Funding provided by NOAA
Sectoral Applications Research Project

# ALTERING CLIMATE

Basic Climatology

Oklahoma Climatological Survey

# ATMOSPHERIC POLLUTANTS

# Acid Rain

- *Acid Rain* is the precipitation that carries higher-than-normal amounts of nitric or sulfuric acid
  - Actually includes *dry deposition*; some of these particles may settle out of the atmosphere in the absence of rain
- 'Neutral' rain is slightly acidic (pH around 5.6) due to naturally-occurring chemicals
  - *pH* of 7.0 is neutral; less than that is considered acidic, greater than that is alkaline
  - Each 1.0 decrease in the scale indicates a 10-fold from the next-higher number (e.g., water with a pH of 5.0 is 10 times more acidic than one with a pH of 6.0)
  - The most acidic rain in the U.S. (as of 2000 according to the EPA) had a pH of 4.3
- Causes of Acid Rain:
  - Volcanic eruptions
  - Decomposition of organic matter
  - Burning wood
  - Burning fossil fuels
- Main *anthropogenic* (man-made) sources are sulfur dioxide ($SO_2$) and Nitrogen Oxides ($NO_x$) emitted by power plants, industry, and automobiles

***Source: NASA***

# Impacts of Acid Rain

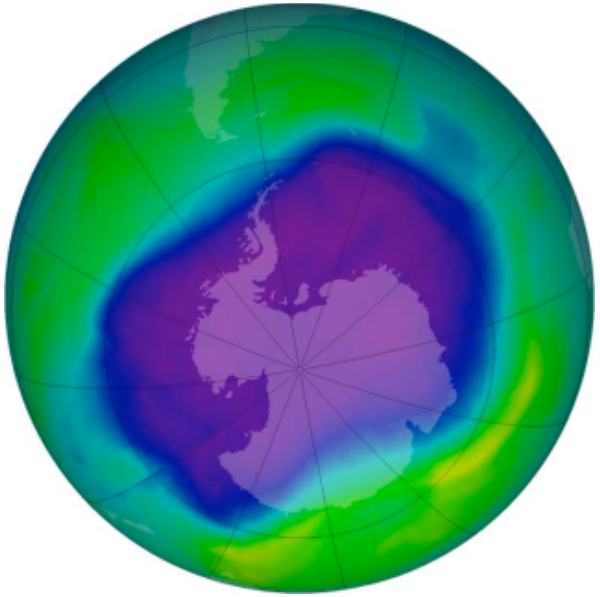
- Surface Waters:
  - Kills or sickens fish and other food sources (such as insects) upon which they rely
  - Excess nitrogen depletes oxygen (*eutrophication*), causing algae blooms and fish kills
  - Leaches heavy metals, particularly aluminum, from the soil, which is toxic to many fish and plants
  - Alkaline substances in the soil may counteract the effects of acid rain, but may become overwhelmed
  - May get a 'shock' with spring snowmelt, runoff
- Forests:
  - Acid buildup in soil weakens trees, making them more susceptible to other threats
  - Dissolves and washes away nutrients
  - Fog at higher elevations constantly bathe trees in acid, washing away nutrients
- Materials:
  - Causes blotches and fading of painted surfaces, including cars
  - Deterioration of stone, particularly marble and limestone
  - Corrosion of metals such as bronze and steel
- Visibility:
  - Molecules are larger and scatter more incoming light, reducing visibility
  - Accounts for 50-70% of visibility reduction in the eastern U.S.
- Human Health:
  - Increase in heart and lung disorders, including asthma and bronchitis
  - Causes an estimated $50 billion annually in premature mortality, hospital admissions, and emergency room visits

# Reducing Acid Rain

- Monitor and Report
- Reduce smokestack emissions
  - Remove sulfur at the source; clean coal
  - Use *scrubbers* to remove $SO_2$ before it leaves the smokestack (chemical interactions that bind it with other substances that can be collected)
  - Use *catalytic converters* to remove $NO_x$ from automobile emissions
- Use alternative energy sources
  - Natural gas: still pollutes, but not as much
  - Nuclear energy
  - Hydropower
  - Renewable energy: wind, solar, geothermal
  - Electric vehicles
- Restore damaged environments
  - Limestone may be added to water to cancel out some of the acidity on a short-term basis (but very expensive)

# Ozone

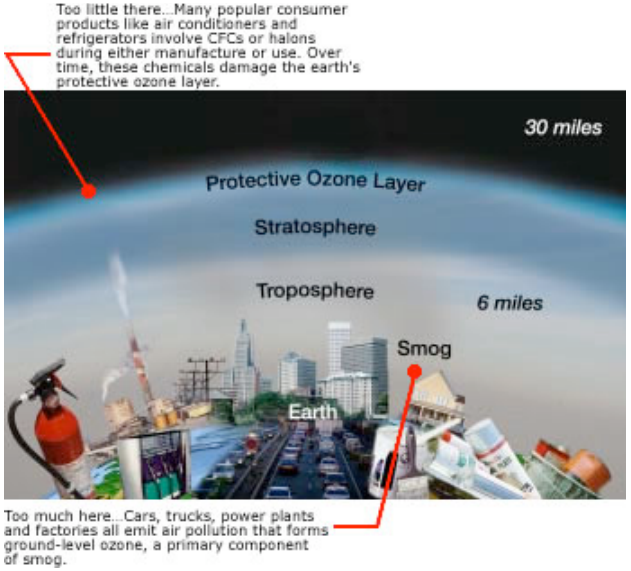
- The ozone layer is a concentration of ozone ($O_3$) particles in the stratosphere
- Ozone is very good at absorbing harmful high-energy ultraviolet radiation from the sun
- During the 1980s it was discovered that chemicals, called *chlorofluorocarbons* (CFCs), were depleting the concentration of atmospheric ozone
  - CFCs were commonly used in refrigeration, aerosol sprays, and solvents
  - One chlorine atom can break apart more than 100,000 ozone molecules
- The Montreal Protocol agreement in 1987 put in place a ban on CFCs
  - Alternative chemicals and technologies have been developed to replace CFCs
- As a result of these actions, the ozone layer is expected to recover by 2050



