

# Climate Change

What we know

What we expect

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Association Summer Conference  
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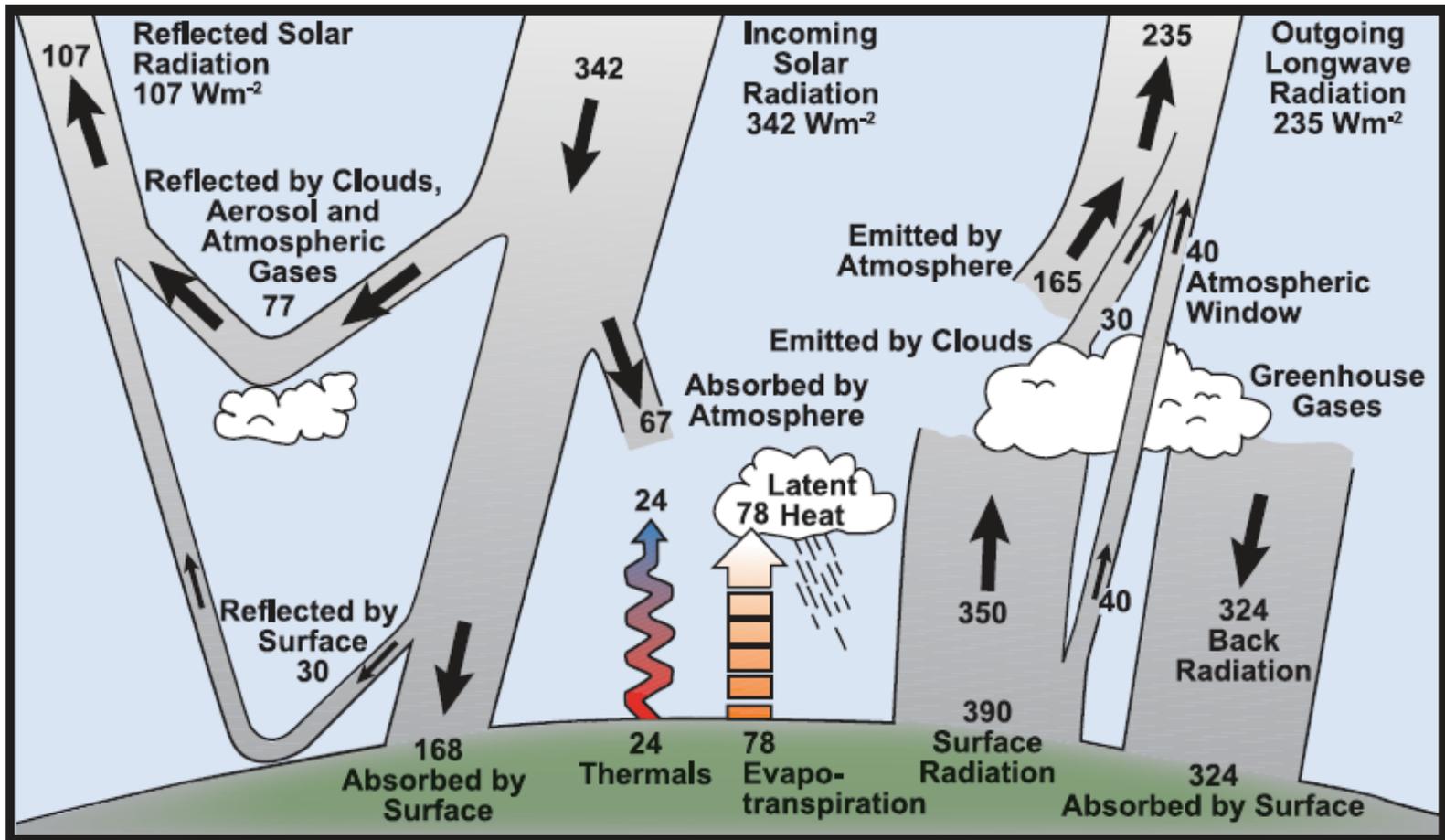
## *Advancing the Science of Climate Change,* National Research Council, 2010

- “... scientific evidence that the Earth is warming is now overwhelming. There is also a multitude of evidence that this warming results primarily from human activities, especially burning fossil fuels and other activities that release heat-trapping greenhouse gases (GHGs) into the atmosphere.” (p. 19)
- “Although the details of how the future impacts of climate change will unfold are not as well understood as the basic causes and mechanisms of climate change, we can reasonably expect that the consequences of climate change will be more severe if actions are not taken to limit its magnitude and adapt to its impacts.” (p. 19)



# The “greenhouse” effect

- greenhouse gases (such as water vapor, carbon dioxide, methane, nitrous oxide) absorb radiation and radiate energy back toward the surface
  - keeps Earth’s average surface temperature warmer
  - about 33°C (59°F) higher

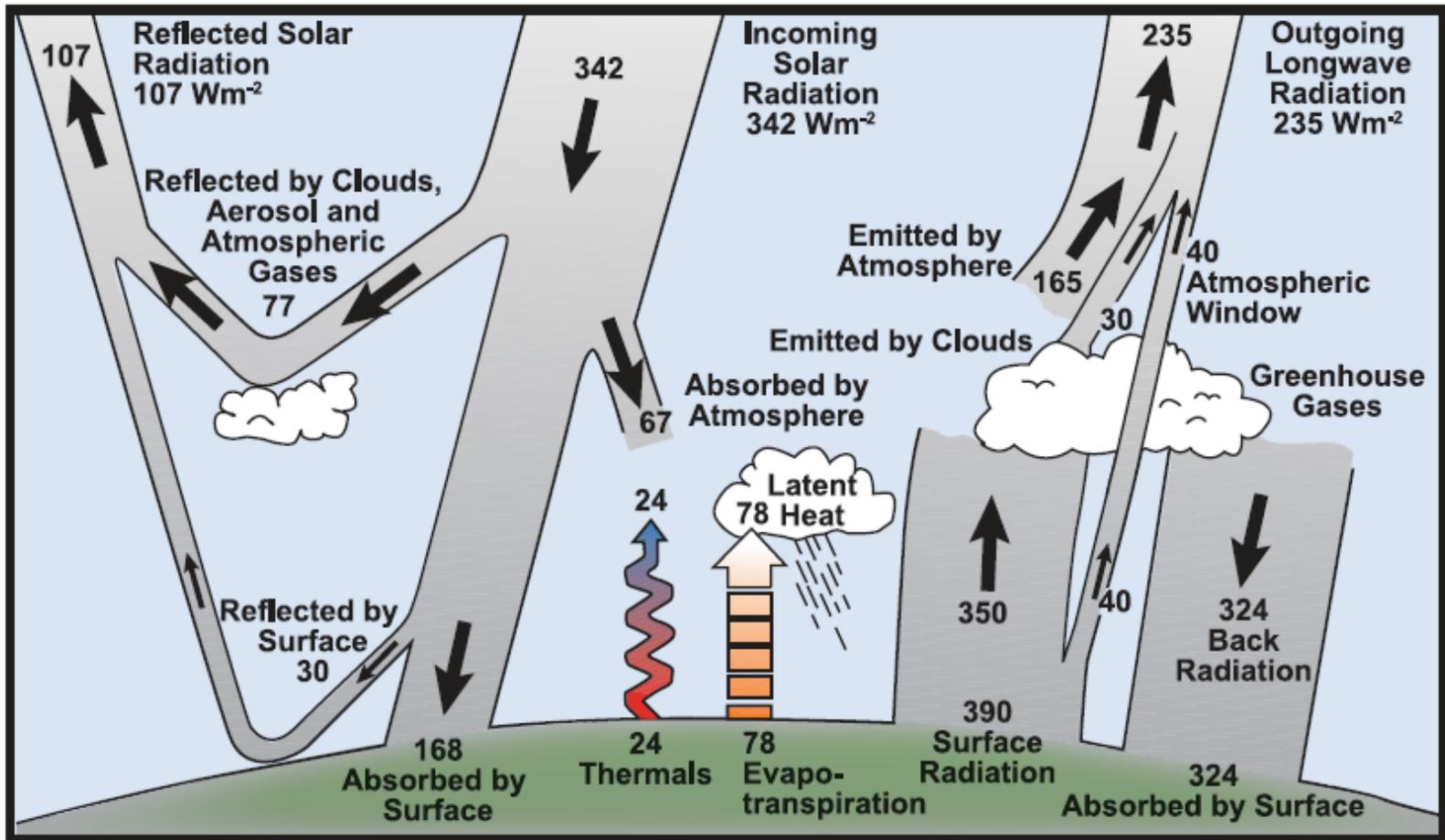


Le Treut et al., 2007



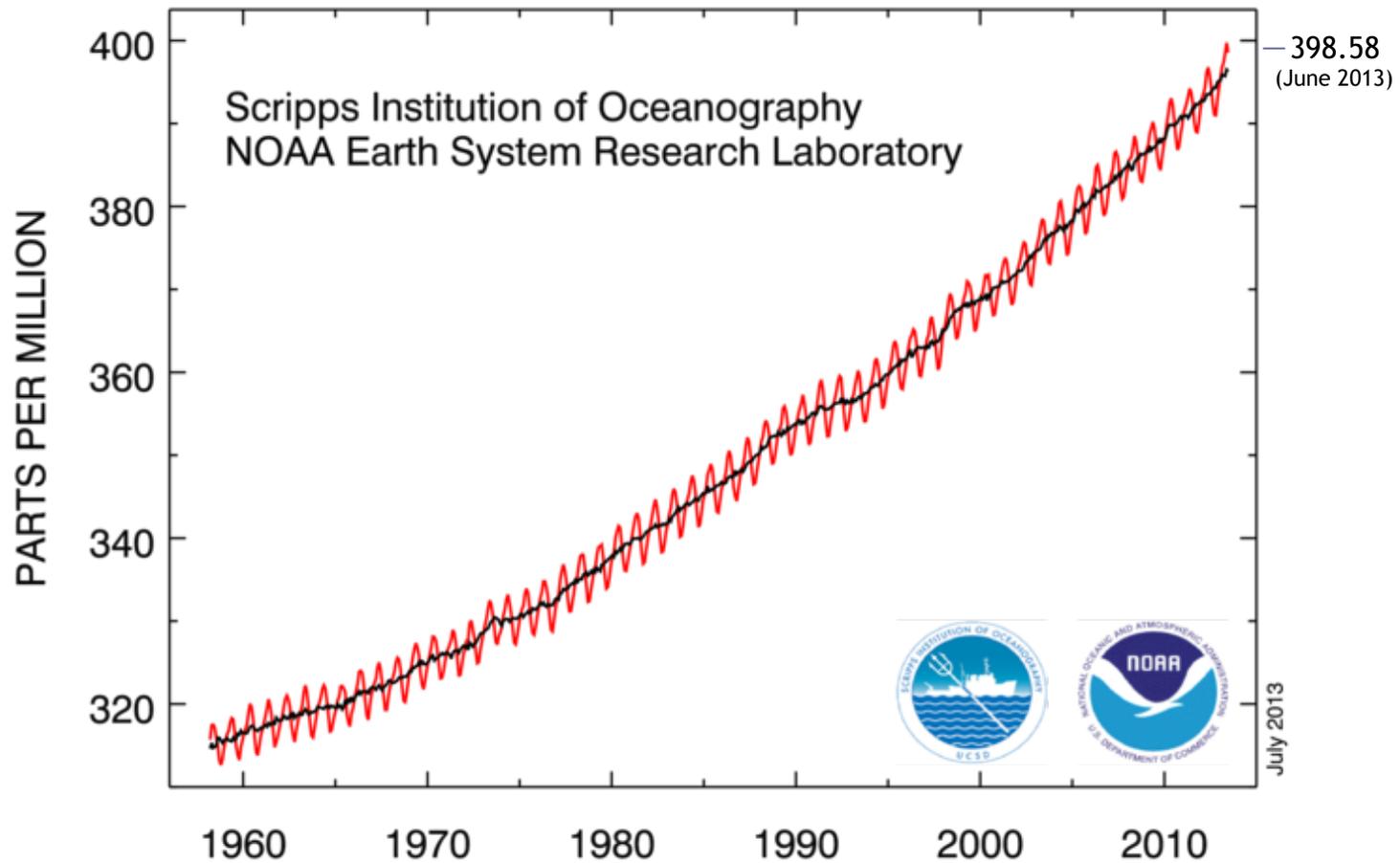
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- **increasing concentrations of GHGs from human activities cause Earth’s temperature to rise (enhanced “greenhouse” effect)**

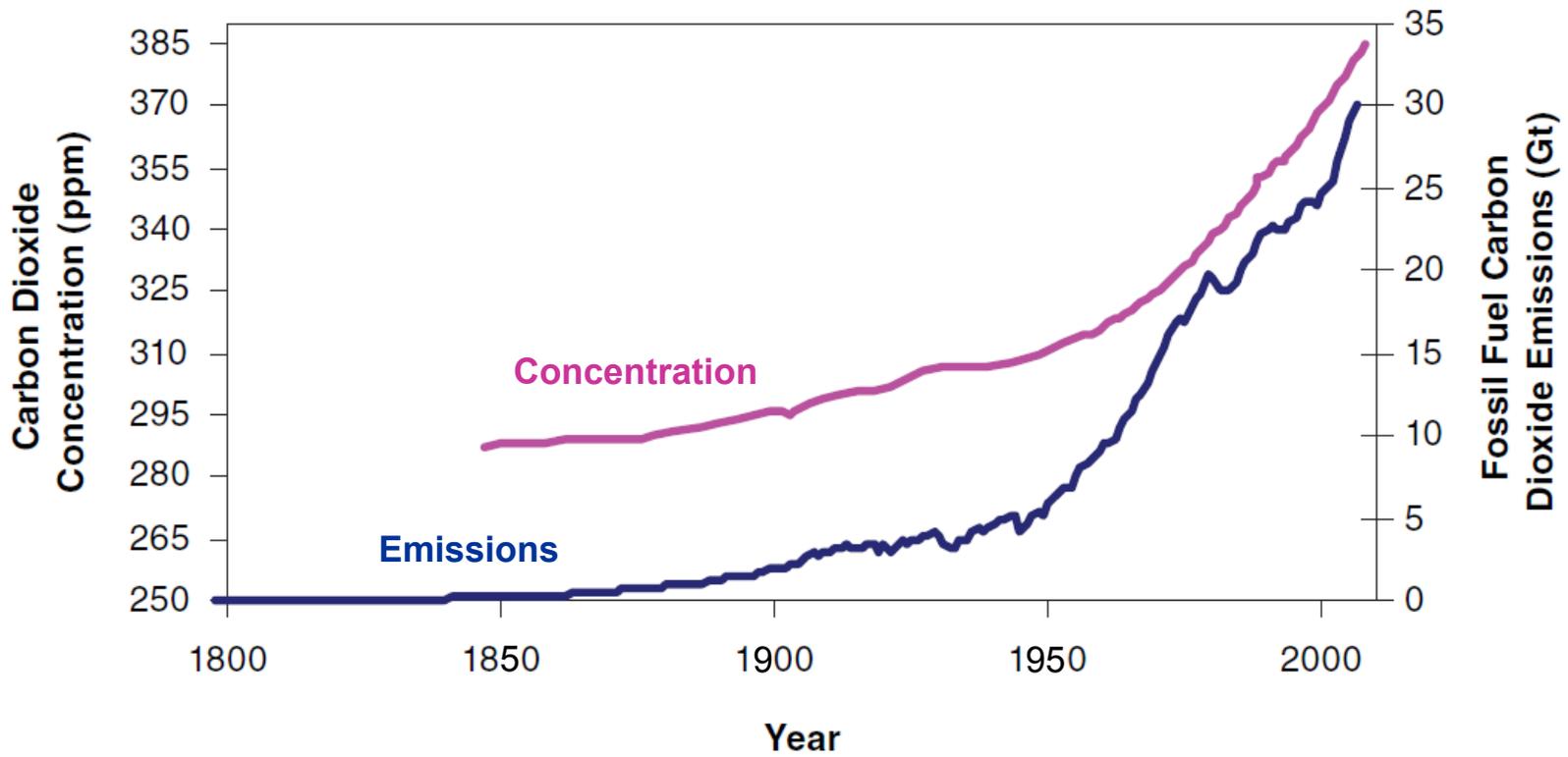


Le Treut et al., 2007

## Atmospheric CO<sub>2</sub> at Mauna Loa Observatory



<http://www.esrl.noaa.gov/gmd/ccgg/trends/>



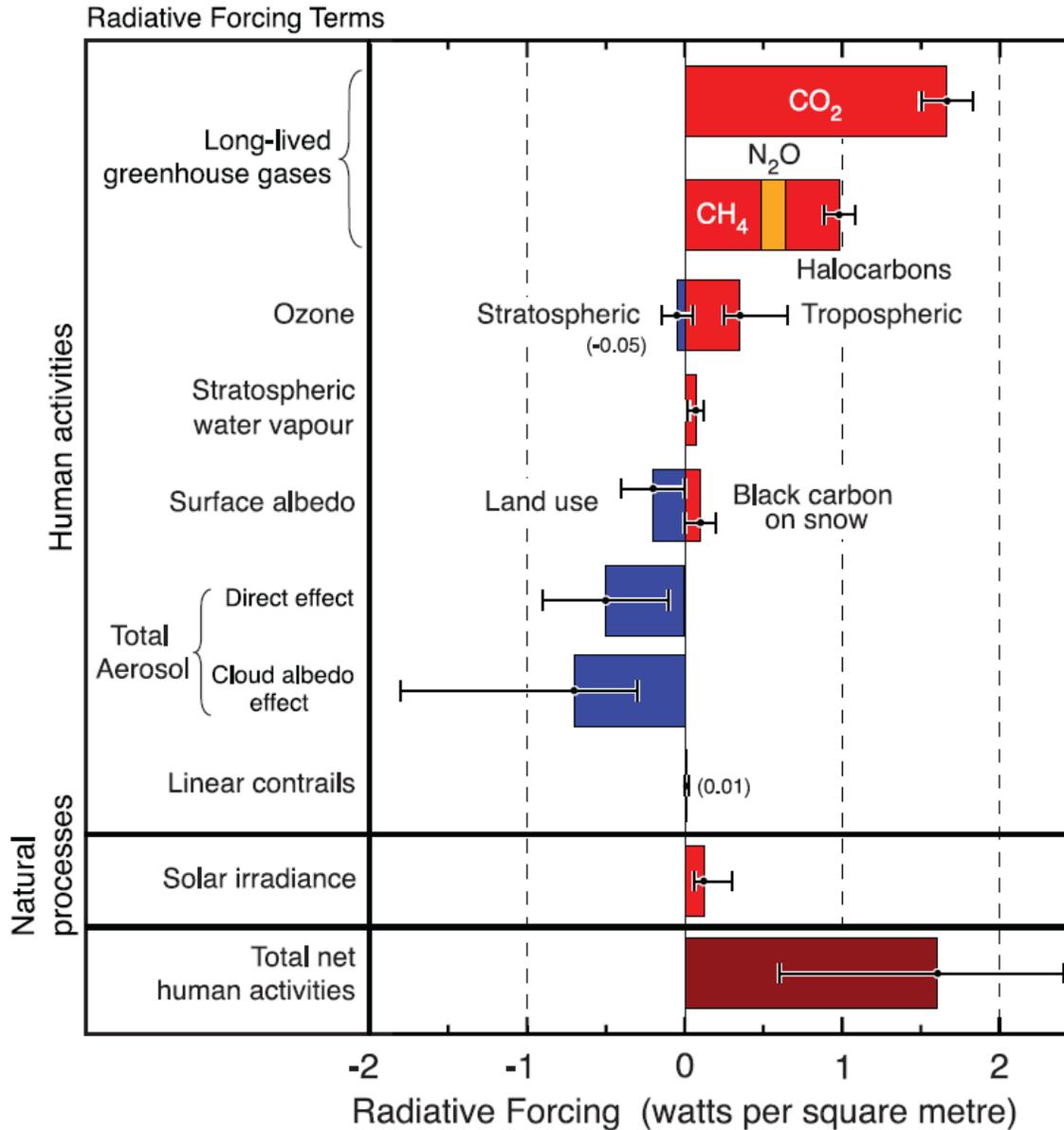
NRC, 2010



# The “greenhouse” effect

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- increasing concentrations of GHGs from human activities cause Earth’s temperature to rise (enhanced “greenhouse” effect)
- increasing concentrations of some aerosols could offset part (but not all) of this warming by increasing reflection of sunlight

## Radiative forcing of climate between 1750 and 2005



GHGs: large increase,  
little uncertainty

aerosols: decrease,  
much uncertainty

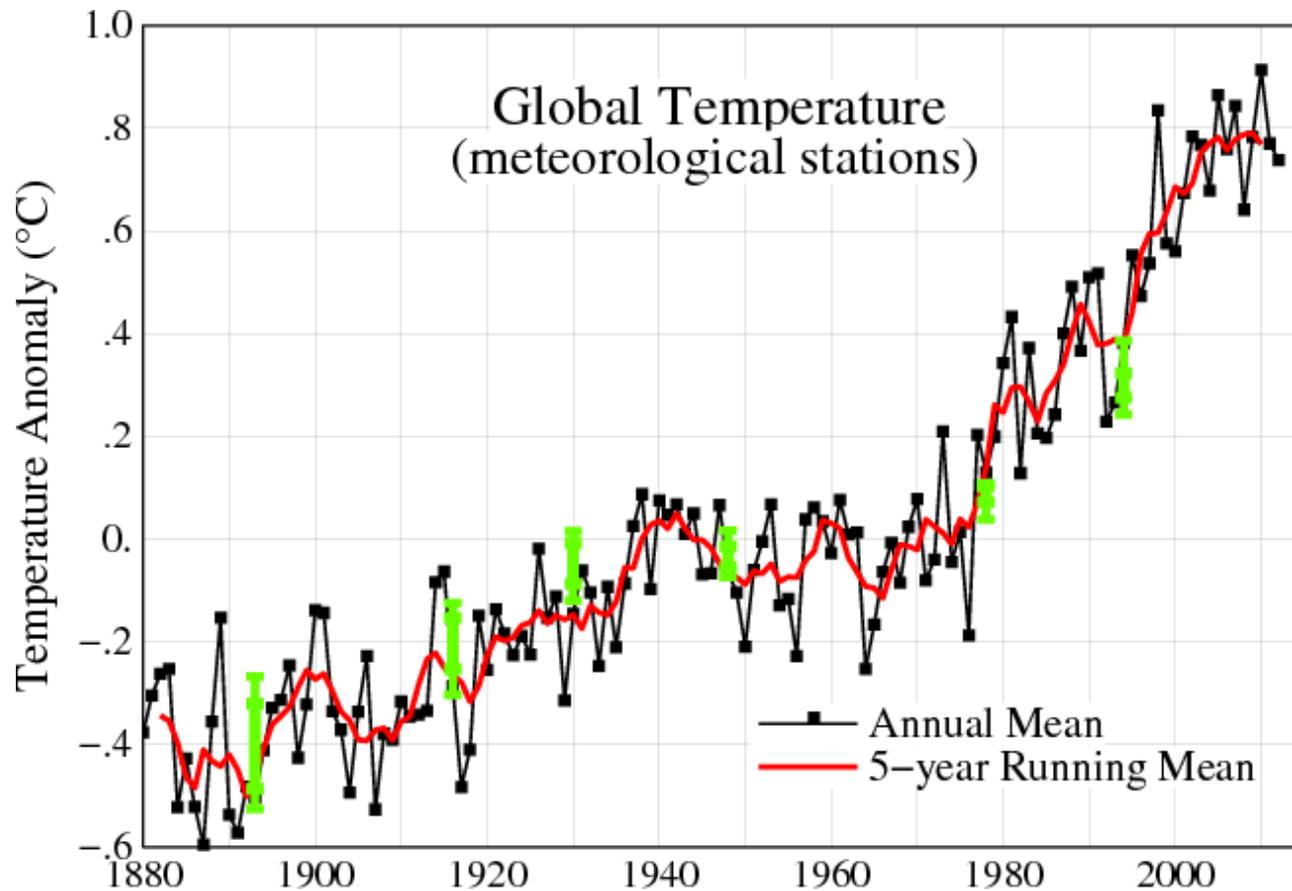
overall: large increase,  
much uncertainty

Forster et al., 2007



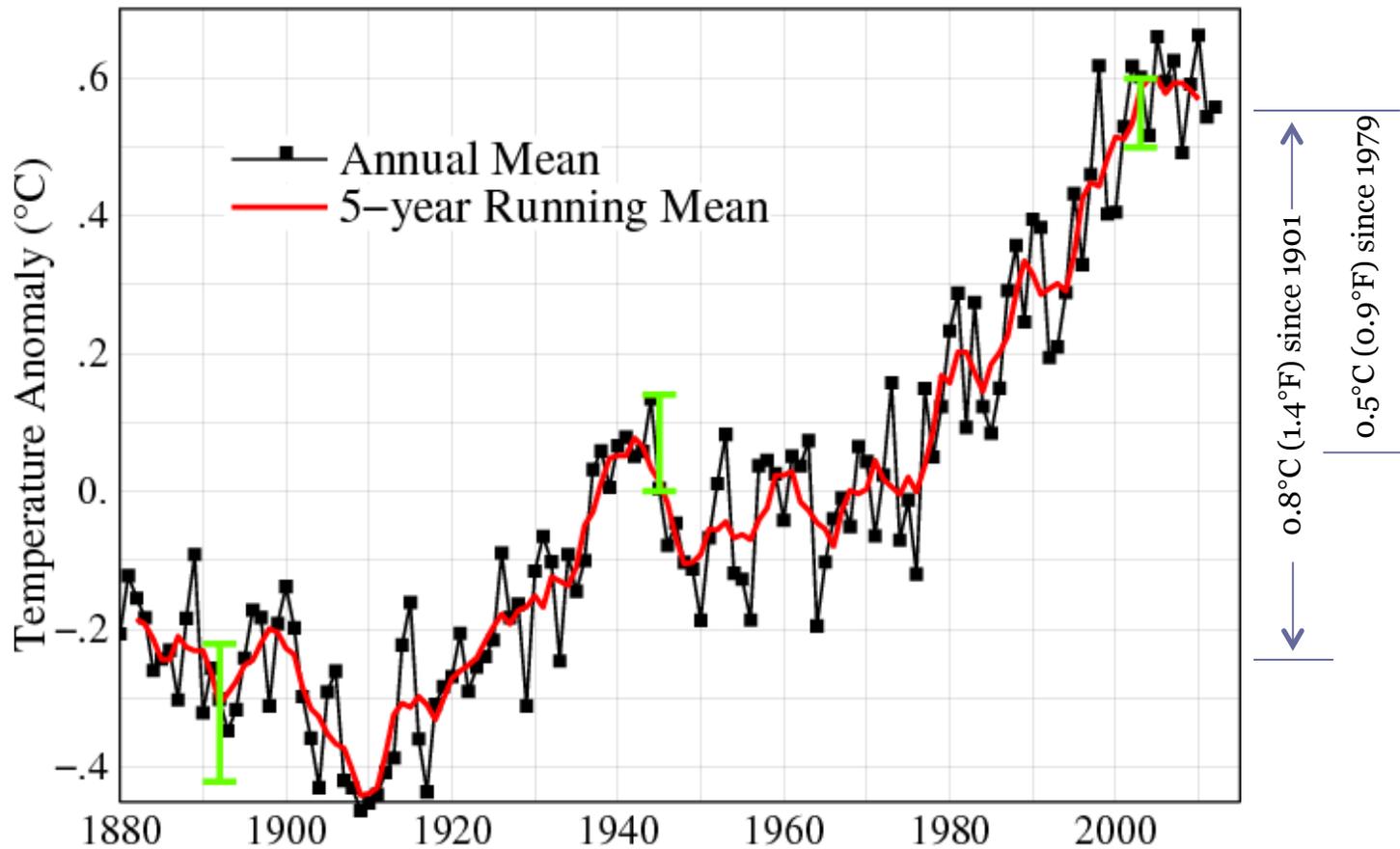
# Temperatures are increasing

- Surface thermometer measurements show the first decade of the 21st century was 0.8°C (1.4°F) warmer than the first decade of the 20th century
- Oceans show a warming trend over the past several decades that is similar to the atmospheric warming trend
- Hot days and nights have become warmer and more frequent
- Cold snaps have become milder and less frequent
- Northern Hemisphere snow cover is decreasing
- Northern Hemisphere sea ice is declining in both extent and average thickness
- Rivers and lakes are freezing later and thawing earlier
- Glaciers and ice caps are melting in many parts of the world
- Precipitation, ecosystems, and other environmental systems are changing in ways that are consistent with global warming



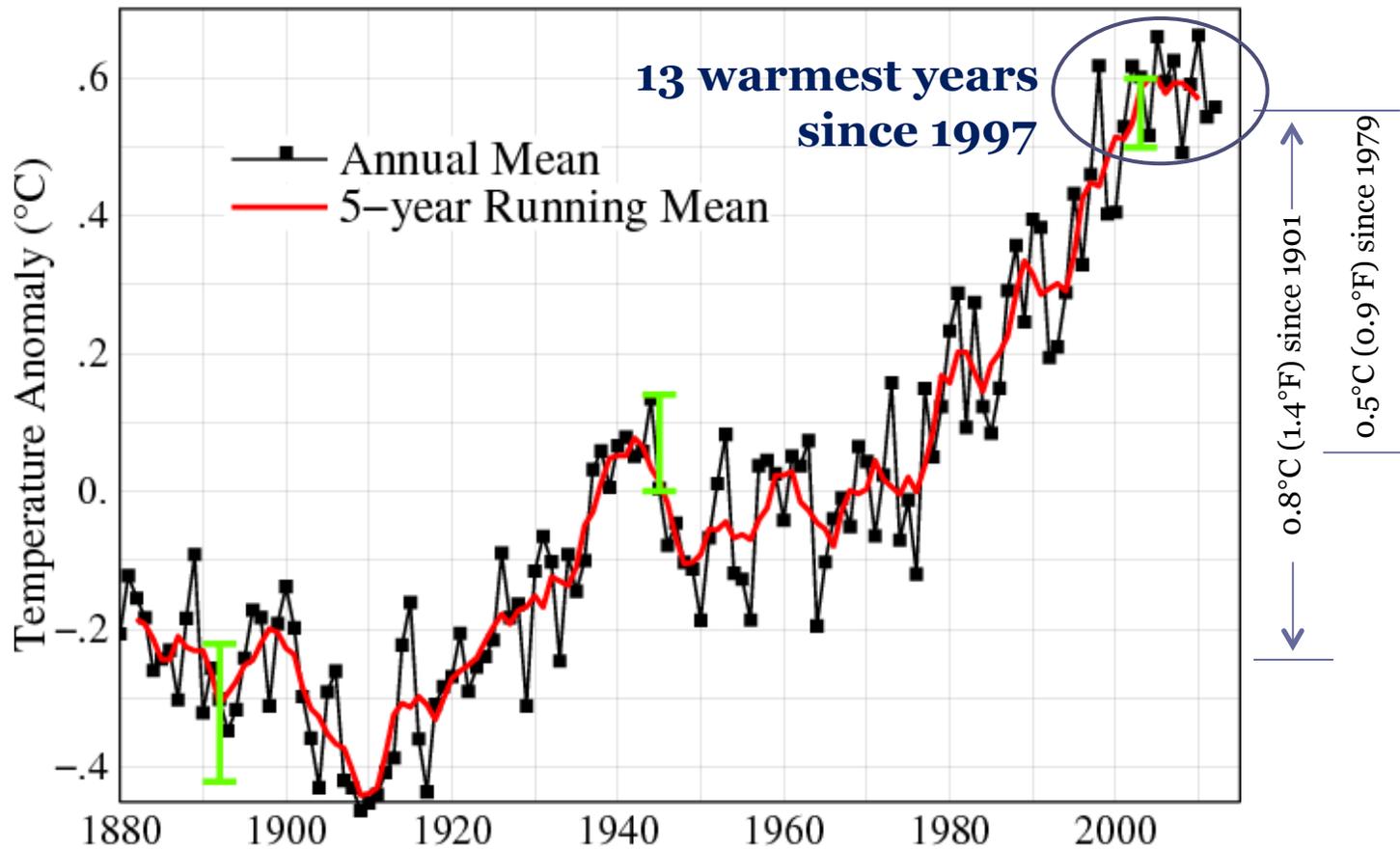
[http://data.giss.nasa.gov/gistemp/graphs\\_v3/Fig.A.gif](http://data.giss.nasa.gov/gistemp/graphs_v3/Fig.A.gif)

## Global Land–Ocean Temperature Index

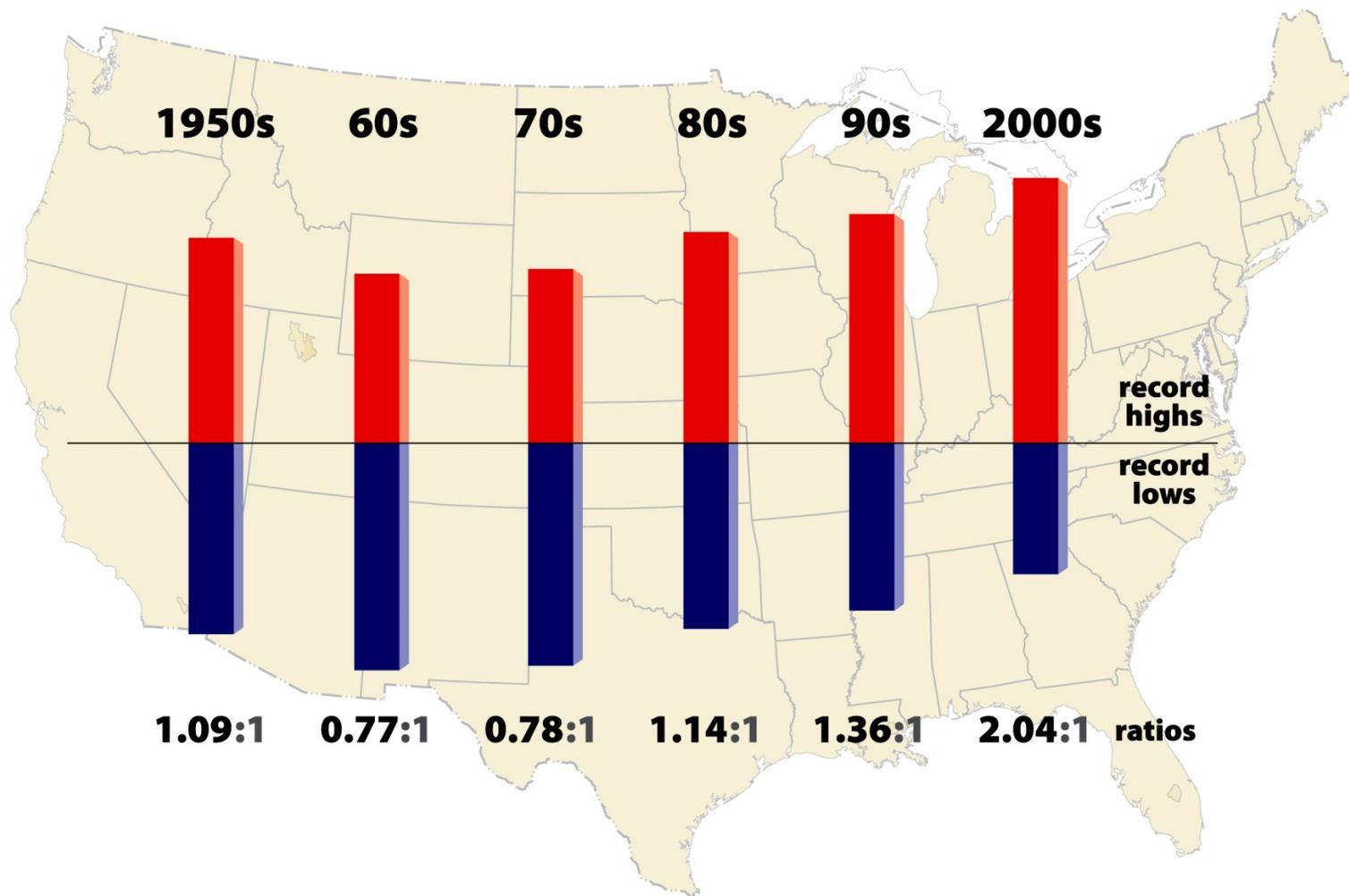


[http://data.giss.nasa.gov/gistemp/graphs\\_v3/Fig.A2.gif](http://data.giss.nasa.gov/gistemp/graphs_v3/Fig.A2.gif)

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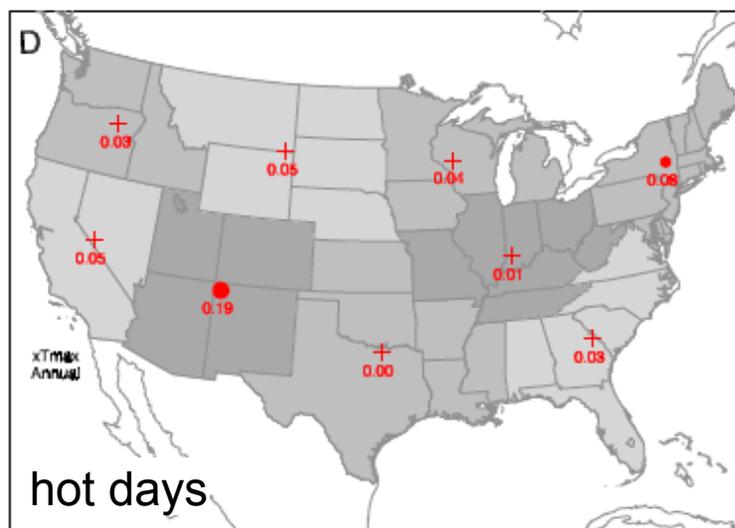
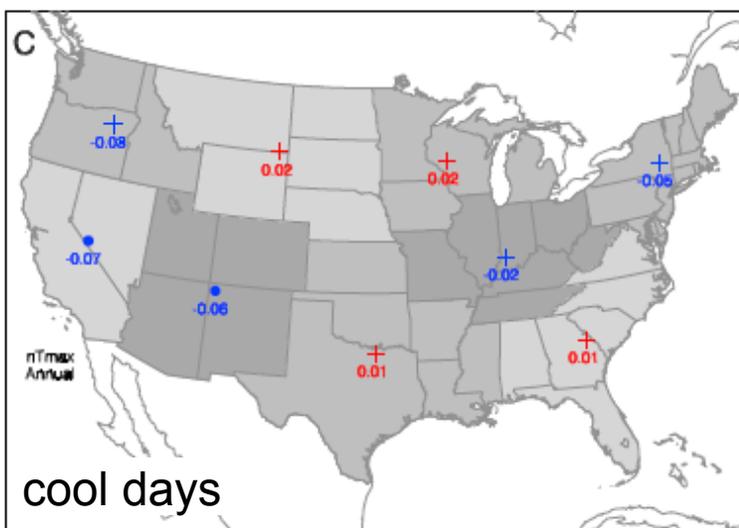
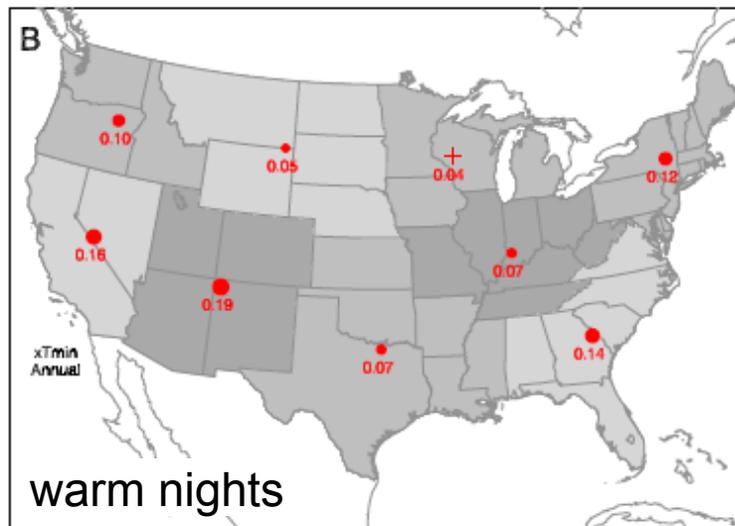
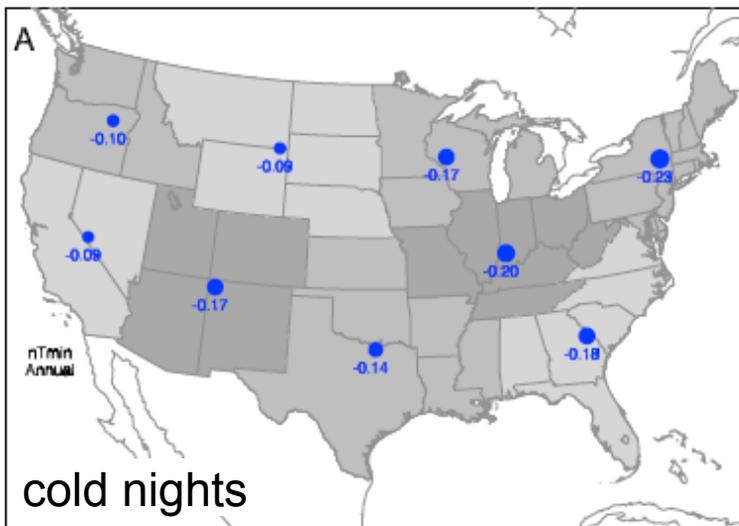


