

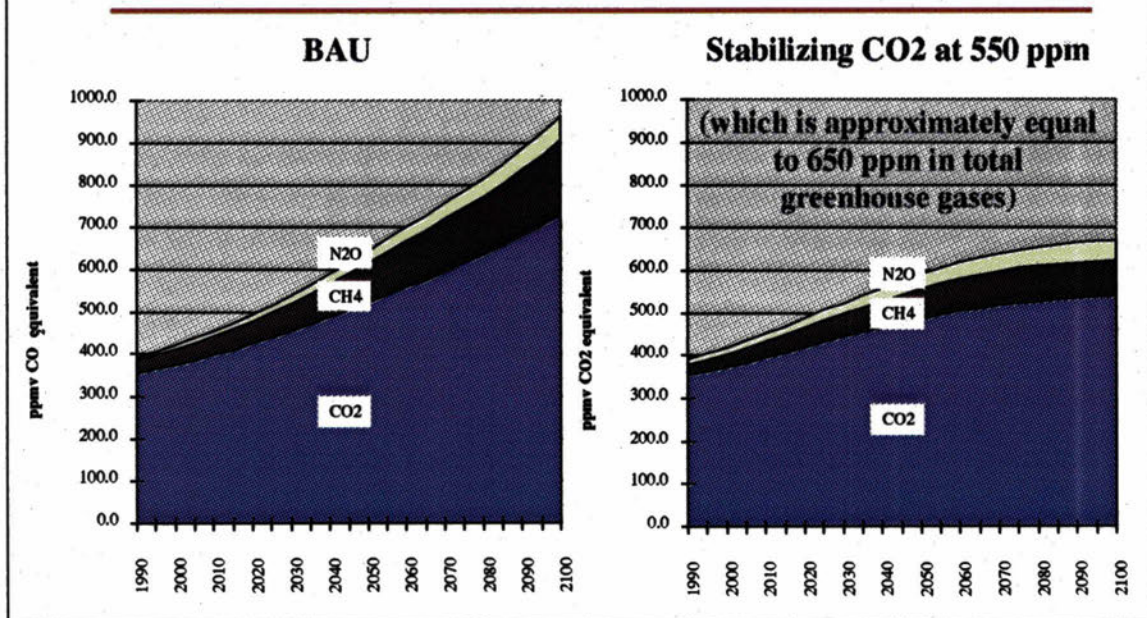
## **KEY POINT #1:**

### **Impacts expected in a doubled-CO<sub>2</sub> world:**

- There will be significant changes in water availability nationwide. Additionally, the frequency and intensity of floods and droughts will change. In the United States, the Great Basin, California, Missouri, Arkansas, Texas Gulf, Rio Grande, and Lower Colorado River Basins are likely to be most vulnerable.
- One-third of the Earth's forests could undergo a major change in vegetation: the Northeast United States will likely lose beech trees and sugar maples. Western conifer forests will decrease in area.
- A sea level rise of 20 inches is expected over the next century. This could inundate more than 5000 square miles of dry land and an additional 4000 square miles of wetlands. The Atlantic and Gulf Coasts are particularly vulnerable.
- There will be significant shifts in the ideal range for many agricultural crops. Food scarcity may increase, especially in the tropics and sub-tropics.
- Heat-related mortality and illness will increase. Reduced air quality will exacerbate respiratory disease, asthma, and allergic disorders.
- Geographic ranges for disease will expand, leading to an increase in diseases such as malaria, dengue and yellow fever. 50-80 million additional cases of malaria per year are projected worldwide.

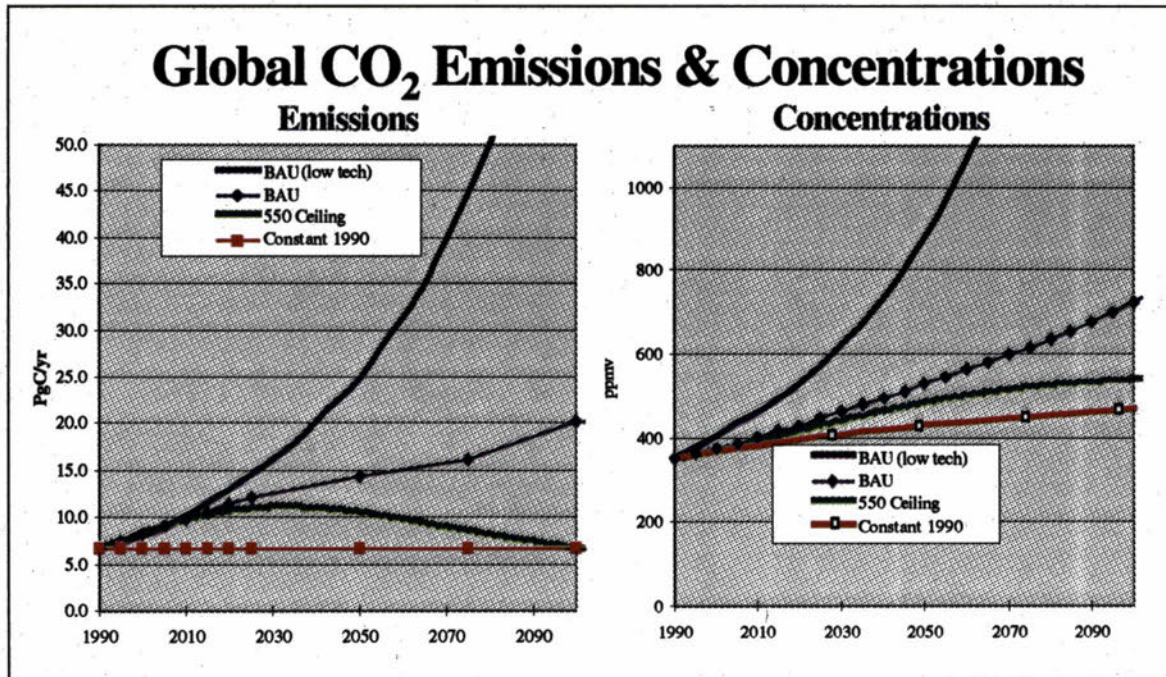
## KEY POINT #2:

### Non-CO<sub>2</sub> Greenhouse Gases Make the “Effective” Atmospheric Concentration Higher.



- Other greenhouse gases, principally methane and nitrous oxides, make the “effective” atmospheric concentrations about 20% higher than carbon dioxide alone.
- 550 ppm is about two times pre-industrial carbon dioxide (CO<sub>2</sub>)

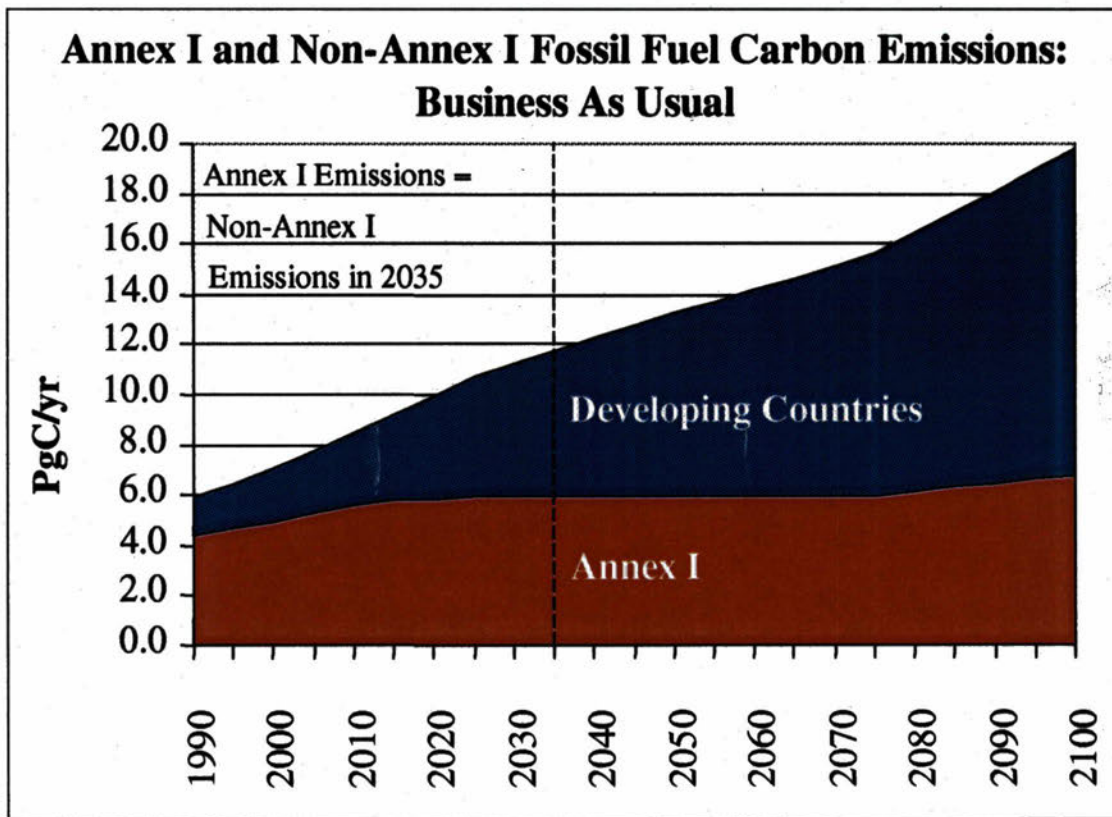
### KEY POINT #3:



- If we continue on a Business-As-Usual (BAU) path (top 2 lines in above figures), concentrations will double over the next few decades, never achieving stabilization.
- Stabilizing emissions will not stabilize concentrations.



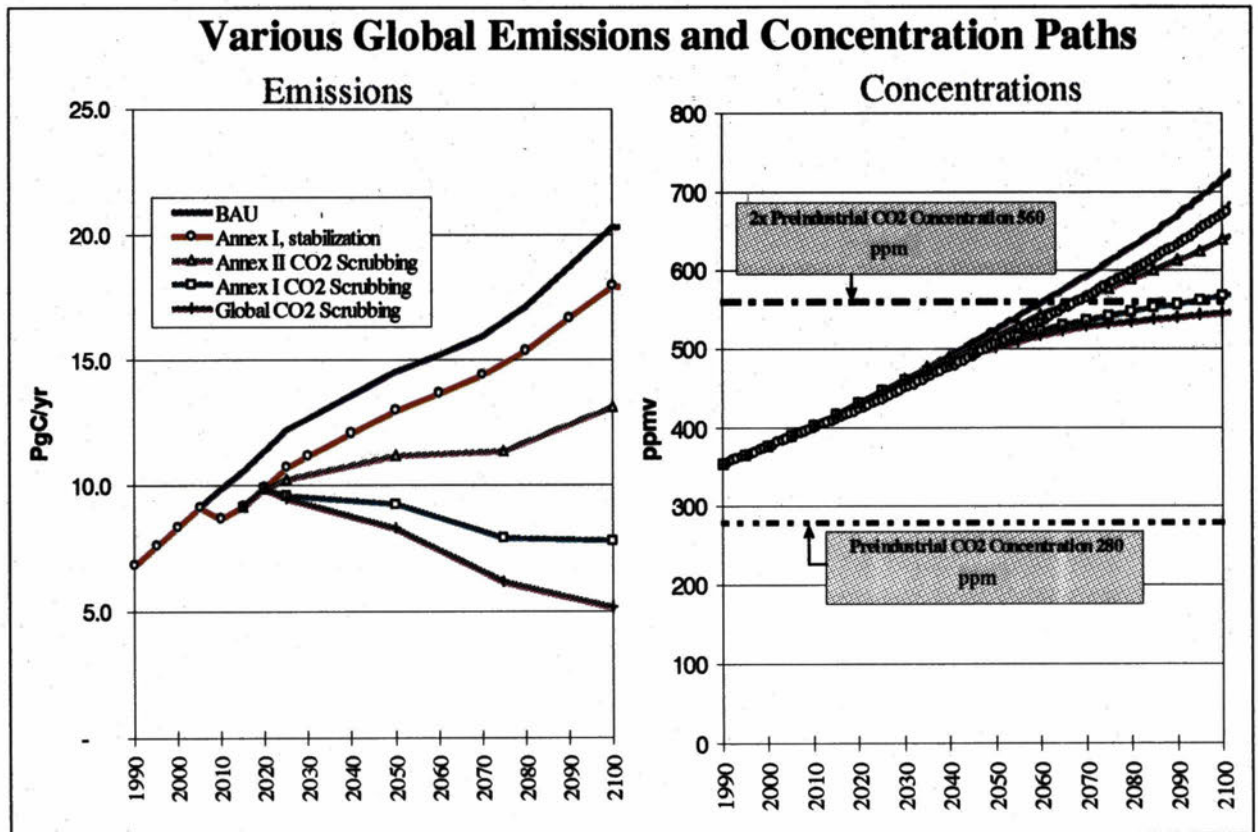
#### KEY POINT #4:



- A Business-As-Usual path implies that over time the majority of emissions will shift from developed to developing nations.



## KEY POINT #5:



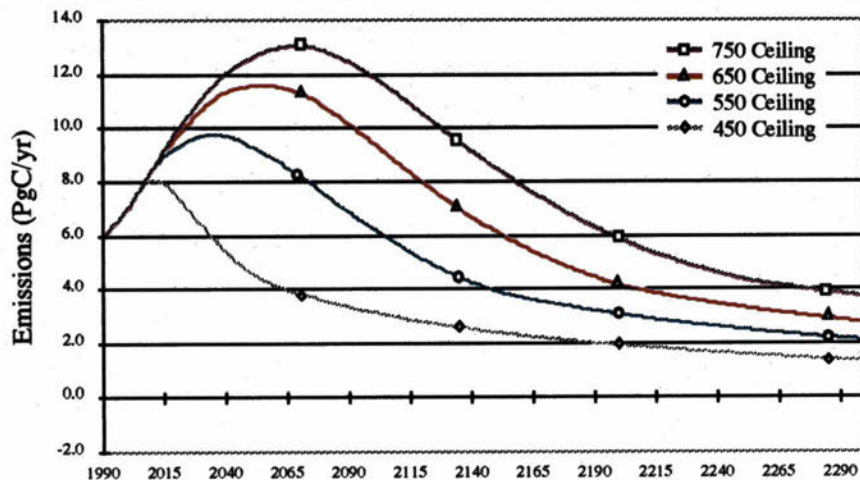
- Actions by Annex I alone are insufficient to achieve stabilization
- In order to cap emissions at just under a doubling of pre-industrial CO<sub>2</sub> levels, actions by Annex I countries need to be coupled with actions by non-Annex I countries in the next few decades.

**KEY POINT #6:****Energy emission pathways and stabilization concentrations**

| Steady-State Concentration→             | 450<br>ppm | 550<br>ppm | 650<br>ppm | 750<br>ppm |
|-----------------------------------------|------------|------------|------------|------------|
| <b>Deflection Date BAU <sup>a</sup></b> | 2007       | 2013       | 2018       | 2023       |
| <b>Maximum Emission Date</b>            | 2011       | 2033       | 2049       | 2062       |
| <b>Maximum Emission <sup>b</sup></b>    | 8.0        | 9.7        | 11.4       | 12.5       |

<sup>a</sup> The deflection date is the year in which emissions in the emissions stabilization trajectory first fall below BAU emissions by more than 0.1 PgC/yr.

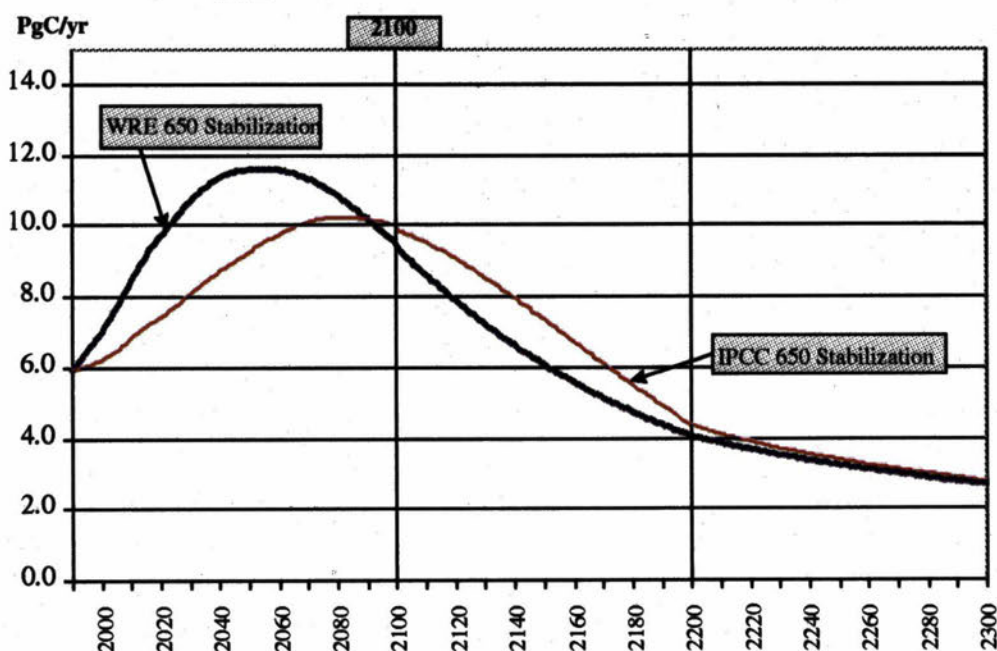
<sup>b</sup> Maximum PgC/yr fossil fuel carbon emissions. If other greenhouse gases are included, emissions would be effectively 20% higher; thus, reductions would have to occur sooner than the deflection date noted to achieve a given concentration.



- To meet atmospheric concentrations of 450-750 ppm CO<sub>2</sub> requires a significant reduction in annual emissions during the next century.
- For example, to meet a target of 550 ppm CO<sub>2</sub>, the table shows that global CO<sub>2</sub> emissions due to fossil fuel burning must begin to deflect from the business-as-usual curve by 2013. In that scenario, energy-related emissions would peak at 9.7 PgC/yr in 2033 and drop rapidly thereafter. (Because of the other greenhouse gases, the effective concentration would be about 650 ppm.)

