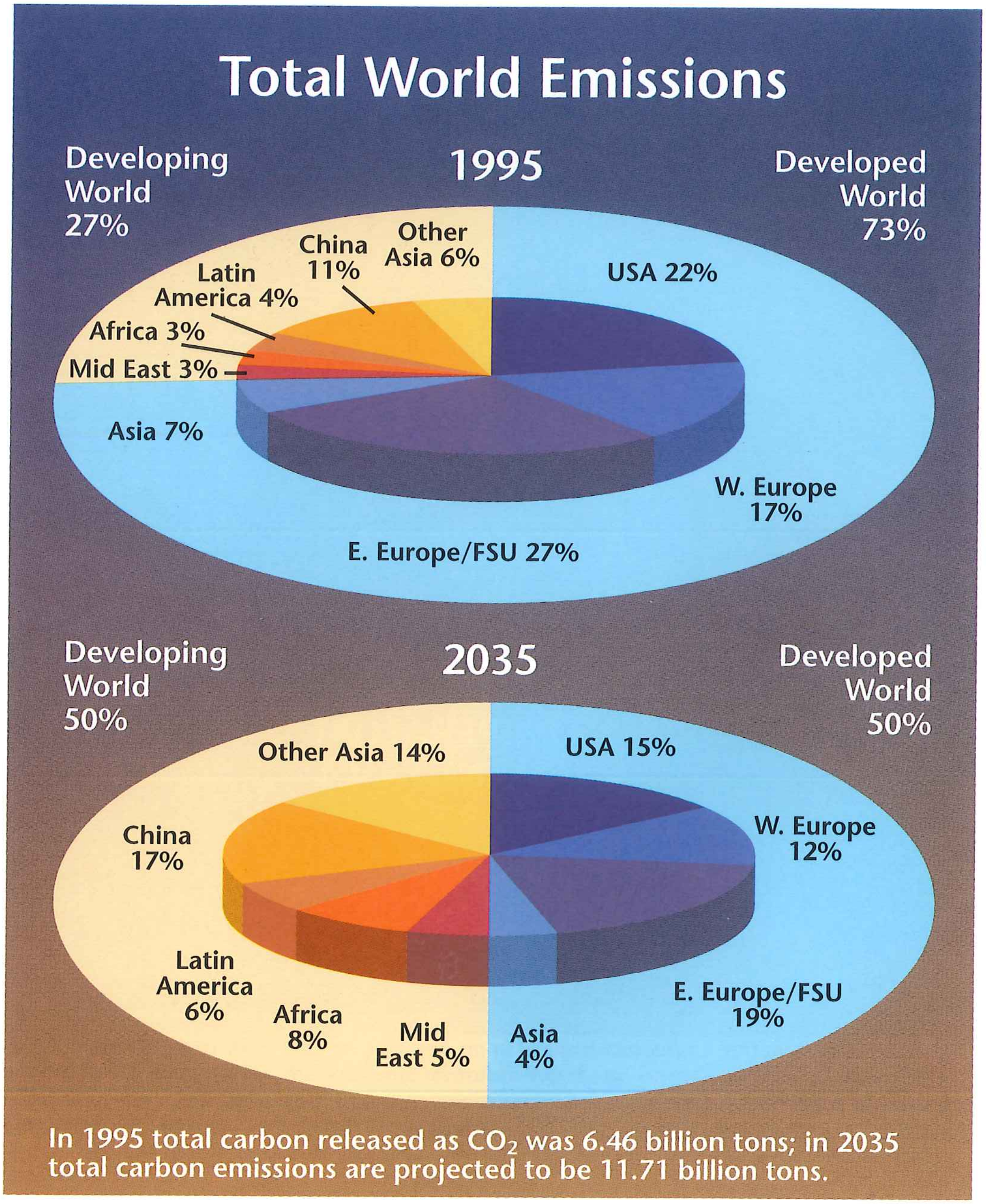


Figure 6. In 1995, the industrialized nations of the world contributed nearly three-quarters of the global emissions of carbon dioxide, with the U.S. being the largest single emitter. By 2035, developing nations will catch up and contribute half of the global emissions, with China becoming the largest single emitting country. Rapid population growth, industrialization, and increasing consumption per person in the developing world will contribute to this shift.

Climate Change Over the Last 100 Years

Global surface temperature has been measured since 1880 at a network of ground-based and ocean-based sites. Over the last century, the average surface temperature of the Earth has increased by about 1.0° F. The eleven warmest years this century have all occurred since 1980, with 1995 the warmest on record (Figure 7). The higher latitudes have warmed more than the equatorial regions.

Beginning in 1979, satellites have been used to measure the temperature of the atmosphere up to a height of 30,000 feet. The long-term surface record and the recent satellite observations differ, but that fact is not surprising: the two techniques measure the temperature of different parts of the Earth system (the surface, and various layers of the atmosphere). In addition to this, a variety of factors, such as the presence of airborne materials from the 1991 eruption of the volcano Mt. Pinatubo, affect each record in a different way. Satellite observations were initially interpreted as showing a slight cooling, but more recent analyses accounting for natural, short-term fluctuations imply warming, just as the ground-based measurements have indicated over a longer time period. As more data from the satellite record become available, and as the quality of measurements is improved, comparison of these two records should yield additional insights.