[http://data.giss.nasa.gov/gistemp/graphs\\_v3/Fig.A2.gif](http://data.giss.nasa.gov/gistemp/graphs_v3/Fig.A2.gif)

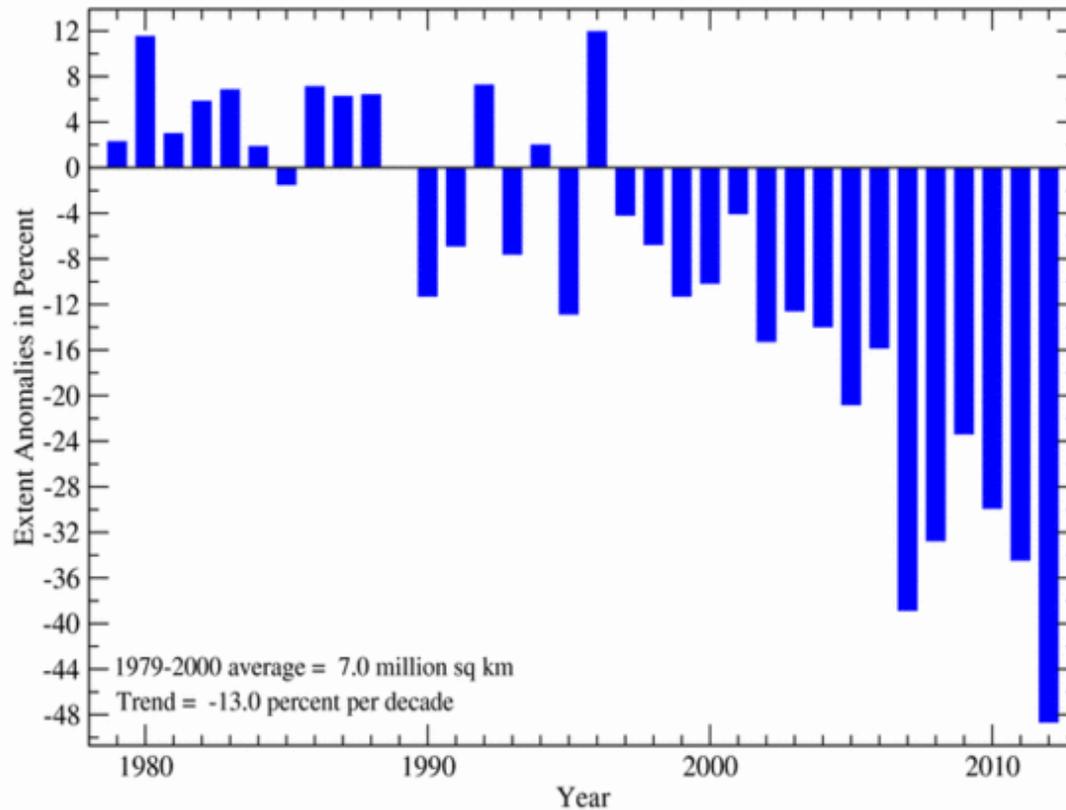


Meehl et al., 2009

## Trends in record\*-breaking temperatures



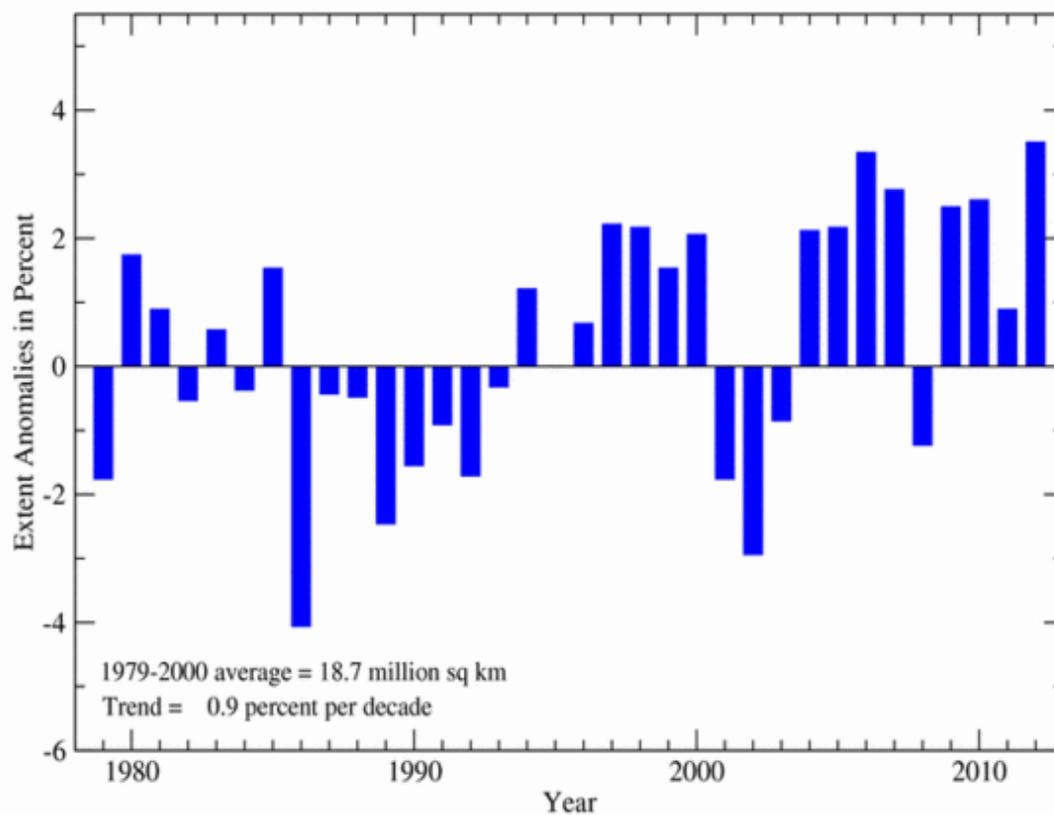
## Northern Hemisphere Sea Ice Extent September Anomalies, 1979-2012



Data provided by the National Snow and Ice Data Center (NSIDC)

<http://www.ncdc.noaa.gov/sotc/global-snow/2012/9>

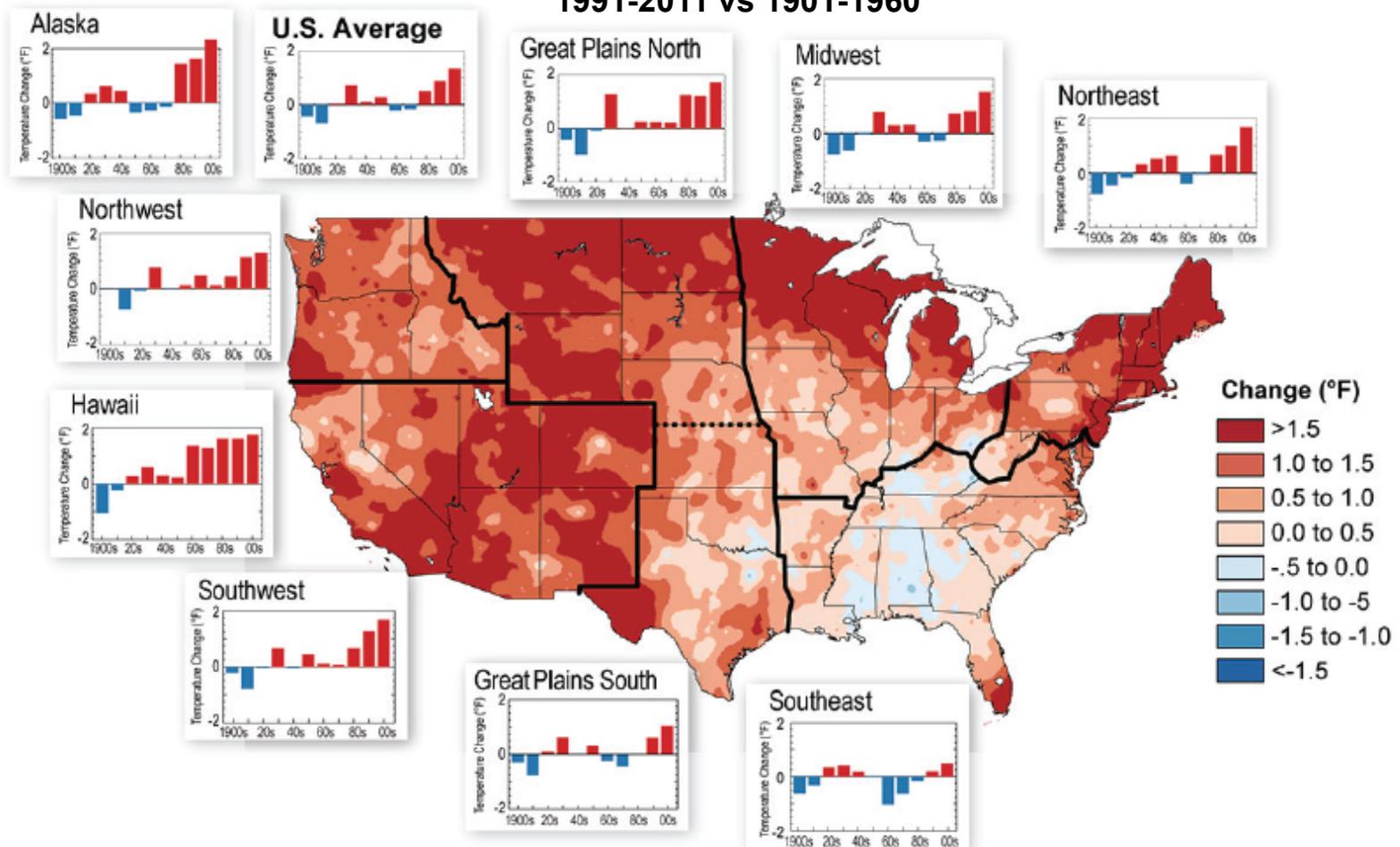
## Southern Hemisphere Sea Ice Extent September Anomalies, 1979-2012



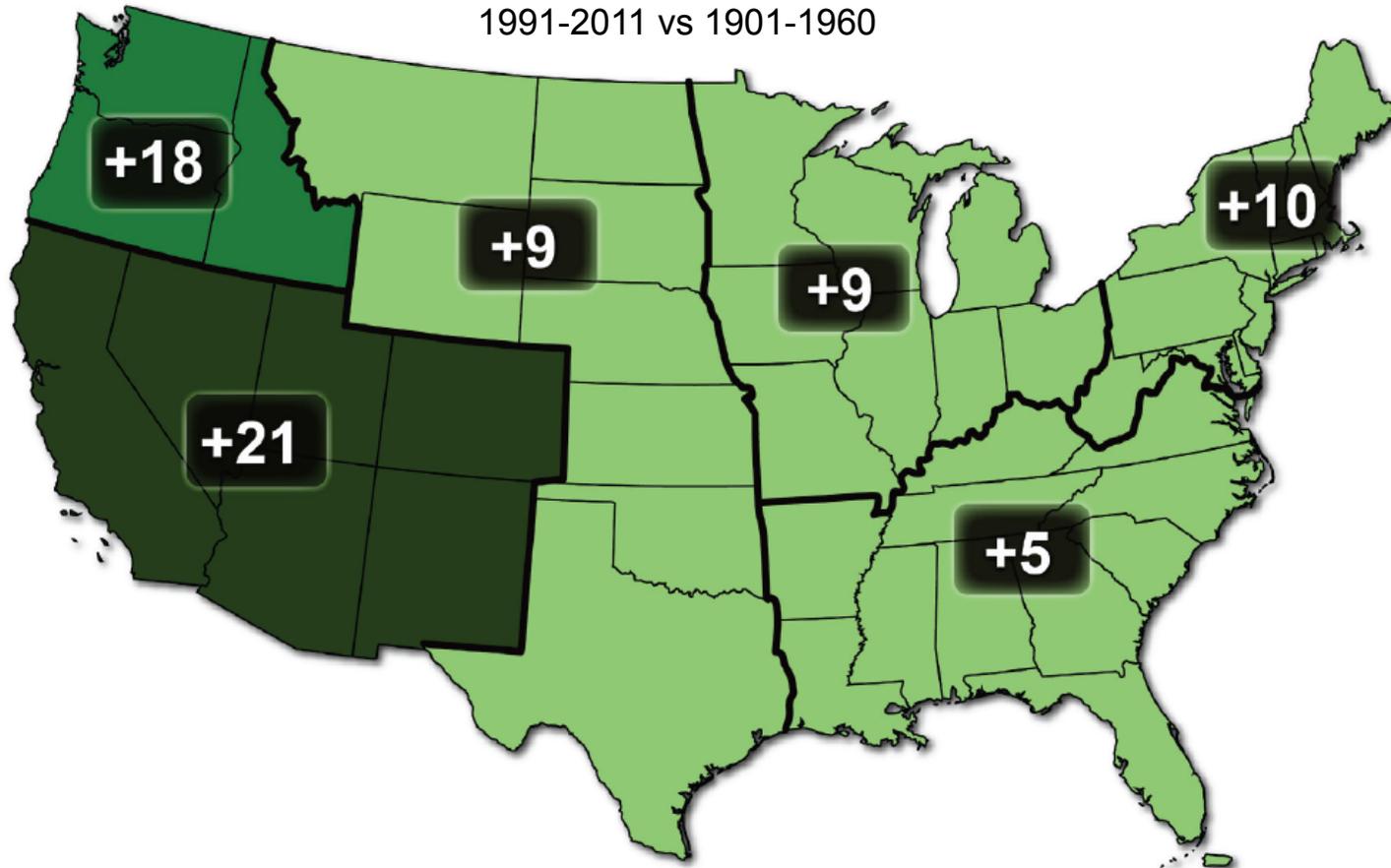
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<http://www.ncdc.noaa.gov/sotc/global-snow/2012/9>

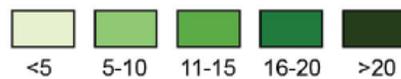
## Observed U.S. Temperature Change 1991-2011 vs 1901-1960



## Observed Changes in Frost-Free Season 1991-2011 vs 1901-1960

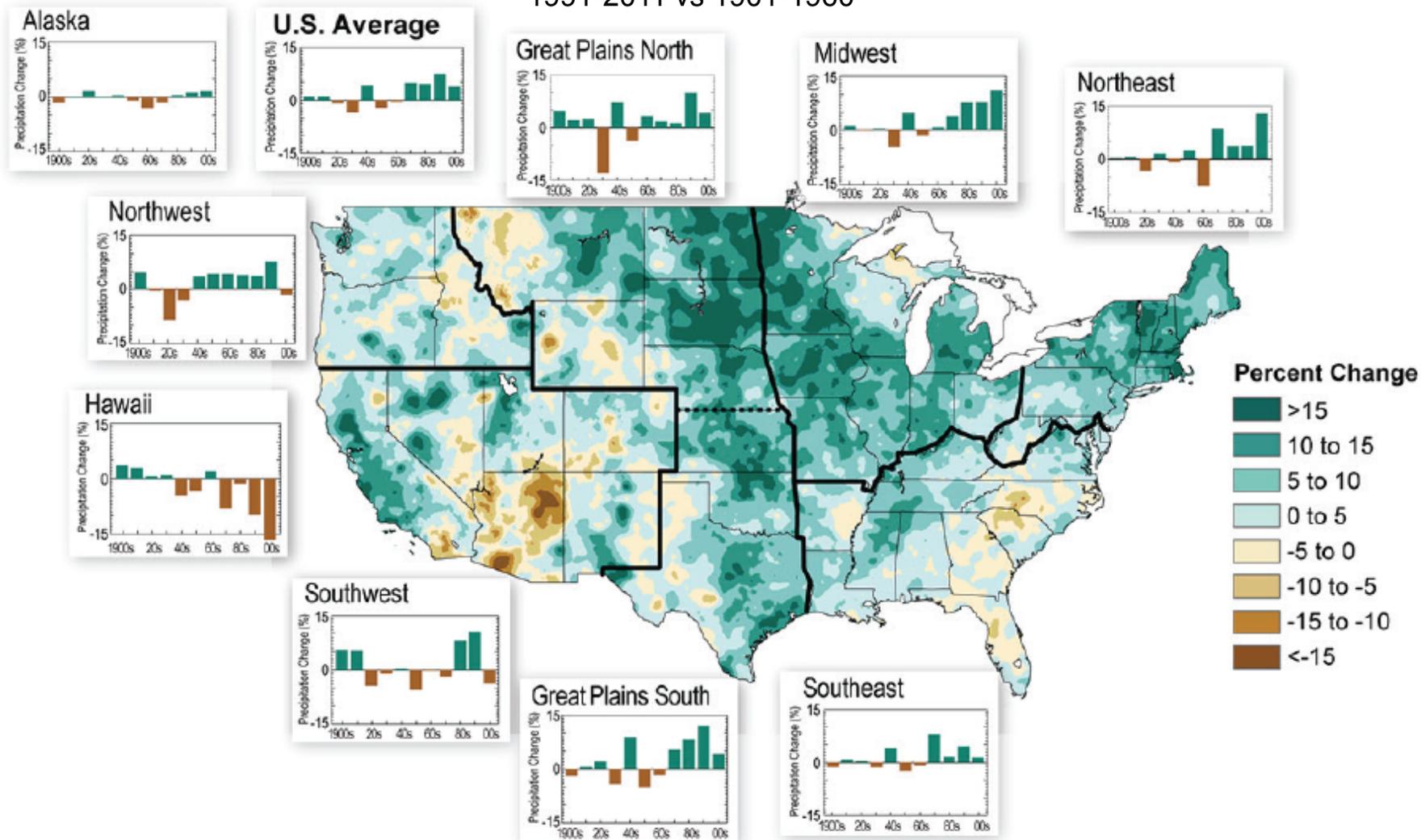


Increases in Annual Number of Days

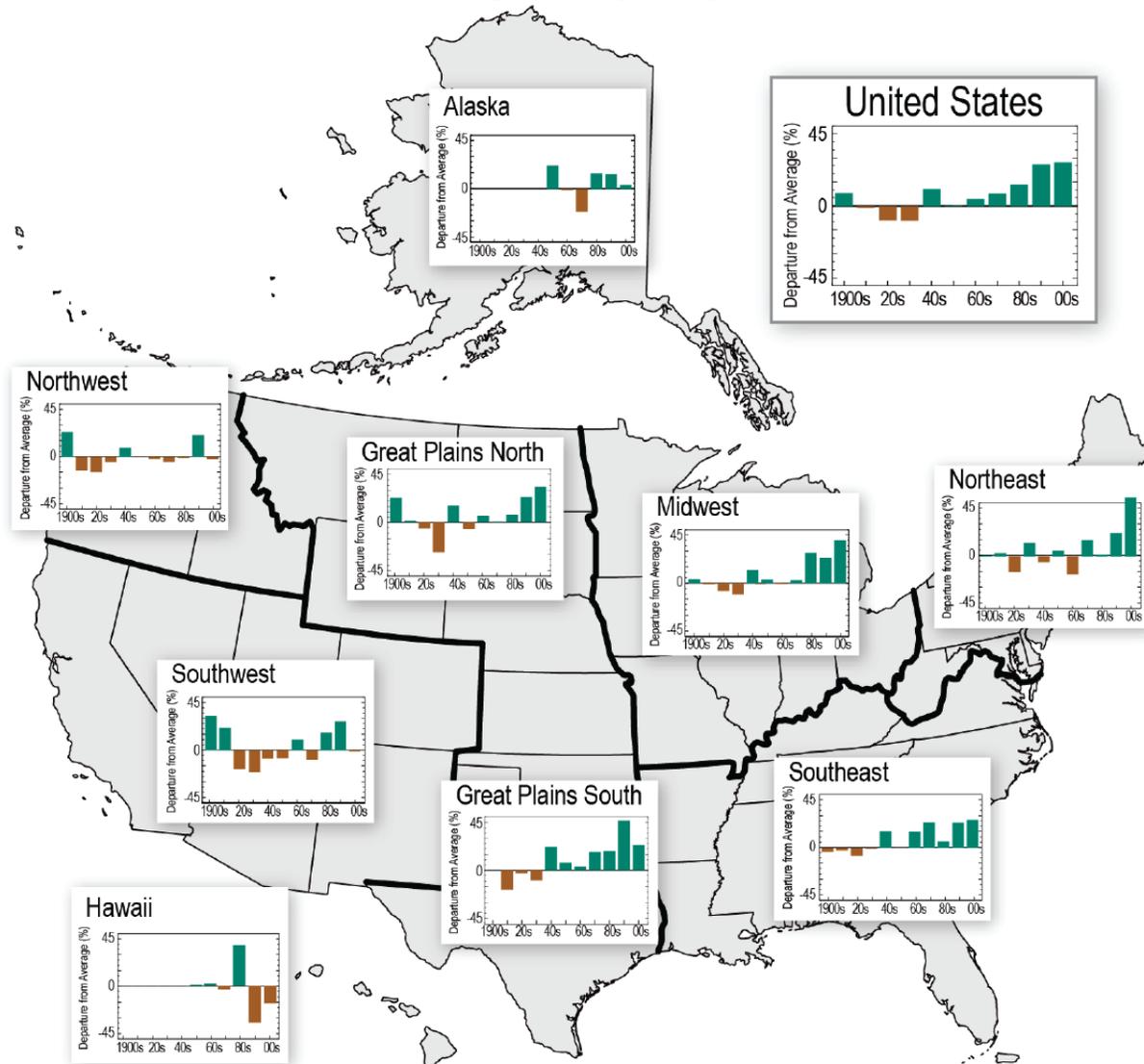


# Observed U.S. Precipitation Change

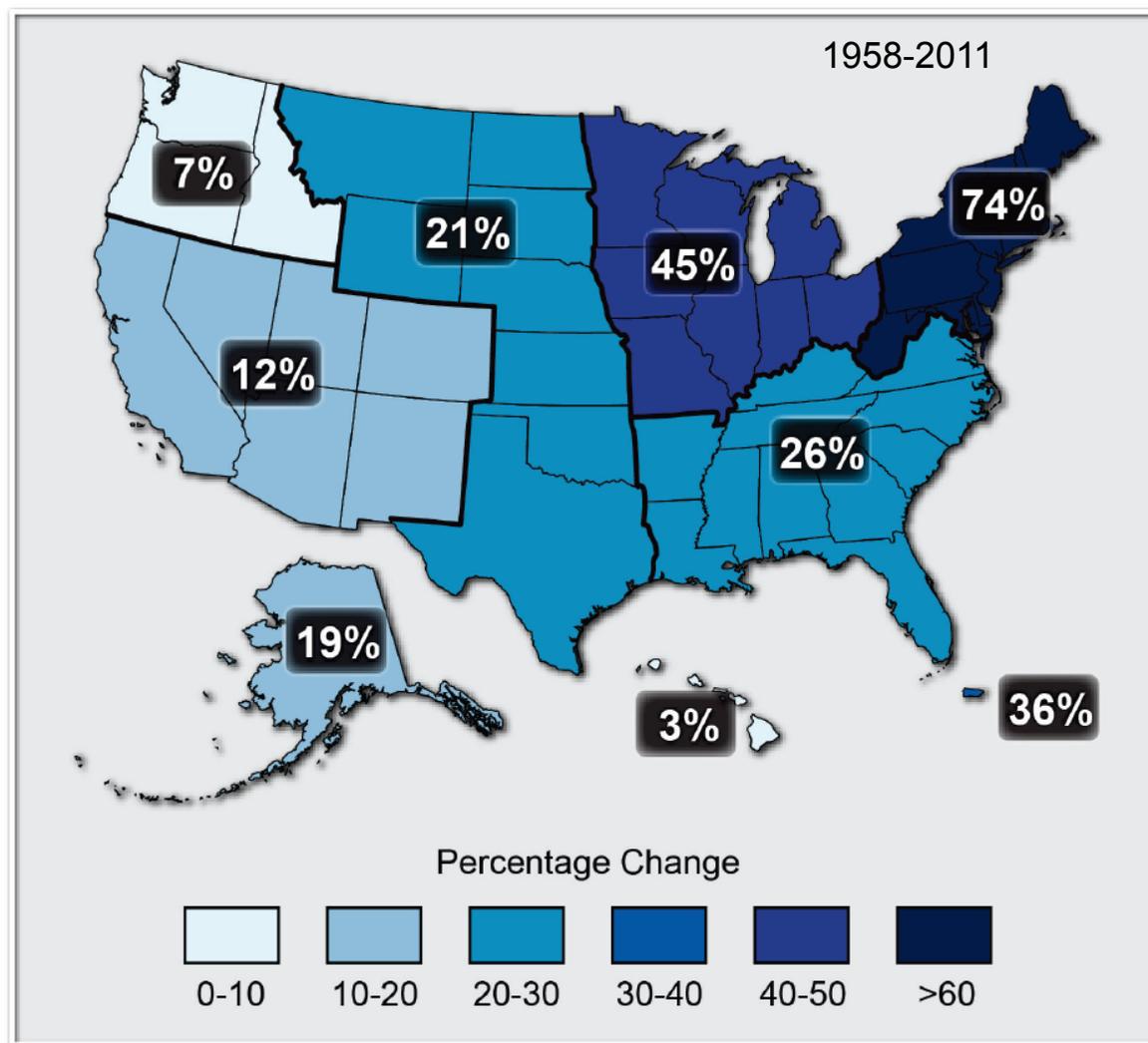
1991-2011 vs 1901-1960



## Observed Changes in Very Heavy Precipitation

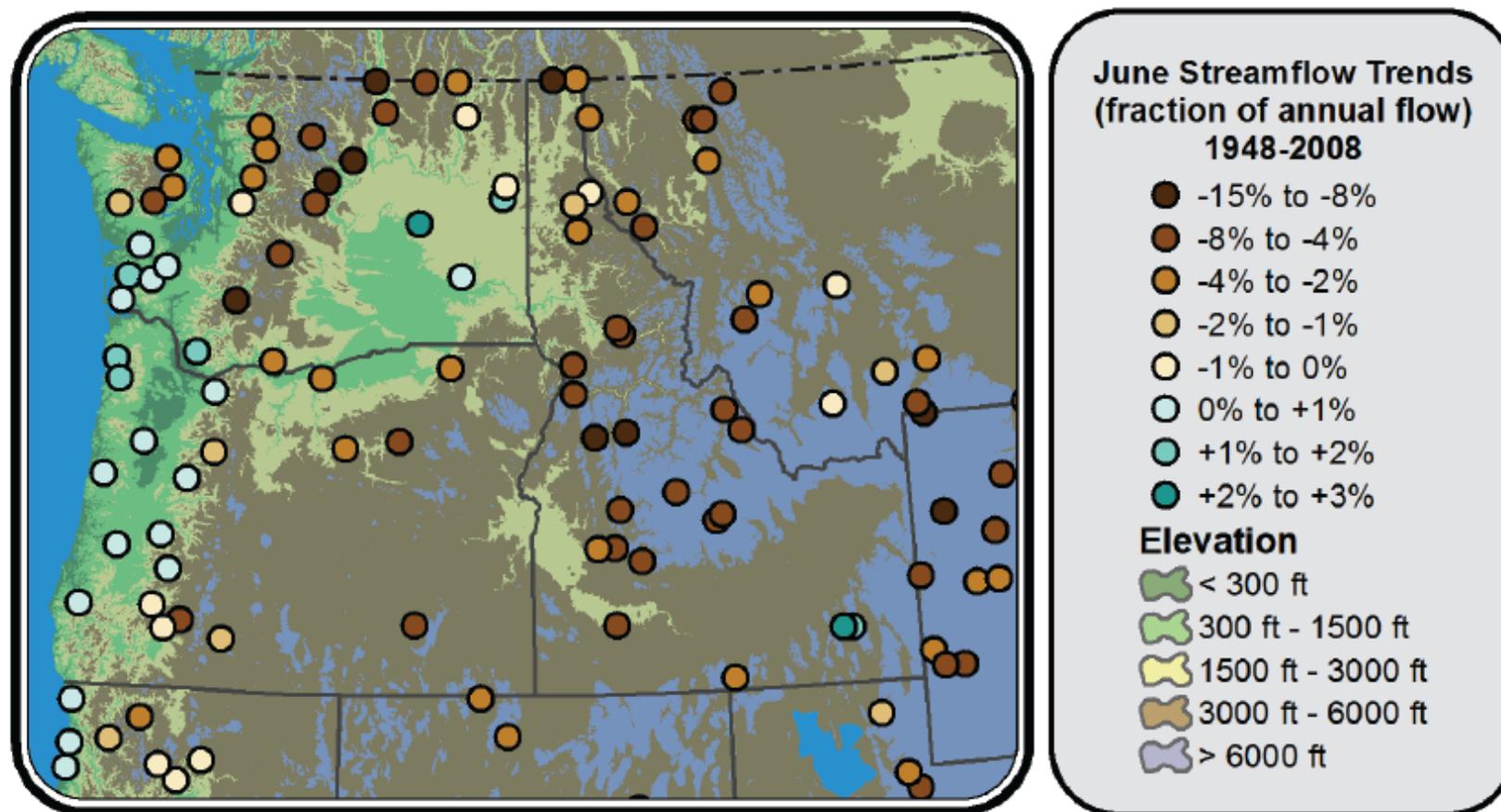


## Percentage Change in Very Heavy Precipitation

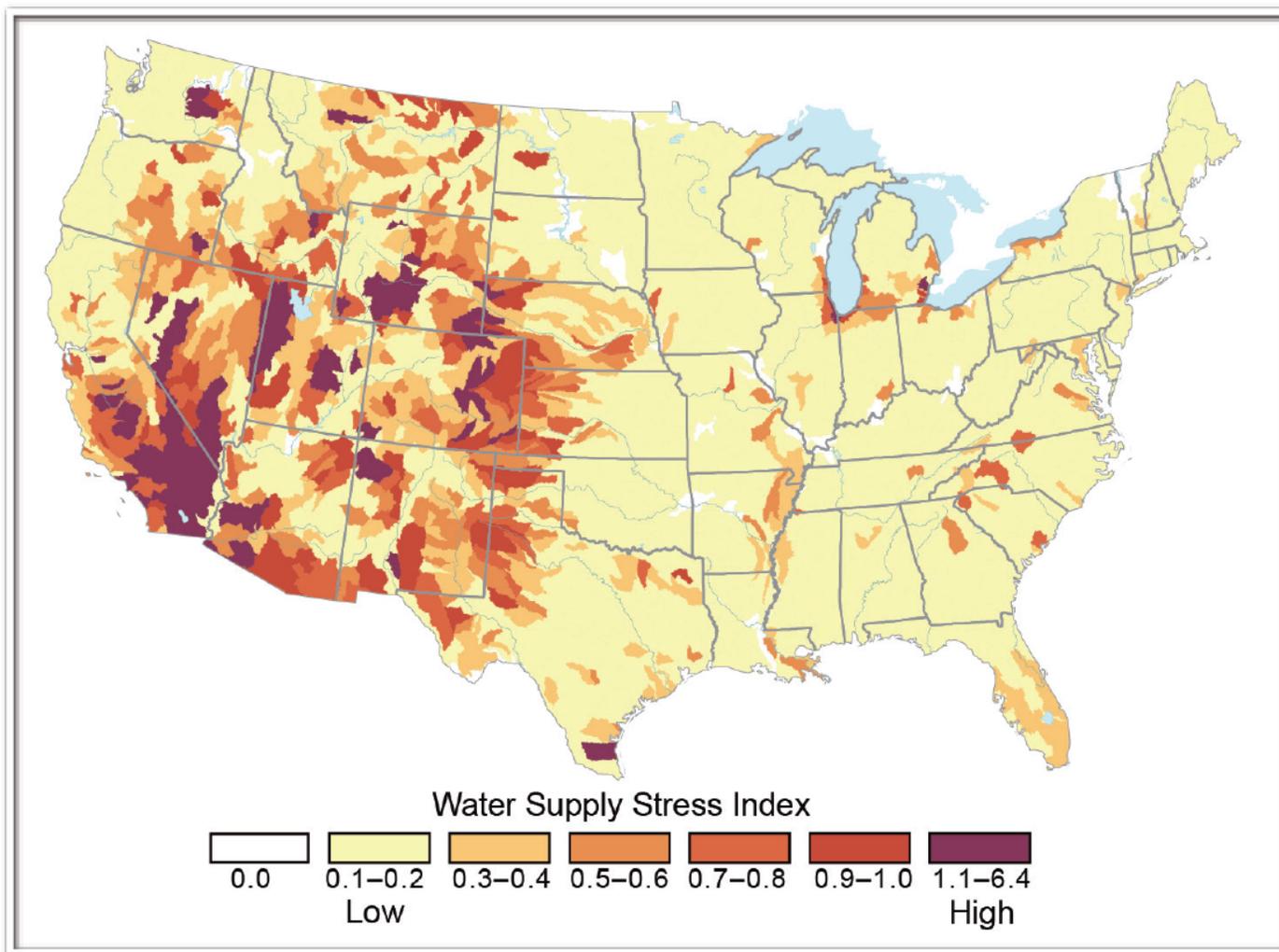


# Observed Shifts in Streamflow Timing

1948-2011



## Water Stress in the U.S.

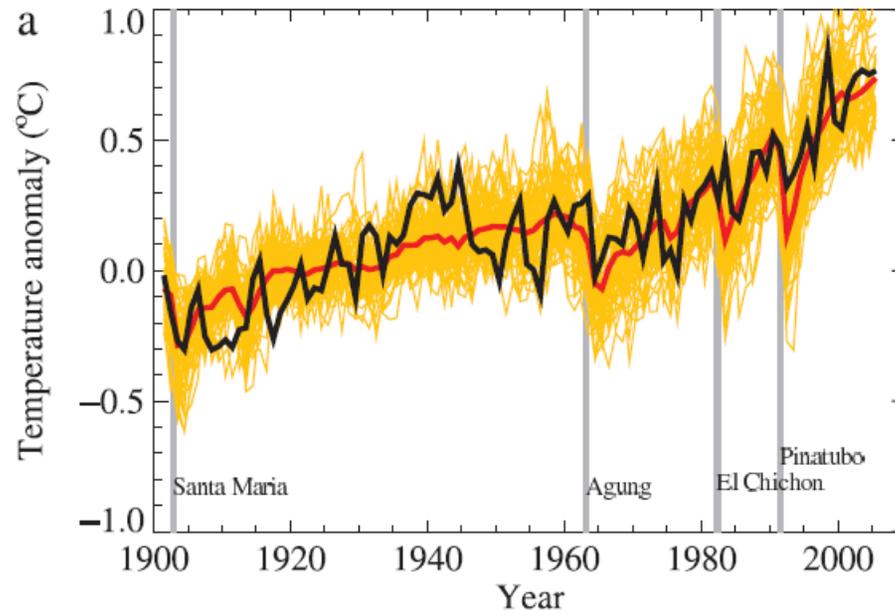


Third National Climate Assessment (NCA) - 11 Jan 2013 draft

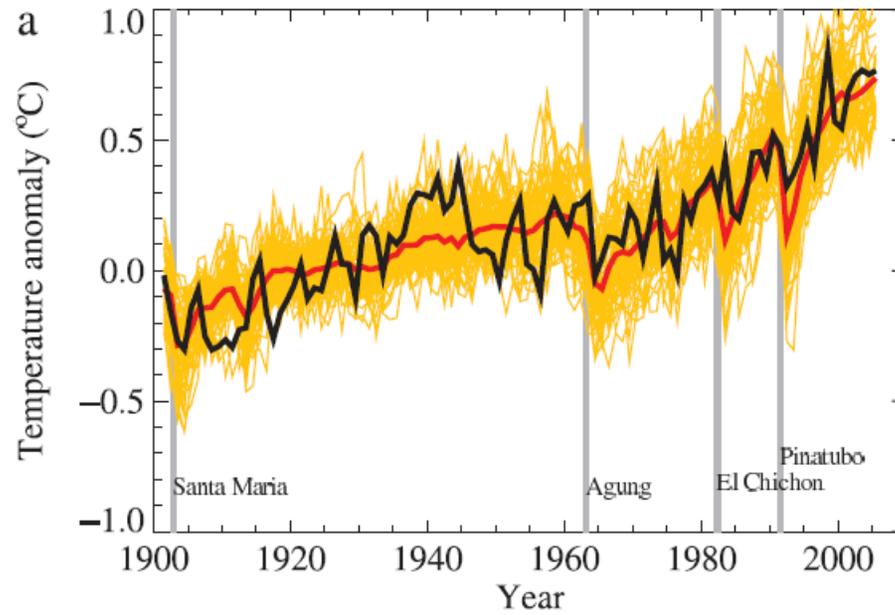
# How do we know it's humans?

- Many lines of evidence support the conclusion that most of the observed warming since the start of the 20th century, and especially over the last several decades, can be attributed to human activities, including the following:
  - Earth's surface temperature has clearly risen over the past 100 years, at the same time that human activities have resulted in sharp increases in CO<sub>2</sub> and other GHGs.
  - Both the basic physics of the greenhouse effect and more detailed calculations dictate that increases in atmospheric GHGs should lead to warming of Earth's surface and lower atmosphere.
  - The vertical pattern of observed warming—with warming in the bottommost layer of the atmosphere and cooling immediately above—is consistent with warming caused by GHG increases and inconsistent with other possible causes.
  - Detailed simulations with state-of-the-art computer-based models of the climate system are only able to reproduce the observed warming trend and patterns when human-induced GHG emissions are included.