**KEY POINT #7:**

## Fossil Fuel CO<sub>2</sub> Emissions for Two 650 ppm Stabilization Cases



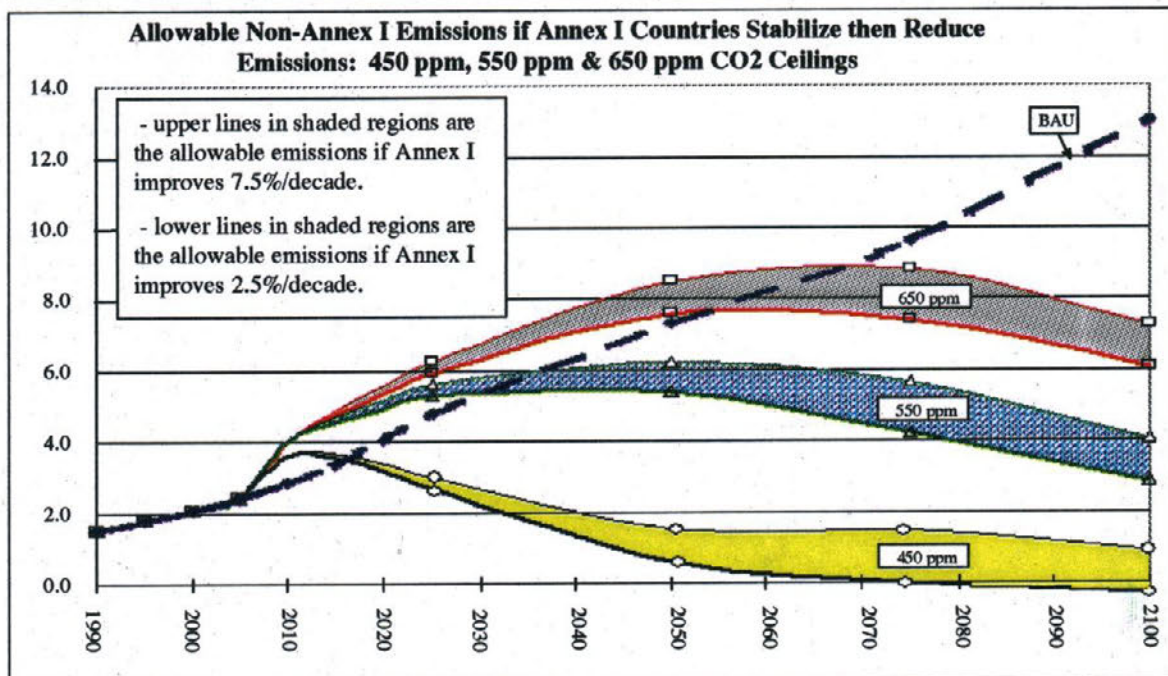
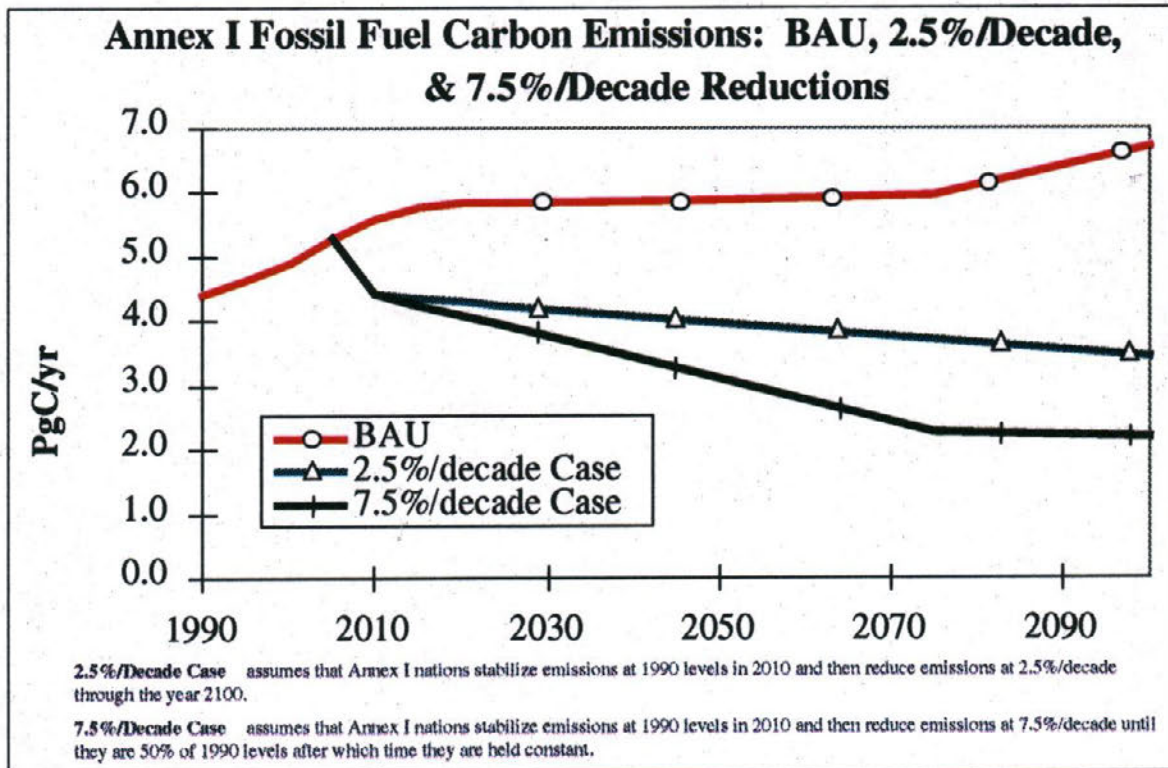
| WRE TRAJECTORY                                        |      |
|-------------------------------------------------------|------|
| Global Deflection Date BAU (Tech+) <sup>a</sup>       | 2018 |
| Non-Annex I Deflection Date BAU (Tech+) <sup>a</sup>  | 2055 |
| Maximum Global Fossil Fuel Emission Date              | 2049 |
| Maximum Global Fossil Fuel Emission <sup>b</sup>      | 11.4 |
| Maximum Non-Annex I Fossil Fuel Emission Date         | 2060 |
| Maximum Non-Annex I Fossil Fuel Emission <sup>b</sup> | 7.7  |
| S SERIES TRAJECTORY                                   |      |
| Global Deflection Date BAU (Tech+) <sup>a</sup>       | 1991 |
| Non-Annex I Deflection Date BAU (Tech+) <sup>a</sup>  | 1991 |
| Maximum Global Fossil Fuel Emission Date              | 2081 |
| Maximum Global Fossil Fuel Emission <sup>b</sup>      | 10.3 |
| Maximum Non-Annex I Fossil Fuel Emission Date         | 2090 |
| Maximum Non-Annex I Fossil Fuel Emission <sup>b</sup> | 6.7  |

<sup>a</sup> The deflection date is the year in which emissions in the stabilization trajectory first fall below BAU emissions by more than 0.1 PgC/yr.  
<sup>b</sup> PgC/yr fossil fuel carbon emissions on the date of maximum total anthropogenic carbon emissions.

- These 2 curves show two different paths to achieve stabilization at CO<sub>2</sub> emissions of 650 ppm. The WRE line – estimated to be less expensive – allows emissions to initially grow and then drop more steeply as new technologies come online. For example, the developing countries could emit 150 billion tons more carbon under the WRE scenario.

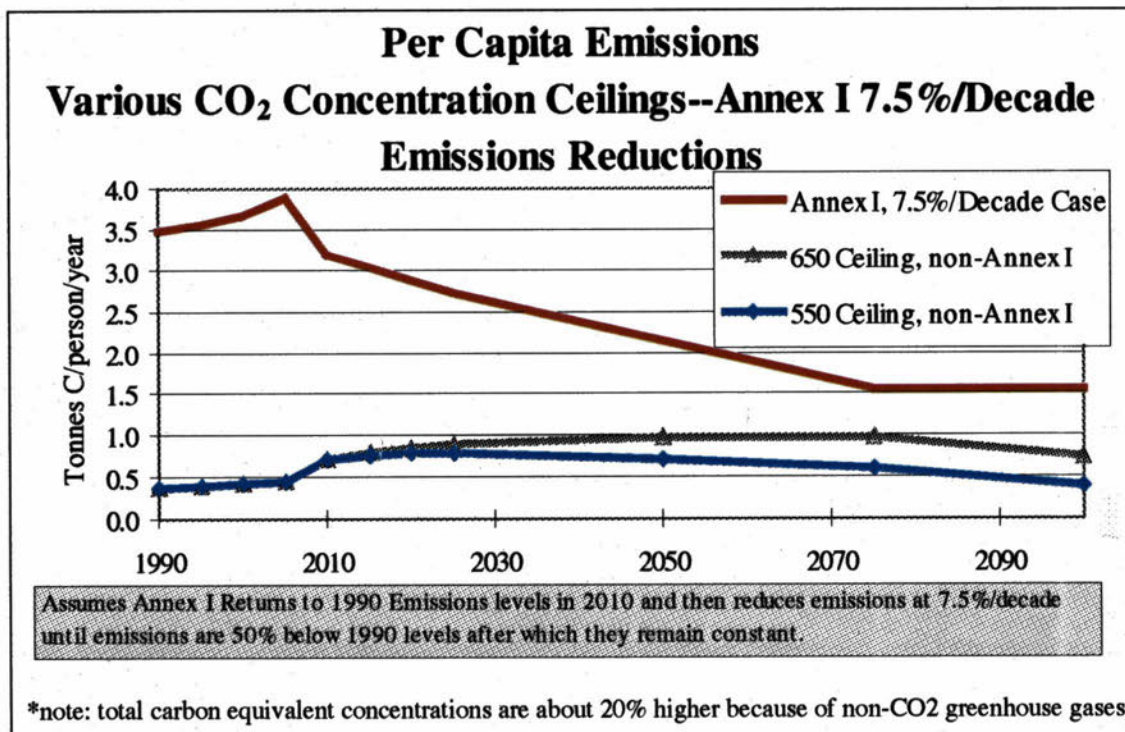
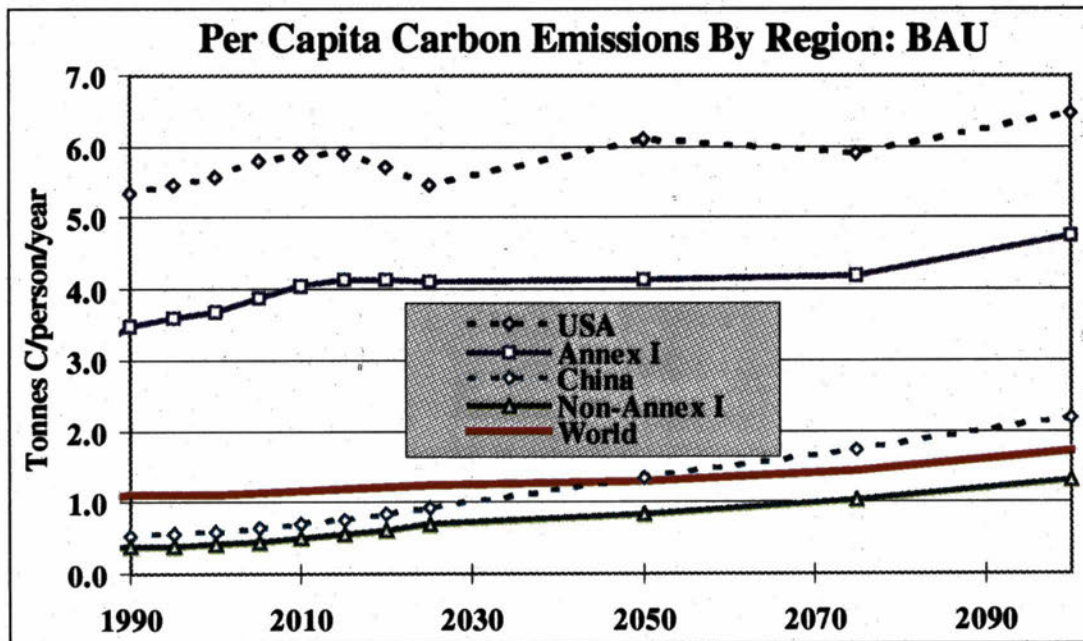


## KEY POINT #8:



- If Annex I countries freeze emissions in 2010 and then reduce steadily (upper chart), developing countries can continue on business-as-usual paths for some time before reducing emissions (lower chart).

## KEY POINT #9:

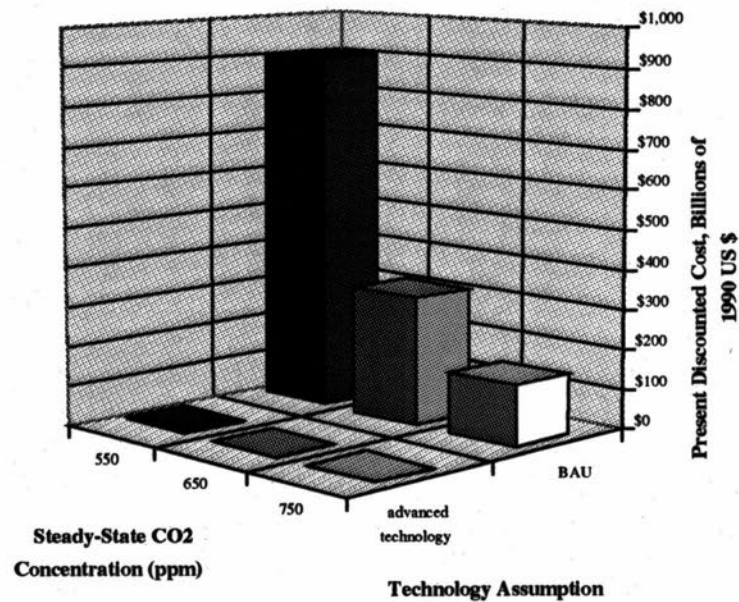


- Although they remain widely disparate, per capita emissions of Annex I and non-Annex I countries begin to converge over time. The top figure shows Business As Usual per capita emissions. The lower figure shows per capita emissions under one policy scenario.



## KEY POINT #10:

### The Relationship Between Technology and Minimum Cost of Stabilizing the Atmosphere Below Various Ceilings

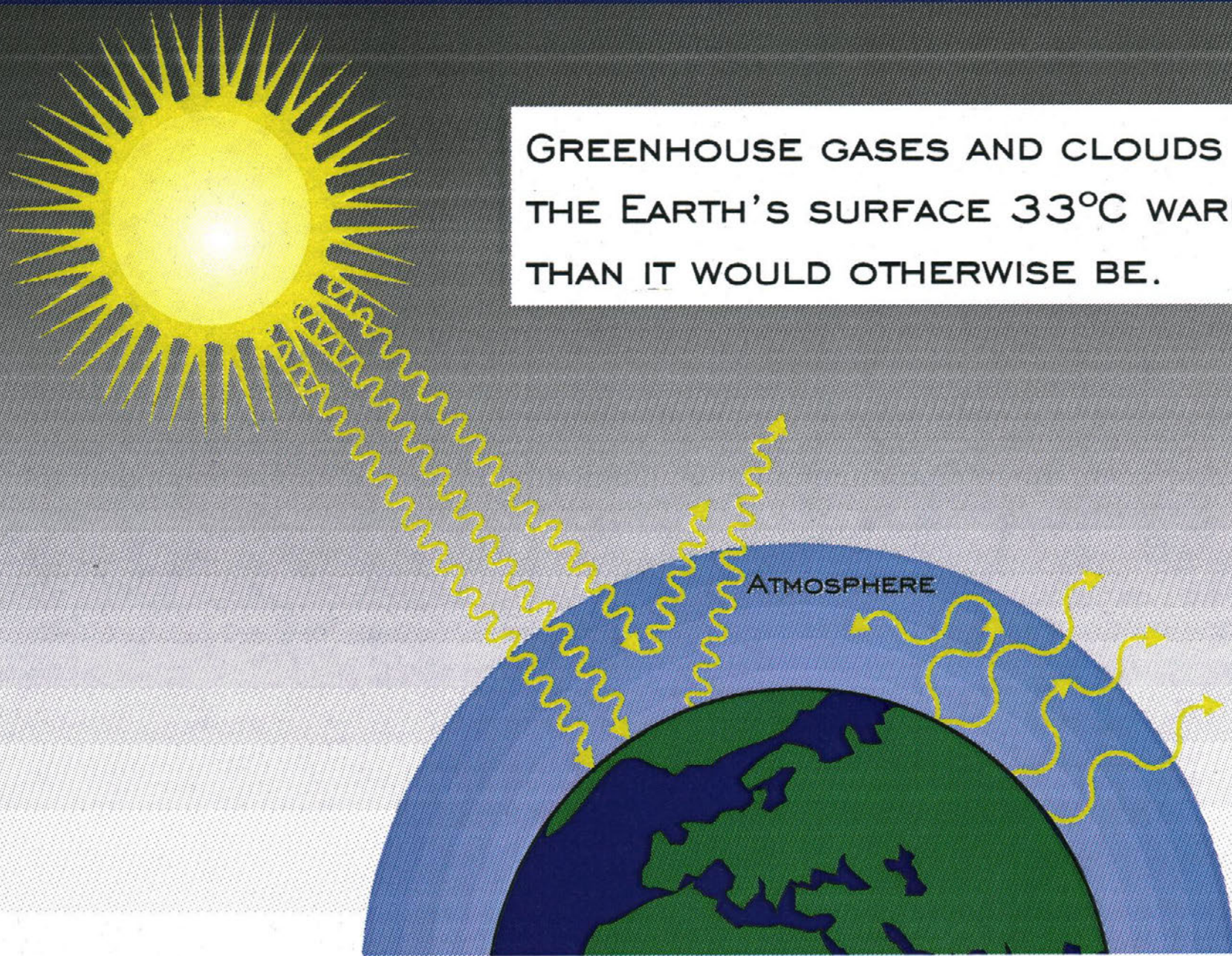


- If a functional, cost-effective cap and trade system is in place, investments in technology can greatly reduce global costs.



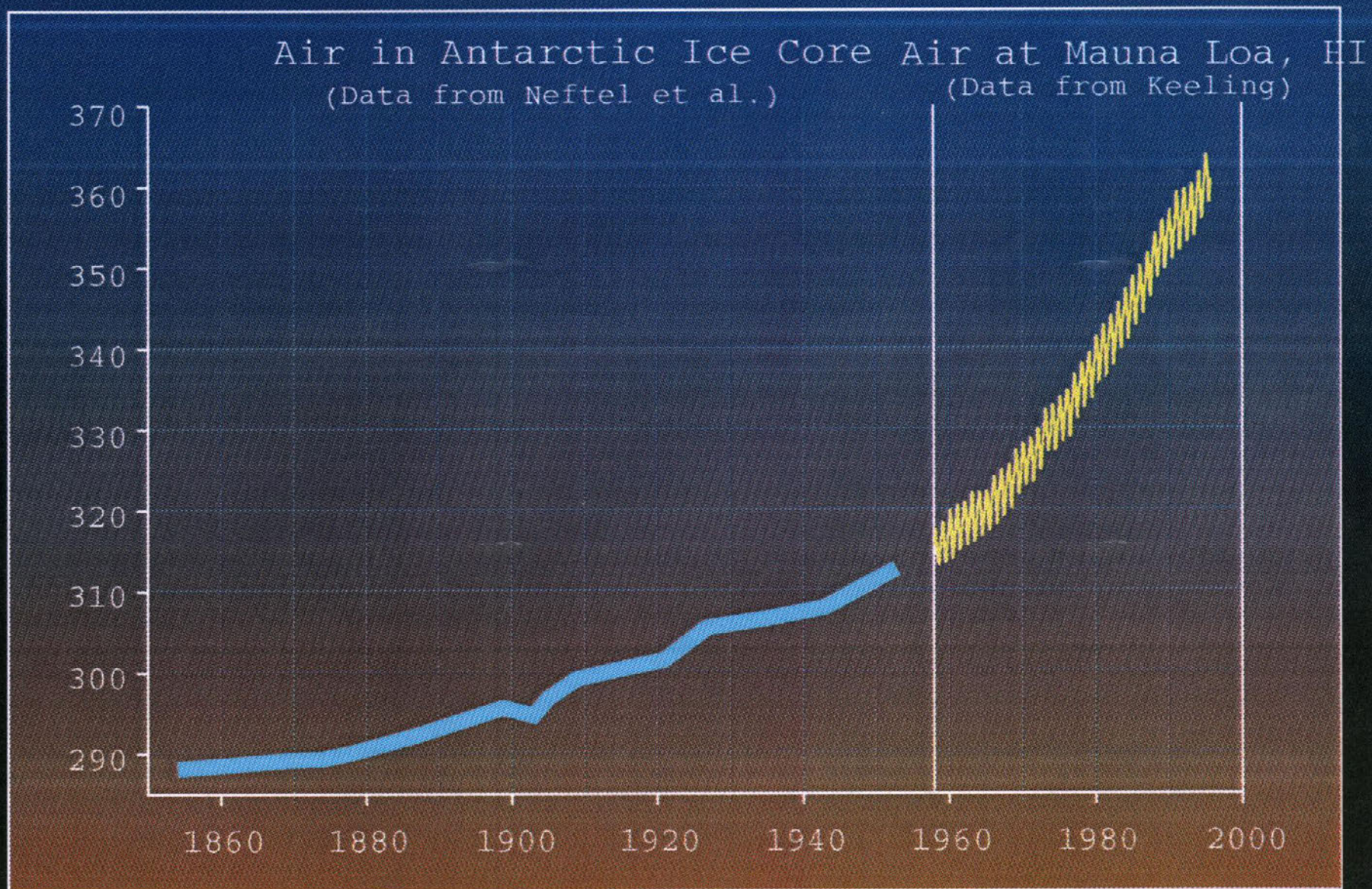
# THE GREENHOUSE EFFECT

GREENHOUSE GASES AND CLOUDS KEEP  
THE EARTH'S SURFACE 33°C WARMER  
THAN IT WOULD OTHERWISE BE.