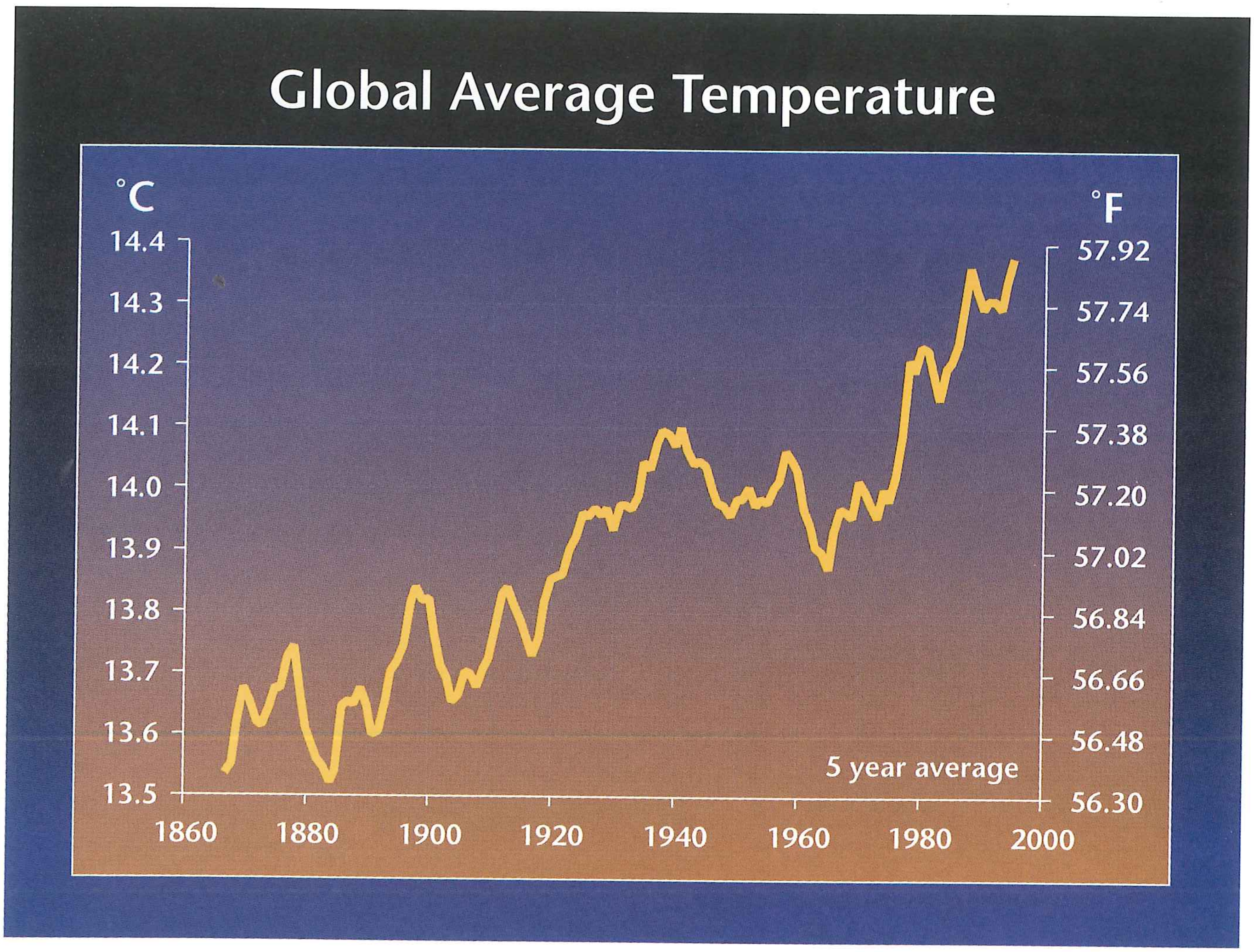


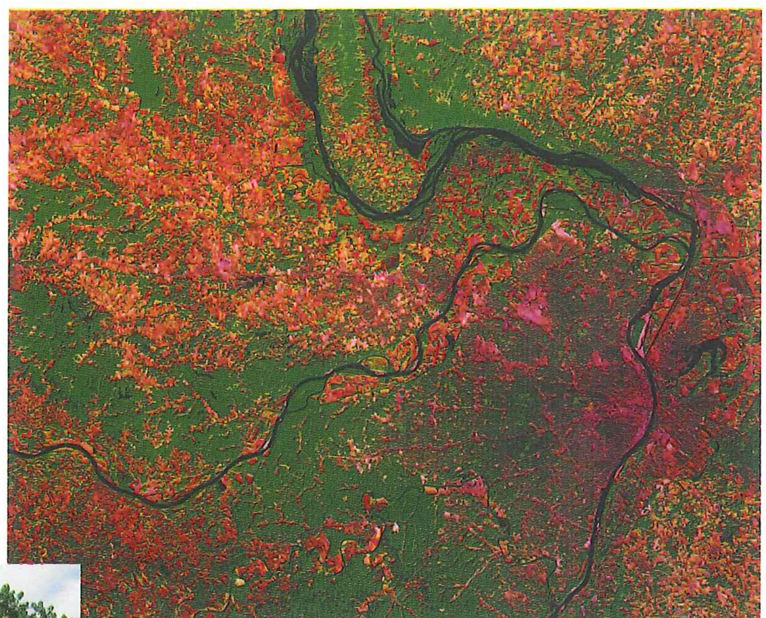
Figure 7. The global average temperature has risen by approximately 1° F over the last century.

What does warming do? A warmer Earth speeds up the global water cycle: the exchange of water among the oceans, atmosphere, and land. Higher temperatures cause more evaporation, and soils will tend to dry out faster. Increased amounts of water in the atmosphere will mean more rain or snow overall.

We may be seeing the first signs of changes in the water cycle. Since the beginning of the century, precipitation in the United States has increased by about 6 percent, while the frequency of intense precipitation events (heavy downpours of more than two inches per day) has increased by 20 percent. Such events can cause flooding, soil erosion, and even loss of life (Figures 8 and 9). In some midcontinental areas, increased evaporation has led to drought because the heavy rains fell elsewhere.

There is also evidence that ecosystems are reacting to warming. Between 1981 and 1991, the length of the growing season in the northern high latitudes (between 45° and 70° N) increased by a total of up to twelve days, as documented by satellite imagery. "Greening" in spring and summer occurred up to eight days earlier, and vegetation continued to photosynthesize an estimated four days longer.

Global mean sea level has risen 4 to 10 inches over the last 100 years, mainly because water expands when heated. The melting of glaciers, which has occurred worldwide over the last century, also contributes to the rise. Formerly frozen soils (permafrost) in the Alaskan and Siberian arctic have also begun to melt, damaging both ecosystems and infrastructure. Melting and tundra warming will also lead to decay of organic matter and the release of trapped carbon and methane, creating an additional source of greenhouse gases.



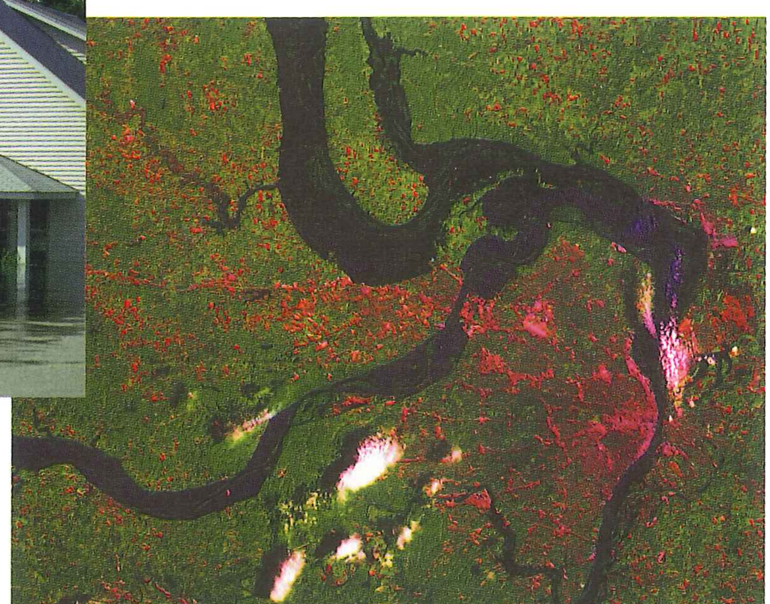


Figure 8 and 9. Our society is already vulnerable to extreme weather events such as floods. These images show the devastating effects of the 1993 Mississippi River flood on St. Louis, Missouri. Climate change is likely to increase the frequency of severe flood events.

Climate Change Over the Next 100 Years

Where is the climate headed? If the world proceeds on a "business as usual" path, atmospheric CO_2 concentrations will likely be more than 700 ppm by 2100, and they will still be rising. This is nearly double the current level and much more than double the preindustrial level of 280 ppm (Figure 10). State-of-the-art climate models suggest that this will result in an increase of about 3.5° F in global temperatures over the next century. This would be a rate of climate change not seen on the planet for at least the last 10,000 years. It is the combined threat of elevated concentrations of greenhouse gases and this unprecedented rate of increase that causes great concern.

What are the projected extent and pattern of warming over the globe? The higher latitude regions will warm relatively more than areas nearer to the equator. The land surface will warm more than the oceans, and there will be less variation in temperature from night to day.