***Source: NASA***

# But I Thought Ozone Was Good…

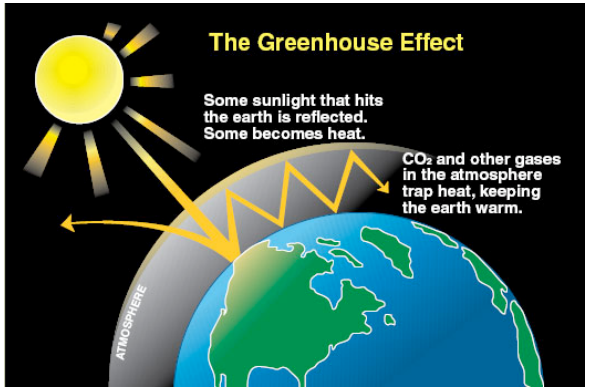
- Up high, ozone filters harmful solar radiation…
- …but it's not a good thing to breathe
  - Can worsen bronchitis, asthma, and emphysema
  - Prolonged exposure can irritate and scar lung tissue
- Ozone can also harm vegetation and ecosystems and make trees more susceptible to disease
- Ozone is created from Nitrogen Oxides ($NO_x$) – the same bad guys as in acid rain
- Ultraviolet radiation from the sun converts $NO_x$ near the surface into ozone
  - Strong sunlight and high temperatures accelerate the process
  - Winds may carry emissions far from their sources, so regions downwind may have similar air quality problems