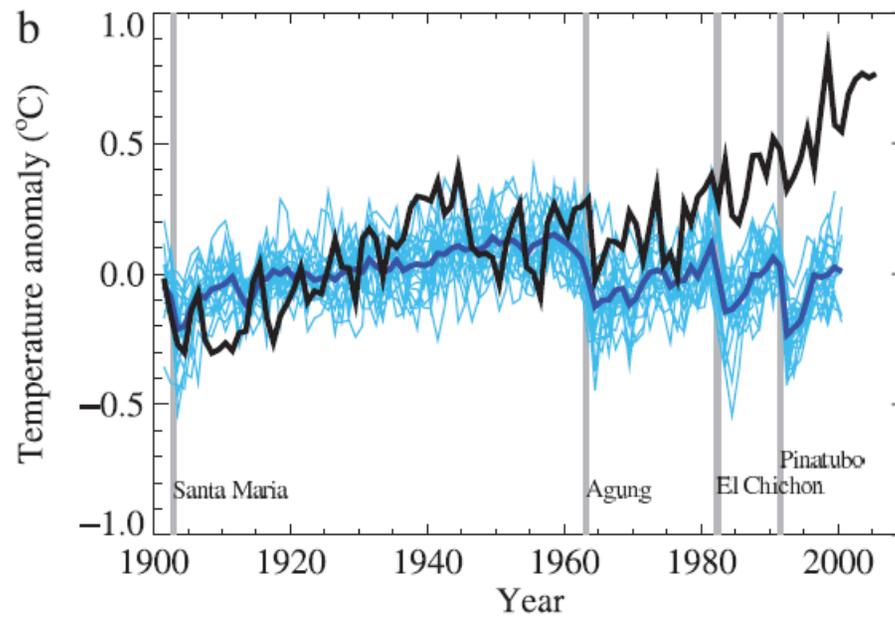
Natural &  
anthropogenic  
forcing

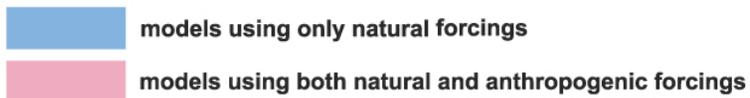
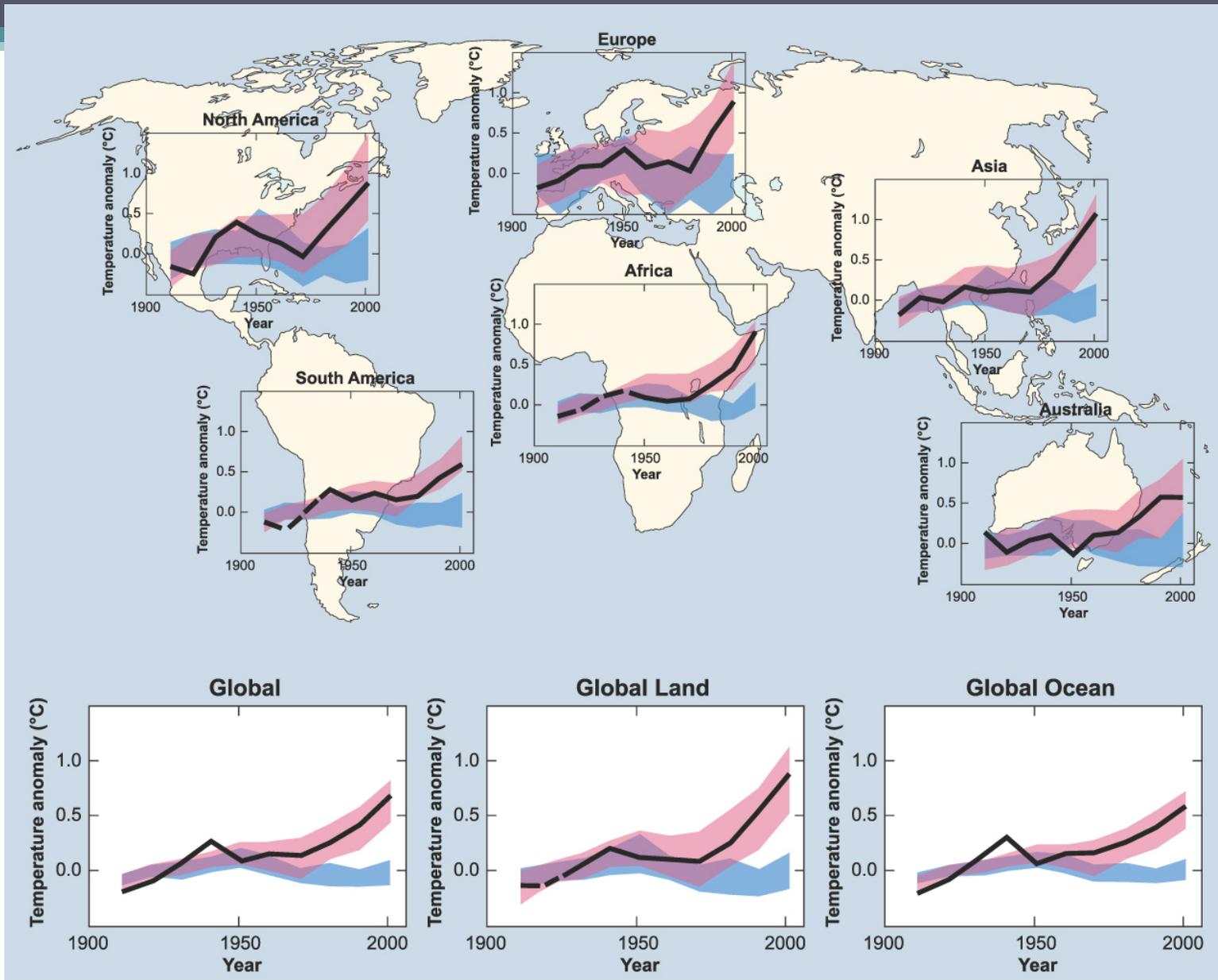


Natural &  
anthropogenic  
forcing



Natural forcing  
only



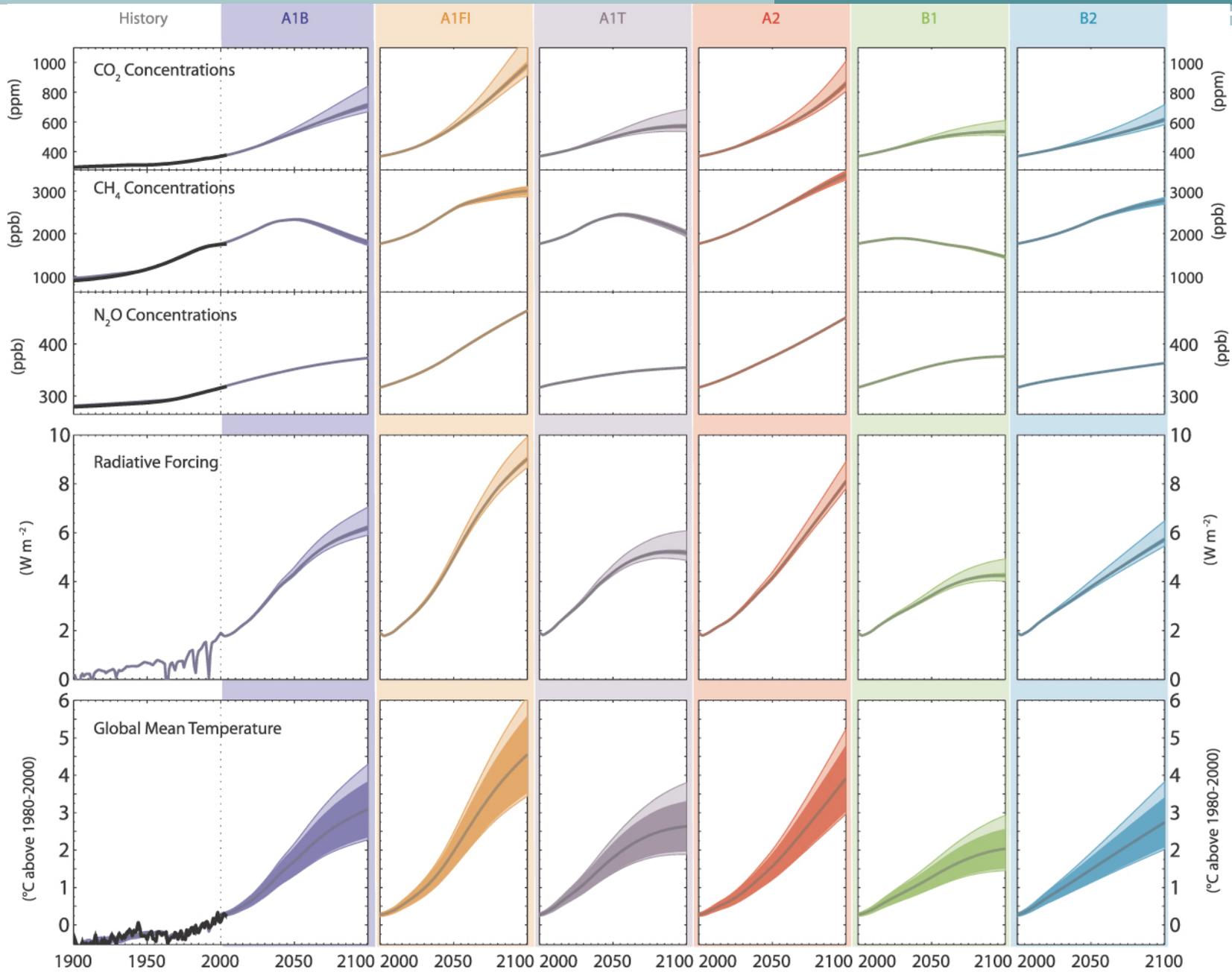


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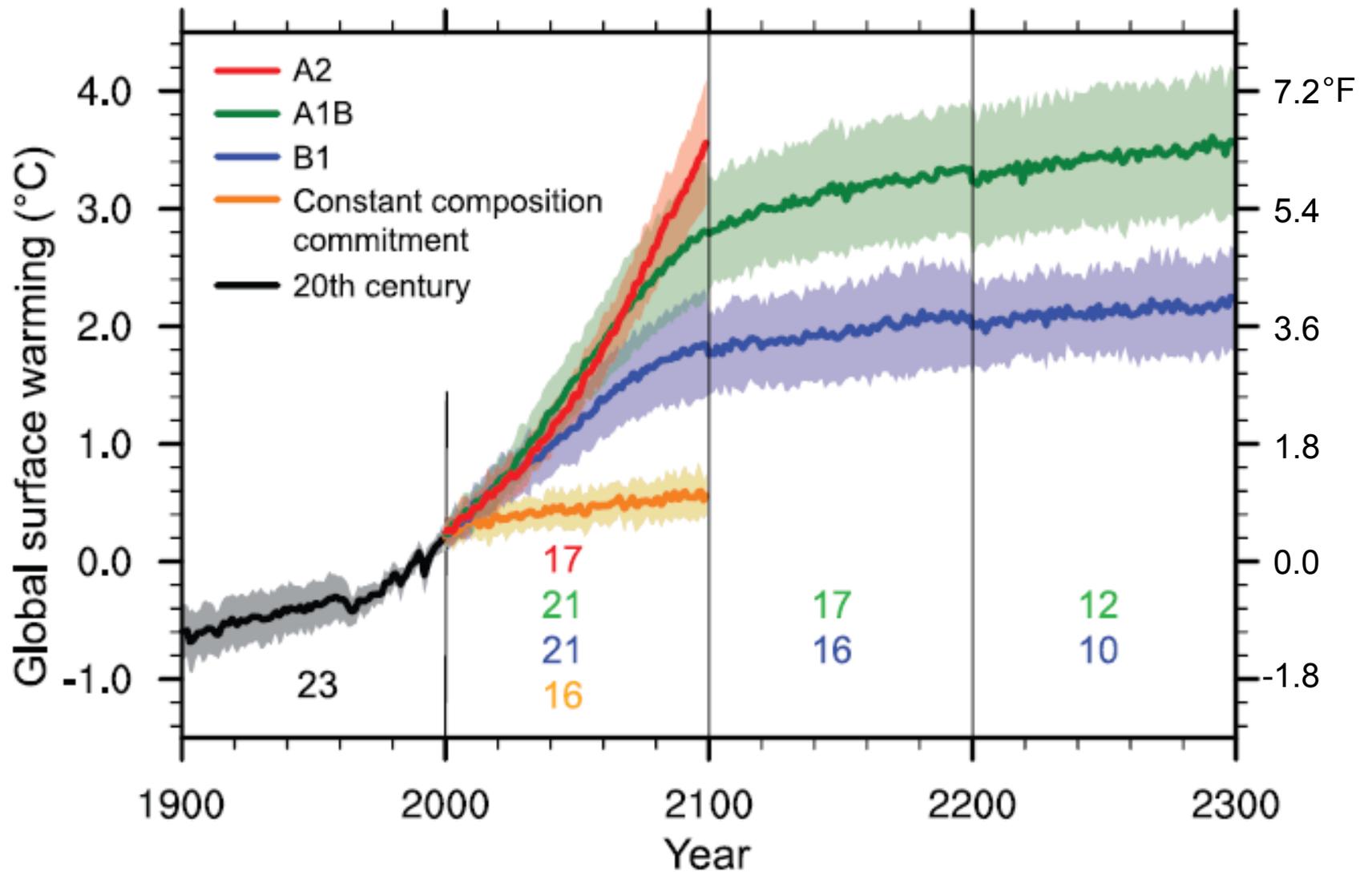
- In addition, other possible causes of the observed warming have been rigorously evaluated:
  - The climate system varies naturally on a wide range of time scales, but a rigorous statistical evaluation of observed climate trends, supported by analyses with climate models, indicates that the observed warming, especially the warming since the late 1970s, **cannot be attributed to natural variations.**
  - Satellite measurements conclusively show that solar output has not increased over the past 30 years, so **an increase in energy from the Sun cannot be responsible for recent warming.** There is evidence that some of the warming observed during the first few decades of the 20th century may have been caused by a slight uptick in solar output, although this conclusion is much less certain.
  - Direct measurements likewise show that the number of cosmic rays, which some scientists have posited might influence cloud formation and hence climate, have neither declined nor increased during the last 30 years. Moreover, **a plausible mechanism by which cosmic rays might influence climate has not been demonstrated.**

# What is going to happen?

- Need to create scenarios of how CO<sub>2</sub> emissions and atmospheric concentrations will change in the future
  - A1: convergent world, decreasing population after mid-century
    - A1FI (fossil intensive), A1T (non-fossil), A1B (balanced)
  - A2: heterogeneous world, local solutions, increasing population
  - B1: convergent world, decreasing population after mid-century, service and information economy
  - B2: heterogeneous world, local solutions, increasing population (lower than A2), environmental protection and social equity
- Use best computer models to project climate change in response to GHG forcings
  - include all known additional forcings and feedbacks

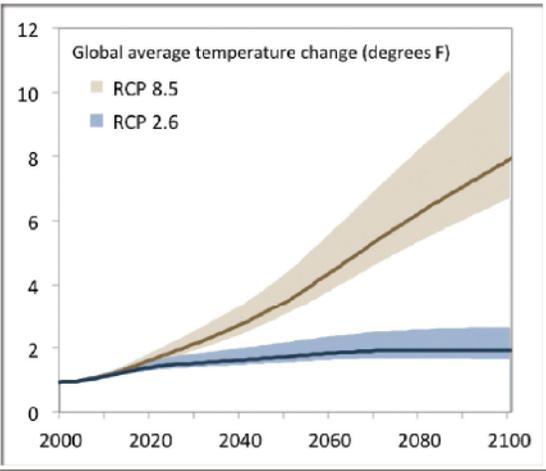
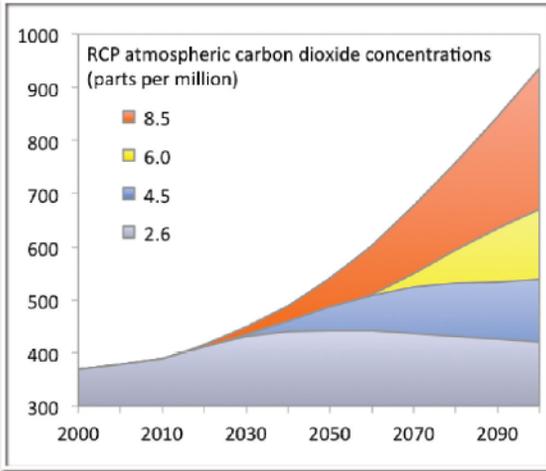
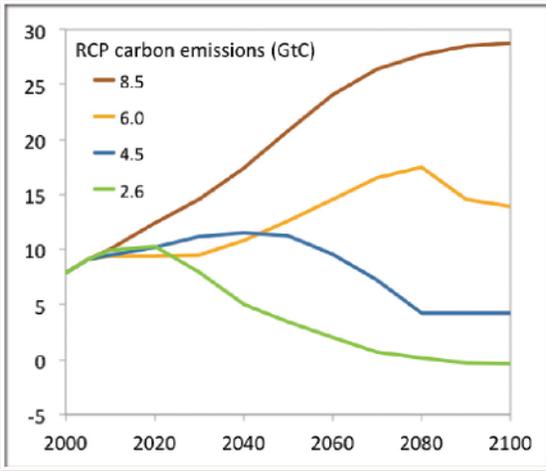
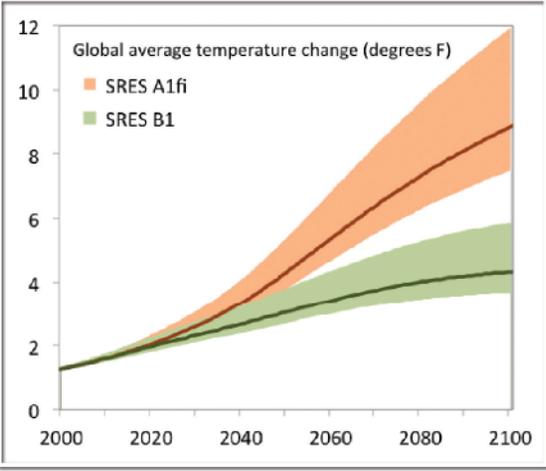
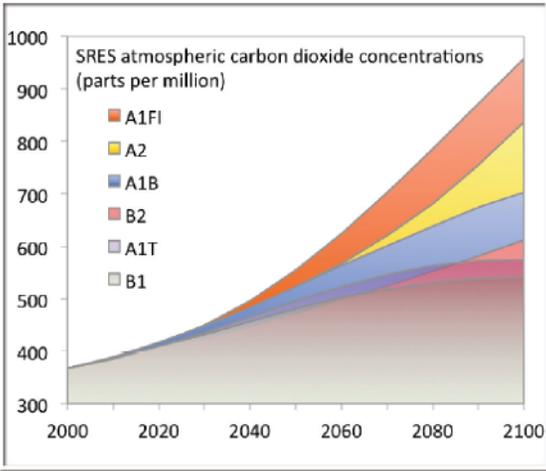
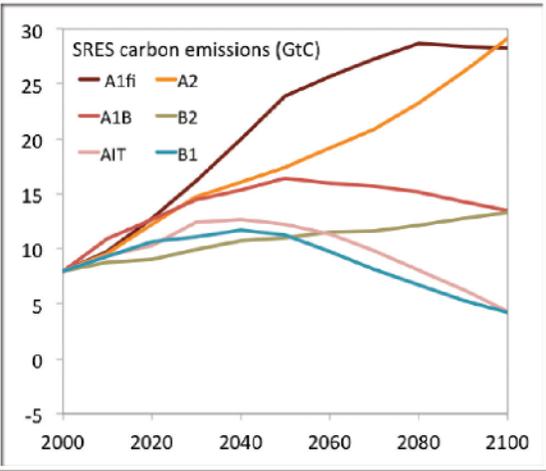


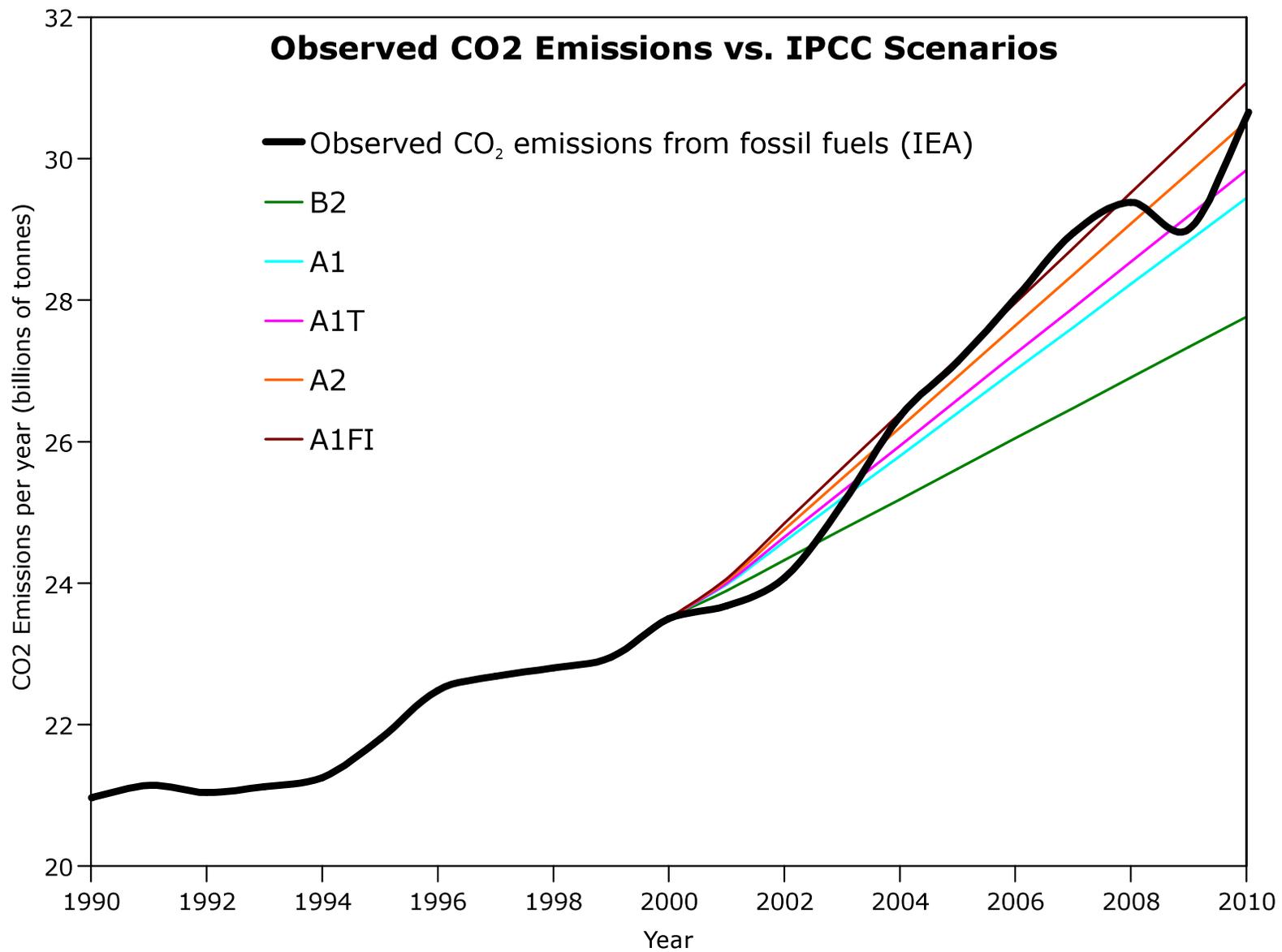
Meehl et al., 2007



Meehl et al., 2007

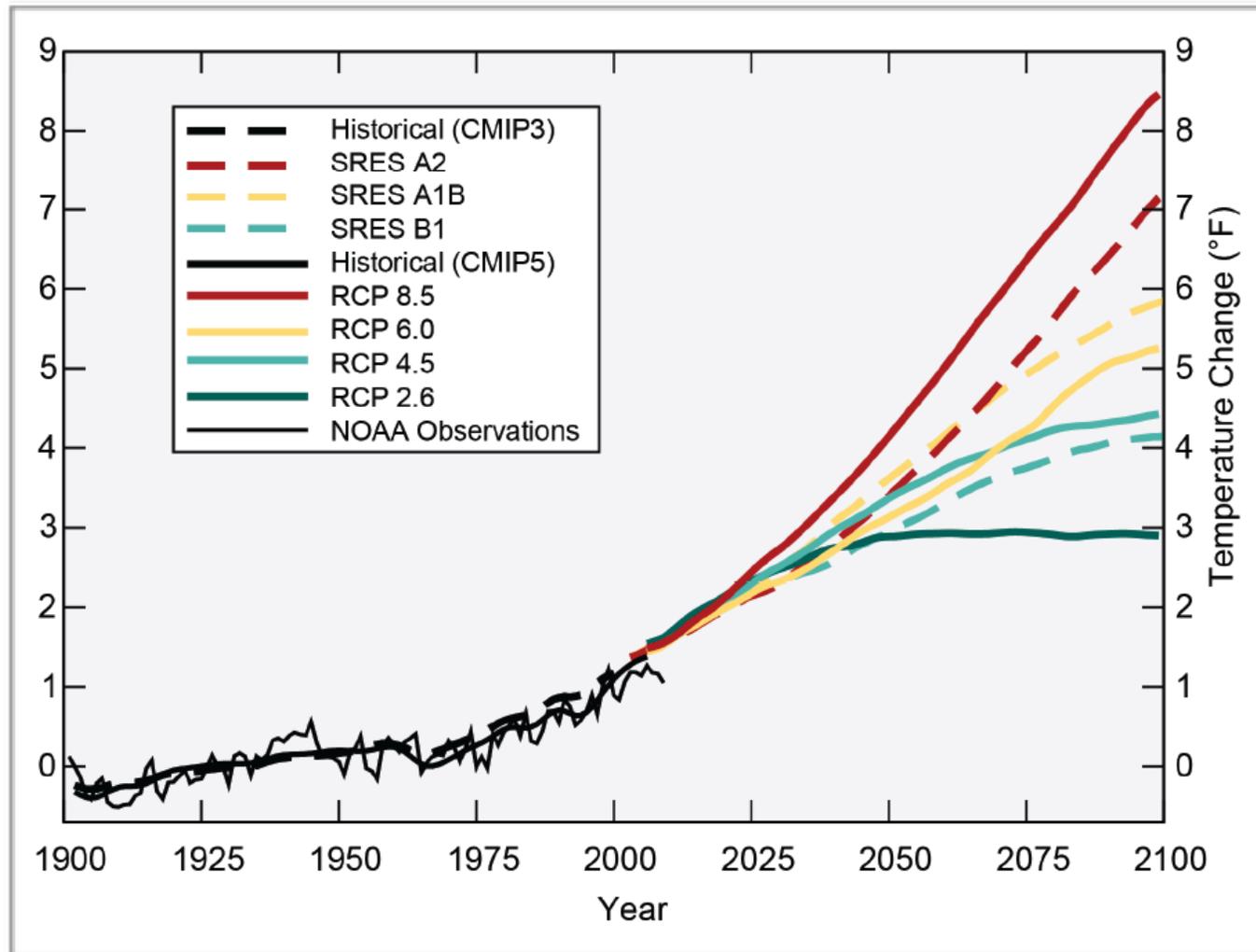
### Emissions, Concentrations, and Temperature Projections



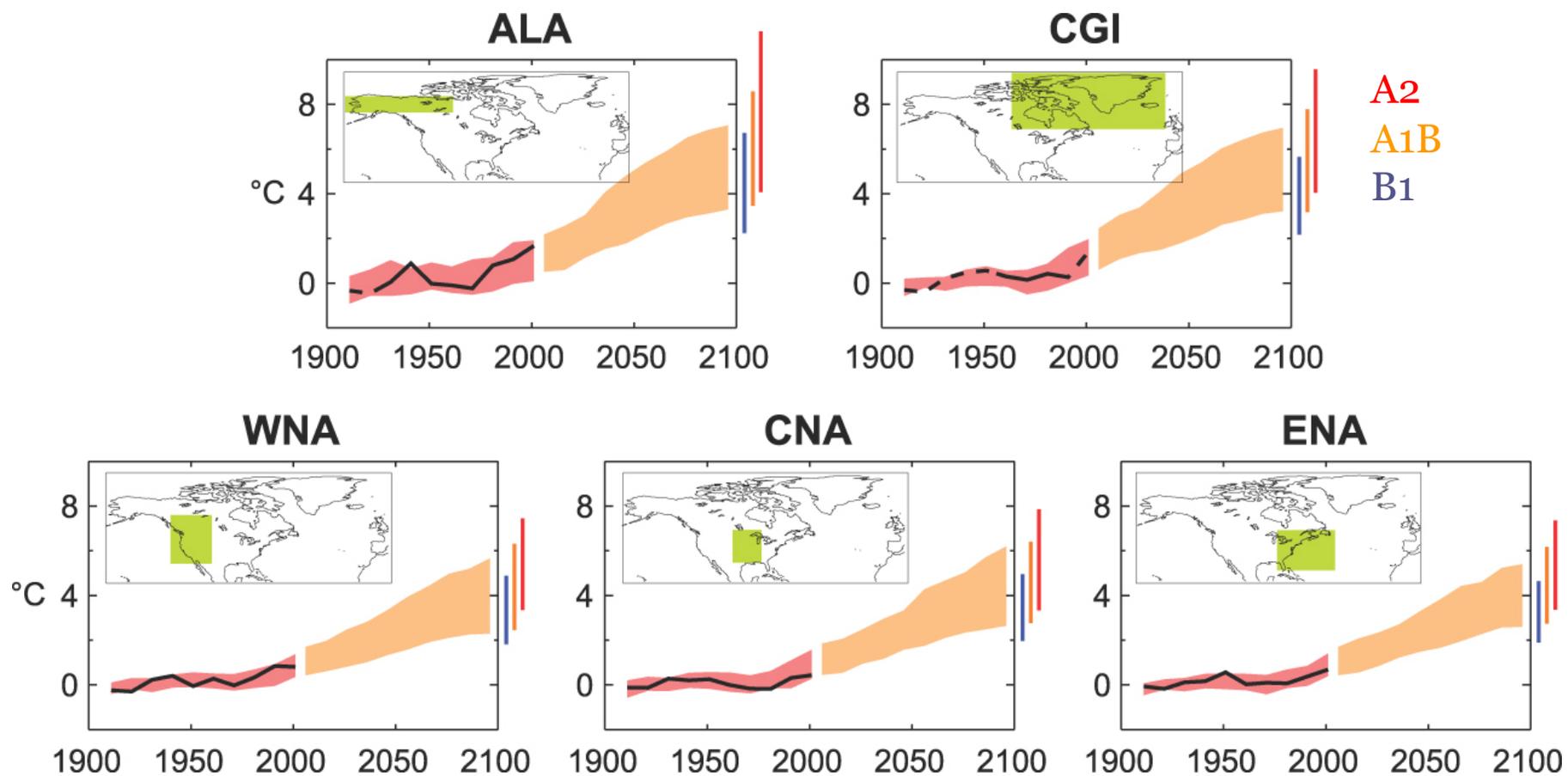


<http://www.skepticalscience.com/iea-co2-emissions-update-2010.html>

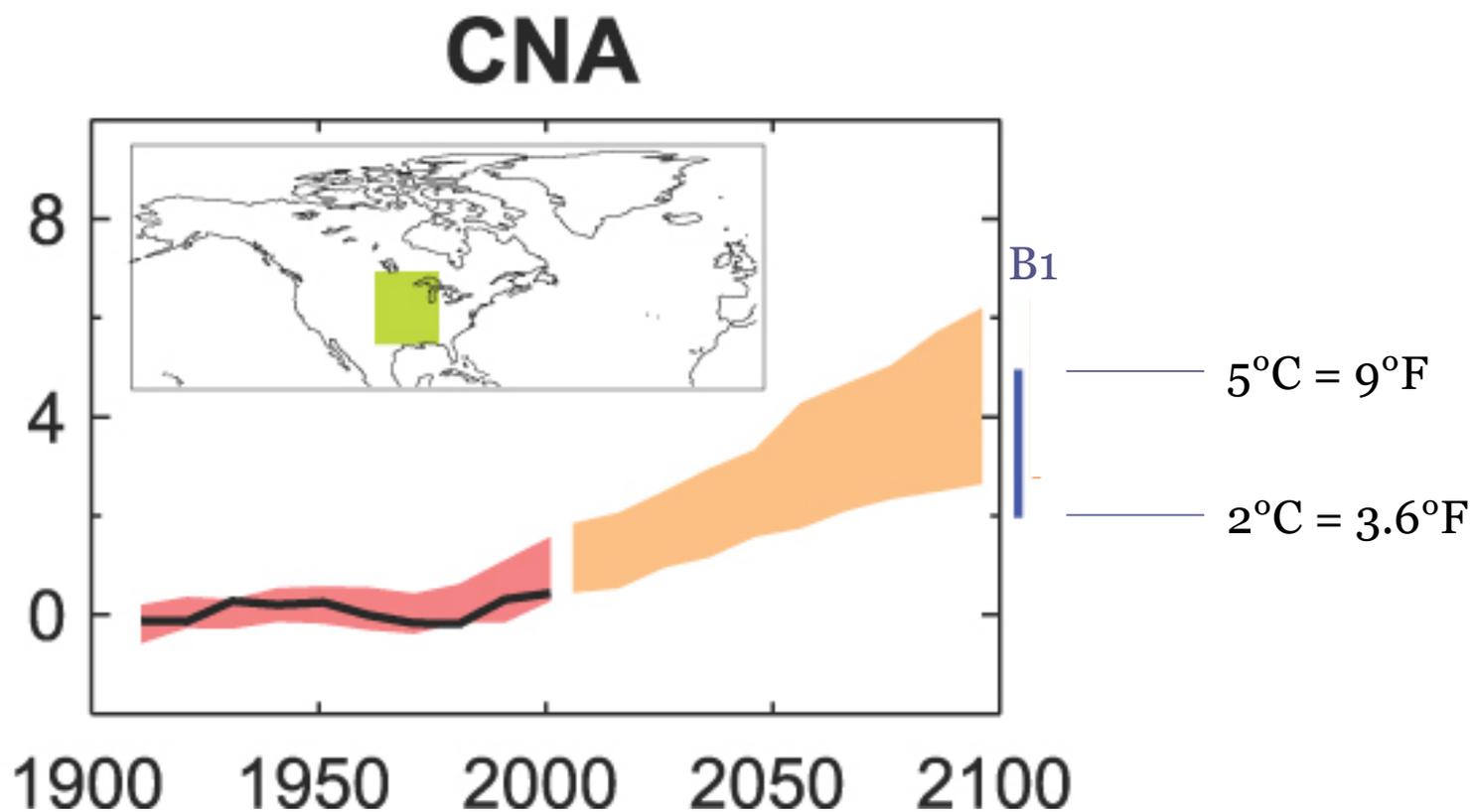
## Average Global Temperature Projections



*Temperature anomalies with respect to 1901 to 1950*

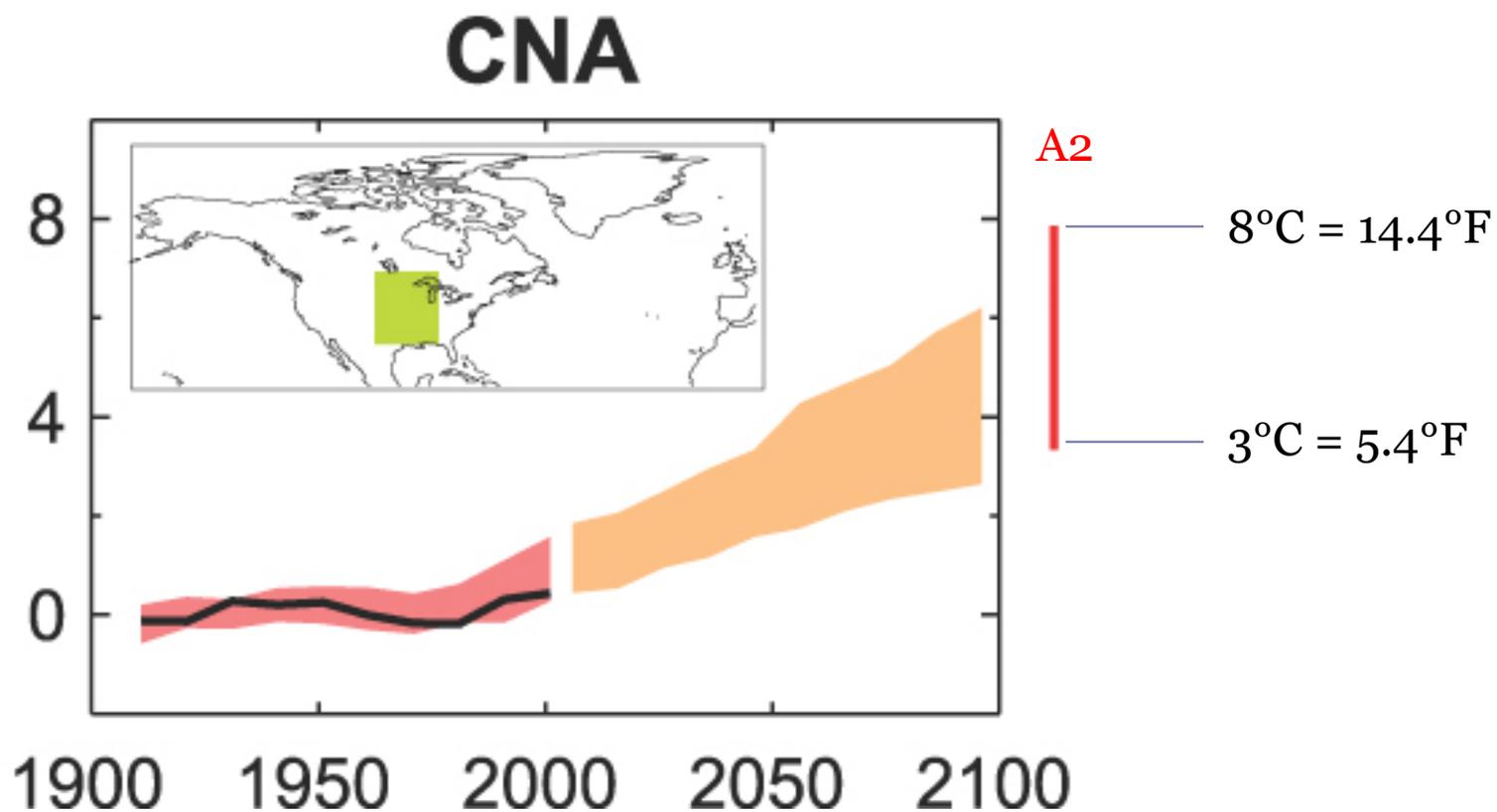


*Temperature anomalies with respect to 1901 to 1950*



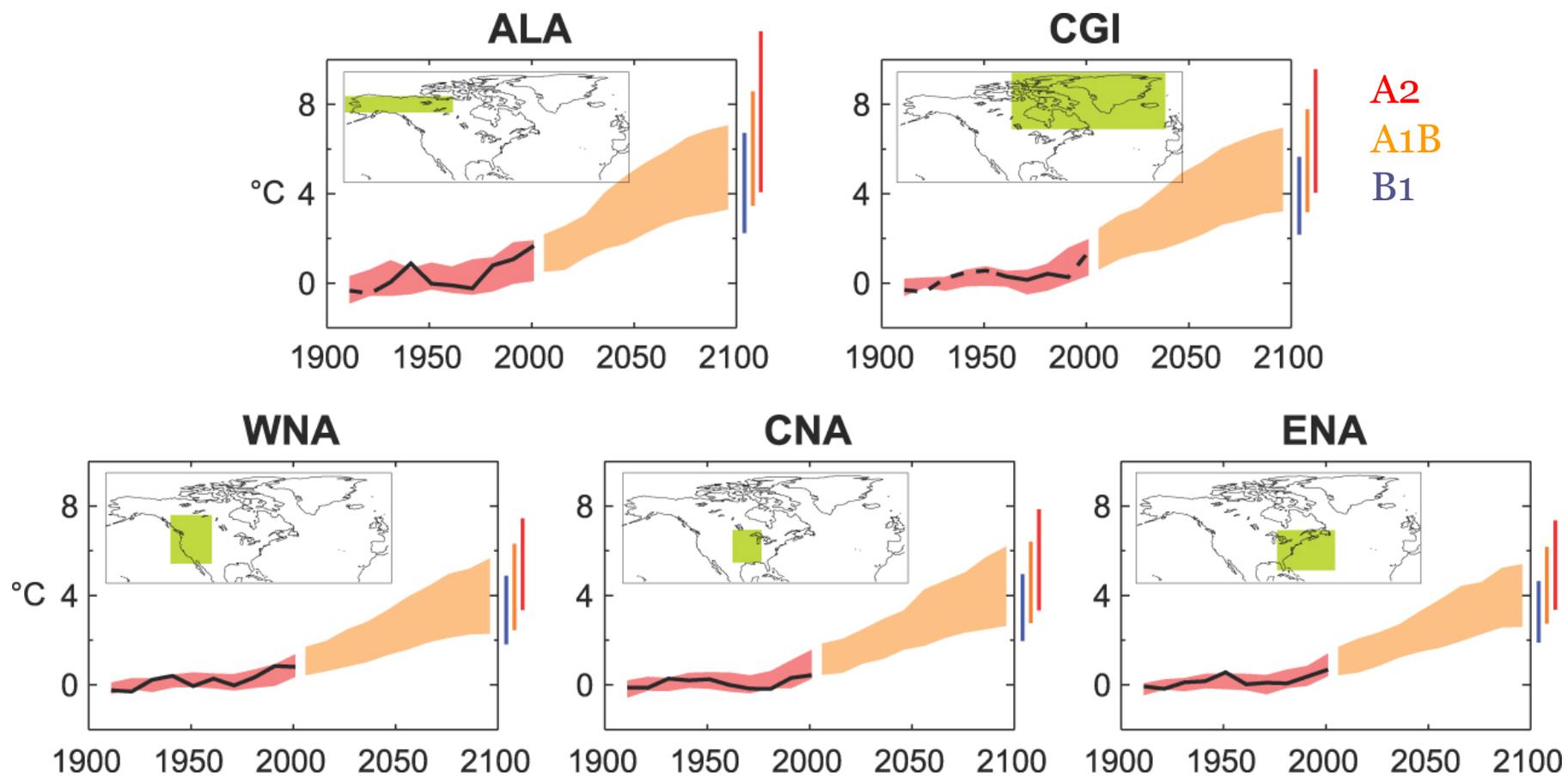
Christensen et al., 2007

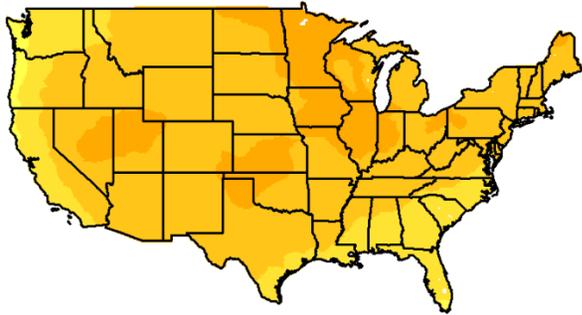
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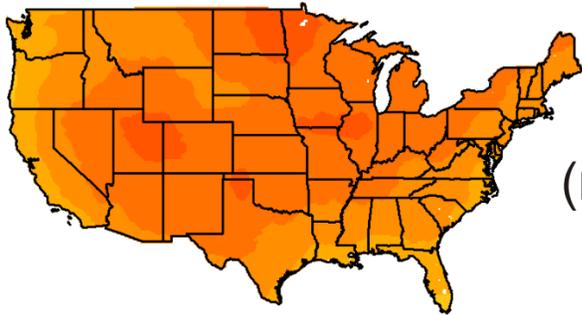
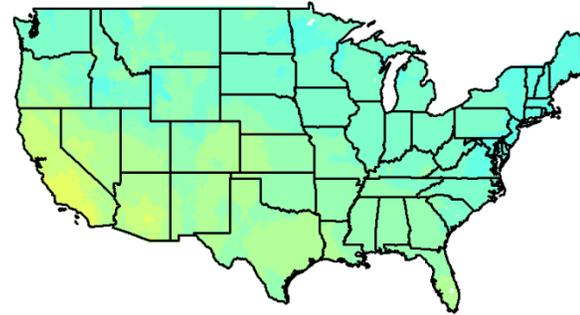
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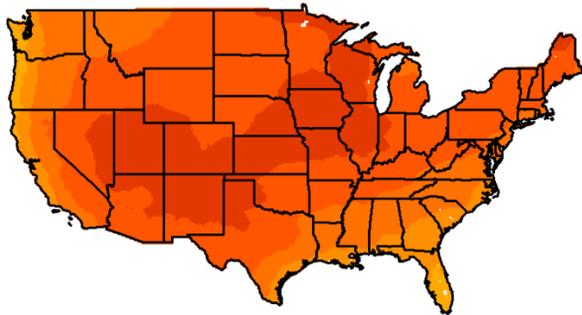
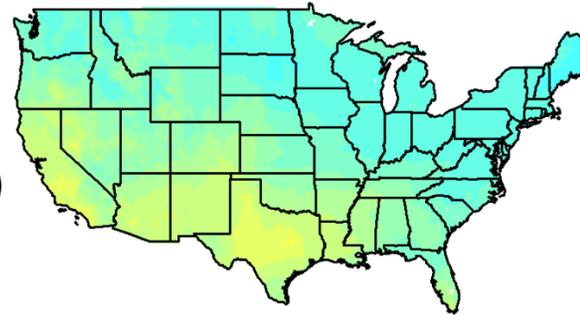




