



Climate Change and its Likely Consequences

**Presentation by Michael MacCracken to the
Legislative Commission on Global Climate Change
of the General Assembly of North Carolina**

4 April 2006

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Climate Institute
Washington DC*

*Photo taken from first
Apollo flight to the Moon,
December, 1968*

The World at Night Gives an Indication of the Global Extent of Human Influences



Fossil Fuels--coal, oil, and natural gas--provide about 80% of the world's energy and support the existing standard-of-living, ***but the release of CO₂ and other greenhouse gases is altering the climate***

Understanding and Projecting Climate Change is (arguably) the Most Difficult Scientific Challenge

- While rigorous physical and chemical conservation laws provide some insights, the problem also involves complex biological, technological, and sociological relationships and decisions
- We have only one “Earth”--we have only a limited record of the one path of many that it could have taken (and there are no close analogs to what is happening in the climate record)
- We are asked to project ahead for a century and more, and to do so at relatively fine time and space scales
- The problem we are dealing with is central to the operation and experience of society--it requires bridging science and society

“Uncertainty is inevitable, but risk is certain”--Pittock (2005)

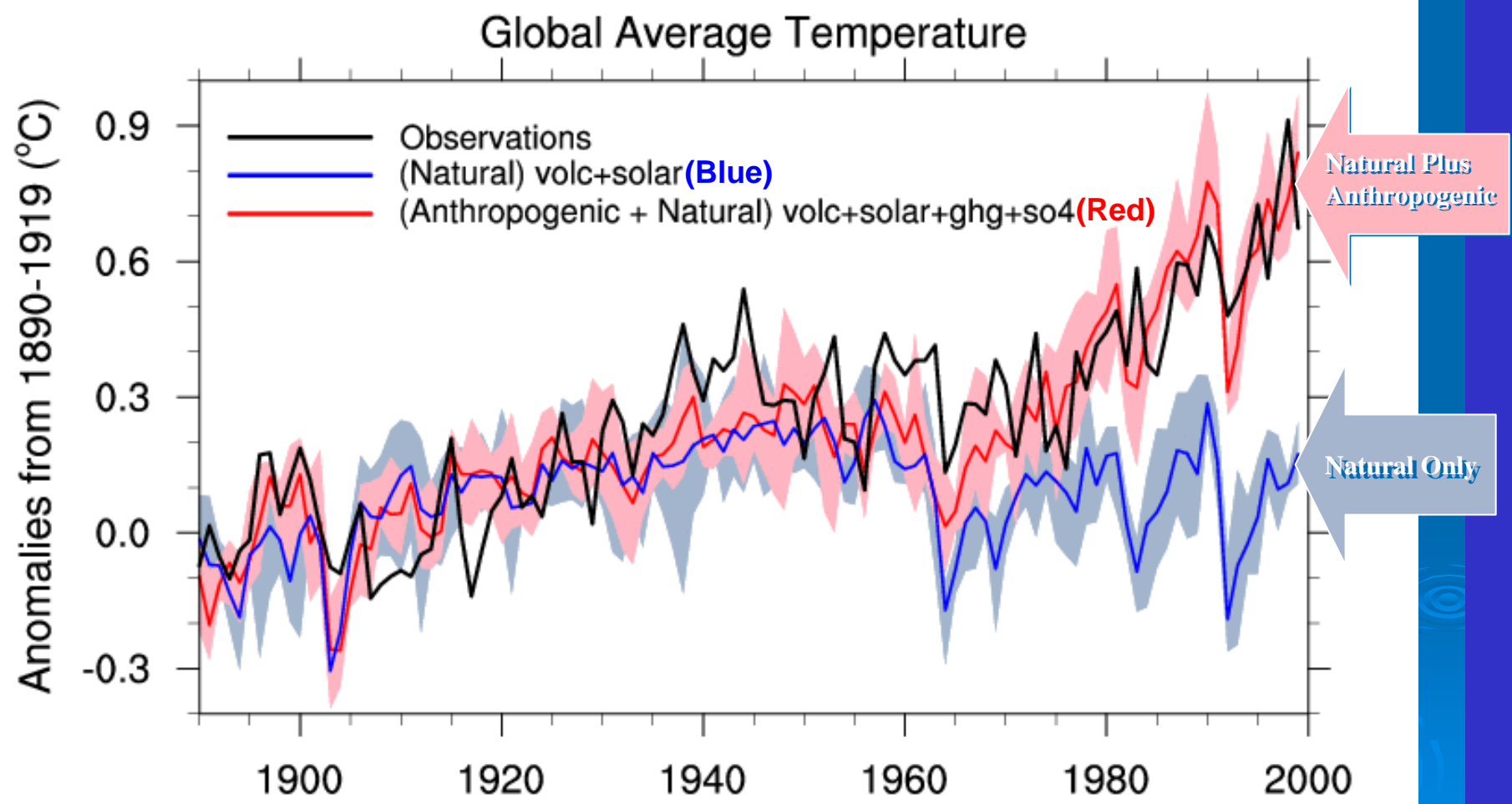
Scientific understanding has been summarized in the Intergovernmental Panel on Climate Change (IPCC), Arctic, and the US National Assessments

- The results presented here generally draw from the **periodic assessments** of the Intergovernmental Panel on Climate Change (IPCC) and similar widely reviewed reports.
- They represent the **consensus views of the most plausible explanations**, even though scientific uncertainties of various types remain and continue to be investigated.
- While science advances by resolving conflicts in observations and theory, government and business leaders, the public and other **decision-makers generally decide what to do based on relative likelihood**--not absolute certainty.

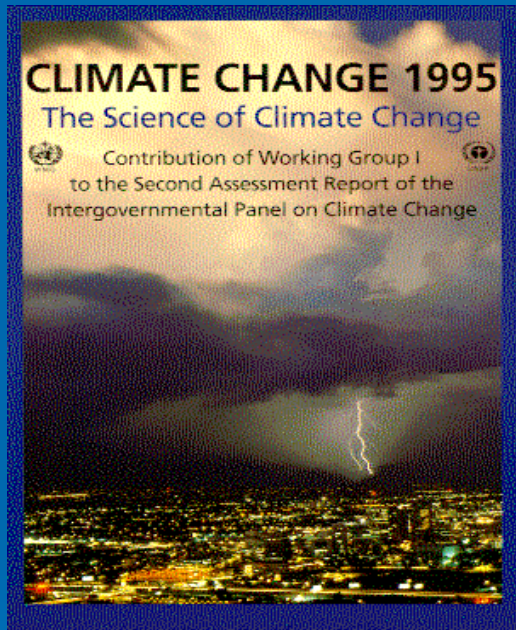
Six Key Findings Summarize the Last 100 Years of Research on Climate Change (i.e., “Global Warming”)

- 1. Emissions from human activities are changing atmospheric composition**
- 2. Enhancing the natural greenhouse effect will lead to long-term global warming**
- 3. Changes in the climate are already evident, and consistent with a human influence**
- 4. Future warming is projected to be substantial**
- 5. The environment and society will both be impacted**
- 6. Substantially slowing the ongoing change will require substantial early actions, with payoffs coming mainly after several generations**

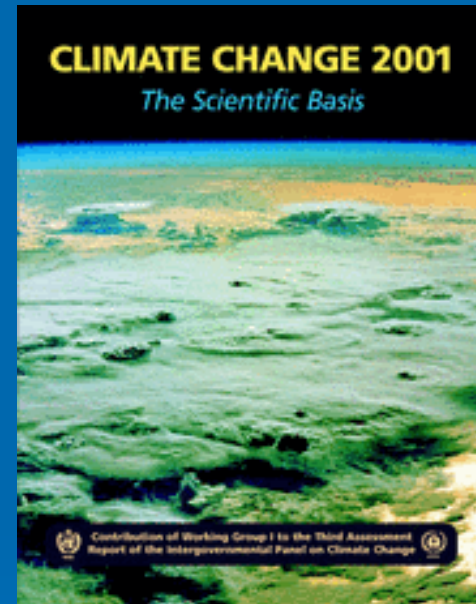
Model simulations of the 20th C indicate that human influences are the cause of the late-century warming



The IPCC Has Concluded that the Evidence for Human Influences on Climate is Getting Stronger



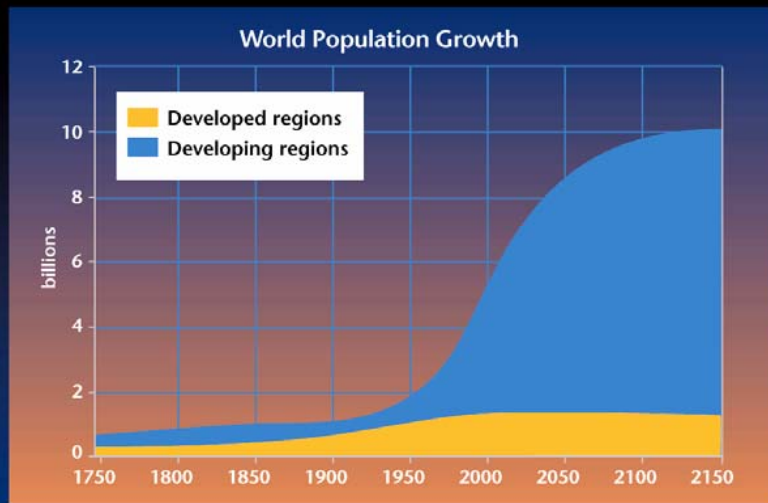
“The balance of evidence suggests a discernible human influence on global climate”



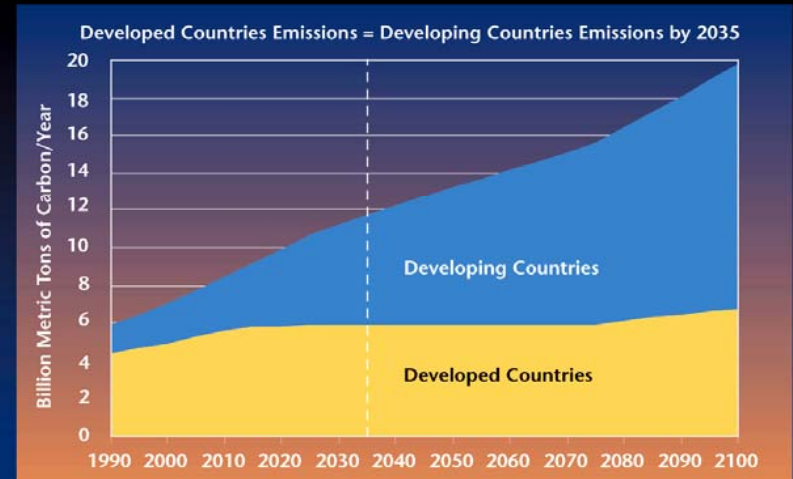
“There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities”

The continued increase in global population and use of fossil fuels is projected to global CO₂ emissions to increase by a factor of >1 to 4, depending on population increase, technology advances, and international cooperation

Population and Human Development



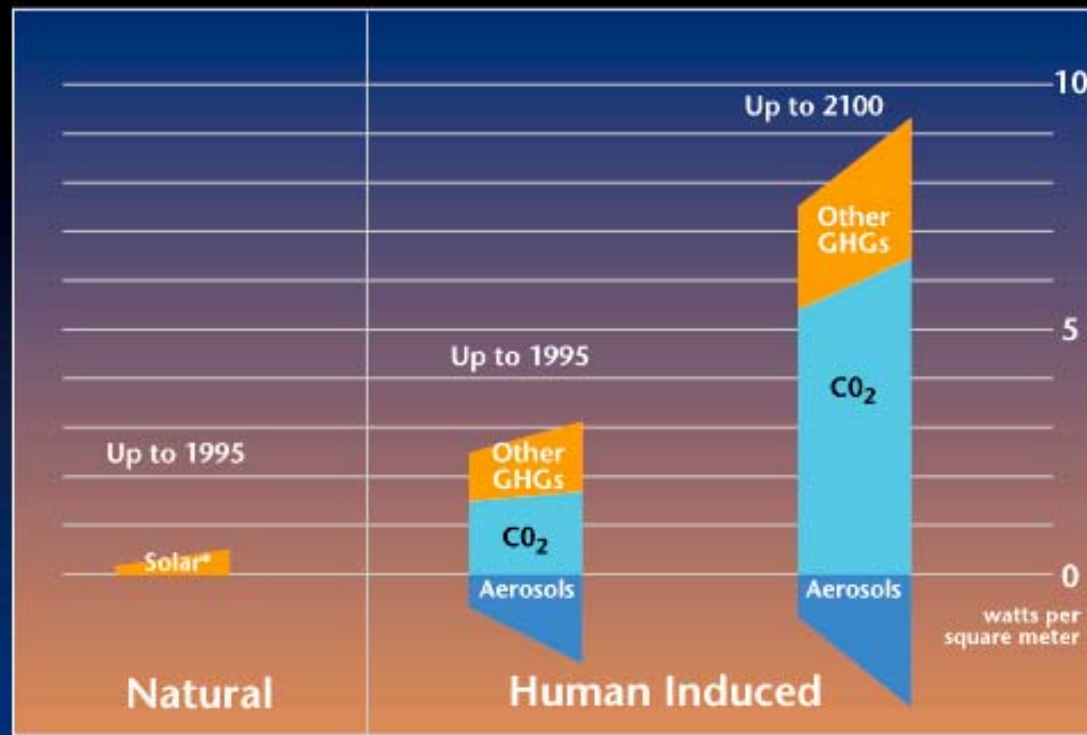
Developed and Developing World CO₂ Emissions, 1990-2100



Past emissions came primarily from developed countries, but future emissions will come primarily from developing countries--even though their per capita use will remain significantly less than in the developed nations

Mid-range emission scenarios for 2100 project that human-induced radiative forcing will greatly exceed natural and pre-21st century increments

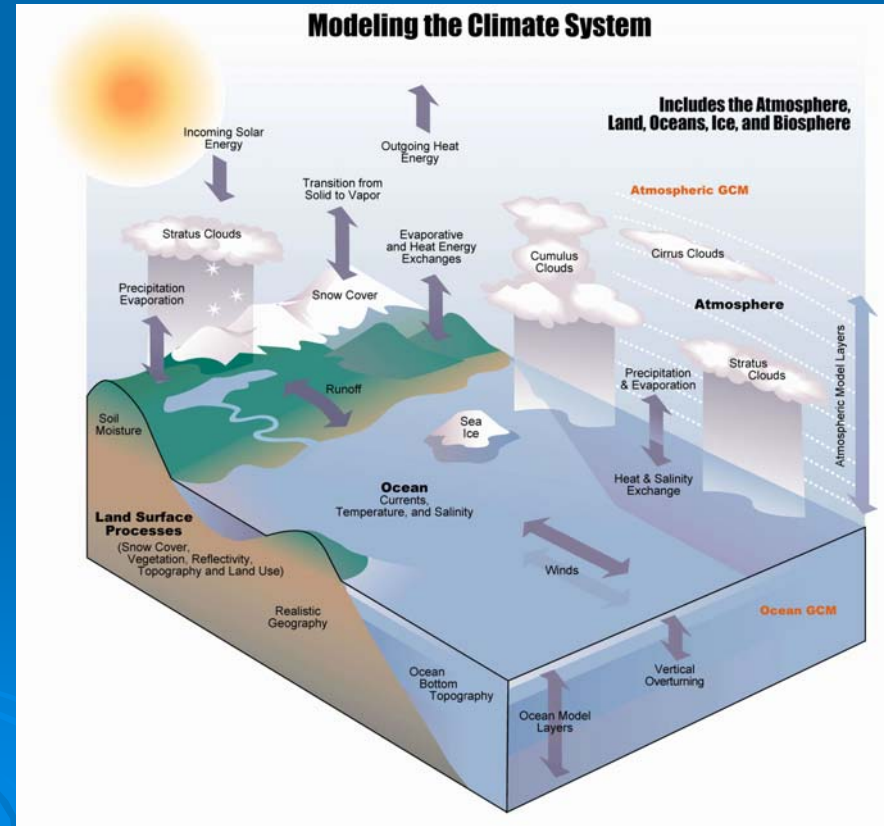
Radiative Forcing from Pre-Industrial Times



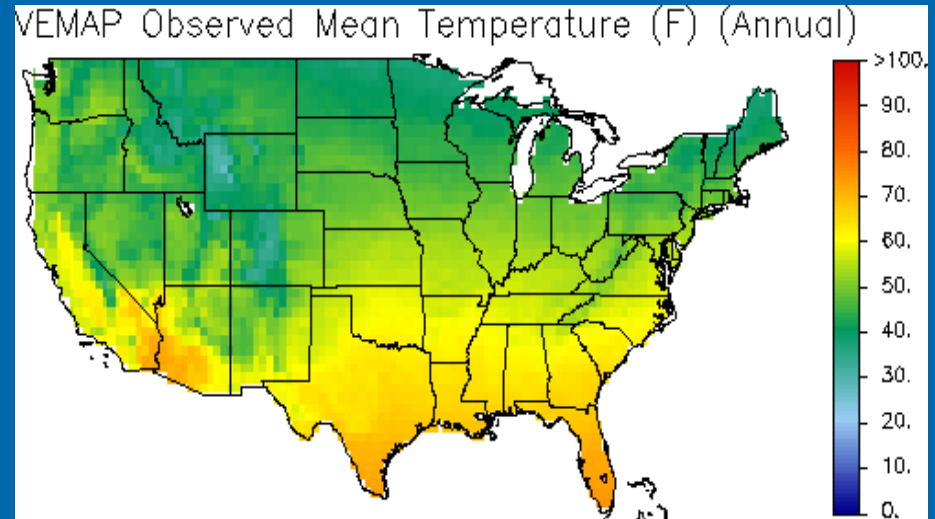
The Earth has yet to fully adjust to the effects of pre-1995 emissions-- and now 21st century forcing will be much larger!

