Oklahoma's climate, droughts, and projected future climate

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For Water Management, Ecological Flows, and Climate Variability Tribal Class

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Shawnee, Oklahoma

USGS
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Oklahoma's climate

Fire, flood, ice, and wind

USGS, Deseret News, Associated Press, News9.com, and NOAA images

General climate features

- Climate describes long-term weather patterns and characteristics over 30 years or longer that are typical of a region (weather consists of short-term observations).
- Oklahoma, located in the southern Great Plains, has a temperate continental climate ranging from humid subtropical in the southeast to semi-arid in the High Plains.

- Warm, humid air moving north from the Gulf of Mexico has a strong influence over the climate, particularly the southern and eastern parts of the state, which receive the most precipitation.
- Clashes of cooler, dryer air from the north and west with warmer, humid air from the south and east cause severe storms in the spring and fall.

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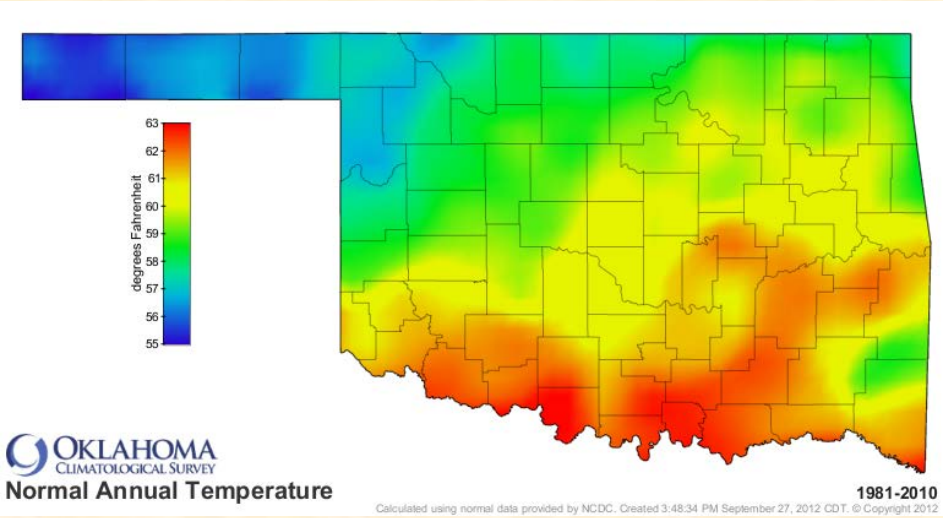
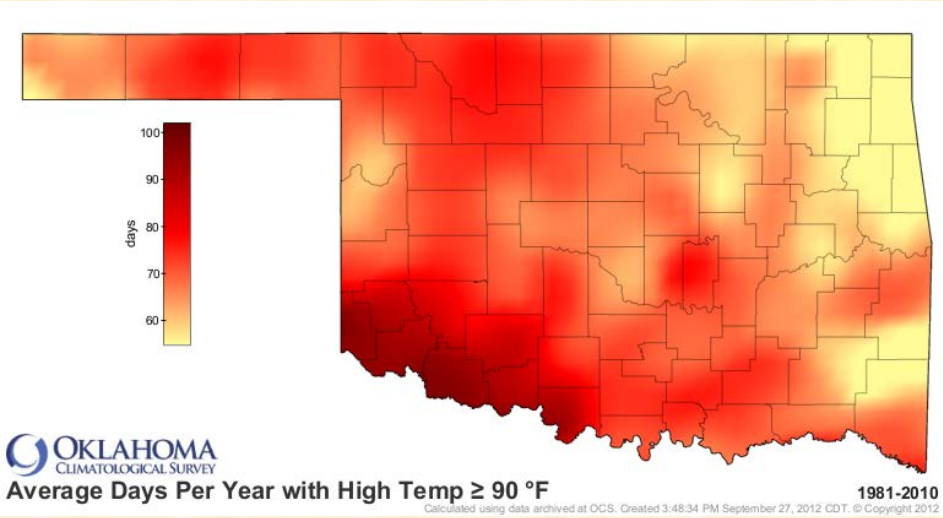
Air temperatures

