

Global change: Scientific understanding and challenges for the future

KBS GK12 program

3 Oct 2012

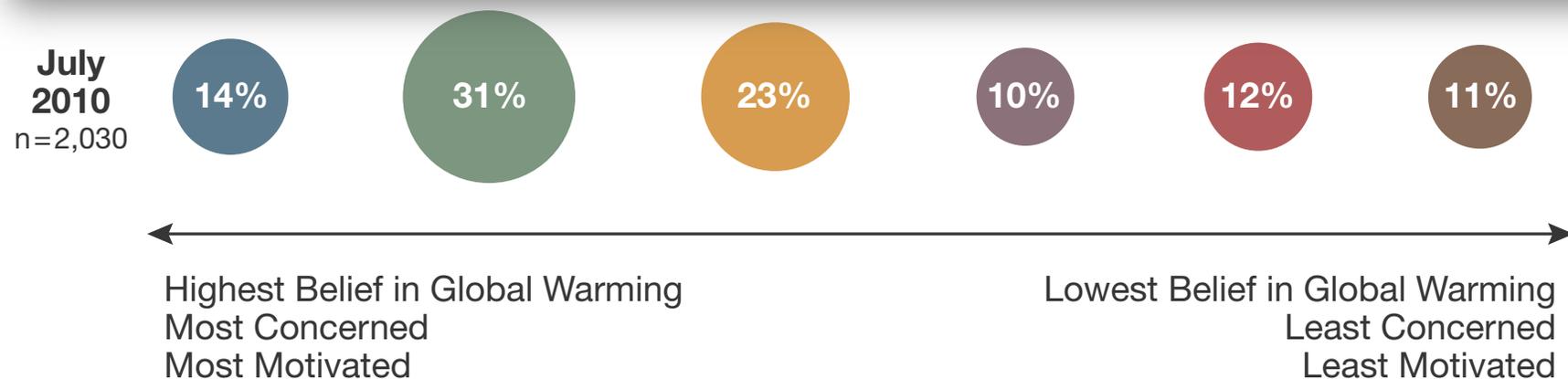
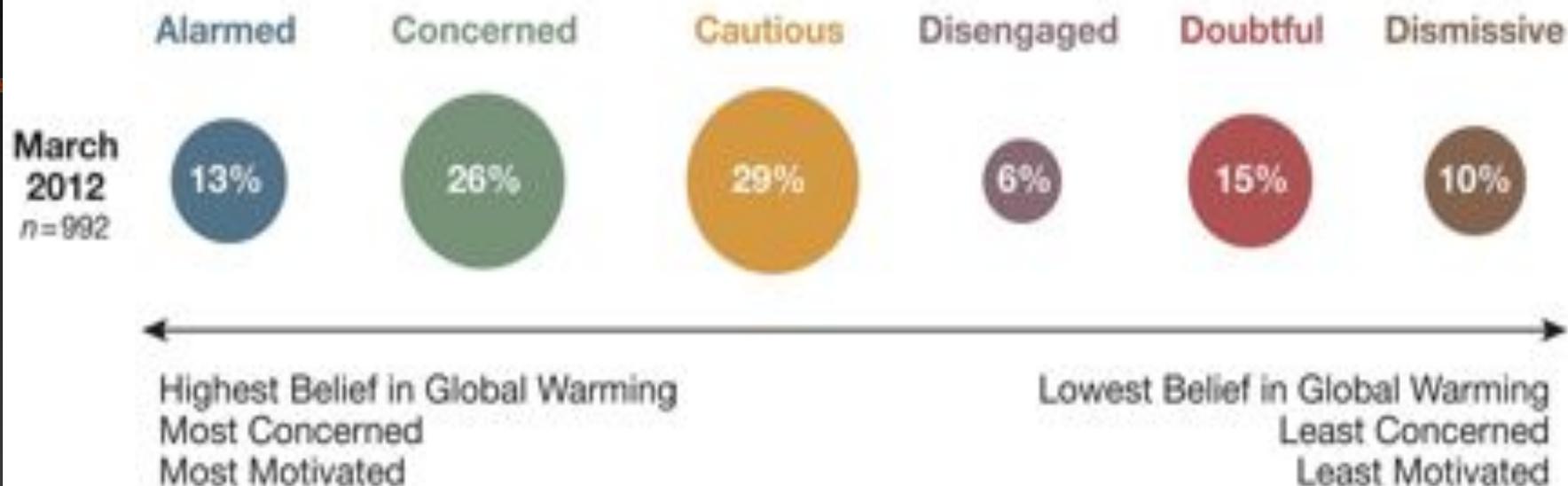
Steve Hamilton



Global change, climate change, global warming?

- Warming is the greatest driver of global change
 - But warming will not happen everywhere
 - Many other climate changes expected:
 - Hydrological cycle
 - Extreme weather
 - Effects extend throughout Earth system:
 - Less snow and ice
 - Ocean acidification by carbon dioxide
-

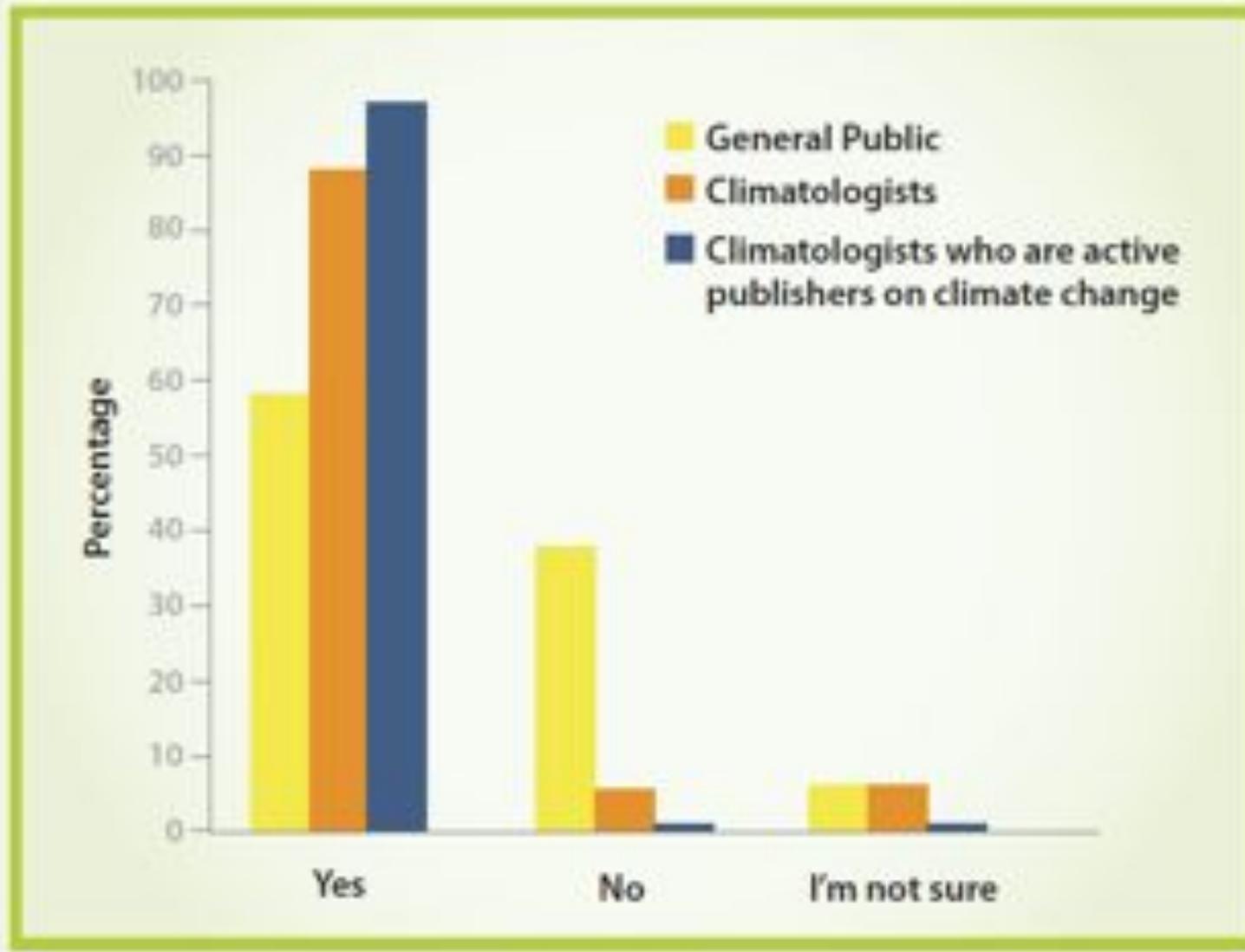
Do people understand the challenge?



Proportion represented by area

Source: Yale Project on Climate Change Communication

Scientific consensus vs. public confusion



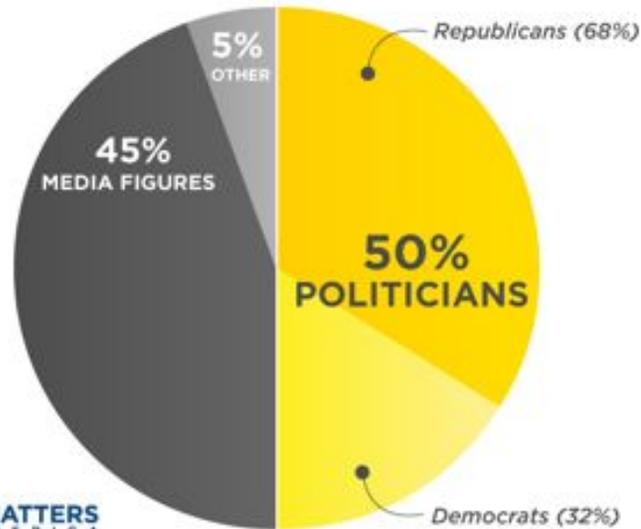
Are Humans Changing the Temperature of the Earth?
A recent study asked this question of the public, of climate scientists who don't publish many papers, and of those who do.

From "Twenty questions and answers about climate change" (Sally Ride Science and Climate Central, 2010)

Scientists are often not even in the public discourse on global change

WHO DID THE SUNDAY SHOWS
HOST OR QUOTE ON CLIMATE CHANGE?

2009-2011



MEDIAMATTERS
FOR AMERICA

Mainstream Media's Climate Coverage Is Overwhelmingly Misleading

Wall Street Journal Opinion Page
Coverage of Climate Science



From August 2011 to July 2012, 39 of 48 references to climate science were misleading. Only 9 were accurate.
© State of Colorado Science 2012

Fox News Channel
Coverage of Climate Science



From February to July 2012, 37 of 40 references to climate science were misleading. Only 3 were accurate.
© State of Colorado Science 2012

International and national scientific consensus on global change

- IPCC – Intergovernmental Panel on Climate Change
 - Latest (2007) report concludes: “**Warming of the climate system is unequivocal**, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level.”
- AGU – American Geophysical Union
 - 41,000 Earth and space scientists
 - “**Human activities are increasingly altering the Earth's climate...** Scientific evidence strongly indicates that natural influences cannot explain the rapid increase in global near-surface temperatures...”

Mounting evidence that the climate is already warming

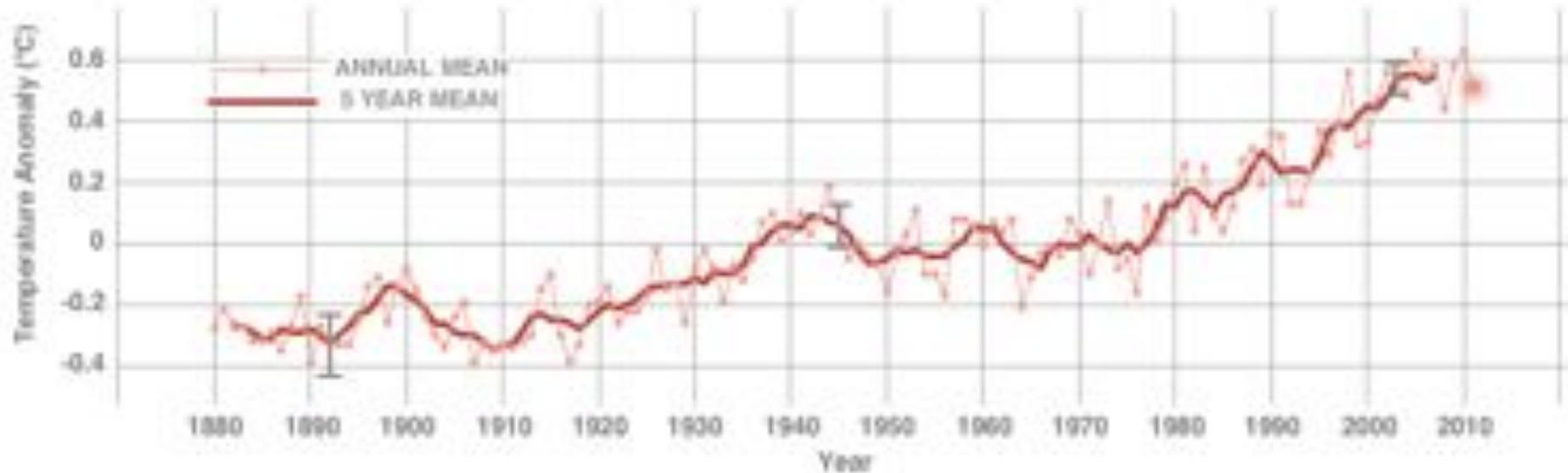
- First 8 months of 2012 hottest ever recorded (1 deg F warmer than record)
 - 2000-09 was warmest decade on record
 - 1990s second warmest
 - Arctic sea ice, Greenland land ice diminishing faster than expected
 - Glaciers in retreat worldwide
 - Antarctic ice shelves degrading
-

Long term temperature record (to 2011)