# Carbon Dioxide Concentrations





# 1950-1995: CUMULATIVE EMISSIONS OF CO<sub>2</sub>

GLOBAL TOTAL: 183 BILLION TONNES CARBON

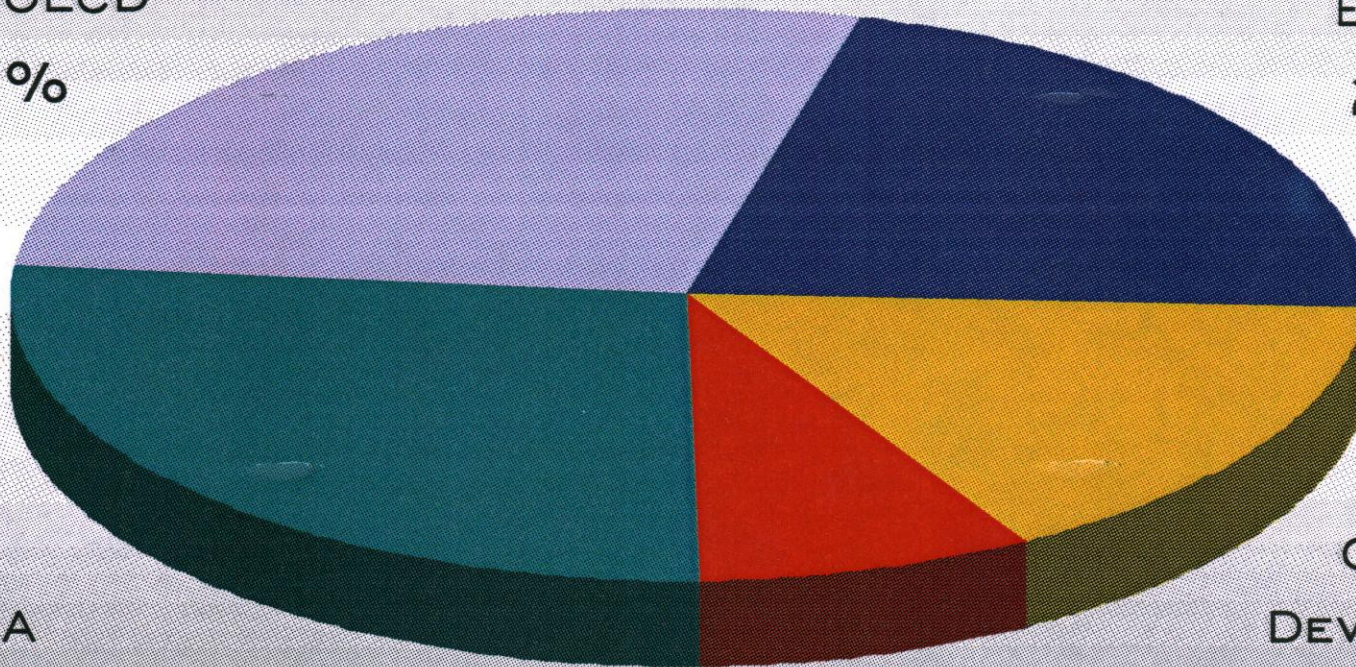
OTHER OECD  
27%

EE/FSU  
22%

USA  
27%

OTHER  
DEVELOPING  
16%

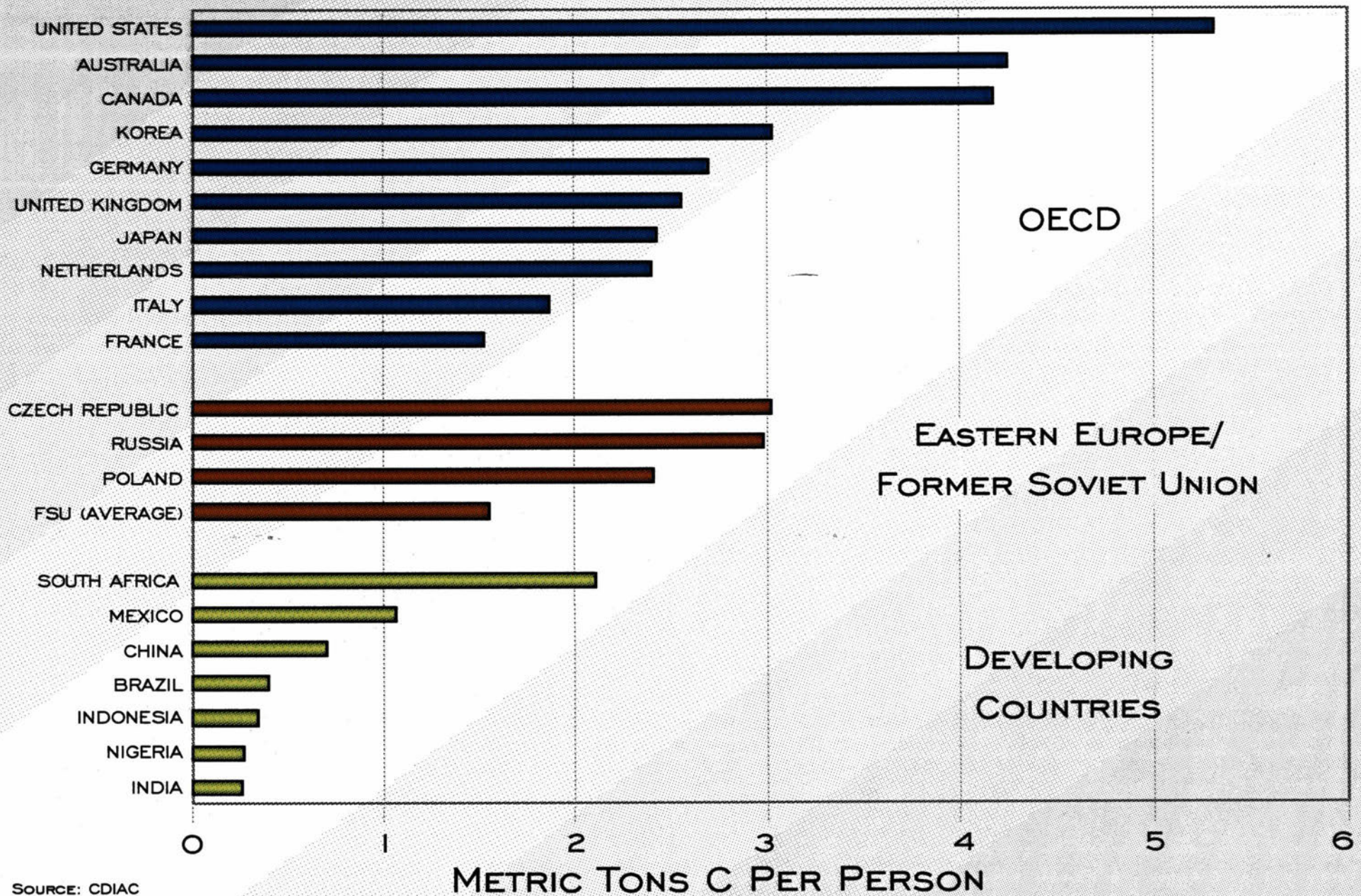
CHINA  
8%



SOURCE: GREGG MARLAND AND TOM BODEN, CDIAC

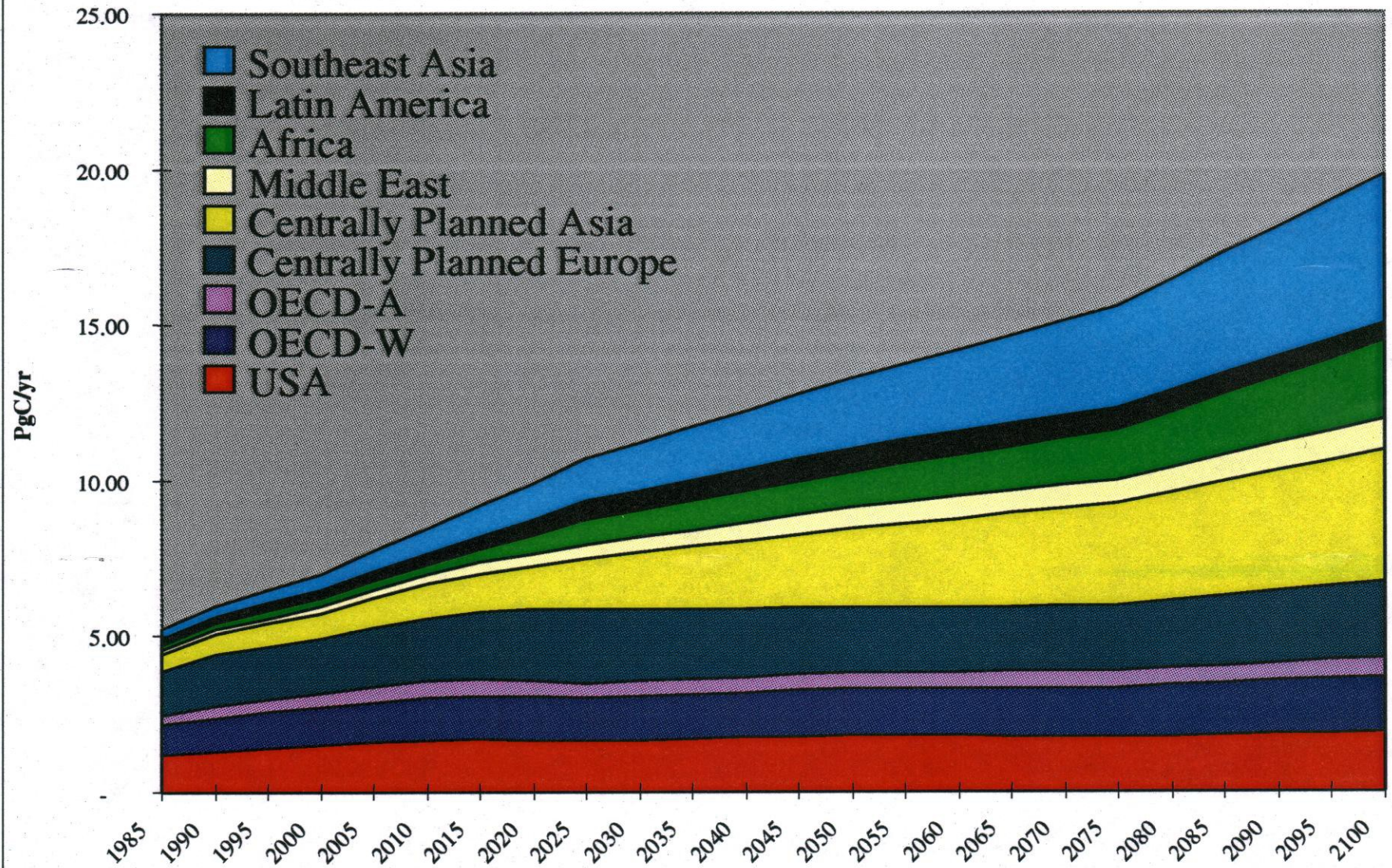


# PER CAPITA CARBON EMISSIONS



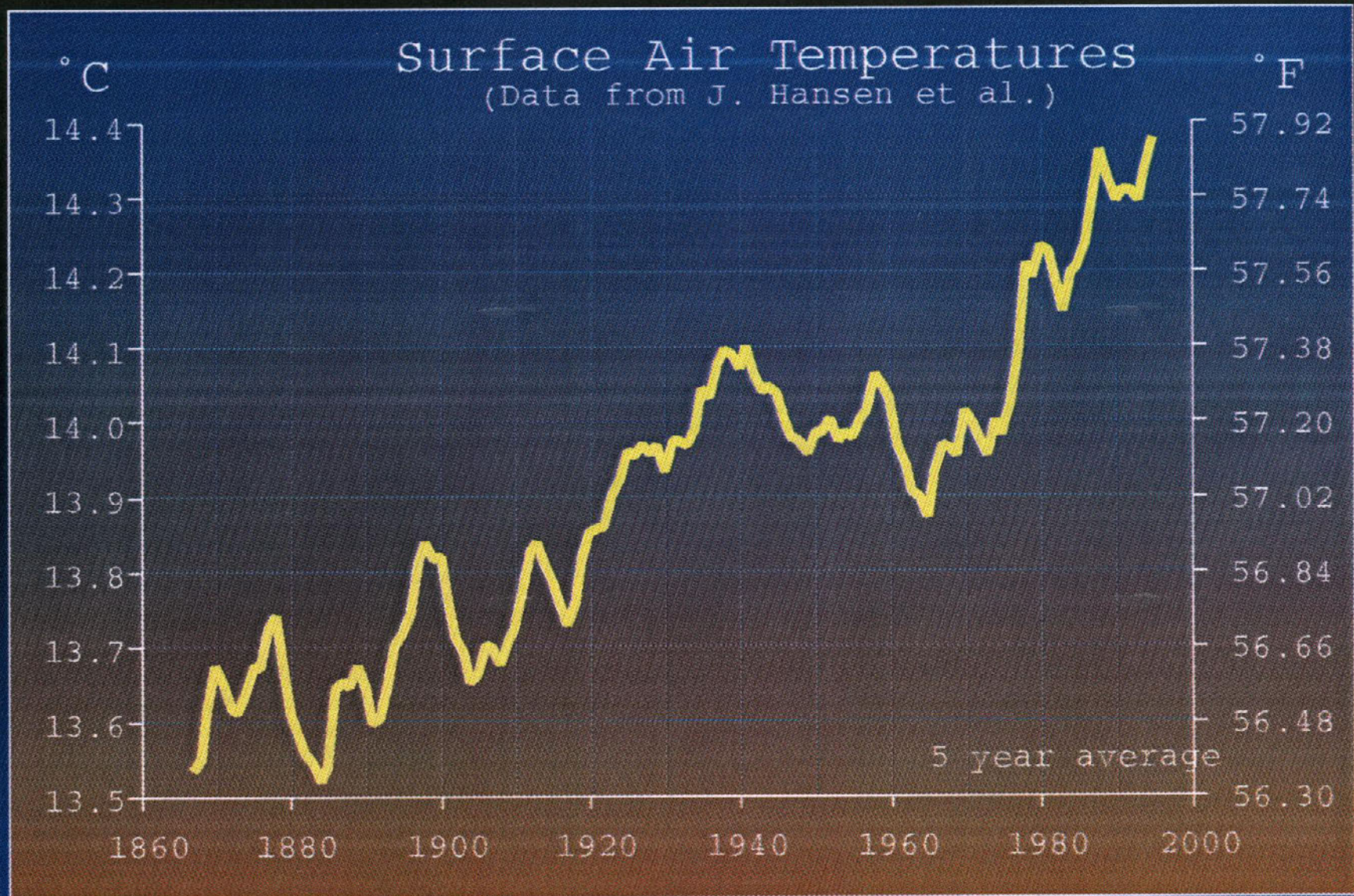


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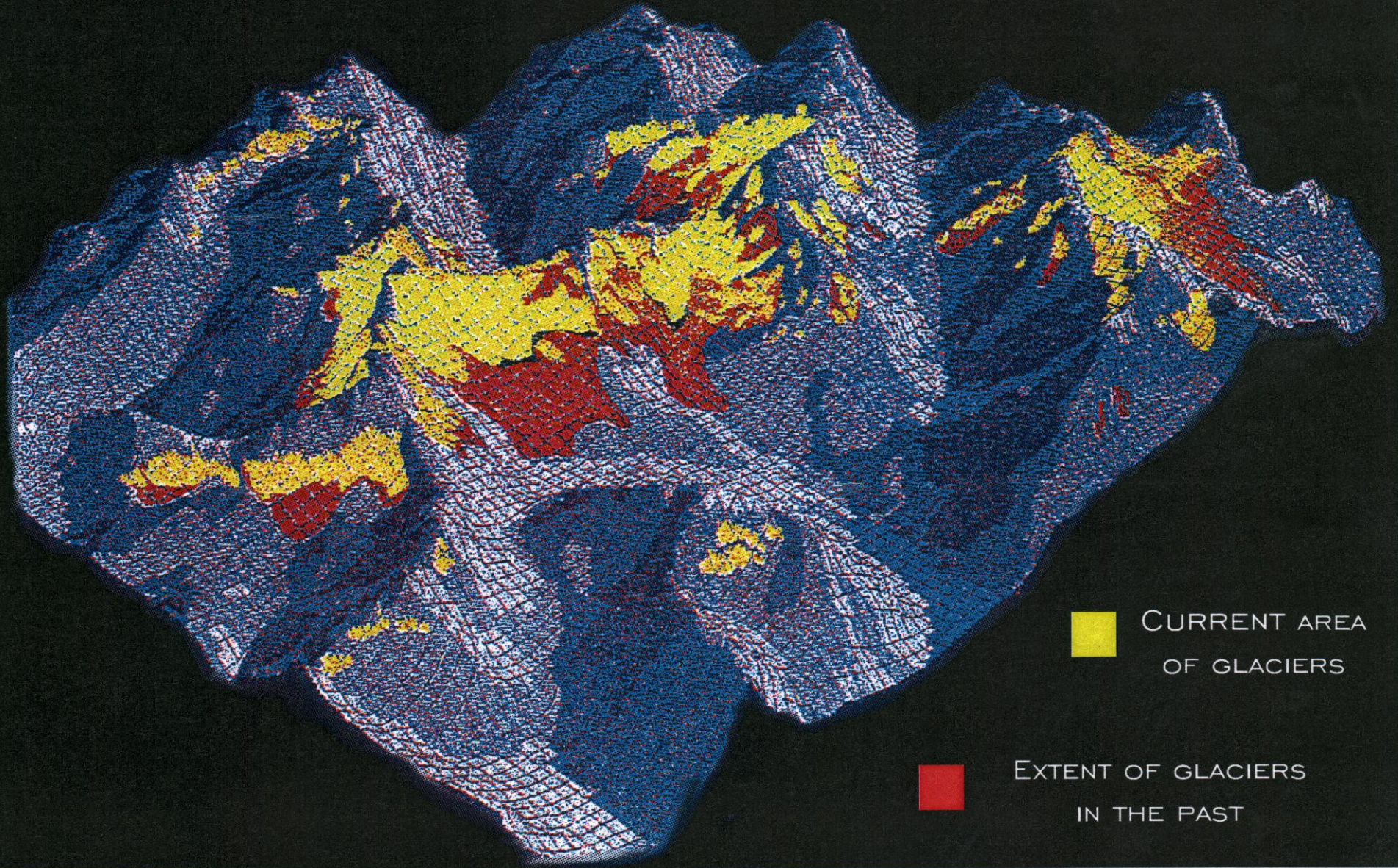
# Global Average Temperature





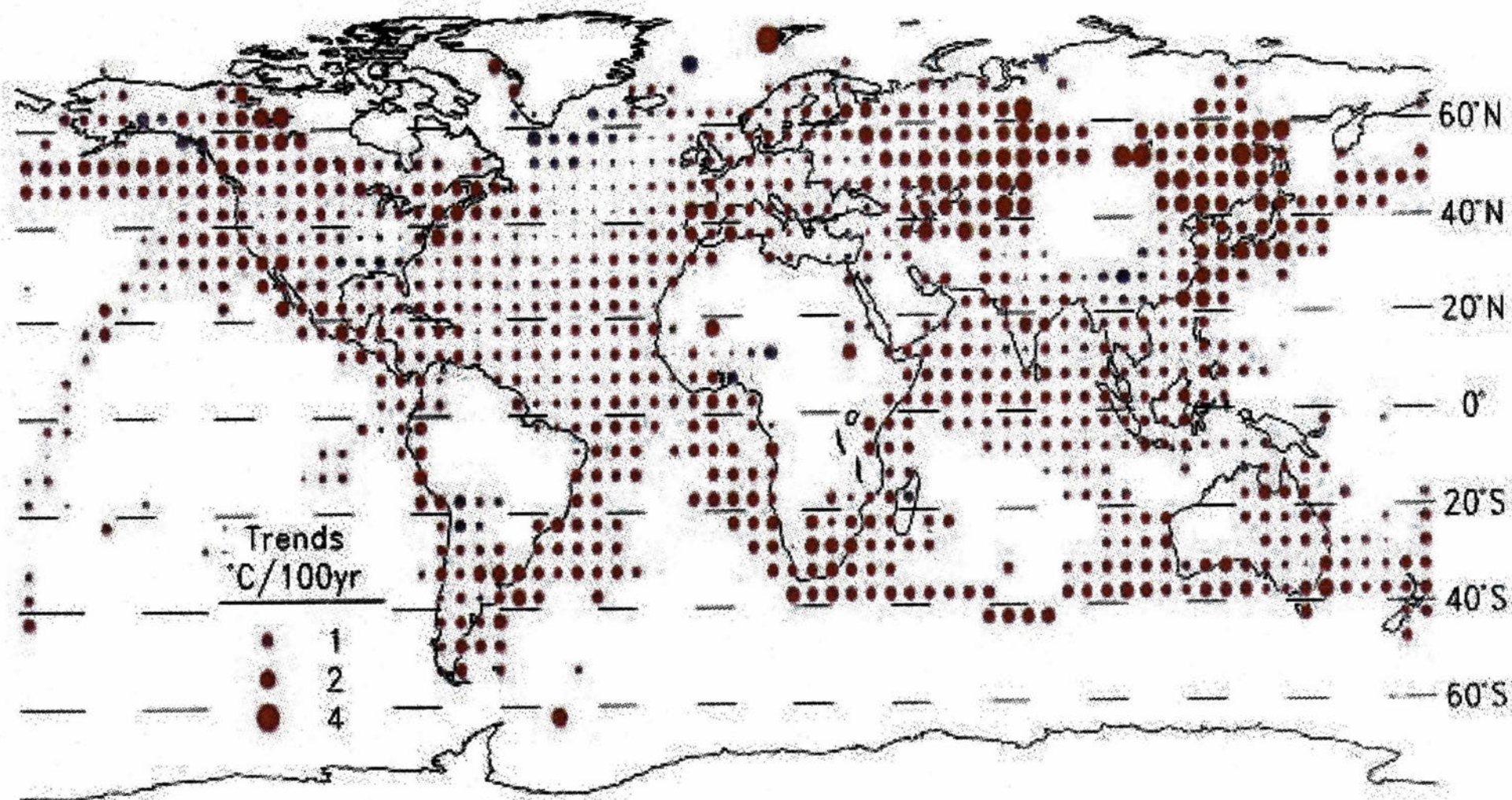
# GLACIER SHRINKAGE IN GLACIER NATIONAL PARK