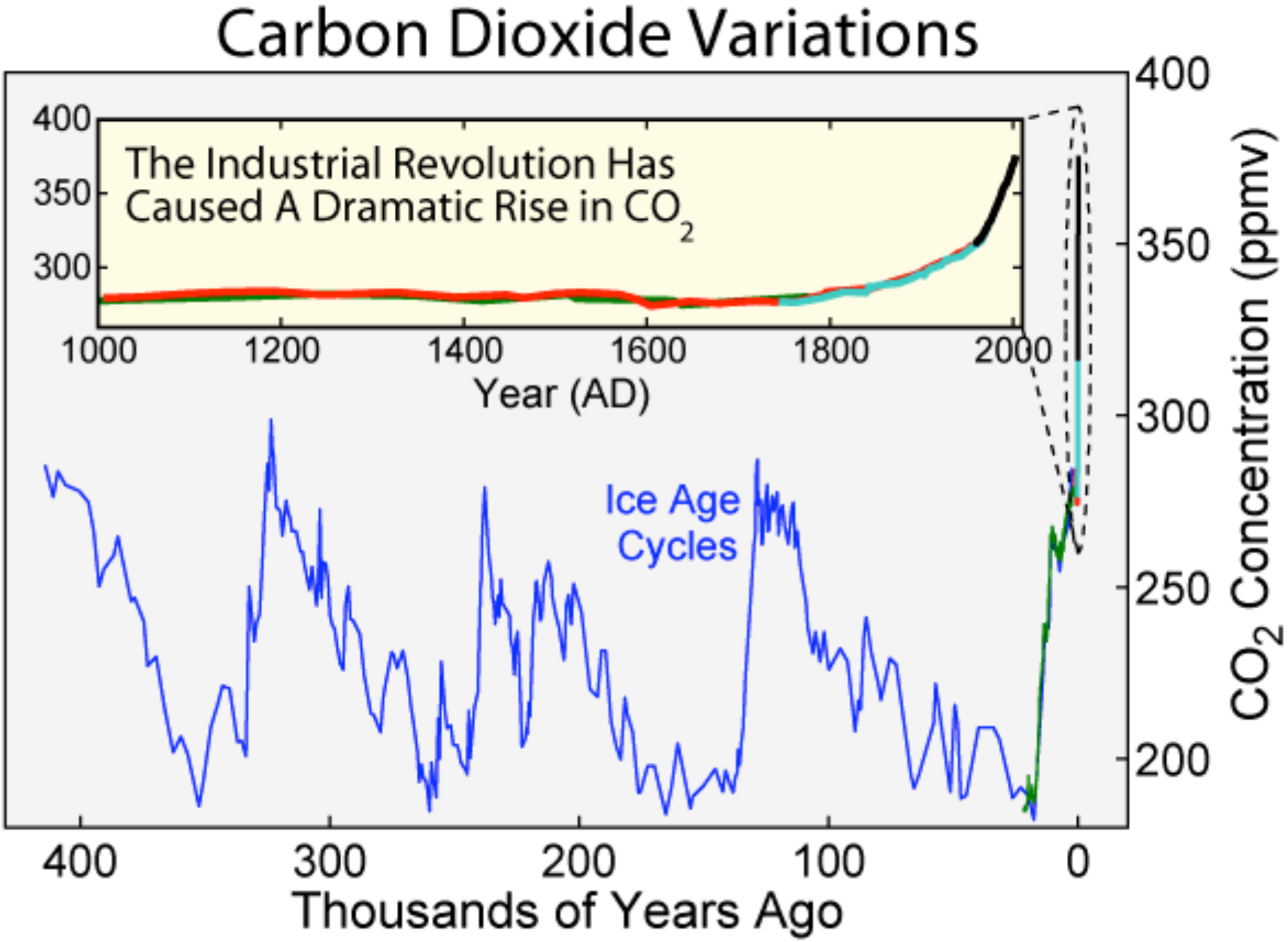

***Source: EPA***

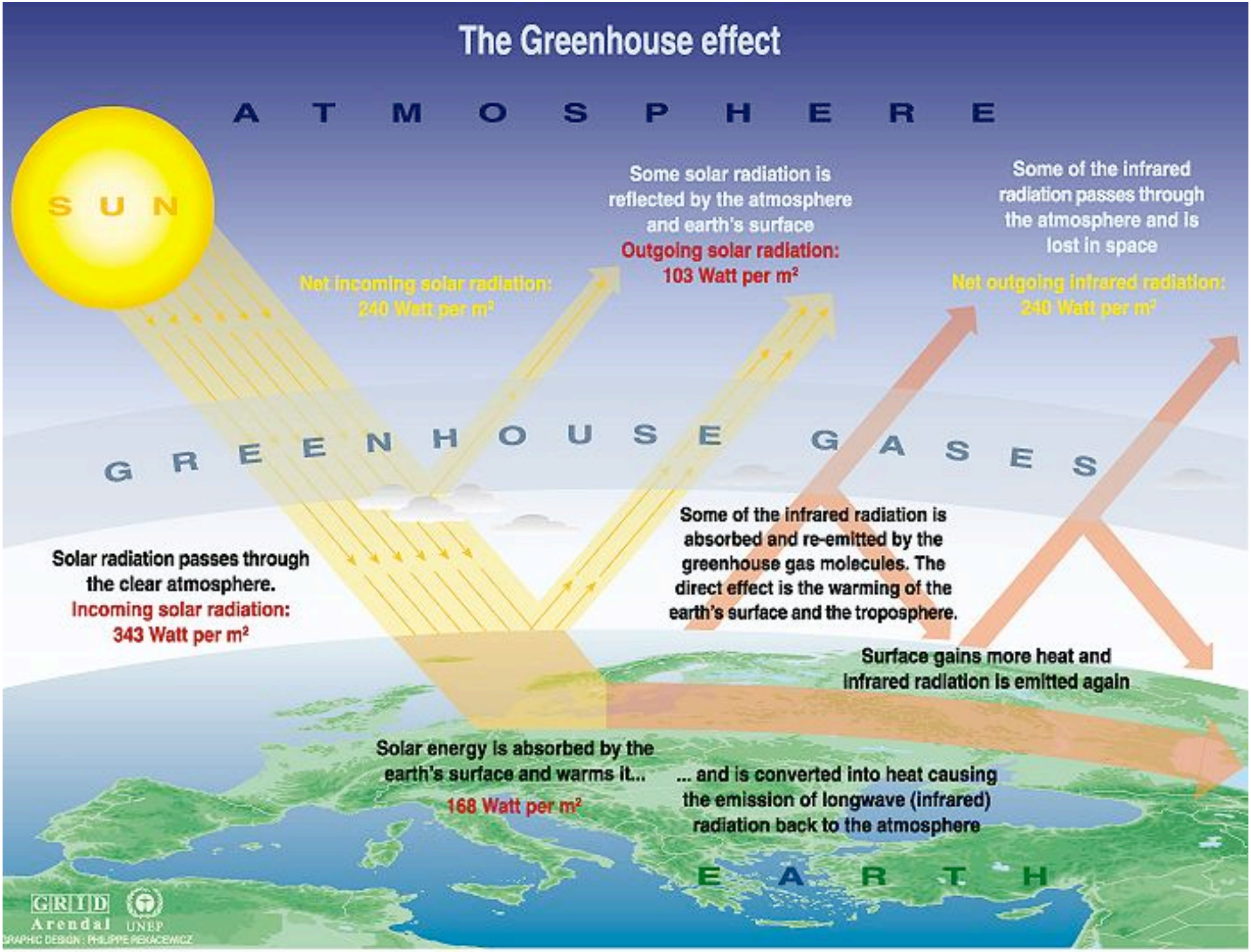
# Carbon Dioxide

- *Carbon Dioxide (CO2)* is a critical component of the Earth's biosystems
  - Used by plants to convert to sugars (energy)
  - Plants release oxygen as a waste product, which animals use
  - Animals, in turn, release carbon dioxide as a waste product
- However, high in the atmosphere, the radiative properties of CO2 cause trouble
  - Relatively transparent to incoming solar radiation but a good absorber of longer-wavelength radiation emitted by the Earth
  - CO2 essentially allows in the sun's energy but traps the outgoing energy from the Earth, causing temperatures to rise in what is known as the Greenhouse Effect
- Carbon dioxide has been building in the atmosphere as a byproduct of the combustion of fossil fuels – coal, oil, and natural gas
  - Some CO2 is a good thing – recall that the Earth's average temperature would be about 0°F without it
- Other gasses can also add to the greenhouse effect, particularly methane, which is a byproduct of agricultural production




***Source: Washington Department of Ecology***


Carbon Dioxide Variations
The Industrial Revolution Has Caused A Dramatic Rise in $CO_2$
400
350
300
1000
1200
1400
1600
1800
2000
Year (AD)
Ice Age Cycles
400
300
200
100
0
Thousands of Years Ago
400
350
300
250
200
$CO_2$ Concentration (ppmv)

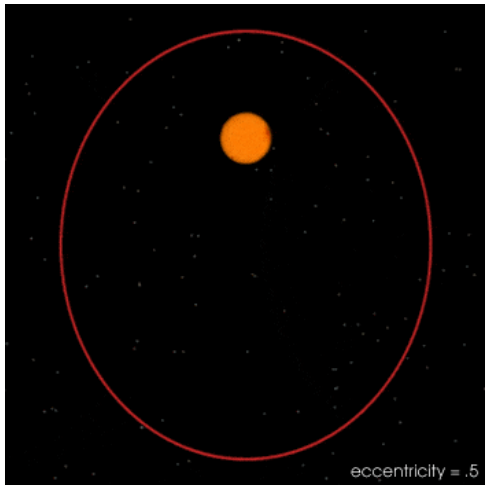


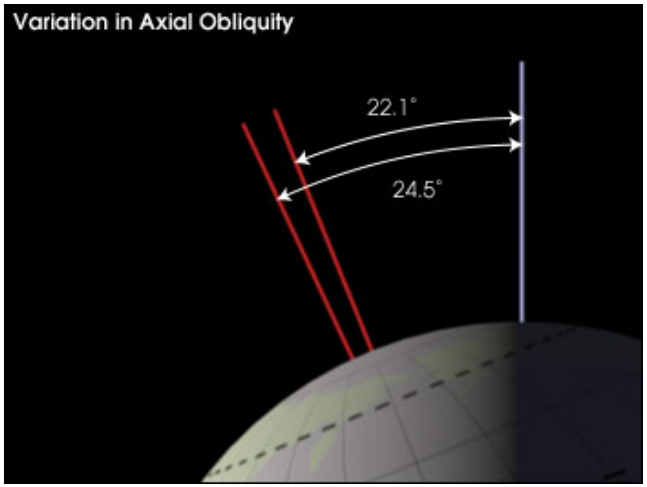

Sources: Okanagan university college in Canada, Department of geography, University of Oxford, school of geography; United States Environmental Protection Agency (EPA), Washington; Climate change 1995, The science of climate change, contribution of working group 1 to the second assessment report of the intergovernmental panel on climate change, UNEP and WMO, Cambridge university press, 1996.

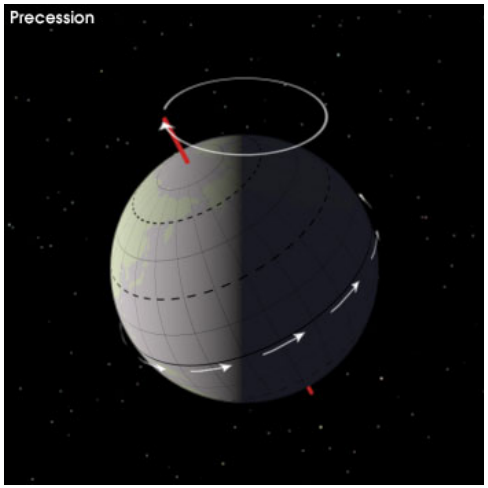
# HOW THEY AFFECT CLIMATE

# Factors Affecting Climate

- Orbital Variations (millennia)
  - *Eccentricity* – the shape of the orbit around the sun (90,000-100,000 years)
  - *Obliquity* – changes in the angle that Earth's axis makes with the plane of Earth's orbit (40,000 years)
  - *Precession* – the change in the direction of the Earth's axis of rotation (25,800 years)