Data updated 1/20/12

GLOBAL LAND-OCEAN TEMPERATURE INDEX

Data source: [NASA's Goddard Institute for Space Studies \(GISS\)](#). This trend agrees with other global temperature records provided by the U.S. National Climatic Data Center, the Japanese Meteorological Agency and the Met Office Hadley Centre / Climatic Research Unit in the U.K. Credit: NASA/GISS



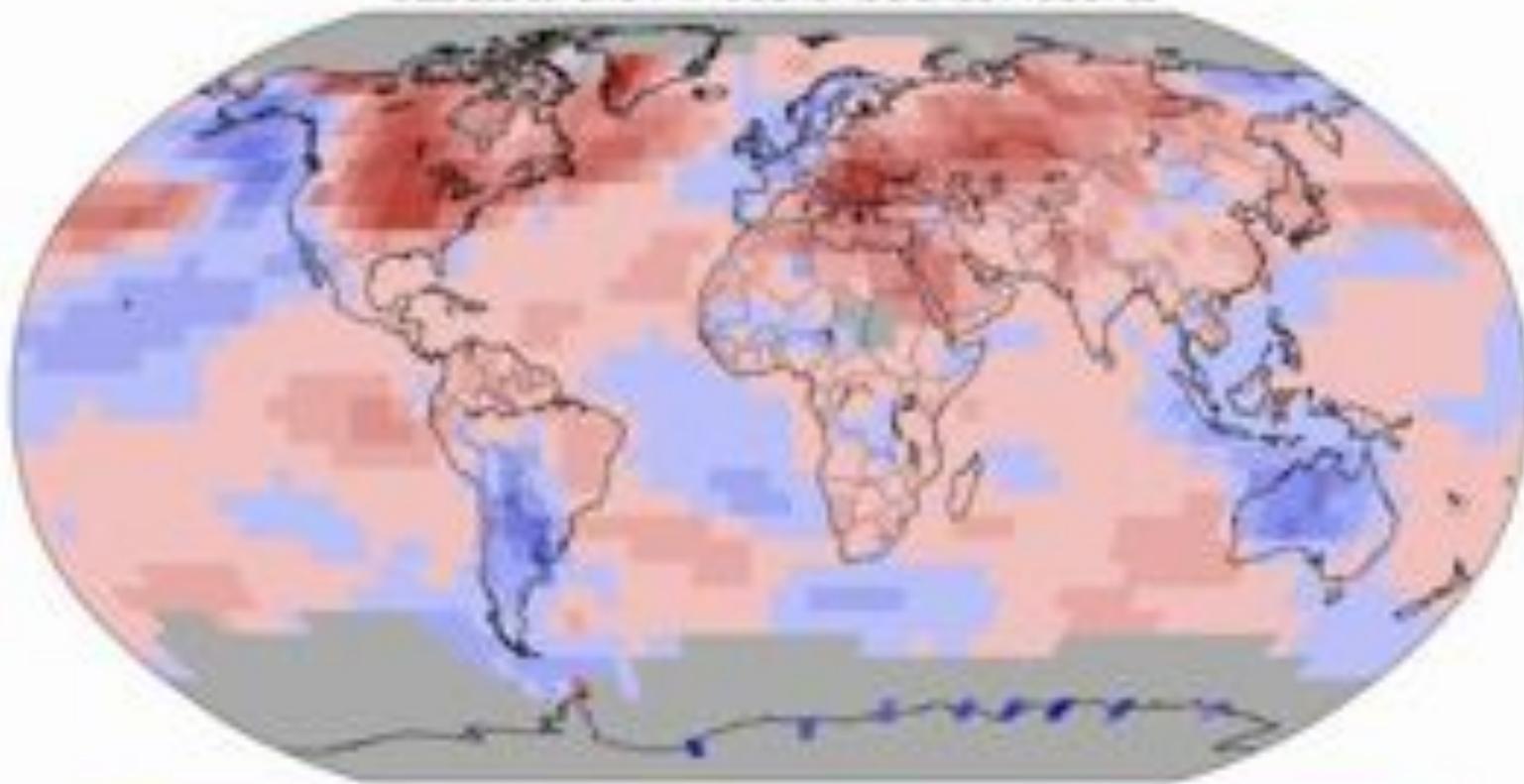
climate.nasa.gov/keyindicators/

Warming is uneven

Land & Ocean Temperature Anomalies Jul 2012

(with respect to a 1981–2010 base period)

Data Source: GHCN-M version 3.1.0 & ERSST version 3b



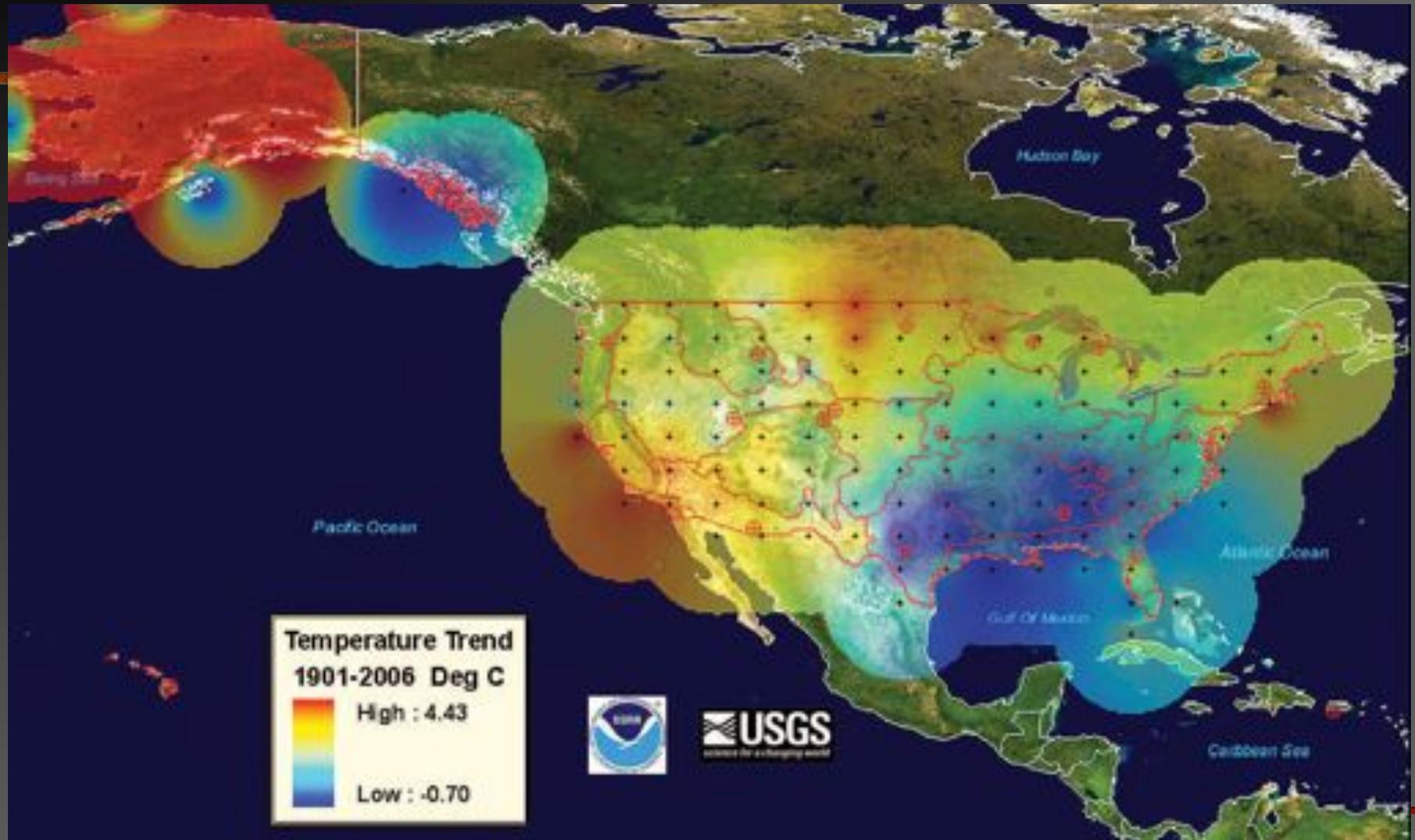
NOAA's National Climate Data Center

Degrees Celsius

Please Note: Grey areas represent missing data

10/2/12

Uneven distribution of warming observed so far in the US



Arctic Sea Ice

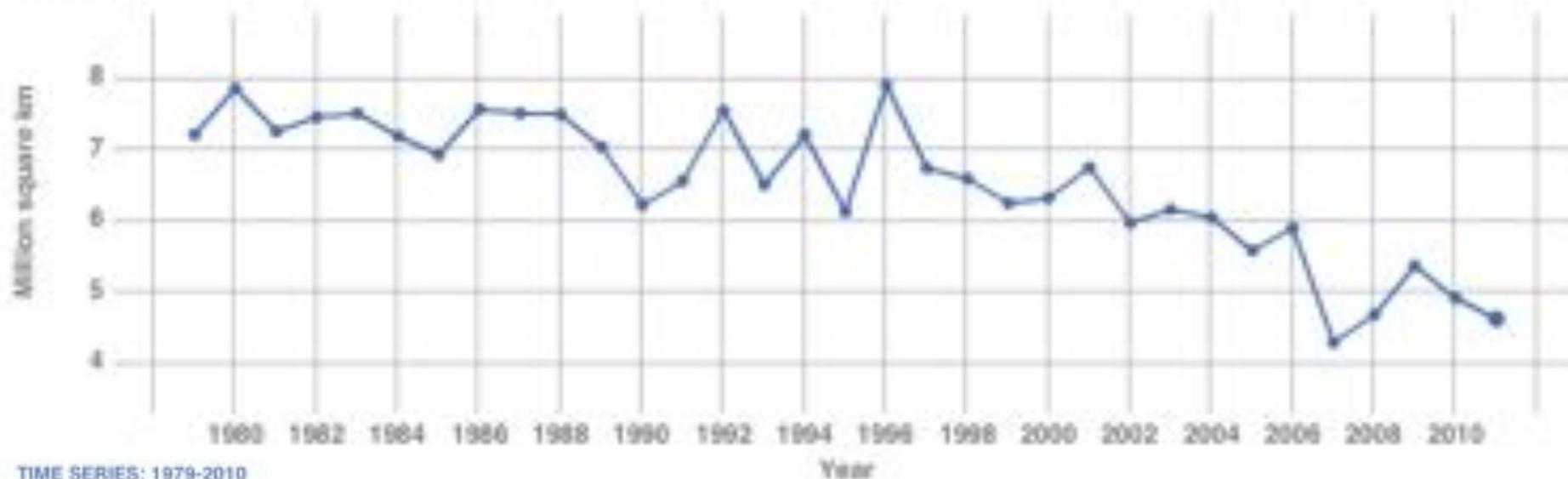
Data updated 10.10.11

↓ DOWNLOAD DATA

AVERAGE SEPTEMBER EXTENT

Data source: Satellite observations

Credit: NSIDC



TIME SERIES: 1979-2010

Data source: Satellite observations

Credit: NASA/Goddard Scientific Visualization Studio

move the slider below to view changes over time

1979



1980 1985 1990 1995 2000 2005 2010

[climate.nasa.gov/
keyindicators/](http://climate.nasa.gov/keyindicators/)

Data source: Satellite observations

Credit: NASA/Goddard Scientific Visualization Studio

2010



1980 1985 1990 1995 2000 2005 2010

Land Ice

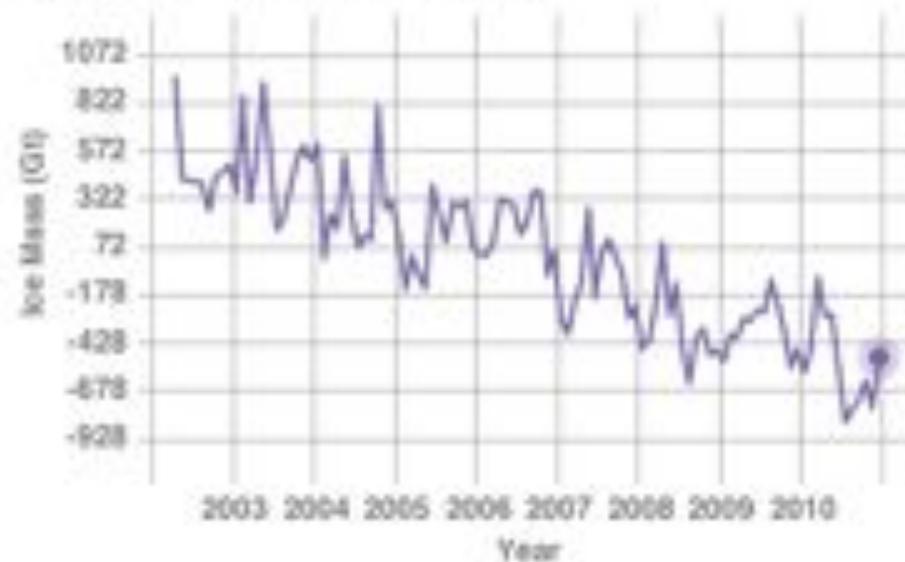
Data updated 11/4/11

DOWNLOAD DATA

ANTARCTICA MASS VARIATION SINCE 2002

Data source: Ice mass measurement by NASA's Grace satellites.