Although other approaches provide supporting results, only climate models can be used to project the likely changes from this global “geophysical experiment”

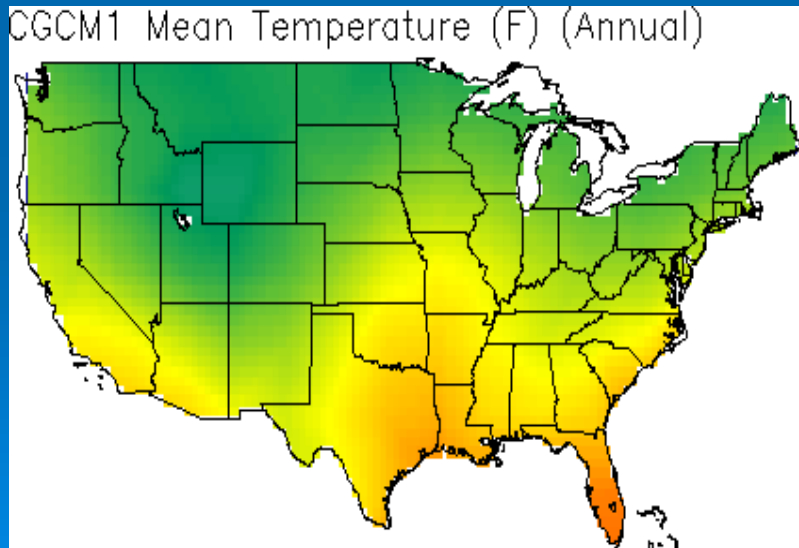
- 1. Laboratory and field experiments are too limited
- 2. Mathematical analyses must greatly simplify the Earth system
- 3. Analogs from the past are suggestive, but insufficiently similar to the current situation
- 4. Trend extrapolation is difficult due to natural variability and the uniquely changing conditions
- 5. Numerical models are theoretical constructs, but can treat the expected types of changes



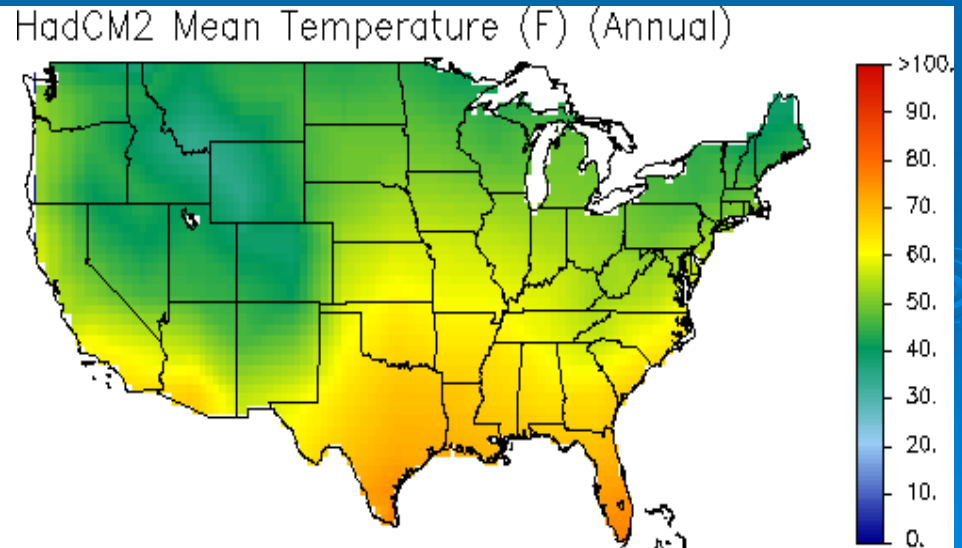
Climate models are, for example, reasonably able to represent the large-scale distribution of annual average temperature (°F) for the present climate



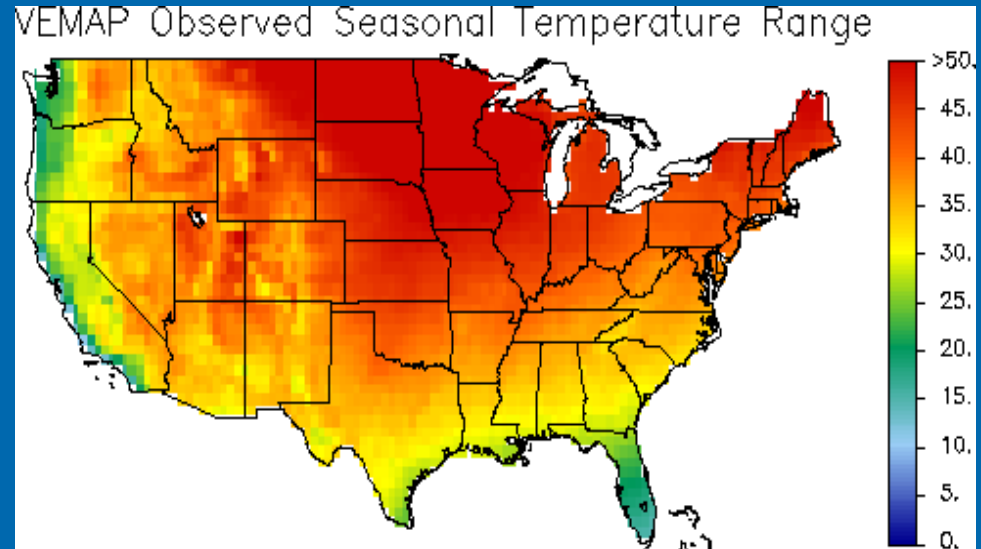
Canadian Model



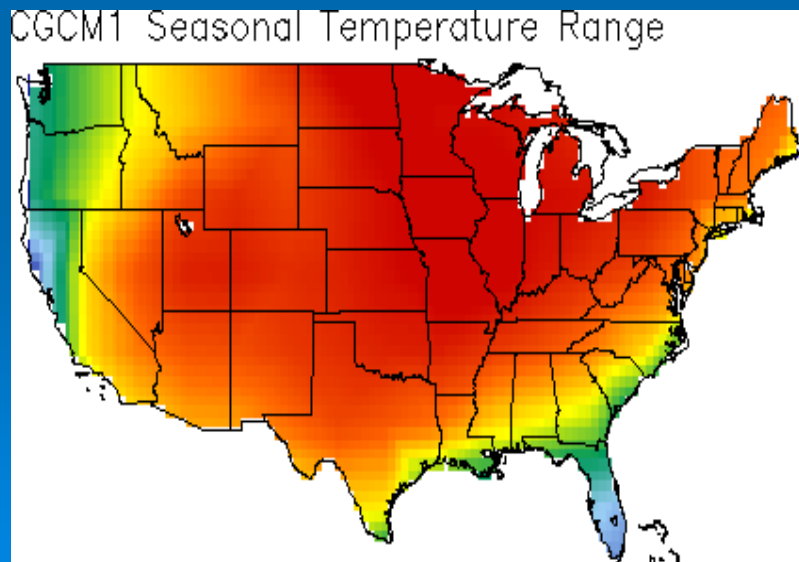
Hadley (UK) Model



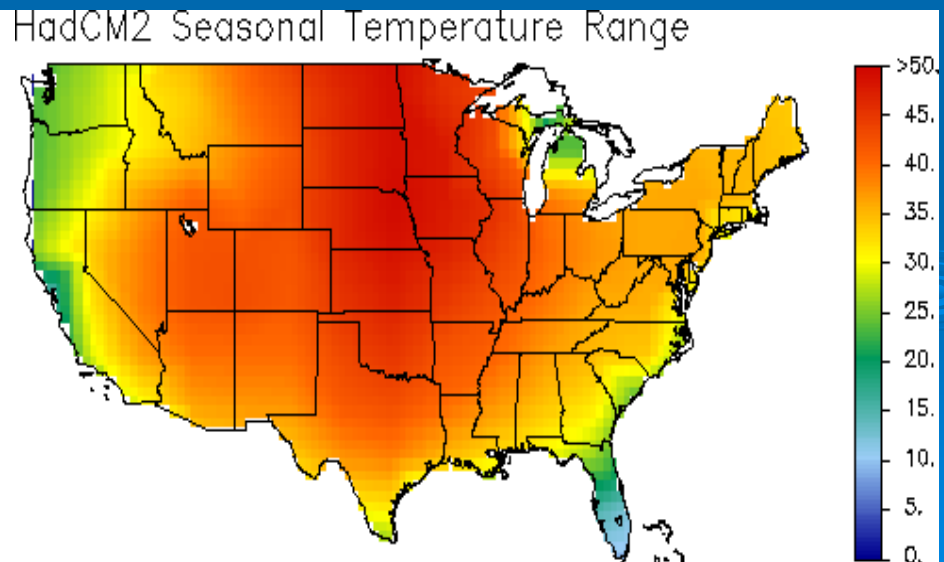
Climate models are also reasonably able to represent the seasonal temperature range (°F) for the present climate



Canadian Model

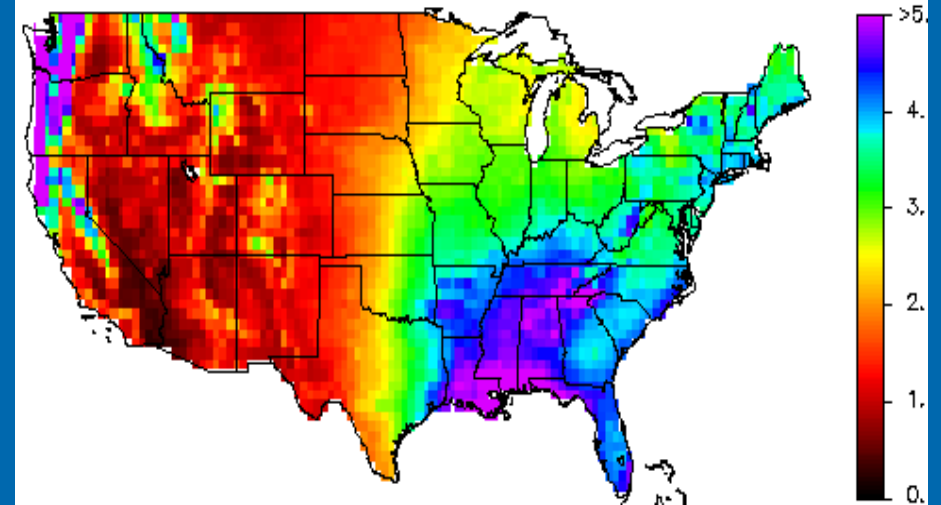


Hadley (UK) Model



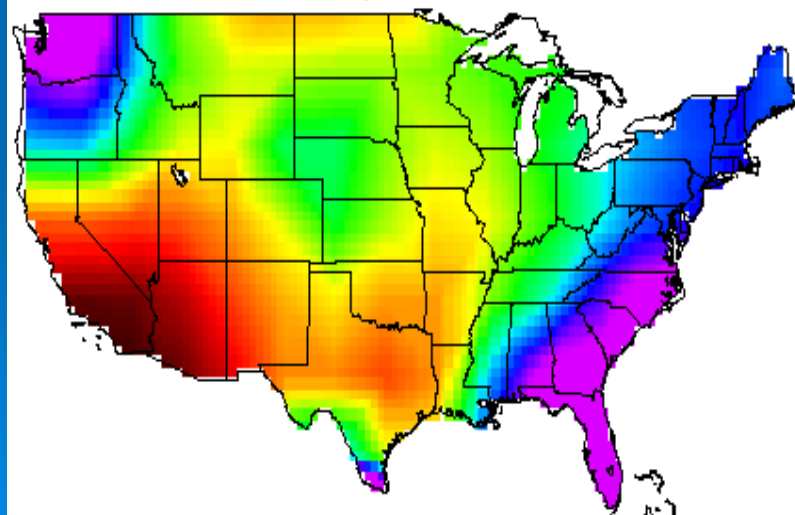
Climate models simulate some features of the monthly average precipitation (in./mo), but do not adequately resolve the complex effects of mountain ranges

VEMAP Observed Annual Precipitation



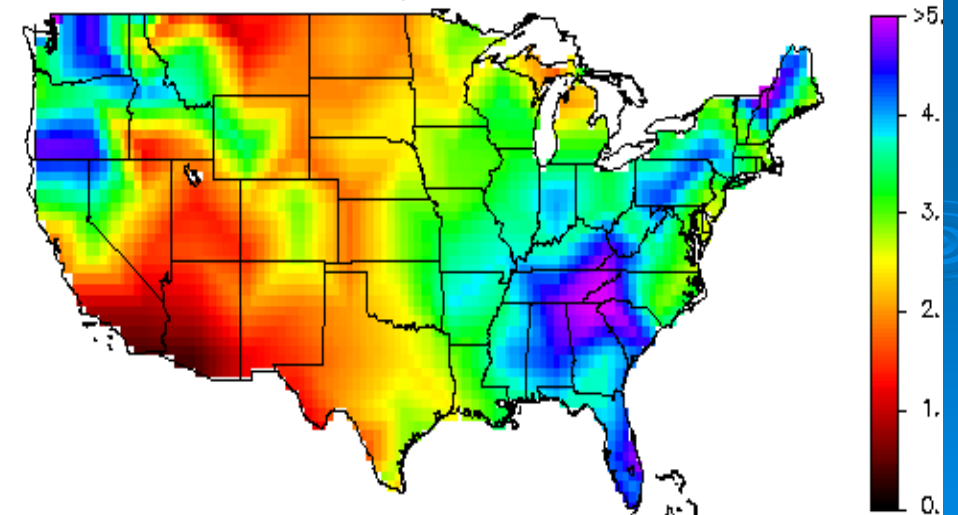
Canadian Model

CGCM1 Annual Precipitation

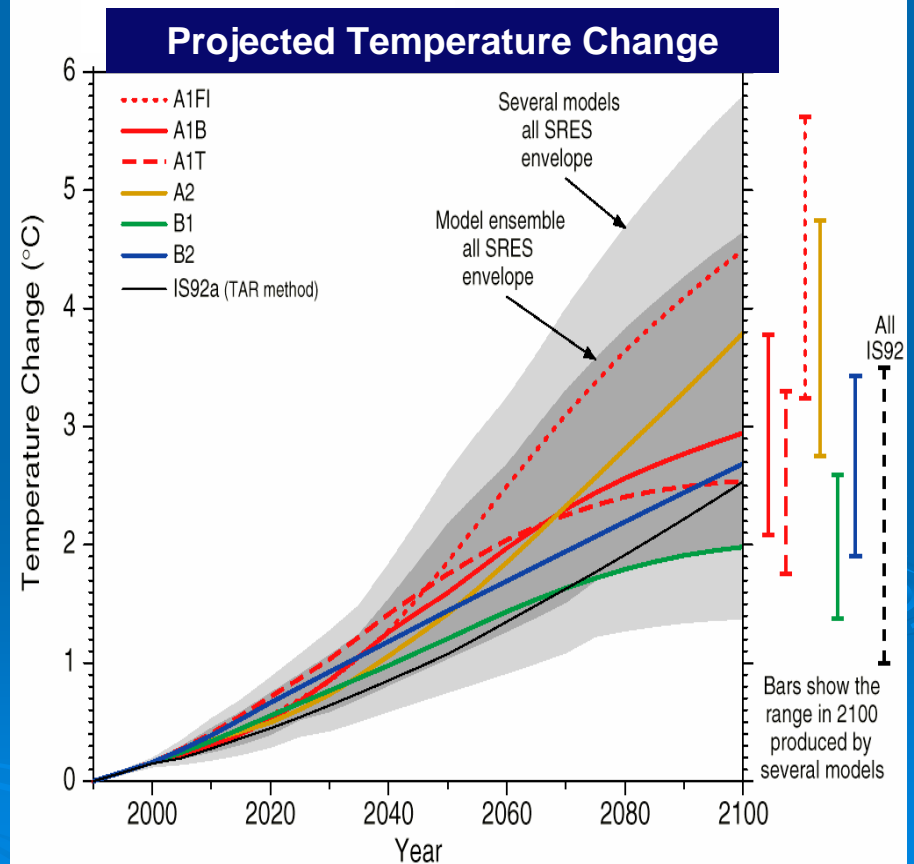
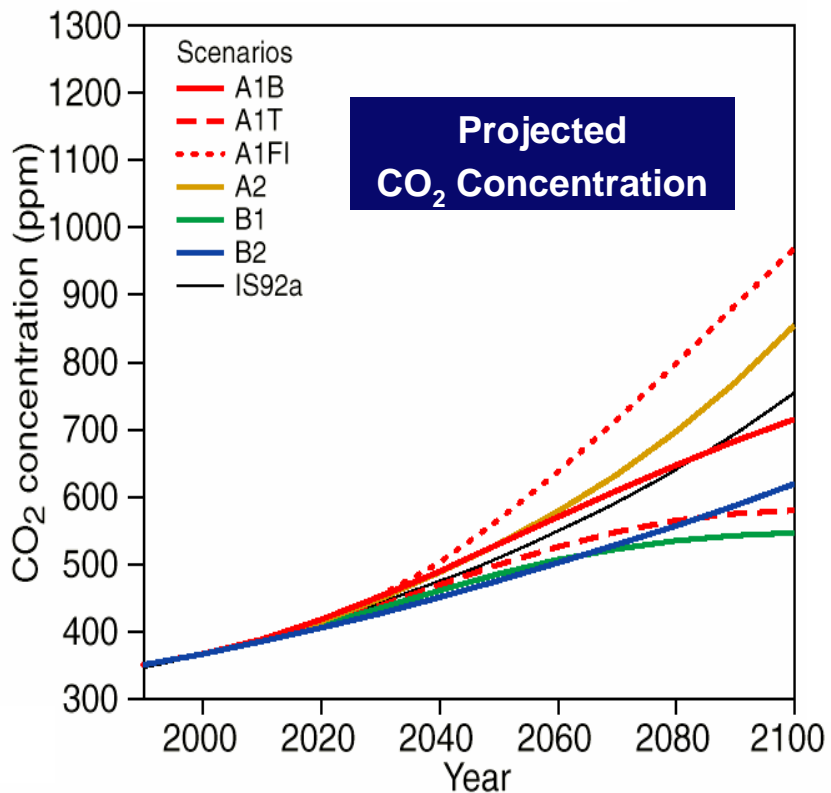


Hadley (UK) Model

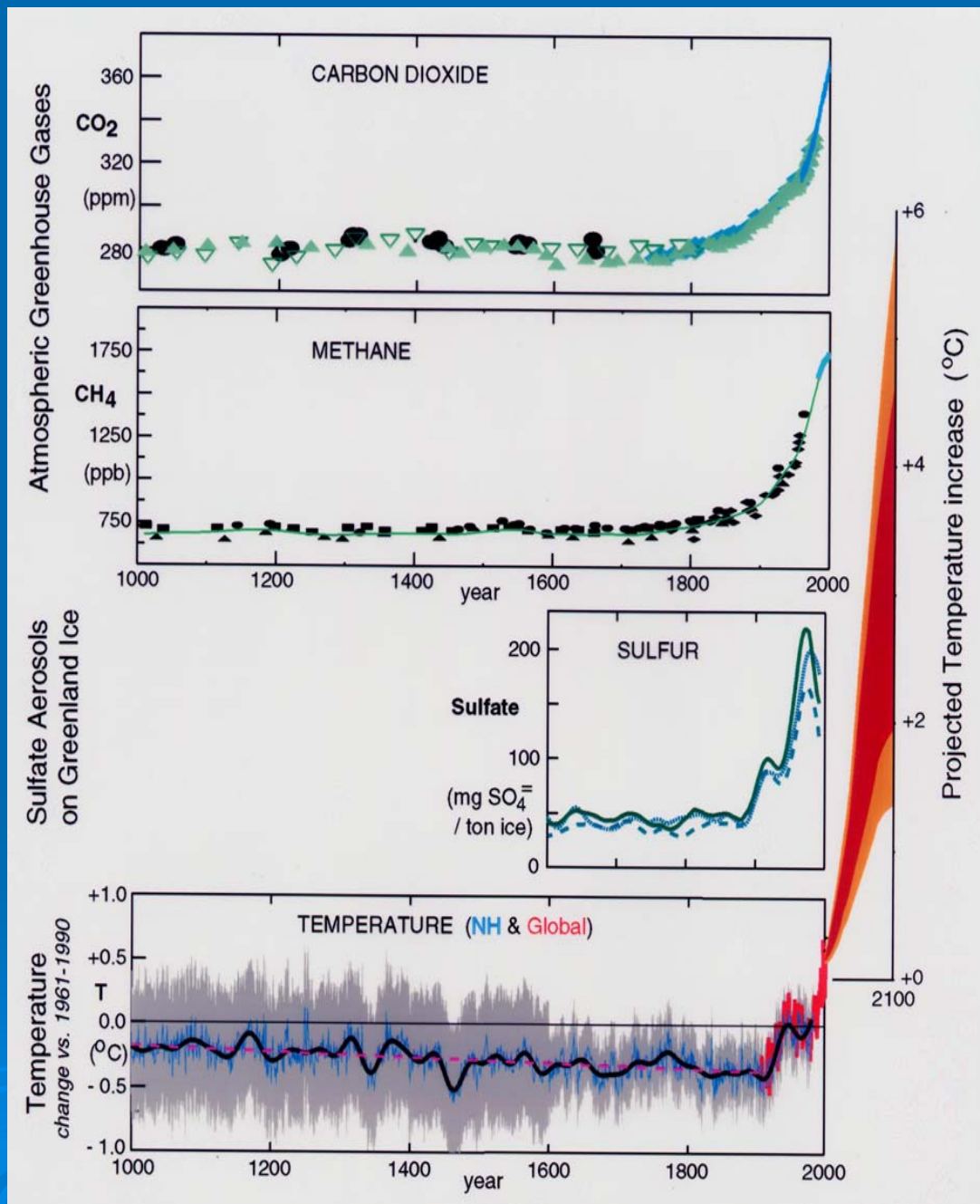
HadCM2 Annual Precipitation



The increase in CO₂ emissions is projected to cause a significant further increase in surface temperature around the world (1.4 to 5.8°C, or about 2.5 to 10°F, by 2100)