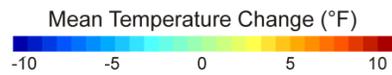
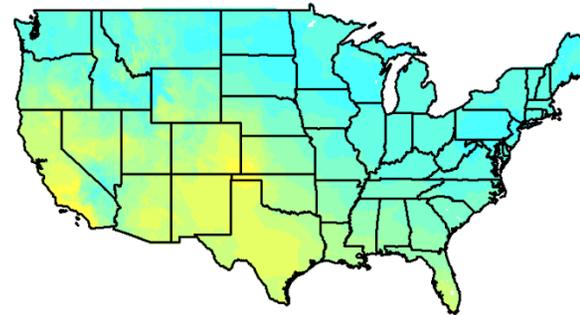
B1  
(low)



A1B  
(medium)

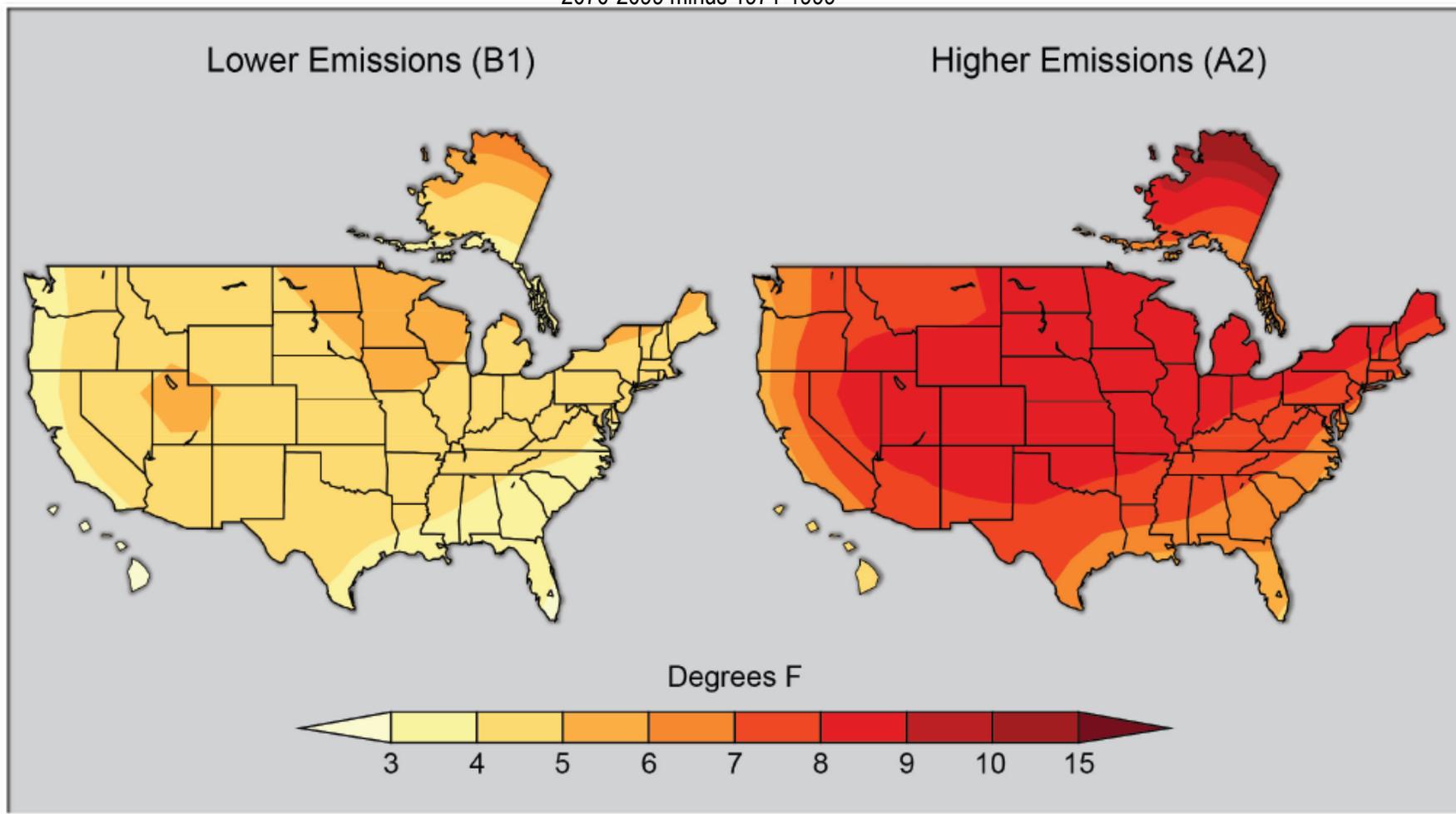


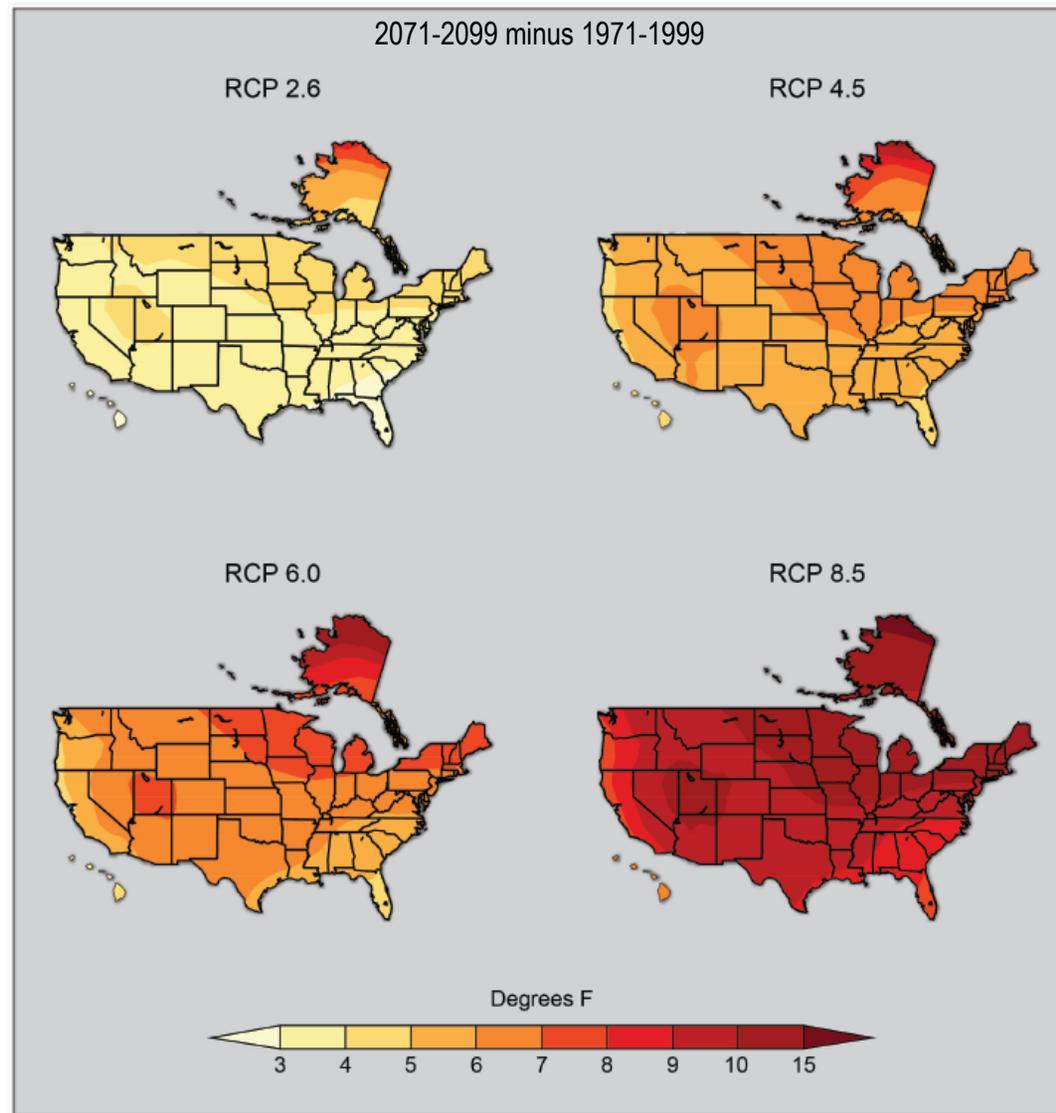
A2  
(high)



# Projected Temperature Change

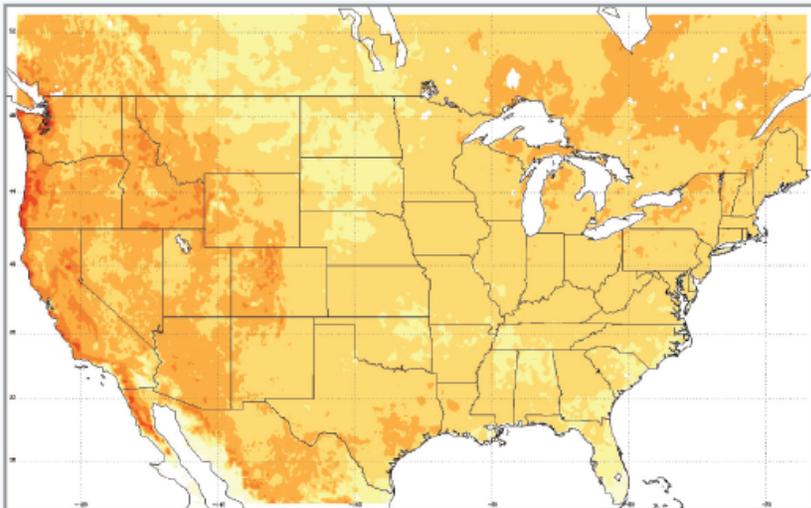
2070-2099 minus 1971-1999



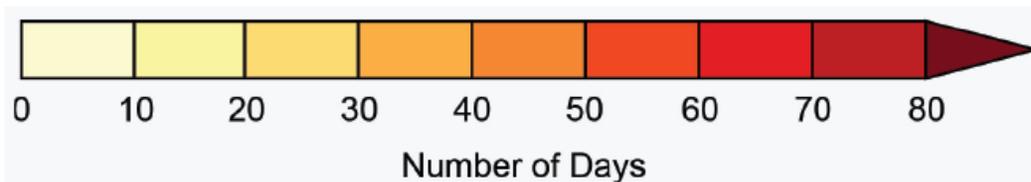
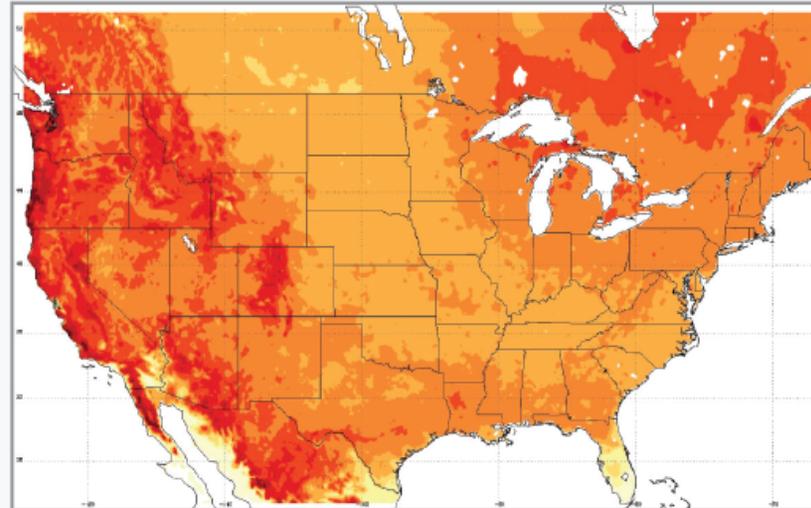


## Projected Changes in Frost-Free Season

Lower Emissions (B1)

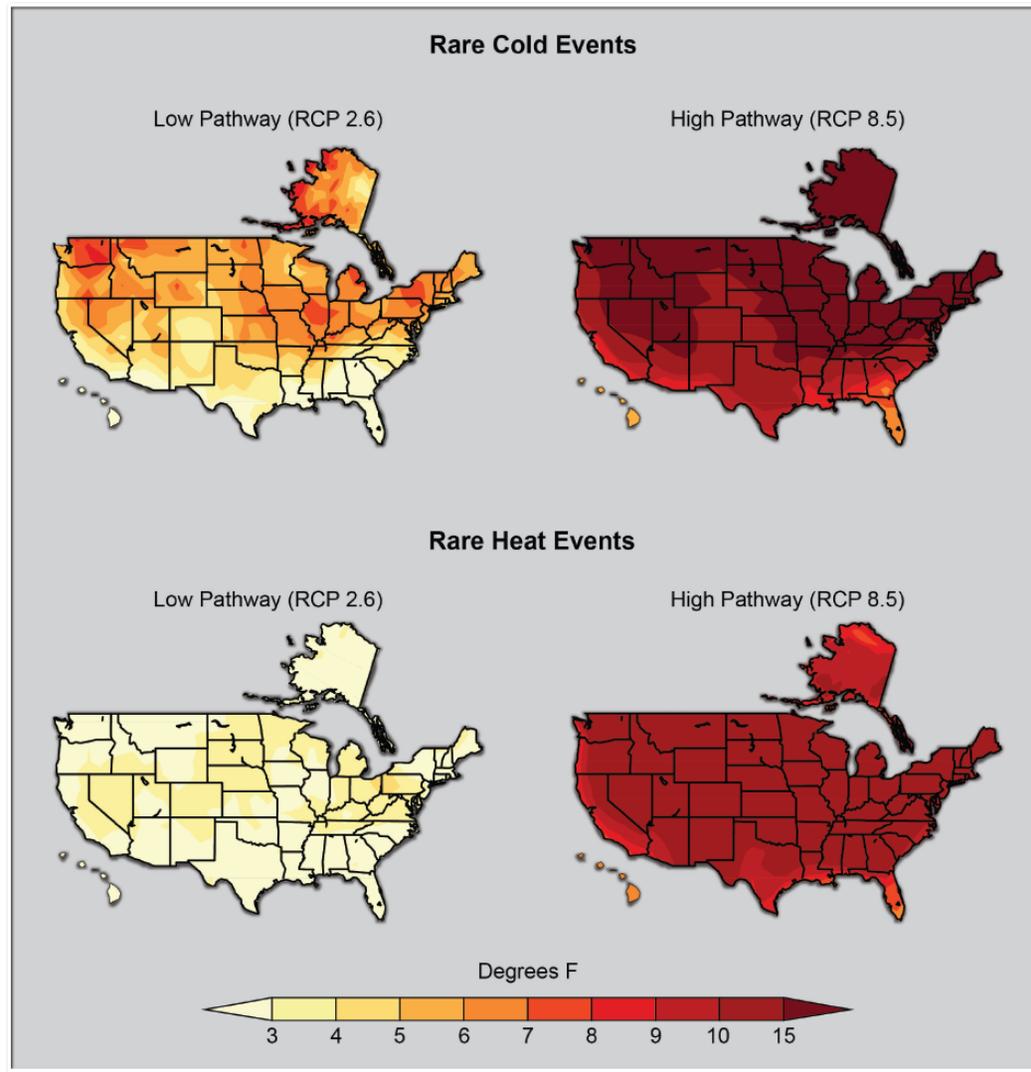


Higher Emissions (A2)



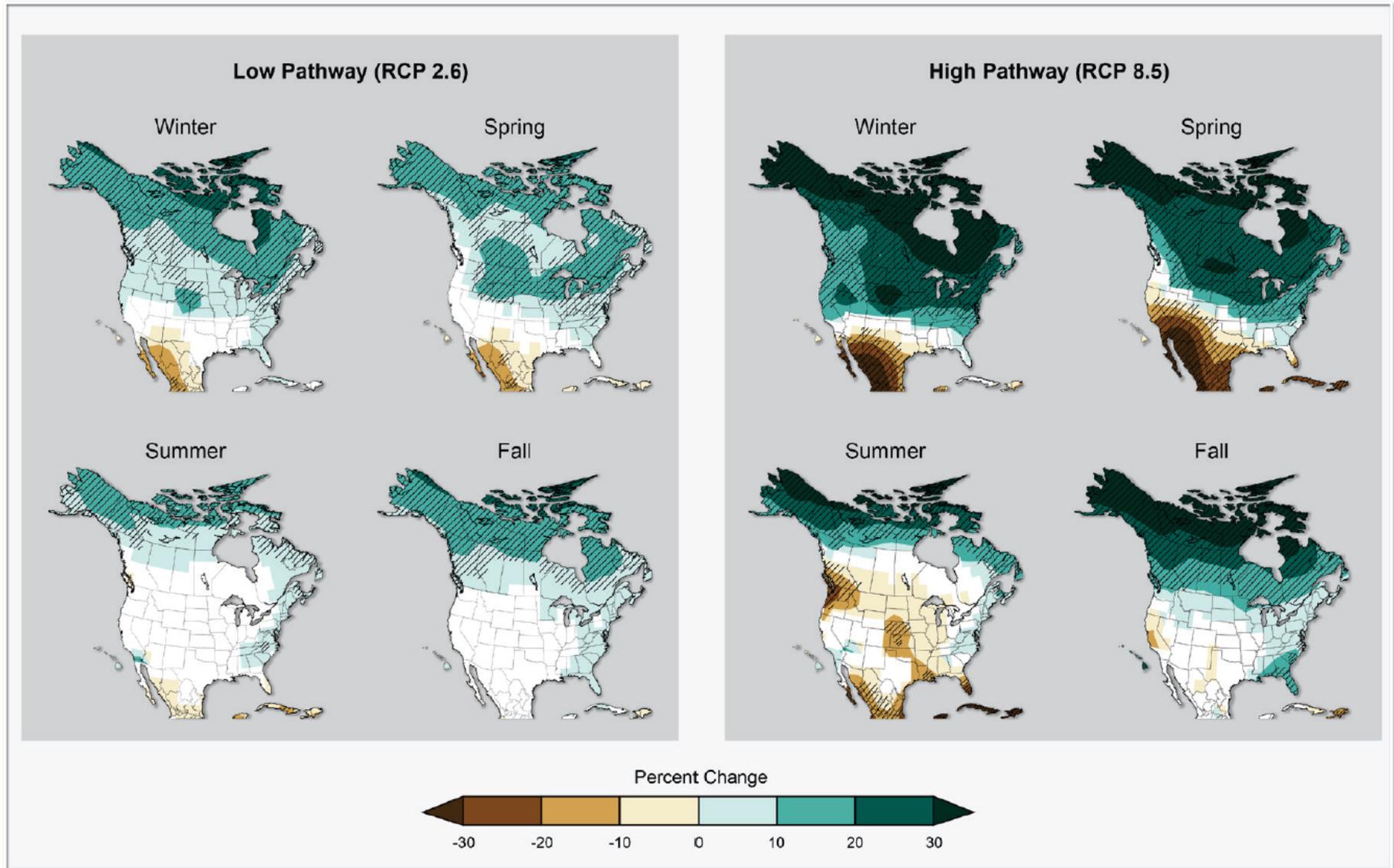
## Projected Changes in Rare Temperature Events

2081-2100 vs 1981-2000

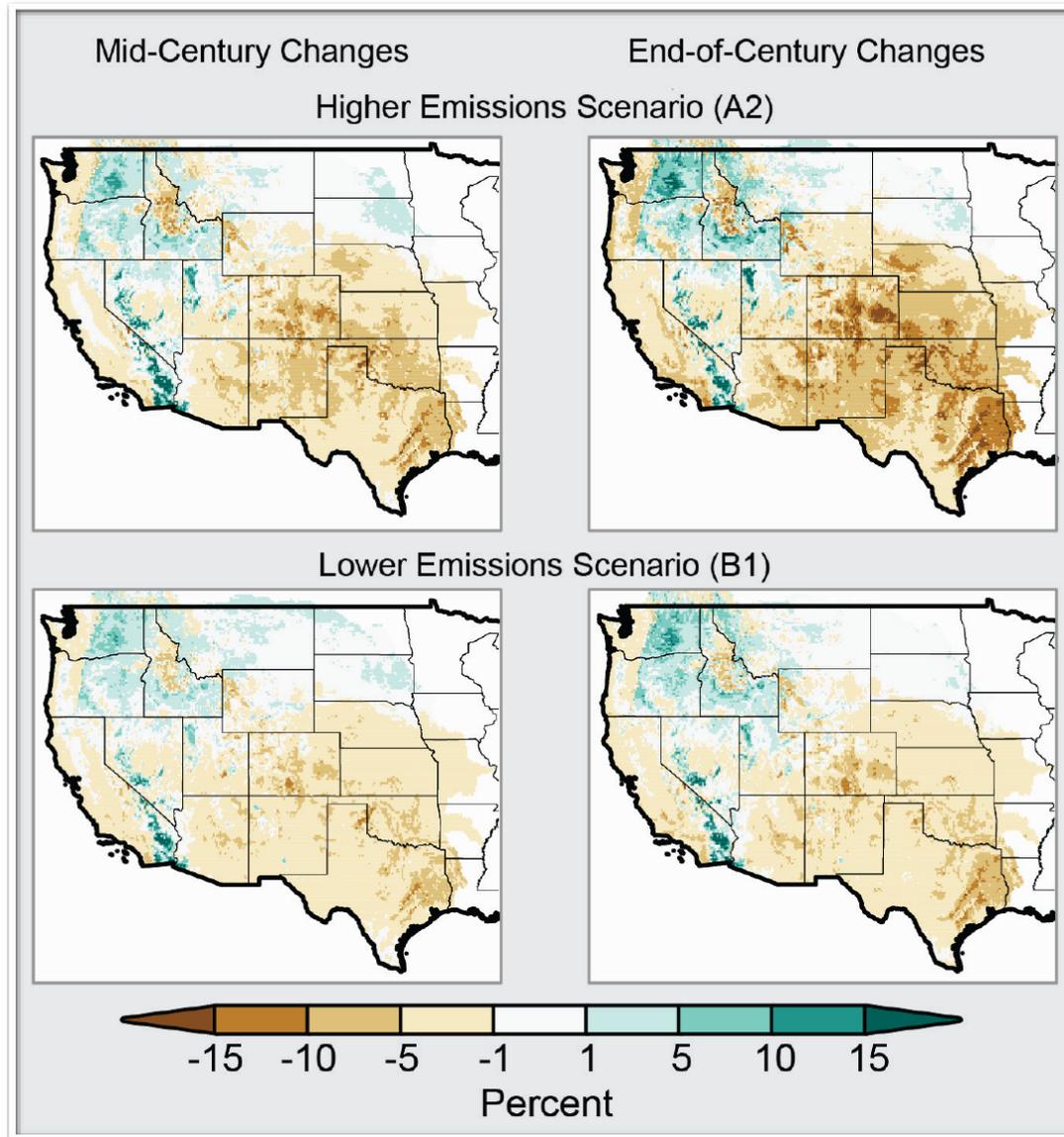


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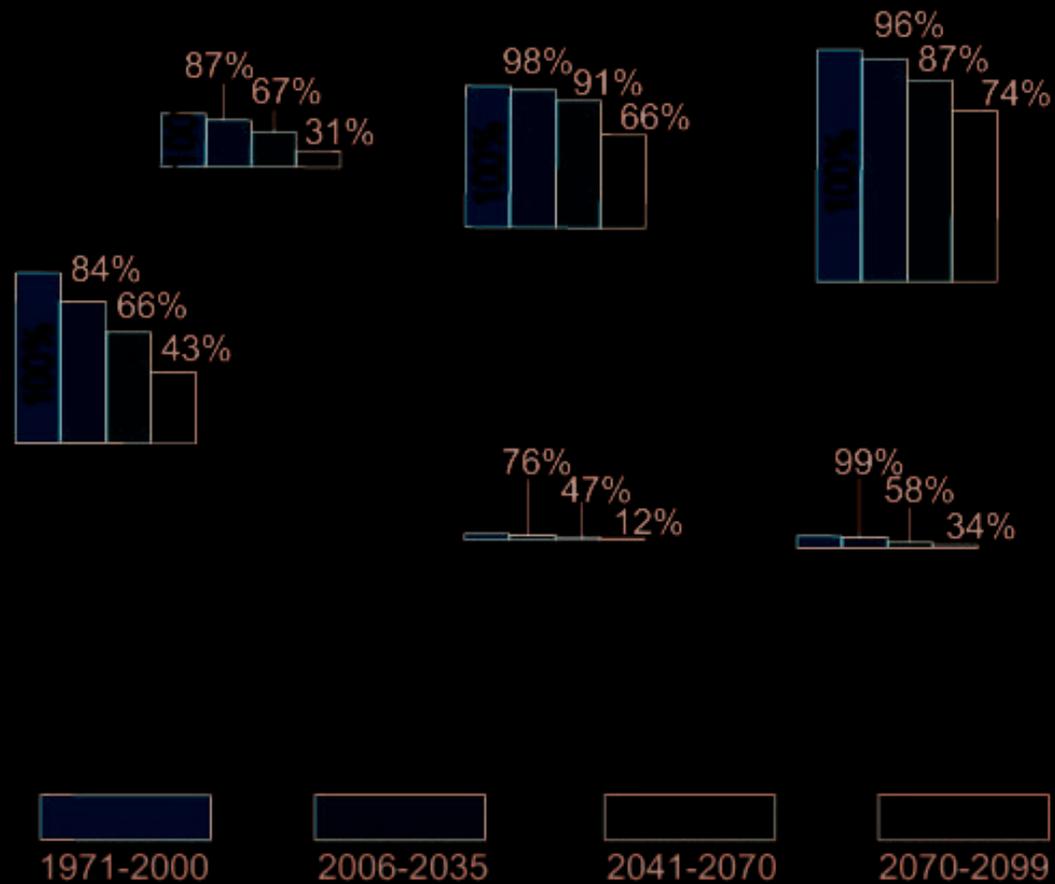
# Projected seasonal precipitation change for 2071-2099 (compared to 1901-1960)



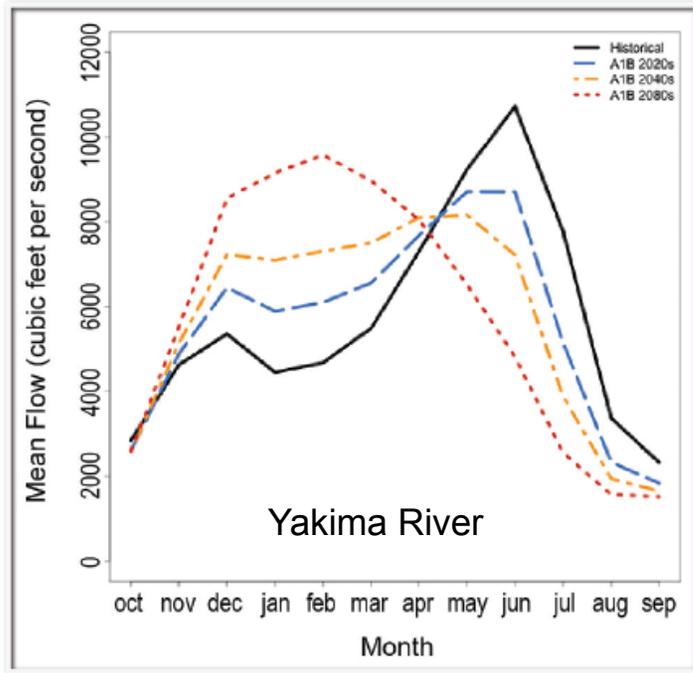
## Pattern of Projected Changes in Soil Moisture



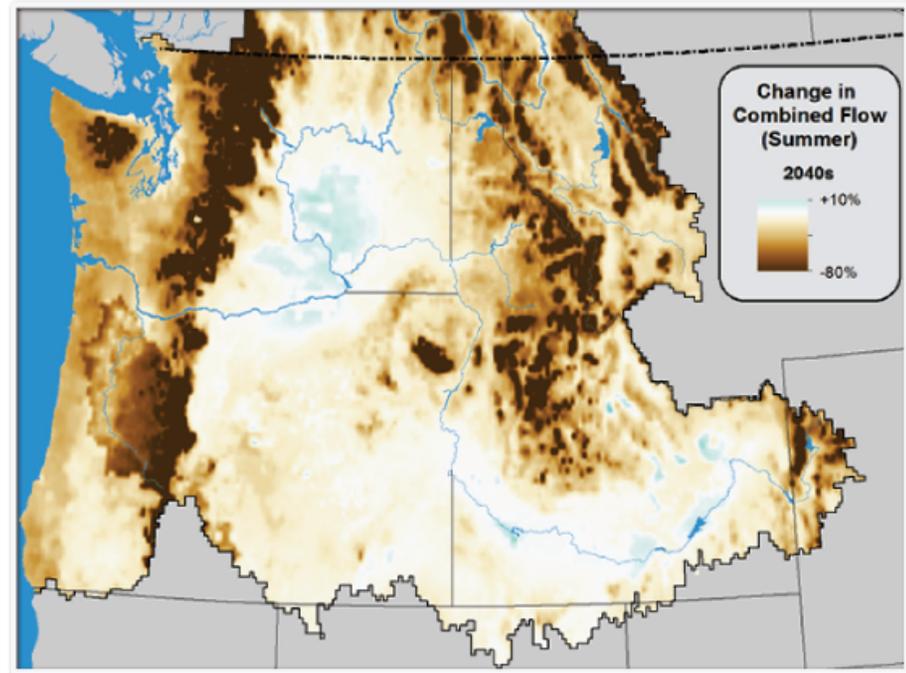
## Projected Snow Water Equivalent



Future Shift in Timing of Stream Flows



Reduced Summer Flows



## in summary ...

- **Global and US climate is changing and is observable.**
  - **Majority of change over the past 50 years is due to human activities, predominantly the burning of fossil fuels.**
- **Some extreme weather and climate events have increased in recent decades.**
  - **Emerging evidence that many of these increases are related to human activities.**
- **Reliability of water supplies is reduced by climate change.**
  - **Even where precipitation is projected to increase, seasonal distribution may change in adverse ways.**
- **Impacts related to climate change are already evident.**
  - **Expected to increase through the 21<sup>st</sup> century and beyond.**

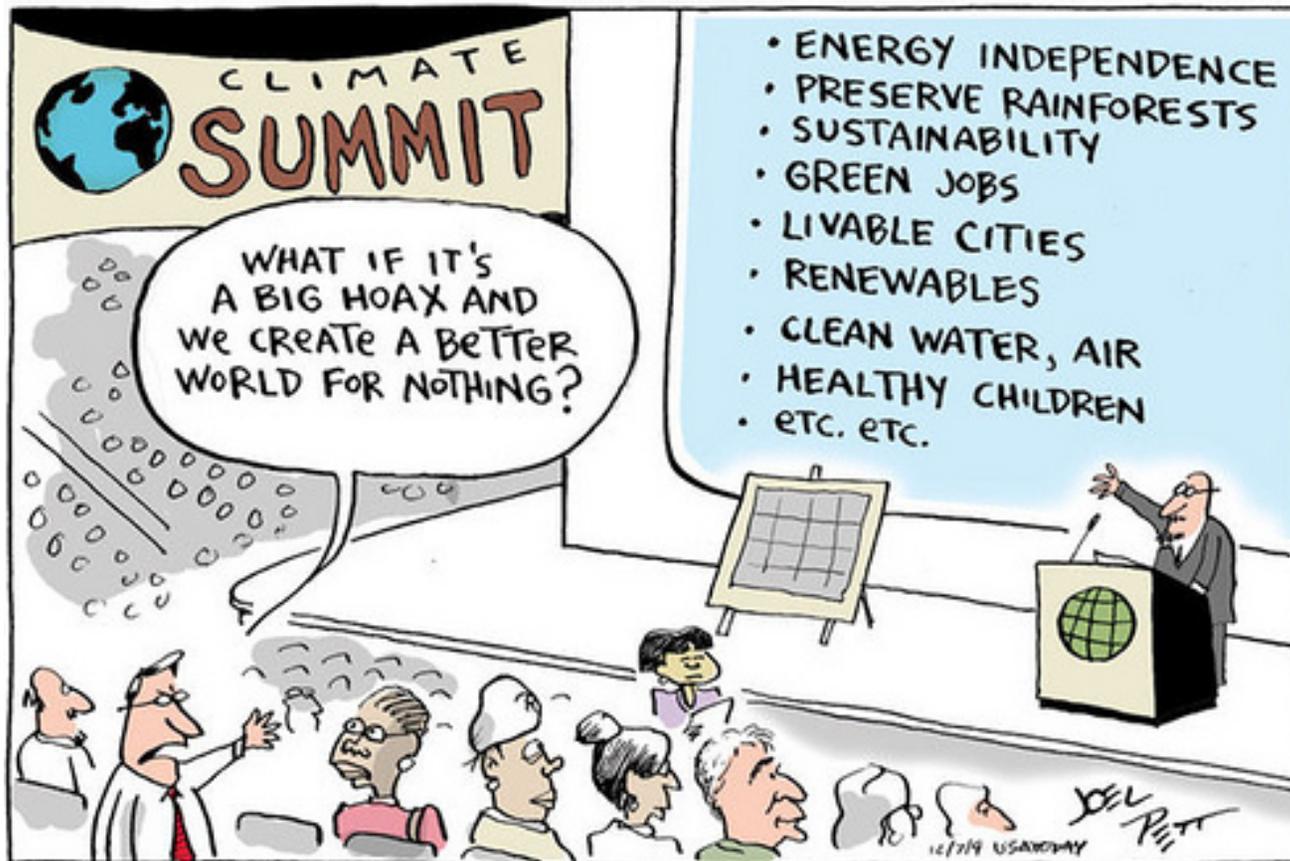


Questions?