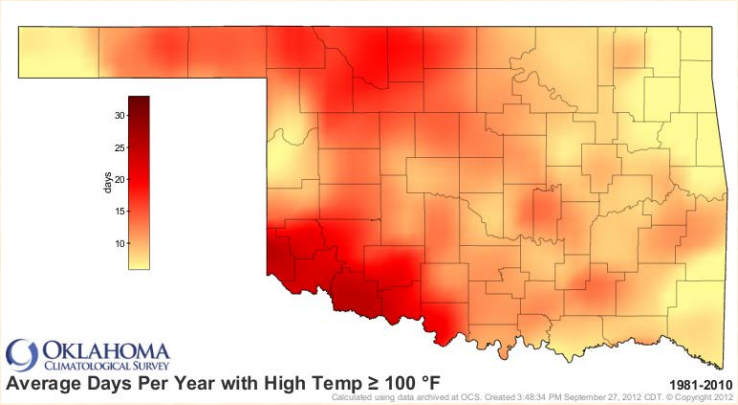
- Summers are long and very hot. Winters are shorter, with moderate amounts of snow and ice. *Have you seen changes in these patterns in the past two decades?*
- The mean annual air temperature ranges from 62° F near the Red River in the south to about 58°F along the northern border.
- Temperatures of 90° F or more occur 60-65 days per year in the north, 115 days in the southwest, and 85 days in the southeast.

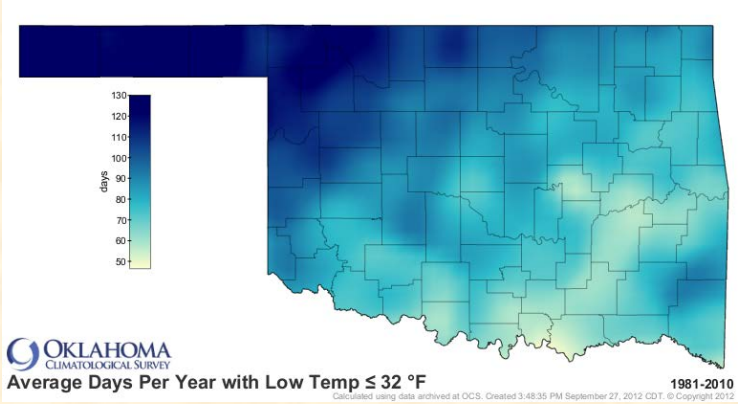


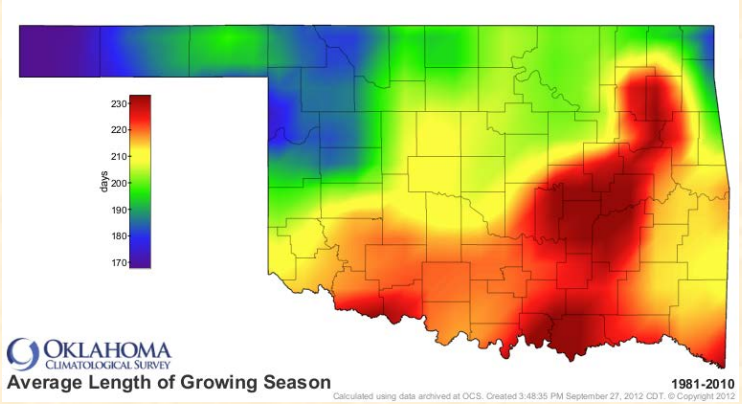


Air temperatures, continued

- Temperatures of 100° F or more occur up to 35 days per year in the southwest and 25 days in the northwest. The eastern half of the state and the panhandle tend to have less than 15 days of such high temperatures.
- Temperatures of 32° F or less occur from 60 days per year in the southeast to 140 days per year in the western panhandle.
- The frost-free growing season ranges from about 225 days in the southern and southeastern counties to 175 days in the western panhandle.