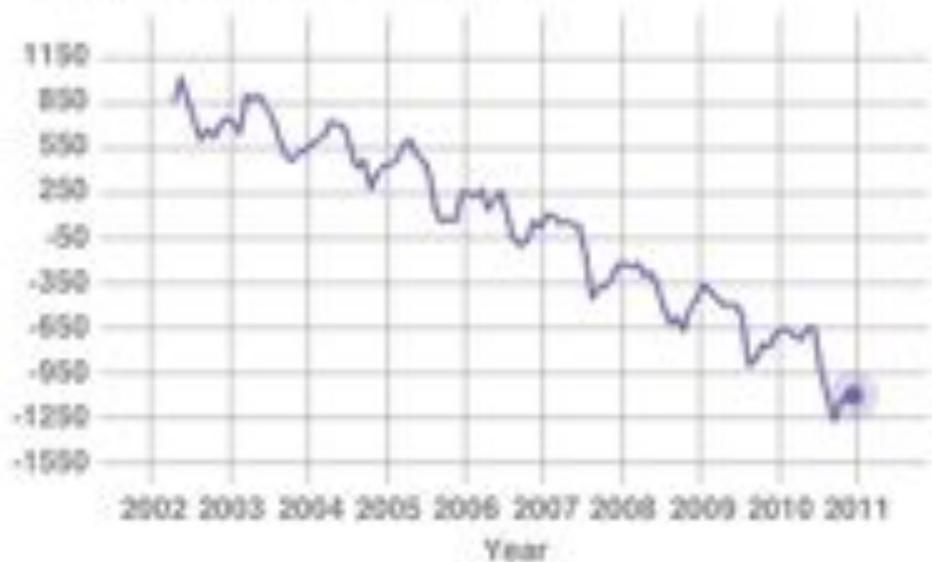
Credit: NASA/University of California, Irvine



GREENLAND MASS VARIATION SINCE 2002

Data source: Ice mass measurement by NASA's Grace satellites.

Credit: NASA/University of California, Irvine



Note: In the above charts, mass change is relative to the average during the entire period. (Reference)

[climate.nasa.gov/
keyindicators/](http://climate.nasa.gov/keyindicators/)

Historical sea level record

Sea Level

Data updated 5/30/12

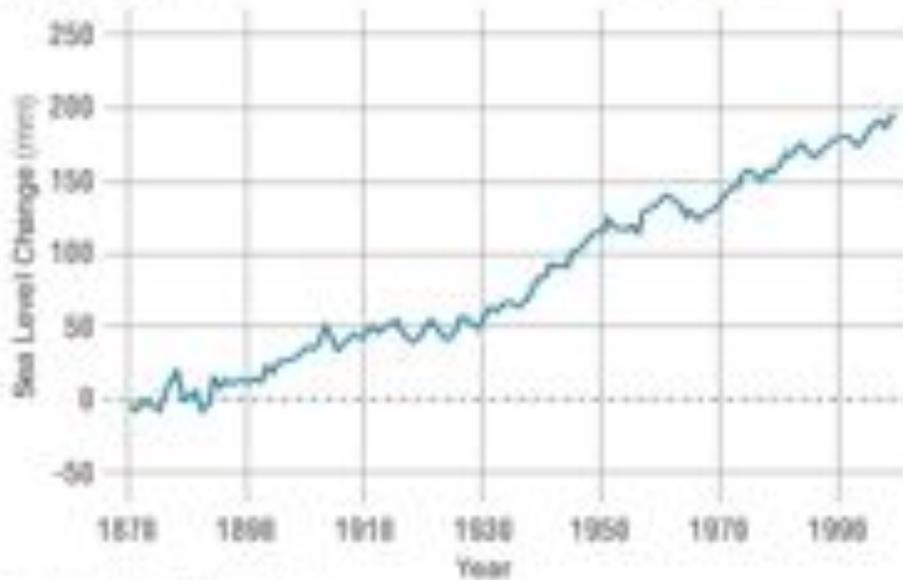
DOWNLOAD DATA

GROUND DATA: 1870-2000

Data source: Coastal tide gauge records.
Credit: [NOAA](#)

RATE OF CHANGE

↑ 1.70 mm^a



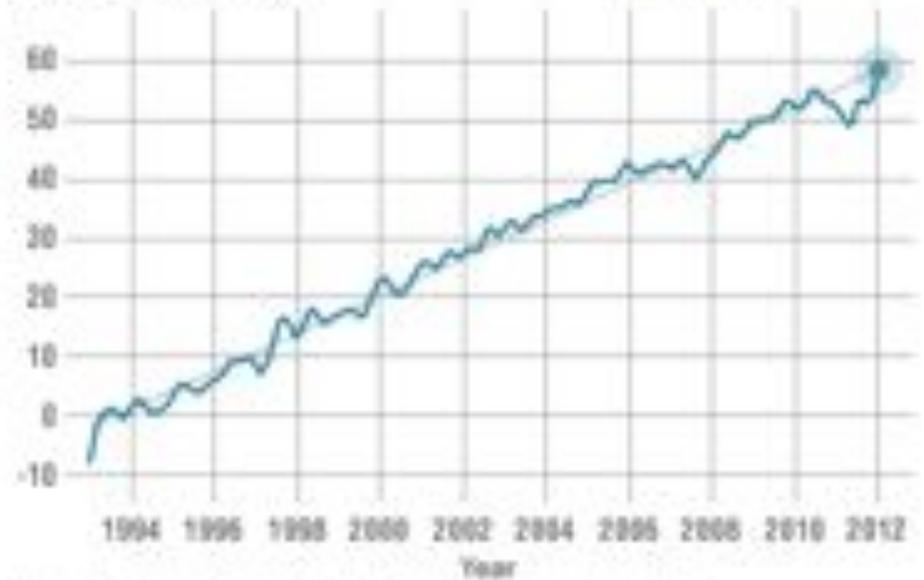
^aestimate for 20th century

SATELLITE DATA: 1993-PRESENT

Data source: Satellite sea level observations.
Credit: [JPL/Cornell/Leos](#)

RATE OF CHANGE

↑ 3.17 mm

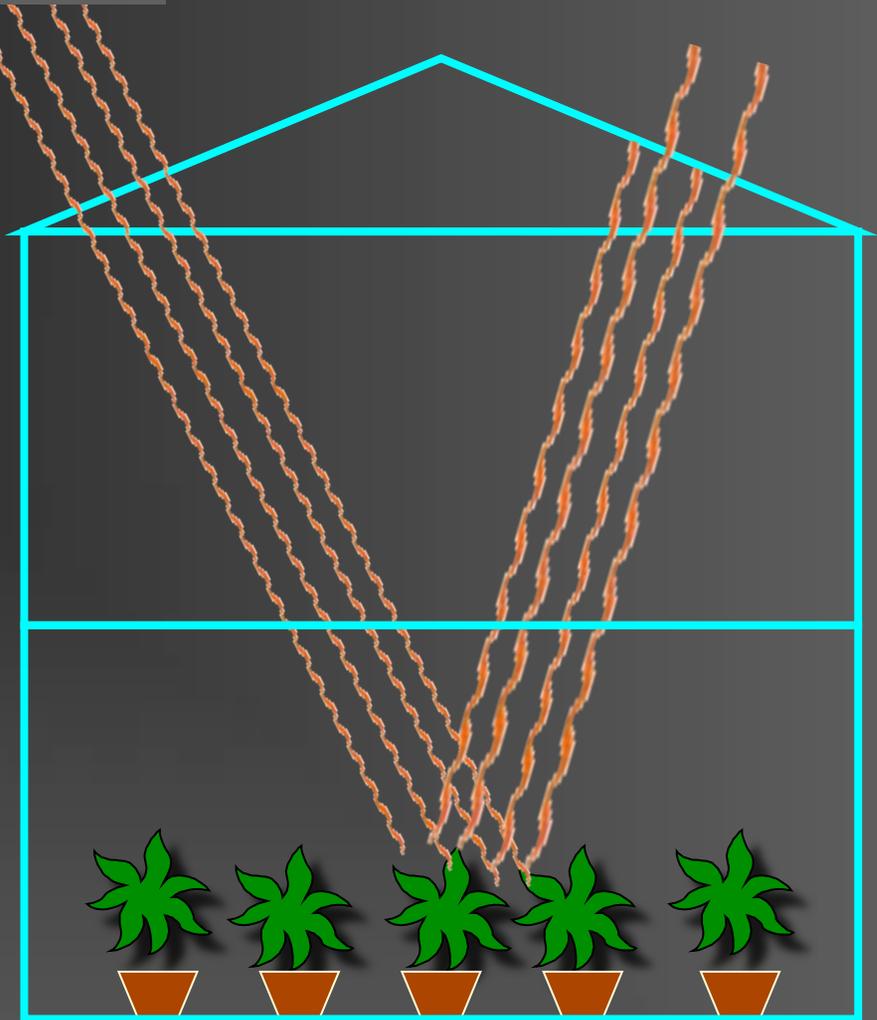


Inverse barometer applied and seasonal signals removed.

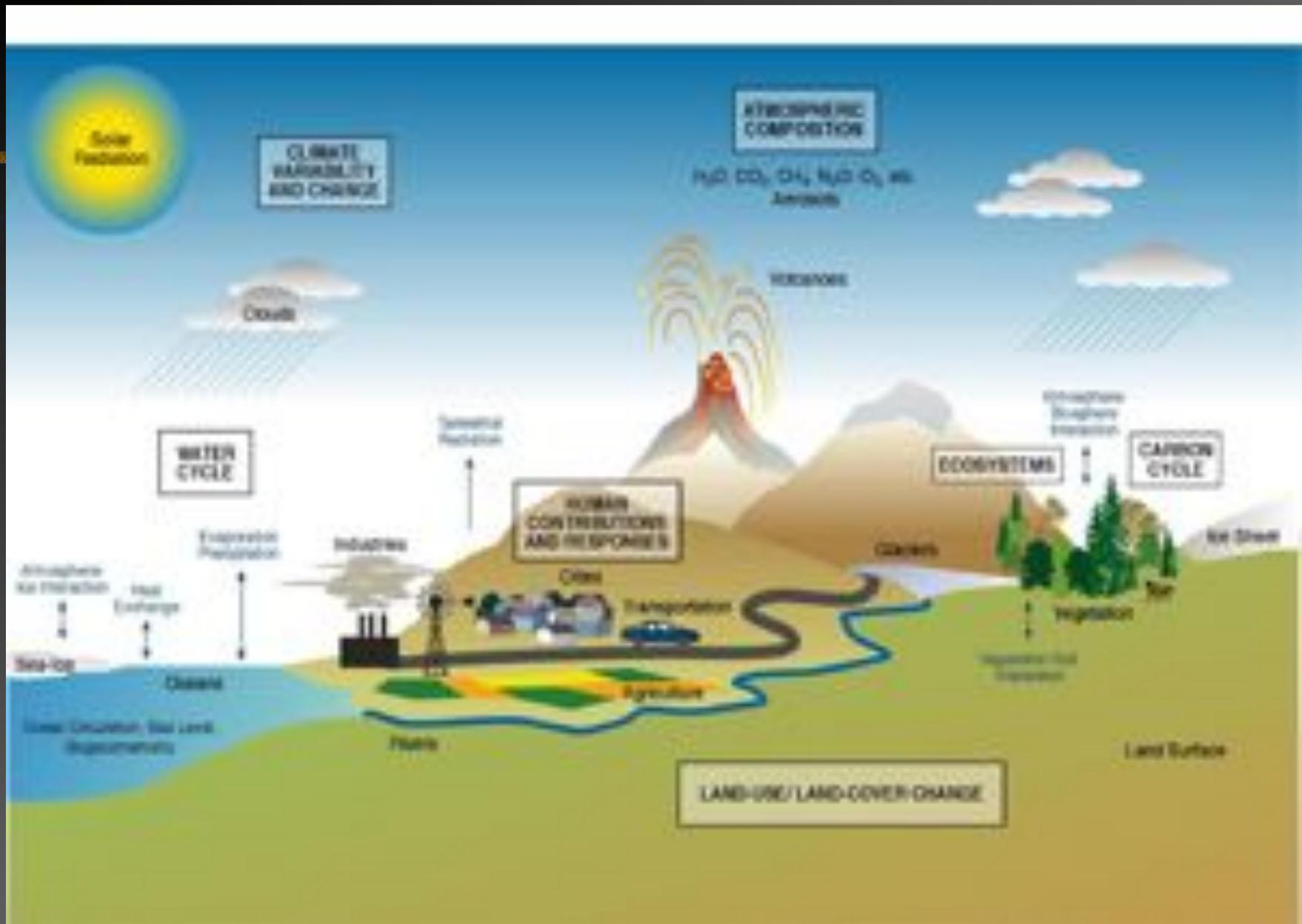
The greenhouse effect

- Heat-trapping gases make the Earth's surface warm
- Human activities -- fossil fuel combustion, agriculture, deforestation -- increase heat-trapping "greenhouse gases"
 - Carbon dioxide, methane, nitrous oxide, ozone, CFCs
- Heat balance of the land surface also important