1850 - 1993



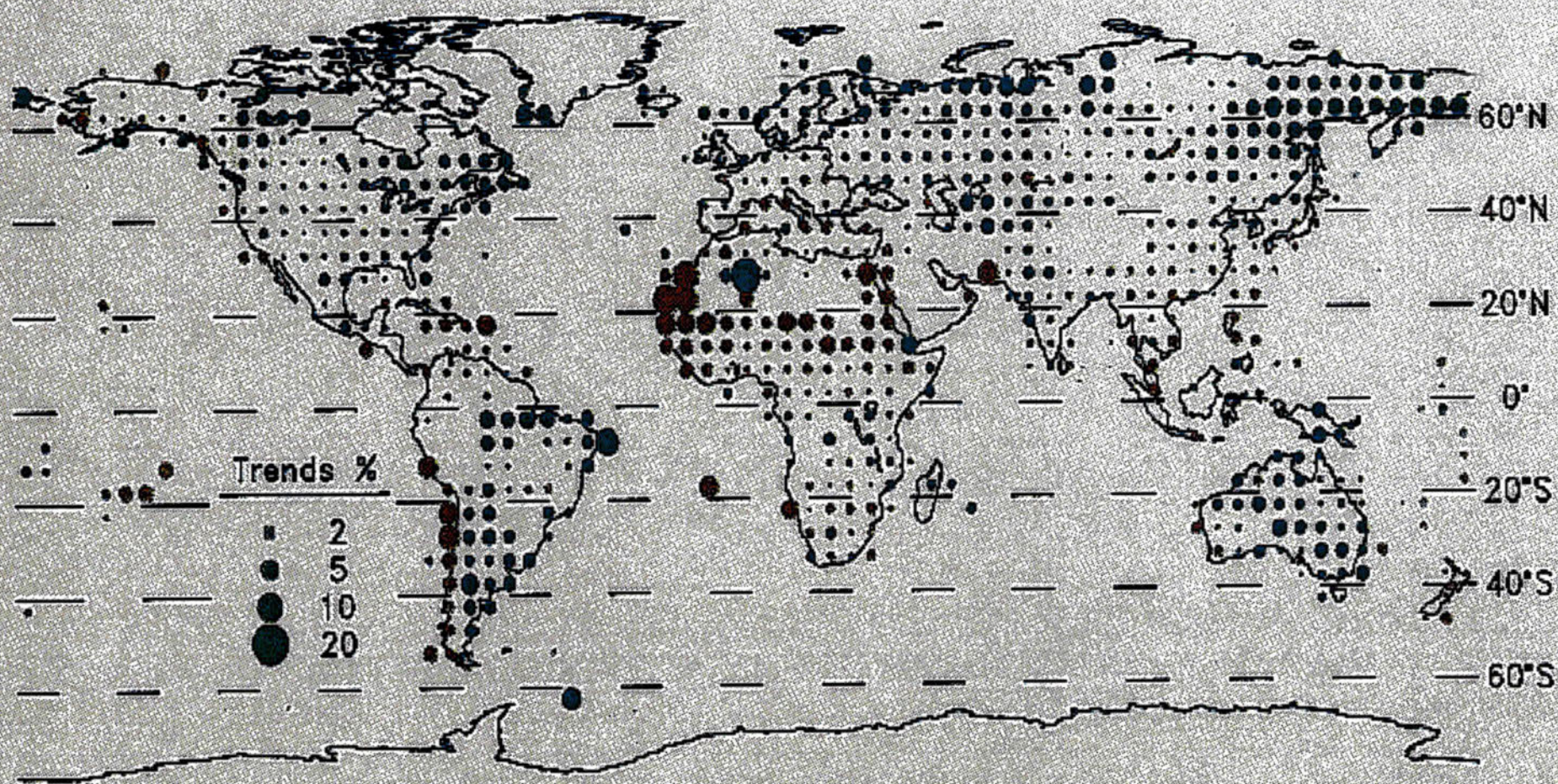


# Temperature Annual 1901–1996

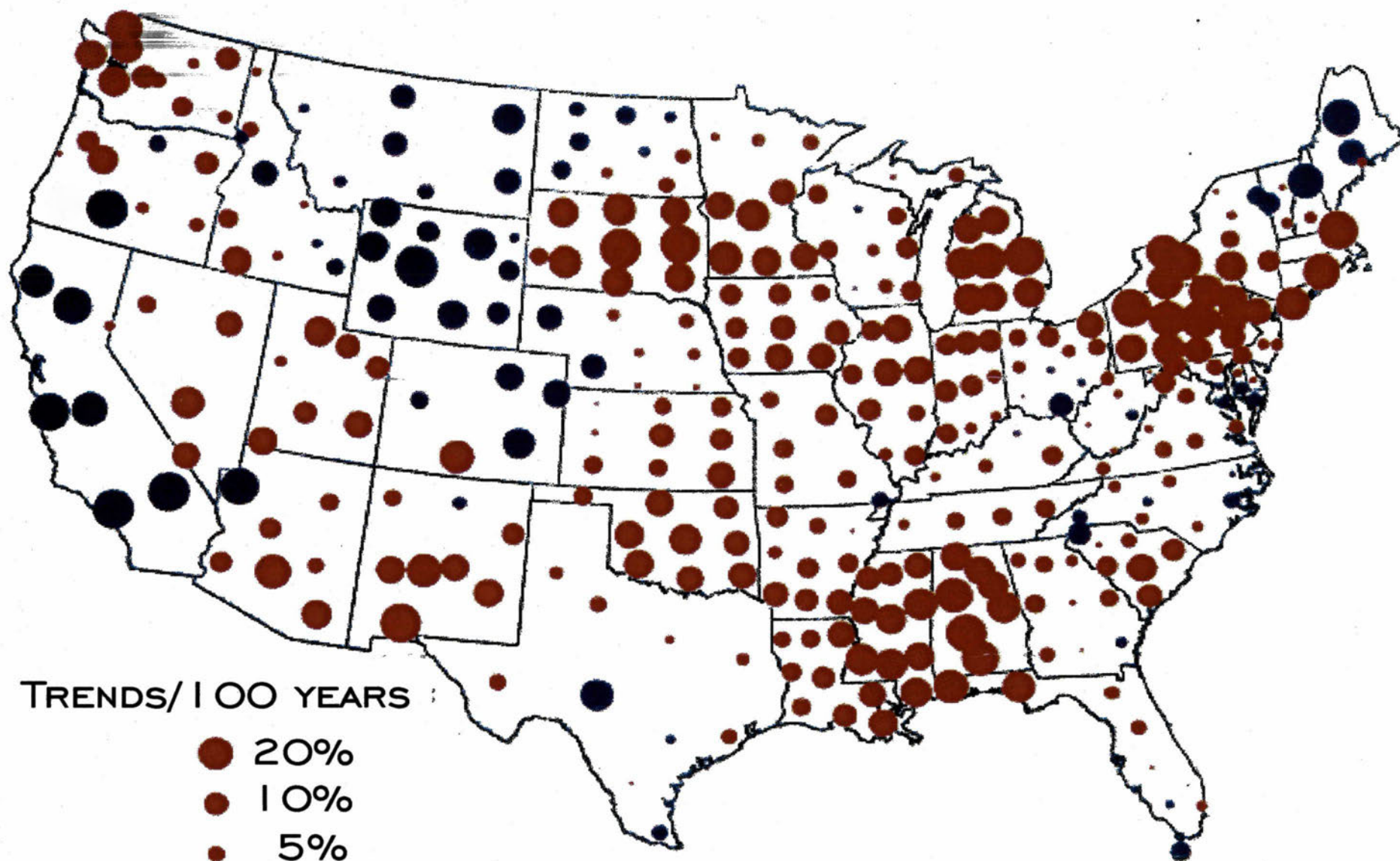




# Precipitation Trends (%) per Decade (1900-1994) green, increasing; brown, decreasing

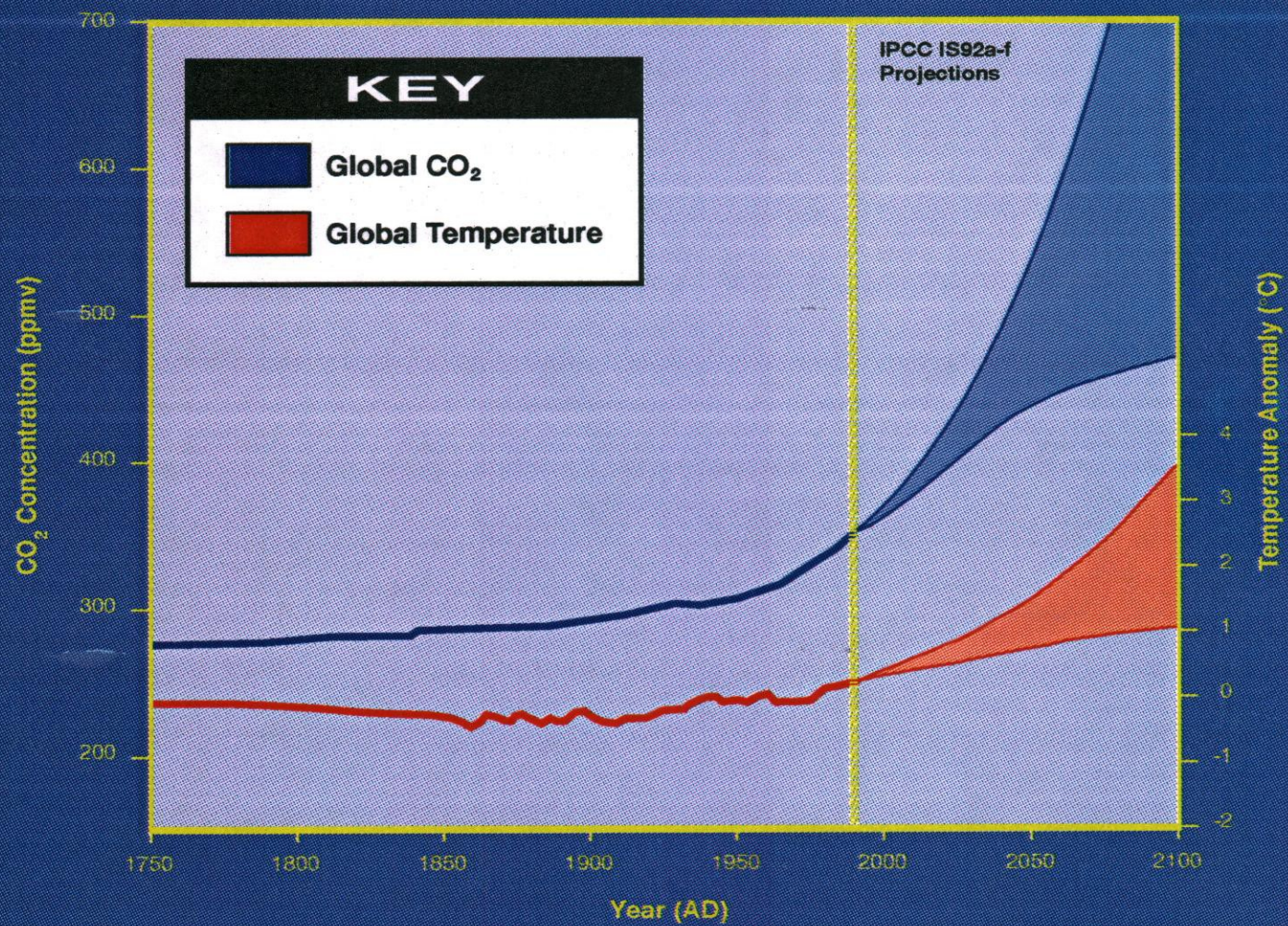






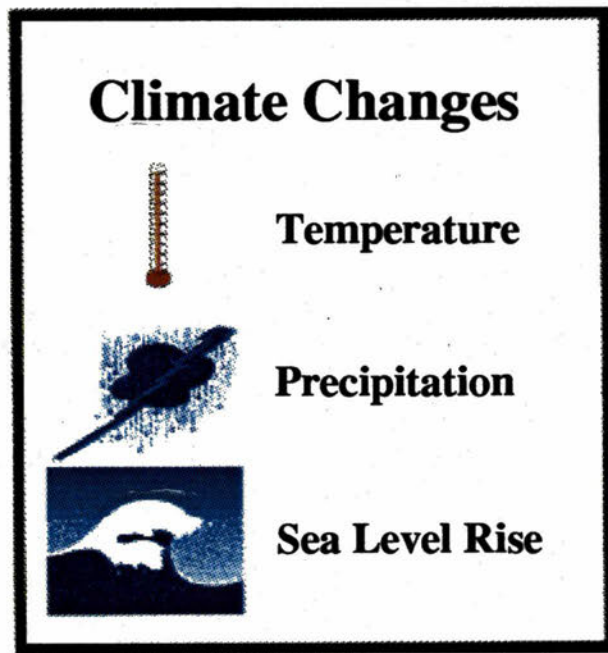
Precipitation trends (1900-present, in percent of normal annual precipitation) within state climatic divisions. The diameter of the circle centered within each climatic division reflects the magnitude of the trend. Larger circles have the greater trends. Red reflects increasing precipitation and blue decreasing.







# Potential Climate Change Impacts



## Health Impacts

Weather-related Mortality  
Infectious Diseases  
Air Quality-Respiratory Illnesses



## Agriculture Impacts

Crop Yields  
Irrigation Demands



## Forest Impacts

Forest composition  
Geographic range of forests  
Forest health and productivity



## Water Resource Impacts

Water supply  
Water quality  
Competition for water



## Impacts on Coastal Areas

Erosion of beaches  
Inundation of coastal lands  
Additional costs to protect coastal communities

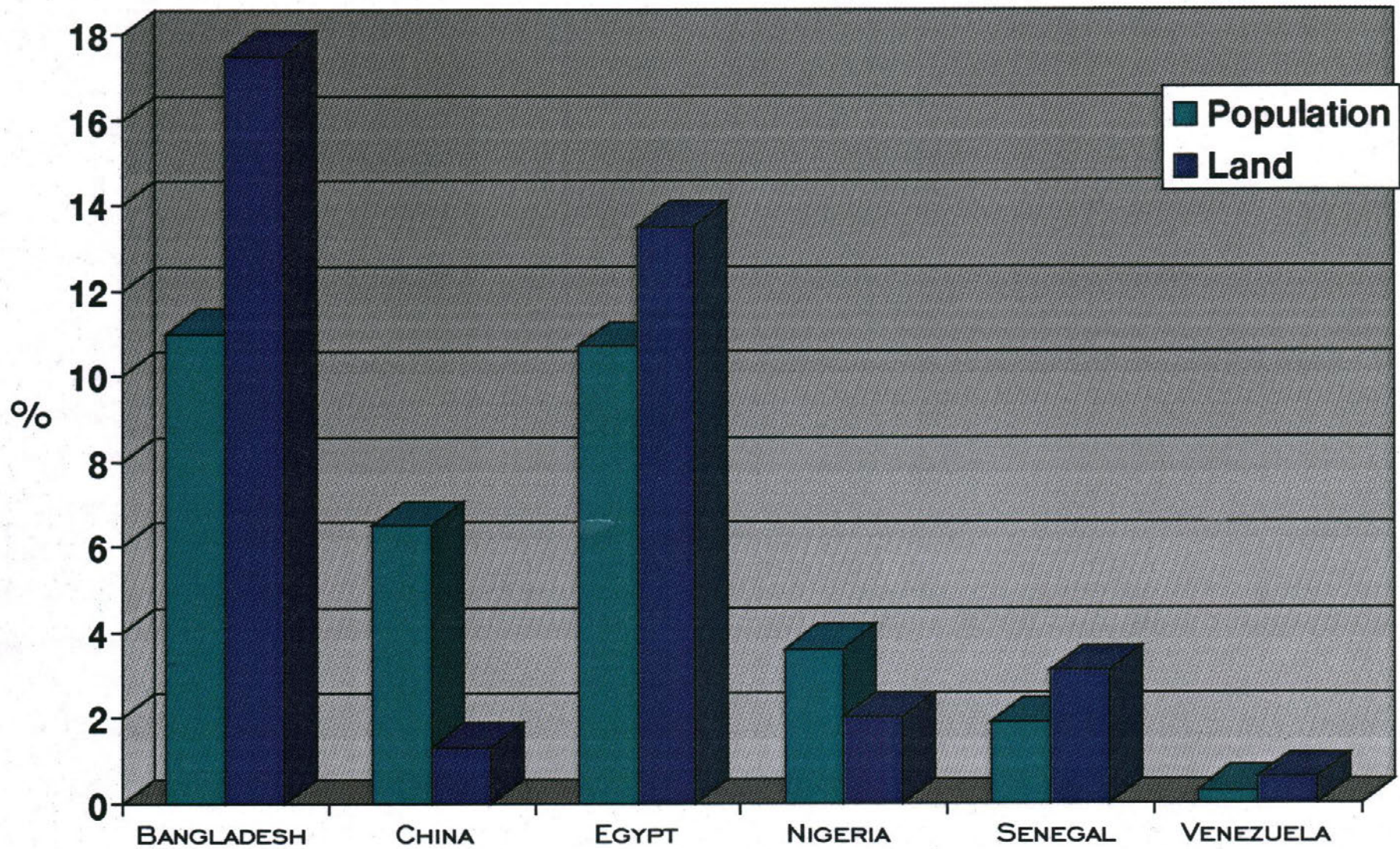


## Species and Natural Areas

Loss of habitat and species



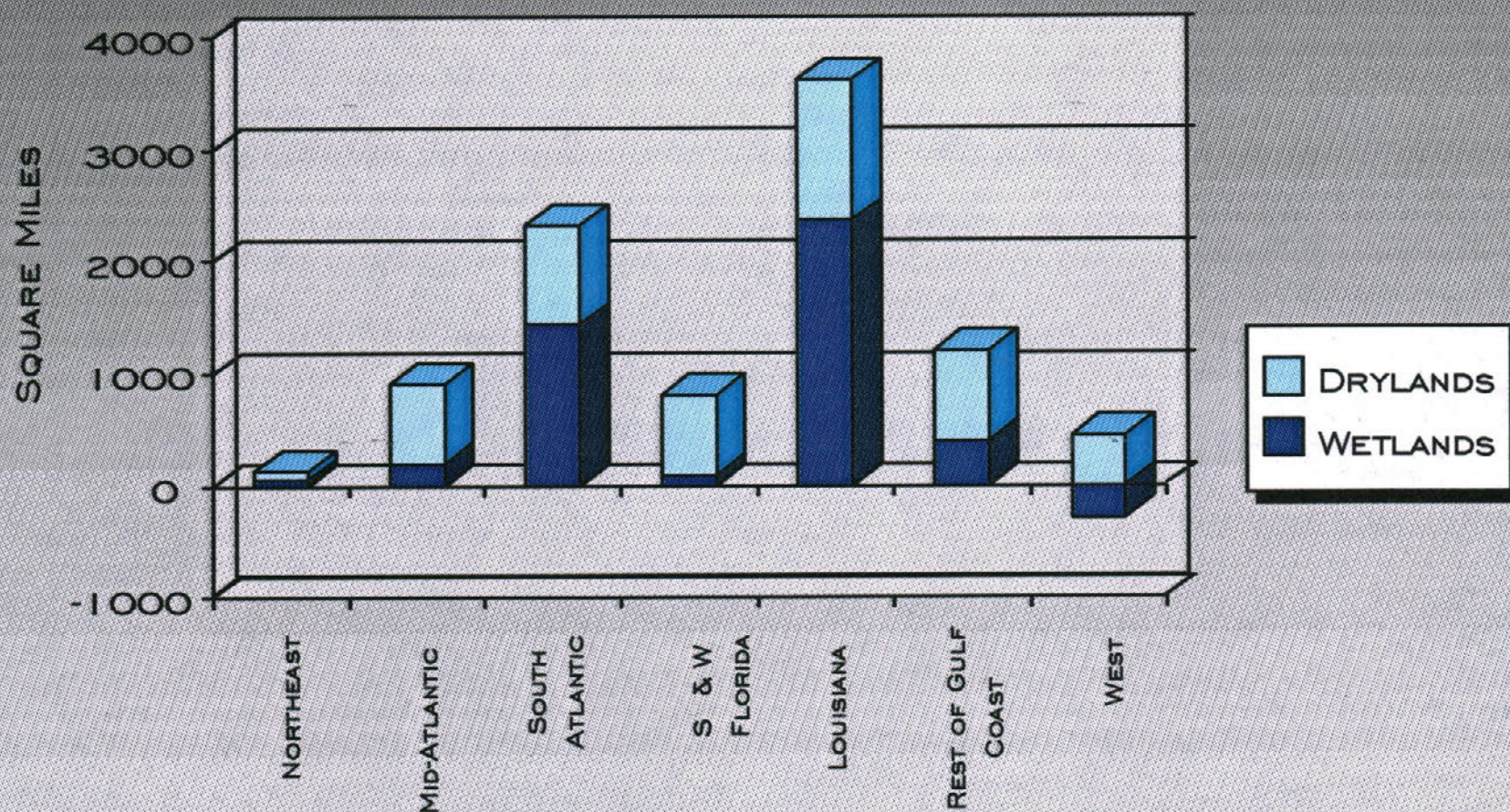
# COASTAL RESOURCES: INTERNATIONAL LANDS AND POPULATIONS AT RISK FROM A 1 METER SEA LEVEL RISE