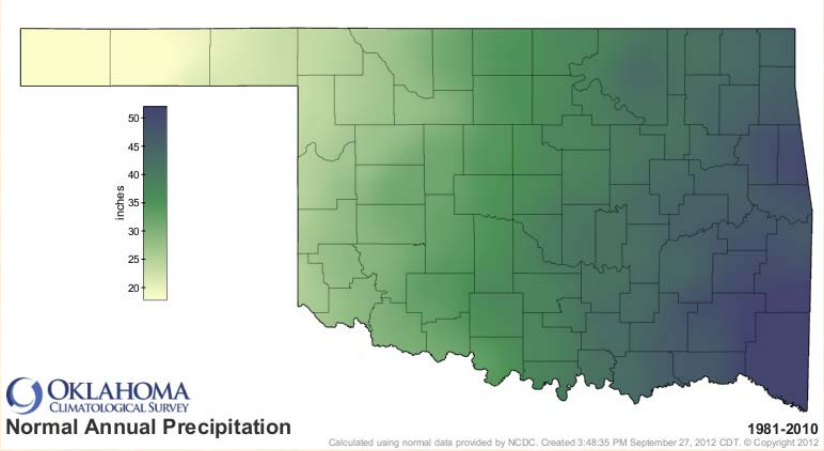


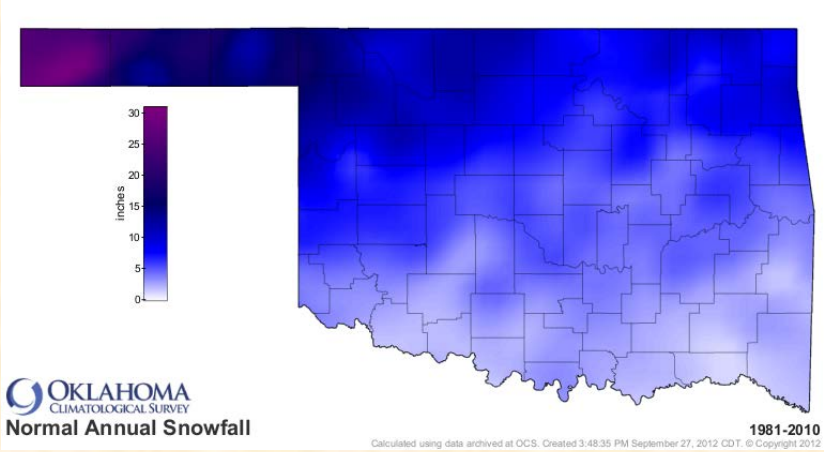




Precipitation

- Precipitation amounts range from about 56 inches per year in the far southeast (similar to Florida!) to about 17 inches per year in the western panhandle.
- Precipitation peaks in May for the body of the state, with a secondary maximum in September. In the western panhandle July is the wettest month (similar to Arizona!). Precipitation tends to be widespread in the winter and locally intense in the spring from convective storms.
- Snowfall ranges from less than 2 inches per year in the far southeast to nearly 30 inches in the western panhandle. Snow and ice typically melt within a few days of falling.





Precipitation, continued

- Floods typically occur during the precipitation maximums in spring and fall, with reservoirs and other flood-control measures having attenuated flood peaks on many major rivers.
- Droughts recur in long-term cycles, with western Oklahoma being most affected due to lower and more variable precipitation (*more on droughts later*).
- Average relatively humidity ranges from 60 percent in the panhandle to more than 70 percent in the east and southeast.
- Average annual lake evaporation ranges from 48 inches in the east to 65 inches in the southwest.

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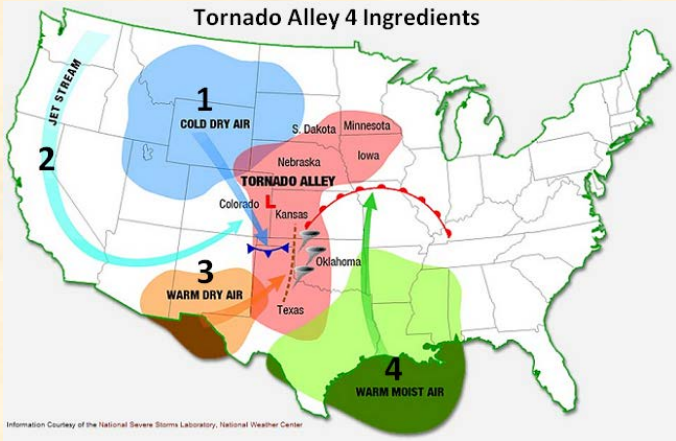
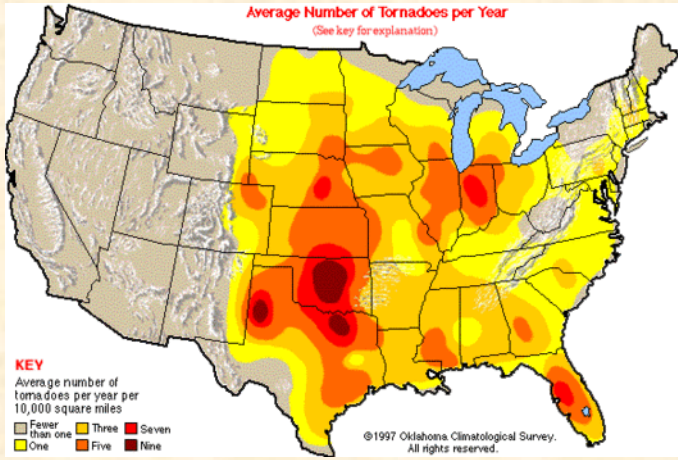
Severe weather