Sunlight

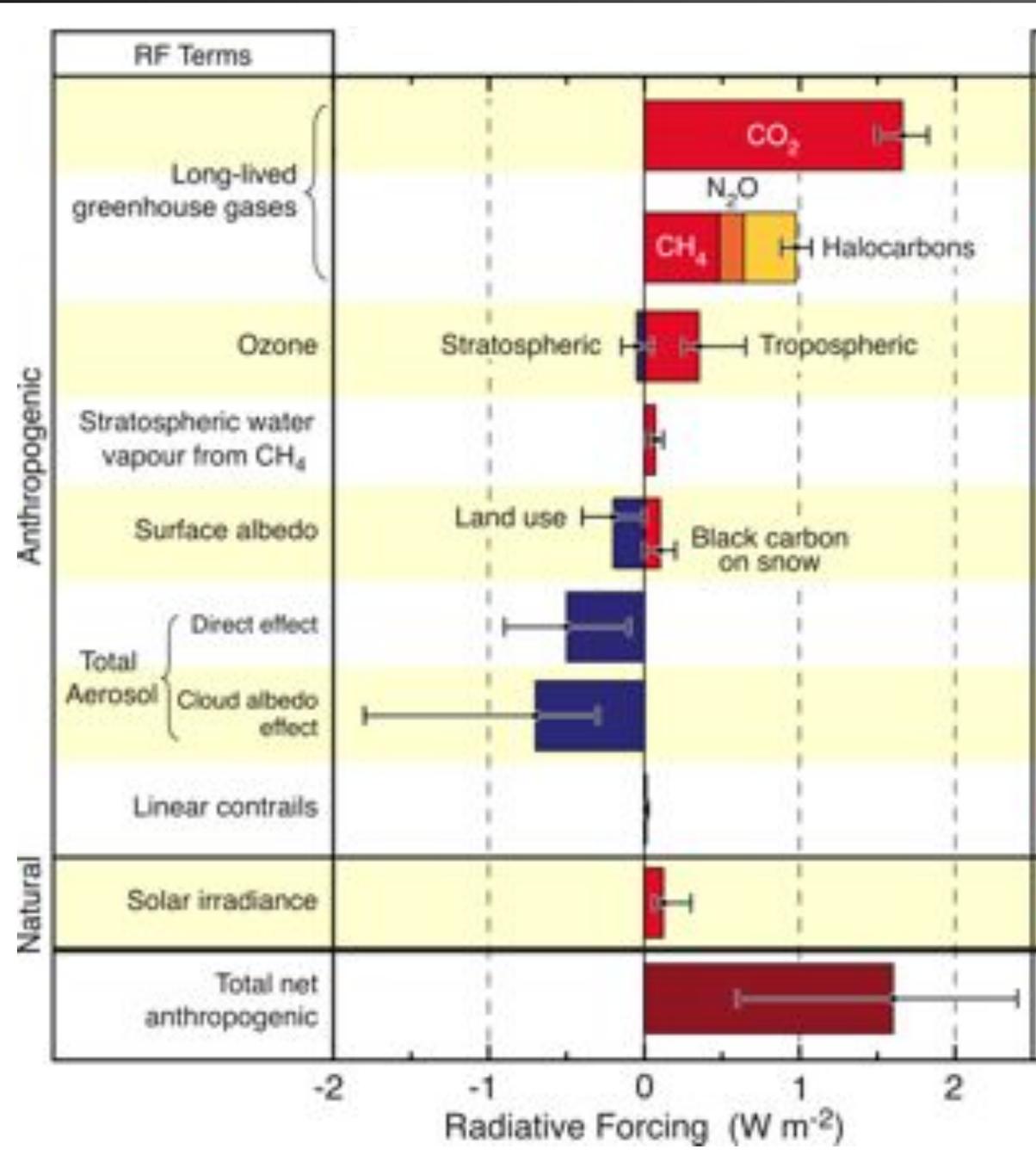


The global climate system is complex!



Radiative forcing

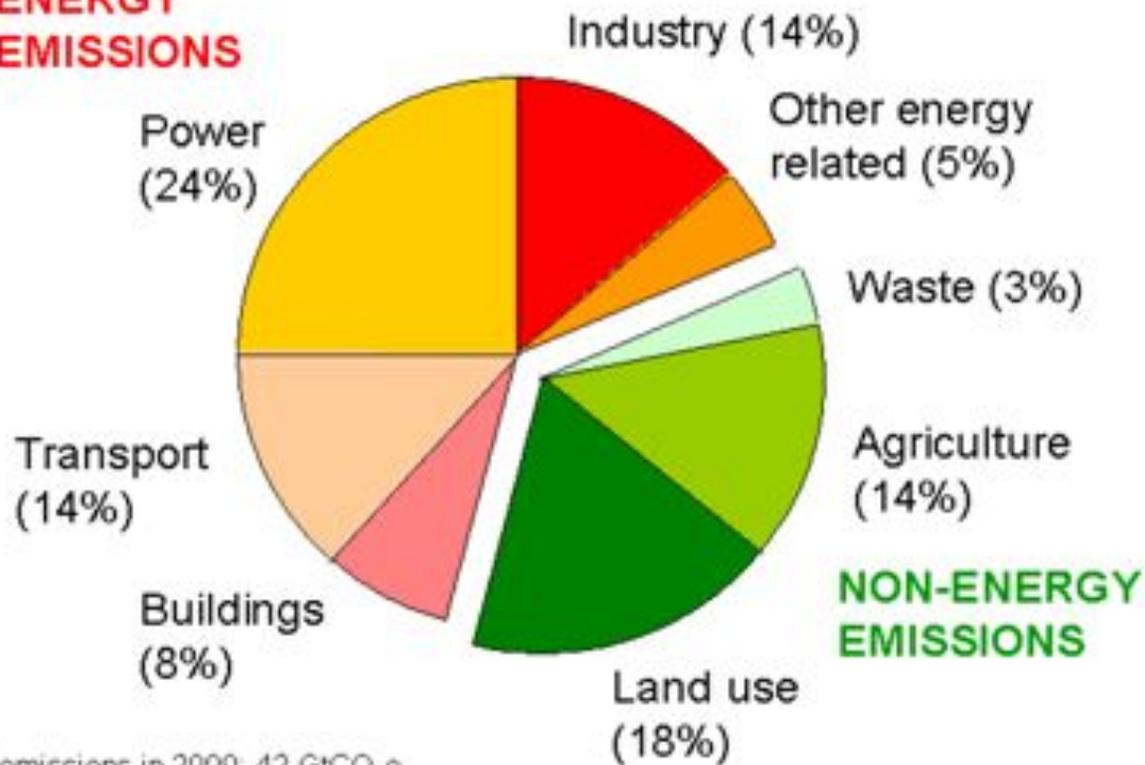
- Positive = heating
- Compensating effects
- Net result = heating
- Note uncertainties (error bars)



Diverse activities cause climate change

Global Emissions by Sector

ENERGY EMISSIONS

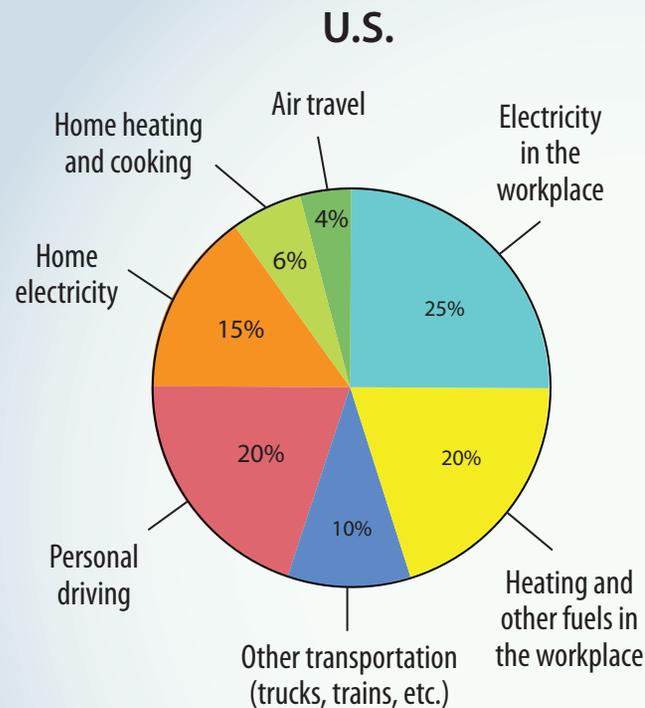


Total emissions in 2000: 42 GtCO₂e.

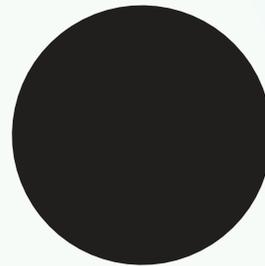


Fossil fuel contributions

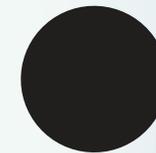
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Non-U.S. Industrialized Countries



Rest of the World



19.9 metric tons of CO₂ per person per year

8.4 metric tons of CO₂ per person per year

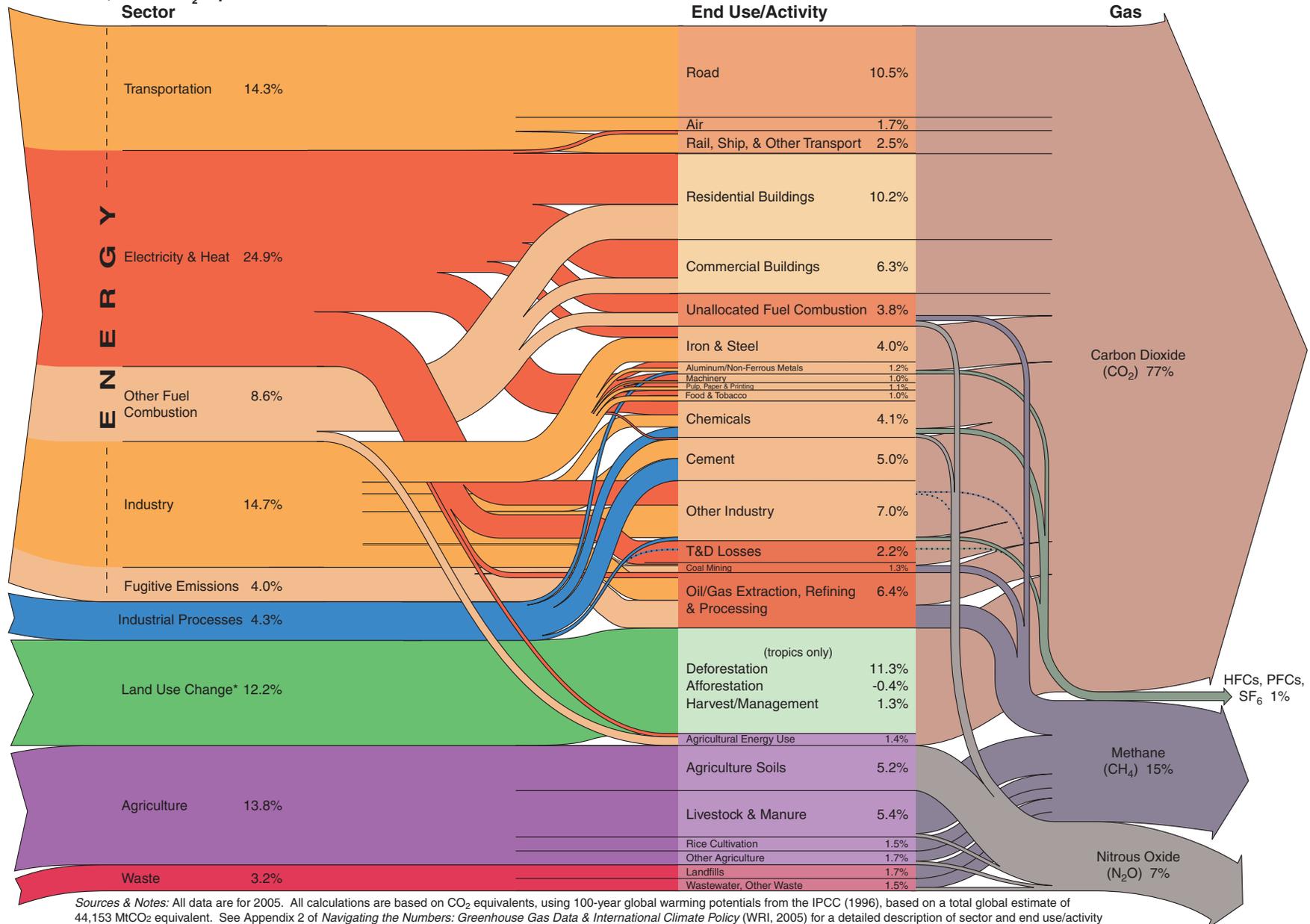
2.7 metric tons of CO₂ per person per year

POPULATION	0.3 billion (5% of world)	0.9 billion (12% of world)	5.3 billion (82% of world)
CO ₂ EMISSIONS (TONS)	5.9 billion (21% of world)	7.3 billion (27% of world)	14.3 billion (5.2% of world)

Average Per-Capita CO₂ Emissions from Fossil Fuels in 2005 The U.S. emits lots more carbon per person than the rest of the world; it also emits more than other developed countries.

From "Twenty questions and answers about climate change" (Sally Ride Science and Climate Central, 2010)

World Greenhouse Gas Emissions in 2005
 Total: 44,153 MtCO₂ eq.



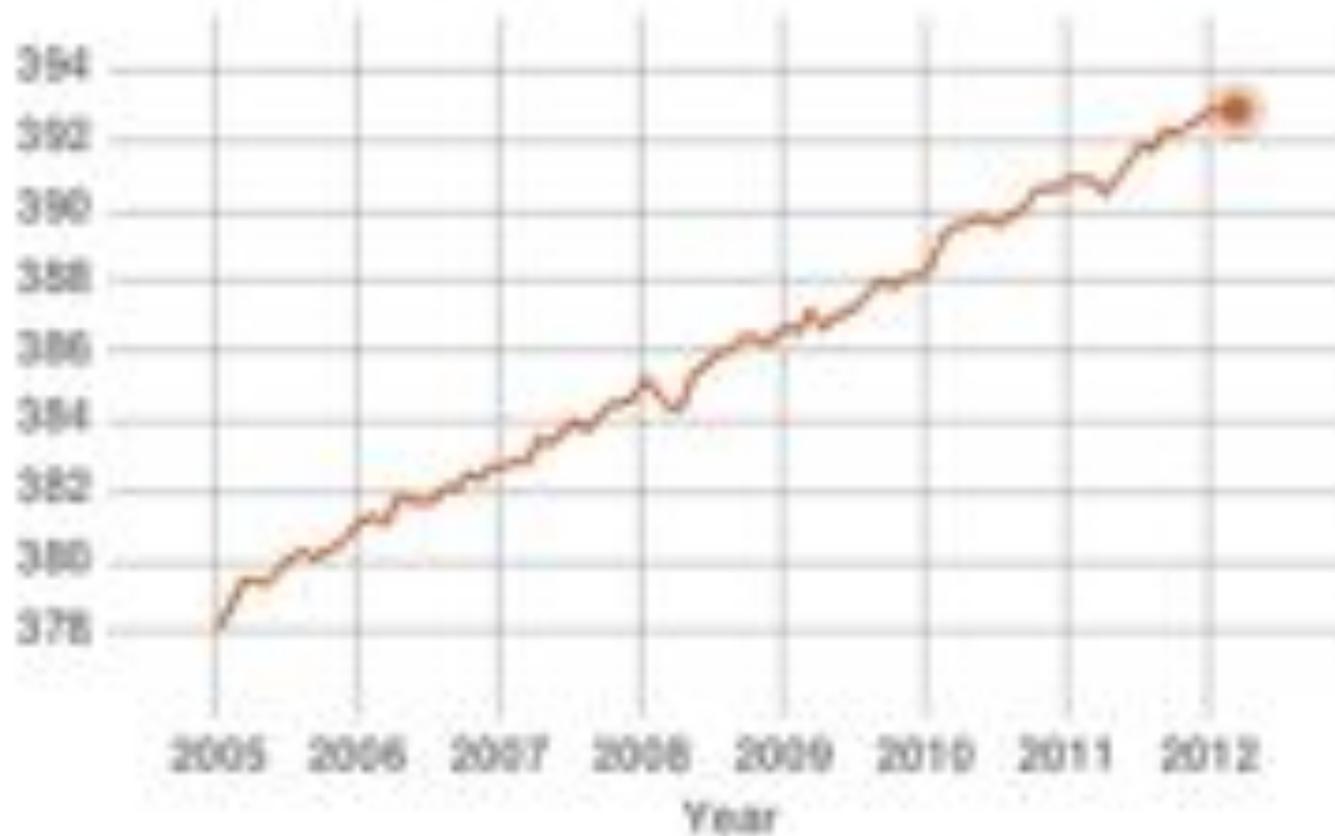
Sources & Notes: All data are for 2005. All calculations are based on CO₂ equivalents, using 100-year global warming potentials from the IPCC (1996), based on a total global estimate of 44,153 MtCO₂ equivalent. See Appendix 2 of *Navigating the Numbers: Greenhouse Gas Data & International Climate Policy* (WRI, 2005) for a detailed description of sector and end use/activity definitions, as well as data sources. Dotted lines represent flows of less than 0.1% percent of total GHG emissions.