SOURCE: STRZEPEK AND SMITH (1995)



# U.S. COASTAL LANDS AT RISK FROM A 20-INCH SEA LEVEL RISE IN 2100

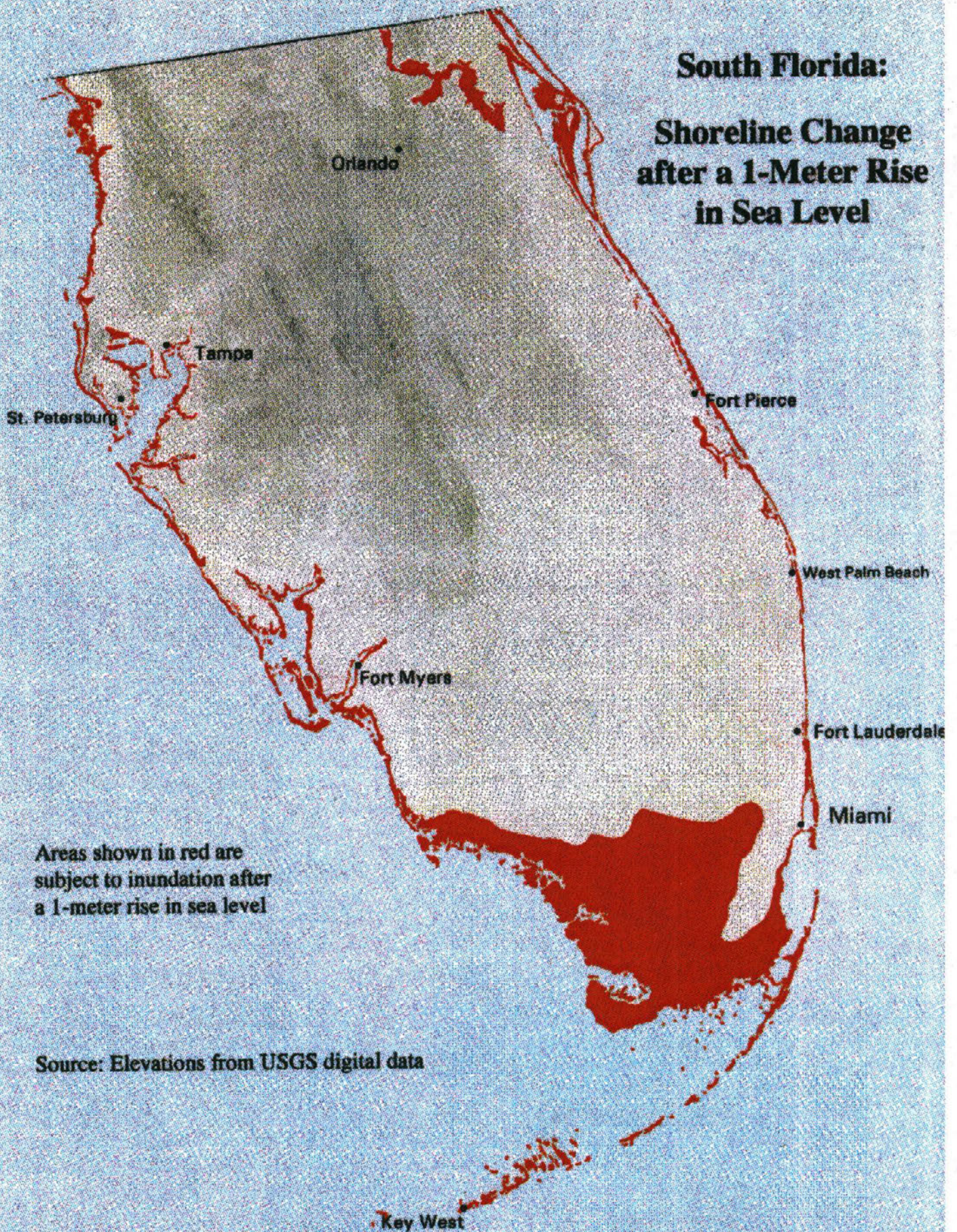


SOURCE: U.S. EPA (1989).



## **South Florida:**

### **Shoreline Change after a 1-Meter Rise in Sea Level**



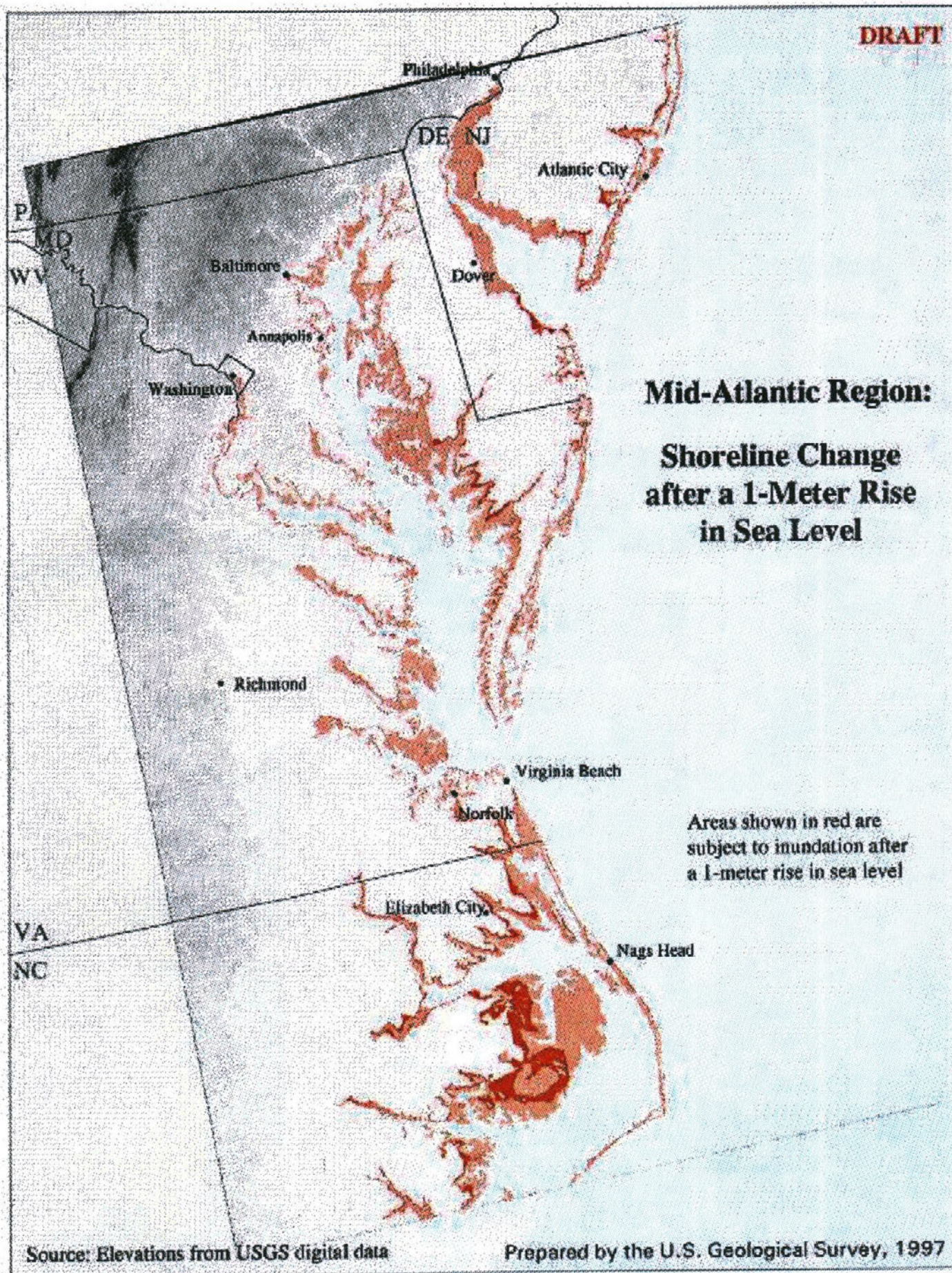
Areas shown in red are  
subject to inundation after  
a 1-meter rise in sea level

Source: Elevations from USGS digital data

Prepared by the U.S. Geological Survey, 1997

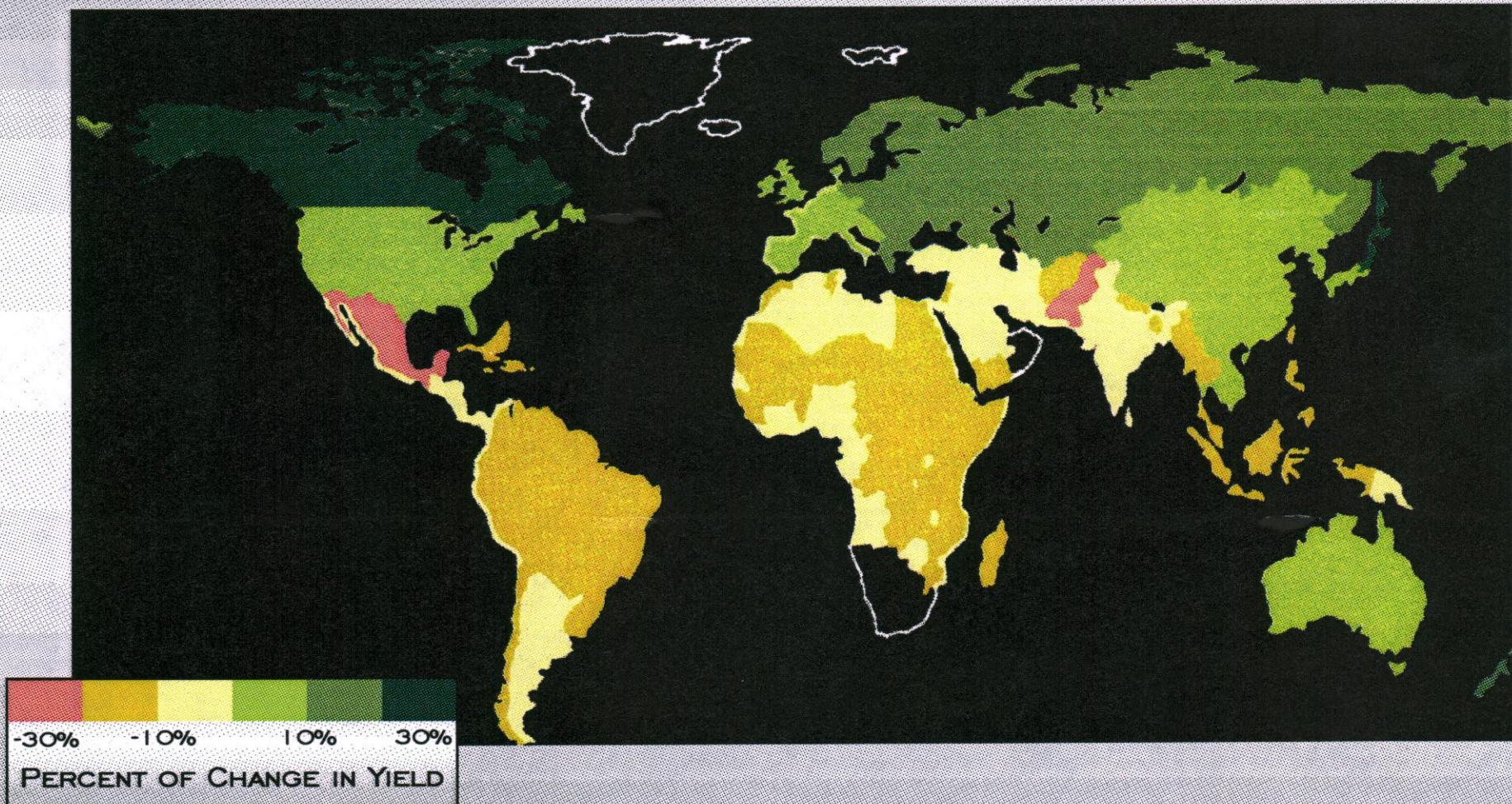


**DRAFT**





# AGRICULTURAL RESOURCES: POTENTIAL CHANGE IN GRAIN YIELD DUE TO DOUBLED $\text{CO}_2$



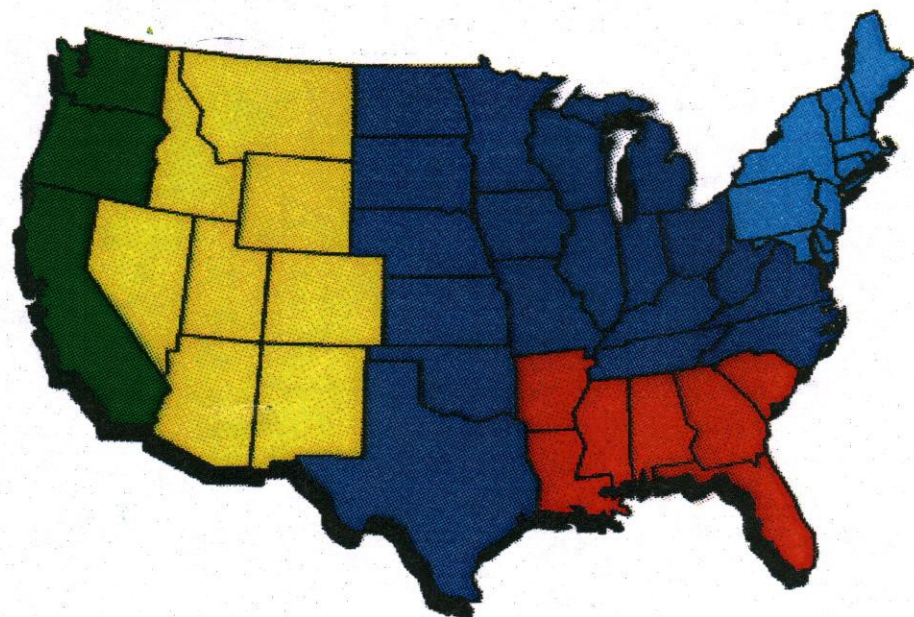
BASED ON GISS MODEL; PHYSIOLOGICAL  $\text{CO}_2$  EFFECTS INCLUDED

SOURCE: ROSENZWEIG AND HILLEL (1993)

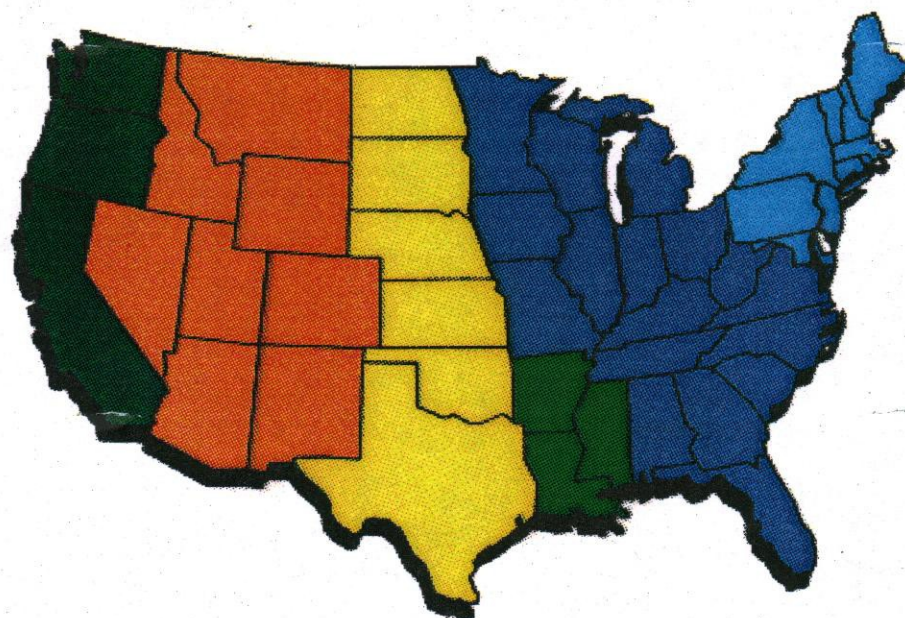


# Changes in Agricultural Yields

## Change in Wheat Yield



## Change in Corn Yield



**Percent Change**



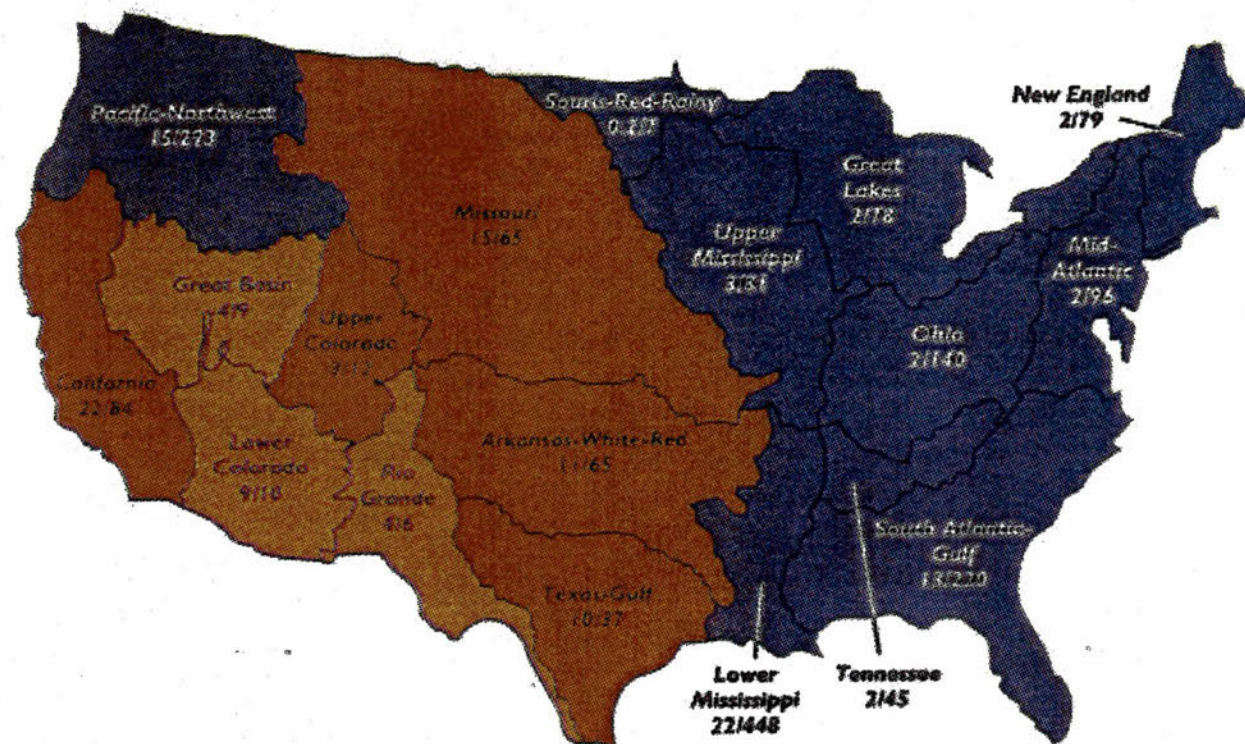
+ 2.5°C; + 7% Precipitation  
530 ppmv CO<sub>2</sub>

Source: Rosenzweig, 1995



## WATER WITHDRAWALS AND CONSUMPTION IN THE CONTERMINOUS U.S.

The U.S. water-resource regions most vulnerable to climate change are the Great Basin, California, Missouri, Arkansas, Texas Gulf, Rio Grande, and Lower Colorado.