- Thunderstorms occur about 55 days per year, with an average of eight thunderstorms per month at any given location in the spring.
- Severe storms (wind, hail, tornadoes) typically occur from clashes of warm, humid Gulf air and cooler, drier continental air, with the primary storm season from May to July and the primary times of day being late afternoon to early evening.
- Tornado occurrence is among the highest in the world, with 54 tornadoes being recorded annually, and an average of 20 tornadoes occurring in May.
- In May 1999, an outbreak of 75 tornadoes caused 40 deaths and 700 injuries, destroying about 1,000 homes and causing more than $1 billion in damages.
- In May 2013, an outbreak of 4 large tornadoes in 2 days killed 26 people, injured hundreds, destroyed 1,300 homes, damaged about 12,000 homes, and caused about $2 billion in damages.





NWS photo by Mike Branick

Climate effects--ecosystems

Measuring streamflow with acoustic doppler profiler, April 2011

Climate affects ecosystems, the economy, and human culture.

<u>Ecosystem effects—</u>

A) <u>Floods</u> can:

i. Scour or fill aquatic habitats with debris
ii. Strand aquatic biota on floodplains
iii. Disrupt reproductive cycles of aquatic biota
iv. Cause direct mortality of aquatic biota
v. Increase water turbidity, causing problems with respiration and obtaining food
vi. Disrupt terrestrial riparian habitats
vii. Cause germination of plants in floodplain seedbanks
viii. Erode streambanks
ix. Transport nutrients to downstream lakes
x. Scour, redeposit, and improve floodplain soils
xi. Other effects?

Are the above effects entirely negative?

Climate effects on ecosystems

North Canadian or Beaver River near Fort Supply, Okla.

Ecosystem effects—

B) Droughts can:

i. Deteriorate or eliminate aquatic and terrestrial habitats, causing mortality and disrupting food availability and reproductive cycles of plants and animals

ii. Change soil structure and lead to windblown erosion of top soils

iii. Diminish photosynthesis and respiratory ability and other measures of health and productivity

iv. Cause migration of aquatic and terrestrial species

v. Diminish ecosystem richness and diversity, affecting ecosystem structure and function

vi. Increase wildfire extents

vii. Make room for colonization by invasive plants and animals

viii. Recovering from these effects may take years or decades.

ix. Other effects?

Are the above effects entirely negative?

Climate effects on ecosystems

<u>Ecosystem effects—</u>

C) <u>Temperature variability</u> can:

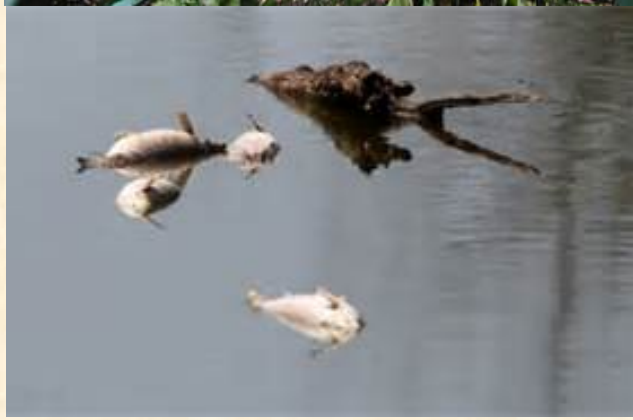
i. Increase mortality and interfere with reproduction of animals from the effects of hyperthermia or hypothermia

ii. Cause heat stress or freeze damage in plants

iii. Disrupt food chains

iv. Reduce ecosystem richness, diversity, function, and productivity

v. Create openings for colonization by invasive plant and animal species



Iowa state Extension, Mountain Empire Community College, and the gazette.com images