* Land Use Change includes both emissions and absorptions, and is based on analysis that uses revised methodologies compared to previous versions of this chart. These data are subject to significant uncertainties.

Recent carbon dioxide record

DIRECT MEASUREMENTS: 2005-PRESENT

Data source: Monthly measurements (corrected for average seasonal cycle). Credit: [NOAA](#)

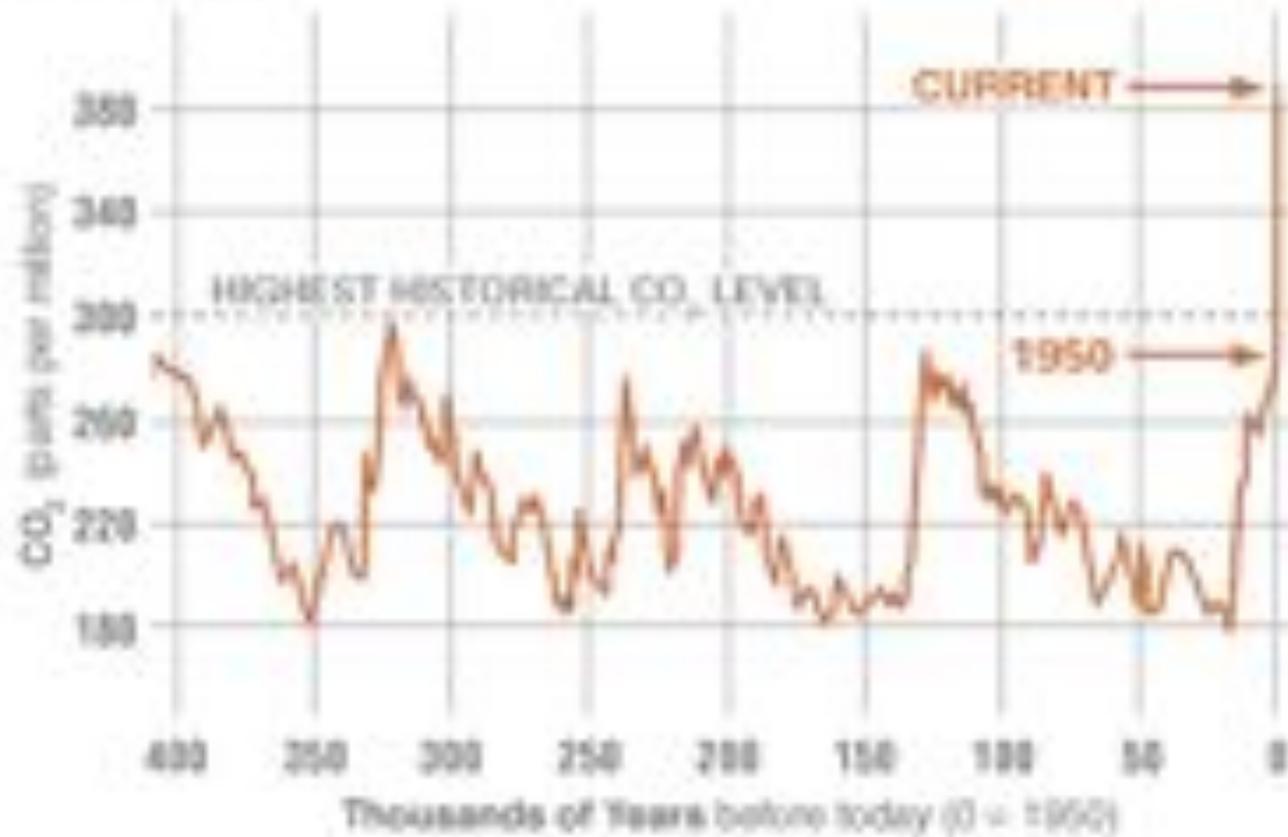


Long-term carbon dioxide record

PROXY (INDIRECT) MEASUREMENTS

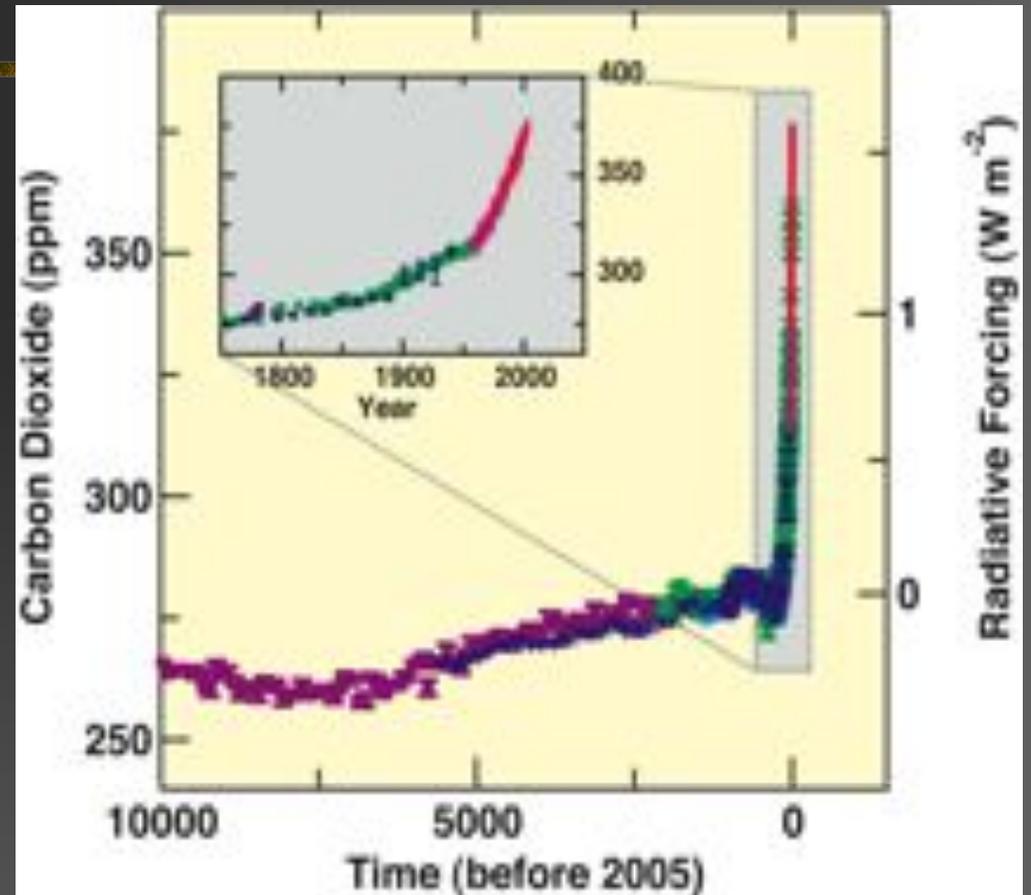
Data source: Reconstruction from ice cores.

Credit: NOAA



Atmospheric carbon dioxide increase

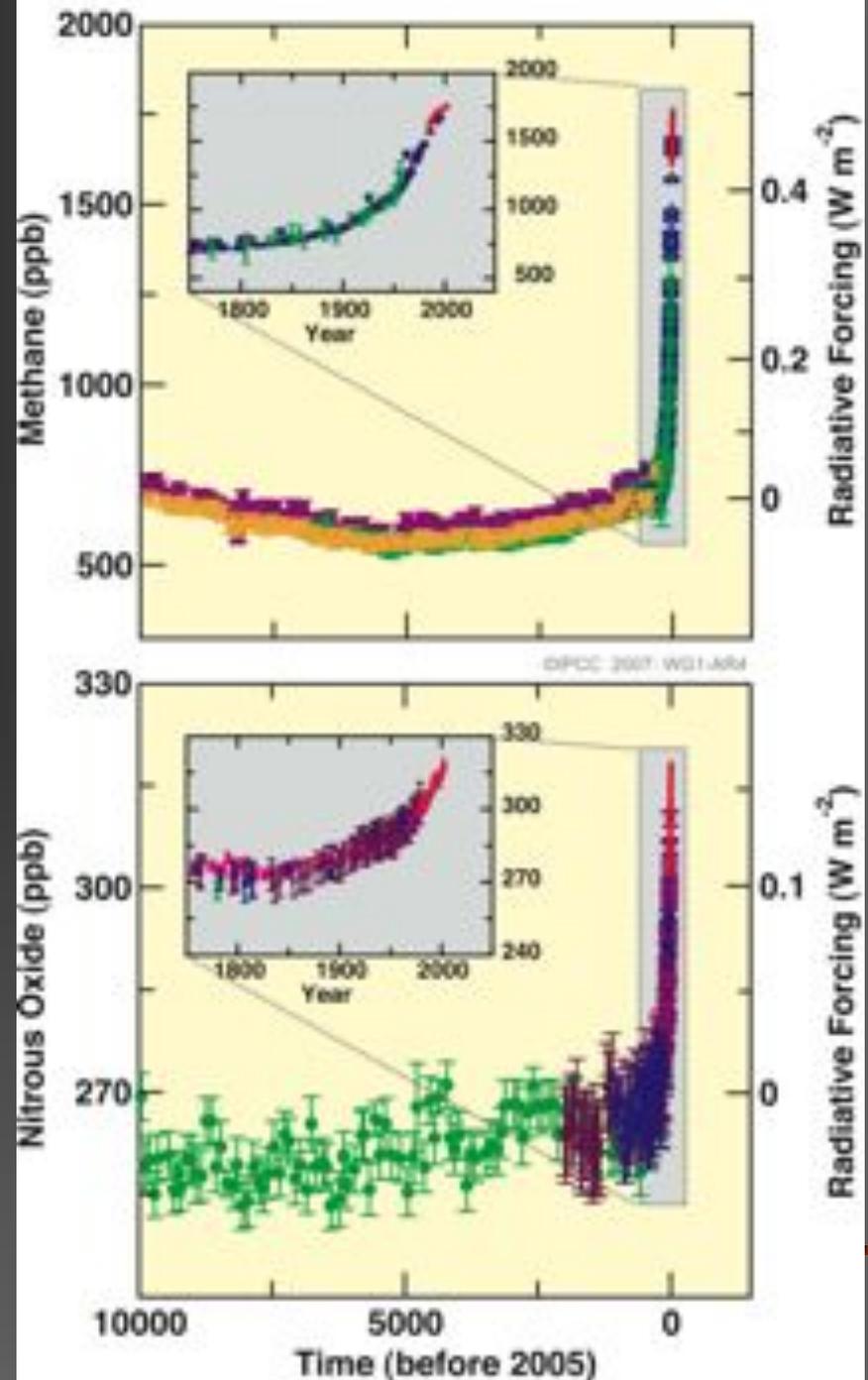
- Combustion of fossil fuels is main source
- Land use change, causing reduction in organic carbon stocks, is also important
- Accounts for ~70% of greenhouse forcing to date