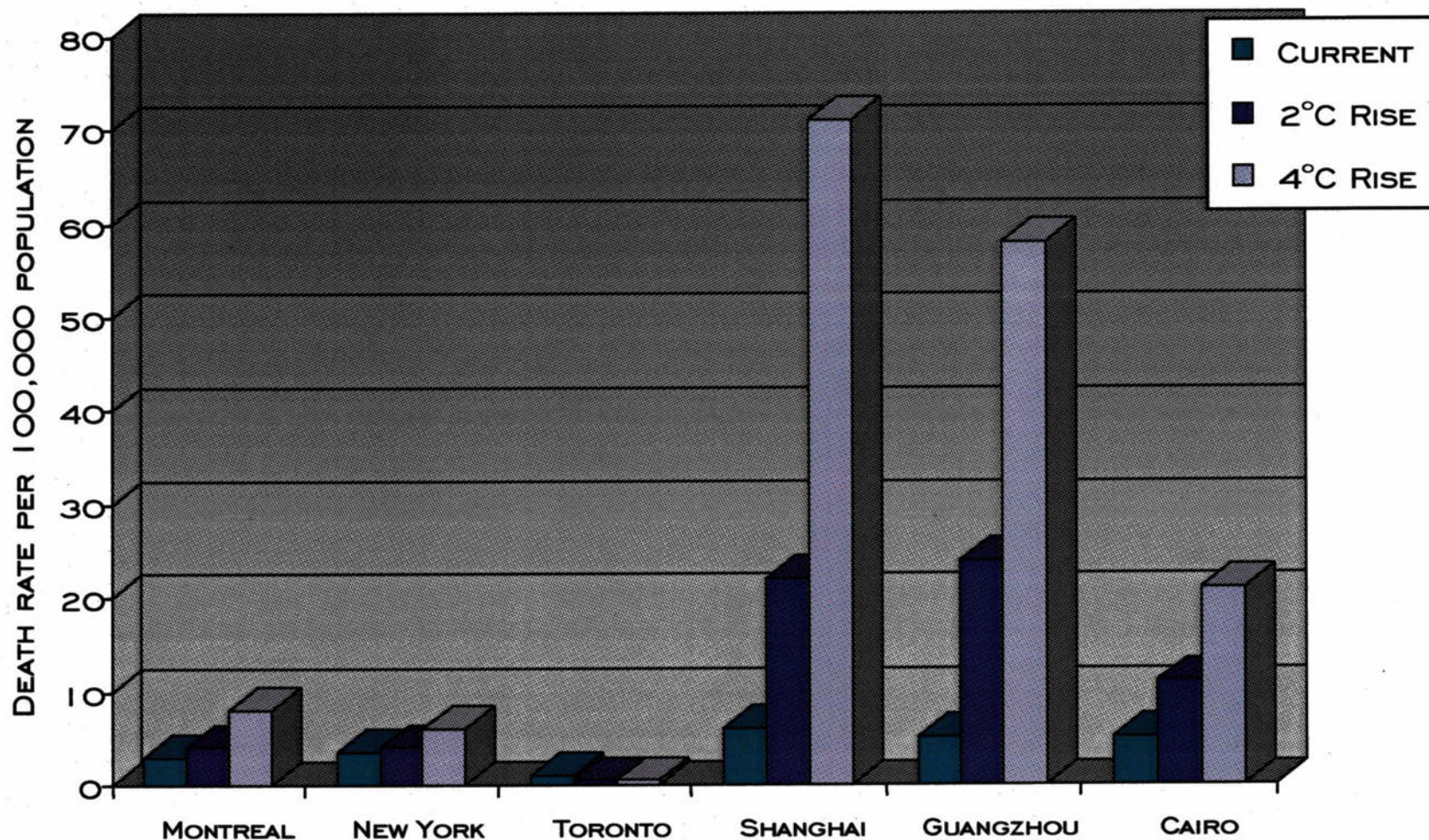


CONSUMPTIVE USE / RENEWABLE WATER SUPPLY  
(BILLIONS OF GALLONS PER DAY)

0 - 10 %    10 - 40 %    40 - 100 %



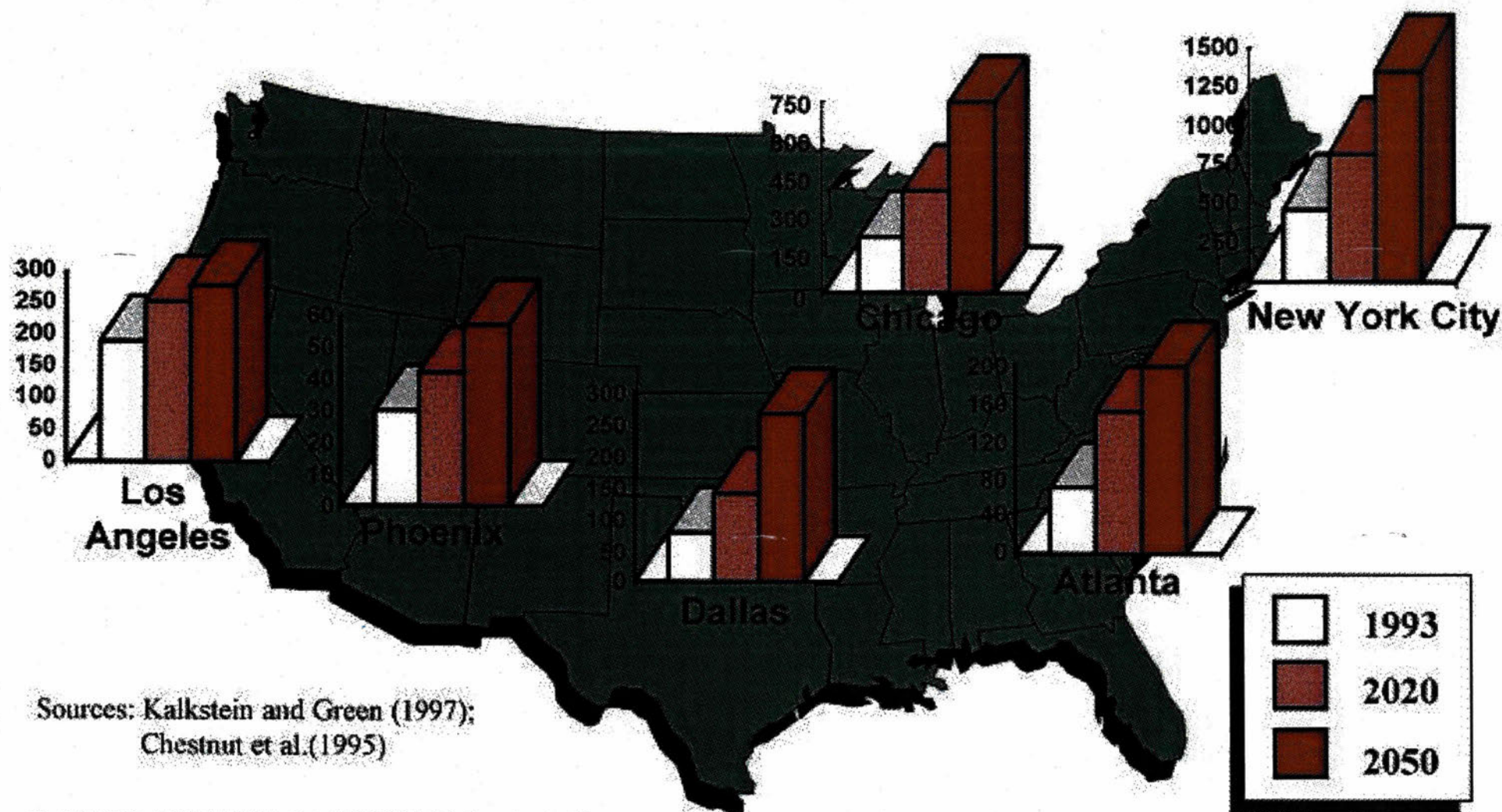
# HUMAN HEALTH: HEAT-RELATED MORTALITY RATES FOR 6 LARGE CITIES



SOURCE: STRZEPAK AND SMITH (1995)



# Average Annual Excess Weather-Related Mortality for 1993, 2020 and 2050 Climate



Sources: Kalkstein and Green (1997);  
Chestnut et al.(1995)

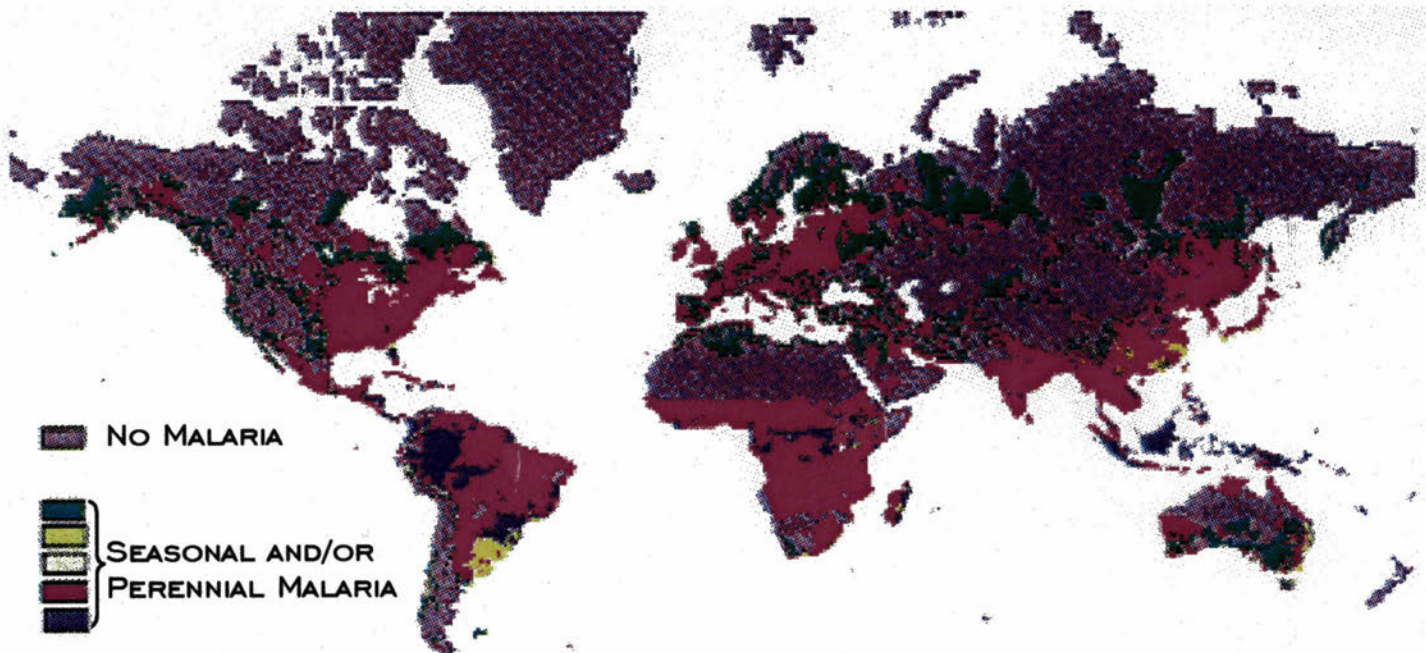
Note: Includes both summer and winter mortality.  
Assumes full acclimation to changed climate.  
Includes population growth.

GFDL Climate Change Scenario

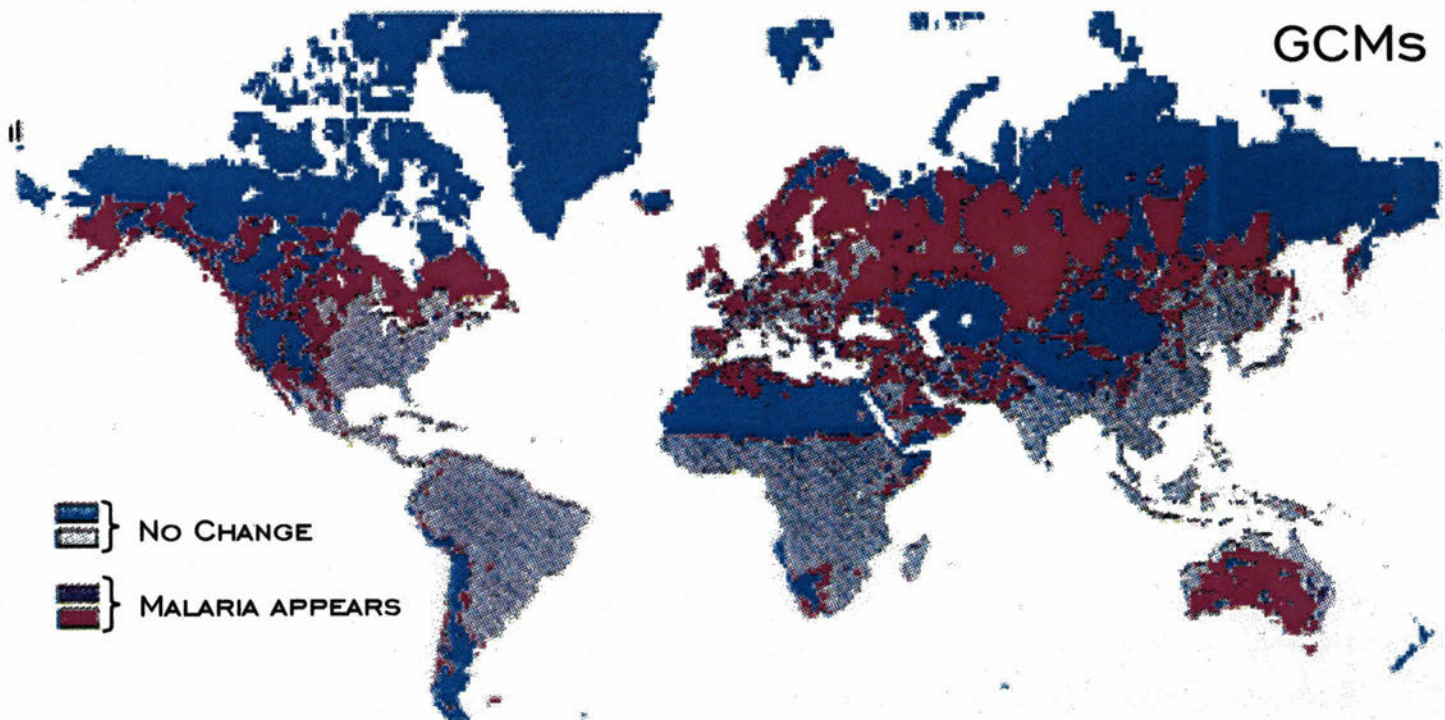


# THE EFFECT OF CLIMATE CHANGE ON WORLDWIDE MALARIA DISTRIBUTION

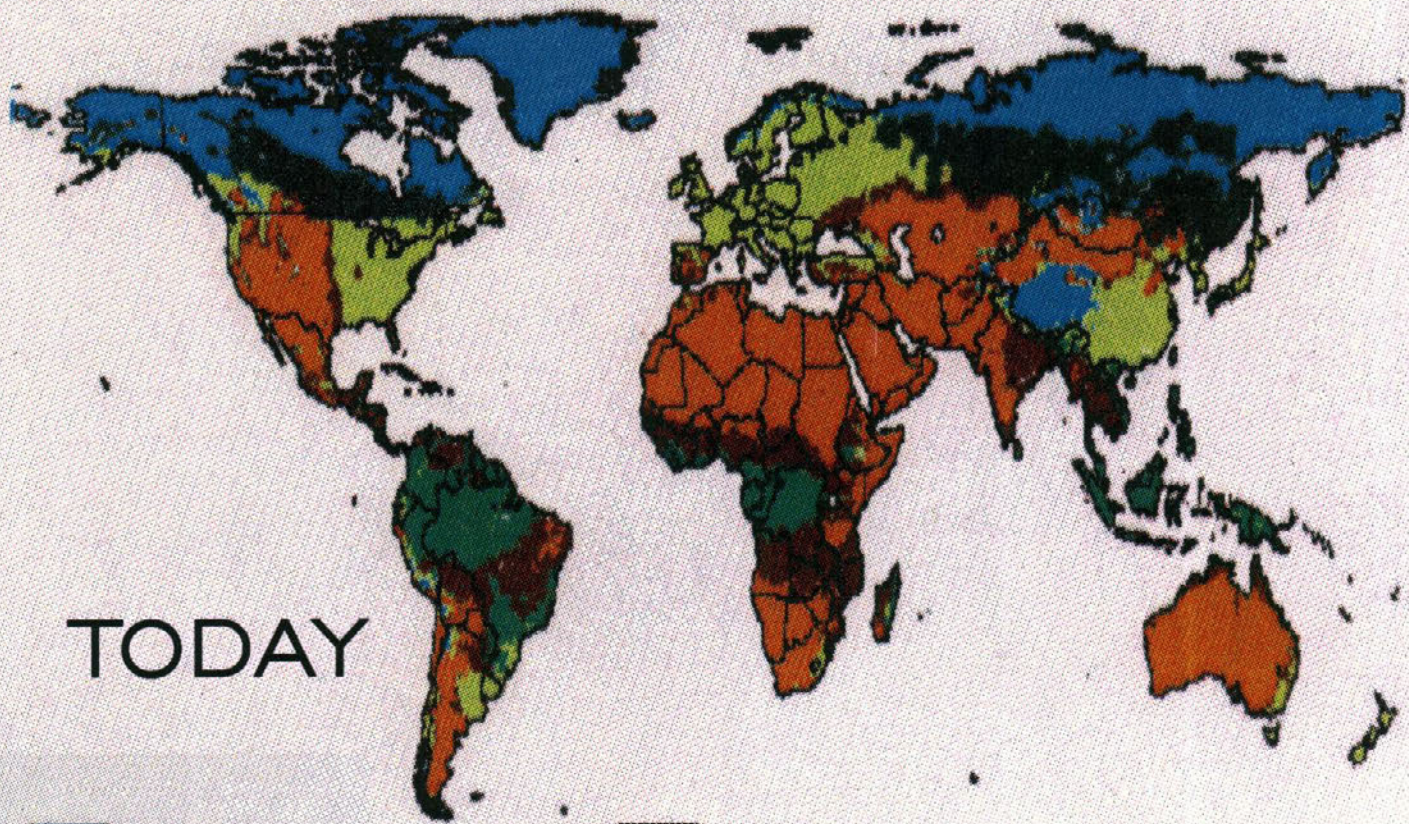
## CURRENT ANNUAL MALARIA POTENTIAL TRANSMISSION