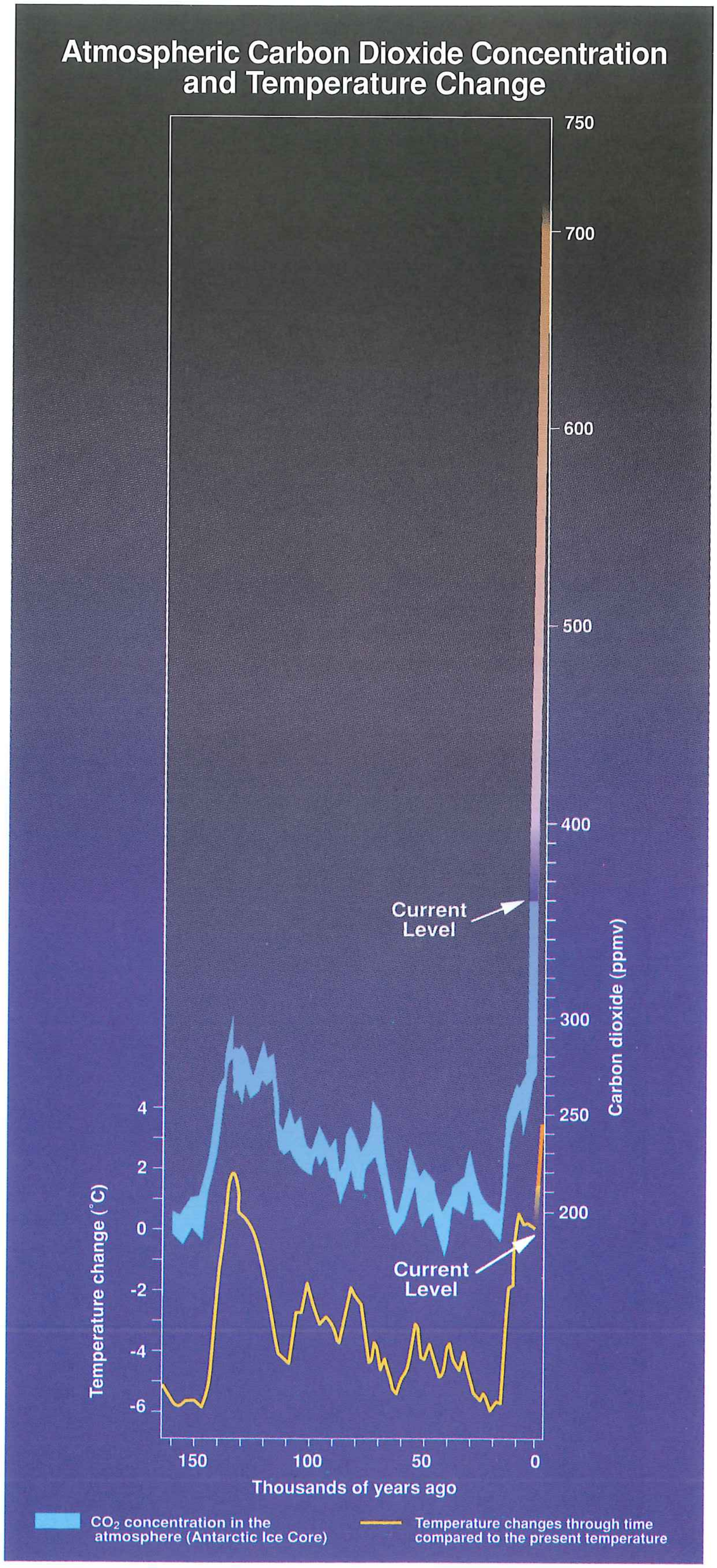


Figure 10. The CO_2 level has increased sharply since the beginning of the Industrial Era and is already outside the bounds of natural variability seen in the climate record of the last 160,000 years. Continuation of current levels of emissions will raise concentrations to over 700 ppm by 2100, a level not experienced since about 50 million years ago.

Even if the rate of emissions is slowed enough to limit atmospheric concentrations to about 550 ppm, or roughly double the preindustrial level, the U.S. could experience temperature increases of 5° F to 10° F (Figure 11). These warmer temperatures would lead to soil drying in some regions, with drying estimated at 10 percent to 30 percent for the United States during the summer growing season (Figure 12).

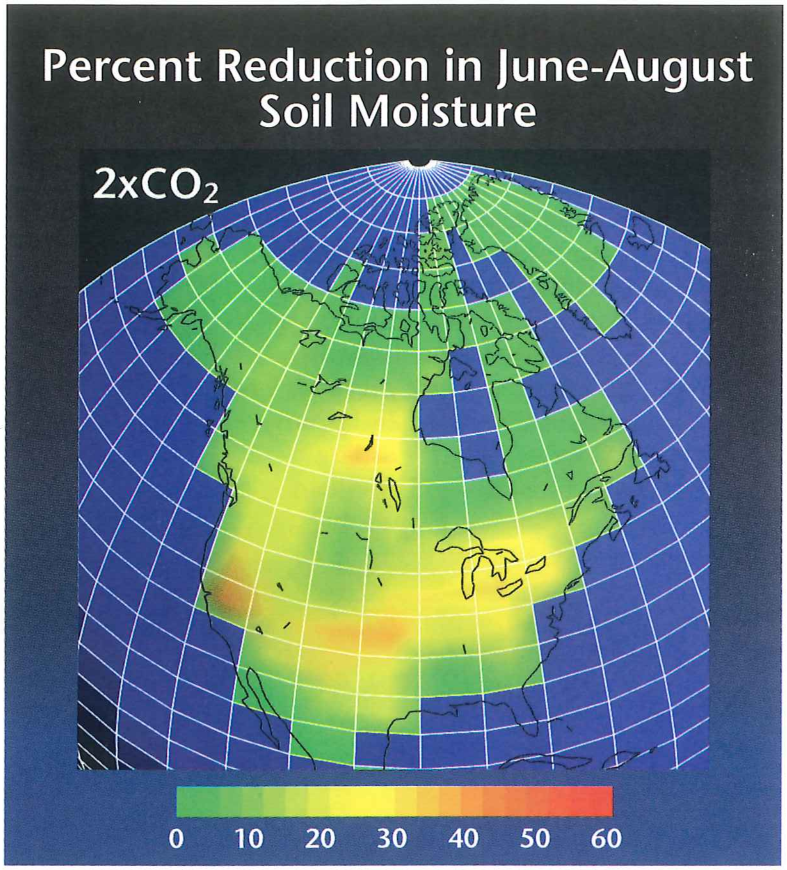


Figure 12. The extent of warming indicated in Figure 11 will lead to substantial soil drying throughout the world, causing soil moisture decreases of 10 percent to 30 percent over North America.

