US Global Change Research Program
www.usgcrp.gov
Updated 12 October, 2003

CLIMATE CHANGE: STATE OF KNOWLEDGE

The Climate System
Agriculture
Health
Coastal Resources
Water Resources
Impacts of Climate Change
Forests
Energy & Transportation

[Note: A later (1997) updated version of this report is available as PDF file and is available in hardcopy from the GCRIO Online Catalog]

From the Environmental division, Office of Science and Technology Policy, Executive Office of the President, Washington, DC, March 1995.

The Earth's climate is predicted to change because human activities are altering the chemical composition of the atmosphere. The buildup of greenhouse gases-primarily carbon dioxide, methane, nitrous oxide and chlorofluorocarbons-is changing the radiation balance of the planet. The basic heat-trapping property of these greenhouse gases is essentially undisputed. However, there is considerable scientific uncertainty about exactly how and when the Earth's climate will respond to enhanced greenhouse gases. The direct effects of climate change will include changes in temperature, precipitation, soil moisture, and sea level. Such changes could have adverse effects on ecological systems, human health, and socio-economic sectors.

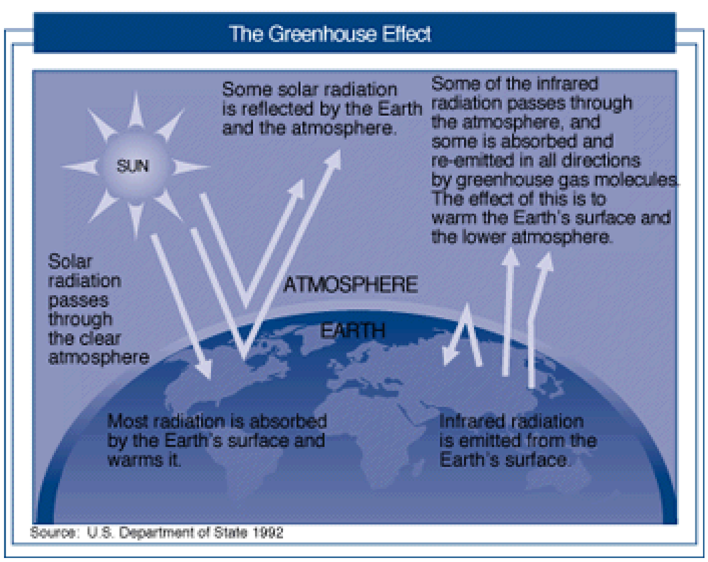
Human-induced climate change is a complex problem, which can impact the economy and the quality of life for this and future generations. The lag time between emission of the gases and their impact is on the order of decades to centuries; so too is the time needed to reverse any effects. Thus, policy decisions in the near term will have long-term consequences.

The Climate System

A natural greenhouse effect keeps the Earth 33 degrees C. warmer than it otherwise would be. Without this, life as we know it would not be possible. Water vapor, carbon dioxide, and other trace gases trap heat as it is re-radiated from the Earth back to space. However, since pre-industrial times, human activities have added to the natural greenhouse effect by releasing additional greenhouse gases to the atmosphere. The burning of fossil fuels (coal, oil, and gas) for energy is the primary source of emissions; changing land-use patterns through agriculture and deforestation also contribute a significant share. Current global emissions of carbon dioxide from energy use are approximately 6 gigatons of carbon (GtC) per year.

Future greenhouse gas emissions are sensitive to changes in demographic, economic, technological, policy, and institutional developments. By the year 2025, world emissions could range from 8 to 15 GtC per year. In the year 2100, world emissions are projected to range from 5 to 36 GtC per year, depending on energy use. The U.S. and the rest of the OECD countries currently contribute about 40 percent of global carbon dioxide emissions. Future growth in emissions from OECD countries is predicted to be significantly smaller than growth in developing countries and countries with economies in transition.