Climate effects on ecosystems

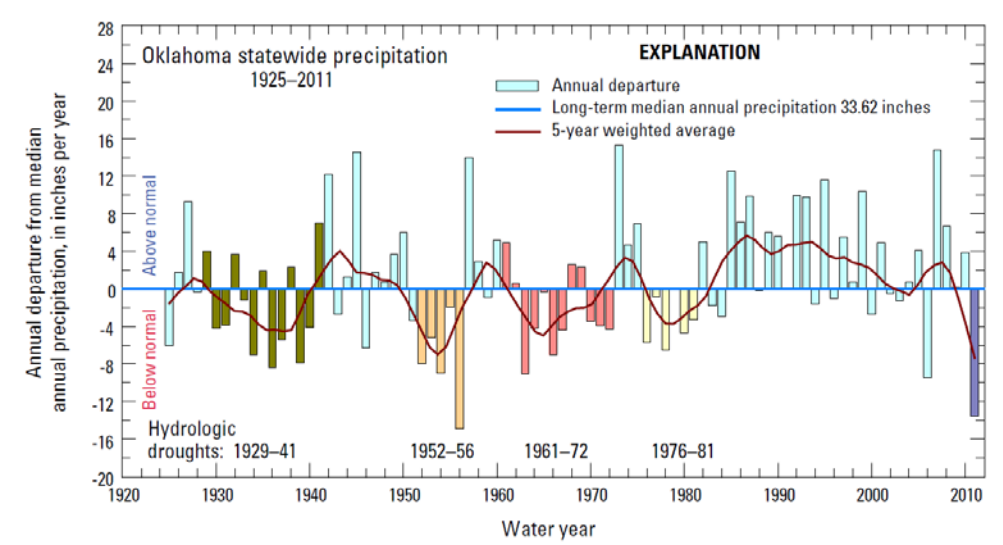
<u>Ecosystem synopsis</u>

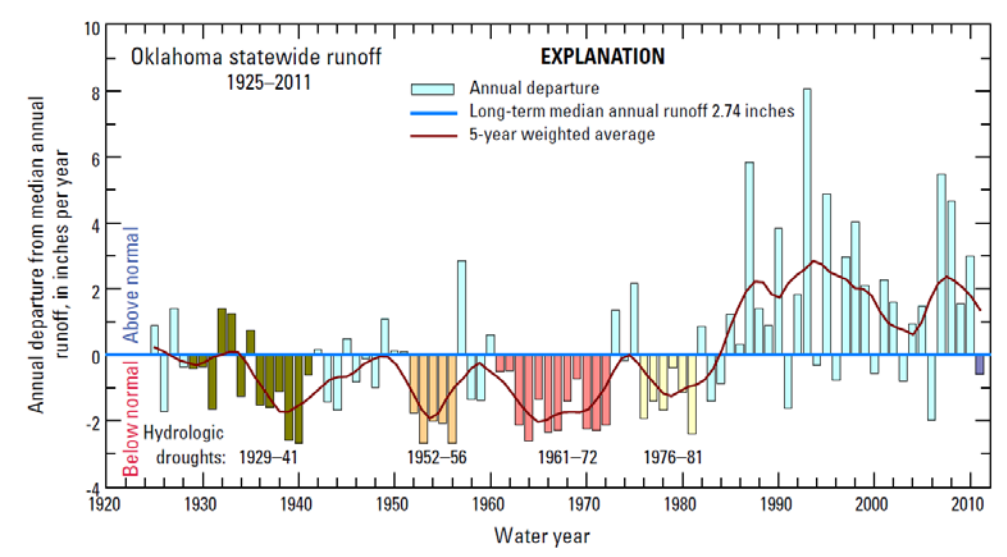
- In the early 20th century and before, the climate of Oklahoma produced short-grass prairies, mixed-grass prairies, scrubby oak cross-timbers, and tall-grass prairies (from west to east).
- Our extreme climate, including floods, drought, fire, ice, and winds was the primary influence forming those ecosystems.
- Through irrigation, fire suppression, large-scale planting, and application of pesticides and fertilizers, we've increased ecosystem productivity, but decreased ecosystem diversity and resilience to this highly variable climate. Traditional knowledge has led to use of fire to manage prairies and pastures.
- <u>Question:</u> *Are the landscape changes that have happened since the early 1900s sustainable for the long term?*