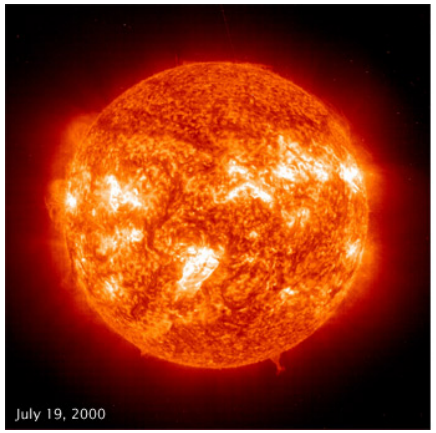


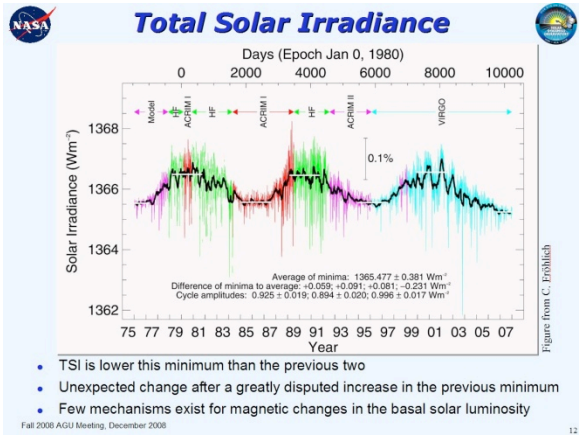



# Factors Affecting Climate

- Orbital Variations (millennia)
- Solar Variations (decades)
  - A fairly regular 9-14 year (average 11) cycle in solar energy output, seen through the number of *sunspots*
  - Last solar maximum was in 2001; next is predicted for May 2013



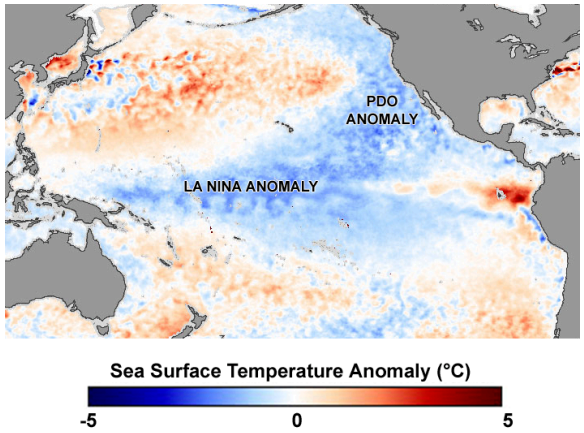


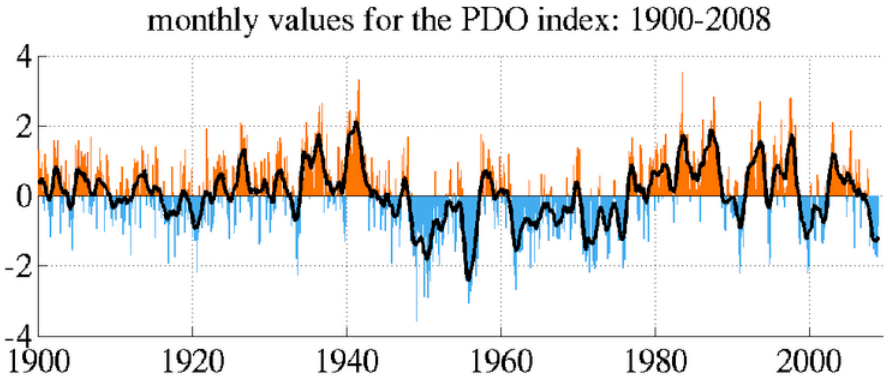



***Source: NASA***

# Factors Affecting Climate

- Orbital Variations (millennia)
- Solar Variations (decades)
- Oceanic Circulations (decades)
  - Periodic episodes of warming or cooling in different ocean basins
  - May combine with other circulation patterns to reinforce or counteract other climate trends

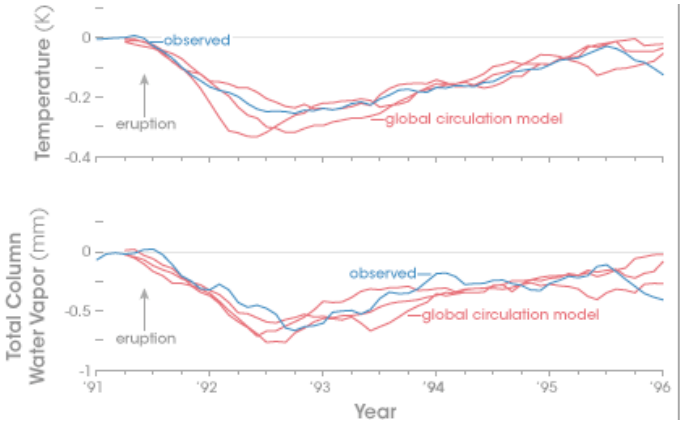


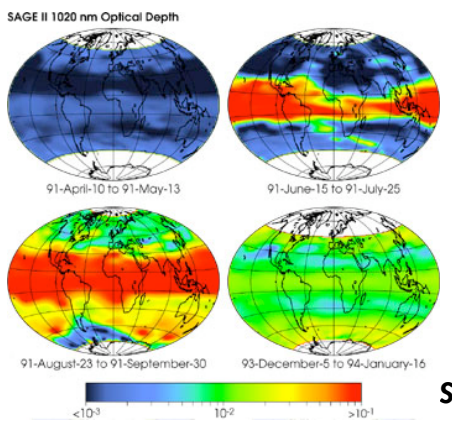




***Source: NASA***

# Factors Affecting Climate

- Orbital Variations (millennia)
- Solar Variations (decades)
- Oceanic Circulations (decades)
- Volcanic Emissions (1-2 years)
  - Sulfate aerosols block solar radiation from surface, causing much lower temperatures (lasts 1-2 years)
  - Only eruptions whose plumes penetrate the lower stratosphere cause large variability; very few volcanoes do so