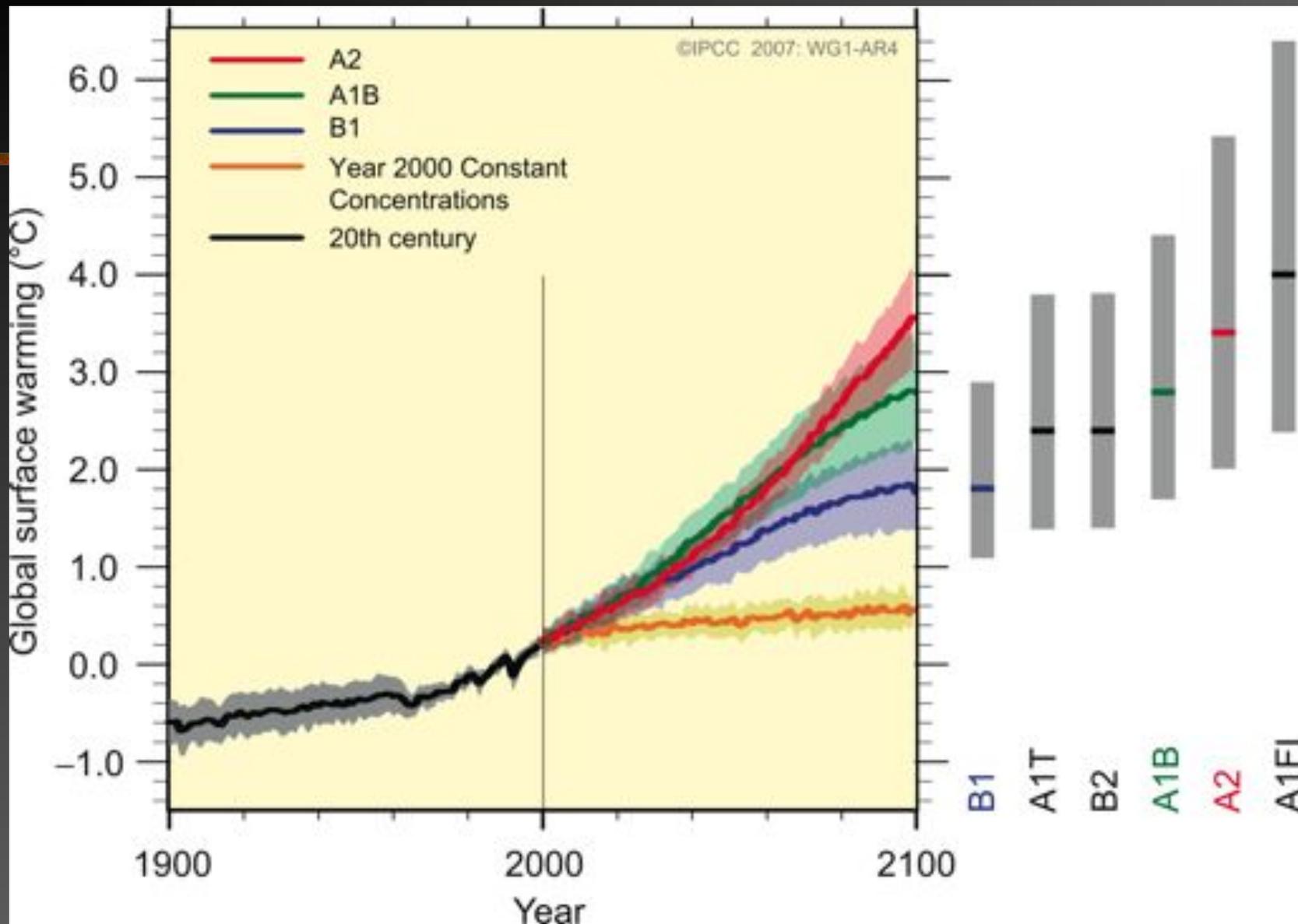
Atmospheric methane, nitrous oxide increases

- Methane mainly from rice paddies, ruminant livestock, natural gas, landfills
- Nitrous oxide mainly from agriculture
- Rates of increase are greater than carbon dioxide
- Both are more potent greenhouse gases

IPCC (2007)



Global climate projections



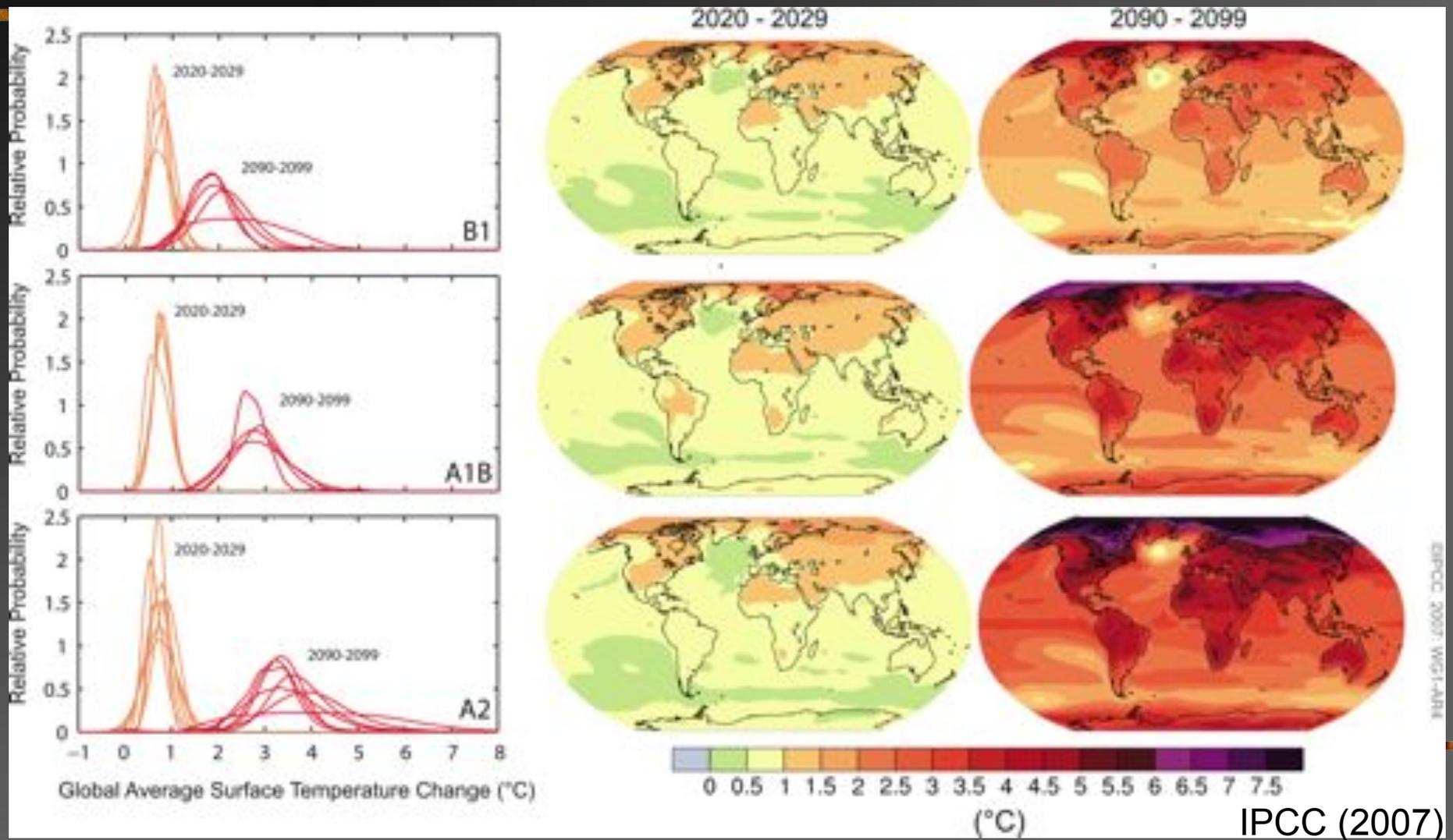
Does this projected temperature change matter?

Warmer
water feels
great!



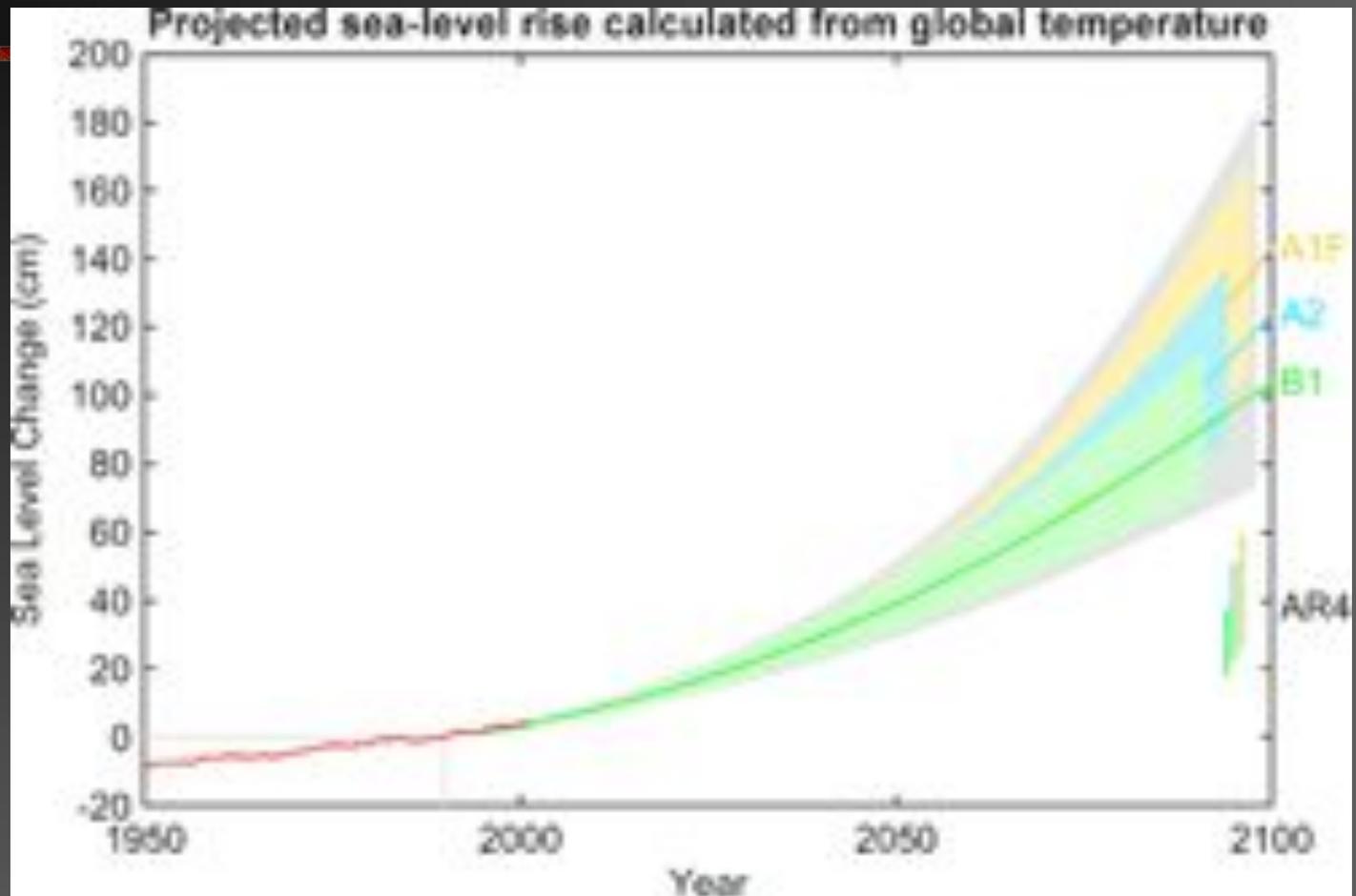
- Global average temperatures could increase from 4-7°F
 - The difference between the Ice Age and now was only 9-11°F!
- Rate of warming will be faster than at any time in the past 10,000 years
- High latitudes including Great Lakes region will warm more
- Arctic warming may exceed range over the past *million* years

Future warming will be unevenly distributed



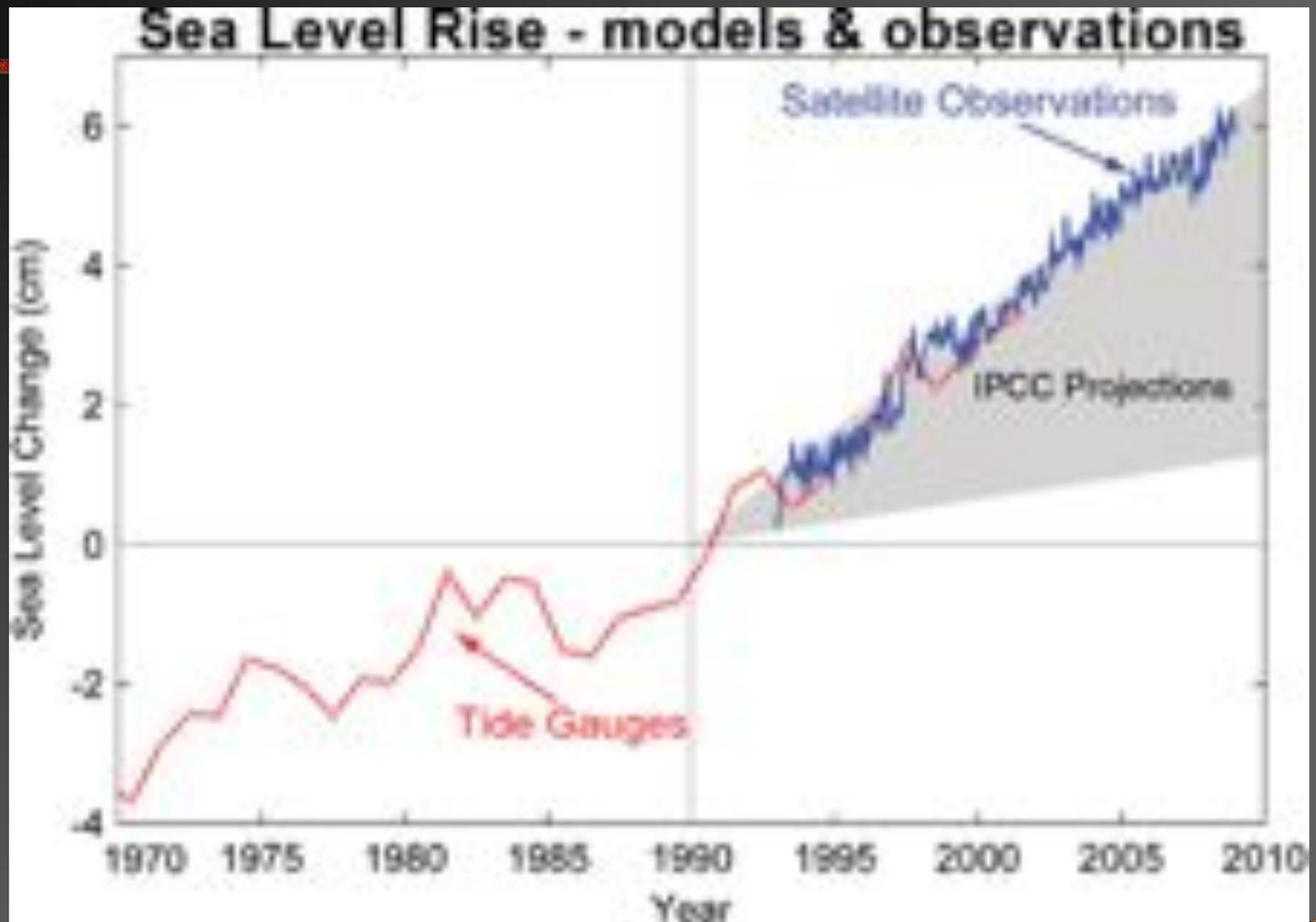
Projected rise in sea level

- Already increased ~20 cm (8 inches)
- Thermal expansion, glacier melting
- Delay to equilibrate