[crowe1@unl.edu](mailto:crowe1@unl.edu)



# Questions?



# Additional resources

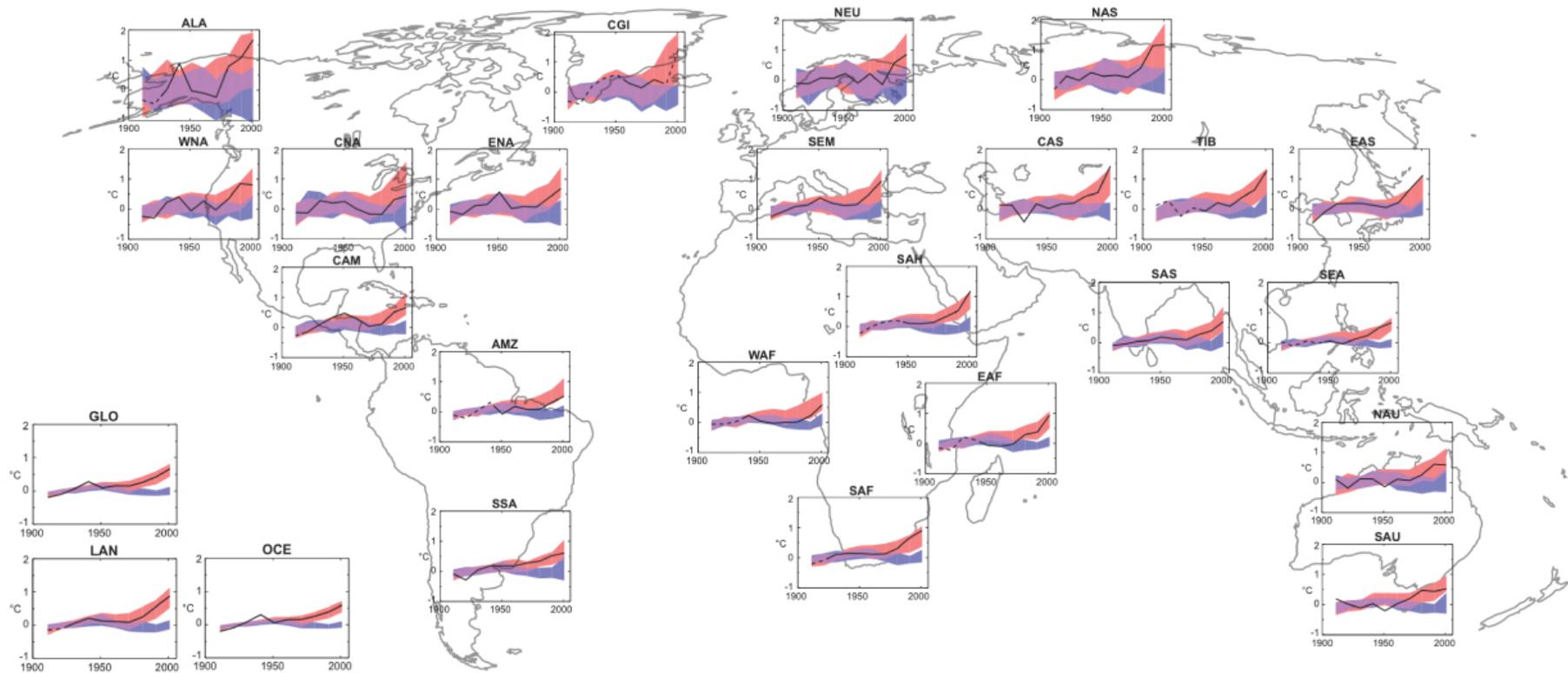
- **National Research Council, National Academy of Sciences**
  - *Advancing the Science of Climate Change*
  - *Limiting the Magnitude of Future Climate Change*
  - *Adapting to the Impacts of Climate Change*
  - *Informing an Effective Response to Climate Change*
  - *America's Climate Choices*
- **Intergovernmental Panel on Climate Change**
  - *Climate Change 2007 - The Physical Science Basis*
  - *Climate Change 2007 - Impacts, Adaptation and Vulnerability*
  - *Climate Change 2007 - Mitigation of Climate Change*
- **U.S. Global Change Research Program**
  - [www.globalchange.gov](http://www.globalchange.gov)
  - National Climate Assessment (<http://ncadac.globalchange.gov/>)
- *What We Know About Climate Change, 2<sup>nd</sup> edition, Kerry Emanuel*
- **Nature Conservancy**
  - [www.climatewizard.org](http://www.climatewizard.org)



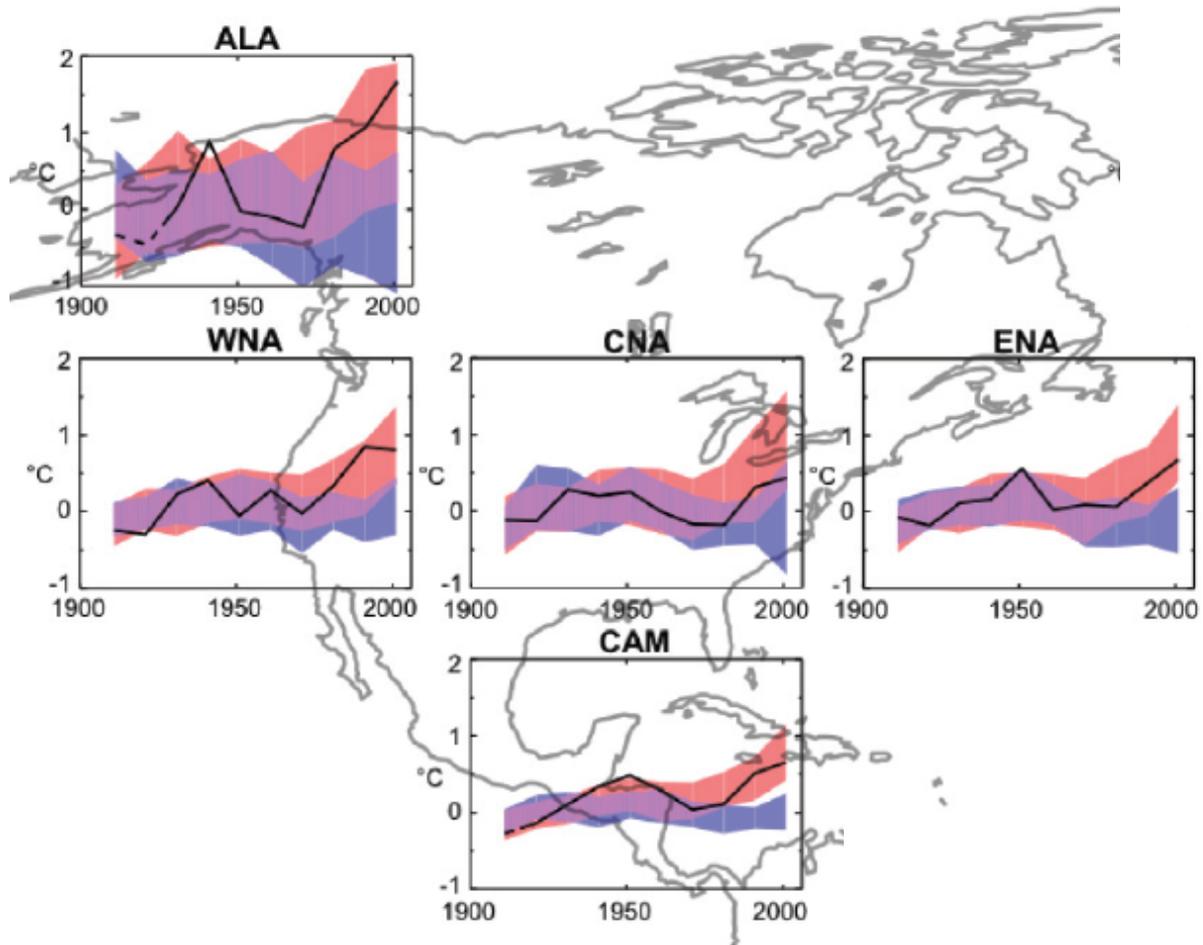
We, the undersigned, are all faculty in climate, or climate-related disciplines, at the University of Nebraska-Lincoln. Based on our informed scientific judgment, we most strongly support the policy statements on climate change of the American Meteorological Society and the American Geophysical Union, the two most prominent U.S. scientific societies whose members are studying the climate system. Climate change is real, and human activities have a profound effect on the way in which it is occurring. Over the coming decades it will get warmer in Nebraska, by 4-10°F. Changes in mean rainfall are less clear, as all models predict wetter to our east and drier to our west; the 'no-change' line cuts somewhere through Nebraska. Of most concern, snowpack in the central Rockies is forecast to decrease dramatically with strong implications for the Platte River (will Lake McConaughy become a ditch in mid-summer?). In addition to a trend towards more drought, we can expect this trend to be interspersed with more extreme flooding events due to enhanced climate variability. The time for debate is over. The time for action is here.



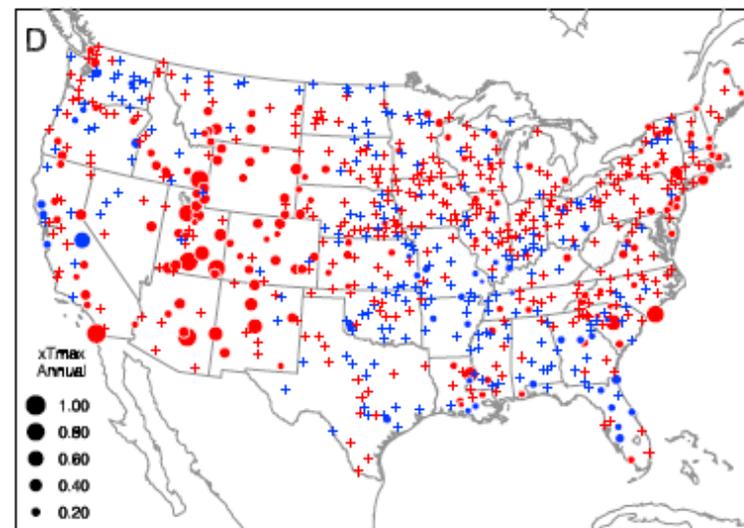
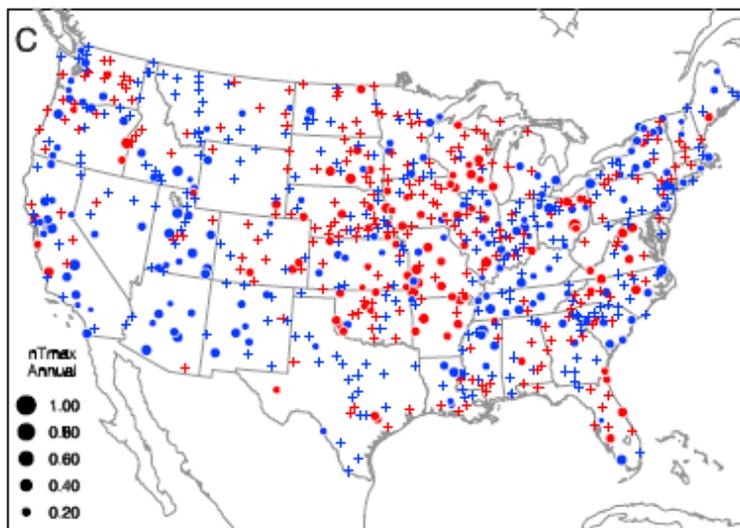
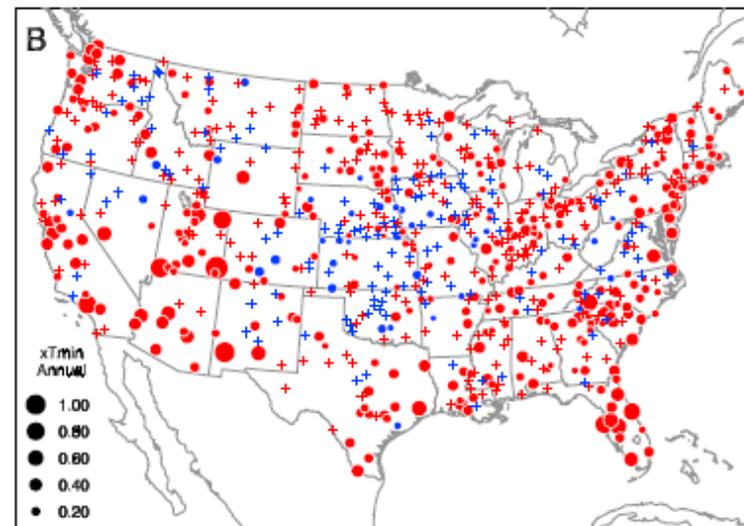
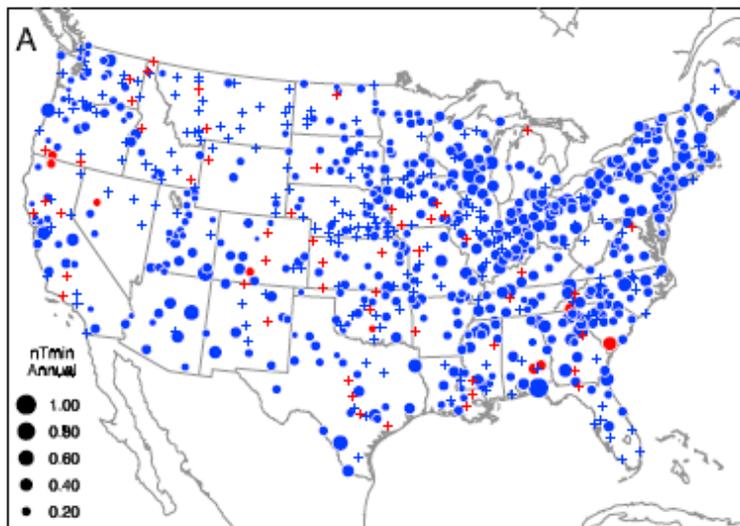
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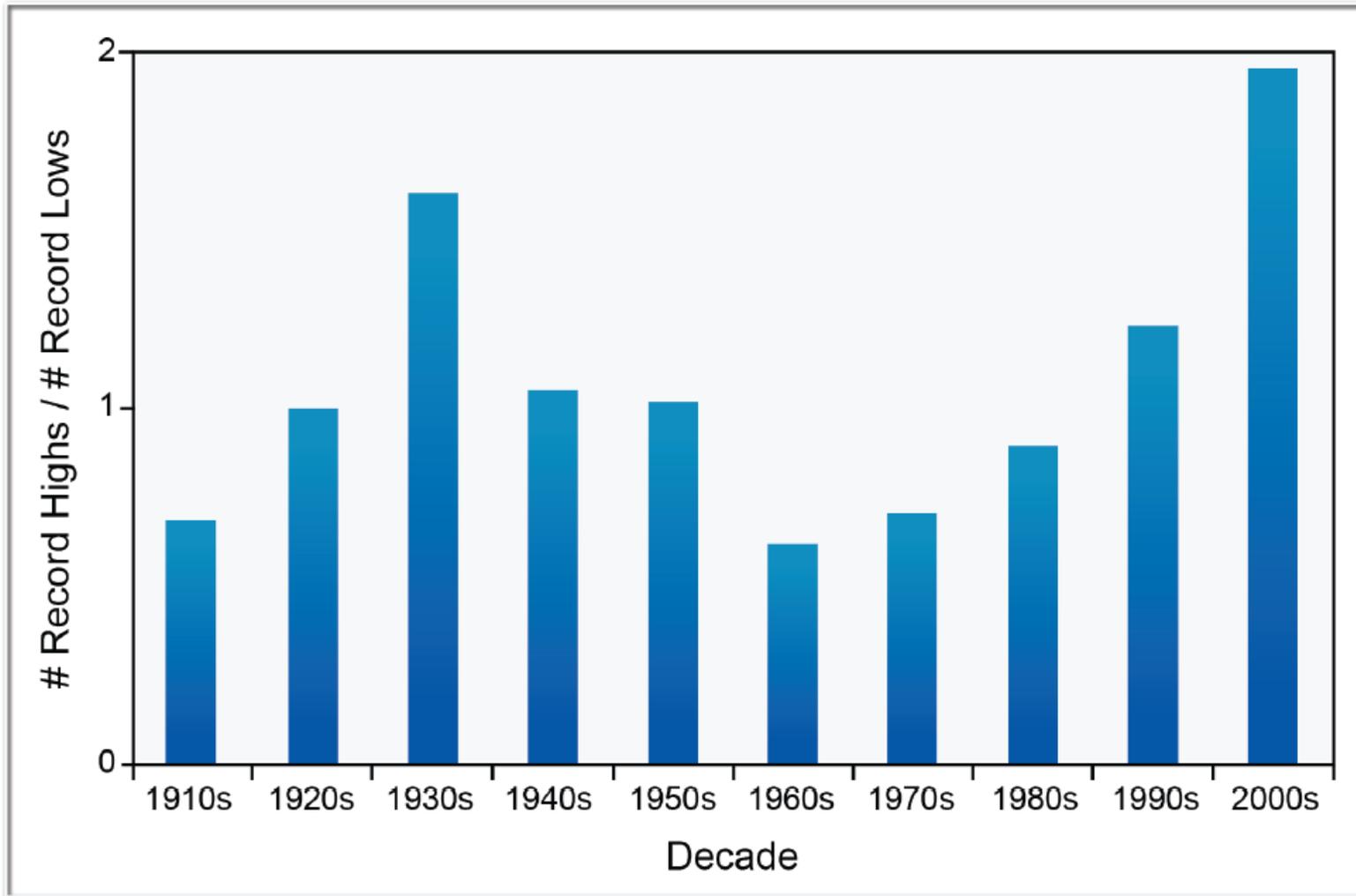
Hegerl et al., 2007



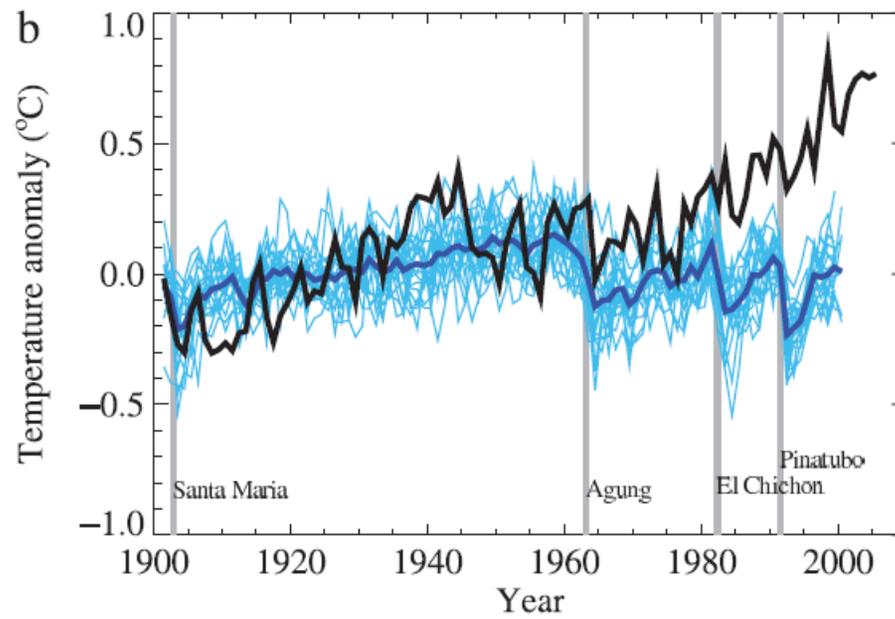
Hegerl et al., 2007



## Ratio of Record Daily High to Record Daily Low Temperatures

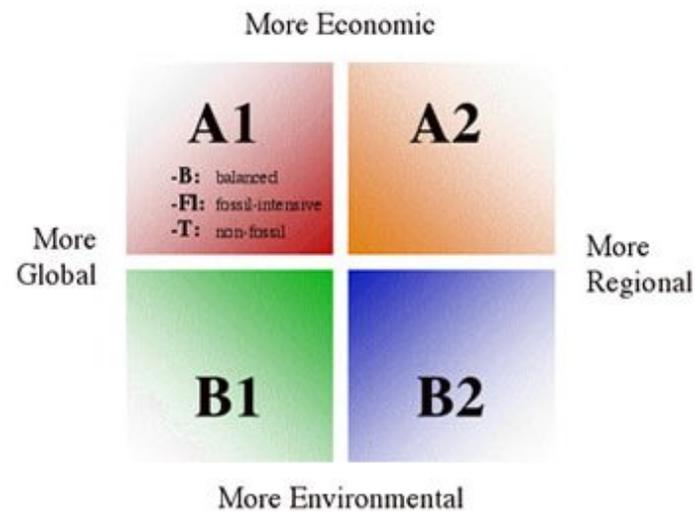


Natural forcing  
only



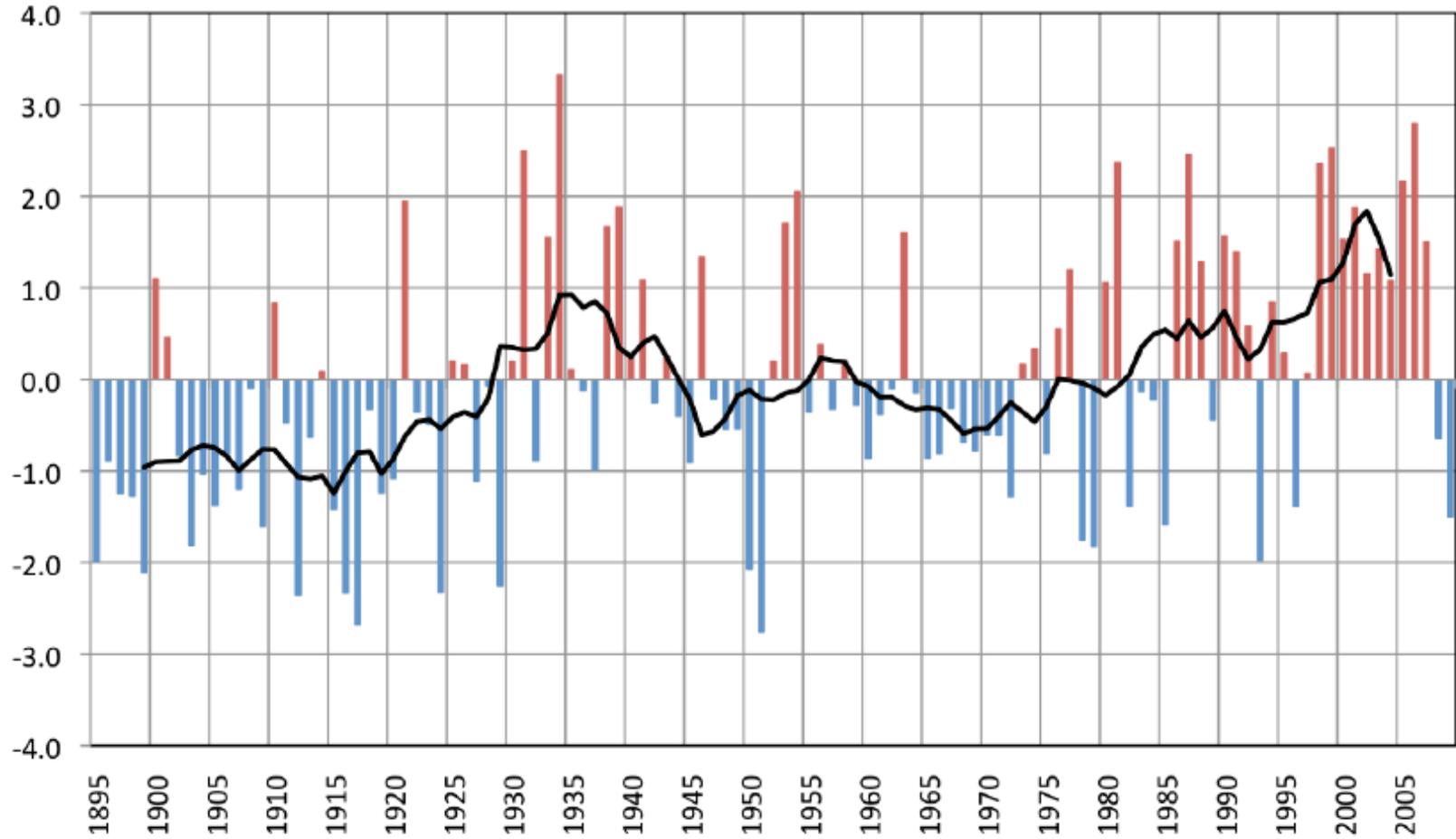
Hegerl et al., 2007

# What is going to happen?

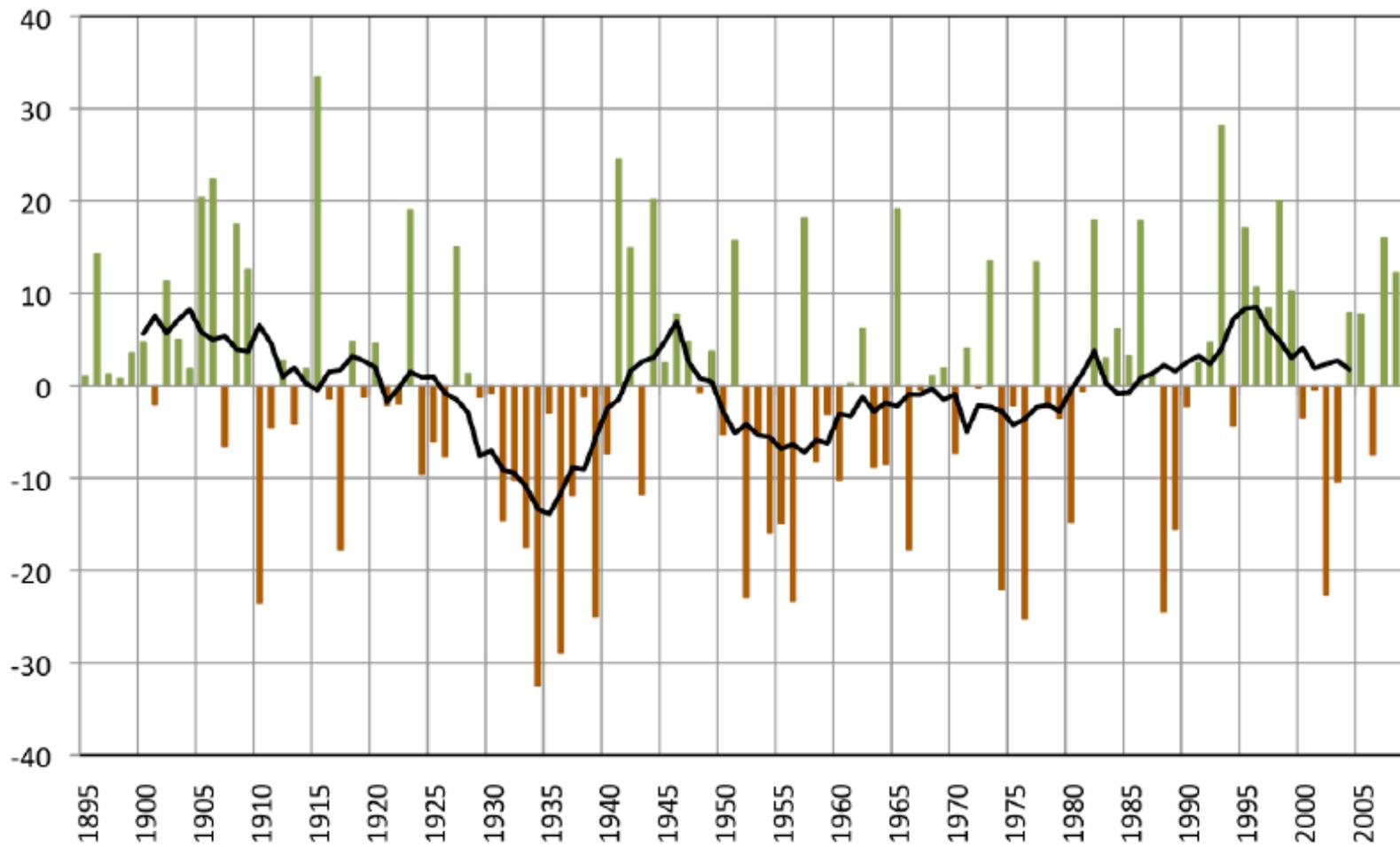


- Use best computer models to project climate change in response to GHG forcings
  - include additional forcings and feedbacks

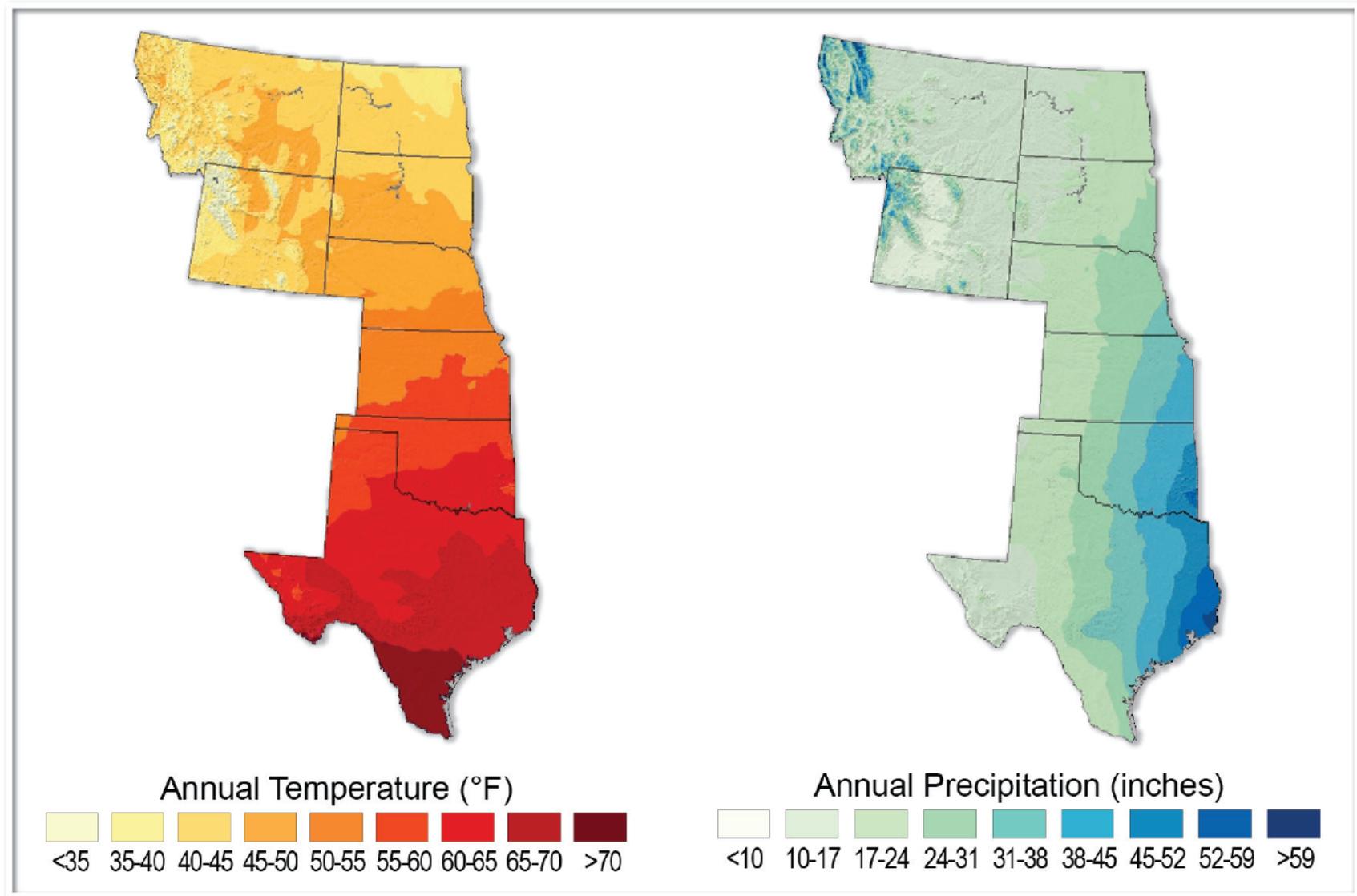
High Plains Average Annual Temperature Departure from Normal (°F)

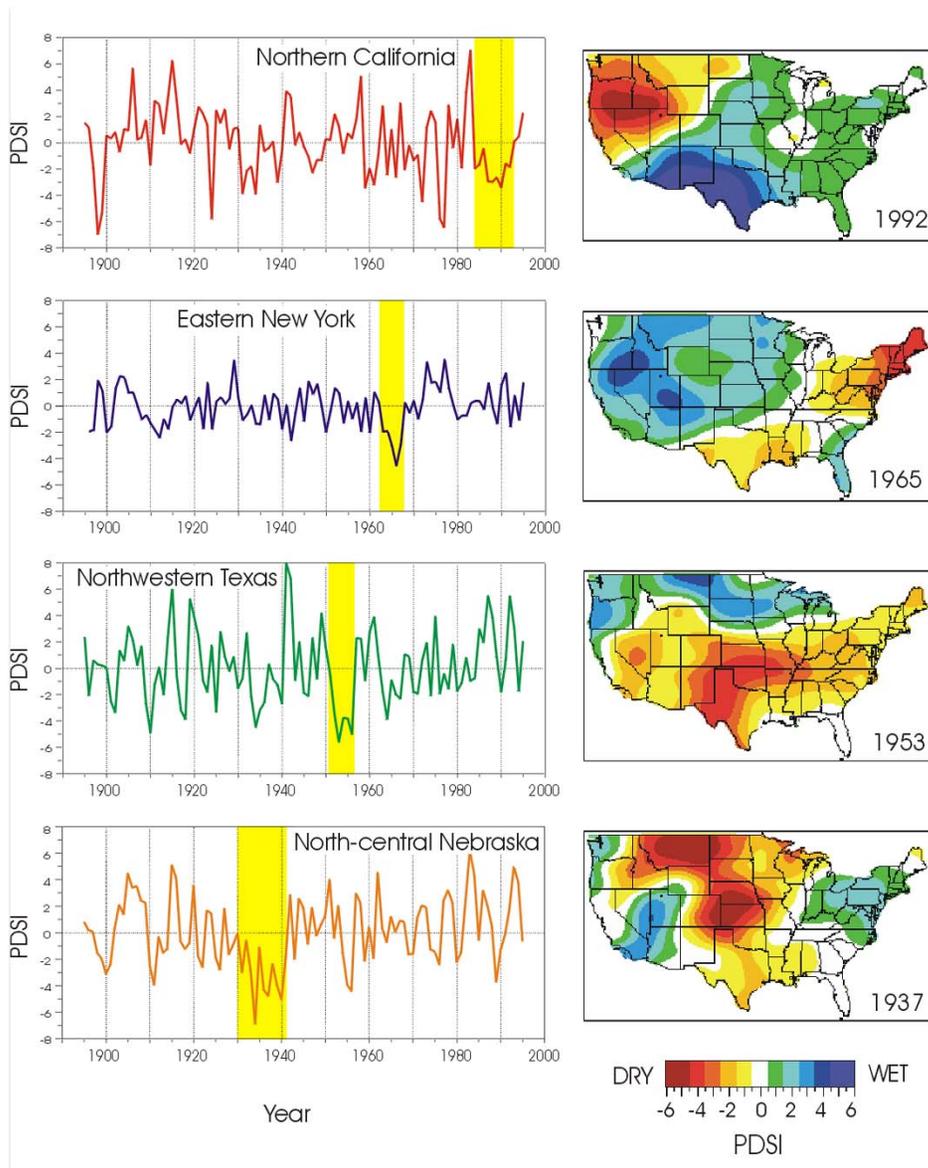


High Plains Annual Precipitation Departure from Normal (%)



## Temperature and Precipitation Distribution in the Great Plains

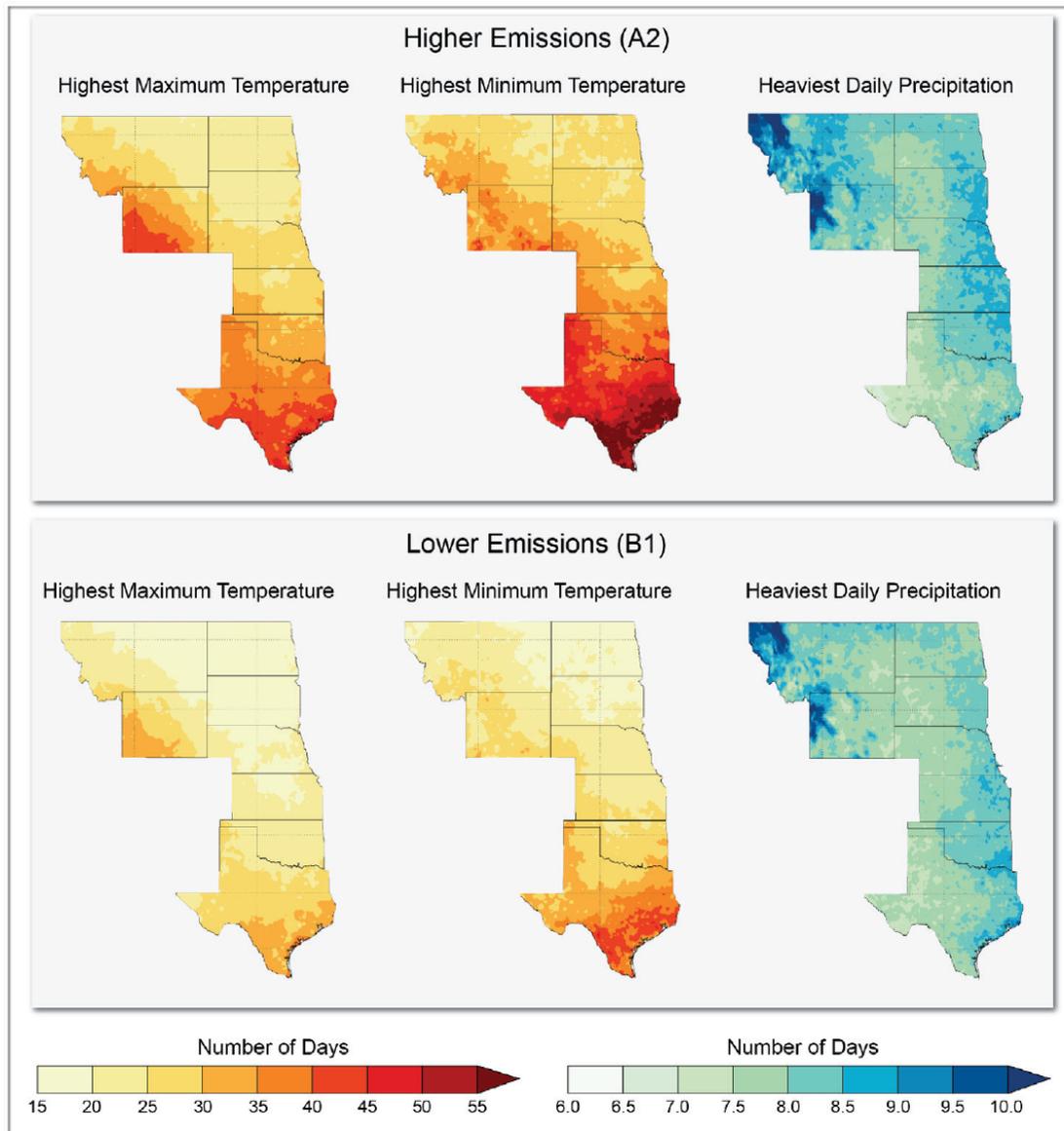




The southern Plains, and parts of Texas in particular, appear to suffer from the highest frequency of drought

The central High Plains appears to be the region most often affected by the most persistent droughts

## Higher Emissions Lead to More Heat and Heavy Downpours



- number of days per year (2041-2070) exceeding top 2% of days (~7 days) in 1971-2000

## THE EMISSIONS SCENARIOS OF THE IPCC SPECIAL REPORT ON EMISSIONS SCENARIOS (SRES)

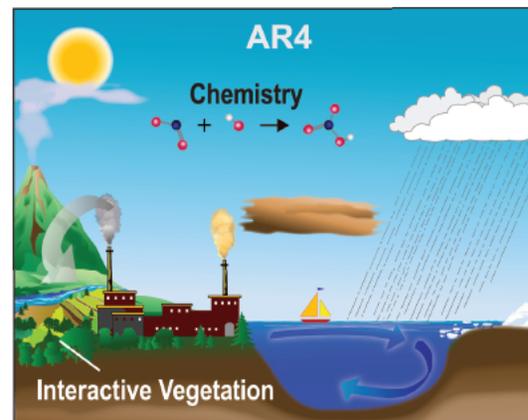
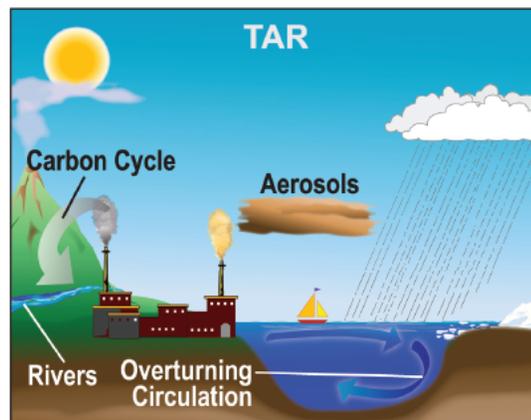
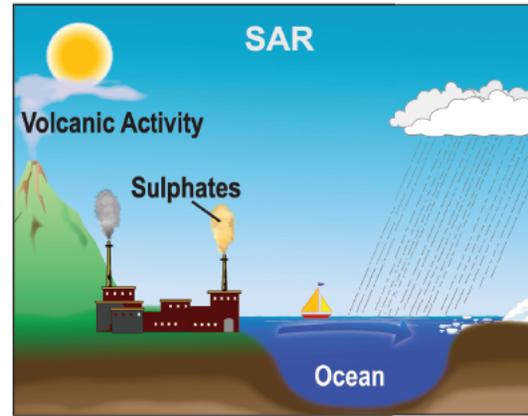
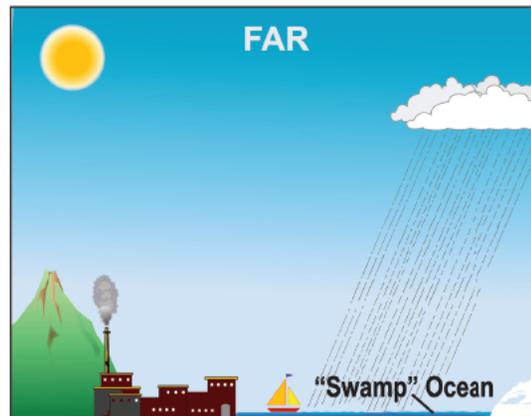
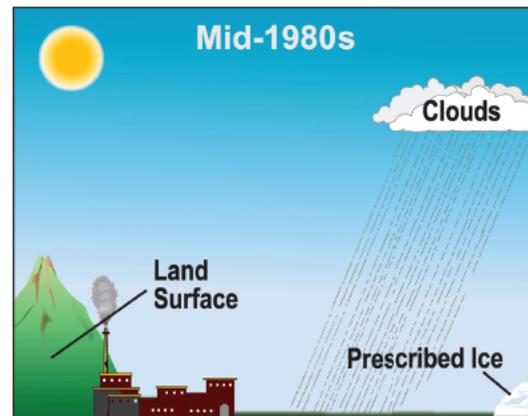
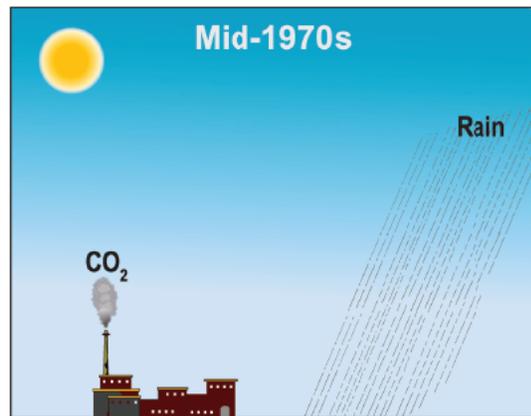
**A1.** The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in midcentury and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergent among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B) (where balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end-use technologies).