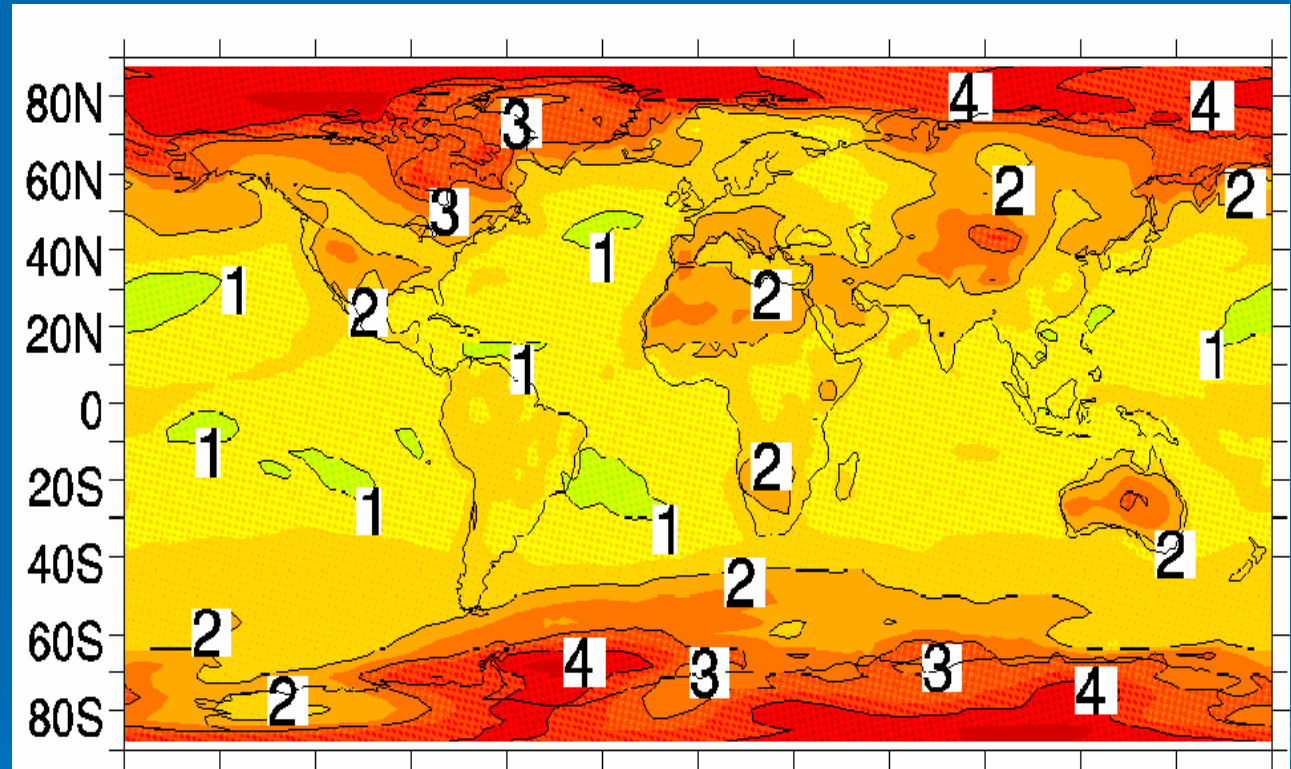
The projected increase in global average temperature could result in global temperatures being higher than they have been in tens of millions of years



Model simulations project greater warming over land areas and in polar regions

(values in °C, roughly double for °F)

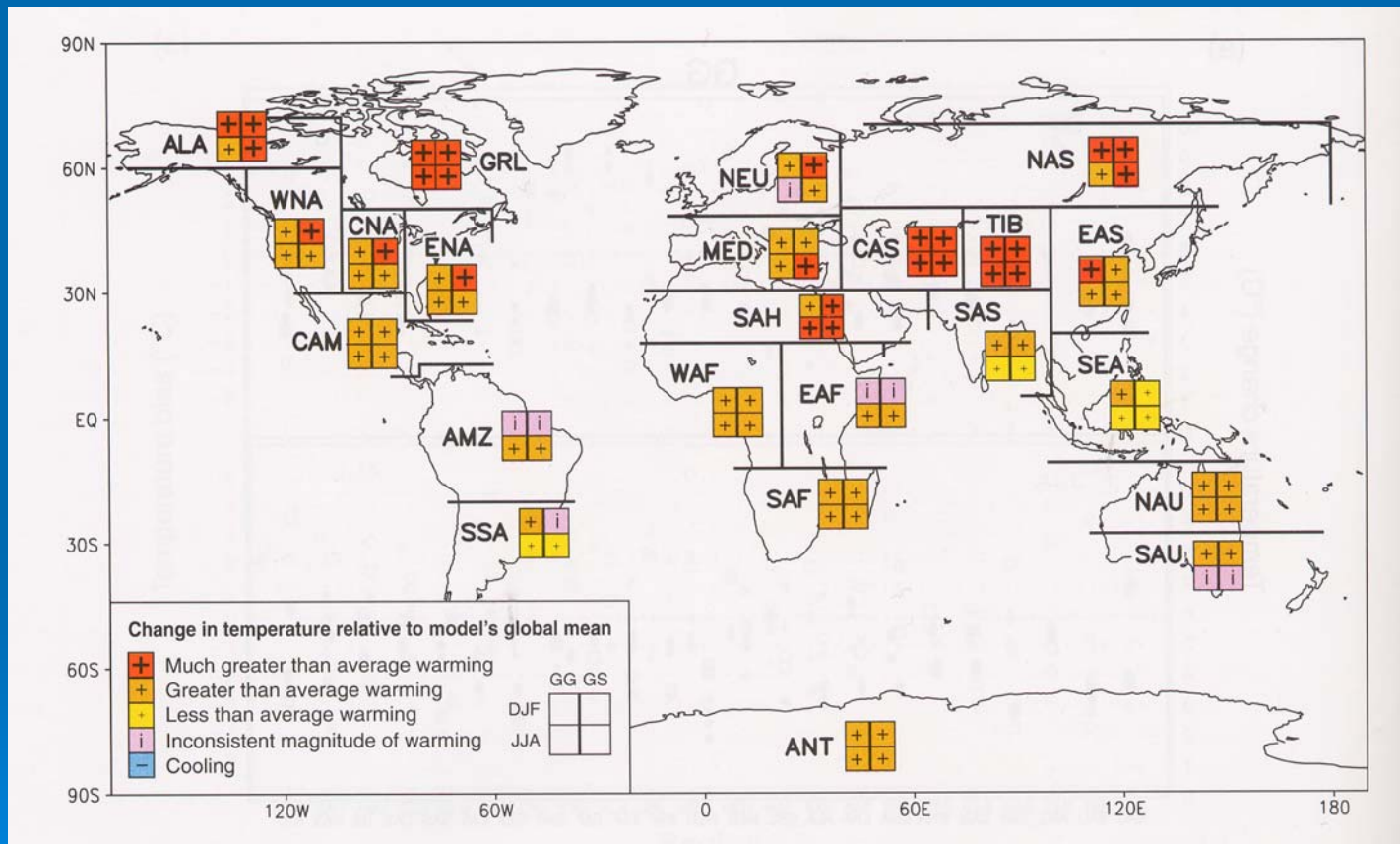
In most current climate models, the projection of the carbon dioxide (CO₂) concentration is prescribed and the results are then compared the results from a control run without a CO₂ increase. The newest models are actually simulating the full carbon cycle.



Simulated change in annual mean temperature (°C) resulting from a doubling of CO₂ in the atmosphere in a typical climate model.

Source: Govindasamy and Caldeira (2000)

Model simulations of the global pattern of warming suggest greater warming in mid- to high latitudes, over land, and during the winter



“Global warming” is shorthand for a wide array of potential changes in the climate

- **Warming** is very likely to be greater in high than low latitudes, greater in winter than in summer, and greater over land than over the oceans
- **Total evaporation** is very likely to increase, more rapidly leading to dry soil conditions and drought
- **Total global precipitation** is very likely to increase, coming especially in relatively intense events that could increase flood likelihood in some regions.
- The highest percentage increase in precipitation is likely to occur in **mid- to high-latitudes**.
- **The potential for unexpected changes** is high as balancing influences are disrupted and thresholds are exceeded

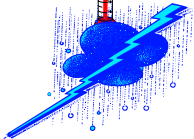
Climate change is likely to lead to a range of important environmental and societal impacts

Adapted from EPA

Climate Changes



Temperature



Precipitation

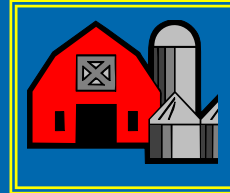


Sea Level Rise



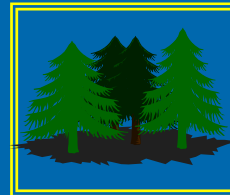
Health Impacts

Weather-related mortality/heat stress
Infectious diseases
Air quality-induced respiratory effects



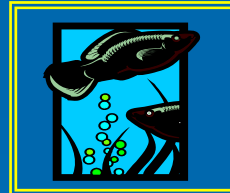
Agriculture Impacts

Crop yields and commodity prices
Irrigation demands
Pests and weed



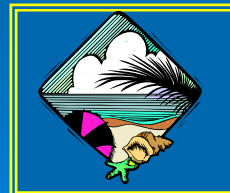
Forest Impacts

Change in forest composition
Shift geographic range of forests
Forest health and productivity



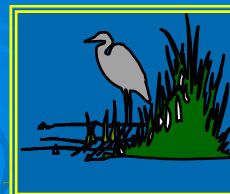
Water Resource Impacts

Changes in water supply and timing
Water quality
Increased competition for water



Coastal Area Impacts

Erosion of beaches
Inundation of coastal wetlands
Costs to defend coastal communities



Ecosystem Impacts

Shifts in ecological zones
Loss of habitat and species
Coral reefs threatened

Societal Impacts

Indigenous peoples and developing nations
Exacerbated impacts on the poor
Dramatically different situation for future generations



The US National Assessment (1997-2000) prepared national, regional, and sectoral reports about past impacts and likely future consequences. These are downloadable from:

<http://www.usgcrp.gov/usgcrp/nacc/default.htm>

CLIMATE CHANGE IMPACTS ON THE UNITED STATES

THE POTENTIAL CONSEQUENCES OF CLIMATE VARIABILITY AND CHANGE

Overview

National Assessment
Synthesis Team

US Global Change
Research Program



This National Overview
report is also available
from Cambridge
University Press

The Southeast region report is available at <http://www.usgcrp.gov/usgcrp/nacc/seregion.htm>

For North Carolina, the two most relevant assessments were Southeast and Coastal

Key Issues from the Southeast Regional Assessment:

- Agriculture
- Forests and forest economics
- Water quality
- Air quality
- Extreme weather events

Additional issues recognized but not dealt with by regional assessment:

- Land use change
- Water resources
- Coastal ecosystems and services
- Health and water quality
- Socioeconomic and insurance issues
- Urban issues (building design and construction, infrastructure, etc.)

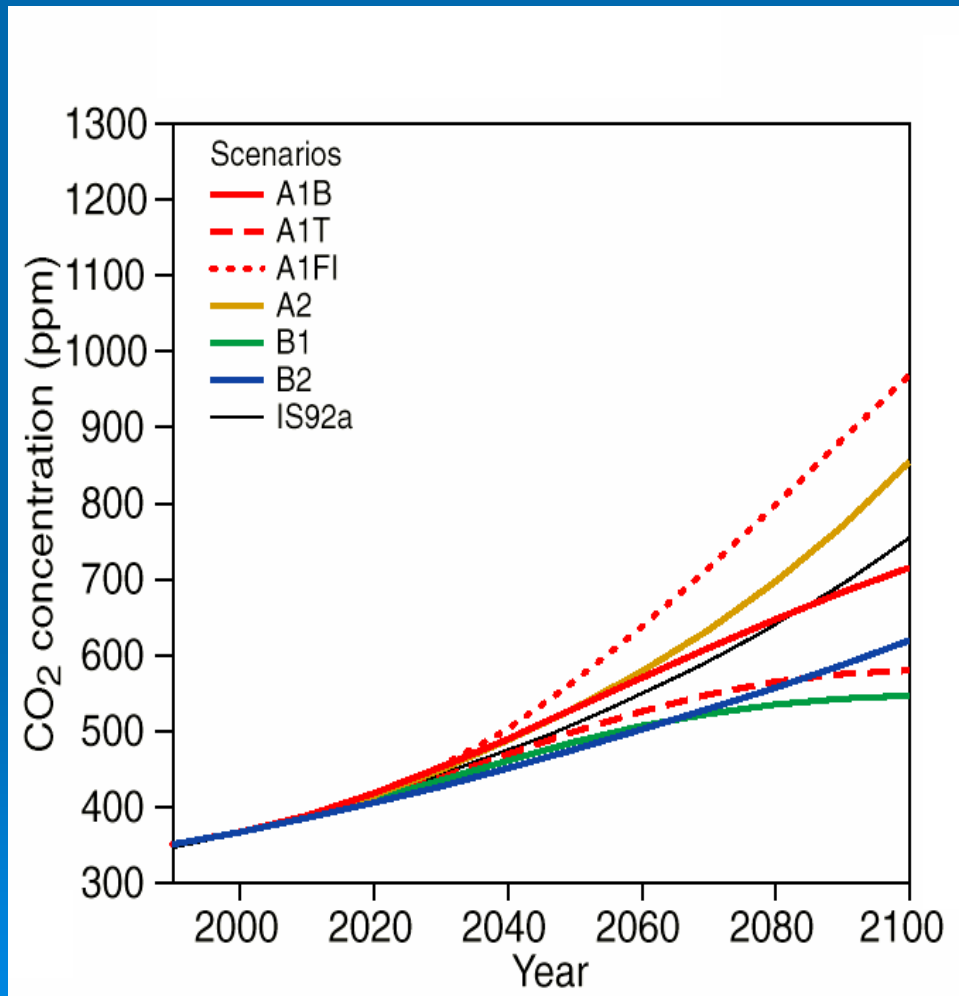
Key Issues from the Coastal Assessment:

- Shorelines and coastal development
- Wetlands
- Estuaries
- Coral reefs
- Ocean margins and fishery resources

Additional topics and issues mentioned:

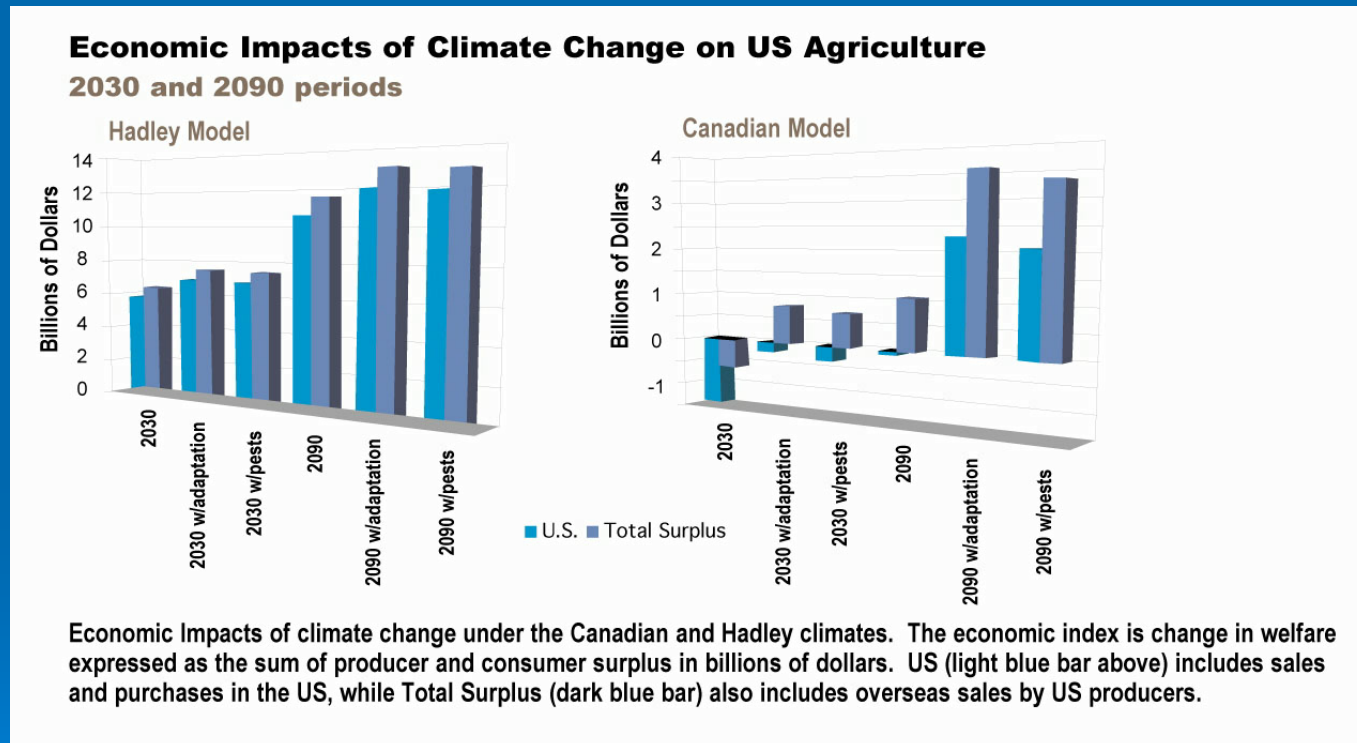
- Coastal areas and populations
- The importance of coastal resources
- Ocean temperatures and currents
- Hurricanes and extratropical storms
- Precipitation and freshwater runoff
- Sea level change

The rising CO₂ concentration itself will have important consequences for the environment



Both the marine and terrestrial environments will be (are already being) affected

The US agricultural sector is likely to be able to adapt to climate change. Overall productivity is likely to increase due to the higher CO₂ concentration and improved water use efficiency.

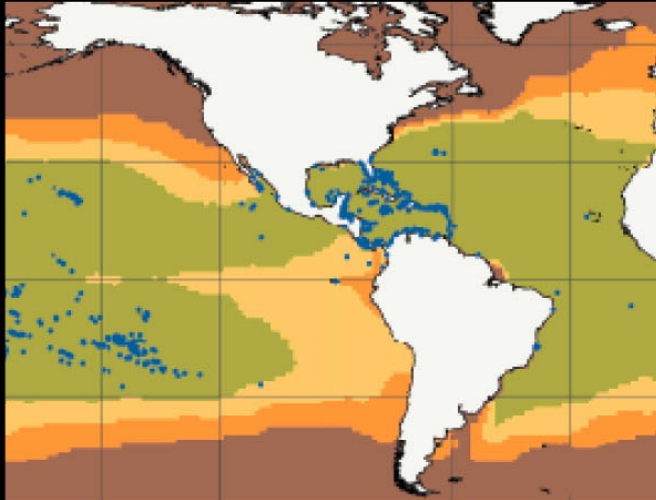


With increased production, commodity prices would be expected to fall, benefiting consumers, but causing economic harm in marginal farming areas. Issues of changes in pests and plant diseases have yet to be evaluated

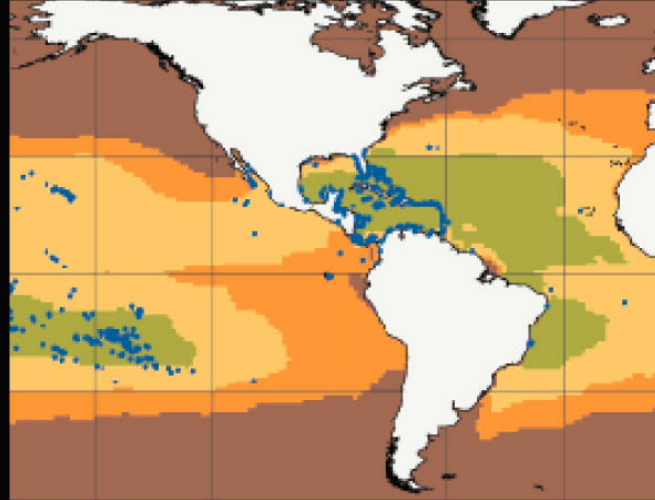
Coral reefs are threatened by both ocean warming and the rising CO₂ concentration

Calcium Carbonate Saturation in Ocean Surface Waters

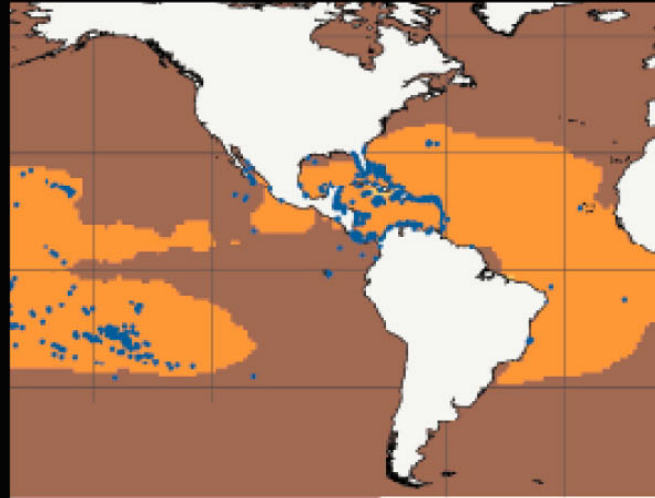
Preindustrial (~1880)



Current (2000)



Projected (~2050)



Corals require the right combination of temperature, light, and calcium carbonate saturation. At higher latitudes, there is less light and lower temperatures than nearer the equator. The saturation level of calcium carbonate is also lower at higher latitudes, in part because more CO₂, an acid, can be dissolved in colder waters. As the CO₂ level rises, this effect dominates, making it more difficult for corals to form at the poleward edges of their distribution. These maps show model results of the saturation level of calcium carbonate for pre-industrial, present and future CO₂ concentrations. The dots indicate present coral reefs. Note that under model projections of the future, it is very unlikely that calcium carbonate saturation levels will provide fully adequate support for coral reefs in any US waters. The possibility of this future scenario occurring demands continued research on effects of increasing CO₂ on entire coral reef systems.