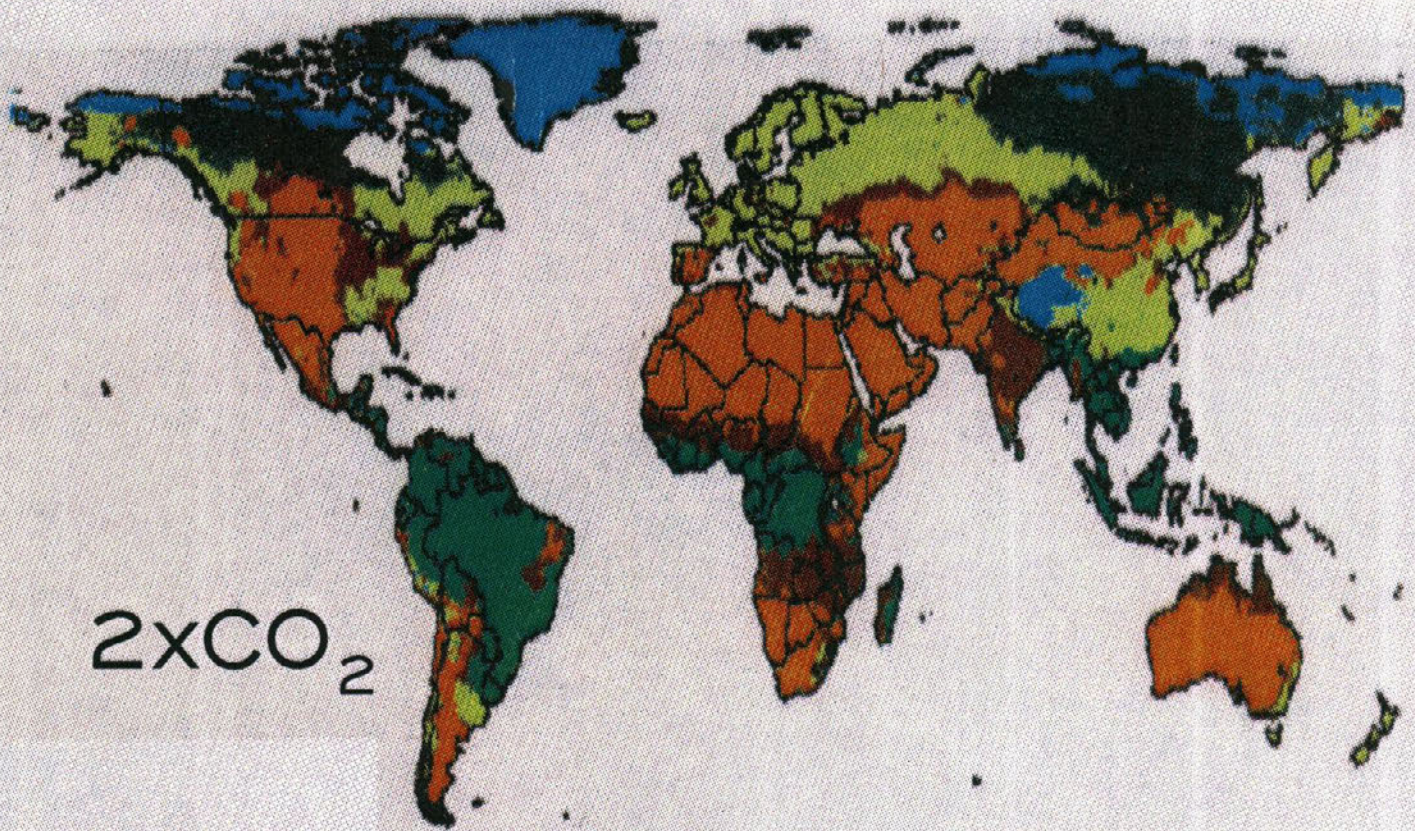
## CHANGES IN MALARIA POTENTIAL TRANSMISSION ACROSS GCMs







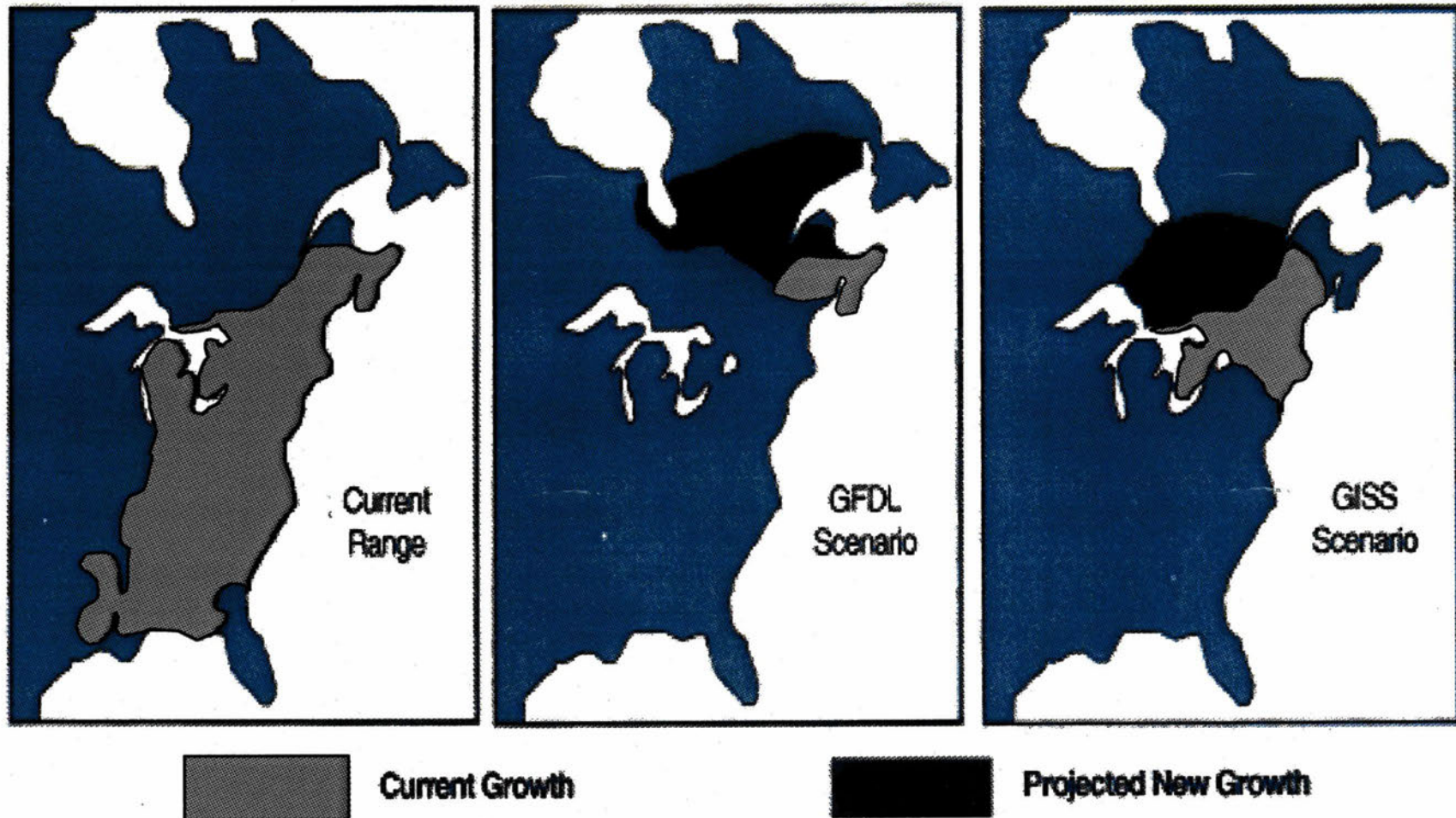
TODAY



2xCO<sub>2</sub>

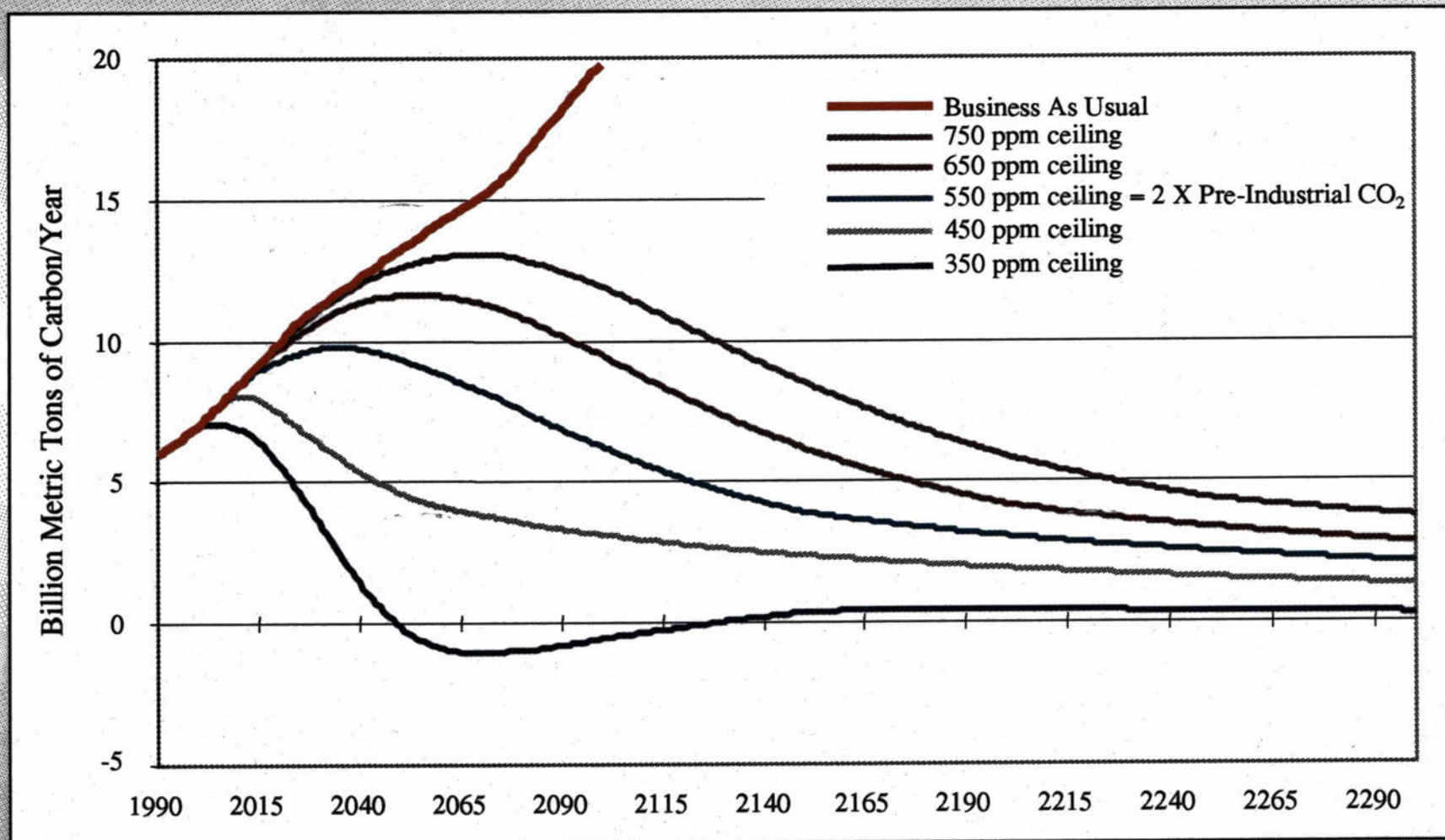


# CURRENT AND PROJECTED RANGES OF BEECH TREES IN THE U.S. UNDER TWO MODEL SCENARIOS



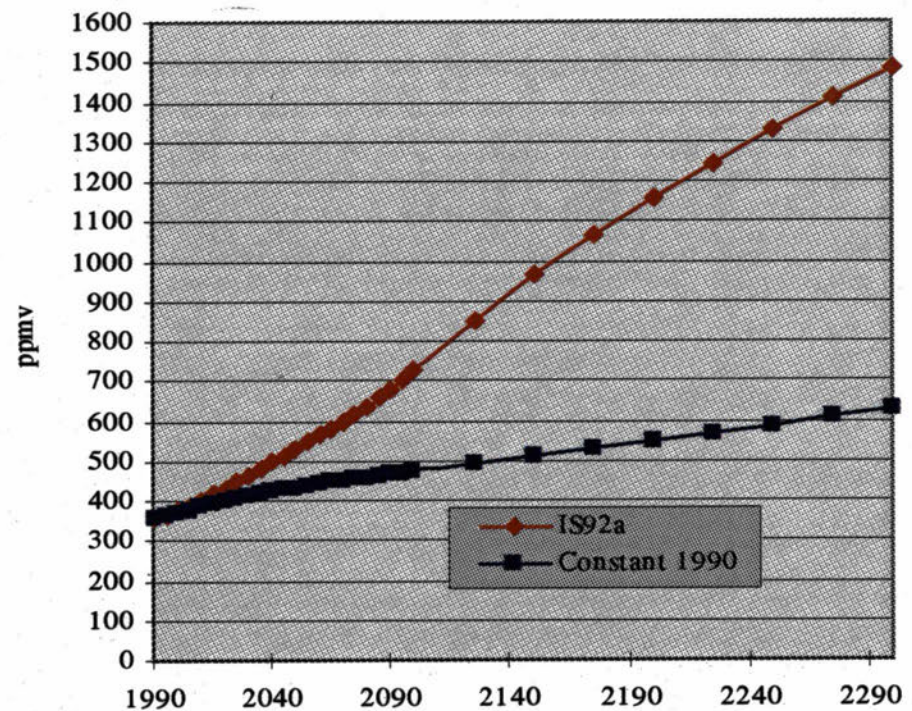
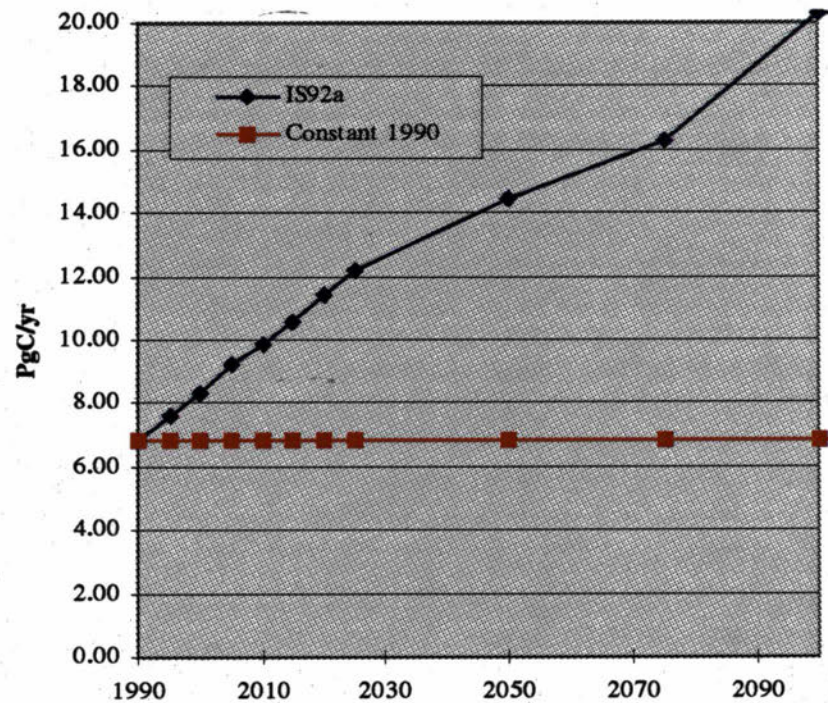