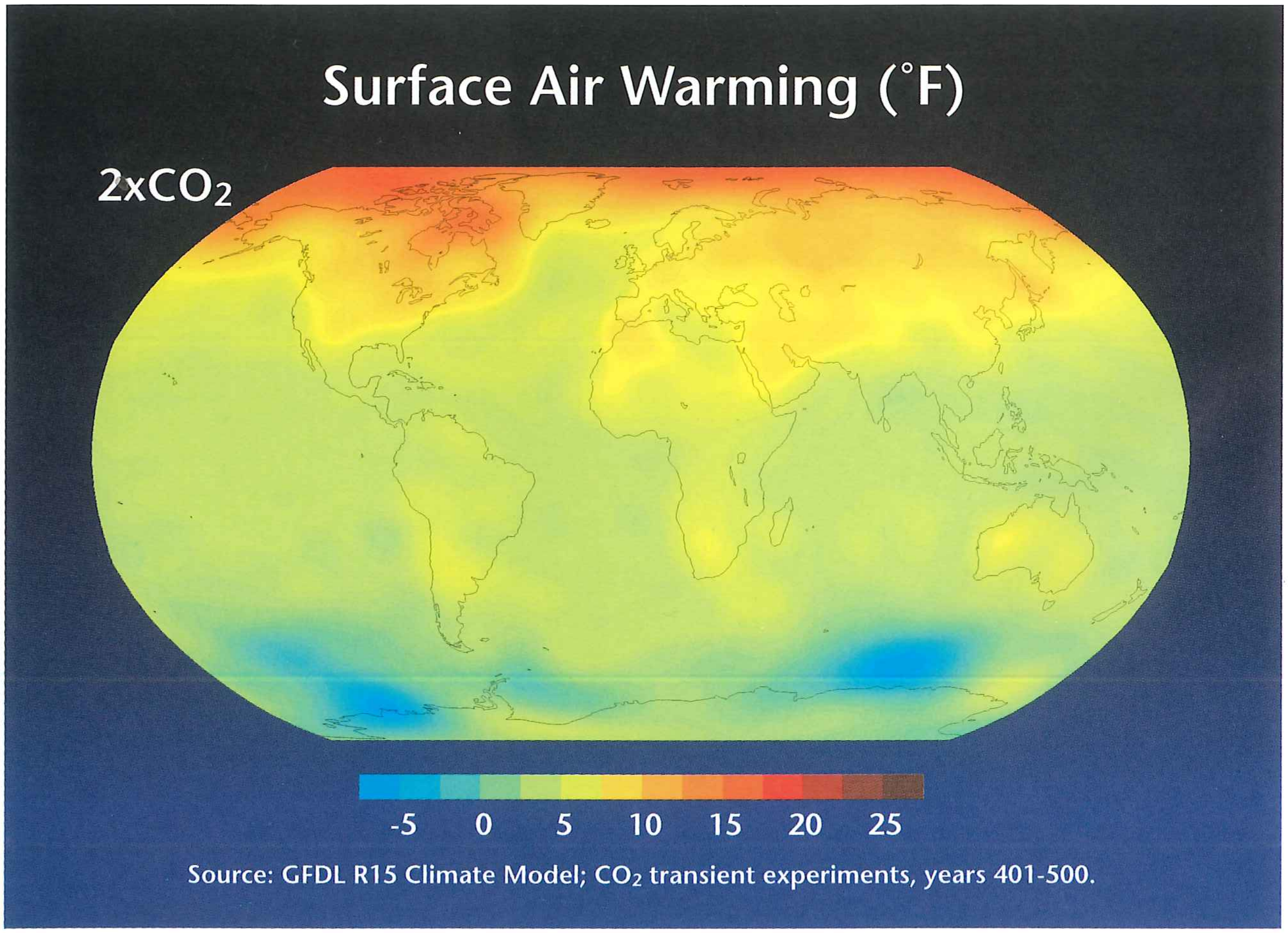
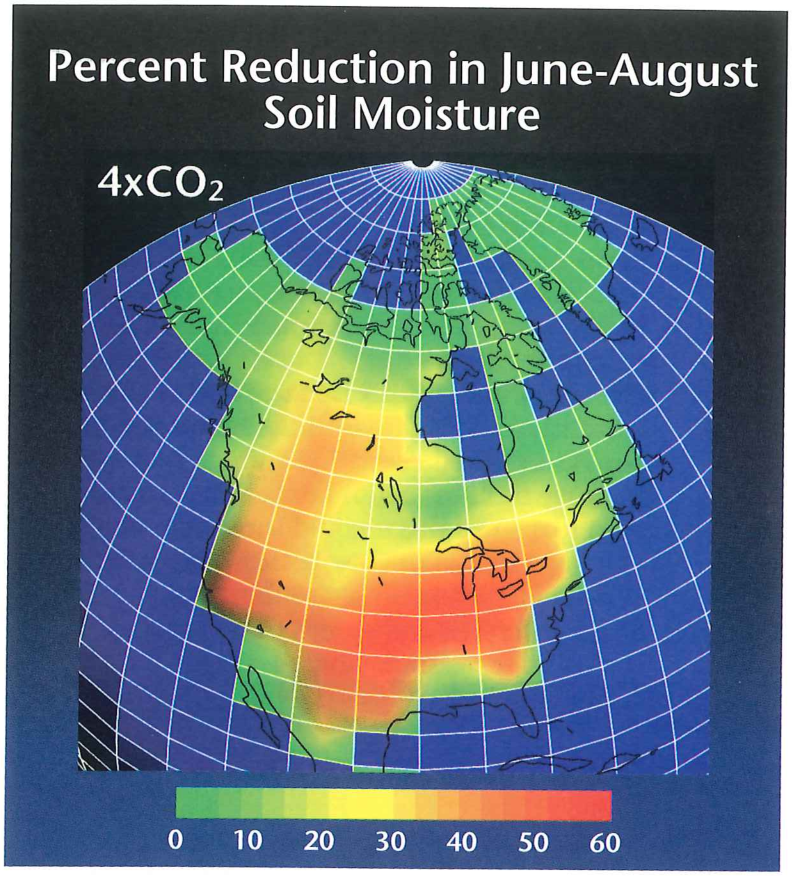


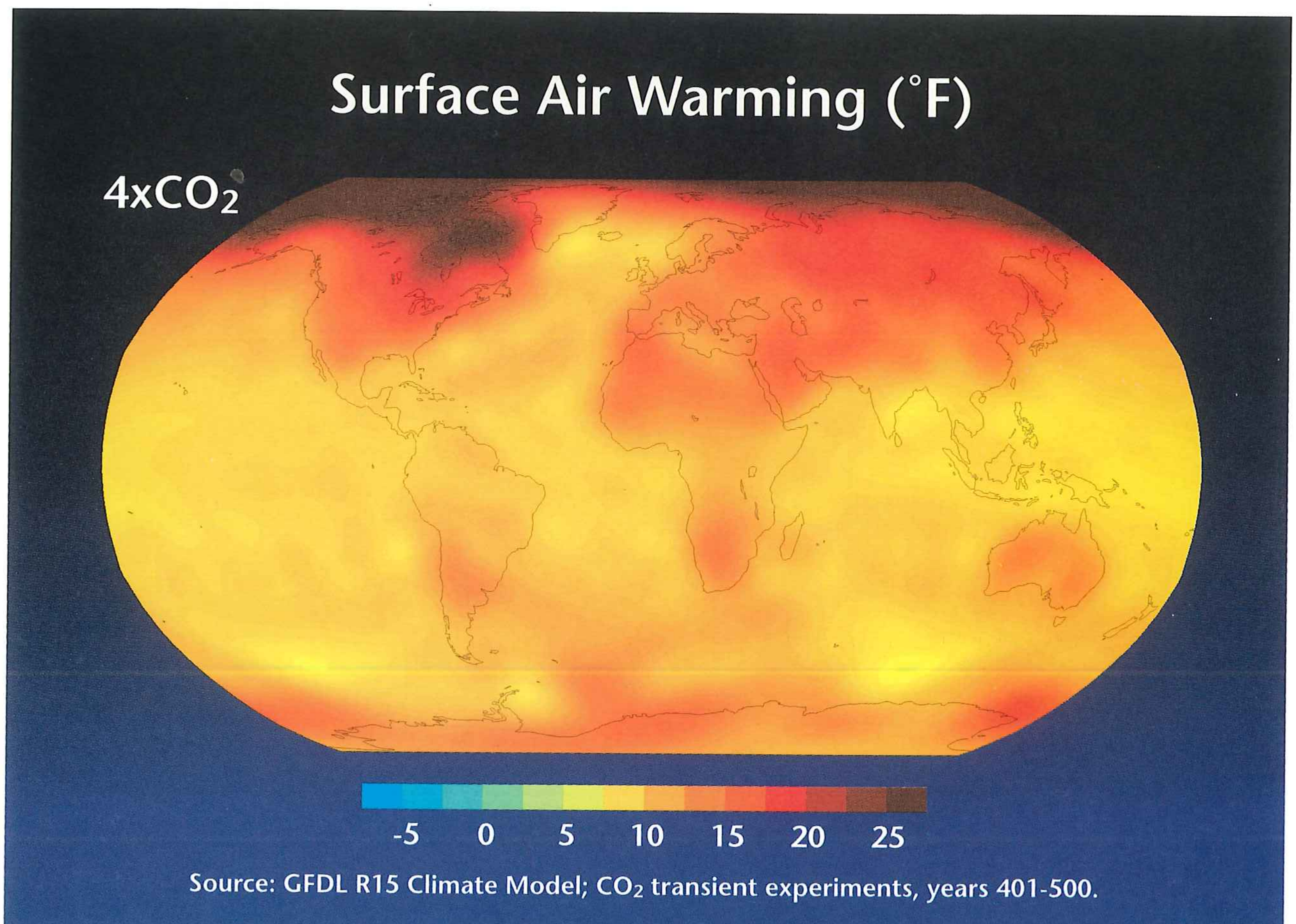
Figure 11. Even if CO_2 levels only rise to 560 ppm by the year 2100, U.S. temperatures will eventually be about 5-10 degrees F warmer than today. Higher latitudes will warm more than equatorial regions.