Since the pre-industrial era, atmospheric concentrations of carbon dioxide have increased by nearly 30 percent, methane concentrations have doubled, and nitrous oxide concentrations have risen by 15 percent.



The Greenhouse Effect

Source: U.S. Department of State 1992

These increases result in a radiative forcing or heat-trapping of energy equivalent to about 2.8 watts per square meter (Wm-2). A significant fraction of warming may have been masked by increased levels of traditional air pollutants-sulfates and carbonaceous aerosols, particularly in the Northern Hemisphere - which reflect incoming solar radiation and alter the reflective properties of clouds. Aerosols are short-lived and vary regionally, hence they should not be regarded as a simple offset to greenhouse gas forcing. Calculations suggest that the projected increases in atmospheric concentrations of greenhouse gases alone will result in an additional radiative forcing of about 3 &shyp; 8 Wm-2 by 2100. For a given concentration of greenhouse gases, the resulting increase in radiation can be predicted with precision; but the resulting impact on climate is more uncertain.

Model calculations, based on plausible ranges of future emissions and climate sensitivities, suggest that the global surface temperature could increase an average of 0.9 &shyp; 5.0 degrees C. by 2100, with significant variation by region. This estimate does not account for offsets from aerosols which would somewhat lower these values. Global-average temperature changes of this magnitude would be greater than recent natural fluctuations and would occur at a rate significantly faster than any observed changes in the last 10,000 years. The U.S. and high latitudes are projected to warm more than the global average.

Model calculations also suggest that the rate of evaporation will increase as the climate warms, leading to an increase in average global precipitation. While precipitation at high latitudes is expected to increase, much of the precipitation increase may fall over the oceans. The models also suggest that the frequency of intense rainfall will increase and there will be a marked decrease in soil moisture over some mid-latitude continental regions during the summer.

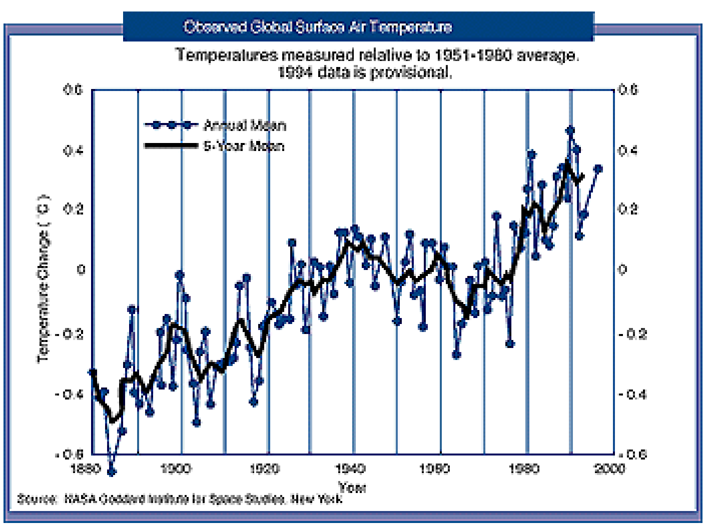
Sea level is projected to increase by several tens of centimeters by the end of the next century, due primarily to the thermal expansion of the oceans and the melting of glaciers and ice sheets.

Calculations of climate change at the regional scale are significantly less reliable than average global values, and it is unclear whether climate will become more variable. The frequency and intensity of extreme weather events of critical importance to ecological systems (droughts, floods, frosts, cloudiness, the frequency of hot or cold spells, and the intensity of associated fire and pest outbreaks) could increase.

Global mean surface temperatures have increased between 0.3 and 0.6 degrees C. over the past century, despite marked regional, seasonal and diurnal differences.

There is consistency between the observed global average temperature trend over this period and model simulations of the warming due to greenhouse gases if allowance is made for the increasing evidence of a cooling effect due to anthropogenic aerosols and stratospheric ozone depletion. However, the warming is also at the upper end of the range of temperature fluctuations observed in the pre-industrial record. Thus, the observed temperature increase could be largely due to natural variability; alternatively, variability and other human factors could have offset a still larger human-induced warming. The unequivocal detection of the enhanced greenhouse effect from observations is likely to require another decade or more of data.