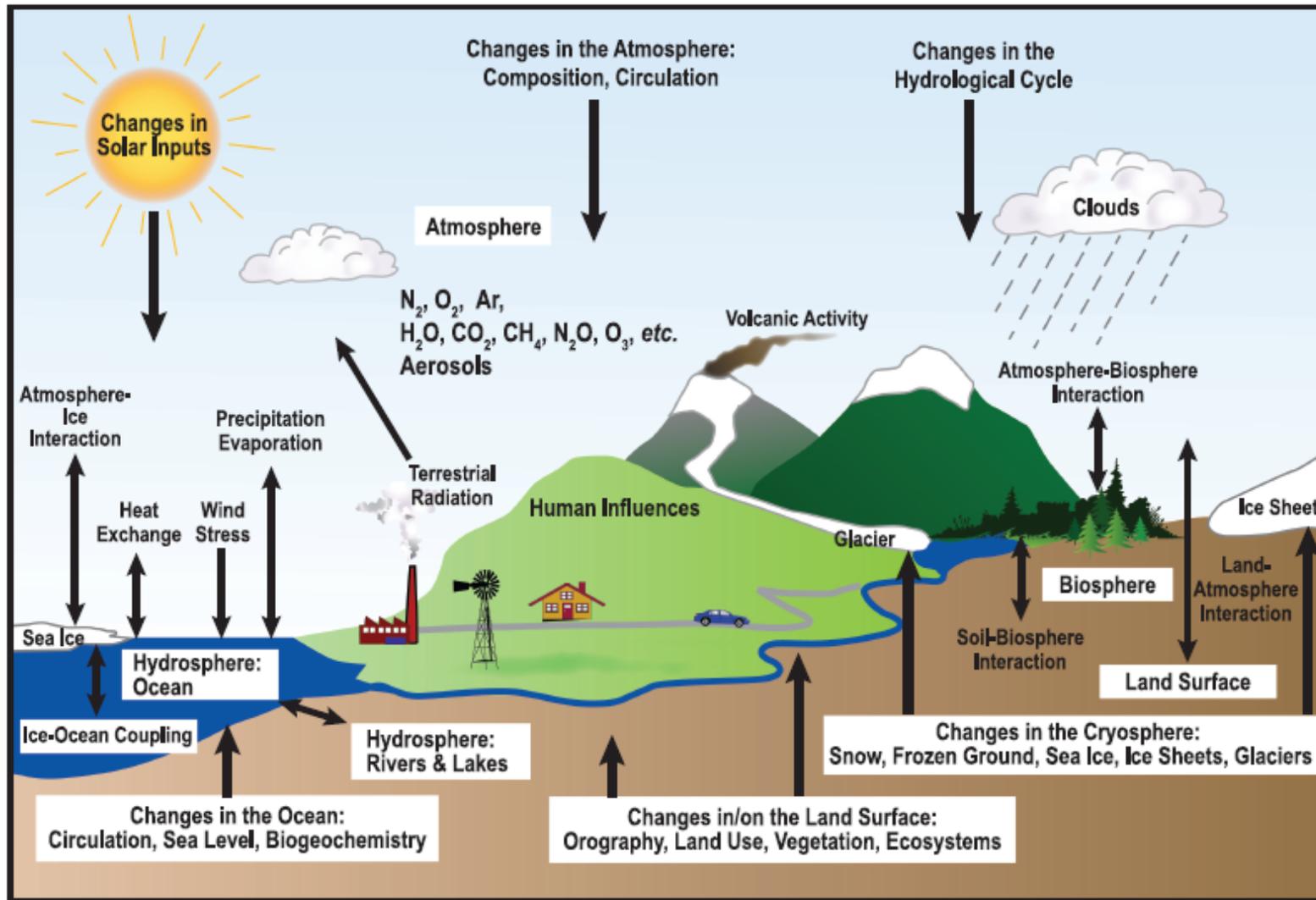
**A2.** The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented, and per capita economic growth and technological change more fragmented and slower than other storylines.

**B1.** The B1 storyline and scenario family describes a convergent world with the same global population as in the A1 storyline (one that peaks in mid-century and declines thereafter), but with rapid change in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives.

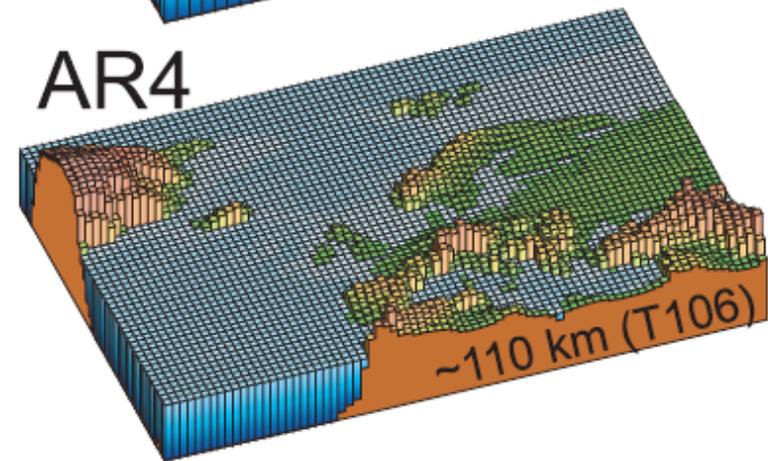
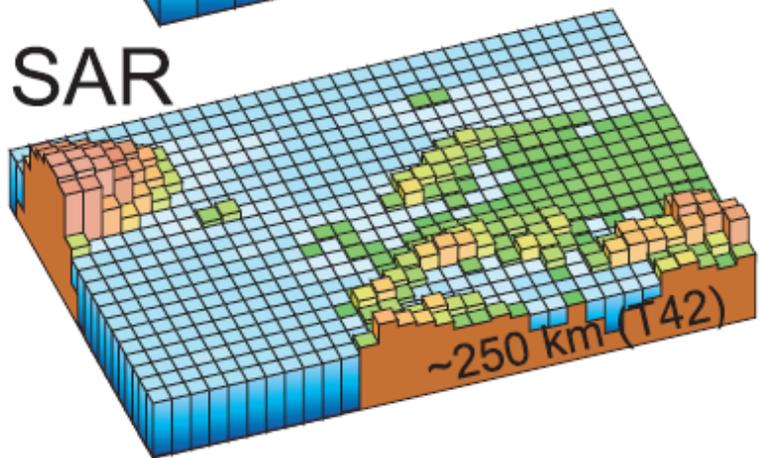
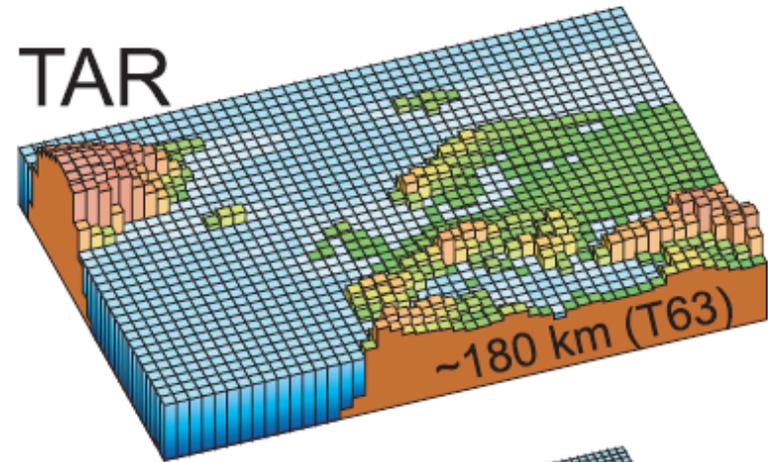
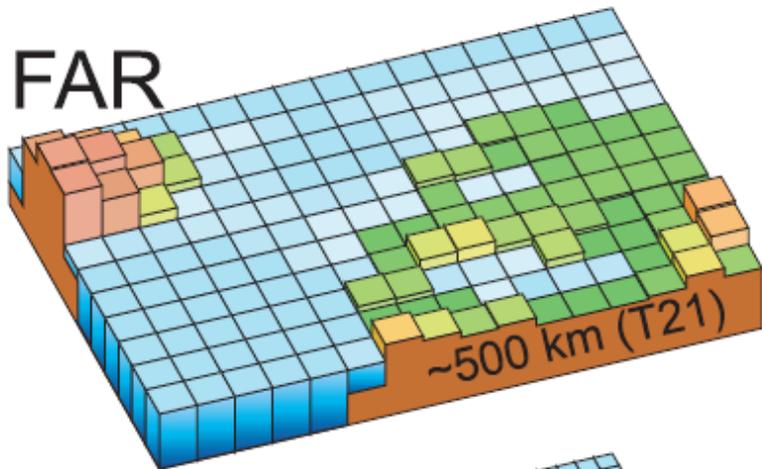
**B2.** The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with continuously increasing global population, at a rate lower than for the A2 storyline, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels.

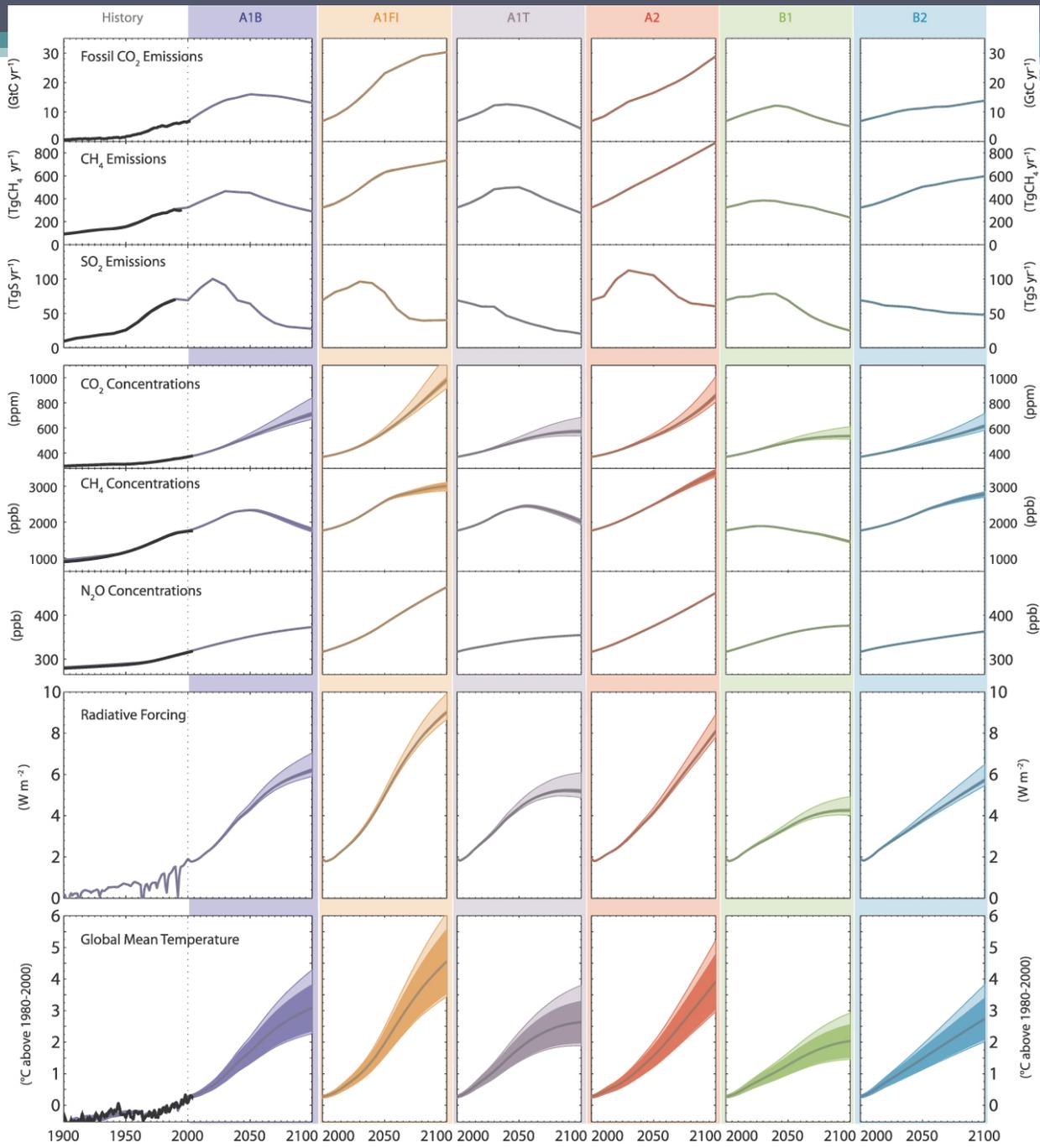
An illustrative scenario was chosen for each of the six scenario groups A1B, A1FI, A1T, A2, B1 and B2. All should be considered equally sound. The SRES scenarios do not include additional climate initiatives, which means that no scenarios are included that explicitly assume implementation of the United Nations Framework Convention on Climate Change or the emissions targets of the Kyoto Protocol.



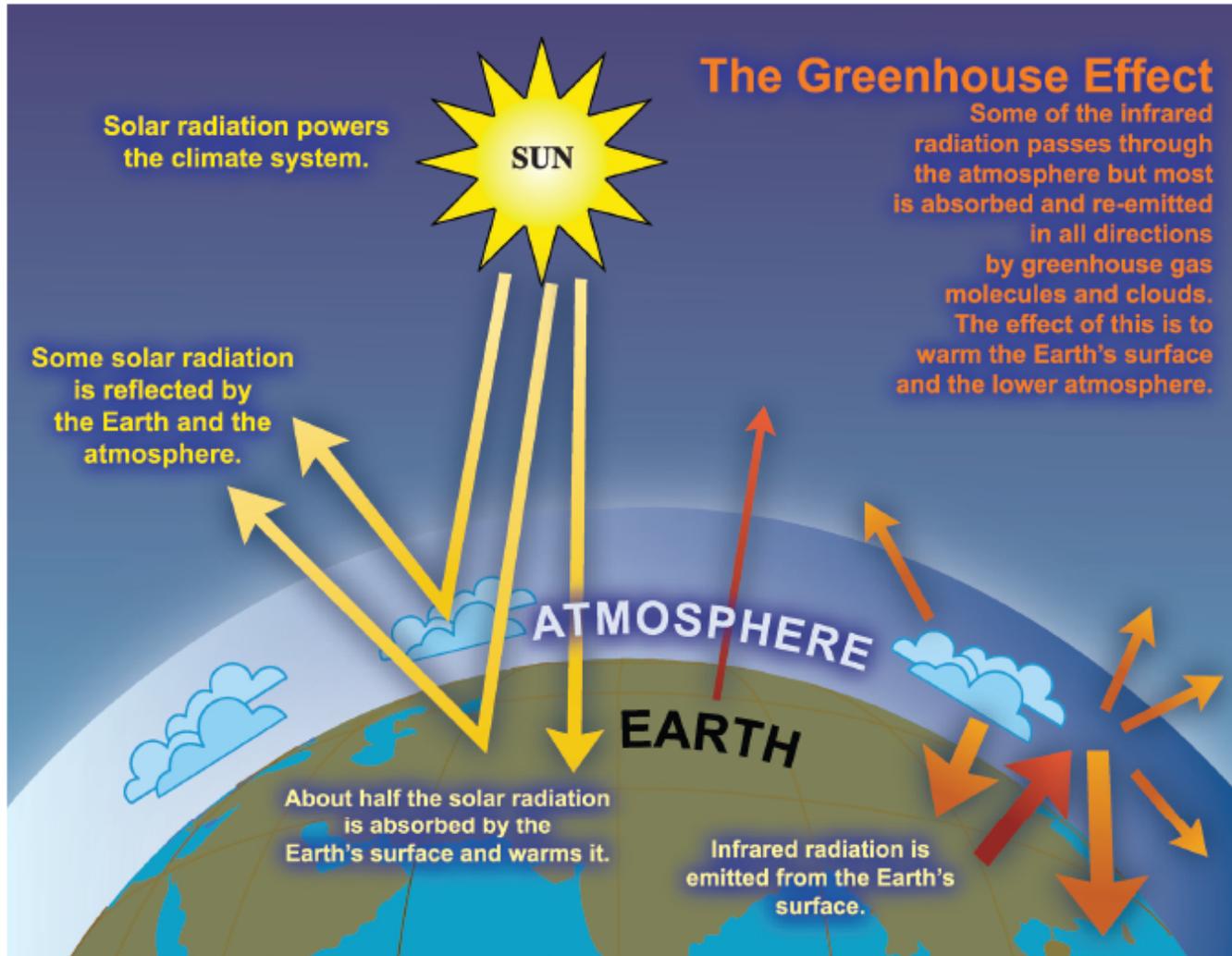


Le Treut et al., 2007

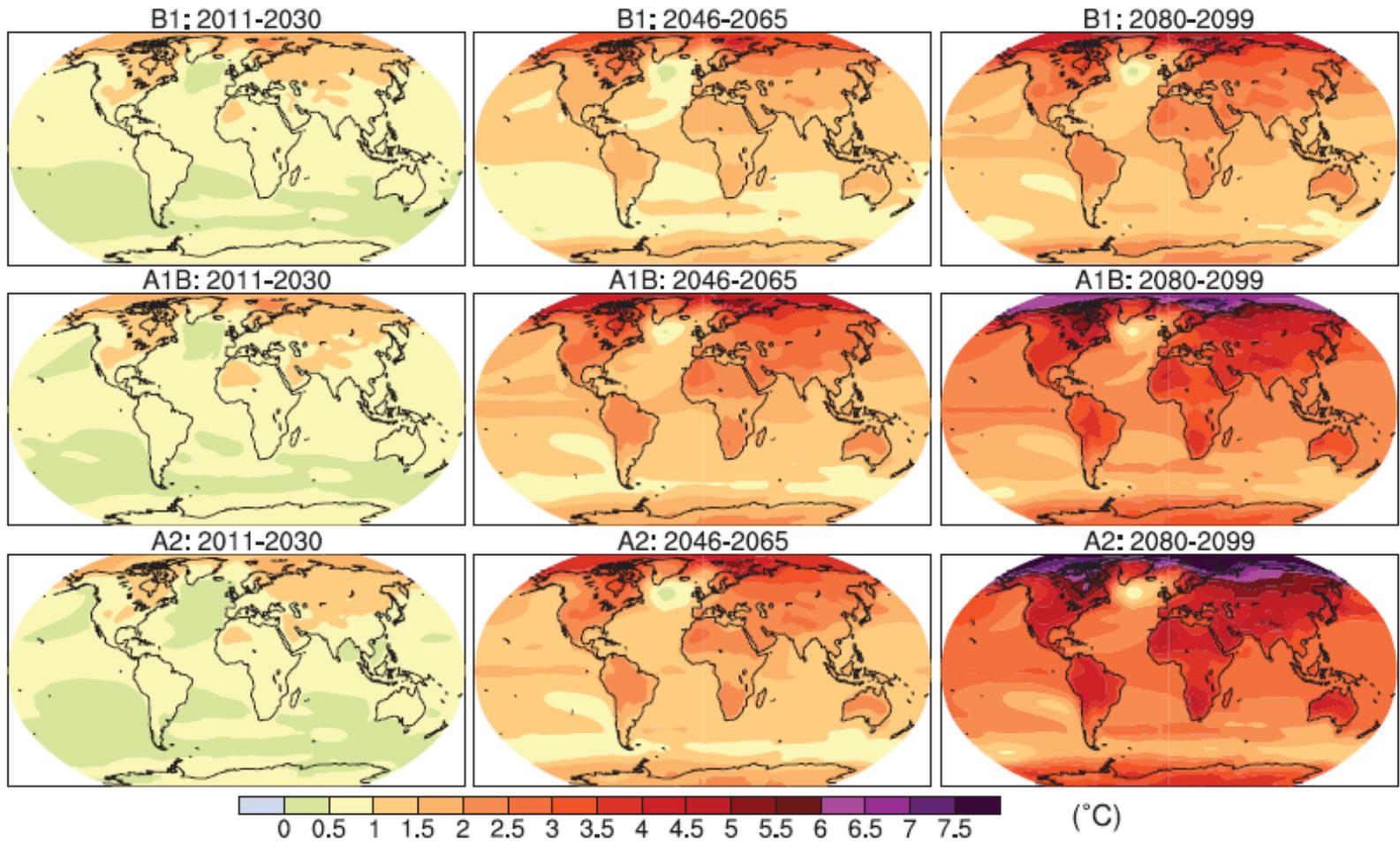




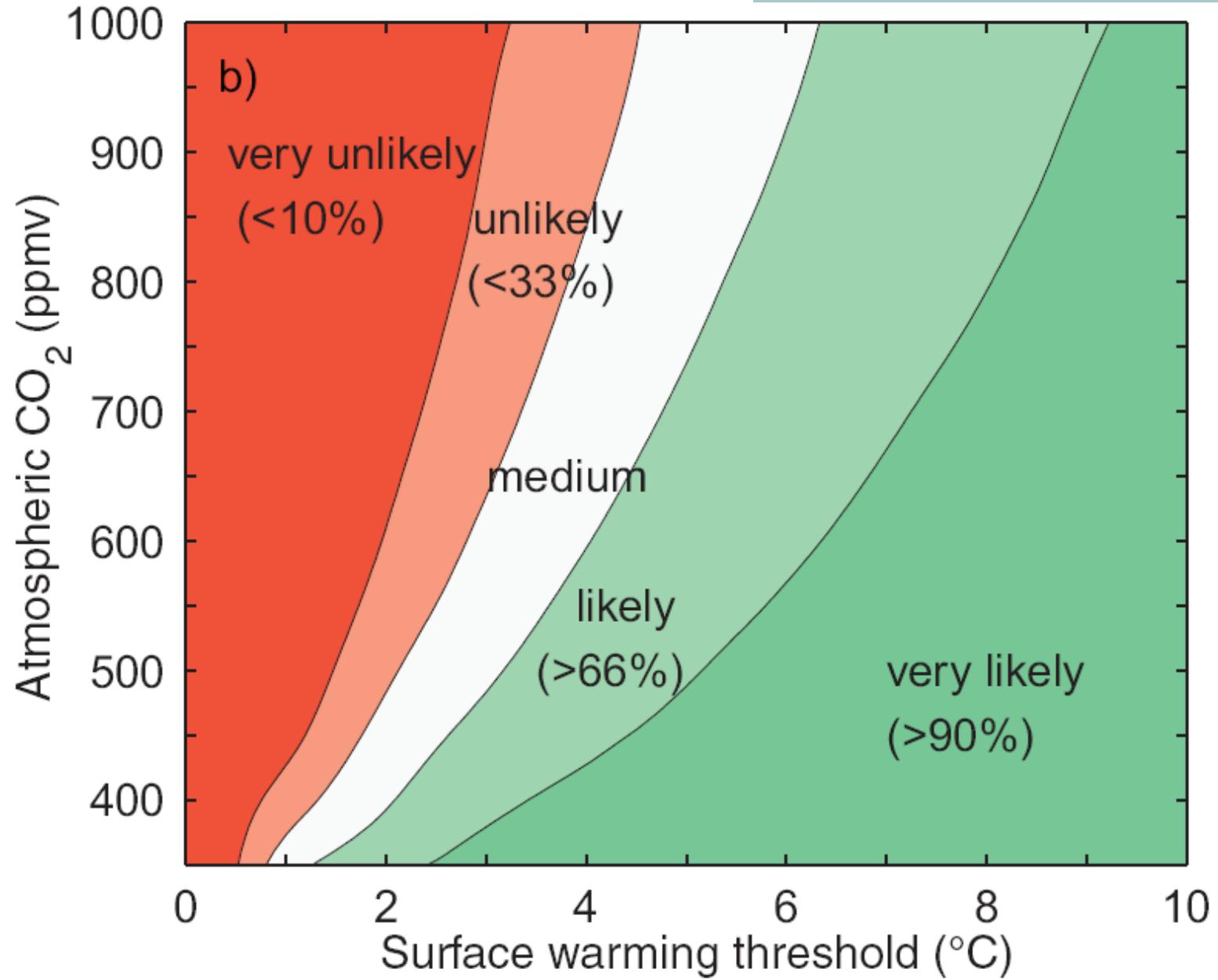
Meehl et al., 2007



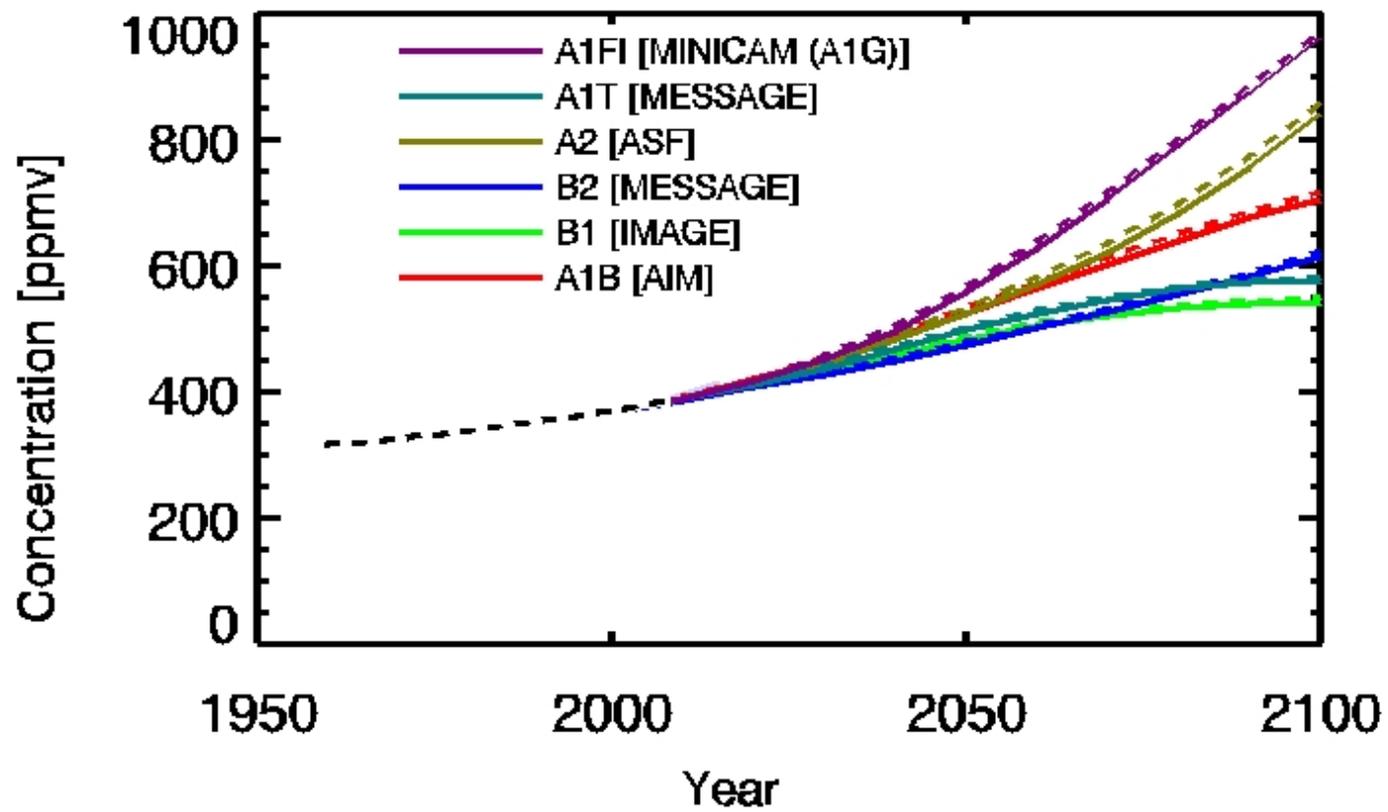
Le Treut et al., 2007



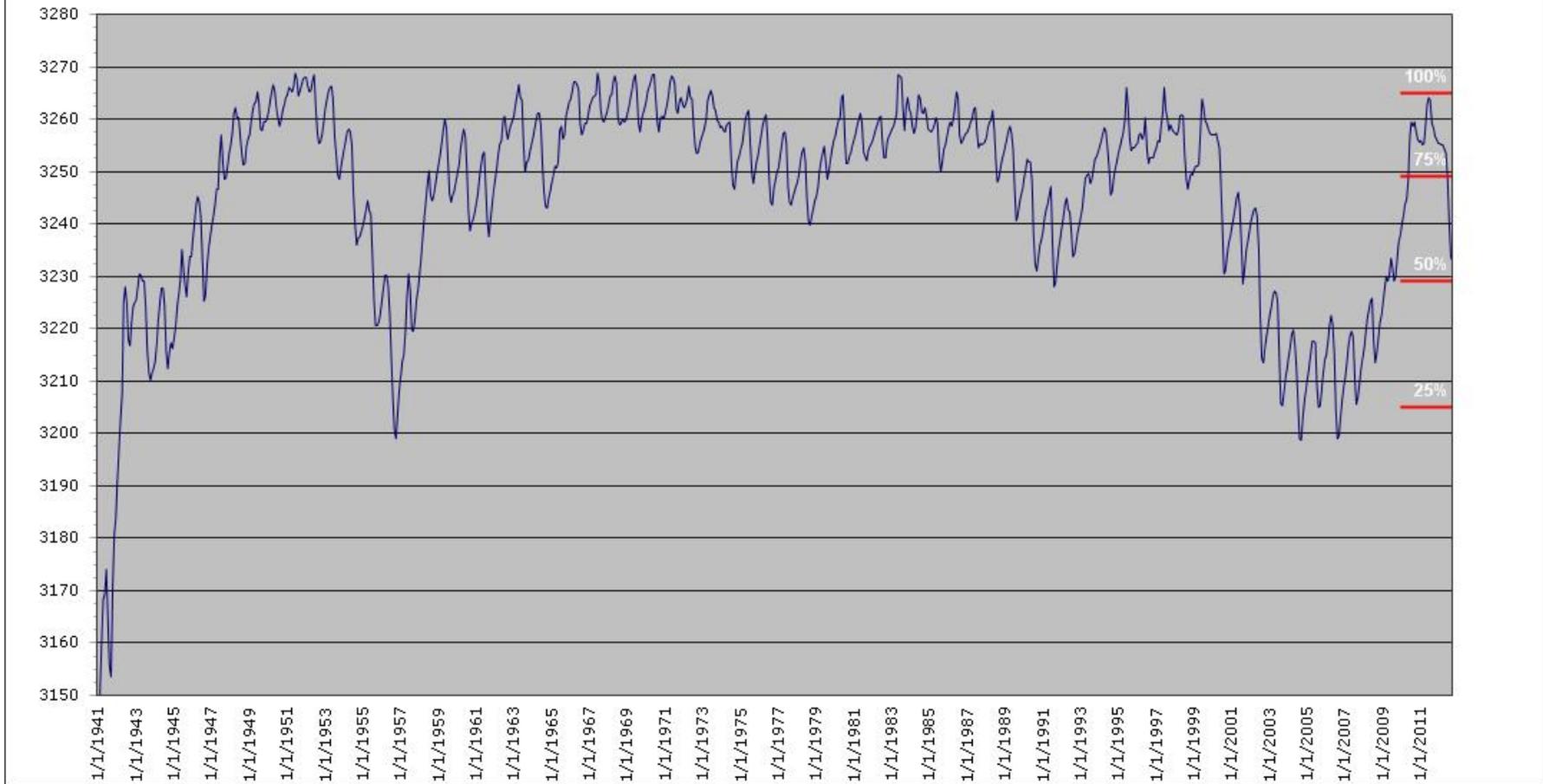
Meehl et al., 2007



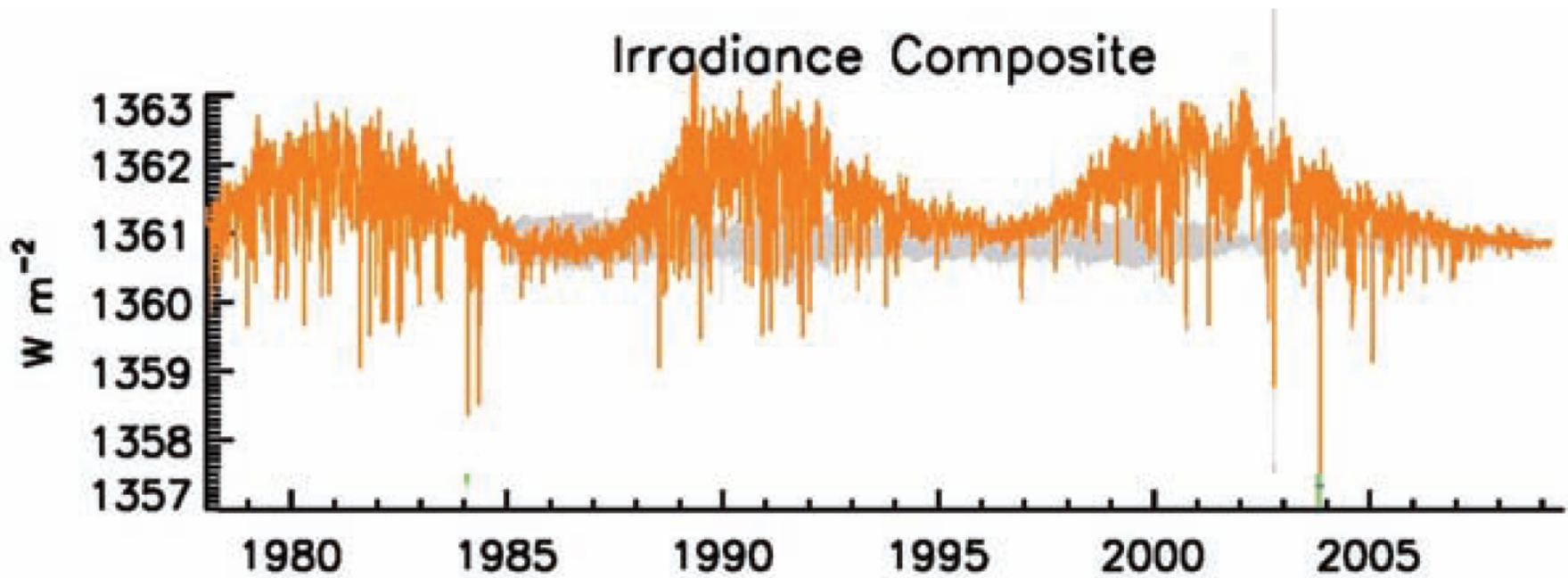
Meehl et al., 2007



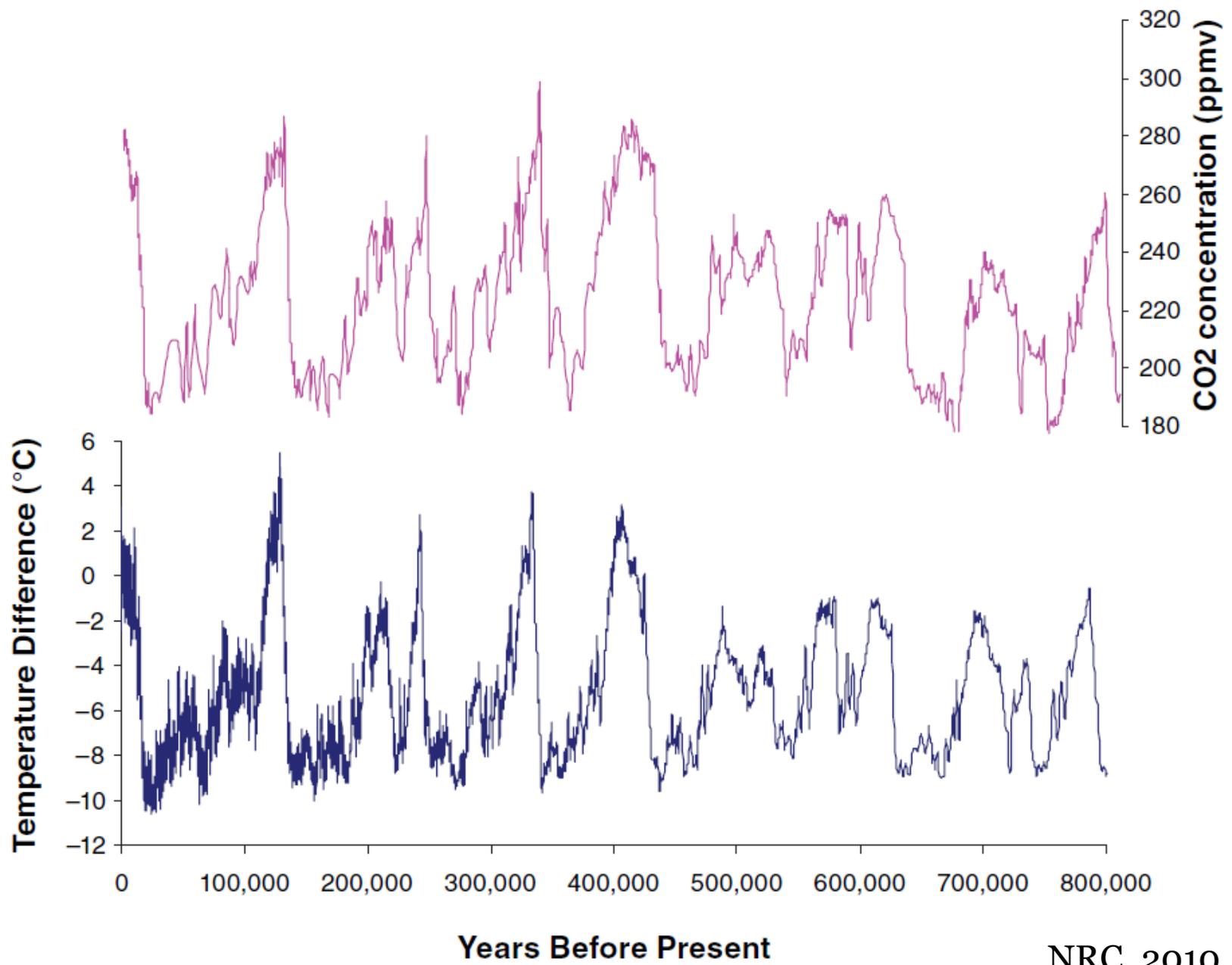
Lake McConaughy Elevation 1941 to Present



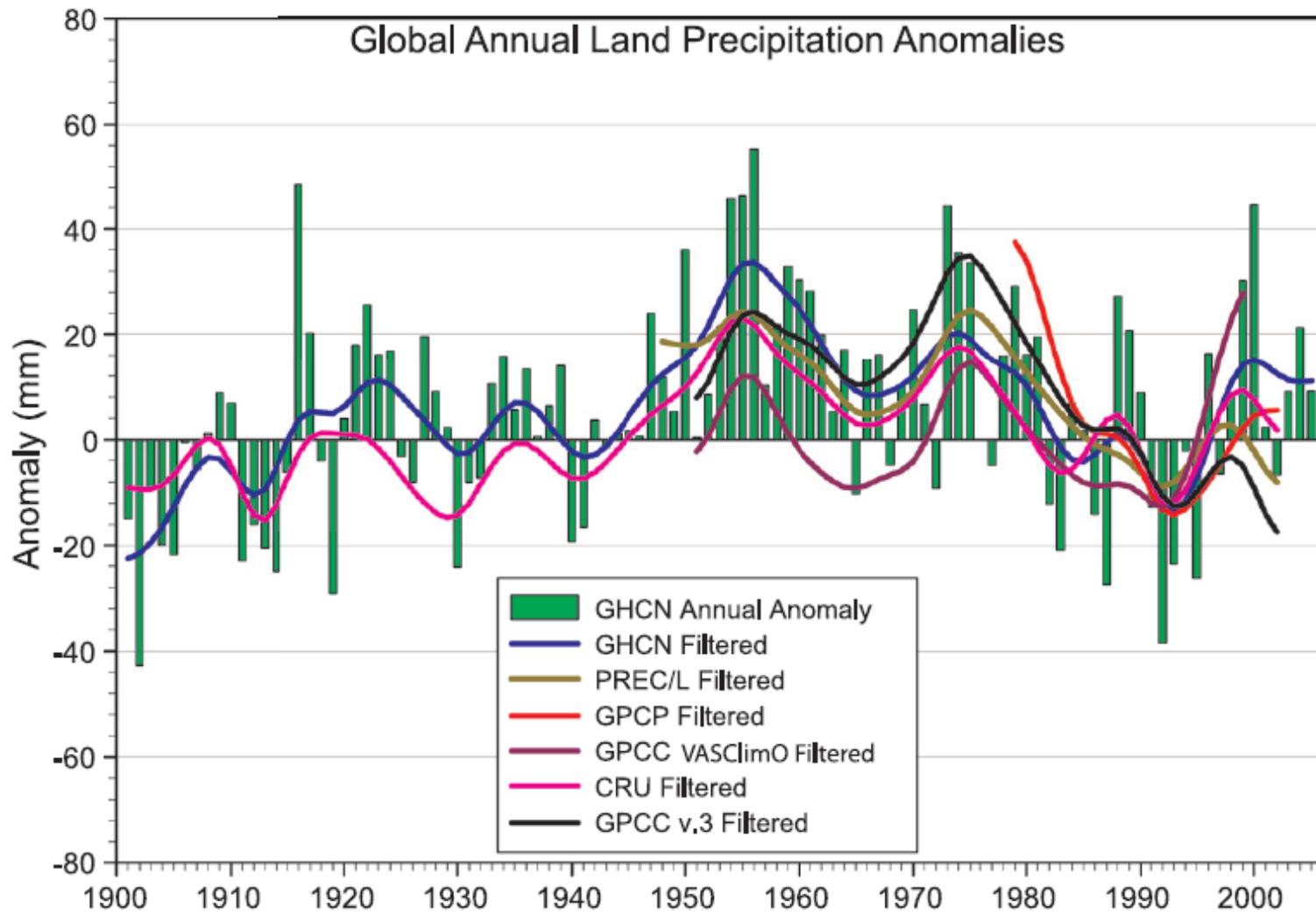
<http://www.cnppid.com/Assets/McConaughy1941-Present.jpg>