Some modeling experiments have examined the consequences of CO_2 levels well beyond 700 ppm, which are likely to occur after 2100 if current emissions trajectories are not altered. If the CO_2 concentration were to continue to rise to four times the preindustrial level, or more than 1100 ppm, the estimated temperature increase for the United States would be 15° F to 20° F, and soil drying could approach 30 percent to 50 percent during the growing season (Figures 13 and 14).

***Figure 13** The extent of warming indicated in Figure 14 would lead to severe soil drying in the U.S., with deficits reaching 30 percent to 50 percent during the growing season.*

***Figure 14.** If the CO_2 levels reach 1100 ppm, U.S. temperatures could be 15 °F to 20 °F higher than current levels.*



Vulnerabilities and Potential Consequences

The climate changes expected from increased atmospheric concentrations of greenhouse gases are likely to have widespread effects, many of them negative, on ecological systems, human health, and socioeconomic sectors. In general, people in developing countries are more vulnerable to climate change because of limited infrastructure and capital and greater dependence on natural resources. Unless otherwise specified, the impacts and vulnerabilities discussed below are based on scenarios of doubling of current levels of CO_2 by 2100 (700 ppm). Beyond such concentrations, impacts appear to worsen, but uncertainty about what will happen increases. In general, uncertainty cuts both ways: outcomes could be less dramatic than expected based on our current understanding, but could just as well be much more severe.

Worsening Health Effects - Climate change will impact human health in a variety of ways. Warmer temperatures increase the risk of mortality from heat stress. For example, in July 1995, 465 deaths in Chicago were attributed to a heat wave with temperatures exceeding 90° F day and night. Today, such events occur about once every 150 years. CO_2 concentrations of 550 ppm (double the pre-industrial level) could make such events 6 times more frequent. The potential increases in the heat index, a calculation combining temperature and humidity, illustrate the magnitude of this threat. Washington, D.C. currently has an average July heat index of 85° F, but if CO_2 levels reach 550 ppm, this could increase to 95° F, and if concentrations quadrupled to 1100 ppm, it could increase to 110° F. Climate change will also exacerbate air quality problems, such as smog, and increase levels of airborne pollen and spores that aggravate respiratory disease, asthma, and allergic disorders (Figure 15). Because children and the elderly are the most vulnerable populations, they are likely to suffer disproportionately with both warmer temperatures and poorer air quality.

Diseases that thrive in warmer climates, such as malaria, dengue and yellow fevers, encephalitis, and cholera, are likely to spread due to the expansion of the ranges of mosquitos and other disease-carrying organisms and increased rates of

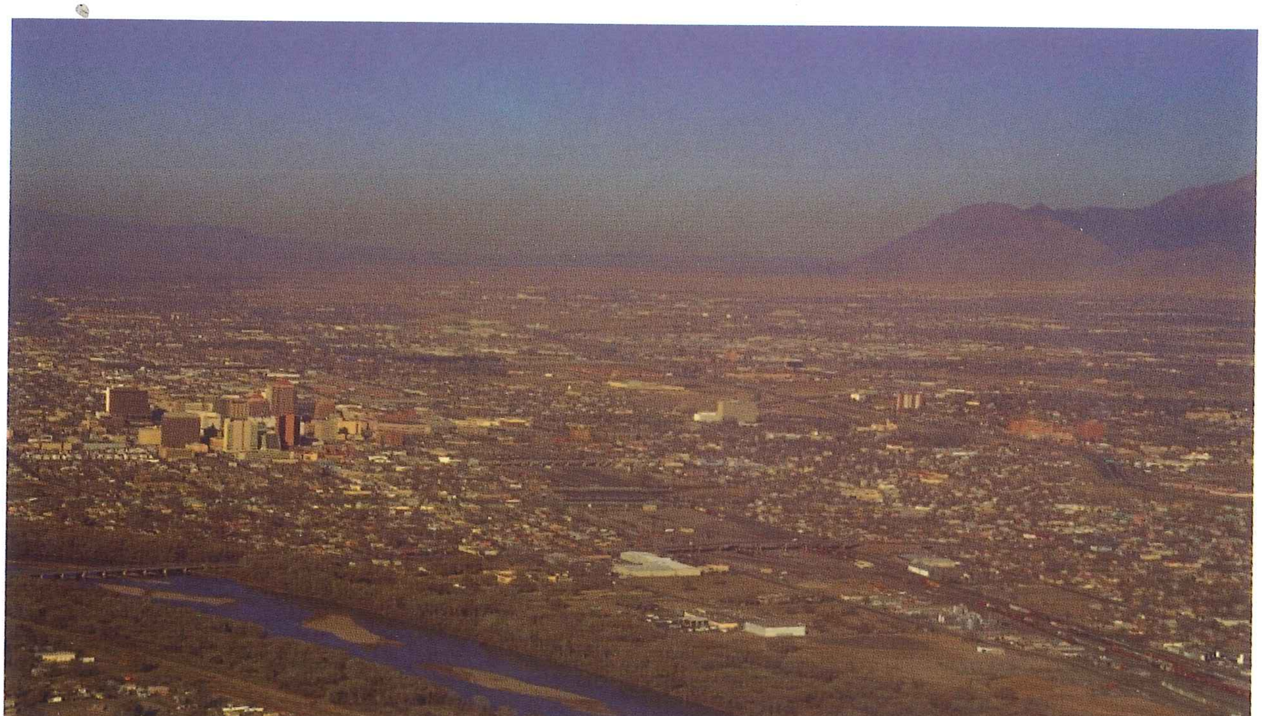


Figure 15. Higher temperatures will exacerbate urban air pollution problems such as tropospheric ozone.

transmission. This could result in 50 million to 80 million additional malaria cases per year worldwide by 2100.

Rising Sea Level - Rising sea level erodes beaches and coastal wetlands, inundates low-lying areas, and increases the vulnerability of coastal areas to flooding from storm surges and intense rainfall. By 2100, sea level is expected to rise by 6 to 37 inches. A 20-inch sea level rise will result in substantial loss of coastal land in the United States, especially along the southern Atlantic and Gulf coasts, which are subsiding and are particularly vulnerable. The oceans will continue to expand for several centuries after temperatures stabilize. Because of this, the sea level rise associated with CO_2 levels of 550 ppm (double pre-industrial levels) could eventually exceed 40 inches. A CO_2 level of 1100 ppm could produce a sea level rise of 80 inches or even more, depending on the extent to which the Greenland and Antarctic ice sheets melt.

- A 20-inch sea level rise would double the global population at risk from storm surges, from roughly 45 million at present to over 90 million, and this figure does not account for any increases in coastal populations. A 40-inch rise would triple the number.

- South Florida is highly vulnerable to sea level rise (Figure 16). A third of the Everglades has an elevation of less than 12 inches. Salt water intrusion would adversely affect delicate ecological communities and degrade the habitat for many species.