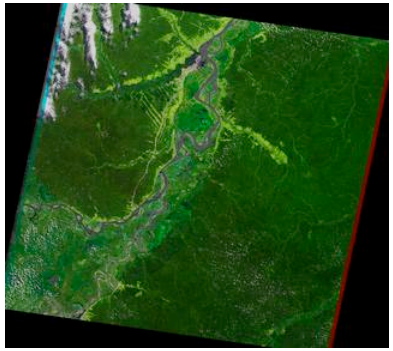


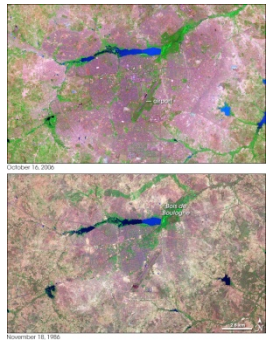



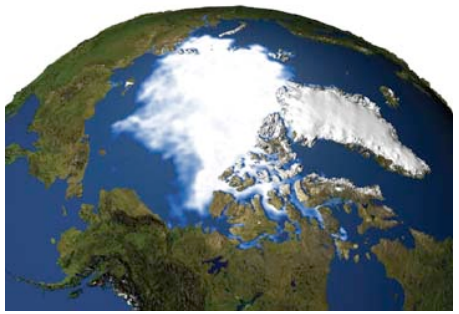

***Source: NASA***

# Factors Affecting Climate

- Orbital Variations (millennia)
- Solar Variations (decades)
- Oceanic Circulations (decades)
- Volcanic Emissions (1-2 years)
- Change in Land Cover (gradual changes, affecting *albedo*)
  - Deforestation: more vegetation creates cooler, wetter surface conditions; less vegetation leads to warmer, drier conditions
  - Ice cover: more ice reflects more sunlight, leading to cooling; less ice allows more sunlight to be absorbed, warming the surface