The nine warmest years this century have all occurred since 1980. 1994 was the third or fourth warmest year on record, suggesting the atmosphere has rebounded from the transient cooling of 0.5 degrees C. caused by Mt. Pinatubo and simulated by the models.



Several ancillary pieces of evidence consistent with warming, such as a decrease in Northern Hemisphere snow cover, a simultaneous decrease in Arctic sea ice, continued melting of alpine glaciers, and a rise of sea level, have also been corroborated. The frequency of extreme rainfall events has increased throughout much of the country, suggestive of an intensification of the hydrologic cycle.

Carbon cycle models imply that limiting atmospheric concentrations of CO2 to any level below 750 parts per million by volume (ppmv), about three times the pre-industrial level, would require emissions worldwide to eventually drop below 1990 levels. The longer emissions continue to increase, the greater reductions would eventually have to be to stabilize concentrations at a given level.

While much is already known about the greenhouse effect, substantial reduction of key uncertainties (detailed quantification of the timing, magnitude and regional patterns of climate change) may require a decade or more. Accurate predictions are limited by our knowledge of the future emissions and atmospheric concentrations of carbon dioxide, aerosols and other greenhouse gases, the role of clouds and water vapor, and the role of the oceans.

Climate change poses threats to resources both domestically and internationally. These threats could have significant, but uncertain, socioeconomic consequences. Changes in temperature, precipitation and sea level driven by climate change can add to existing stresses on resources caused by other influences such as population growth, land-use changes, and pollution.

Overall, various strategies for coping with climate change can be identified for "intensively managed" systems (such as agriculture, water resources, and developed coastlines). For these systems, technological and management options exist to some extent today, although they may be costly to implement. By comparison, fewer options can be identified for natural systems (such as wetlands and wilderness areas).

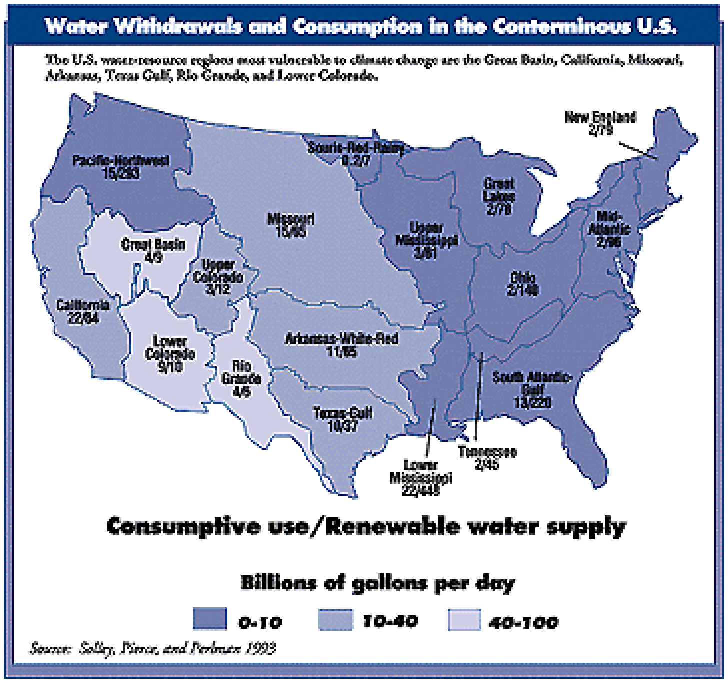
Temperature changes of the magnitude expected from the enhanced greenhouse effect have occurred in the past, but the previous changes took place over centuries or millennia instead of decades. Rates of natural migration and adaptation of species and communities appear to be much slower than the predicted rate of climate change. As a result, populations of many species and inhabited ranges could change as the climate to which they are adapted effectively shifts northward or to higher elevations.