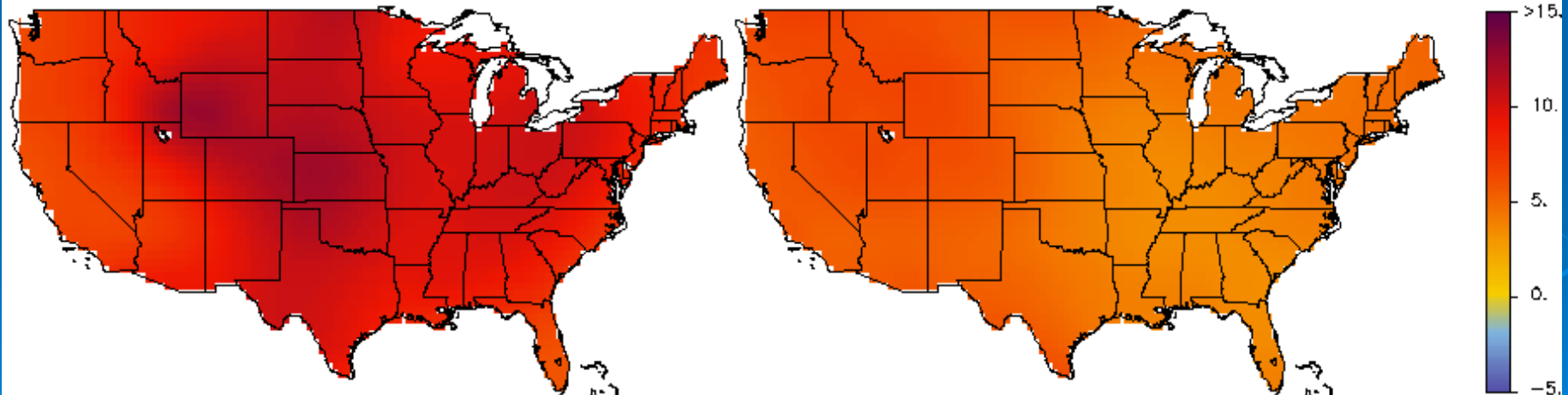
Climate model simulations used in the US National Assessment project a 21st century warming of about 5 - 10°F

Canadian model scenario
for increase by 2100

Hadley (UK) model scenario
for increase by 2100

Canadian 21st Century
Annual Mean Temperature Trend

Hadley 21st Century
Annual Mean Temperature Trend



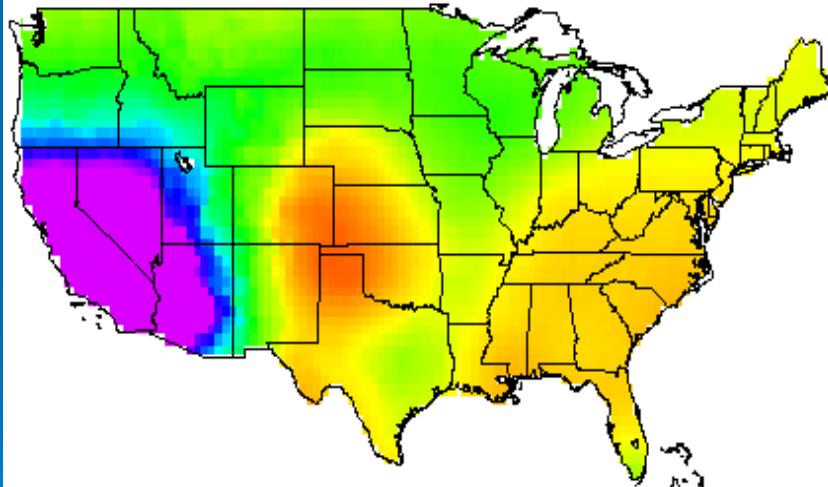
Plots show the projected change in annual average temperature (°F) over the 21st century

Model projections of the change in precipitation suggest the potential for “hot-dry” or “warm-moist” conditions

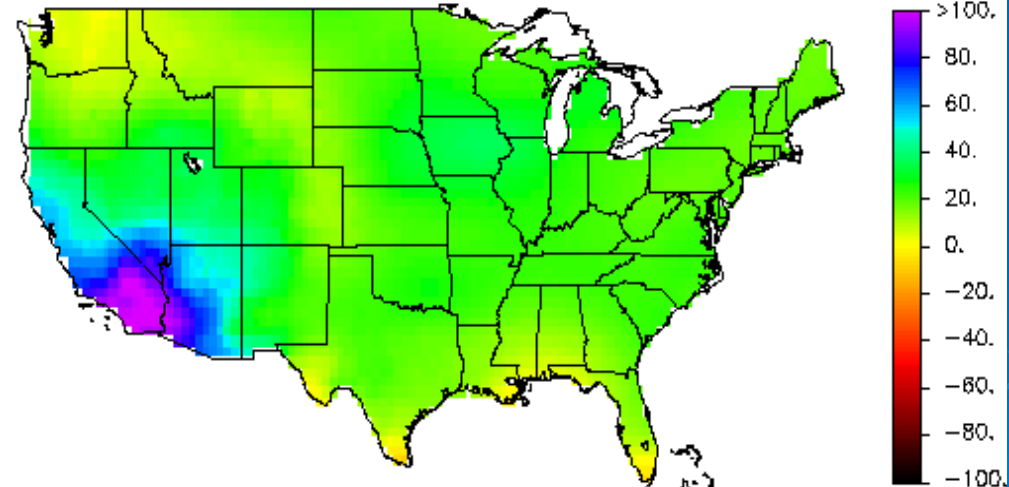
Canadian model scenario
for change by 2100

Hadley model scenario
for increase by 2100

CGCM1 % Trend in Precipitation (Annual)



HadCM2 % Trend in Precipitation (Annual)



The prospective changes in climate are roughly equivalent to imposing climatic conditions many hundreds of miles away

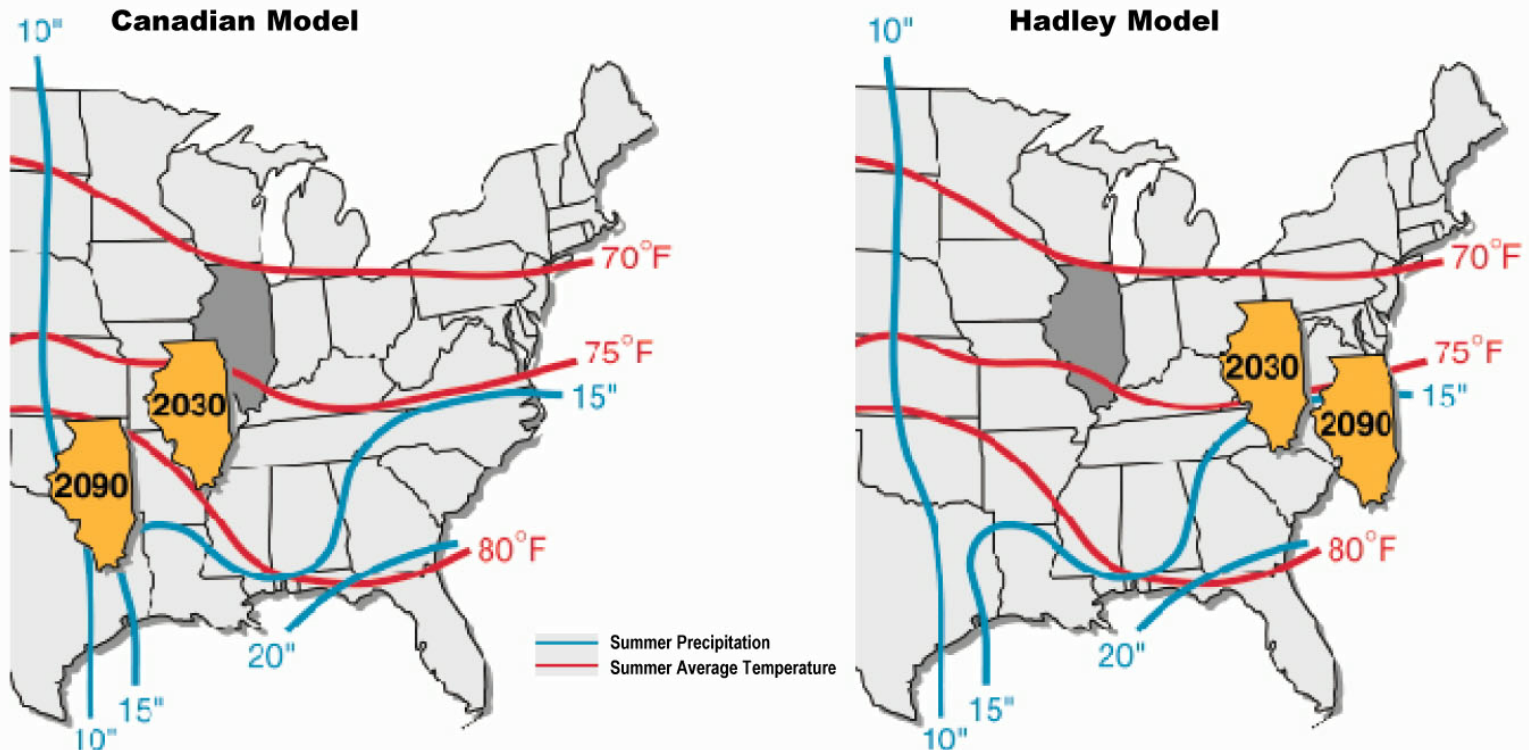


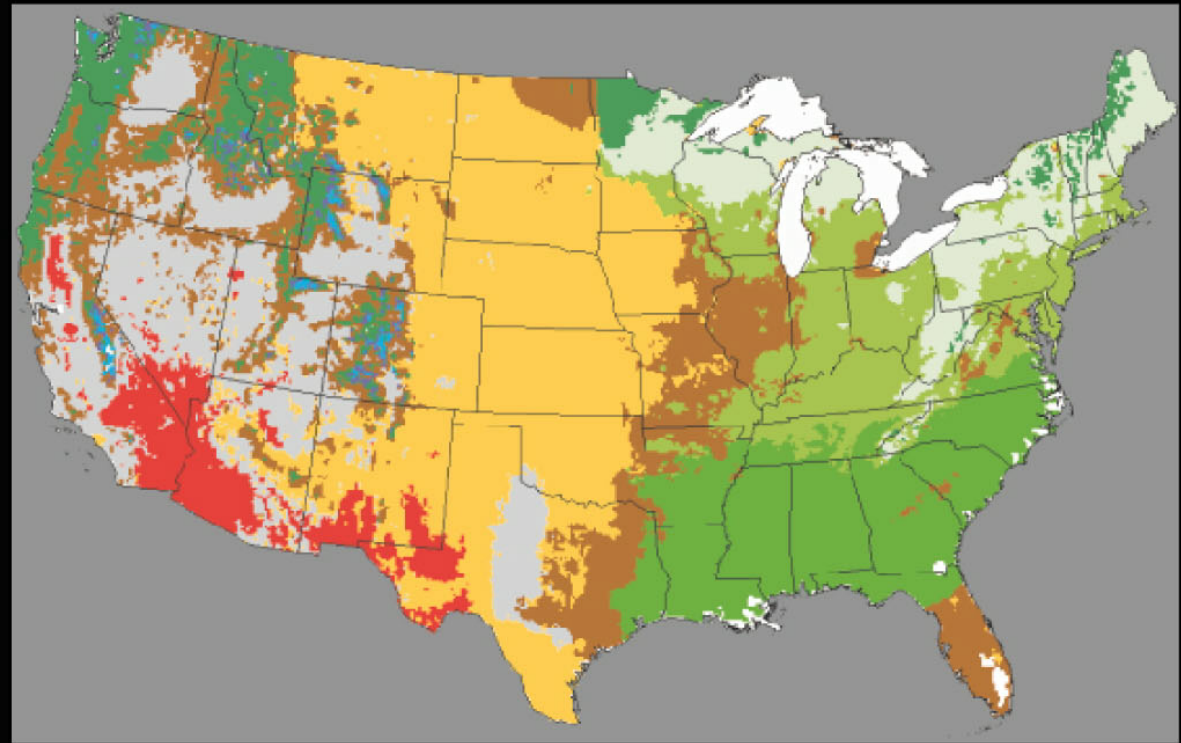
Illustration of how the summer climate of Illinois would shift under the Canadian and Hadley model scenarios. Under the Canadian scenario, the summer climate of Illinois would become more like the current climate of southern Missouri in 2030 and more like Oklahoma's current climate in 2090. The primary difference in the resulting climates of the two models relates to the amount of summer rainfall.

The present distribution of ecosystems is a result of plants and wildlife adapting to prevailing climatic and soil conditions

Ecosystem Models

Current Ecosystems

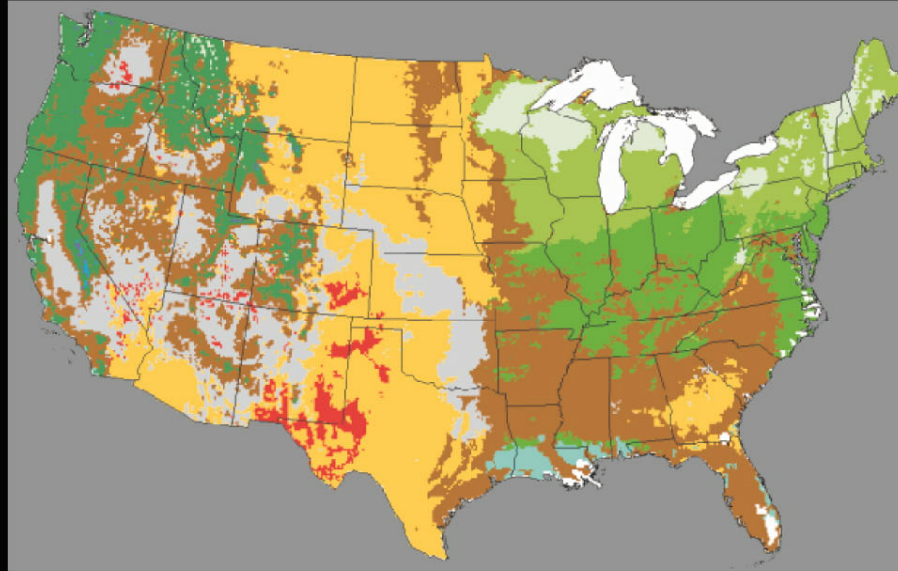
Maps of current and projected potential vegetation distribution for the conterminous US. Potential vegetation means the vegetation that would be there in the absence of human activity. Changes in vegetation distribution by the end of the 21st century are in response to two climate scenarios, the Canadian and the Hadley. Output is from MAPSS (Mapped Atmosphere-Plant-Soil System).



Projected Ecosystem Impacts by 2100

Even accounting for the effects of CO₂ fertilization and enhancement, changes in the climate will lead to regional changes in the predominant vegetation type and, as a result, in the extant wildlife. Some of the transition is likely to occur relatively rapidly as a result of fires and other disturbances

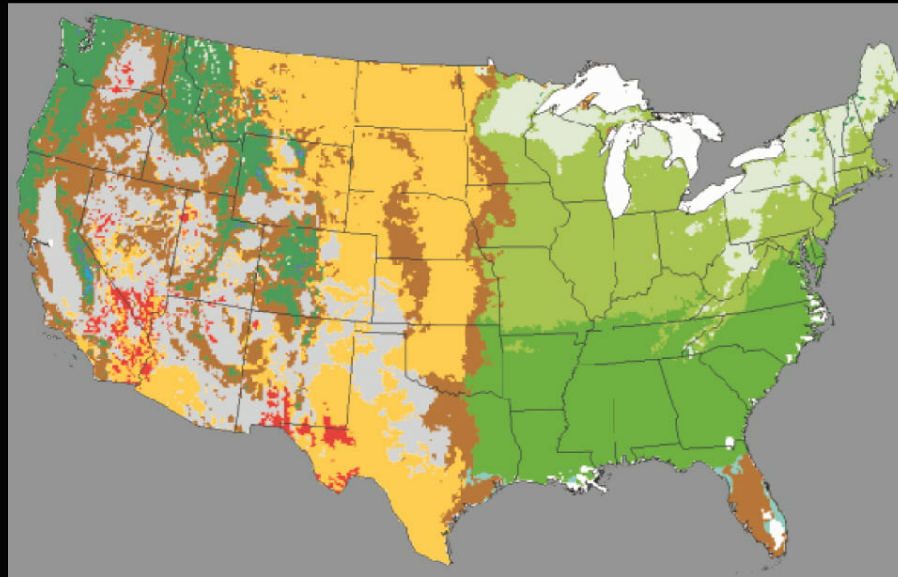
Canadian Model



A substantial portion of the Southeast's mixed forest is replaced by a combination of savanna and grassland in response to fire caused by warming and drying of the region as projected by the Canadian model. The Hadley climate projection leads to a simulated northward expansion of the mixed forest.

These particular model runs show the response of vegetation to atmospheric concentrations of CO₂ that have stabilized at about 700 parts per million, approximately twice the present level.

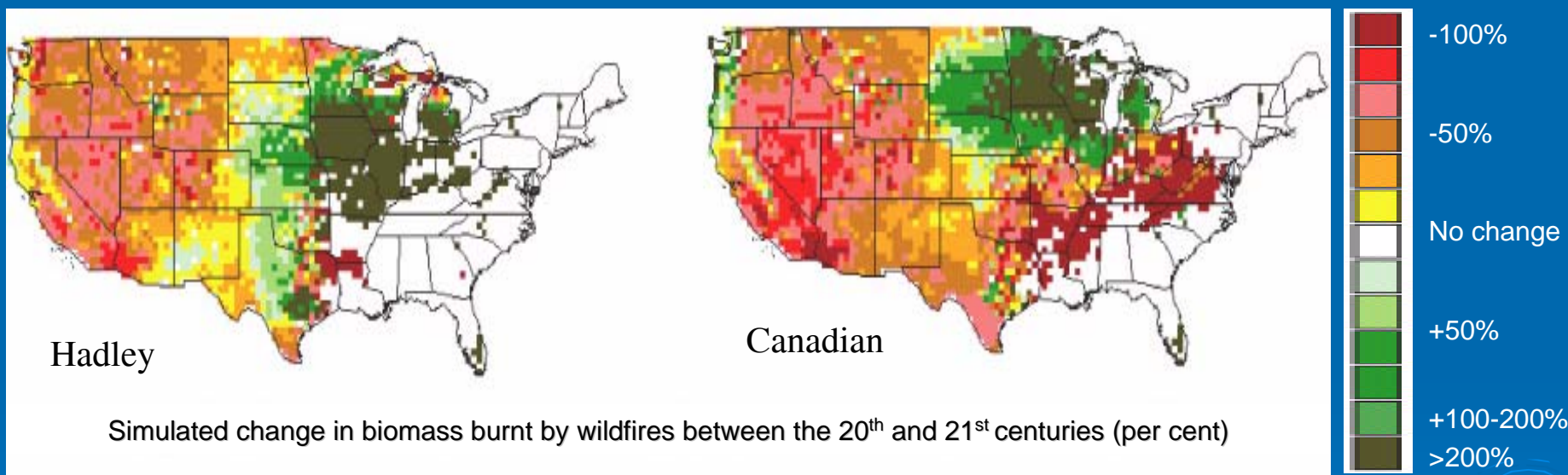
Hadley Model



In the Southwest, large areas of arid lands are replaced with grassland or shrub/woodland in response to increases in precipitation projected by both models.



Overall forest productivity is expected to rise, although the predominant tree species in a location may change. In some areas, drier summers are likely to raise the potential for fires.