NRC, 2010

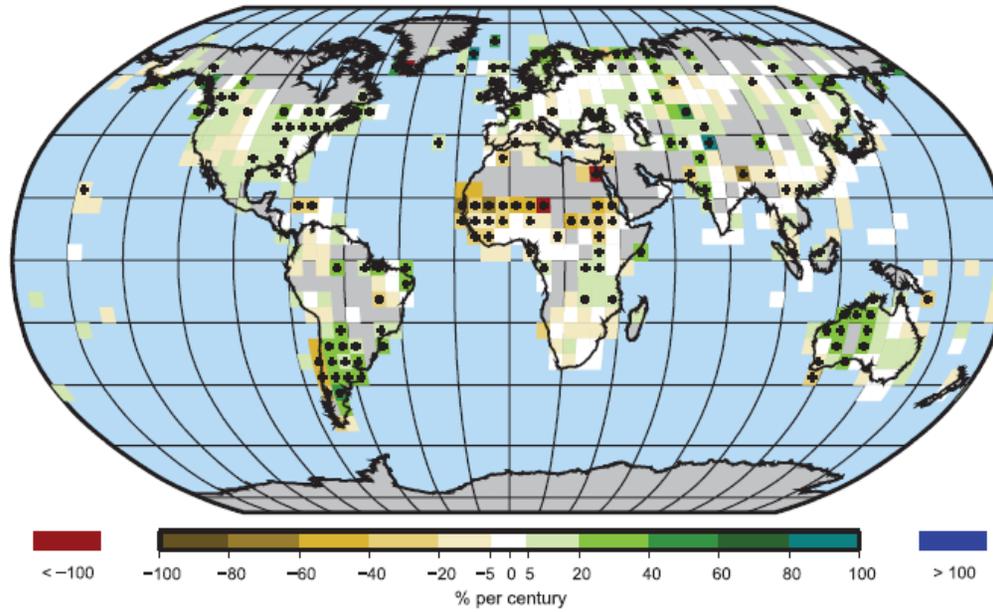


NRC, 2010

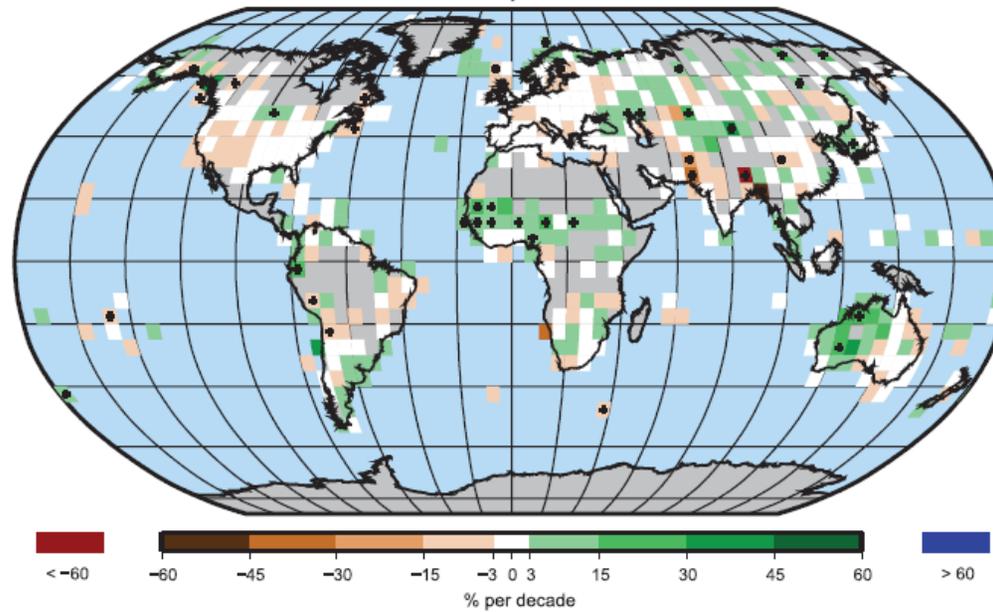


Trenberth et al., 2007

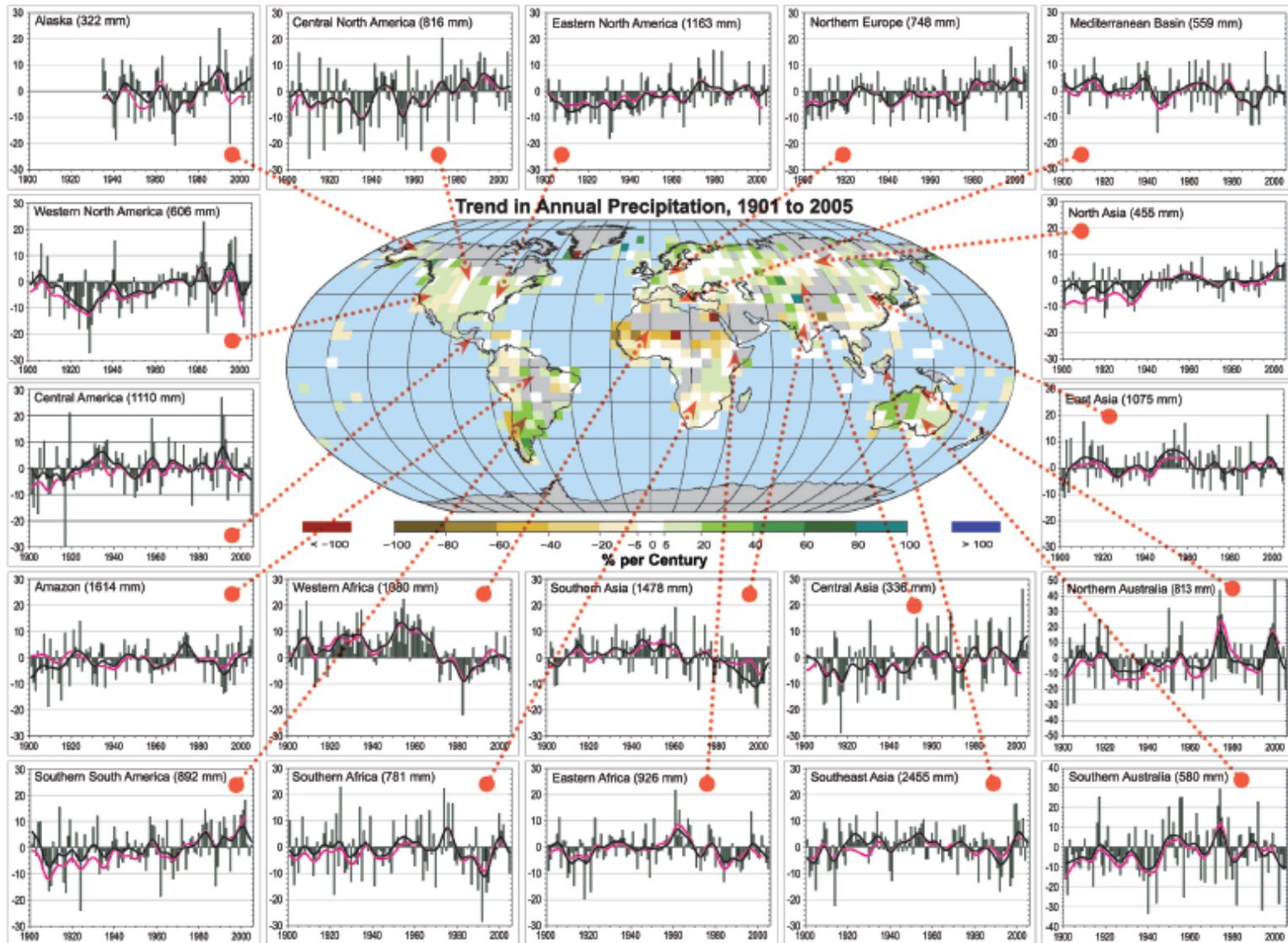
Trend in Annual Precipitation, 1901 to 2005



Trend in Annual Precipitation, 1979 to 2005

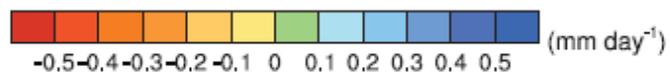
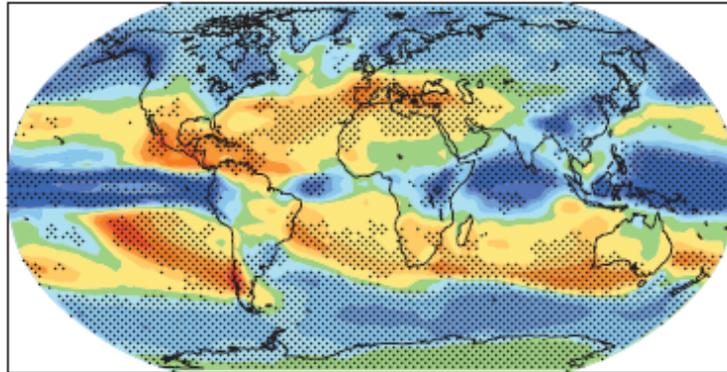


Trenberth et al., 2007

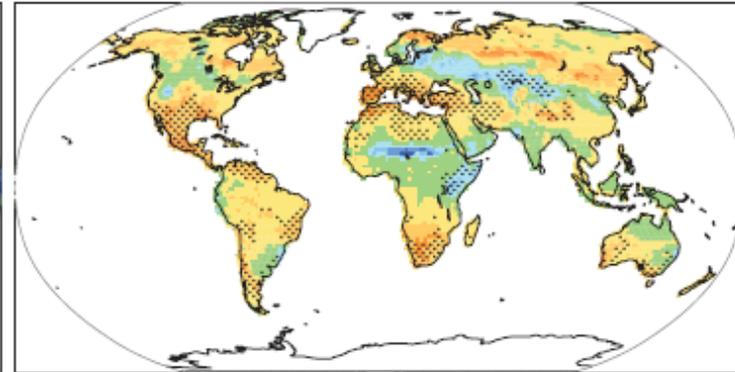


Trenberth et al., 2007

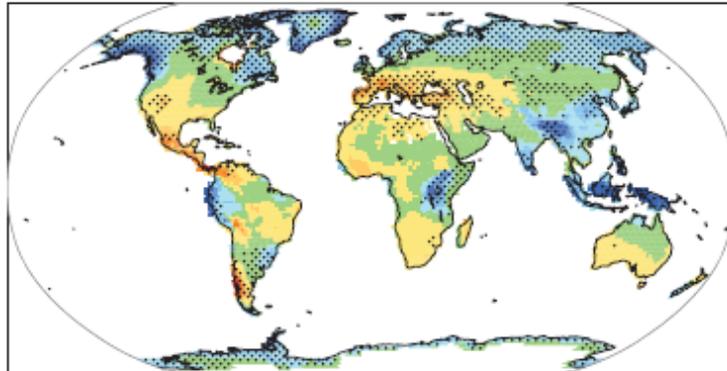
a) Precipitation



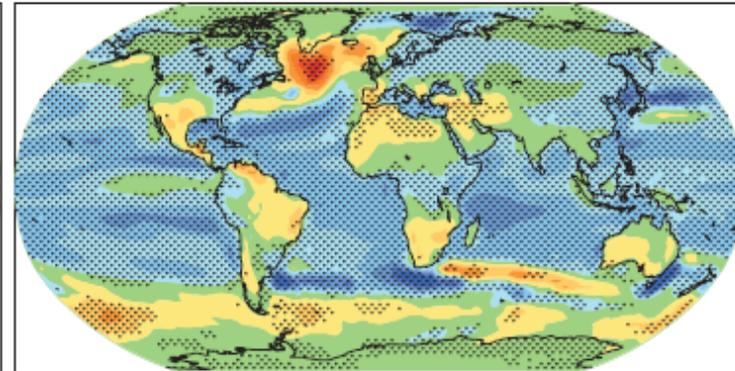
b) Soil moisture

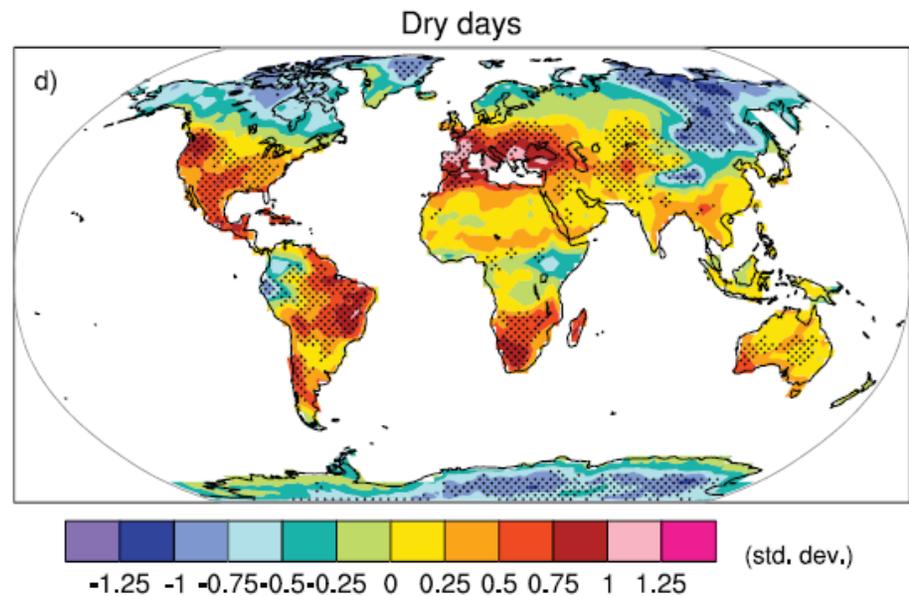
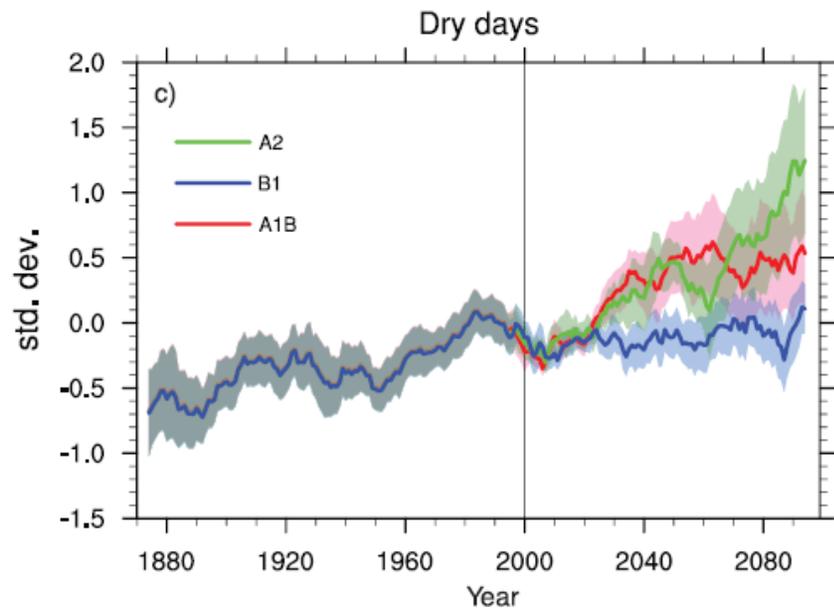
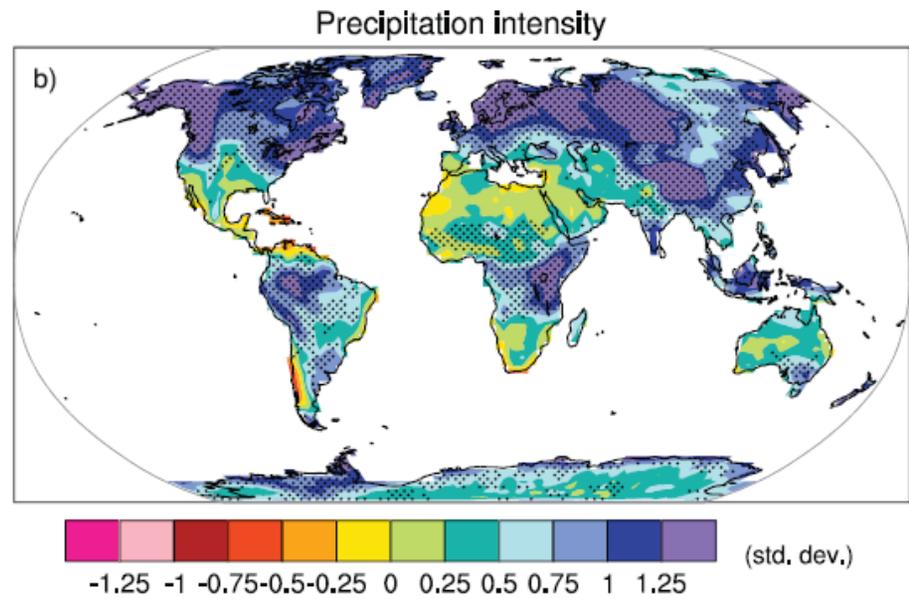
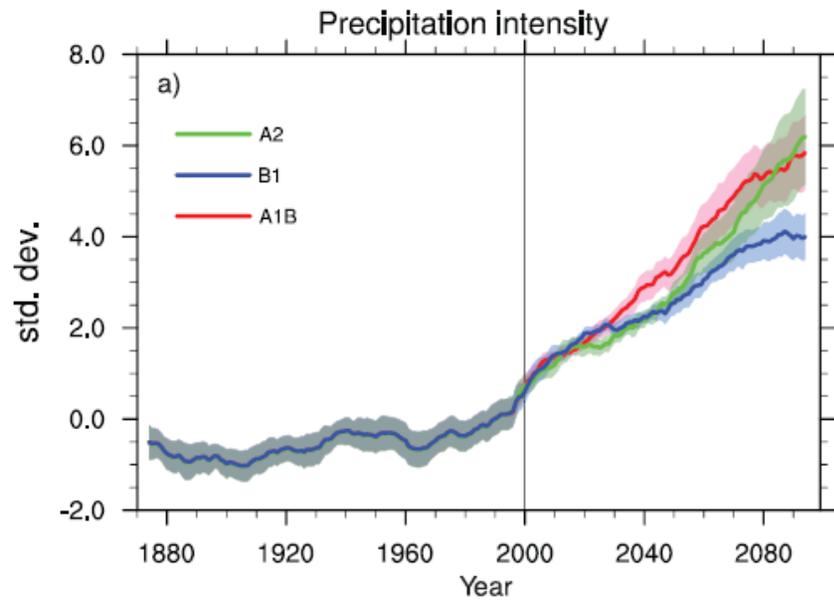


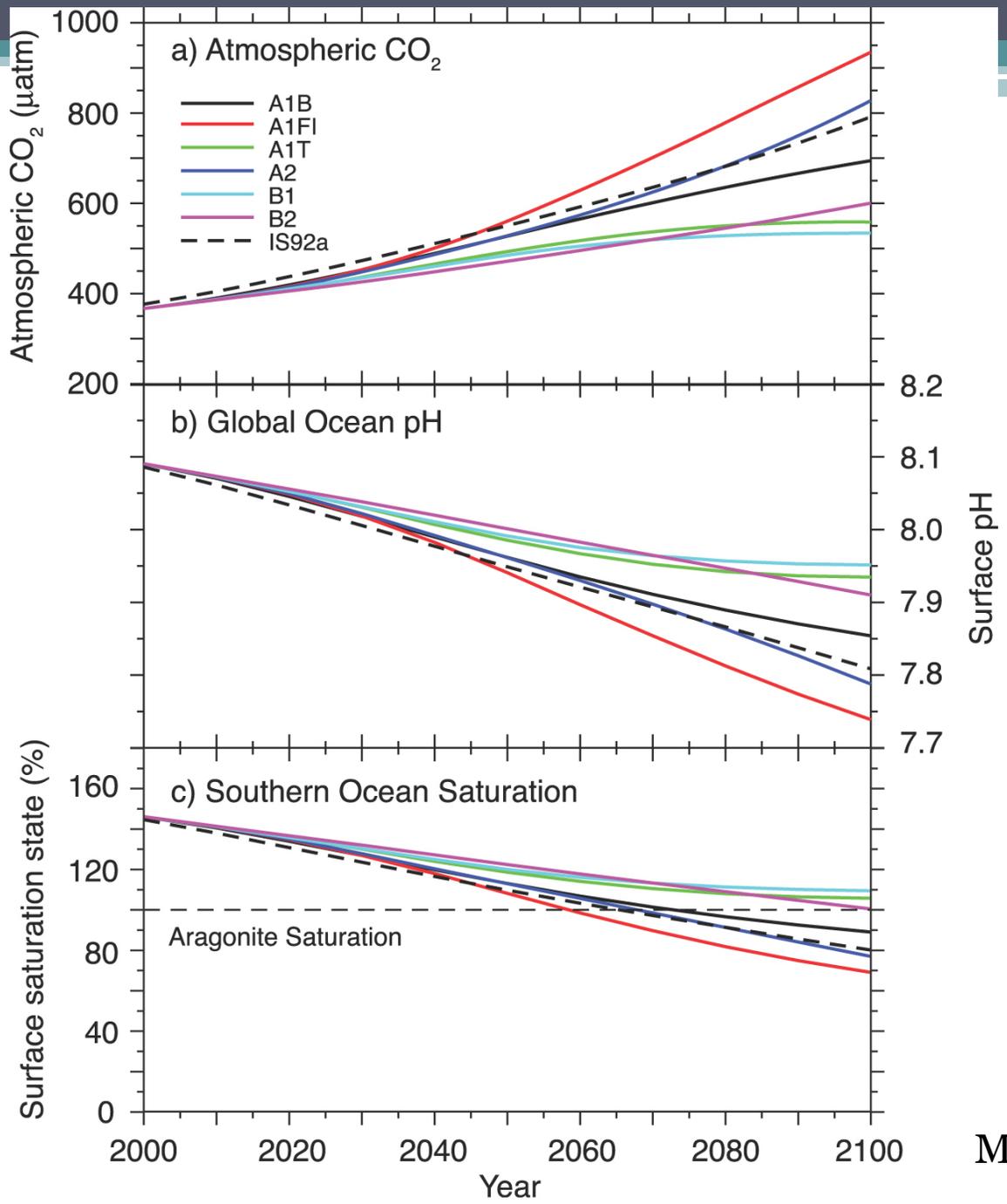
c) Runoff



d) Evaporation



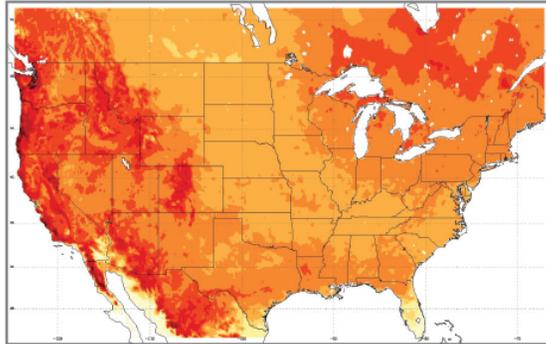




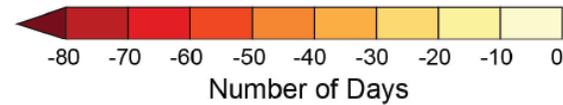
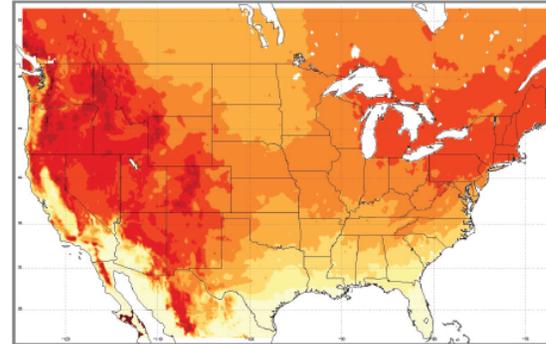
Meehl et al., 2007

## Climate Variables Affecting Agriculture

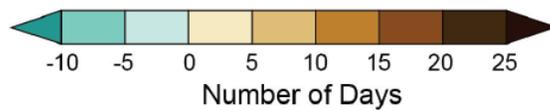
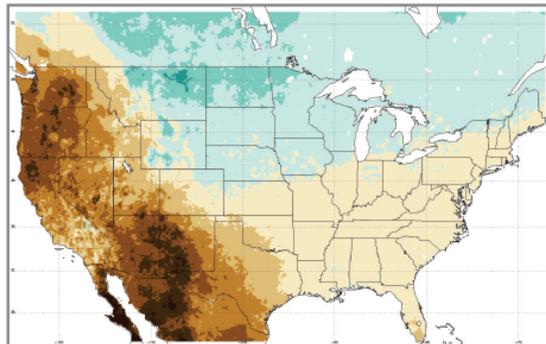
Change in Frost-free Season Length



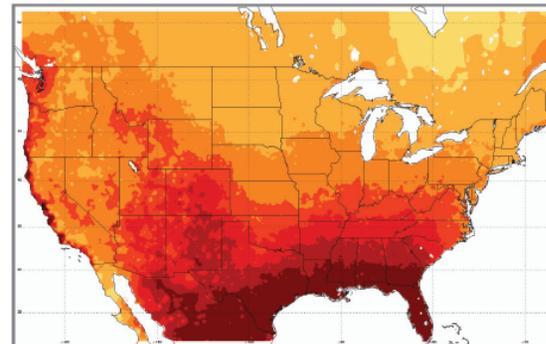
Change in Number of Frost Days



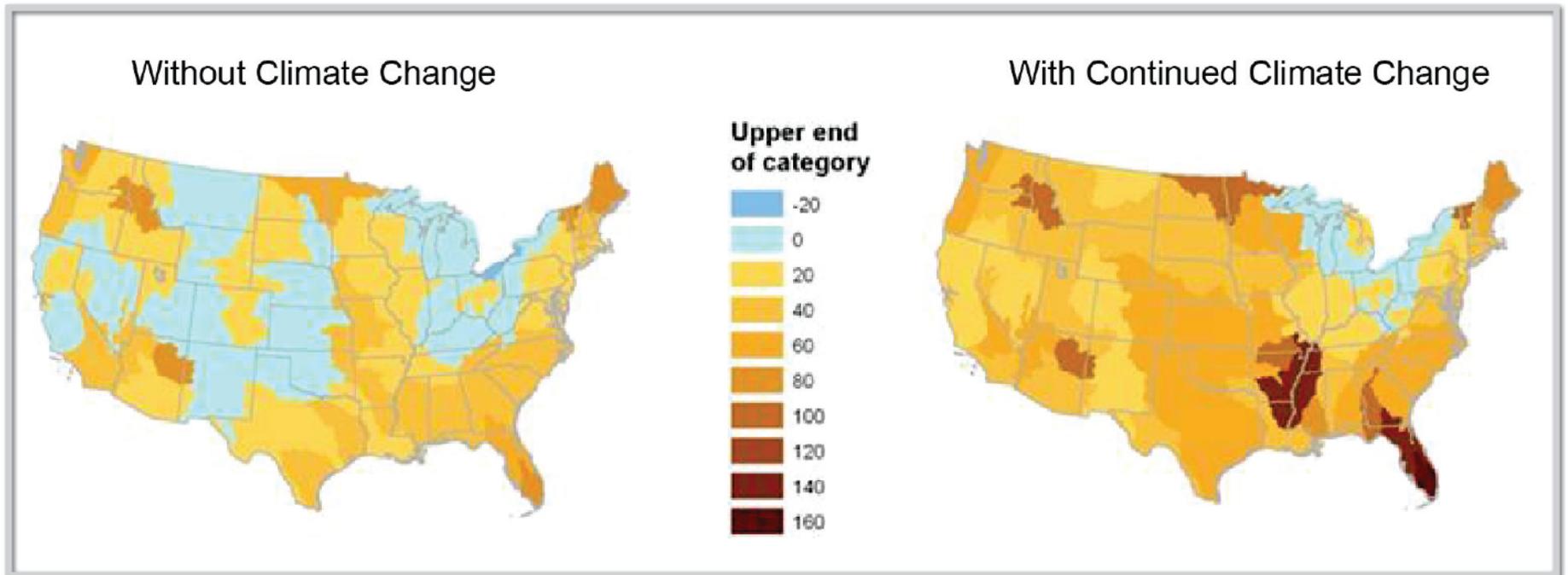
Change in Number of Dry Days



Change in Number of Hot Nights



## Projected Changes in Water Withdrawal





**Questions?**

# A Response to Climate Change Denialism

Richard Somerville, a distinguished professor emeritus and research professor at Scripps Institution of Oceanography, UC San Diego, issued the following statement in response to a recent request to address claims recently made by climate change denialists:

[http://sio.ucsd.edu/Announcements/Somerville\\_denialists/](http://sio.ucsd.edu/Announcements/Somerville_denialists/)

- 
1. The essential findings of mainstream climate change science are firm. This is solid settled science. The world is warming. There are many kinds of evidence: air temperatures, ocean temperatures, melting ice, rising sea levels, and much more. Human activities are the main cause. The warming is not natural. It is not due to the sun, for example. We know this because we can measure the effect of man-made carbon dioxide and it is much stronger than that of the sun, which we also measure.

- 
2. The greenhouse effect is well understood. It is as real as gravity. The foundations of the science are more than 150 years old. Carbon dioxide in the atmosphere traps heat. We know carbon dioxide is increasing because we measure it. We know the increase is due to human activities like burning fossil fuels because we can analyze the chemical evidence for that.

- 
3. Our climate predictions are coming true. Many observed climate changes, like rising sea level, are occurring at the high end of the predicted changes. Some changes, like melting sea ice, are happening faster than the anticipated worst case. Unless mankind takes strong steps to halt and reverse the rapid global increase of fossil fuel use and the other activities that cause climate change, and does so in a very few years, severe climate change is inevitable. Urgent action is needed if global warming is to be limited to moderate levels.

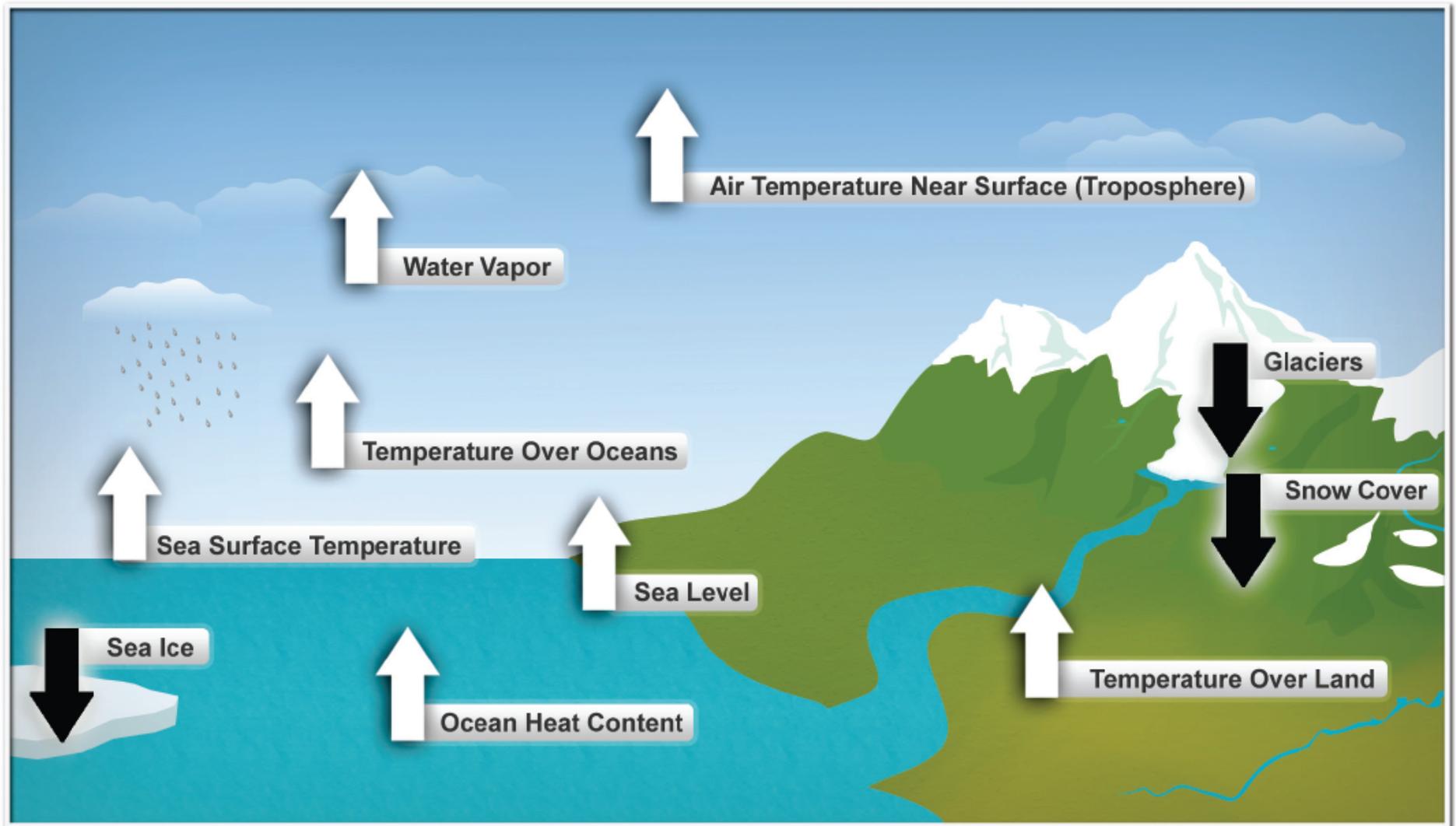
- 
4. The standard skeptical arguments have been refuted many times over. The refutations are on many web sites and in many books. For example, natural climate change like ice ages is irrelevant to the current warming. We know why ice ages come and go. That is due to changes in the Earth's orbit around the sun, changes that take thousands of years. The warming that is occurring now, over just a few decades, cannot possibly be caused by such slow-acting processes. But it can be caused by man-made changes in the greenhouse effect.

- 
5. Science has its own high standards. It does not work by unqualified people making claims on television or the Internet. It works by scientists doing research and publishing it in carefully reviewed research journals. Other scientists examine the research and repeat it and extend it. Valid results are confirmed, and wrong ones are exposed and abandoned. Science is self-correcting. People who are not experts, who are not trained and experienced in this field, who do not do research and publish it following standard scientific practice, are not doing science. When they claim that they are the real experts, they are just plain wrong.

- 
6. The leading scientific organizations of the world, like national academies of science and professional scientific societies, have carefully examined the results of climate science and endorsed these results. It is silly to imagine that thousands of climate scientists worldwide are engaged in a massive conspiracy to fool everybody. The first thing that the world needs to do if it is going to confront the challenge of climate change wisely is to learn about what science has discovered and accept it.