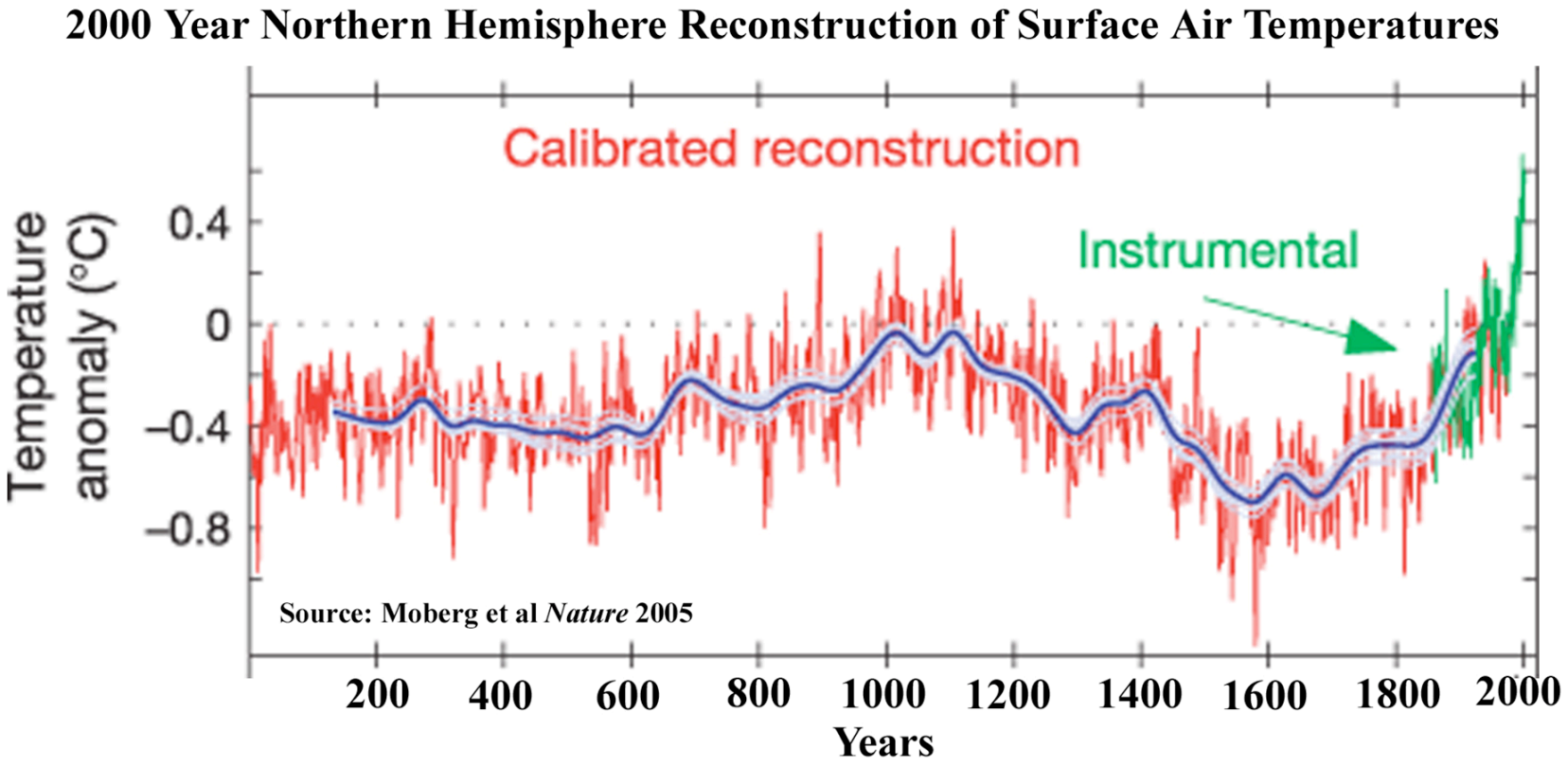




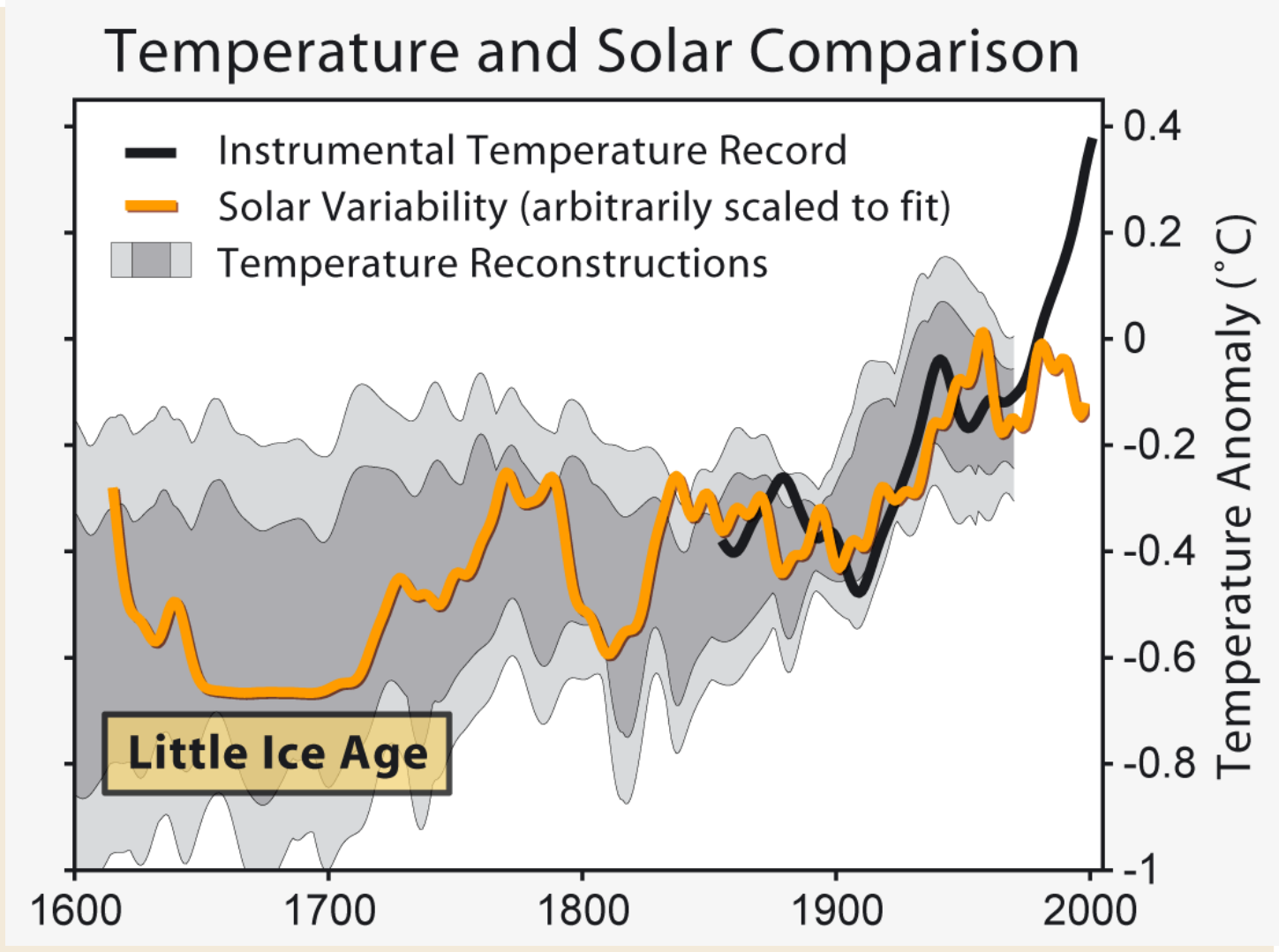


***Source: NASA, USDA***

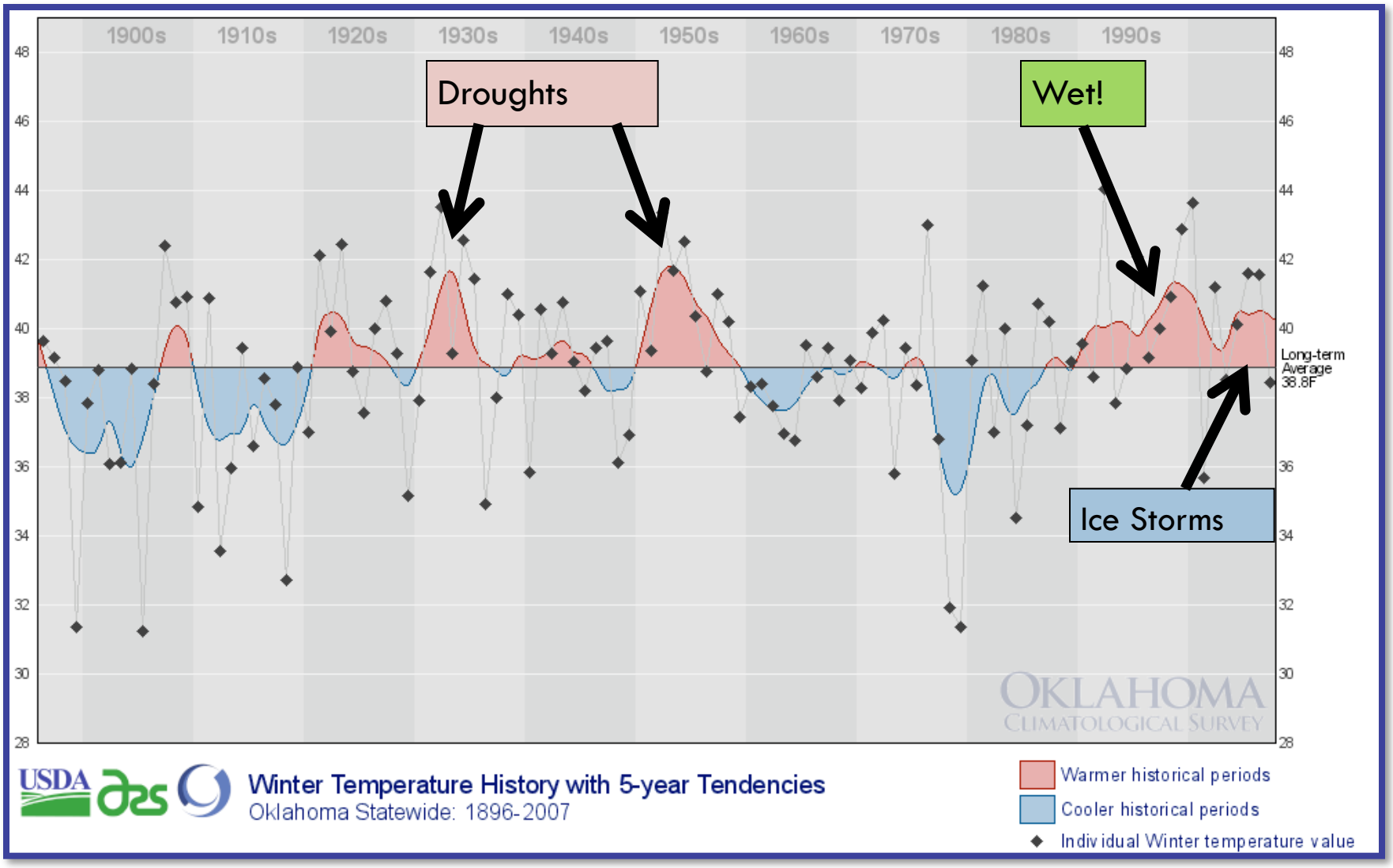
# The recent warming is unusual…



# …and solar variability cannot explain it



# Oklahoma's Winters Have Warmed

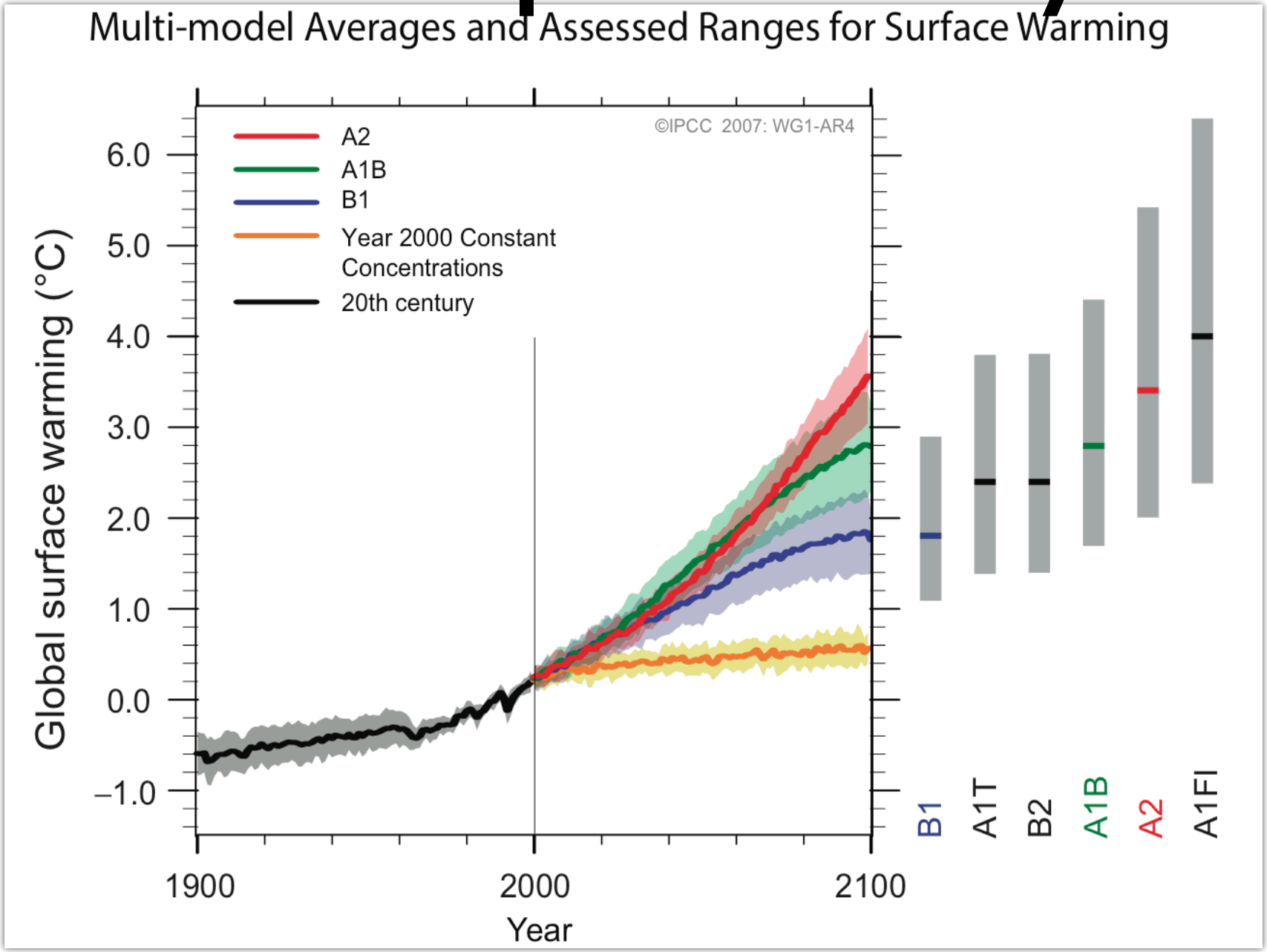


# CLIMATE CHANGE PROJECTIONS

# International Panel on Climate Change

- IPCC Findings from 2007 Assessment:
  - Higher confidence now exists in projected patterns of warming than exists for other elements such as rainfall