Recent rise in sea level vs. projections

- Our models may be too conservative



IPCC (2007) and Allison et al. (2009) data; chart from skepticalscience.com

Sea level rise and coastal ecosystems

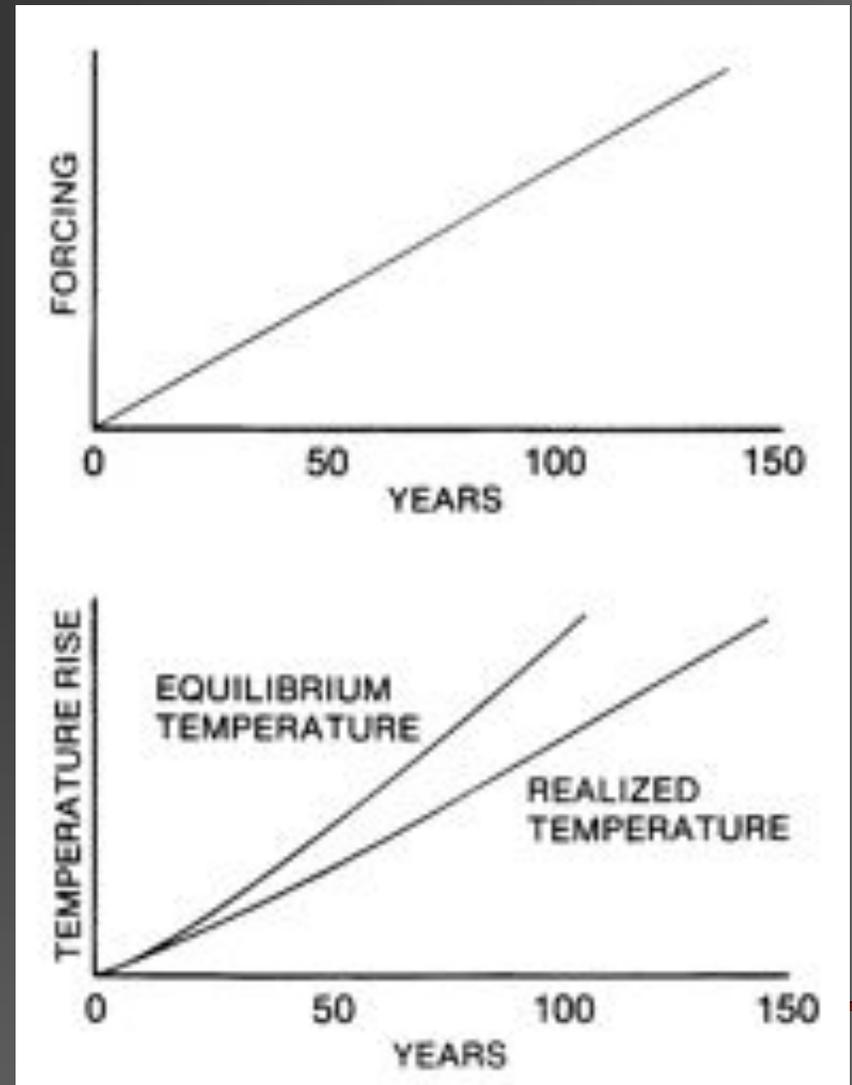
- IPCC (2007) sea level projections do not account for possibility of massive loss of land ice
- 6 m rise is possible with loss of much of the susceptible ice in either Greenland or Antarctica



Fig. 1. Spatial extent of 1- and 6-m potential future sea-level rise along the East and Gulf coasts of the United States and for selected major coastal municipalities. Elevation and connectivity to the ocean determine sea-level rise extent. Proportion of land area within municipalities coincident with sea-level rise extent determines percentage of susceptible area. The U.S. Geological Survey and Census Bureau provided elevation and municipality boundary data, respectively.

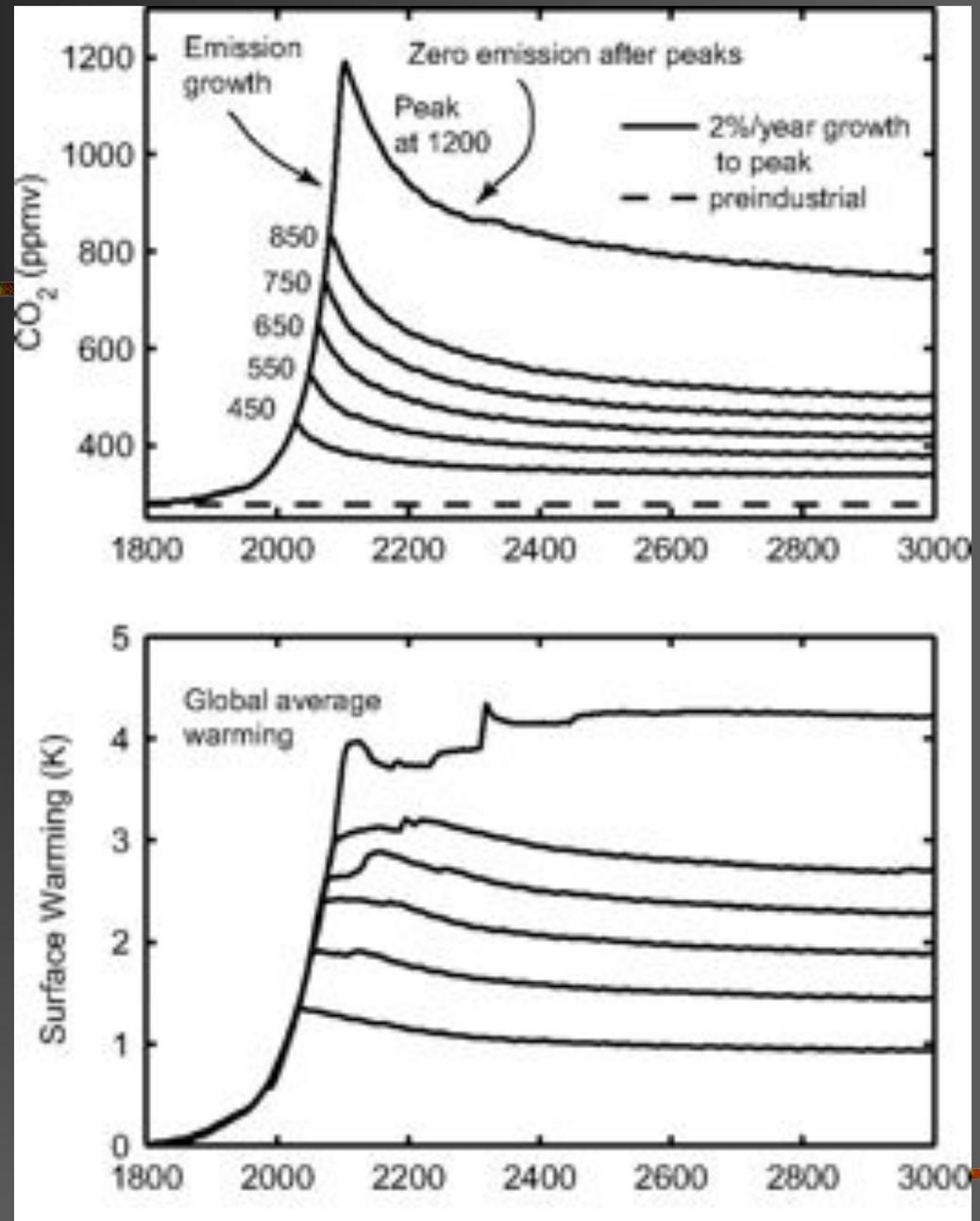
We're already committed to a warmer world

- Impacts of greenhouse gases are long-lasting
- Oceans delay to warm
- Even with immediate stabilization of greenhouse gas emissions, warming would continue for decades



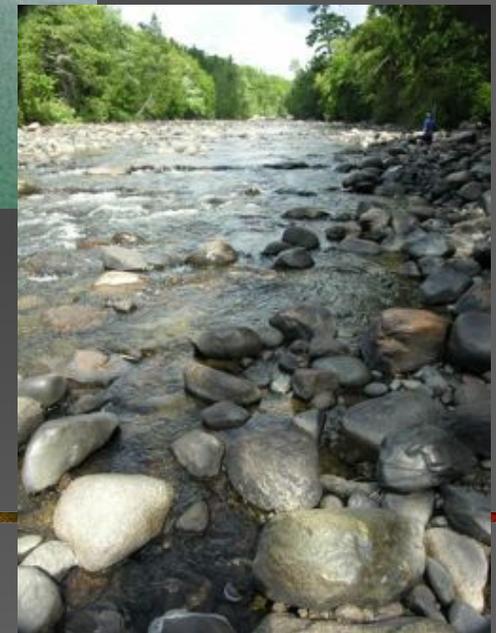
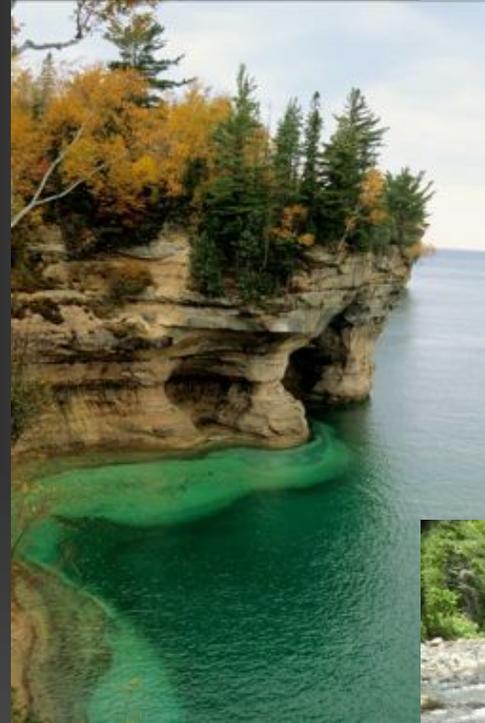
Our irreversible commitment to climate change

- Models illustrate what would happen if emissions ceased after reaching certain peaks
- Long lifetime of CO₂ plus ocean heat exchange largely explain these results



Projections for the Great Lakes region

- All models agree on warming
- Specific details are more uncertain at regional to local scales
- Most likely:
 - Wetter winters and springs
 - Warmer nighttime temperatures
 - Less snow and ice
 - More extreme weather



Migrating climate



Michigan's Climate Migrates South

Changes in average summer "heat index"—a measure of how hot it actually feels based on a specific combination of temperature and humidity—could strongly affect Midwesterners' quality of life in the future. For example, the red outlines track what summers in Michigan could feel like over the course of the century under the higher-emissions scenario; the yellow outlines track what summers could feel like under the lower-emissions scenario.

Extreme weather more common?

- New studies show greater probability (“loaded dice” analogy)
 - Heavy precipitation
 - Droughts
 - Damaging storm events
 - Hurricanes?
- Still cannot attribute a particular event to climate change
 - Only its probability

KALAMAZOO GAZETTE
POWERING MI.LIVE.COM
Saturday, July 15, 2012 \$2.00

SCORCHED EARTH



A farmer watches a crop of corn as he works his field.

DROUGHT FORCES SOUTHWEST MICHIGAN FARMERS TO TAP RIVERS, CREEKS, PONDS IN FIGHT TO SAVE CROPS

BY AN KALLBERG
an.kallberg@mlive.com

LIVONIA — During the nearly half a century Herman Casler has lived on the banks of Turkey Creek, he never has seen the water this low.

A trench running through the side road in two days a foot deep, Casler's corn, soybeans and sunflowers look like lawns.

Last week, the segment of the creek temporarily dried up. An inch, trapping water in puddles along the bank.

"This is the worst it's ever been, and we've lived here 45 years," Casler said.

"You could talk to eight, a thought in southwest Michigan is wearing hard on farming communities, particularly in St. Joseph County. Not only is the lack of 1000th Anniversary crops, but there are concerns that come as an indication that water for irrigation are drying. The water depletion is being accentuated by farmers who pump out hundreds of thousands of gallons per day to sustain their fields.

"We've been getting calls daily, sometimes several daily about water meters being down," said Larry Bennett, a water quality analyst based at the Michigan Department of Environmental Quality's Kalamazoo office.

The St. Joseph River, one of the Michigan's largest, was at a low on Thursday — the lowest level in several years that, according to the National Weather Service.

District of Branch, St. Joseph, Cass and Hillsdale counties are based on the U.S. Drought Monitor as being in a severe drought.

— Roger Gertz

"This is the worst it's ever been, and we've lived here 45 years."
— Herman Casler



"Our sole source of livelihood is pumping water from that creek."
— Roger Gertz



Ecosystem impacts of global change

- Massive changes in ecosystems are possible, such as:
 - Distributions of plants and animals
 - Loss of entire ecosystems (e.g., coral reefs, montane rain forests)
 - Activity of pests and pathogens (e.g., bark beetles)
- Magnitude and rate of change are important, as are interactions with human activities



Ecosystem feedbacks and global climate change?