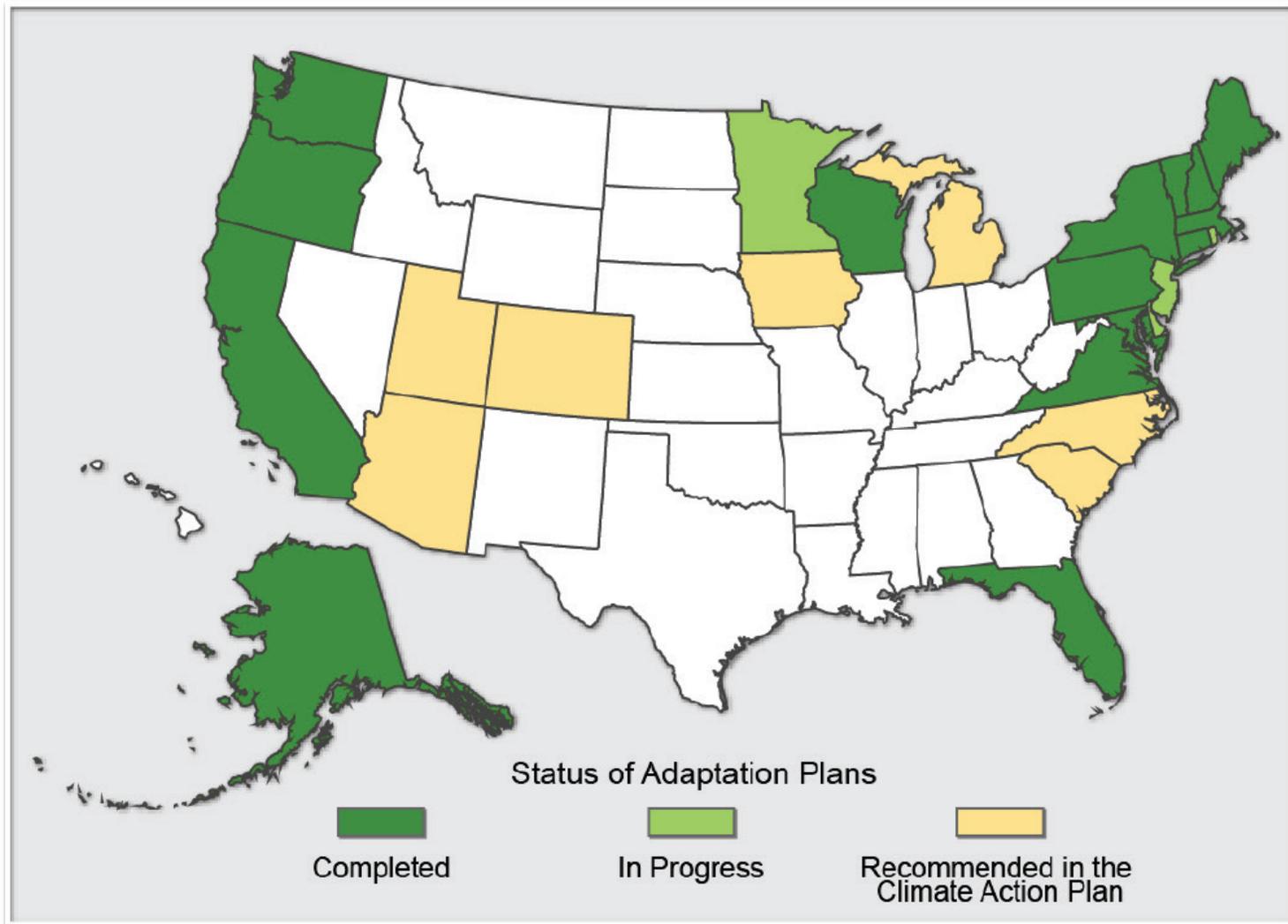
**TOP**

## Ten Indicators of a Warming World

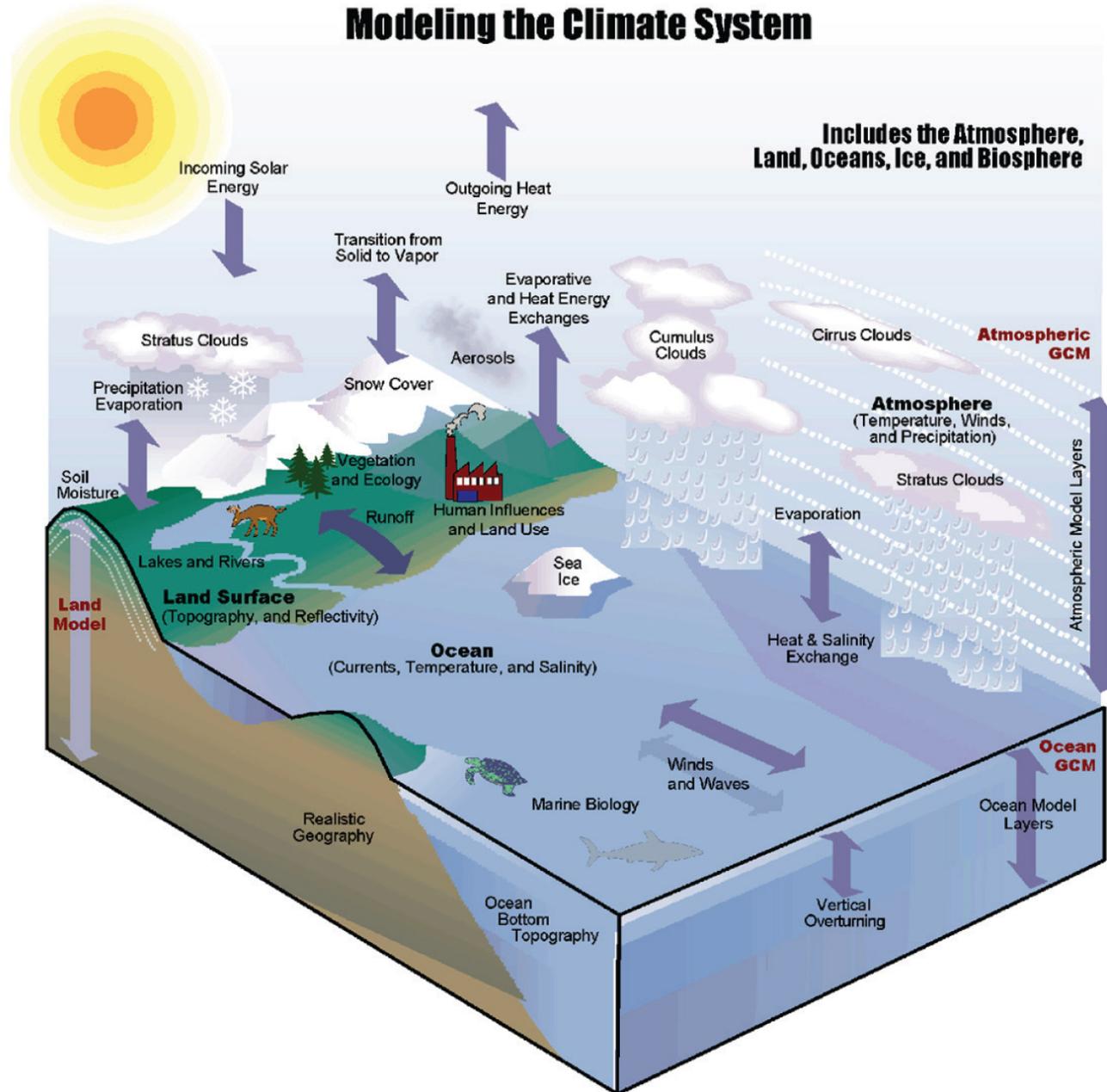


Third National Climate Assessment (NCA) - 11 Jan 2013 draft

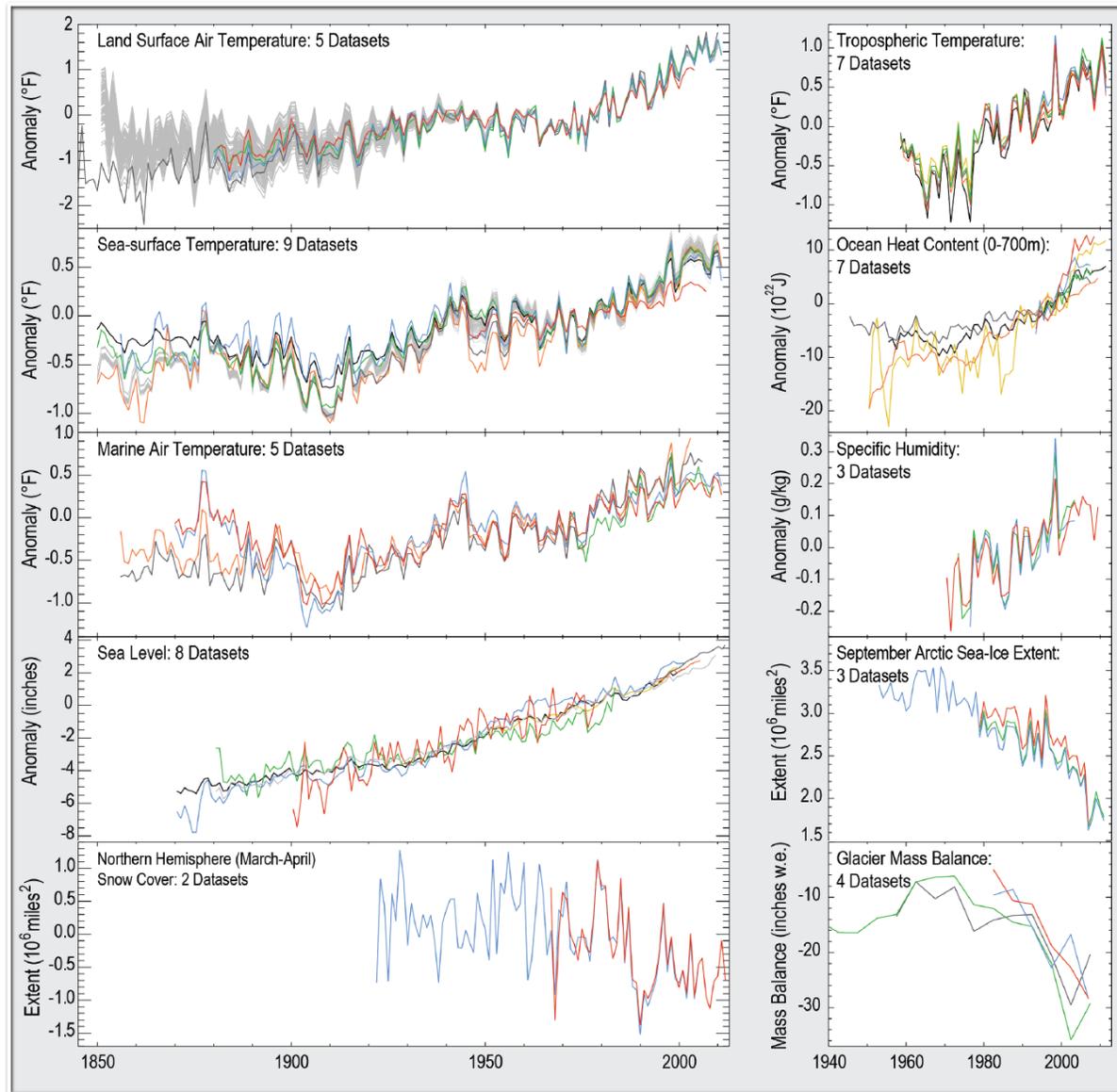
## Status of State Climate Adaptation Plans



# Modeling the Climate System

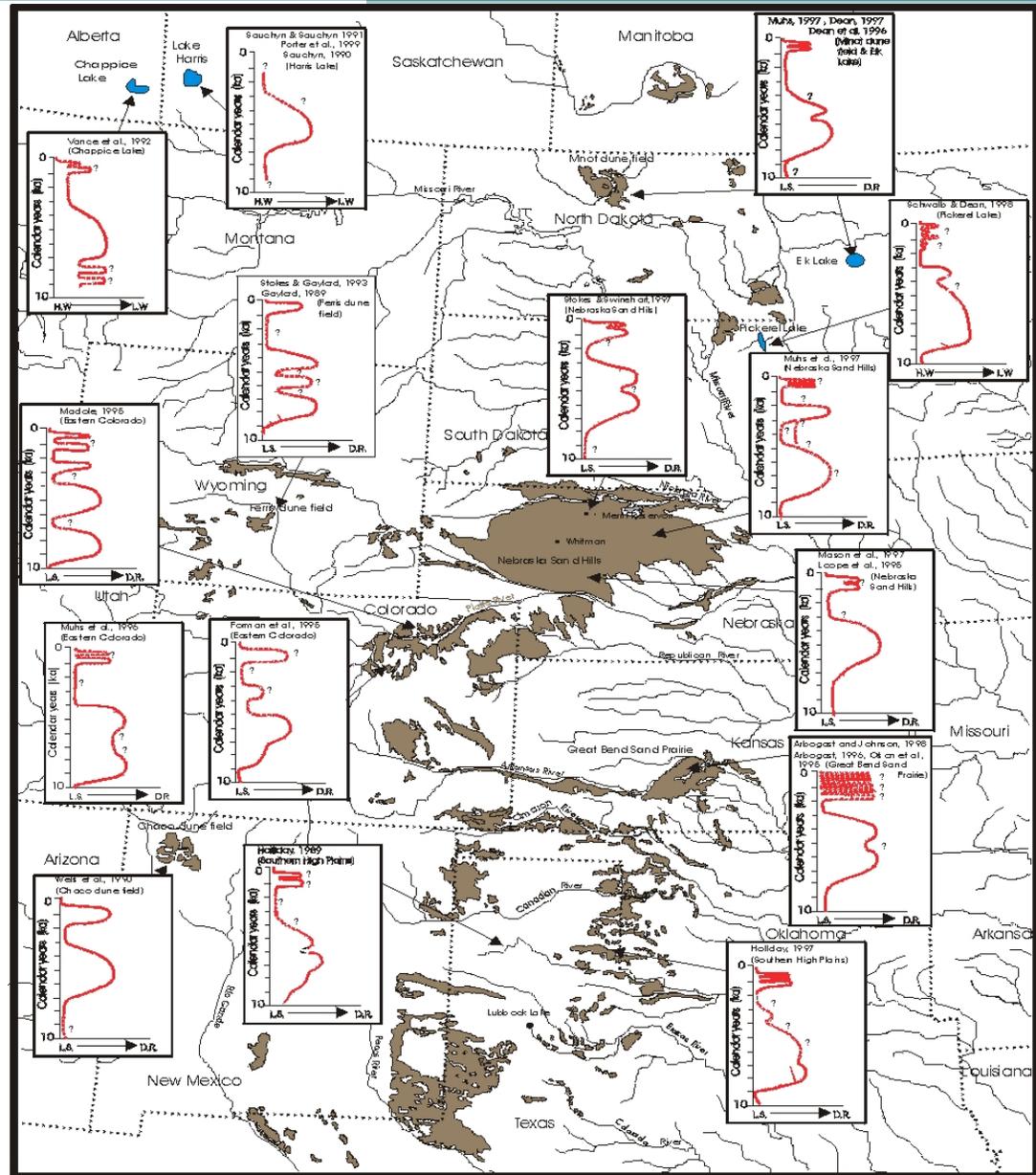
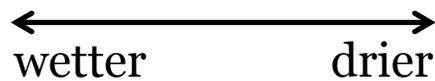


## Ten Indicators of a Warming World



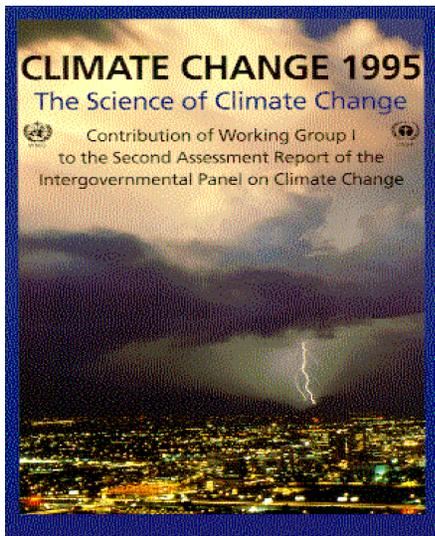
For dunes, LS denotes landscape stability (wetter), DR denotes dune reactivation (drier)

For lakes, HW denotes high water level (wetter), LL denotes low water level (drier)

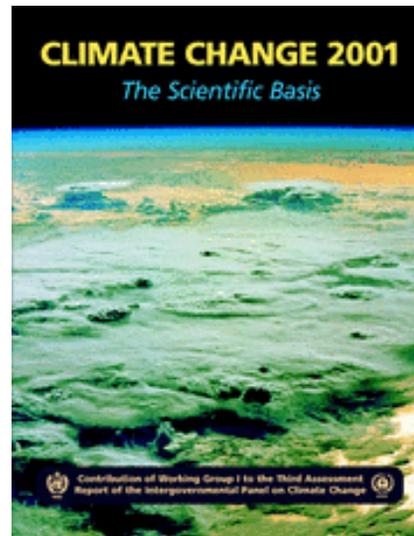


Forman and Munyikwa, 1999

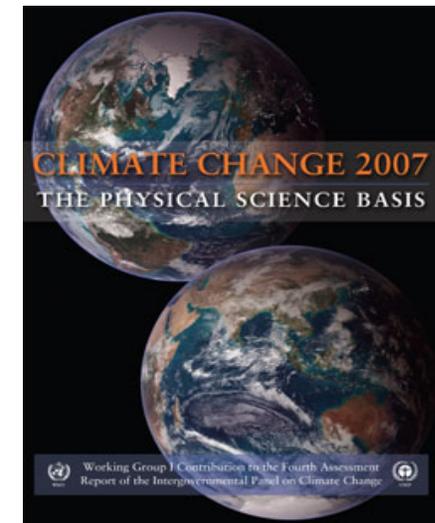
Over the last 20 years, scientific certainty has been increasing



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

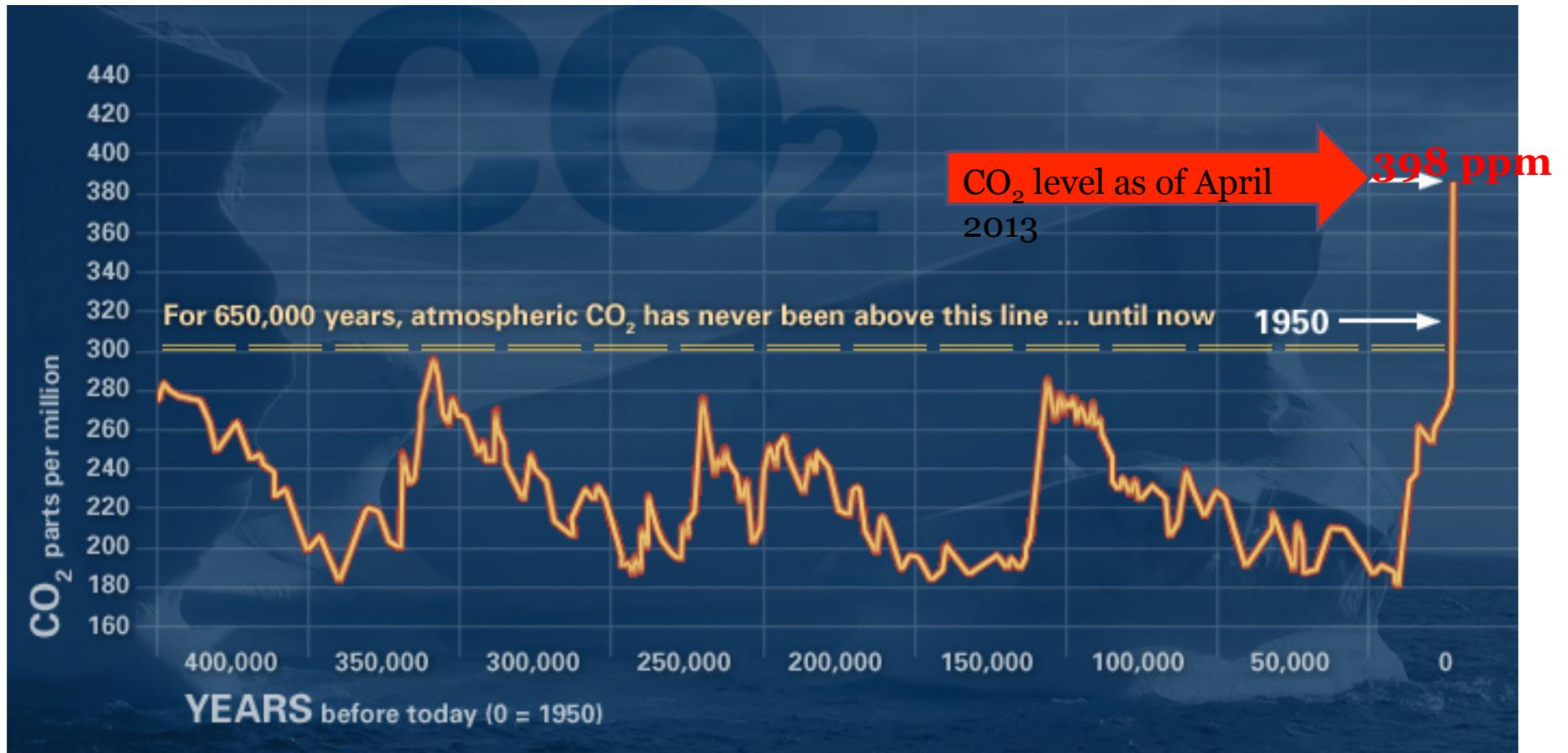


“There is new and stronger evidence that **most of the warming observed over the last 50 years is attributable to human activities**”



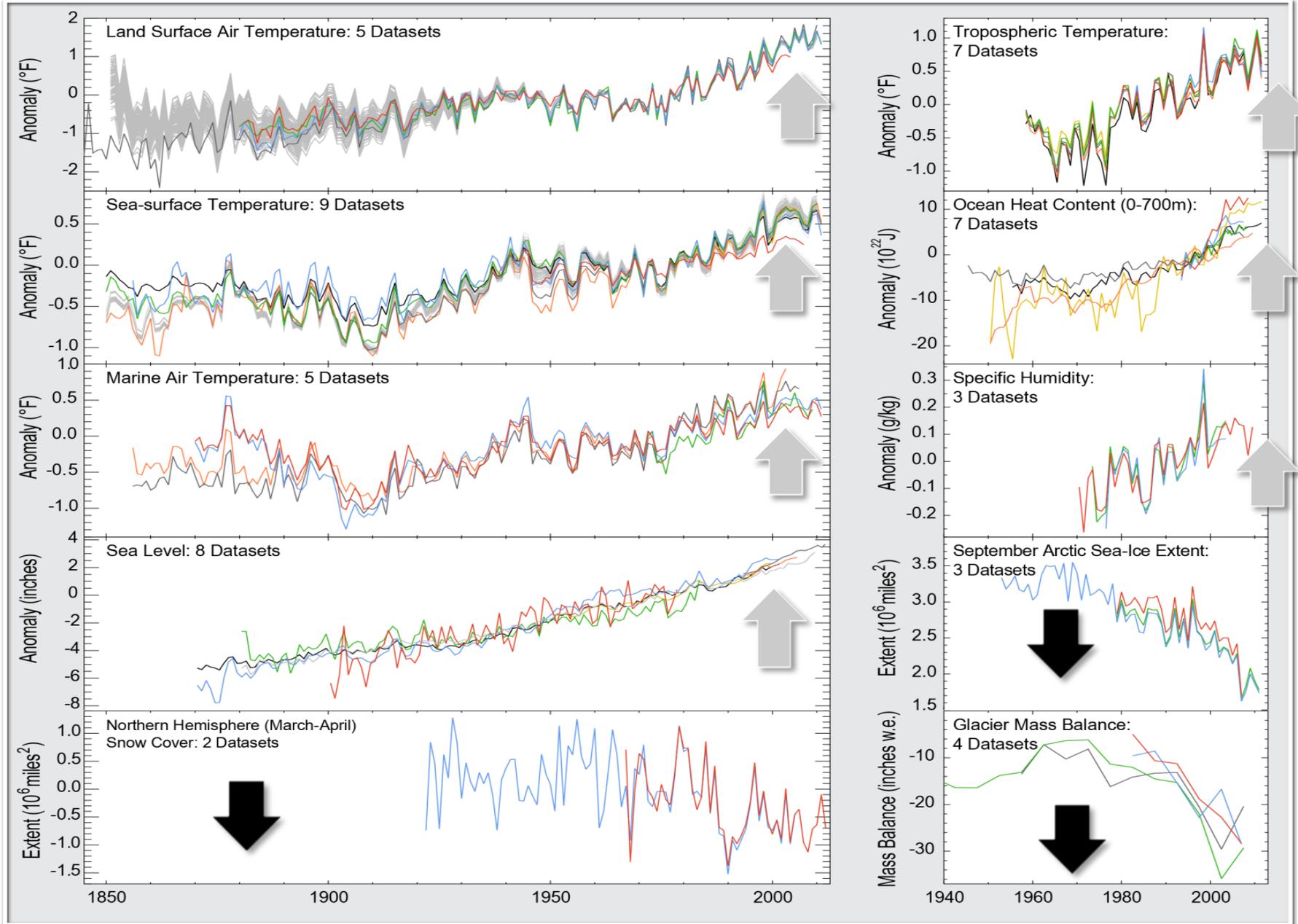
“Warming of the climate system is **unequivocal....** Most of the observed increase since the mid-20<sup>th</sup> century is **very likely [>90%]** due to the observed increase in anthropogenic greenhouse gas concentrations.”

Atmospheric CO<sub>2</sub> is now higher than it's been for 650,000 years and increasing rapidly



This graph, based on the comparison of atmospheric samples contained in ice cores and more recent direct measurements, provides evidence that atmospheric CO<sub>2</sub> has increased since the Industrial Revolution. (Source: NOAA)

# The ten key indicators are all changing as expected



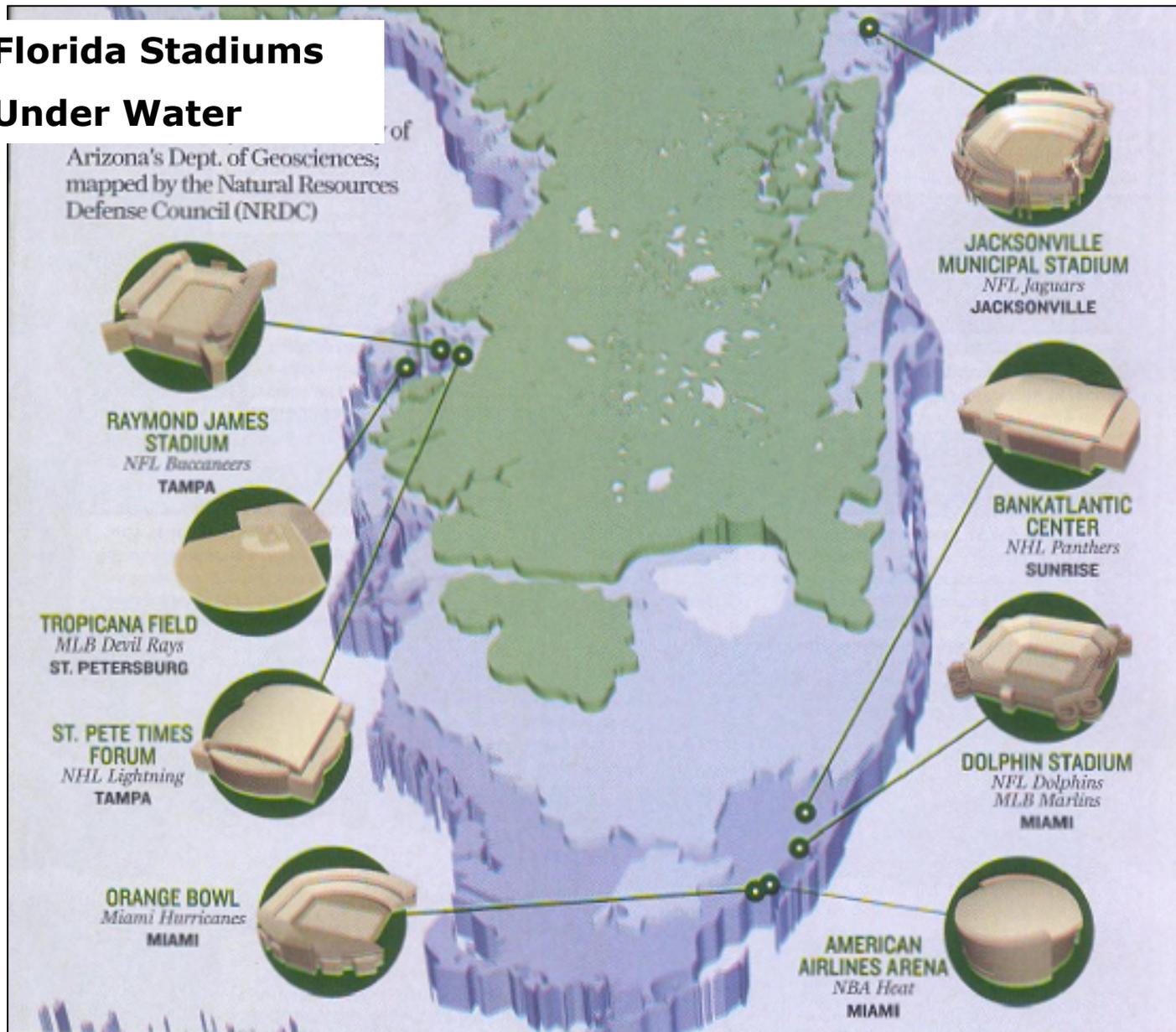
# The Limits of Engineering Solutions

Red Areas Show Inundation with 1-meter Sea Level Rise



# ACT DIFFERENTLY: PROTECTING STADIUMS

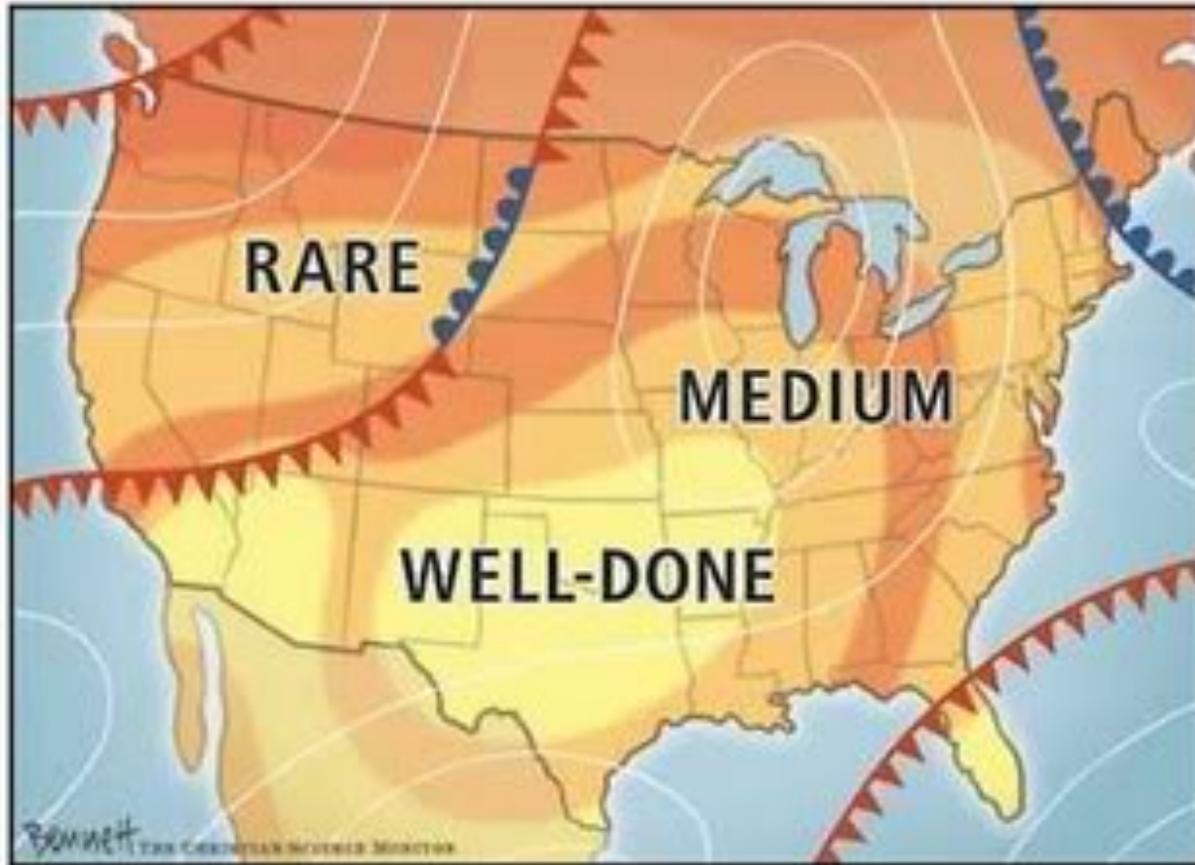
## Florida Stadiums Under Water



## Design concept for new \$500M Warriors Arena

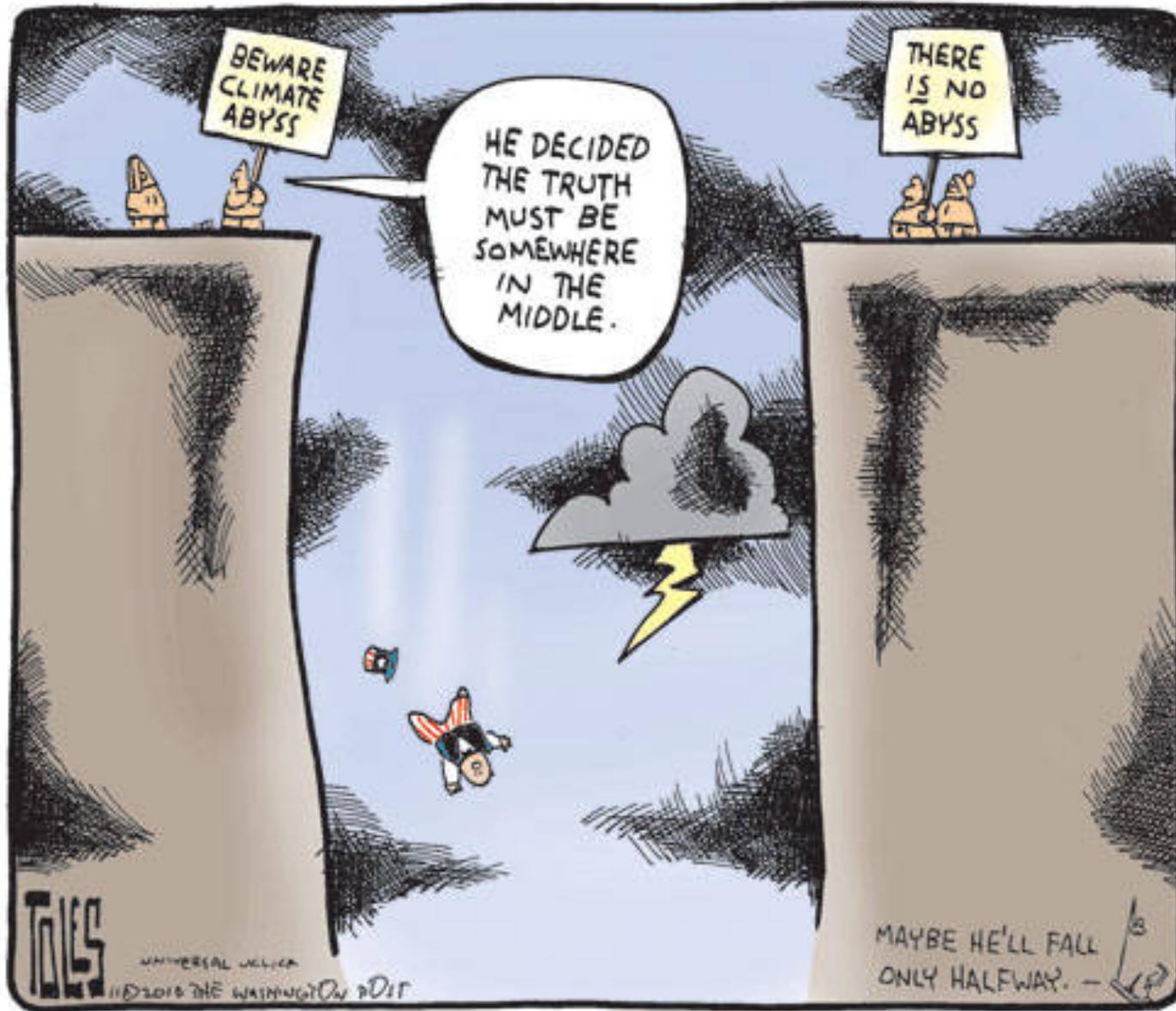


<http://www.nba.com/warriors/sf?venue>



# global warming protest





11-15-10

GUESS WHICH COUNTRY  
IS DELAYING ACTION ON  
CLIMATE CHANGE AGAIN?



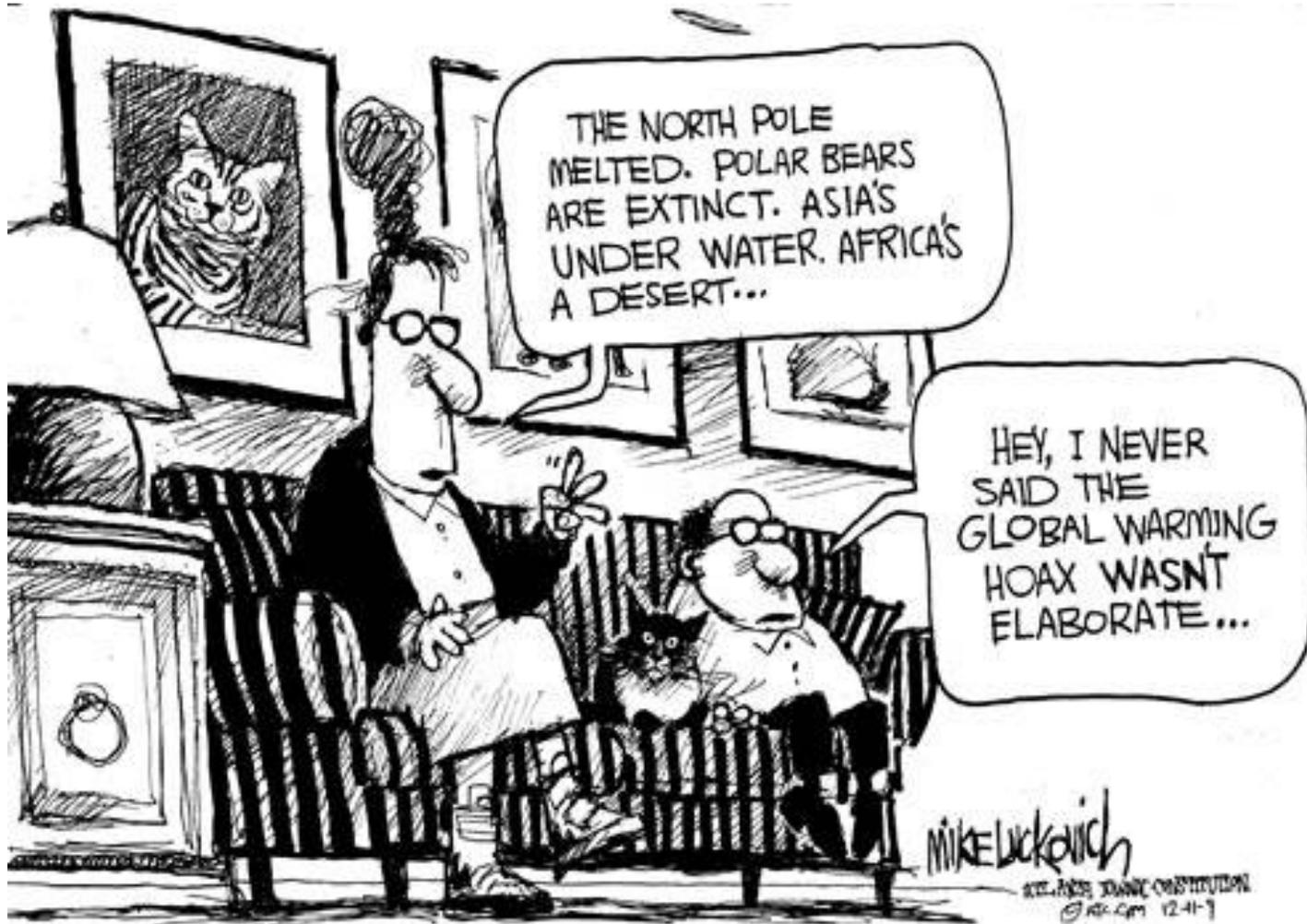
**BRENT** San Diego, Jason, Franchesco  
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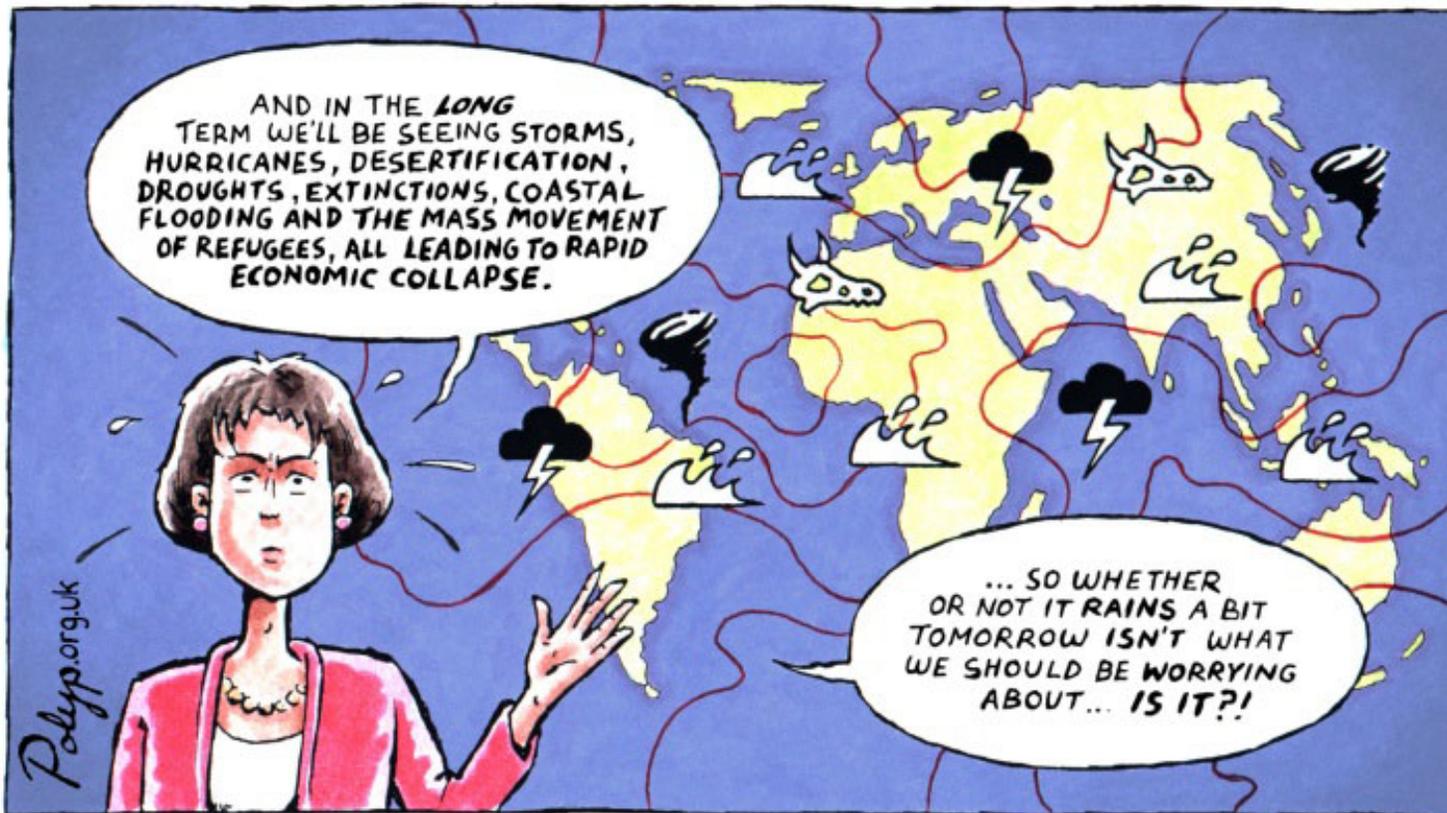




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