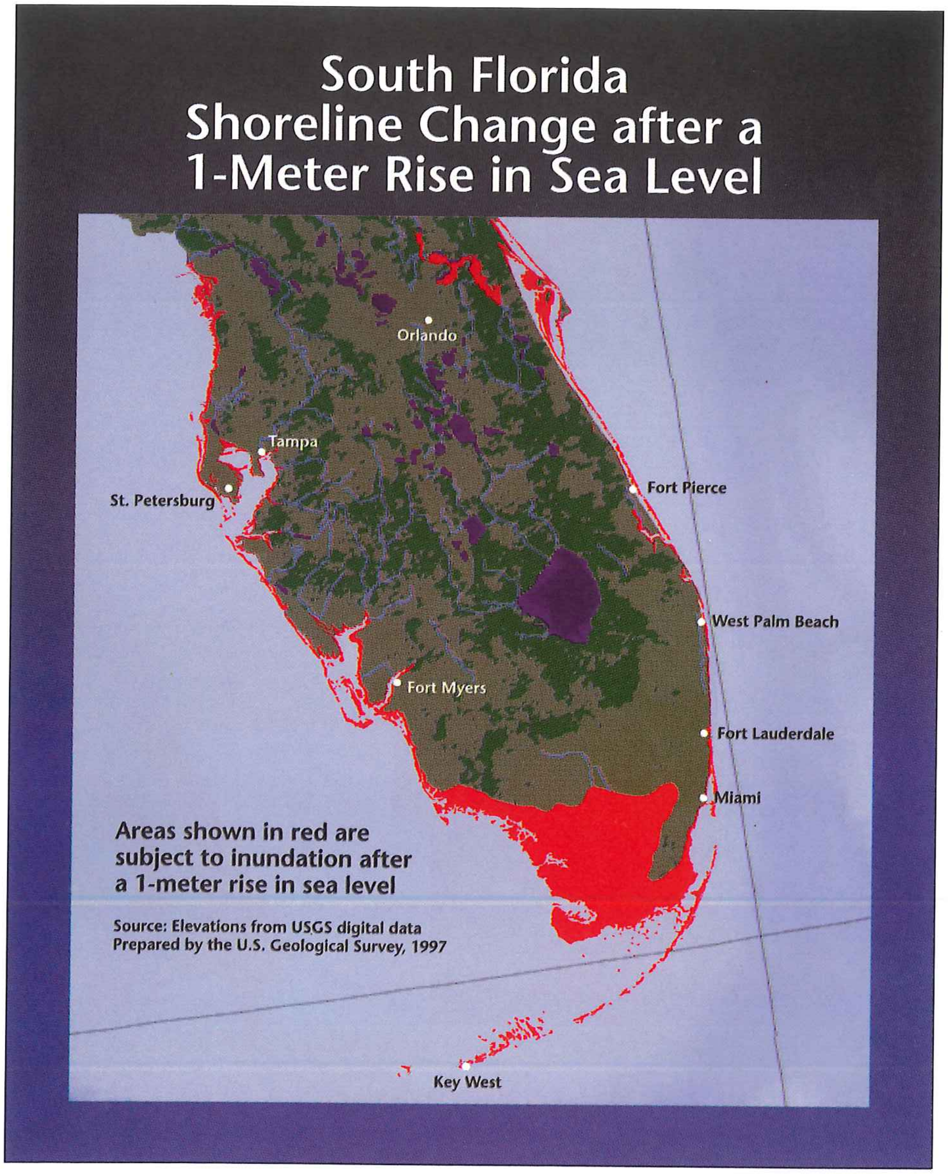


Figure 16. Sea level rise could inundate many low-lying coastal areas in Florida, and will increase the vulnerability of all such areas to storm surges.

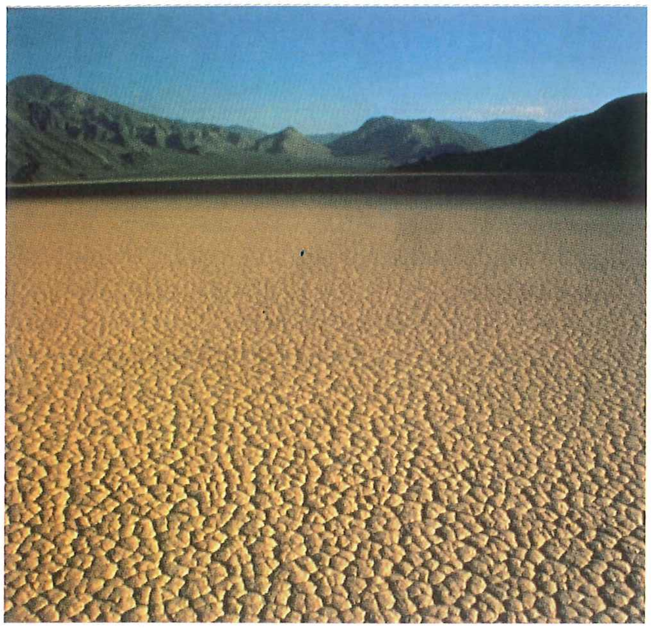


Figure 17. Severe drought will become more frequent in some regions as the precipitation patterns shift.

Disruption of the Water Cycle - Among the most fundamental effects of climate change are intensification and disruption of the water cycle.

Droughts and floods - Intensification of the water cycle will produce more severe droughts in some places and floods in others. Such events are costly. Damages from the Southern Plains drought of 1996 were estimated at $4 billion, the 1993 Mississippi River flood damages at $10 billion to $20 billion, the Pacific Northwest floods in the winter of 1996-1997 at about $3 billion, the 1997 Ohio River flood at about $1 billion, and the 1997 Red River flood in the Northern Plains at about $2 billion.

Water quality and quantity - Areas of greatest vulnerability are those where quality and quantity of water are already problems, such as the arid and semi-arid regions of the United States and the world (Figure 17).

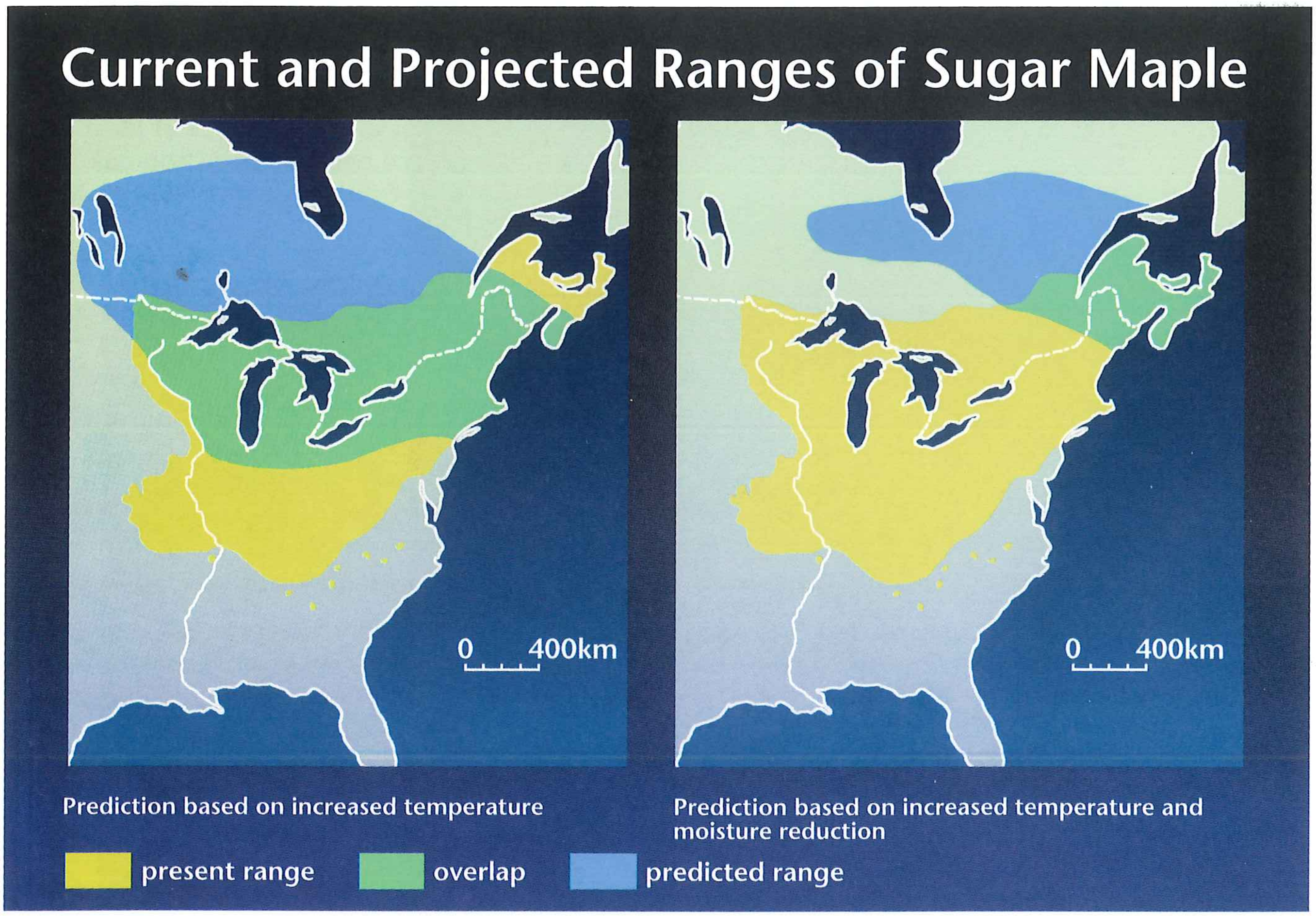


Figure 18. Climatic shifts will force some species to migrate northwards or to higher elevations in order to stay in the appropriate climatic zone. The climatic zone for sugar maple, for example, could shift northwards into Canada. This would compromise the maple syrup industry and the fall foliage colors, both of which make New England famous.