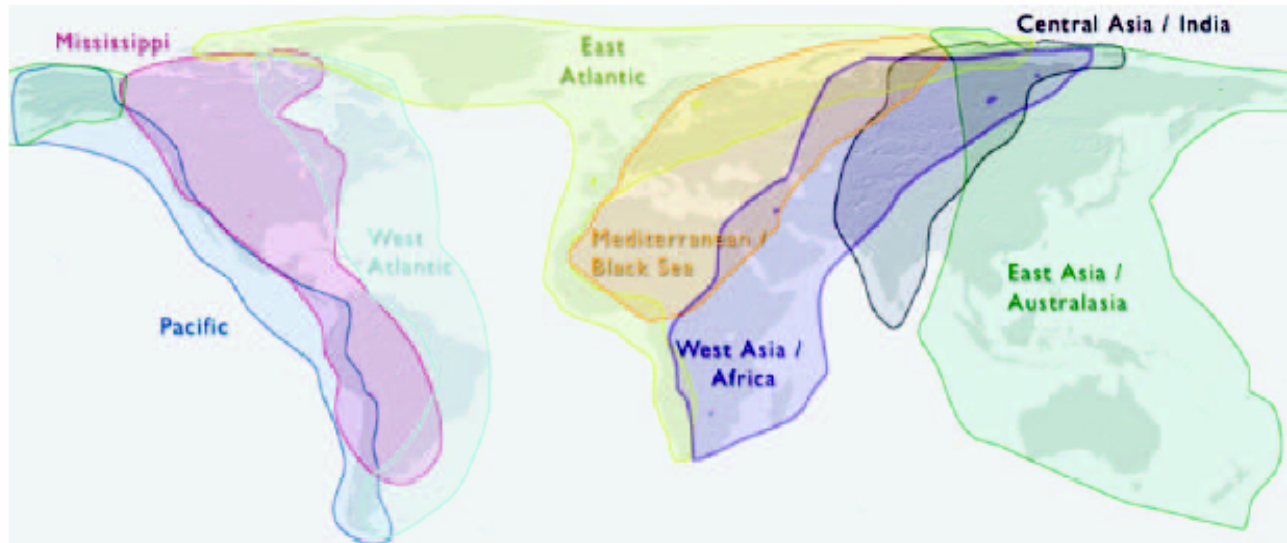


**More Biomass
Consumed by Fire**

For hot, dry summertime conditions (the Canadian model scenario), the forest mass burned is projected to increase significantly, especially in the western US and the lower Mississippi-central Appalachians region. For warm, moist conditions (the Hadley model scenario), increased fire likelihood is projected to occur mainly in the western US

Conditions will be changing at the ends and all along the pathways of migrating species, with the potential for significant disruption

Migratory Bird Flyways



©2004, ACIA

Several hundred million birds migrate to the Arctic each summer and their success in the Arctic determines their populations at lower latitudes. Important breeding and nesting areas are projected to decrease sharply as treeline advances northward, encroaching on tundra, and because the timing of bird arrival in the Arctic might no longer coincide with the availability of their insect food sources. At the same time, sea-level rise will erode tundra extent from the north in many areas, further shrinking important habitat for many living things. A number of bird species, including several globally endangered seabird species, are projected to lose more than 50% of their breeding area during this century.

Changes in precipitation will alter the availability of water resources

- **Storm intensity, track, and number** are likely to shift, although most types of changes remain uncertain
- Warmer conditions will lead to **reduced springtime snowpack** and altered timing of river runoff (with less in summer)
- A larger fraction of the precipitation is likely to come in **intense storms**, continuing the 20th century trend
- Warmer conditions will lead to **warmer water temperatures and faster drying of soils** between storms
- **Average river flows and lake levels** will be lower, especially in summer; creating greater competition for water resources)

Whether a region was relatively wet or dry, potential water-related impacts were of concern across the country

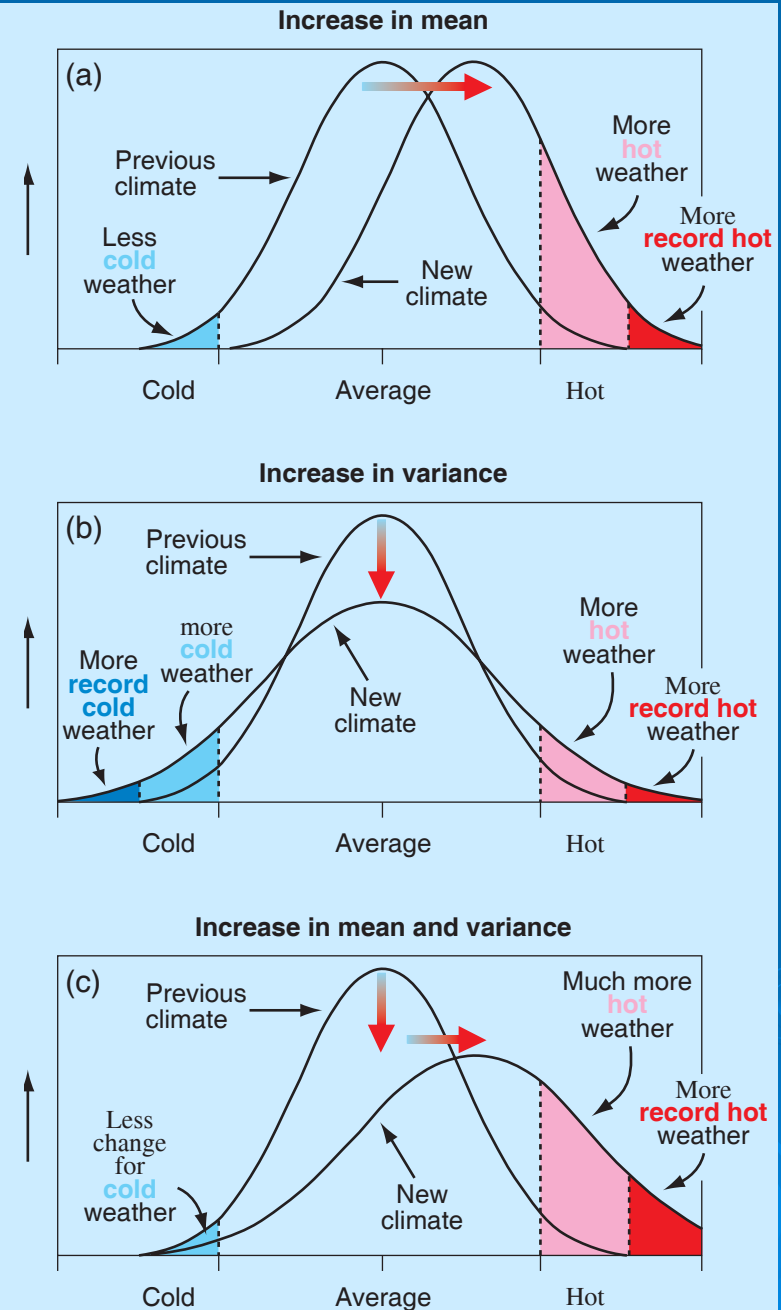
WATER ISSUES



Region	Floods	Droughts	Snowpack/ Snowcover	Groundwater	La re
Northeast	X	X	X	X	
Southeast	X	X		X	
Midwest	X	X	X	X	
Great Plains	X	X	X	X	
West	X	X	X	X	
Northwest	X	X	X		
Alaska		X	X		
Islands	X	X		X	

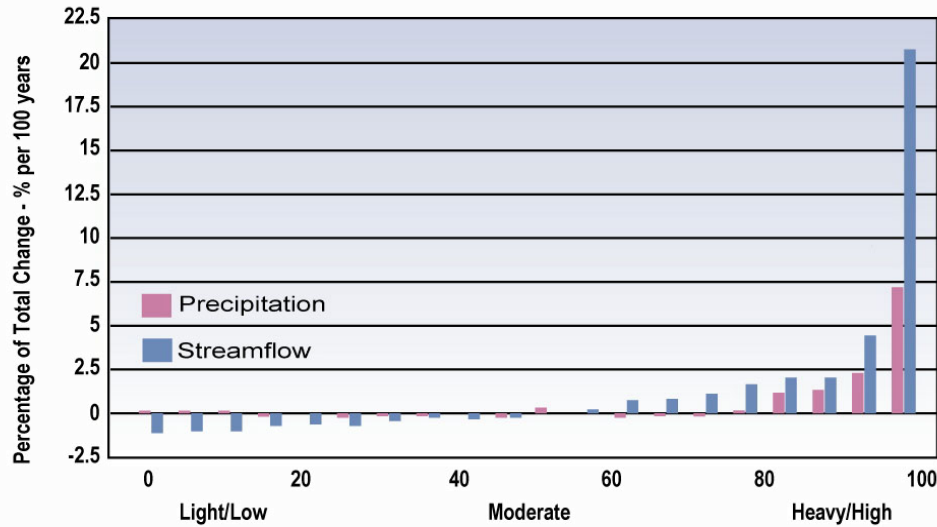
Shifts in climate are expected to lead to changes in the frequency and intensity of extremes

As an example, an increase in the average temperature is expected to lead to a very large increase in the probability that hot extremes may be experienced.



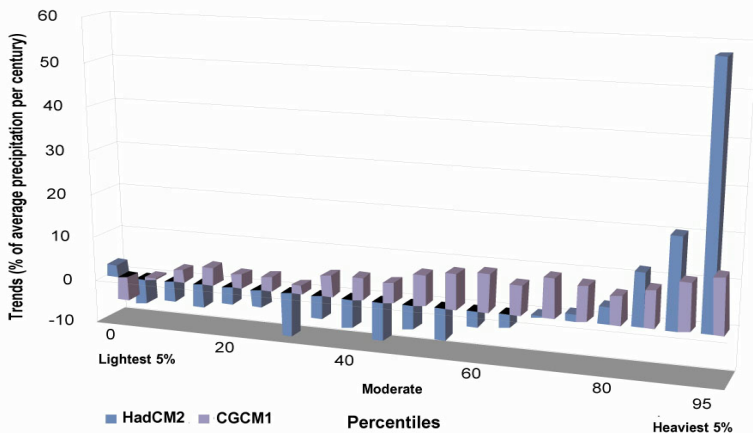
Precipitation has been Becoming More Intense, and Models Project this Tendency to Continue

Observed Changes In Streamflow and Precipitation (1939-99)



A greater share of precipitation has been occurring during the most intense rainfall events, leading to more intense stream flows. This has been occurring in the US and around the world

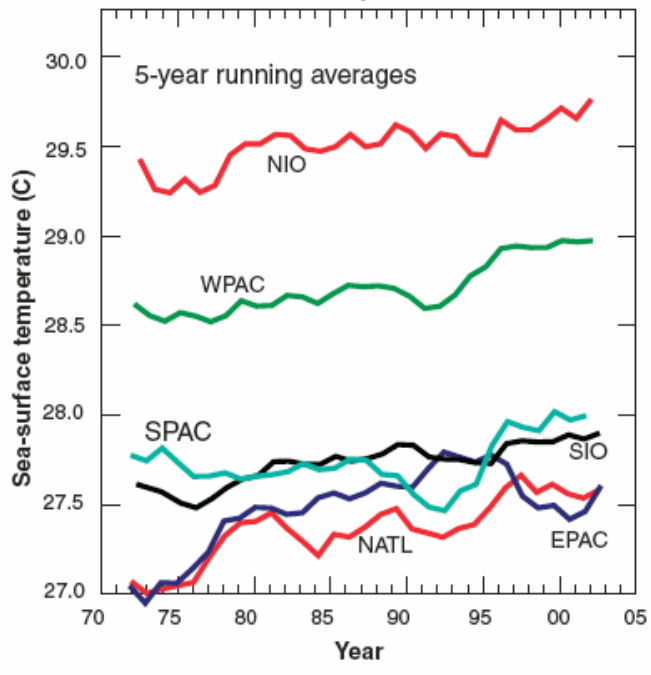
Projected 21st Century Change in US Daily Precipitation



Projections from all models indicate that the increase in temperature and atmospheric humidity will lead to a greater share of precipitation occurring during the most intense rainfall events

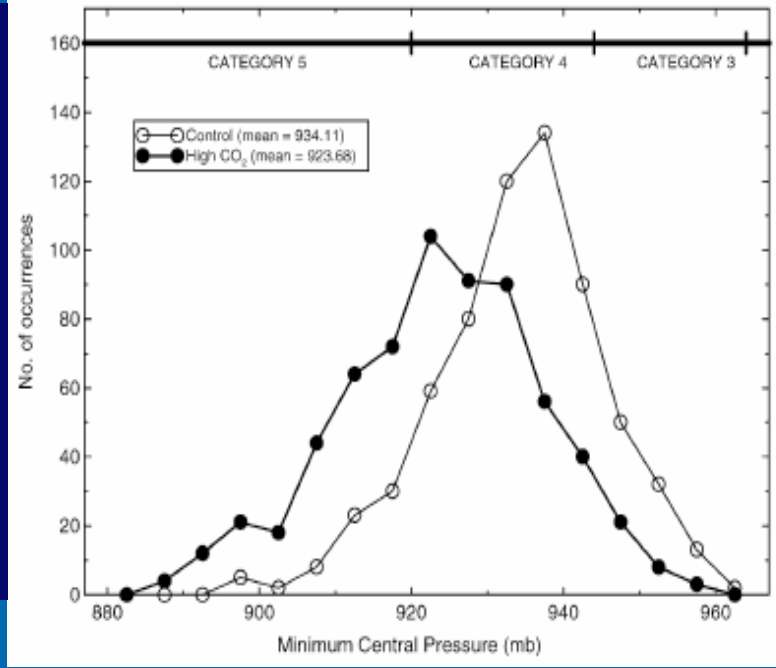
These projections by the Hadley and Canadian models show the changes in precipitation over the 21st century. Each models' projected change in the lightest 5% of precipitation events is represented by the far left bar and the change in the heaviest 5% by the far right bar. As the graph illustrates, both models project significant increases in heavy precipitation events with smaller increases or decreases in light precipitation events.

Summer SST by Ocean Basin



Hurricanes appear to be intensifying and releasing more energy, and we have become more vulnerable due to more coastal residents and buildings

Hurricane Intensity Simulations: Aggregate results

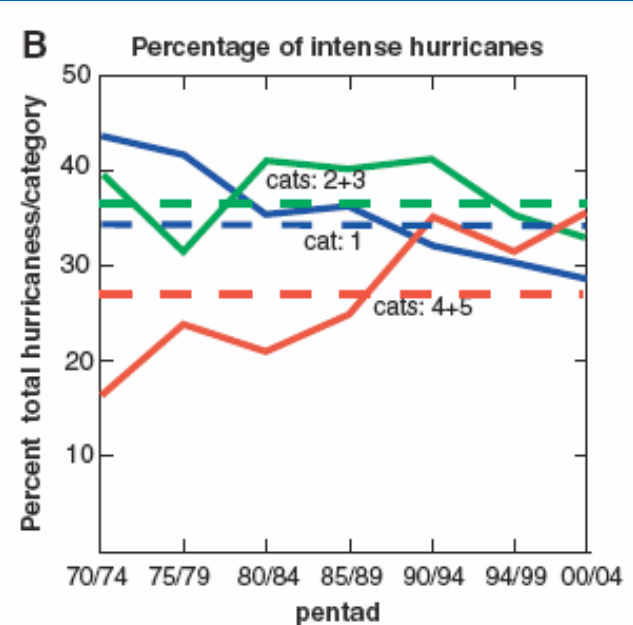
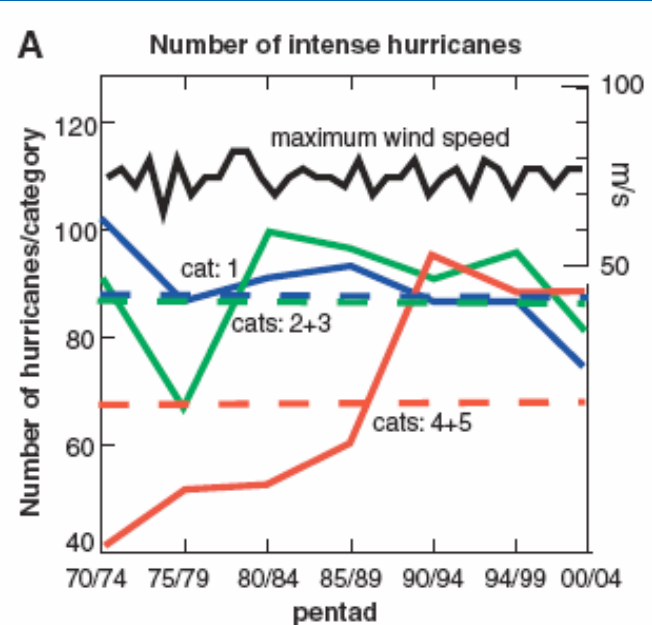


Ocean temperatures are rising

Hurricanes are becoming more intense

Hurricane models project warming will further intensify hurricanes

Source: Webster et al., *Science*, 2005

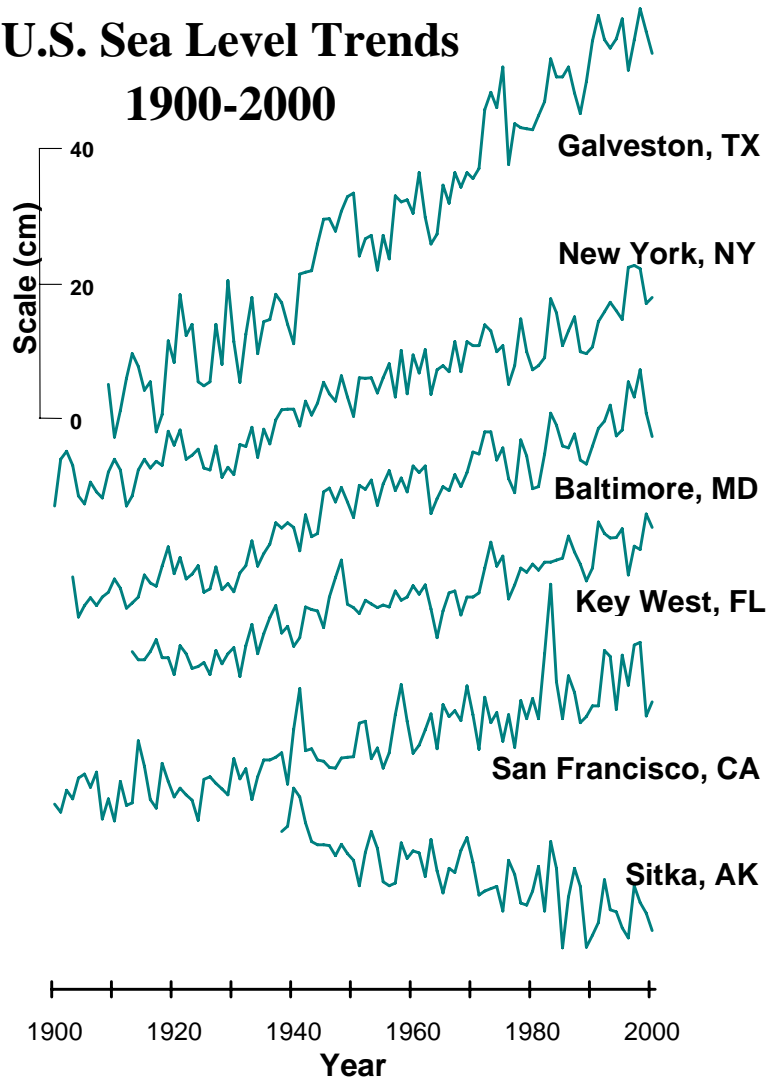


Source: Knutson and Tuleya, *Science*, 2004



Global sea level rose by about 10 to 20 cm (4 to 8 inches) during the 20th century

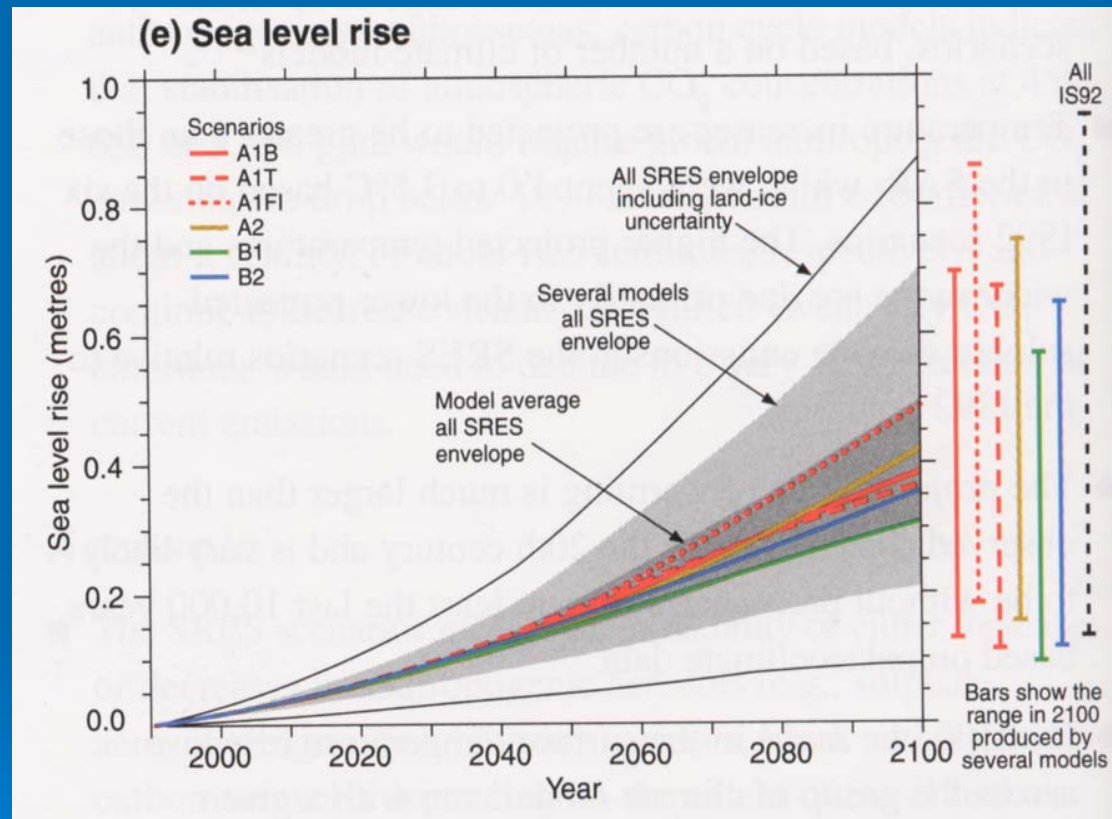
U.S. Sea Level Trends 1900-2000



Contributions to increases in global sea level occur as a result of thermal expansion of warming ocean waters, melting of mountain glaciers, and net losses from the Greenland and Antarctica Ice Sheets. Changes in land stored on land in reservoirs and aquifers can also be important.