One of the consequences of global climate change may be increases in the frequency of extreme weather events, particularly droughts and floods. These events, when they do occur, can be costly. For example:

> Damages from the Mississippi River flooding in 1993 are estimated to range from $10 billion to $20 billion. Almost $4 billion in federal payments went to farmers suffering crop losses during the 1988 drought.

Examples of the kinds of effects that may result from climate change include:

> Changes in precipitation and increased evaporation from higher temperatures can affect water supplies and water quality, posing threats to hydropower, irrigation, fisheries, and drinking water.



>Floods are more likely because the frequency of intense rainfall is predicted to increase.

> Droughts are likely to be more severe because warmer temperatures increase evaporation rates and thereby lead to drier soils during periods of little or no rain.

> Climate change would be likely to add to the stress in several U.S. river basins such as the Great Basin, California, Missouri, Arkansas, Texas Gulf, Rio Grande, and Lower Colorado.

> Water scarcity in Middle Eastern and African countries is also likely to be exacerbated by climate change.

> A 50 cm rise in sea level by the year 2100, which is within the range projected by the IPCC, could inundate more than 5,000 mi2 of dryland and an additional 4000 mi2 of wetlands in the U.S. if no protective actions are taken.

> Areas at highest risk from sea level rise are areas currently experiencing high erosion rates and those with very low elevations, such as parts of the U.S. Atlantic and Gulf coasts.

> Internationally, many low- lying areas such as parts of the Maldives, Egypt, and Bangladesh would be completely inundated and uninhabitable by a similar sea level rise.

> Climate change may shift the range of infectious diseases, with likely increased risks of malaria and dengue in the United States. Changing temperatures and precipitation patterns may produce new breeding sites for pests and pathogens.

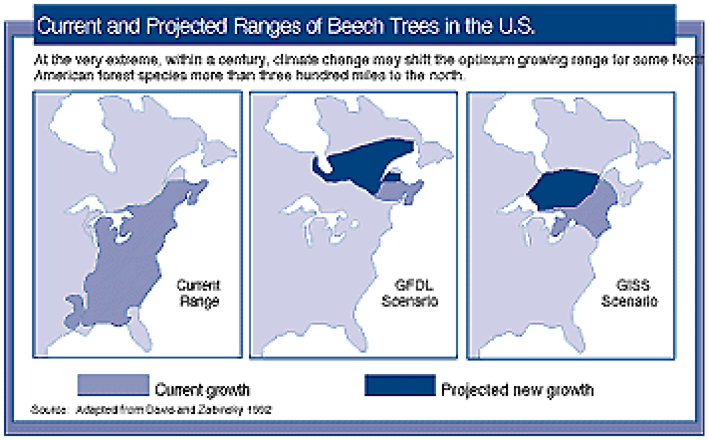
> Climate change may increase heat-stress mortality, particularly in the very young and very old.

> Large areas of the eastern and central United States face moderate to severe drying. Drought could become more frequent, particularly in the Great Plains.

> Changes in management practices and technological advances might reduce or eliminate many of the potentially negative impacts of climate change in the agricultural sector.

> Agriculture production in developing countries is likely to be more vulnerable to climate change given that they have relatively fewer economic resources.

> Climate change over the next several decades might shift the ideal range for some North American forest species by as much as 300 miles to the north, exceeding the ability of forests and other ecological communities to migrate.



> Forest damage from fire and diebacks driven by drought,insects and disease could increase.

> The most vulnerable forest resources are those in regions subject to increased moisture stress, as in the dry continental interiors.

> Warmer temperatures will increase cooling demand but decrease heating requirements.

> Changes in water availability may affect reliability of hydropower output.

> Warming should lead to fewer disruptions of winter transportation, but increased droughts and floods may interfere with water transport.

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