- Climate change would likely increase water supply problems in several U.S. river basins, such as the Missouri, Arkansas, Texas Gulf, Rio Grande, and Lower Colorado.

- Water scarcity in the Middle East and Africa is likely to be aggravated by climate change, which could increase international tension among countries that depend on water supplies originating outside their borders.

Changing Forests and Natural Areas - Climate change could dramatically alter the geographic distributions of vegetation types. The composition of one-third of the Earth's forests would undergo major changes as a result of climate changes associated with a CO_2 level of 700 ppm. Over the next 100 years, the ideal range for some North American forest species will shift by as much as 300 miles to the north, far faster than the forests can migrate naturally. Economically important species, such as the sugar maple, could be lost from New England by the end of the next century (Figure 18).

Such changes could have profound effects on the U.S. system of national parks and refuges, leading to reductions in biological diversity and in the benefits provided by ecosystems, such as clean water and recreation. Wetlands are particularly at risk. The wetlands of the prairie pothole region, which support half the waterfowl population of North America, could diminish in area and change dramatically in character in response to climate change. The glaciers of Glacier National Park have receded steadily for decades (Figure 19). Model projections indicate that all the Park's glaciers will disappear by 2030 unless temperatures begin to cool instead of warm.

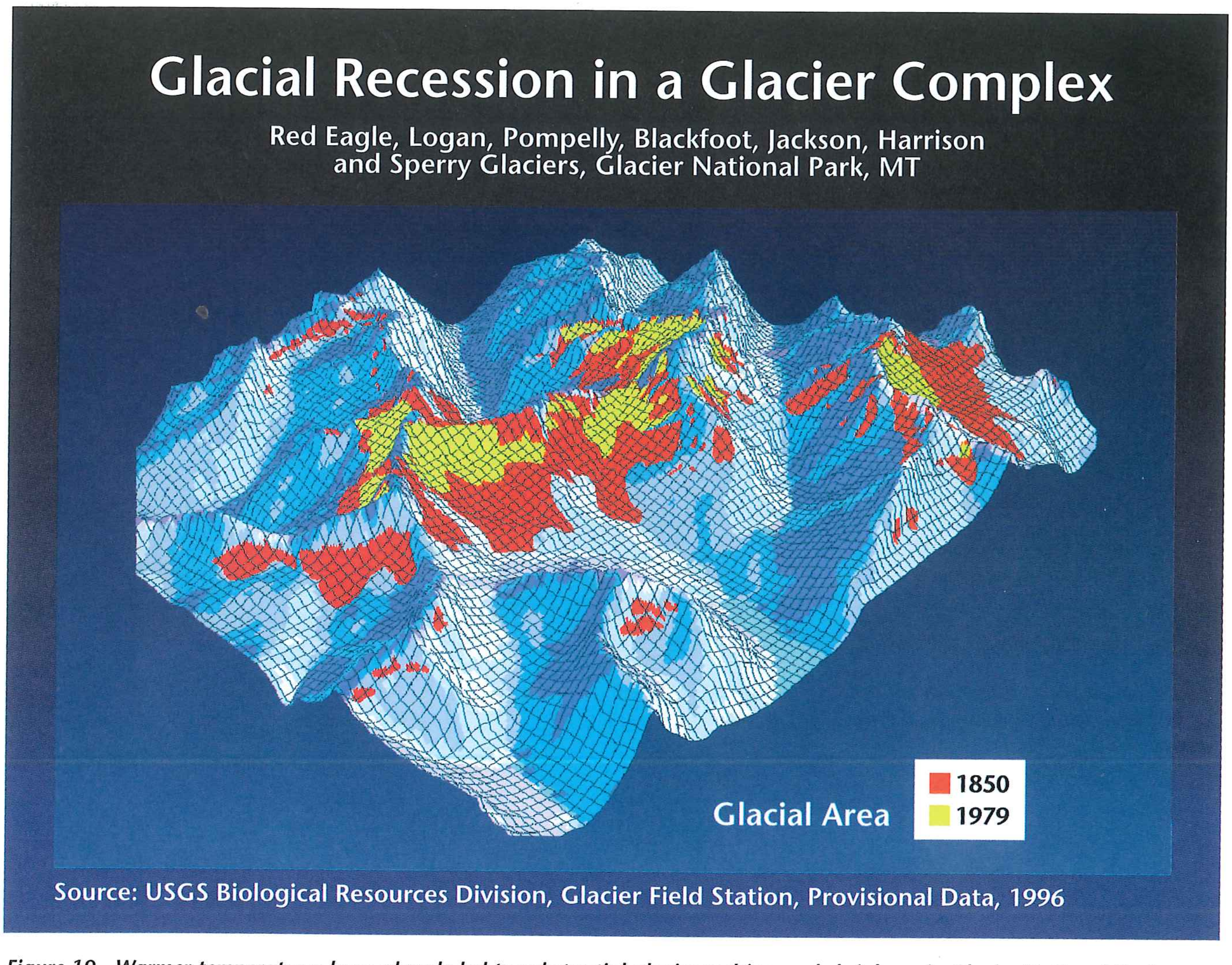


Figure 19. Warmer temperatures have already led to substantial glacier melting and shrinkage in Glacier National Park, Montana. Data indicate that more than 70 percent of some of the glaciers in the National Park have already melted.

Challenges to Agriculture and the Food Supply - Climate strongly affects crop yields. A CO_2 concentration of 550 ppm is likely to increase crop yields in some areas by as much as 30 percent to 40 percent, but it will decrease yields in other places by similar amounts, even for the same crop. A warmer climate would reduce flexibility in crop distribution and increase irrigation demands. Expansions of the ranges of pests could also increase vulnerability and result in greater use of pesticides. Despite these effects, total global food production is not expected to be altered substantially by climate change, but there are likely negative regional impacts. Agricultural systems in the developed countries are highly adaptable and can probably cope with the expected range of climate changes without dramatic reductions in yields. It is the poorest countries, already subject to hunger, that are the most likely to suffer significant decreases in agricultural productivity (Figure 20).