  - Hot extremes and heat waves will increase
  - Heavy precipitation event frequency will continue to increase
  - Snow cover and sea ice continues to shrink
  - Sea levels will rise, but uncertain as to how much and timing
  - Storm tracks are projected to move poleward
  - Increasing acidification of the ocean
  - Further 21$^{st}$ century emissions will contribute to warming & sea level rise for more than a millennium

# Societal response is key



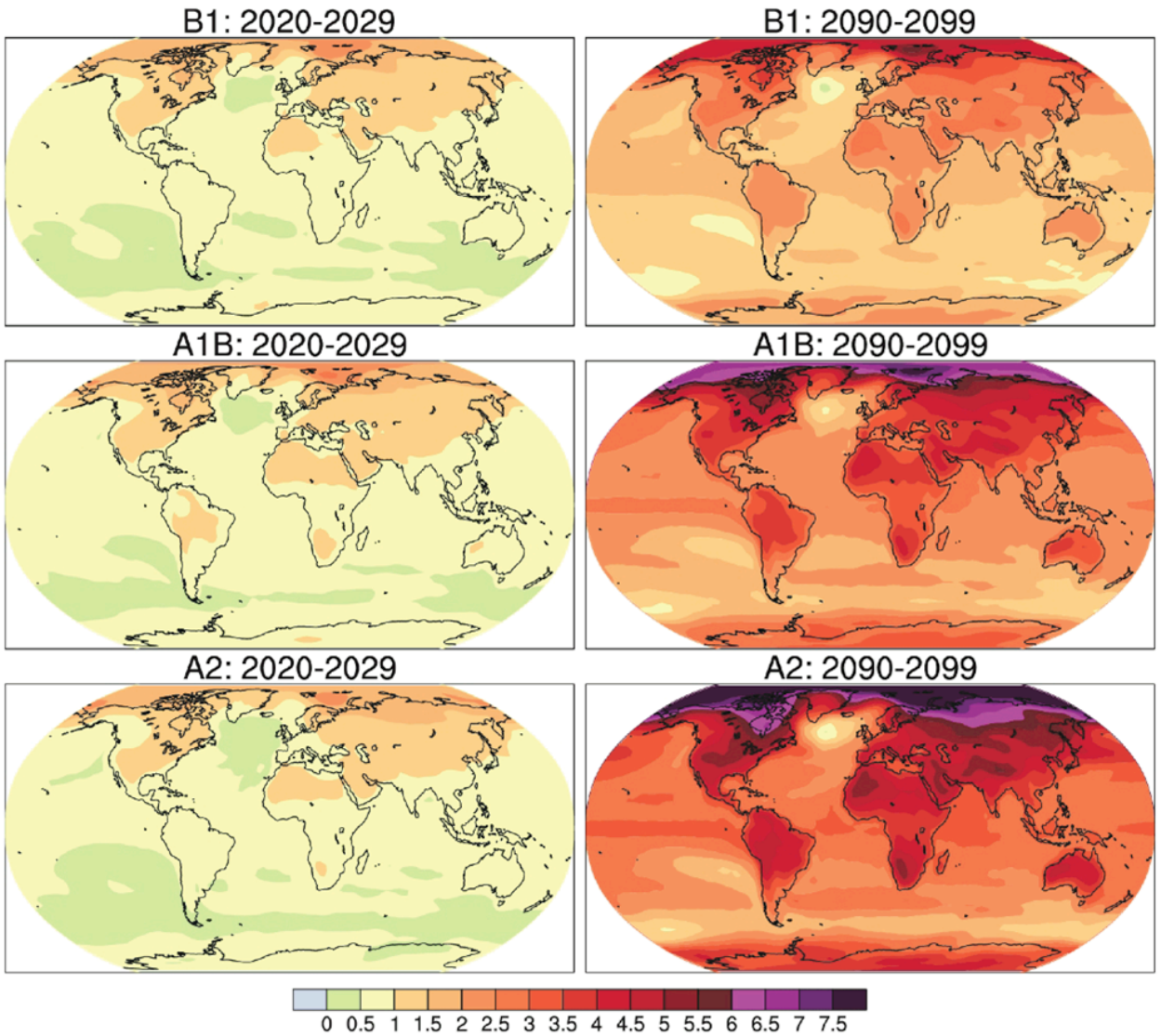
# Temperature Projections: A Range of Possibilities