Changes in local sea level (relative sea level) are also determined by coastal subsidence or emergence due to long-term (e.g., glacial rebound) and short-term (e.g., aquifer pumping) factors.

Global sea level is projected to rise by about 9 to 88 cm (4 to 35 inches) during the 21st century, with a mid-range value or higher increasingly likely



Contributions to global sea level rise are projected to come mainly from thermal expansion of ocean waters and melting of mountain glaciers. These IPCC (2001) estimates suggested that melting of the Greenland and Antarctica Ice Sheets would be small, but more recent indications are that there will be more significant contributions.

The Greenland Ice Sheet Dominates Land Ice in the Arctic--and it is Melting at an Accelerating Rate

Over the past two decades, the melt area on the Greenland ice sheet has increased on average by about 0.7%/year (or about 16% from 1979 to 2002).

There is preliminary paleoclimatic evidence suggesting that sea level was a few meters higher than at present during the Eemian interglacial 120,000 years ago. There is also evidence that this sea level rise occurred over a few centuries, mainly due to rapid melting of about half of the Greenland Ice Sheet.

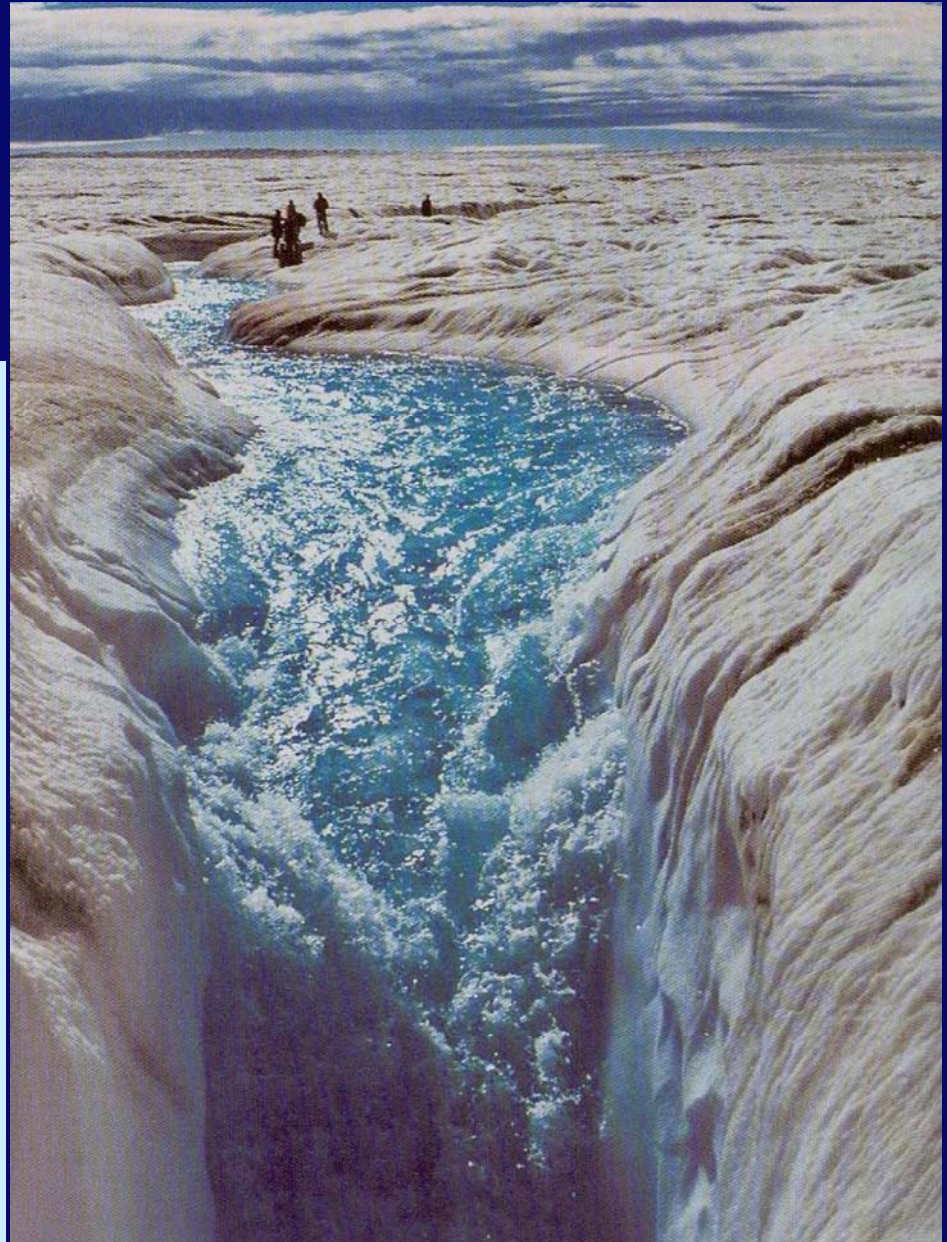
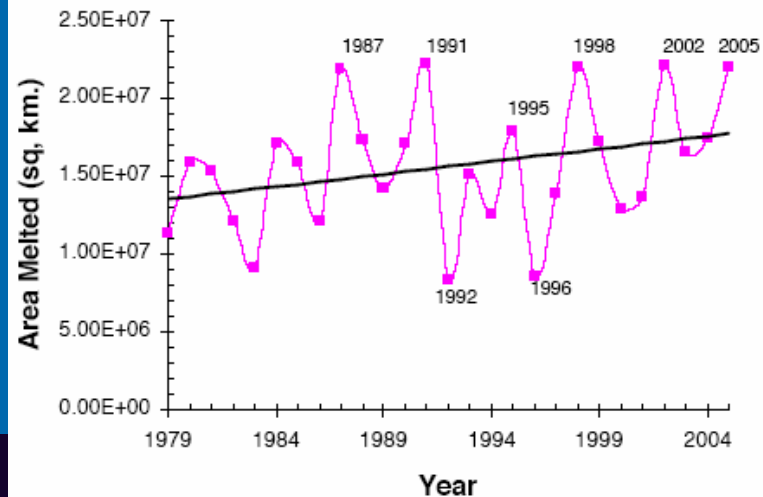


Photo: Business Week Aug. 2004

Melting of the Greenland Ice Sheet in 2005 Exceeded Previous Years

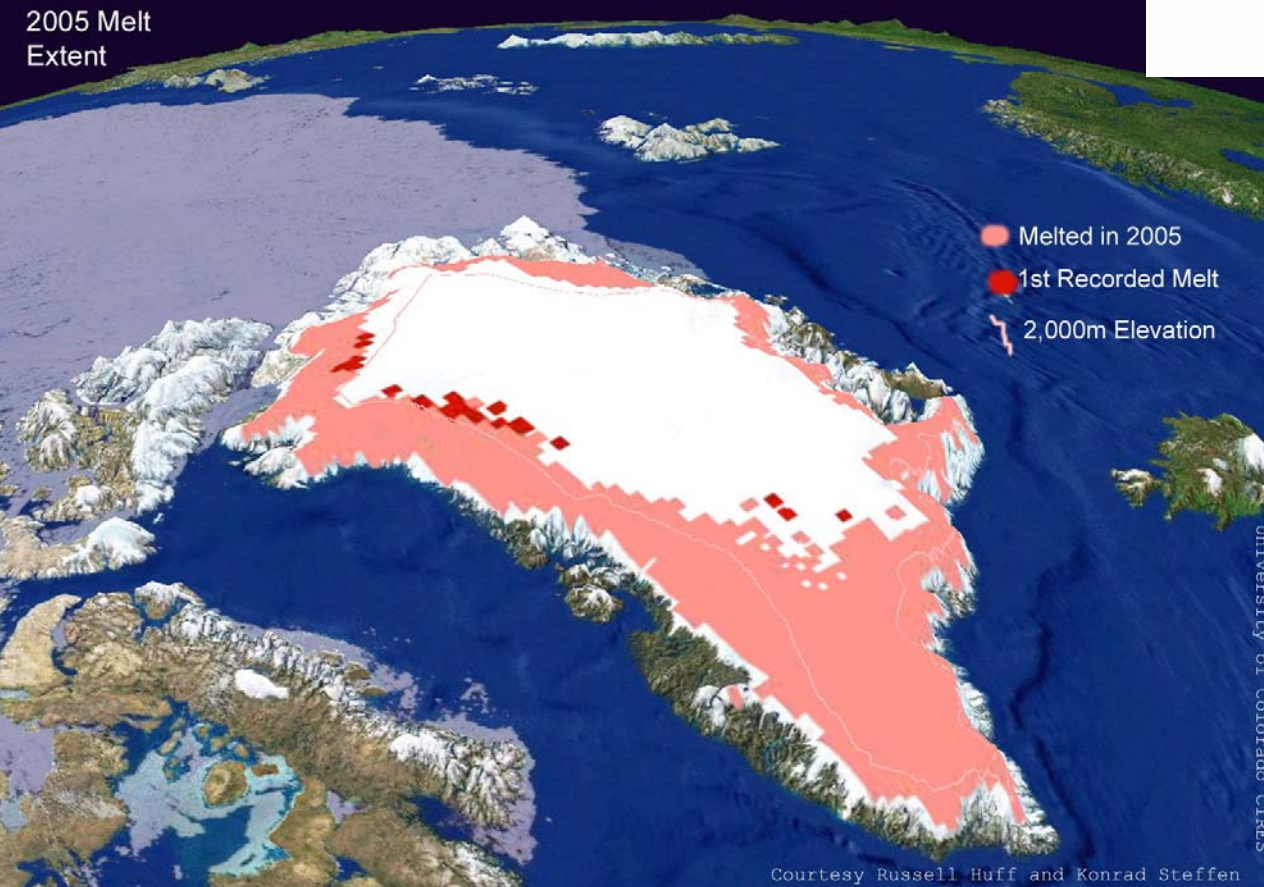
Total Melt
April - September 25



Source: Huff and Steffen, CIRES, University of Colorado

Update: Recent satellite observations of the melt rate are about 3 times as large as the IPCC's projection for the whole 21st century!

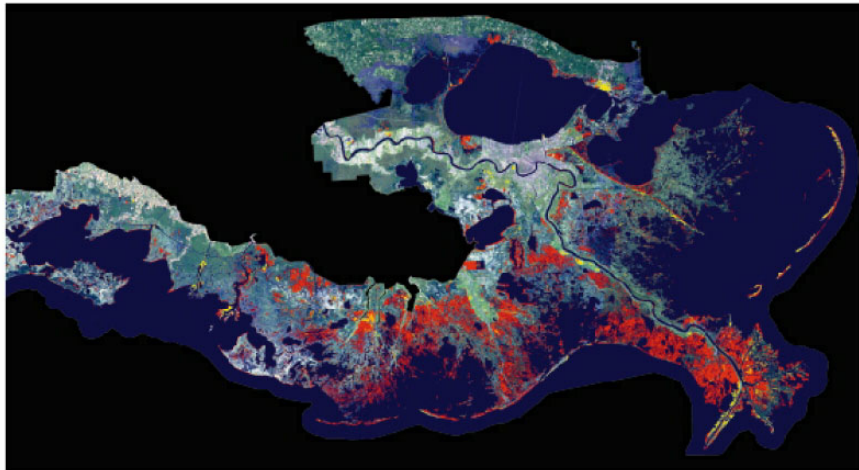
2005 Melt Extent



University of Colorado CIRES

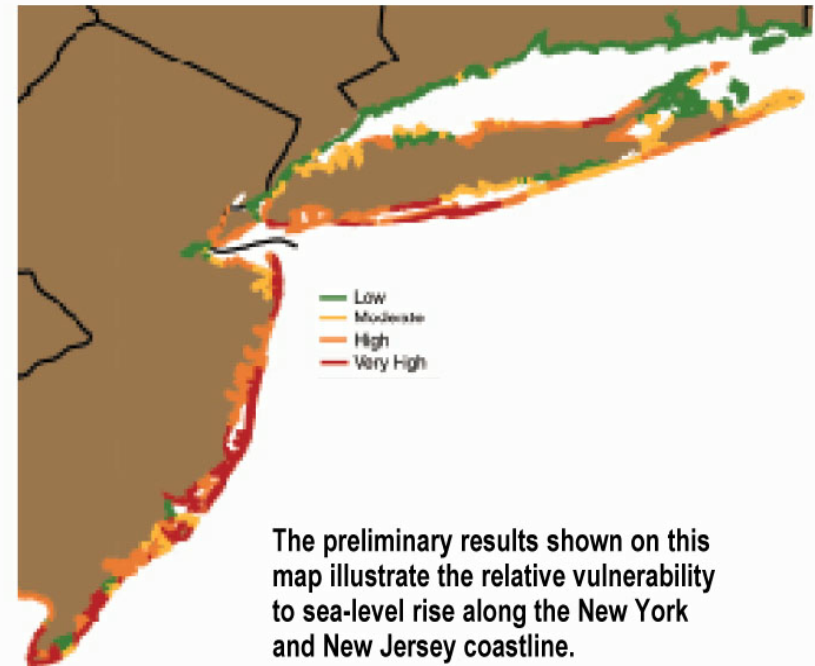
The Gulf and East coasts are particularly vulnerable to projected sea level rise

Louisiana's Coastal Land loss
Between 1956 and 1990 (Shown in Red)



Rising sea level is one of several factors that have caused the loss of about one million acres of Louisiana wetland since 1900. Natural and human-induced processes contributing to these losses include subsidence due to groundwater withdrawal and natural sediment compaction, wetland drainage, and levee construction. In the figure above, red designates land that has been converted to open water.

Coastal Vulnerability



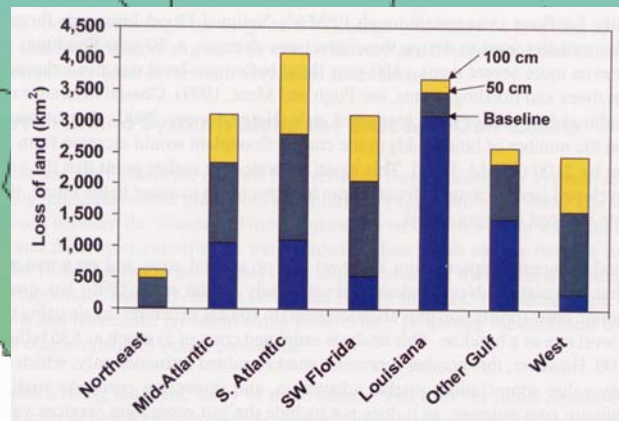
The preliminary results shown on this map illustrate the relative vulnerability to sea-level rise along the New York and New Jersey coastline.

Coastal islands and wetlands are the “**shock absorbers**” in the event of hurricanes

Coastal regions will be exposed to rising sea level and higher storm surges

This map is a preliminary classification of annual shoreline erosion throughout the US, in coarse detail and resolution. The areas most vulnerable to future sea-level change are those with low relief which are already experiencing rapid erosion rates, such as the Southeast and Gulf Coast.