# ATMOSPHERIC STABILIZATION EMISSIONS PATHS

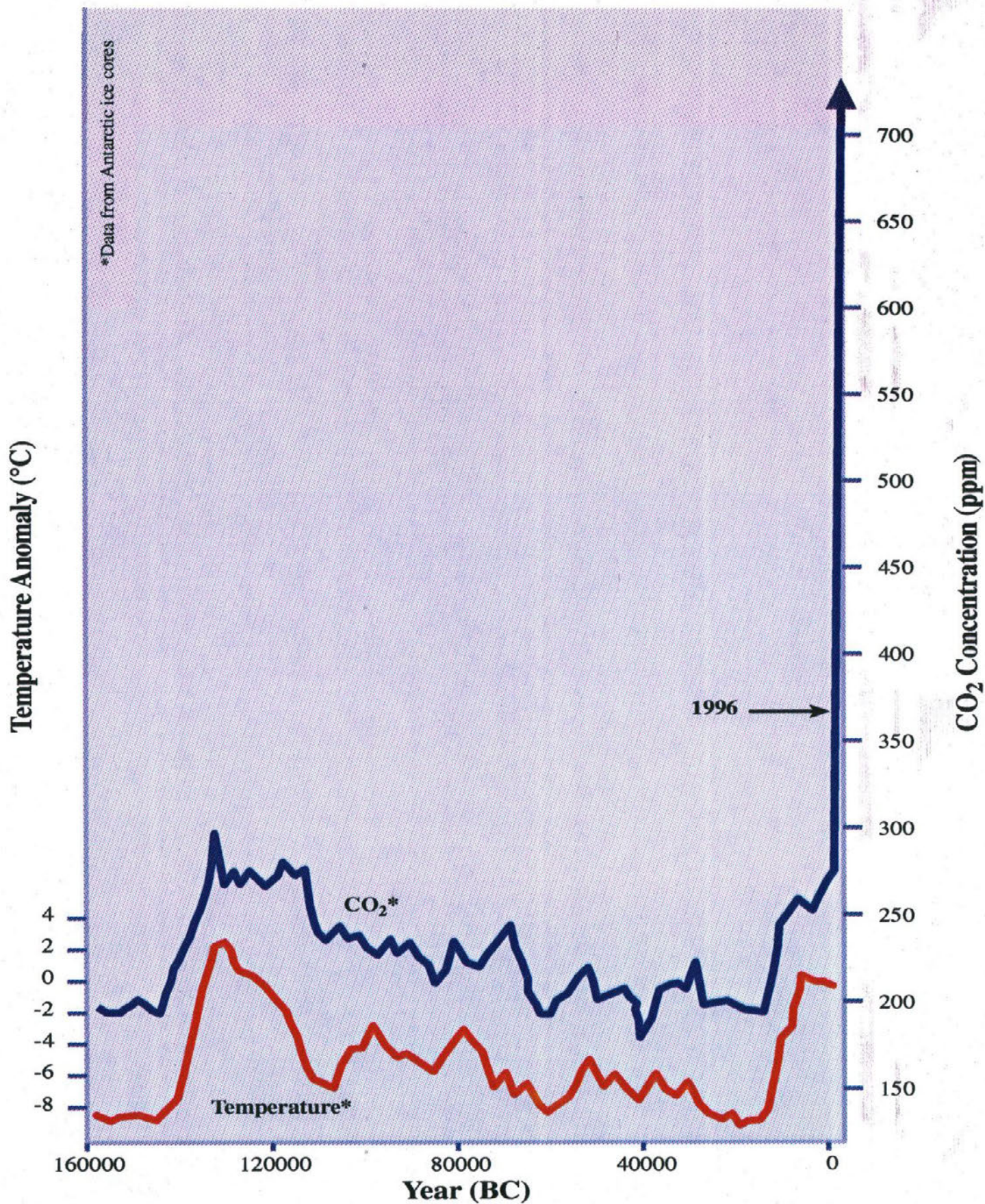




# Emissions & Concentrations



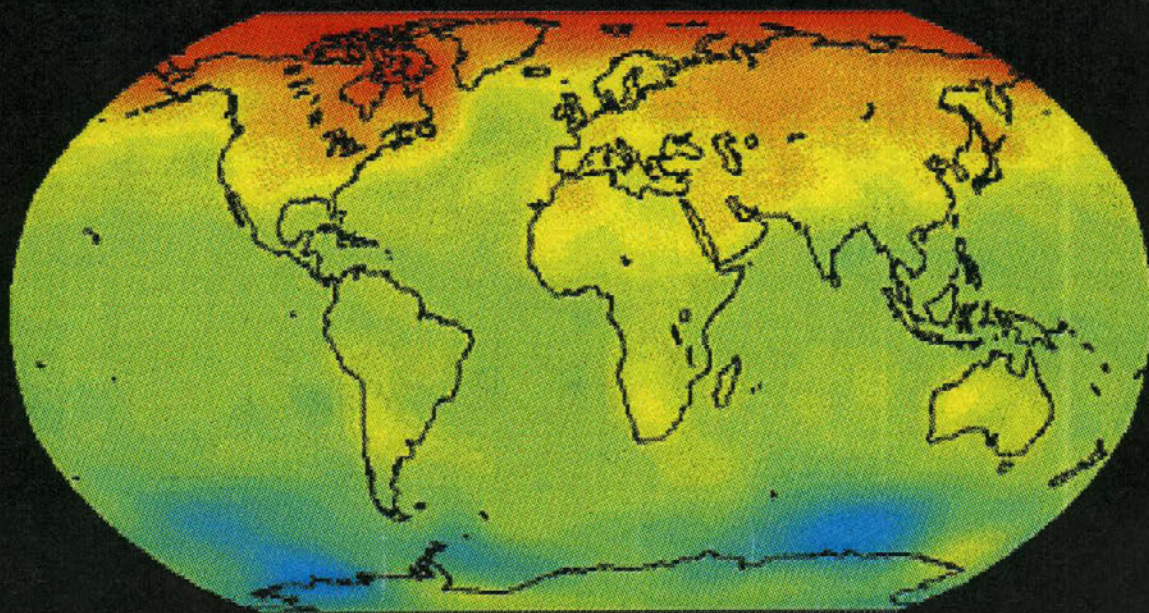




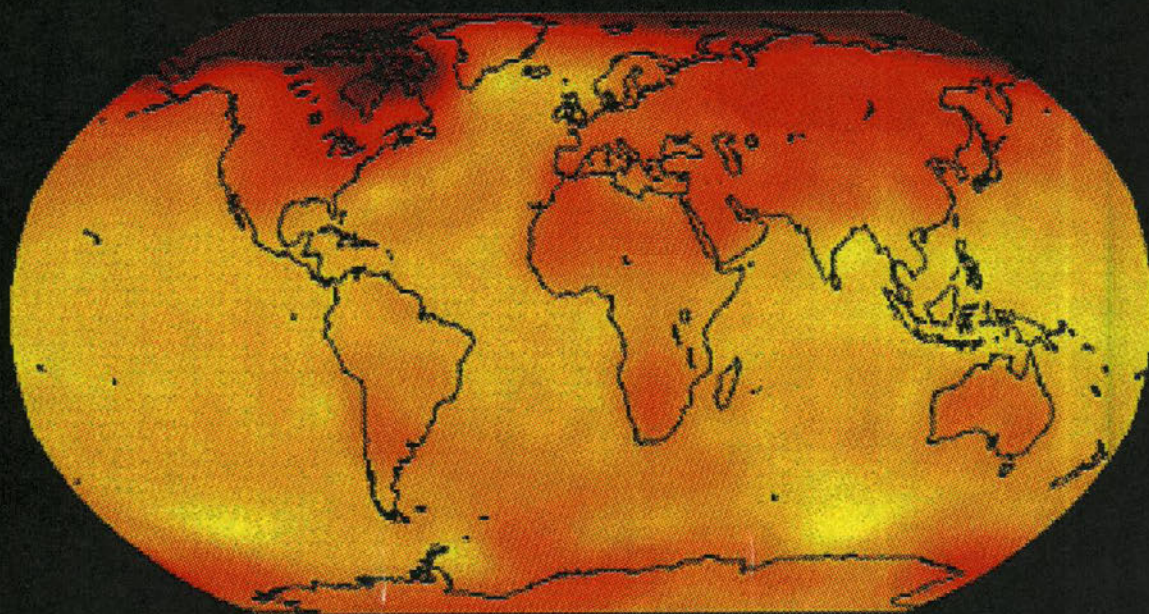


SURFACE AIR WARMING ( $^{\circ}\text{F}$ )

$2\times\text{CO}_2$



$4\times\text{CO}_2$

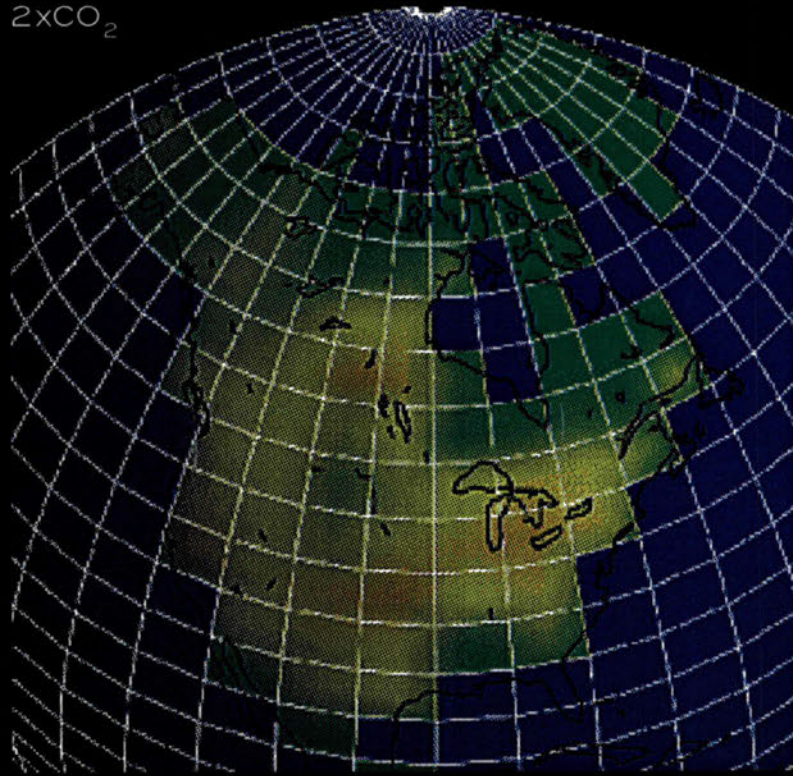


SOURCE: GFDL R15 CLIMATE MODEL;  $\text{CO}_2$  TRANSIENT EXPERIMENTS, YEARS 401-500

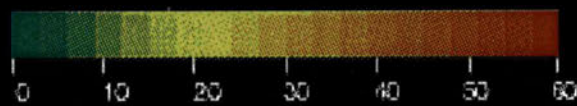
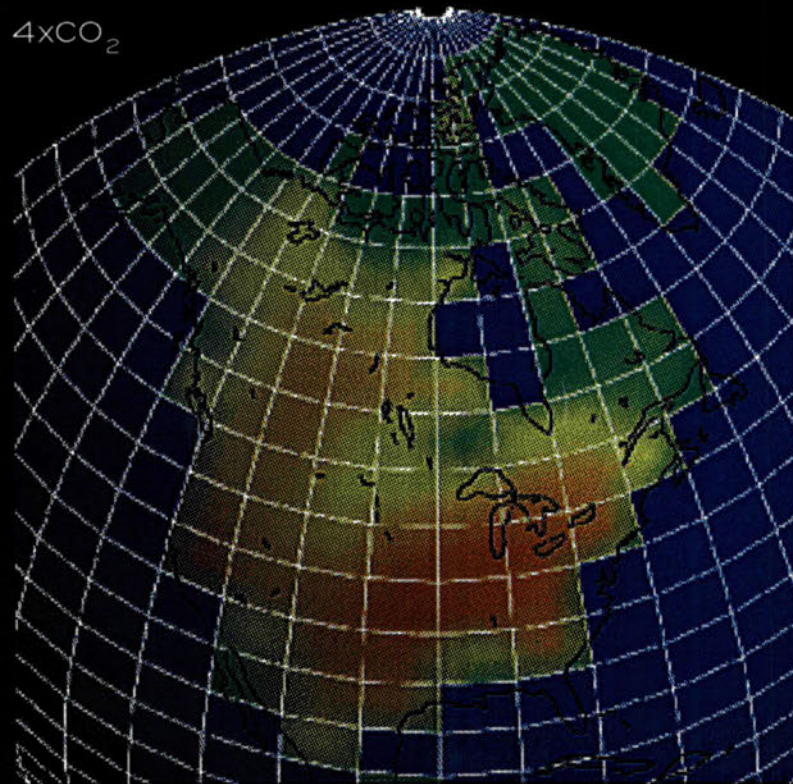


PERCENT REDUCTION IN JUNE-AUGUST SOIL MOISTURE

2xCO<sub>2</sub>



4xCO<sub>2</sub>





# Climate Change

July  
1996

## State of Knowledge

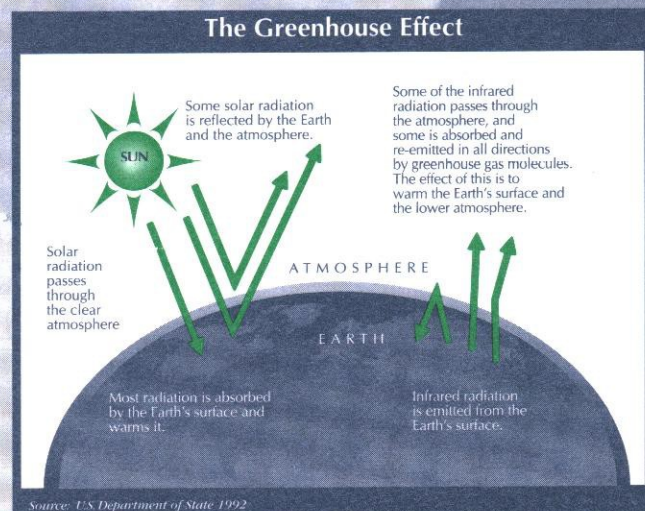
The Earth's climate is predicted to change because human activities are altering the chemical composition of the atmosphere. The buildup of greenhouse gases—primarily carbon dioxide, methane, nitrous oxide and chlorofluorocarbons—is changing the radiation balance of the planet. The basic heat-trapping property of these greenhouse gases is essentially undisputed. Although there is considerable scientific uncertainty about exactly how and when the Earth's climate will respond to enhanced greenhouse gases in the future, observations indicate that detectable changes are underway. 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 about 33°C (60°F) warmer than it otherwise would be. Without this greenhouse effect, 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, populations, technologies and other factors. The United States and the rest of the OECD countries currently

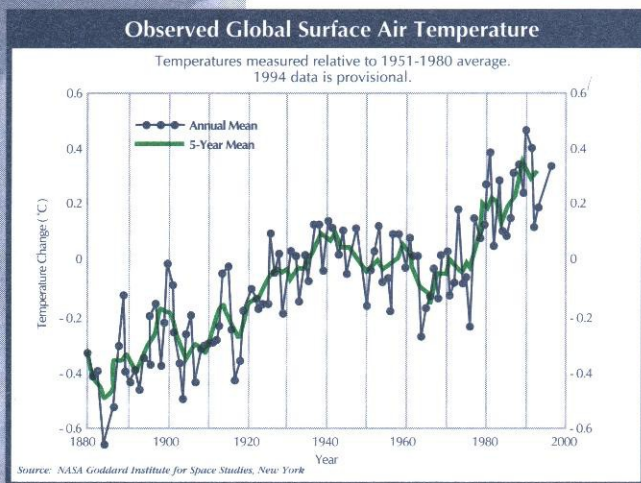


contribute about 40 percent of global carbon dioxide emissions. Future growth in emissions from OECD countries is predicted to be significantly smaller than growth in developing countries and countries with economies in transition.

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. These increases result in a radiative forcing or heat-trapping of energy equivalent to about 2.8 watts per square meter ( $\text{Wm}^{-2}$ ). About half of the radiative forcing may have been masked by increased levels of traditional air pollutants—sulfates and carbonaceous aerosols, particularly in the northern hemisphere—which cool the atmosphere by reflecting incoming solar radiation and altering 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. In addition, due to their health effects, buildup will likely be limited. Calculations suggest that the projected increases in atmospheric concentrations of greenhouse gases alone will result in an additional radiative forcing of about  $3\text{--}8 \text{ Wm}^{-2}$  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 1.0 - 3.5°C (1.8-6.3°F) by 2100, with significant variation by region. This estimate accounts for the offset from aerosols, which has lowered earlier estimates somewhat. 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 United States and high latitudes are projected to warm more than the global average, especially as sulfate aerosol loading is decreased.

Model calculations also suggest that the rate of evaporation will increase as the climate warms, leading to an increase in average global precipitation. Although 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 15 to 95 centimeters (6 to 38 inches) by the end of the next century, due primarily to the thermal expansion of the oceans and the melting of glaciers.

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 some 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°C (0.54 and 1.08°F) since the late 19th century, despite marked regional, seasonal and diurnal differences, raising the decade global temperatures to the highest level in this century.

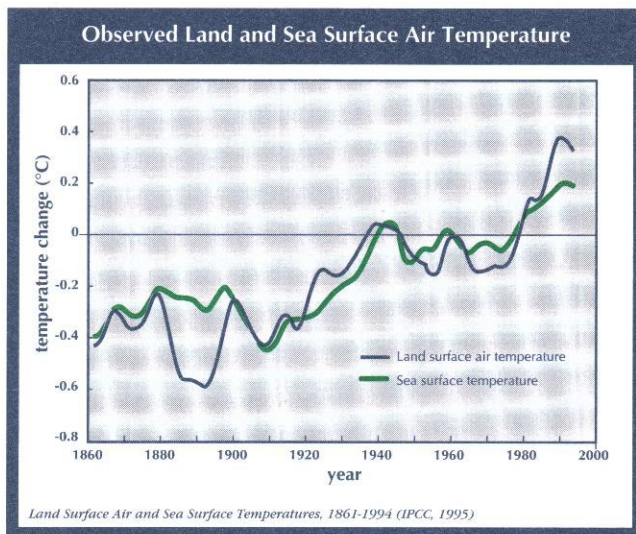
The ten warmest years this century have all occurred since 1980. 1995 was the warmest year on record, suggesting the atmosphere has rebounded from the transient cooling of 0.5°C (0.9°F) caused by the eruption of Mt. Pinatubo and simulated by the models.

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 been corroborated. The frequency of extreme rainfall events also has increased throughout much of the country, suggestive of an intensification of the hydrologic cycle.

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. Analyses of the geographical and vertical patterns of change give us more confidence that we are beginning to detect a human-induced signal despite natural climate variability. The IPCC concludes "the balance of evidence suggests a discernible human influence on global climate."

Carbon cycle models imply that limiting atmospheric concentrations of carbon dioxide 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 the eventual reductions would have to be in order to stabilize concentrations at a given level.

Although 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 and land ecosystems.





# Projected Impacts of Climate Change

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. Developing countries are more vulnerable than developed countries to climate change because of their socioeconomic conditions.

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. With time, more efficient responses can be developed for these sectors. By comparison, fewer options can be identified for natural systems (such as wetlands and wilderness areas).

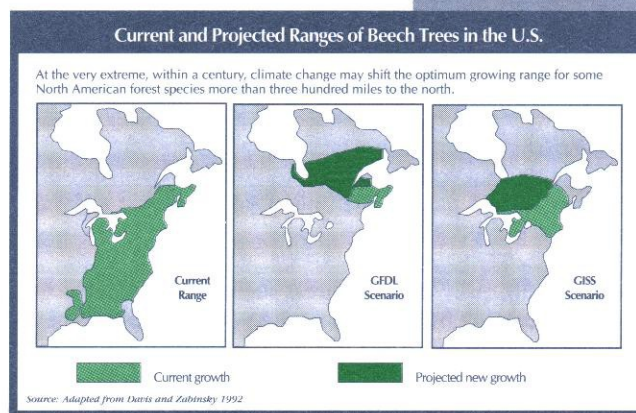
Natural ecosystems will be degraded because the composition, geographic distribution and productivity of many ecosystems will change as individual species respond to changing climate. This will likely lead to reductions in biological diversity and in the goods and services ecosystems can provide for society.

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.

One of the consequences of global climate change may be increases in the frequency of some extreme weather events, particularly droughts and floods. Of course, we cannot unambiguously relate climate change to specific events. However, these events, when they do occur, can be costly. For example:

- Since 1992, 15 weather-related disasters in the United States have cost \$70 billion in damages and several hundred deaths from floods, heat waves, hurricanes, blizzards and hail storms.
- 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:



## Health

Human health will be adversely affected through an increase in the rate of heat-related mortality and in the potential for the spread of vector-borne diseases such as malaria, dengue fever, yellow fever and encephalitis and non-vector borne-diseases such as cholera and salmonellosis.

There will likely be increased risk of malaria and dengue fever 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.

## Water Resources

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 United States 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 also is likely to be exacerbated by climate change.



## Coastal Resources

A 50 centimeters (20 inches) rise in sea level by the year 2100, which is within the range projected by the IPCC, could inundate more than 5,000 square miles of dryland and an additional 4,000 square miles of wetlands in the United States 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 United States 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. This would create large numbers of environmental refugees which would put stress on governments and social structures.

## Agriculture

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

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

Food scarcity is threatened in some regions of the world, especially in the tropics and subtropics, where many of the world's poorest people live, even though the effects of climate change on total global food production may be small to moderate compared with the effects of population growth and increasing nutrition demands.

## Forests

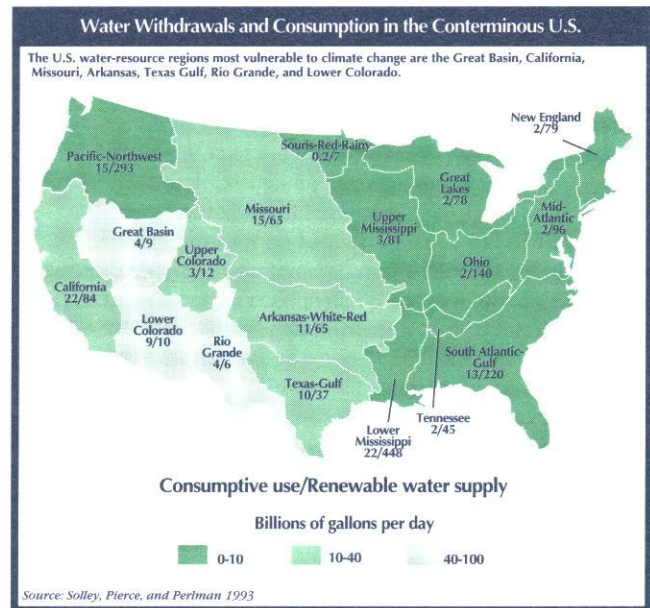
Climate change over the next several decades might shift the ideal range for some North American forest species by as much as 300 miles to the north, exceeding the ability of forests and other ecological communities to migrate.

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.

## Socio-Economic Analyses

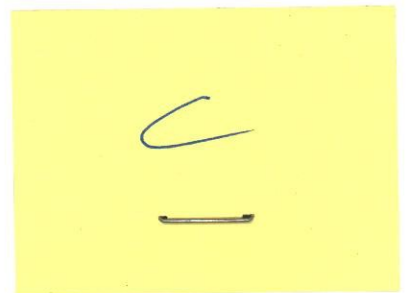
Socio-economic analyses of climate change also are making important contributions. A key insight is that a portfolio of actions aimed at mitigation, adaptation and improving our knowledge would be a prudent way to deal with climate change. It is important to allow activities to be adjusted periodically in light of new information. Another insight is that policy analysis and development must carefully consider both the potential costs of inaction in terms of impacts, as described in the previous section, and the potential economic



costs associated with measures to reduce greenhouse gas emissions.

From the practitioners' perspective, qualitative insights from mitigation cost modeling studies are more important than the absolute numerical results. For example, specific approaches, designs and strategies may emerge as superior when evaluated using a variety of modeling frameworks. Several distinct methodologies are among the tools available to assist policy-makers in evaluating the potential costs associated with reductions in greenhouse gas emissions. These include: technology costing studies, economy-wide macroeconomic models and computable general equilibrium models. The various models each have strengths and weaknesses, and none by themselves can adequately portray the potential economic impacts associated with reductions in greenhouse gas emissions.

Analyses to date highlight the key role of technology innovation, capital stock turnover and capital productivity and their influence on mitigation costs. In addition, recent analyses also suggest that flexible approaches, including the possibility of optimizing reductions across countries and over time, have the potential to significantly reduce the costs of achieving any given mitigation objective.



Source: Office of Science and Technology Policy, 1996