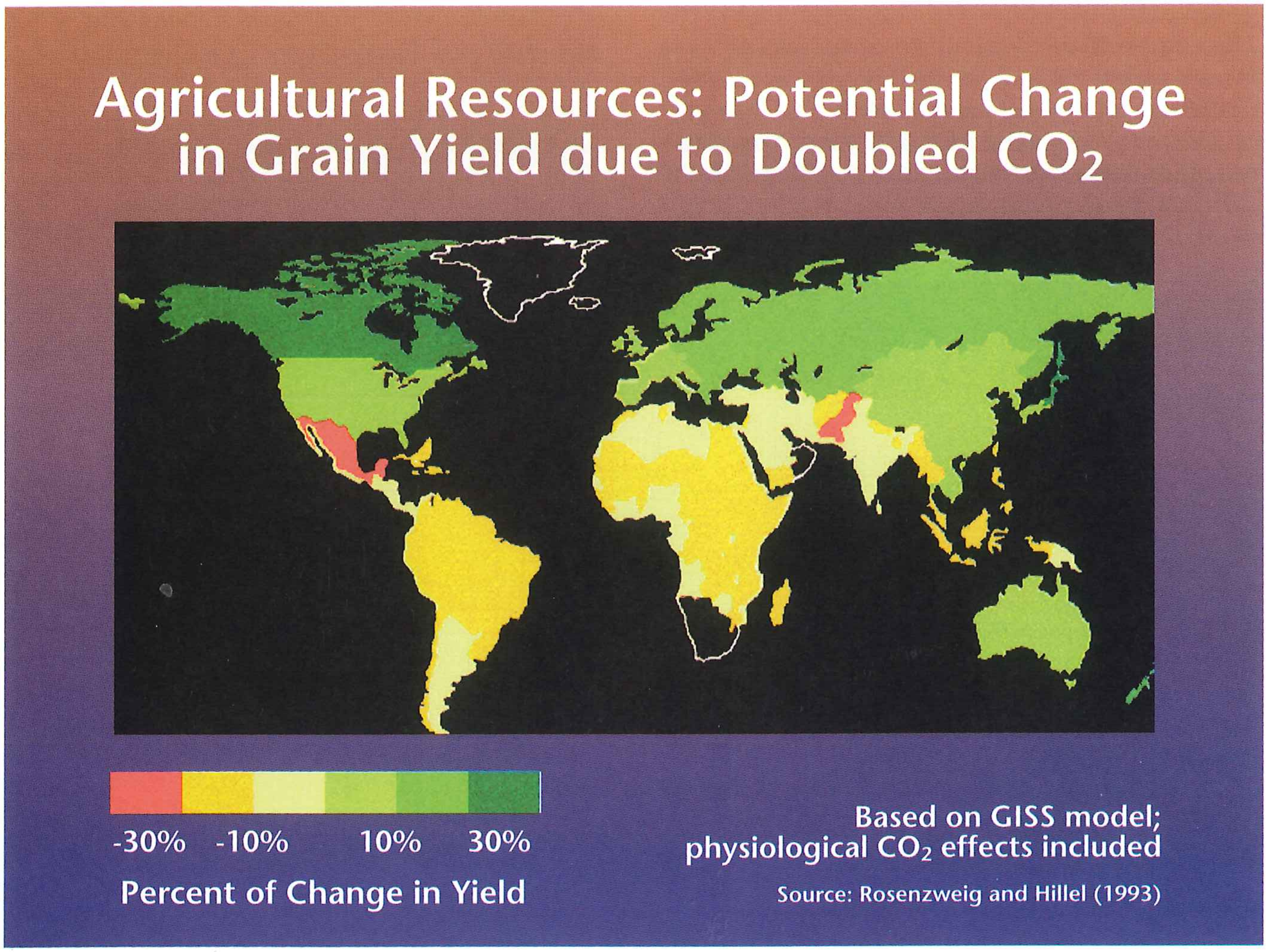


Figure 20. Agricultural production would increase in some areas, and decline in others as the climate warms and the CO_2 levels in the atmosphere increase. Farmers may need to shift crops, or re-locate agricultural lands. The need for irrigation may also increase.

Conclusion

As the world's expanding population burns large quantities of fossil fuels and simultaneously cuts down large expanses of forests worldwide, the concentrations of CO_2 and other greenhouse gases are building up in the atmosphere. There is mounting evidence that this shift in Earth's atmosphere will lead to global changes and potentially major climatic disruptions.

Human and ecological systems are already vulnerable to a range of environmental pressures, including climate extremes and variability. Global warming is likely to amplify the effects of other pressures and to disrupt our lives in numerous ways. Significant impacts on our health, the vitality of forests and other natural areas, the distribution of freshwater supplies, and the productivity of agriculture are among the probable consequences of climate change.

On a business as usual path, the world is headed to concentrations far higher than have been observed during the time of human civilization and to levels not seen on the planet for millions of years--and all in one century, a geologic "blink of an eye." The faster the rate of change in climate, the less time there will be for both ecological and socio-economic systems to adapt and the greater the potential for "surprises" or unanticipated events. Given the long time lags between cause and effect and between effect and remedy, a prudent course of action is to slow the rate of change. Investing now to protect Earth's climate will enable our children and grandchildren to live in a world that is not dramatically altered by an enhanced greenhouse effect.

Credits

Figure 1: The Greenhouse Effect

Source: ©M. Warford, 1995

Figure 2: Burning fossil fuels photograph

Source: ©P. Grabhorn, 1994

Figure 3: Deforestation photograph

Source: ©P. Grabhorn, 1996

Figure 4: Carbon Dioxide Concentrations, 1860 to present

Source: Data from Neftel et al., 1985; Keeling, 1995

Figure 5: Atmospheric Carbon Dioxide Concentration and Temperature Change

Source: Vostok ice core data from Barnola et al., 1987; current data from the Carbon Dioxide Information Analysis Center, 1997, Oak Ridge, TN

Figure 6: Total World Emissions, 1995 and 2035

Source: Carbon Dioxide Information Analysis Center, 1997, Oak Ridge, TN; Edmonds, 1997, Batelle Laboratories, using IPCC IS92A emission scenario

Figure 7: Global Average Temperature

Source: Data from Hansen et al., 1995, Goddard Institute for Space Studies

Figure 8: Mississippi River flood photograph

Source: ©P. Grabhorn, 1993

Figure 9: Mississippi River flood Landsat 5 Thermatic Mapper images

Source: ©EOSAT Corporation, 1995, Lanham, MD

Figure 10: Atmospheric Carbon Dioxide Concentration and Temperature Changes projected to year 2100

Source: Vostok ice core data from Barnola et al., 1987; current data from the Carbon Dioxide Information Analysis Center, 1997, Oak Ridge, TN; 1995 IPCC emission scenarios

Figure 11: Surface Air Warming (˚F), 2xCO_2

Source: Manabe and Stouffer, 1994, NOAA Geophysical Fluid Dynamics Laboratory, Princeton, NJ

Figure 12: Percent Reduction in June-August Soil Moisture, 2xCO_2

Source: Manabe and Stouffer, 1994, NOAA Geophysical Fluid Dynamics Laboratory, Princeton, NJ

Figure 13: Percent Reduction in June-August Soil Moisture, 4xCO_2

Source: Manabe and Stouffer, 1994, NOAA Geophysical Fluid Dynamics Laboratory, Princeton, NJ

Figure 14: Surface Air Warming (˚F), 4xCO_2

Source: Manabe and Stouffer, 1994, NOAA Geophysical Fluid Dynamics Laboratory, Princeton, NJ

Figure 15: Urban smog photograph

Source: ©P. Grabhorn, 1993

Figure 16: South Florida Shoreline Change after a 1-meter Rise in Sea Level

Source: Data from USGS, 1997; Map visualization ©C. Grabhorn, 1995

Figure 17: Severe drought in a dry river bed photograph

Source: ©P. Grabhorn, 1994

Figure 18: Current and Projected Ranges of Sugar Maple

Source: Redrawn from Davis and Zabinski, 1992, University of Minnesota

Figure 19: Glacial Recession in a Glacier Complex

Source: USGS Biological Resources Division, Glacier Field Station, Provisional Data, Department of Interior, 1996

Figure 20: Agricultural Resources: Potential Change in Grain Yield due to Doubled CO_2

Source: Rosenzweig & Hillel, 1993, Goddard Institute for Space Studies

Figure 21: Earth visualization

Source: Hasler et al., 1992, NASA Goddard Laboratory for Atmospheres

Contributors and Authors: Peter Backlund, Susan Bassow, Rosina Bierbaum, Nicholas Lapham, Jerry Melillo, Fran Sharples.

Printed on recycled paper

Executive Office of the President
Office of Science and Technology Policy
Washington, D.C. 20502
202-395-7347