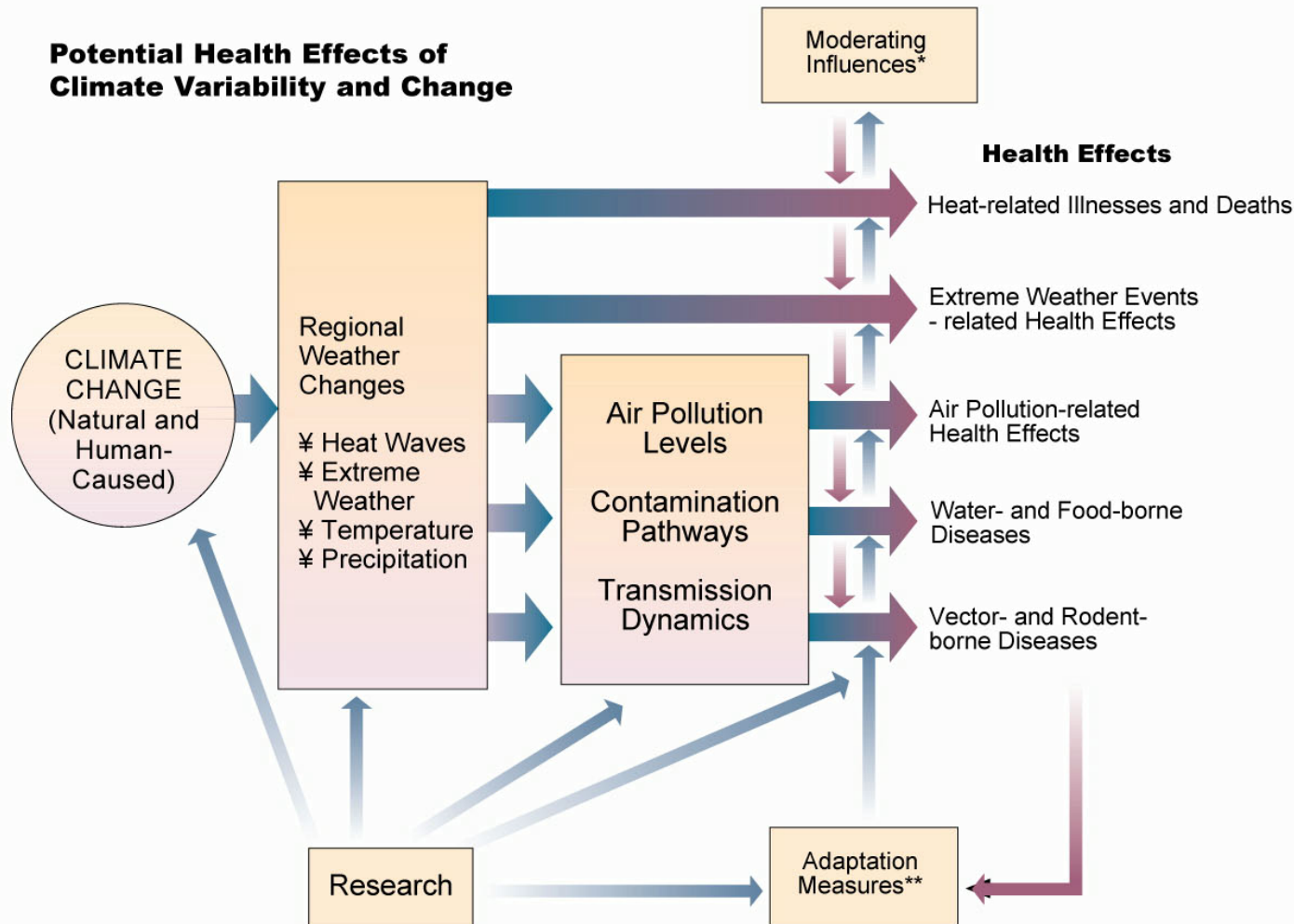
Annual Shoreline Change



Severely eroding Moderately eroding Relatively stable

The potential consequences for human health are of several interacting types

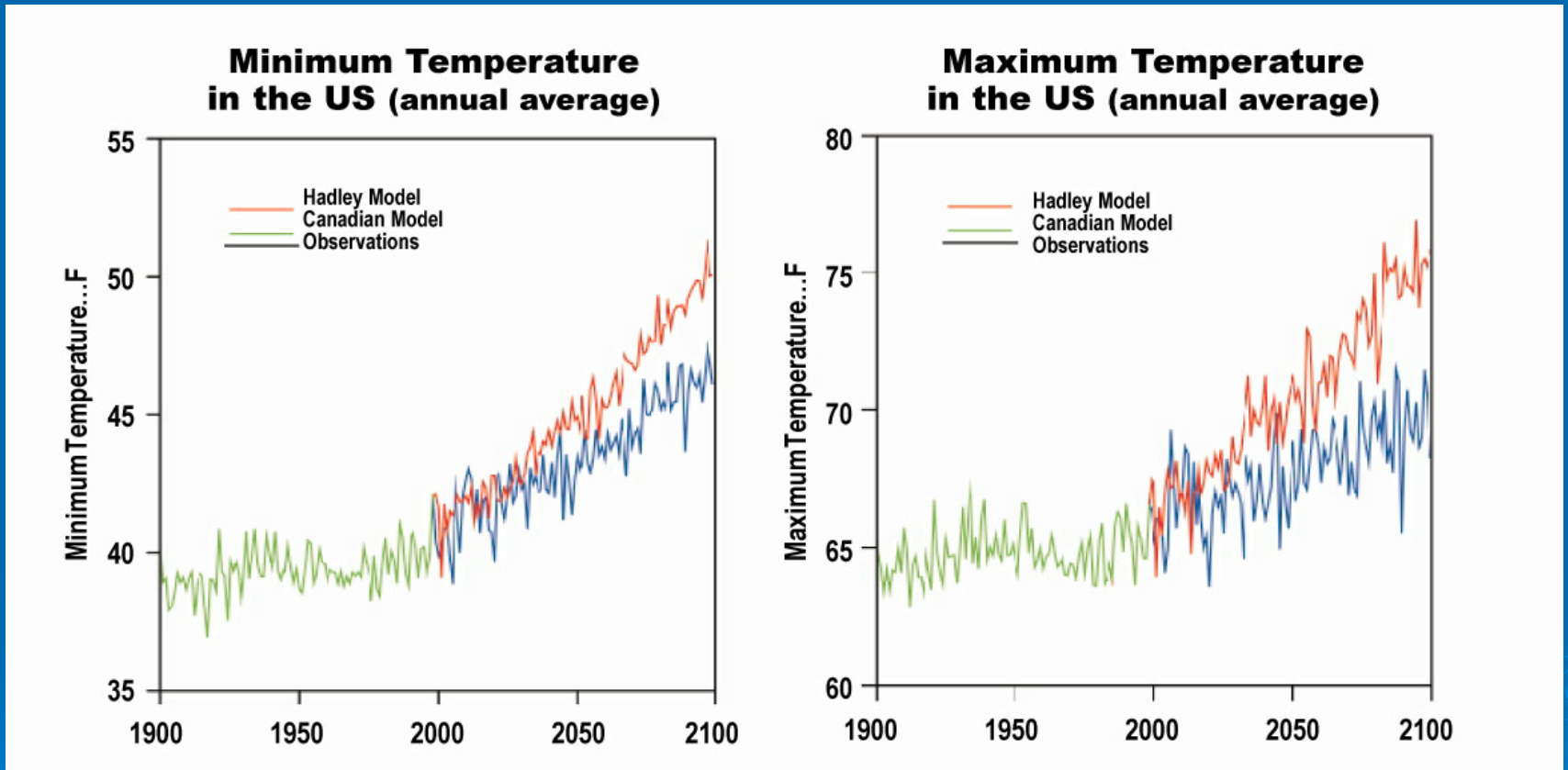
Potential Health Effects of Climate Variability and Change



*Moderating influences include non-climate factors that affect climate-related health outcomes, such as population growth and demographic change, standards of living, access to health care, improvements in health care, and public health infrastructure.

**Adaptation measures include actions to reduce risks of adverse health outcomes, such as vaccination programs, disease surveillance, monitoring, use of protective technologies, such as air conditioning, pesticides, water filtration/treatment, use of climate forecasts and development of weather warning systems, emergency management and disaster preparedness programs, and public education.

The nighttime minimum temperature will increase more than the daytime maximum



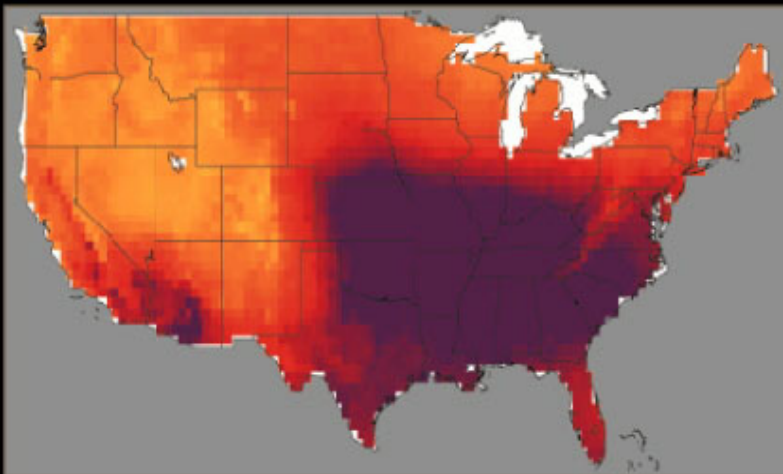
The potential impacts include higher daytime peak electricity demand, longer periods of high demand, and reduced combustion efficiencies

The average summertime heat index will increase more than will the temperature, and the absolute humidity will increase exponentially

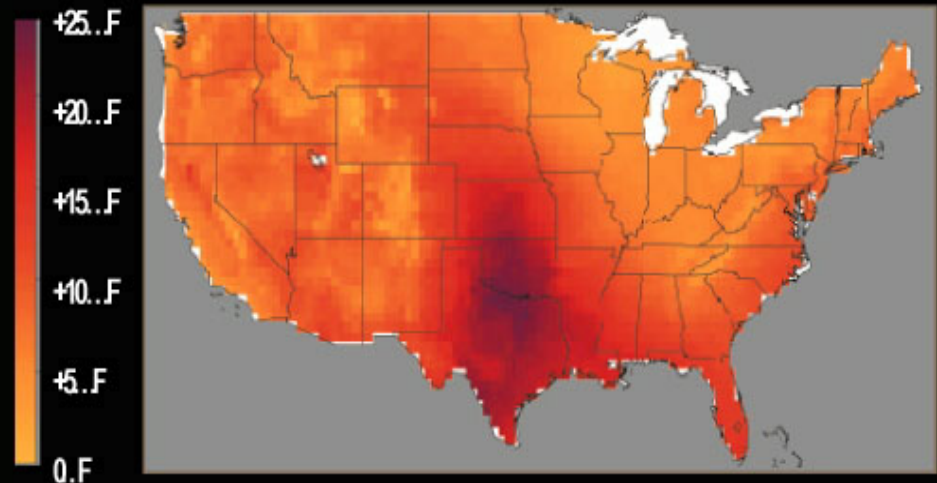
July Heat Index Change

The projected changes in the heat index for the Southeast are the most dramatic in the nation with the Hadley model suggesting increases of 8 to 15...F for the southernmost states, while the Canadian model projects increases above 25...F for much of the region.

Canadian Model 21st Century

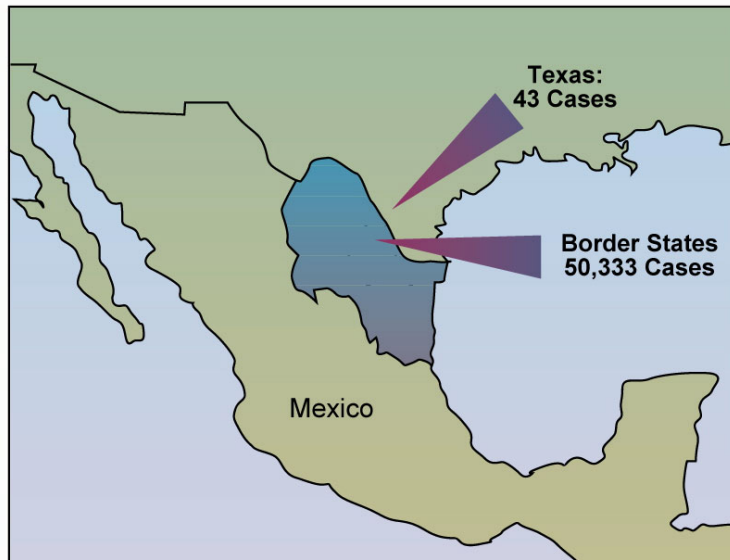


Hadley Model 21st Century



Strengthening public health and community planning is likely to help moderate some types of potential consequences

Reported Cases of Dengue 1980-1996

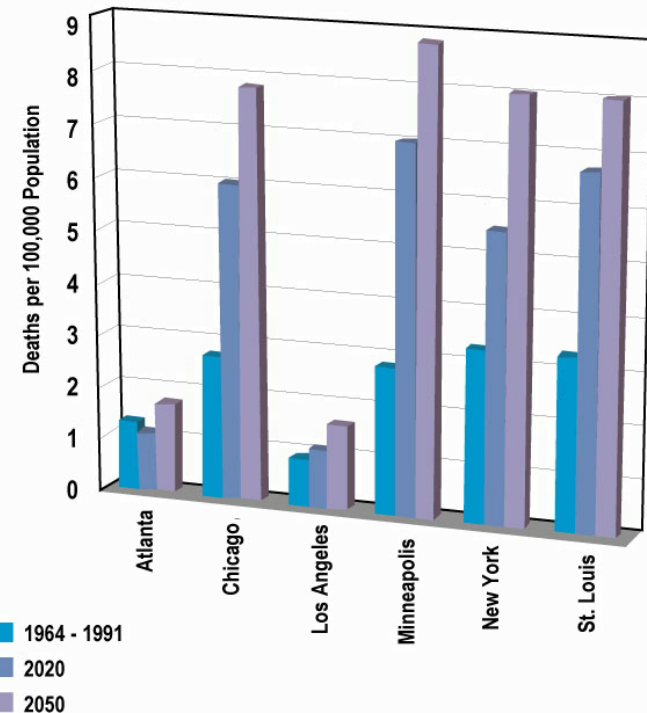


Dengue along the US-Mexico border. Dengue, a mosquito-borne viral disease, was once common in Texas (where there were an estimated 500,000 cases in 1922), and the mosquito that transmits it remains abundant. The striking contrast in the incidence of dengue in Texas versus three Mexican states that border Texas (43 cases vs. 50,333) in the period from 1980-1996 provides a graphic illustration of the importance of factors other than temperature, such as public health infrastructure, use of air conditioning and window screens, in the transmission of vector-borne diseases.

Community design and standards can limit mosquito habitat

Average Summer Mortality Rates

Attributed to hot weather episodes



Air-conditioning and better housing can limit heat stress

Examples of key regional consequences within the US

Region	Environmental Consequences	Economic Consequences	Consequences to People
Northeast	Wetland inundation	Reduced wintertime recreation	Rising summertime heat index
Southeast	Loss of coastal ecosystems; changing forests	Increasing productivity of hardwood forests	Increased coastal flooding; longer, hotter summers
Midwest	Higher lake and river temperatures alter fish species	Increasing agricultural productivity	Lowered lake and river levels; hotter summers
Great Plains	Warmer winters allow more invasive species	Increasing agricultural productivity	Worsened climatic extremes in spring/summer
West	Altered ecosystems, and more fire	Rising snowline intensifies water problems	Shift toward warm season recreation; greater fire danger
Northwest	Stress to cold/cool water ecosystems and fish	Earlier winter runoff tightens water supplies	Shift to warm season recreation; coastal erosion

The closer the examination of potential regional and sectoral impacts in the US, the more couplings appear to worldwide impacts

- ***Economic and Market Couplings:*** imported products, export markets, investments, international well-being
- ***Shared Resources and Environments:*** water resources, hydropower, fisheries, migrating species, ocean resources, biodiversity
- ***Human Health:*** disease prevalence and vectors, health of visitors, disease level of countries where visit and do business
- ***International Security and Well-Being:*** pressures for immigration, environmental refugees, levels of international conflict and requirements for peace-keeping, concern for relatives and peoples

Climate change will affect peoples and environments around the world

Some crops benefit; earlier spring peak river flows; more coastal flooding & storm surges.

Decreased summer water availability in south; increased river floods; northward shift of biotic zones

Sea level rise & more intense cyclones displace tens of millions in coastal areas; mangrove & coral ecosystems at risk.

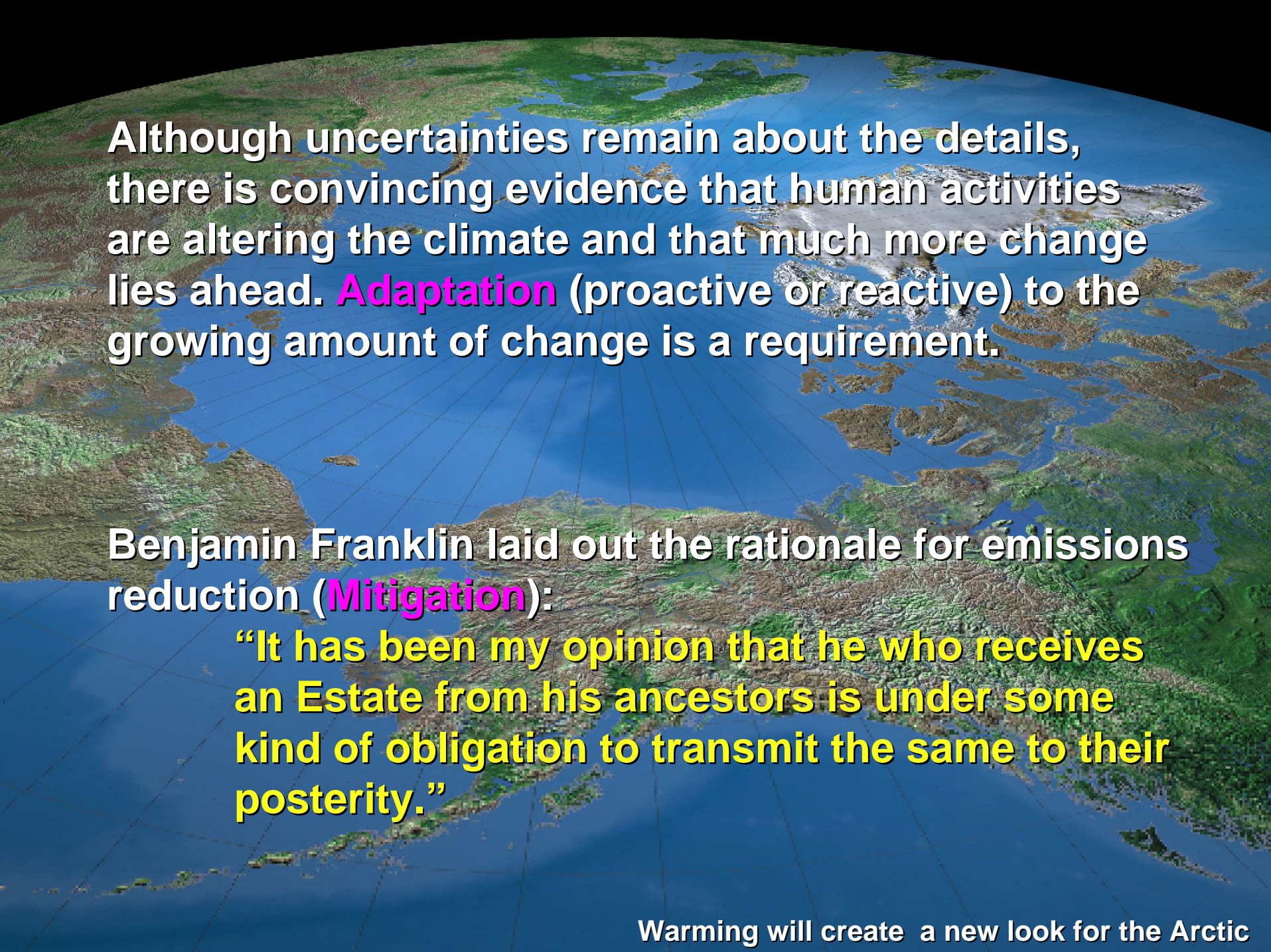
Glacier retreat impacts some water supplies; more frequent floods & droughts; decreased crop yields in many locations;

Diminished food security; floods & droughts stress water supply; some coastal regions inundated & eroded

Drying trends; some species become extinct or endangered

Small Is States:
Loss of coastal land and property; dislocation of people; some islands vulnerable to change in water balance.

Polar regions: Most rapid changes; altered distribution and abundance of species already seen.



Although uncertainties remain about the details, there is convincing evidence that human activities are altering the climate and that much more change lies ahead. **Adaptation** (proactive or reactive) to the growing amount of change is a requirement.

Benjamin Franklin laid out the rationale for emissions reduction (**Mitigation**):

“It has been my opinion that he who receives an Estate from his ancestors is under some kind of obligation to transmit the same to their posterity.”

Warming will create a new look for the Arctic

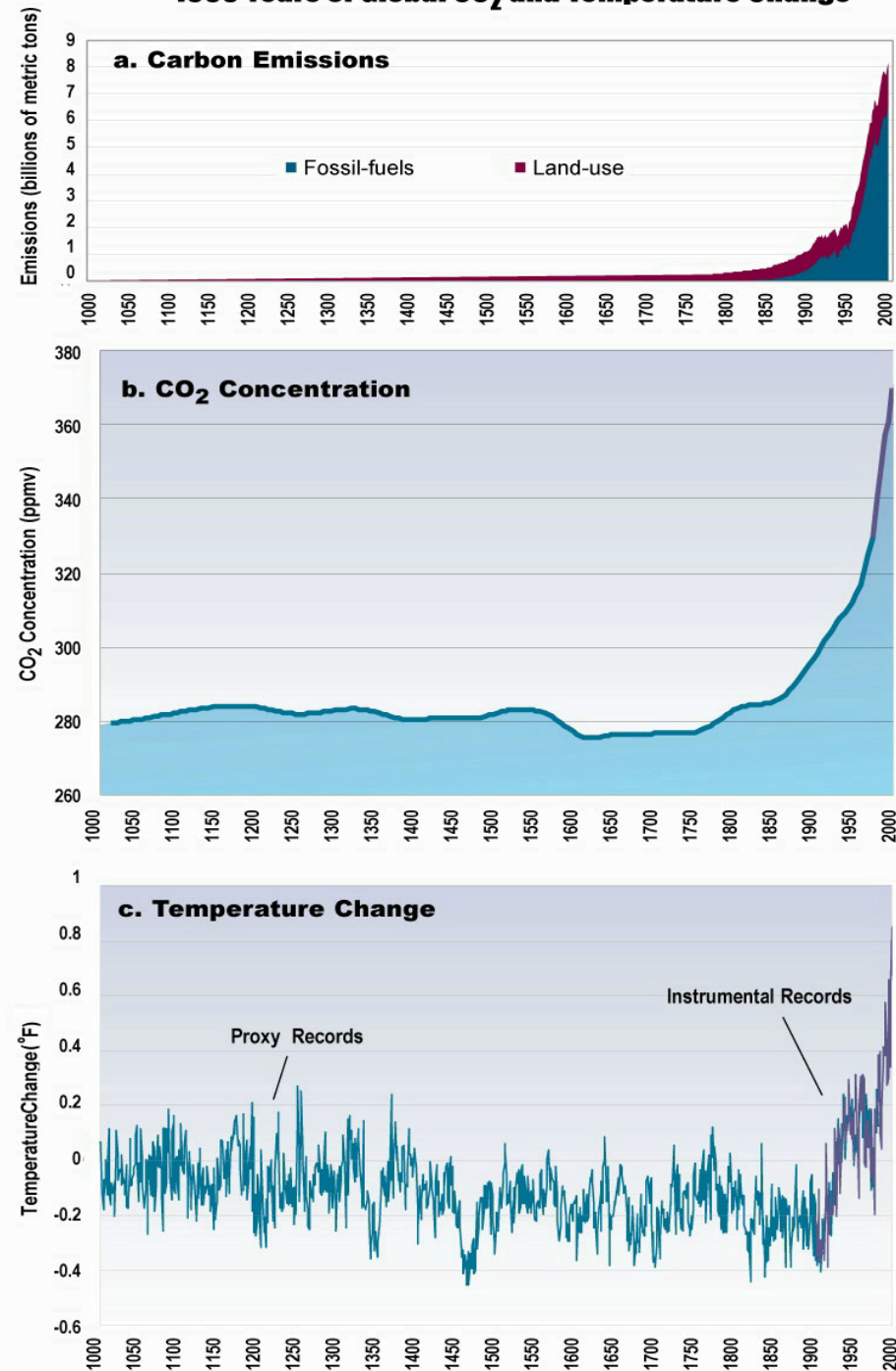
Because Science is Never Certain, There Will Always be Differing Views