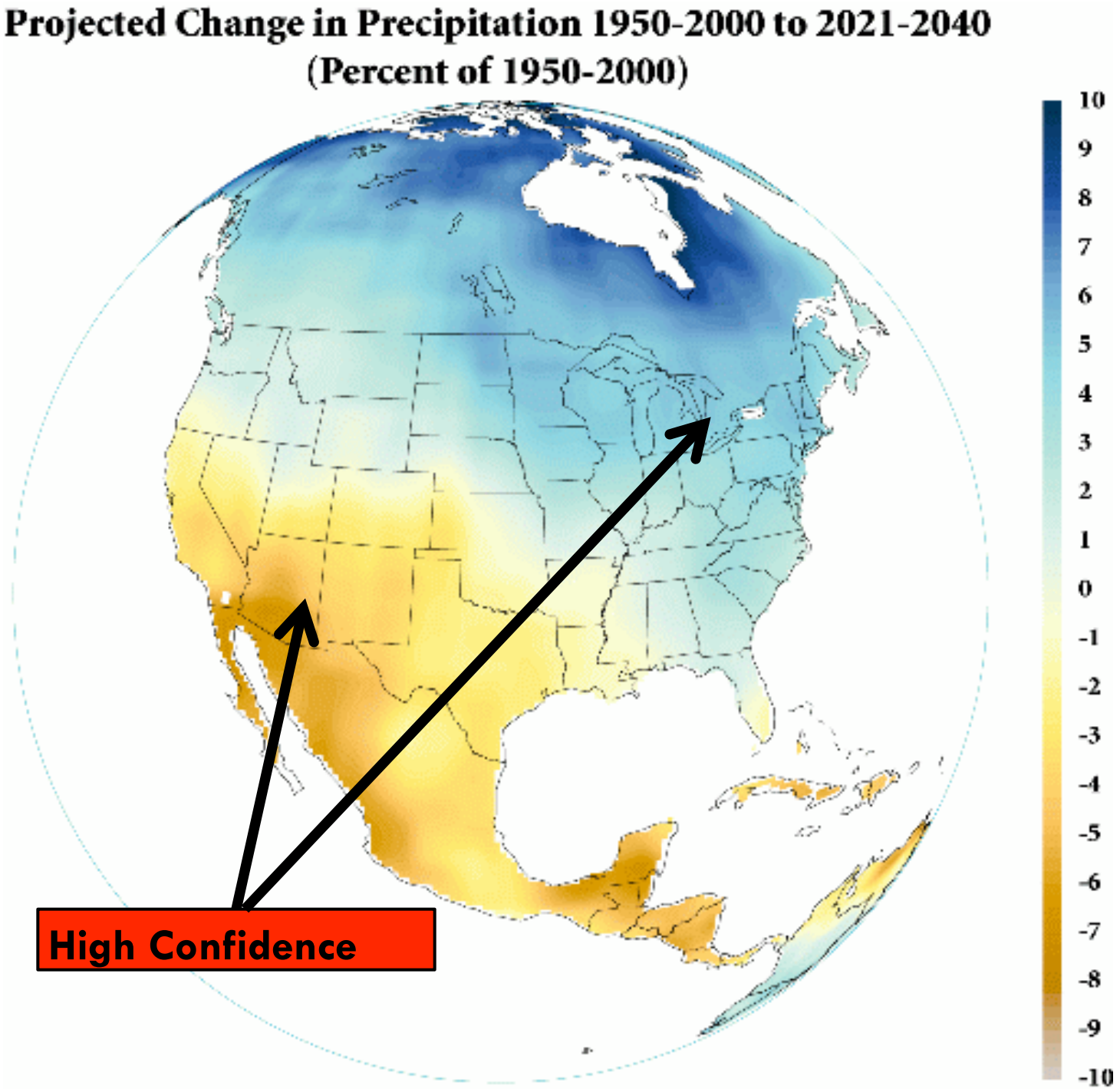
**Societal Response**

**Green Response**

**Middle Road**

**Maximum Growth**






Annual U.S. precip will increase in the northeast and decrease in the southwest

# Oklahoma Projections

- Temperature (Middle Road scenarios)
  - Warming of 2-4°F in annual average temperature by the 2020s
  - Warming of 4-7°F in annual average temperature by the 2090s
  - Summer becomes longer and spring weather arrives earlier
  - Winters warm – longer frost-free periods and a longer growing season
  - Earlier maturation of winter wheat and orchard crops leave them more vulnerable to late freeze events
- Precipitation
  - Rain-free periods will increase, but individual rainfall events will be more intense
  - Increased year-round evaporation from the ground and transpiration from green vegetation
  - Drought frequency and severity increases
  - The risk of wildfires increases, especially during summer

# Oklahoma's Water Future

- Fewer (but more intense) precipitation events:
  - More runoff, more flooding
  - More pollution from runoff
  - Increased erosion
  - Crop damage
- Increased temperatures will increase evaporation
  - Will dry out more severely between precipitation events
- Possibly less water available, even if yearly totals increase

# Winners and Losers

**"There will be winners and losers from the impacts of climate change, even within a single region, but globally the losses are expected to far outweigh the benefits." – from the National Academies' report "Understanding and Responding to Climate Change".**