- Ecological feedbacks could potentially alter the course of global environmental change, but remain poorly understood.
- Examples:
 - The CO₂ fertilization effect on forests (reduces climate change)
 - Higher temperatures may stimulate respiration rates more than photosynthetic rates (enhances climate change)
 - Higher temperatures may stimulate methane production in high-latitude wetlands (enhances climate change)
 - Human activities in response to ecosystem changes (??)

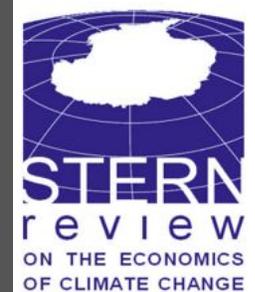
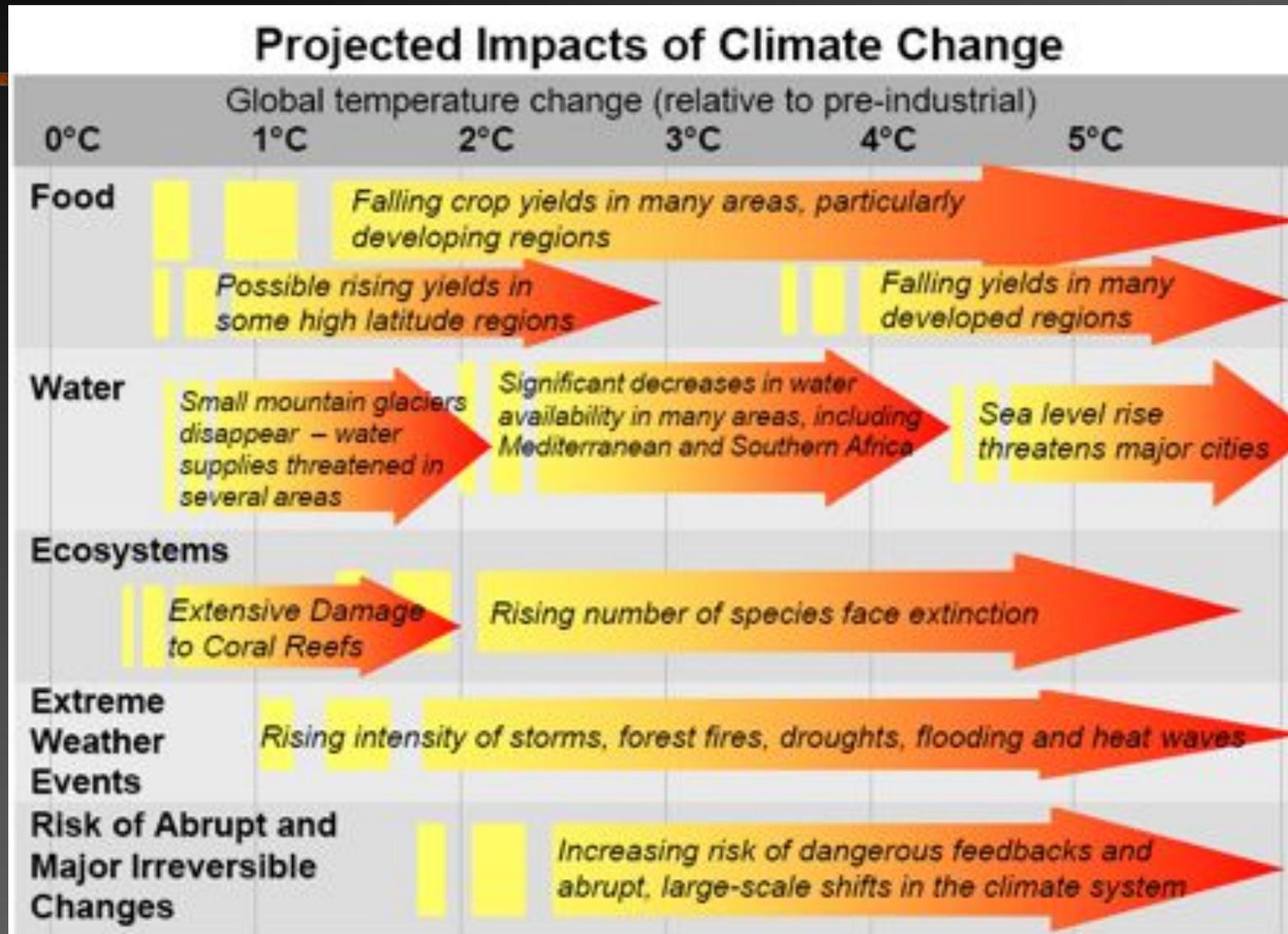
Will humanity succeed in stemming the rate of climate change?

- Kyoto agreement as an example of the political challenges that lie ahead
- The war for public opinion
 - Role of special interest groups
- Rising likelihood of action => rising resistance to defend the status quo



Is climate stabilization too costly?

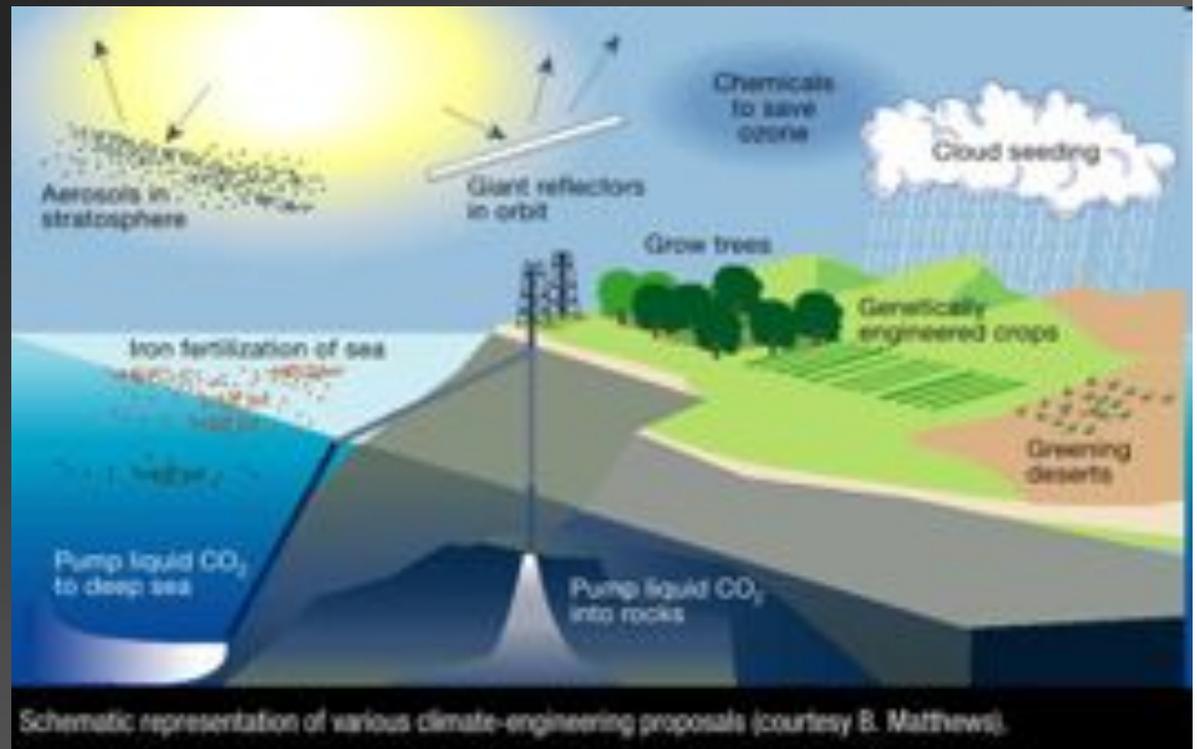
(If yes, for whom and over what timescale??)



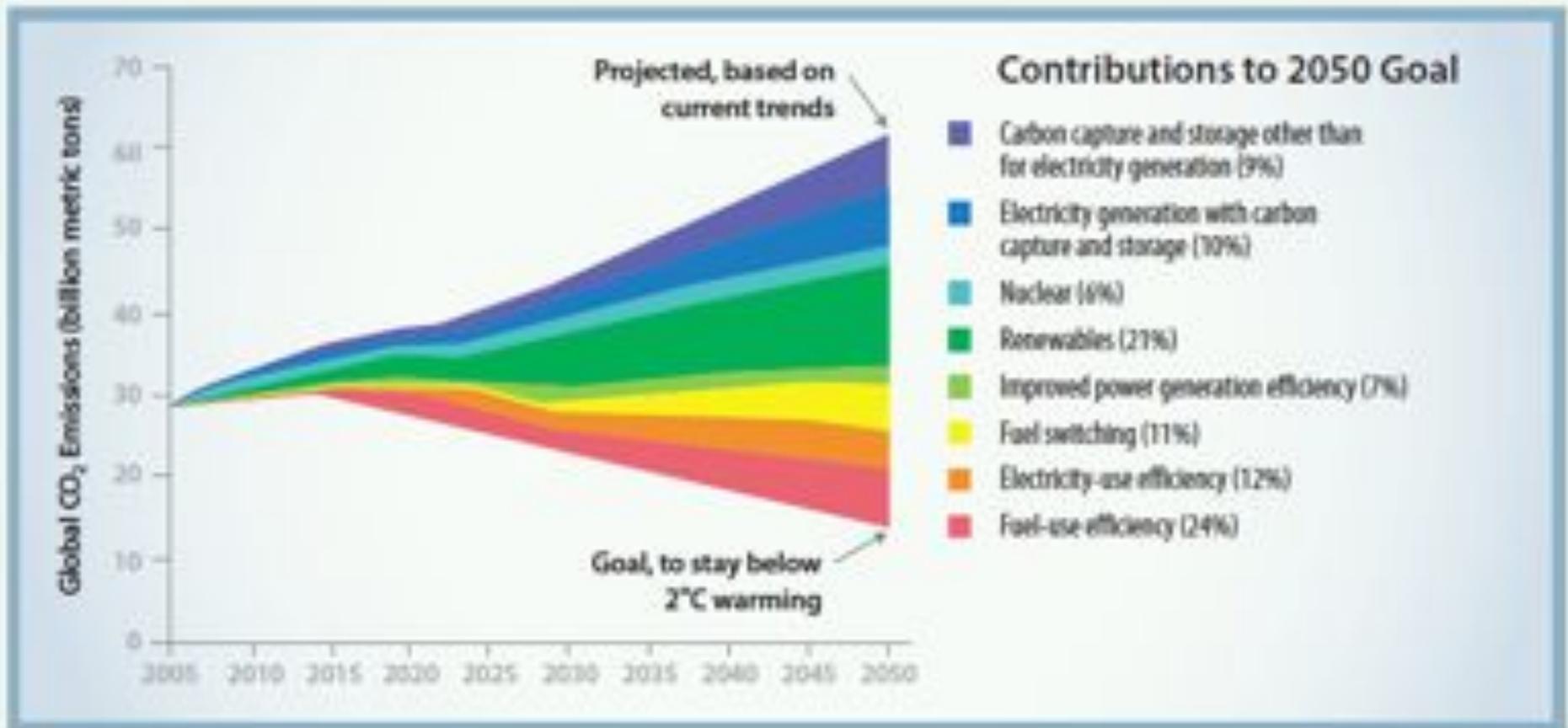
See more detailed figure in IPCC 2007 Summary for Policy-makers

Geoengineering: Technology to the rescue?

- No geoengineering method “can provide an easy or readily acceptable alternative solution...” (Royal Society of London, 2009)
- Yet we should be studying options in case we need them!



A suite of solutions is the best choice



From "Twenty questions and answers about climate change" (Sally Ride Science and Climate Central, 2010)

“What kind of world will our grandchildren inherit?”

- We can moderate the pace and severity of climate change!
- Stabilization of greenhouse gas emissions is a start
- *Reductions* are imperative in the long term
- No single silver bullet...
 - Conserve
 - Invent
 - Mitigate
 - Adapt



Professors, graduate students, and K-12 teachers all have important roles

- Educate yourself on the subject!
- If challenged, seek help!
- Scientists of all fields are trained to recognize and seek out reliable sources of information
- We would be remiss in our duty if we ignore or downplay global change...

The image is a screenshot of the National Center for Science Education (NCSE) website. At the top left is the NCSE logo, which features a stylized tree and the text 'NATIONAL CENTER for Science Education' and 'DEFENDING THE TEACHING OF EVOLUTION & CLIMATE SCIENCE'. To the right of the logo is a mission statement: 'NCSE provides information and advice as the premier institution dedicated to keeping evolution and climate change in the science classroom and to keep out creationism and climate change denial. LEARN MORE <->'. Below the logo and mission statement is a navigation menu with links for 'ABOUT', 'NEWS', 'TAKING ACTION', 'CREATIONISM', 'EVOLUTION', 'CLIMATE', 'PUBLICATIONS', and 'MUL'. The main content area features a breadcrumb trail: 'Home - Climate Change - Climate Change Denial - Climate Change Denial Is Affecting Education -'. The article title is 'Climate Change Denial Is Affecting Education', dated 'January 5th, 2012'. The article text begins with 'Climate change denial is already threatening the integrity of science education in formal and informal education settings. In the public schools, such threats are primarily due to laws adopted or considered at the level of state government, policies adopted or considered at the level of the local school district, and actions adopted or considered at the level of the individual classroom, where teachers may either deny climate change themselves or encounter pressure from climate change deniers in the community. The following is a selection of recent (from 2007 to 2011) incidents, intended to be illustrative rather than comprehensive; NCSE is now routinely monitoring cases of climate change denial affecting education.' Below the article text is a section titled 'At the state level' with a sub-heading 'In 2010, South Dakota's legislature adopted House Concurrent Resolution 1009, in which all three of the pillars of climate change denial were on display. The resolution'. On the left side of the page, there is a sidebar with a 'Climate Change' menu, a 'Climate Change Denial' sub-menu, and a 'QUICK LINKS' section with links to 'Intelligent Design" on Trial', 'Reports of the NCSE', 'Events', and 'Popular Pages'.