- **Scientific Skepticism:** All scientists are taught to be skeptical, to raise questions, and to investigate alternative hypotheses and explanations
- **IPCC Consensus:** Most active research scientists support the IPCC process as a means of expressing consensus understanding and agree with the overall thrust and nature of the findings, even if disagreeing with some details
- **The Skeptics:** A relatively small number of active scientist and a larger number of formerly active scientists, energy experts, and economists--generally also opposed to governmental interventions of many kinds--who focus primarily on the shortcomings in understanding, and tend to be rather uncritically attracted to alternative hypotheses

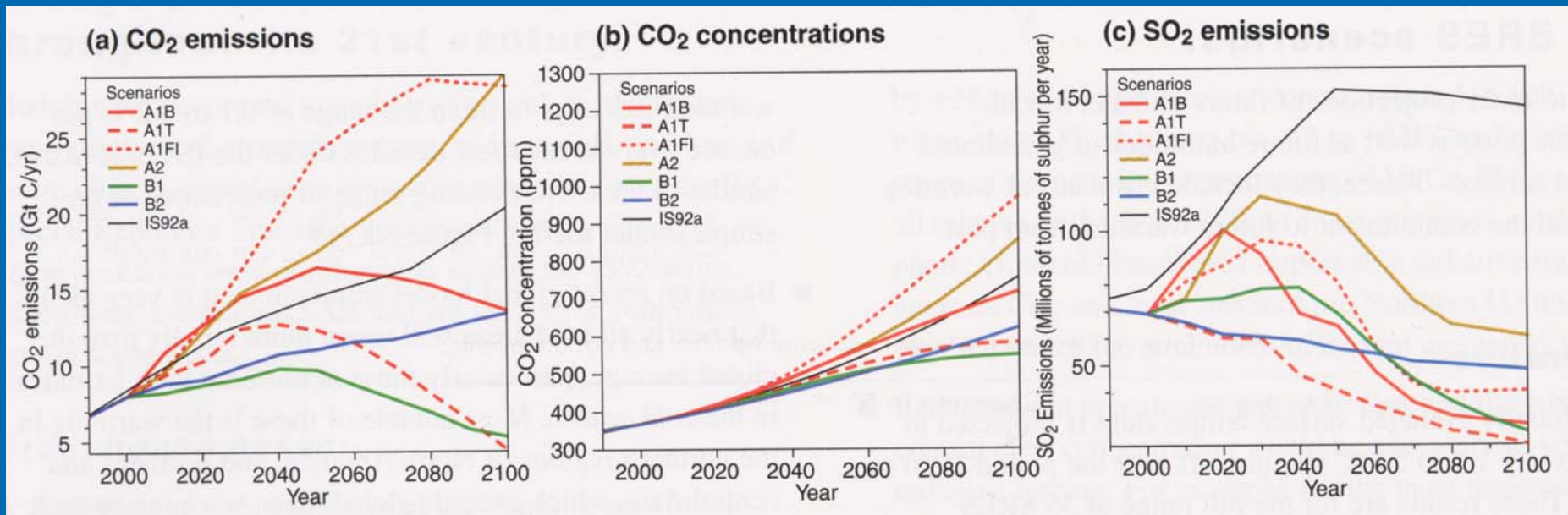
The Observations Alone Create a Very Strong Circumstantial Case for a Strong Human Influence

The consistency of reconstructions of the changes in (a) CO₂ emissions, (b) CO₂ concentrations, and (c) surface temperature over the last 1000 years strongly suggest that the 20th century has been significantly warmed by human activities

1000 Years of Global CO₂ and Temperature Change



To evaluate potential changes in atmospheric composition, 6 storylines were created as possible scenarios for the future



Emissions storylines:

- A1B: Rapid economic growth with balanced set of energy technologies
- A1T: Rapid economic growth with strong emphasis to non-fossil energy technologies
- A1F1: Rapid economic growth with emphasis on fossil fuel energy technologies
- A2: Heterogeneous world with preservation of local identities and fragmented economic growth
- B1: Convergent world economy, moving toward service and information economy and efficient technologies
- B2: Emphasis on local solutions, with continued growth in world population, and emphasis on environmental protection and social equity
- IS92a: Business as usual scenario generated in 1992 and used in IPCC's Second Assessment Report

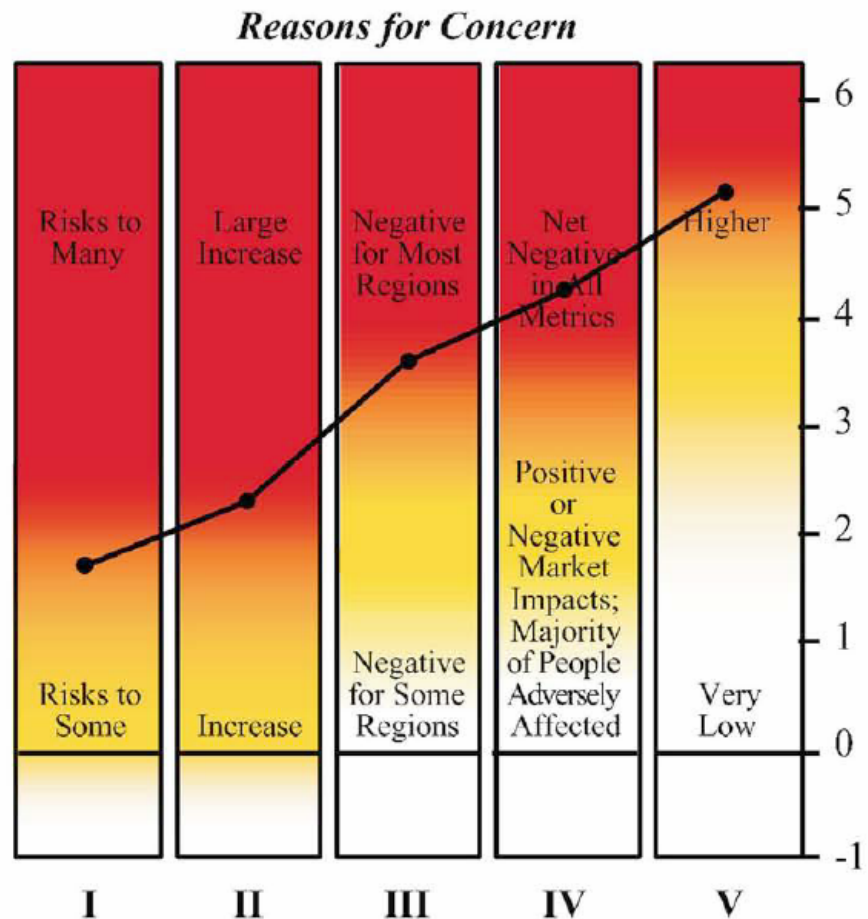
Summary of Impacts by the IPCC--there is not much margin before most systems are significantly impacted

White: neutral or small positive or negative impacts

Yellow: negative impacts for some systems or low risks

Red: negative impacts or risks that are more widespread and/or greater in magnitude

I	Risks to Unique and Threatened Systems
II	Risks from Extreme Climate Events
III	Distribution of Impacts
IV	Aggregate Impacts
V	Risks from Future Large-Scale Discontinuities



Temperature increase (°C)

Reasons for concern about projected climate change impacts

Source: IPCC *Climate Change 2001*; S. Schneider & M. Mastrandrea, *PNAS*, **102**, 15728, 2005.

The World Faces a Difficult Challenge, but it is not yet Technologically Insurmountable

- **Adaptation to ongoing and changes will be required.** Climate change has already begun and will continue for many decades, even with significant cutbacks in emissions. We can either use what scientific information we have to prepare, or we will have to adapt as we go, costly as that may be.
- **Mitigation is essential if we are to avoid initiating the rapid onset of very disruptive impacts.** Because of the time to make changes and the inertia of the climate system, aggressive efforts to limit emissions need to begin now, even though the direct benefits of eventually slowing climate change will mainly be experienced by our grandchildren. In the short-term, the indirect benefits of improving energy security, creating jobs in the US, and some reduction in air and water pollution are likely.
- **Delay is very likely to only make the transition need to be more rapid, and therefore likely more expensive.** California, for example, projects cost savings by making the transition.

The UN Framework Convention on Climate Change, Adopted Internationally in 1992, Set an Objective of Atmospheric Stabilization

Objective 2 of the UNFCCC calls for:

- stabilization of the greenhouse gas concentrations in the atmosphere
- at a level that would prevent dangerous anthropogenic interference with the climate system.
- Such a level should be achieved within a time-frame sufficient
 - to allow ecosystems to adapt naturally to climate change,
 - to ensure that food production is not threatened, and
 - to enable economic development to proceed in a sustainable manner.

Earth Summit, Rio de Janeiro, 1992

(adopted widely by the world community
and approved by the US Senate in 1992)

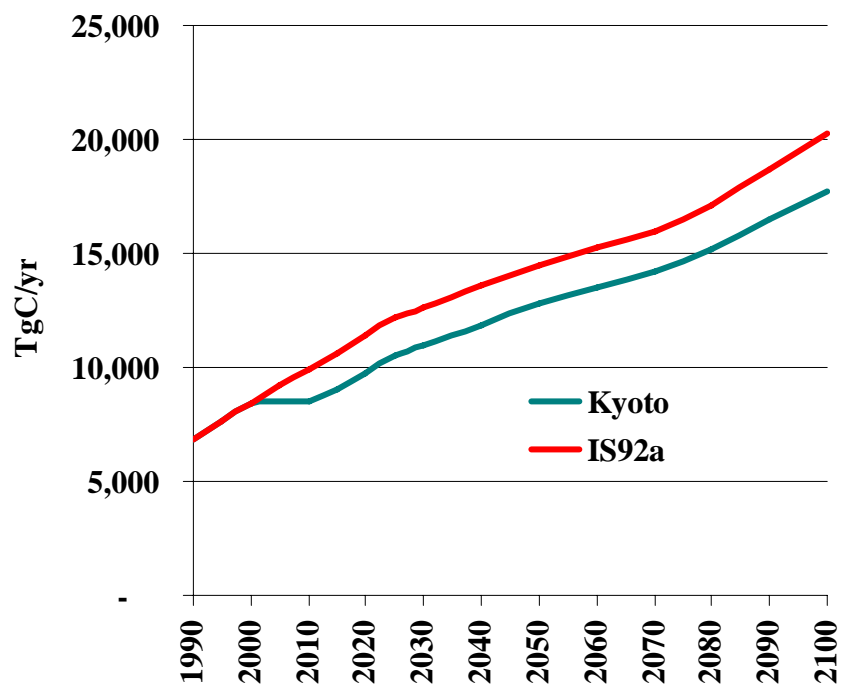
Slowing the rate of climate change will require significant reductions in CO₂ and CH₄ emissions, but the trends are in the opposite direction

Future emissions will be the product of four terms:

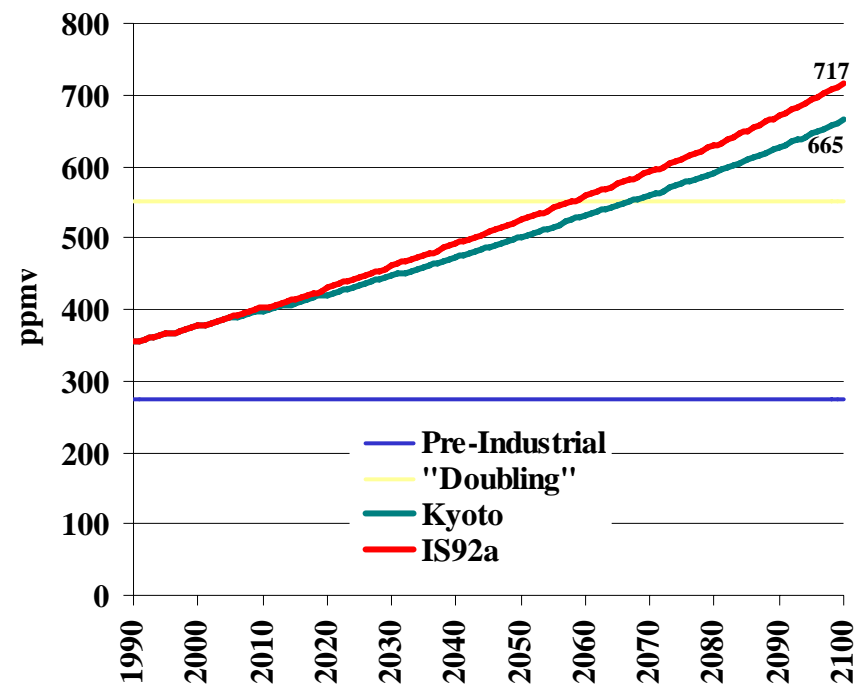
- The global population ⇐ Rising
- Energy use per person ⇐ Rising
(related to standard of living)
- Fraction of energy coming ⇐ Depends on choice
from fossil fuels of technology
- Amount of carbon from fossil ↑ Will rise if go to coal,
fuel generation of energy unless sequester

The Kyoto Protocol, Even if Fully Implemented, Would Have Only a Very Modest Effect-- Challenging as It May Be, It Can Only Be a First Step

Emissions



Concentrations



Actually stabilizing the atmospheric CO₂ concentration will require a significant reductions in emissions

Assuming the world population rises from 6 billion to 10 billion, stabilizing CO₂ implies the following per capita limits for the 21st century (compared to current level of 1 tC/person/yr):

- Current CO₂ level (370 ppmv) ⇔ Near zero
- Double preindustrial (550 ppmv) ⇔ 1 tC/person/yr
- Double 1990s (710 ppmv) ⇔ 2 tC/person/yr
- Unconstrained (>1000 ppmv) ⇔ 3 tC/person/yr
- U.S. usage today ⇔ >5 tC/person/yr

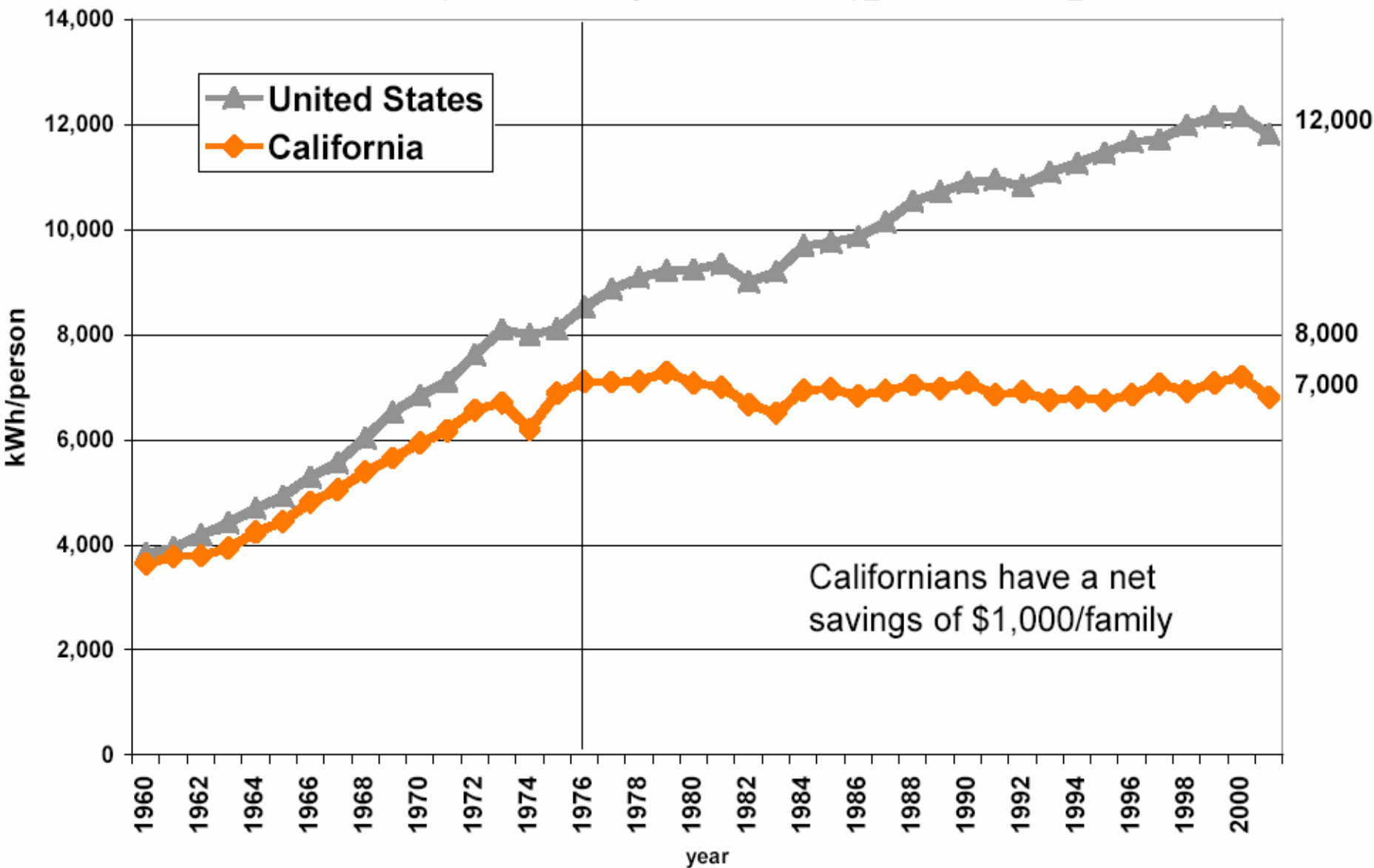
Global average decrement that Kyoto agreement would create is <0.25 tC/person/yr

A Range of Short-term Options are Available to Reduce Greenhouse Gas Emissions

- Improved efficiency (motors, lights, appliances, etc.)
- Insulation and better thermal design of buildings and appliances
- Recycling and reduction of waste generation in manufacturing
- Better electronic controls
- Switching from coal and oil to natural gas so less carbon emitted
- Improving combustion efficiency
- Reducing methane emissions
- Renewables where cost-effective (wind, solar, hydro, biomass)
- Reforestation and reducing deforestation as emissions offsets
- Eliminating CFCs having high Global Warming Potentials
- Lifestyle changes (mass transit, bicycling, carpooling, etc.)
- Others (taxes, parking fees, incentives, etc.)

Per Capita Electricity Consumption

Source: http://www.eia.doe.gov/emeu/states/sep_use/total/csv/use_csv



Getting to Long-term Solutions Appears to be a Very Large Challenge

From a global perspective, it is easy to be discouraged:

- There are many gases to deal with (CO₂, CH₄, etc.)
- Solutions are needed for both transportation and for electric generation
- With fossil fuels supplying 90% of the world's energy, finding a single solution is hard to imagine

Possibilities seem to include:

- Biomass--competes with food and forests for land and nutrients
- Fission--very large numbers required, with consequent environmental issues on a global basis
- Fusion--Appears to be 50 years in the future
- Solar--Requires storage medium (possibly hydrogen)
- Solar power satellites--conceivable, but very visionary
- Ocean kelp farming--massive undertaking
- Geoclimatic engineering (mirrors, aerosols)--important side-effects
- Adaptation starts to appear as an essential option

Taking a Regional Perspective Provides the Basis for some Encouragement

Thinking about solutions on a regional basis:

- Wet tropics: biomass, reforestation, hydropower, etc.
- Dry subtropics: windpower, distributed solar, solar thermal
- Industrialized midlatitudes: efficiency, conservation, natural gas as transition to biomass, solar, wind, nuclear, etc.; dietary changes
- Large developing nations (China, India); efficient coal and other fossil fuels, solar, wind, etc.

While there is a need to think globally, action and solutions are likely most practical if carried out on a local to national scale.

The range of approaches seems to present many opportunities for technology.

(Regional breakdown originally from L. Kulp)