University of Oklahoma Campus ca. 1897 and 2010

Climate effects on hydrology

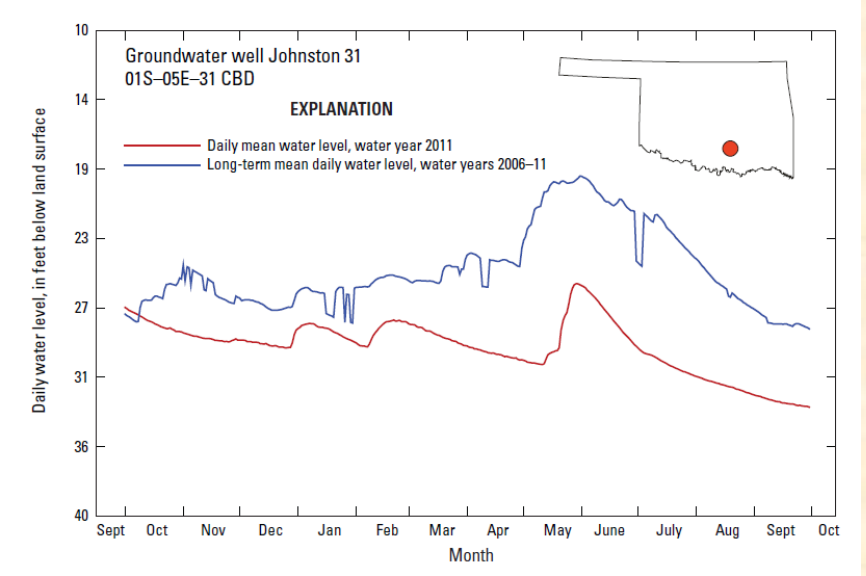
- Climate can have variable effects on streamflow, springflows and groundwater levels.
- All of the above parameters generally are greater during wet periods and less during dry periods.
- However, there are not always direct relations between precipitation and other hydrologic measures.
- For instance, 2011 had the 2nd smallest amount of precipitation, but the 16th smallest average annual streamflow and the 42nd smallest statewide runoff from 1925-2011.

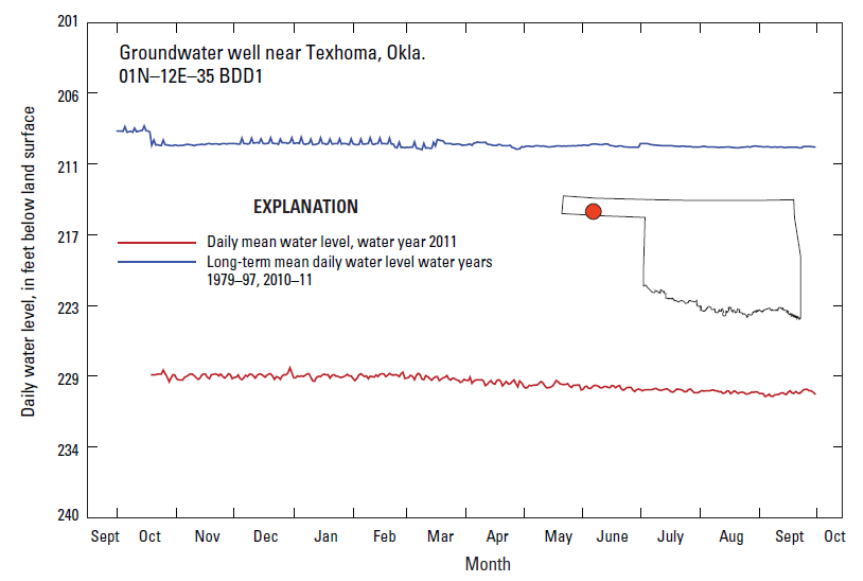




Climate effects on hydrology

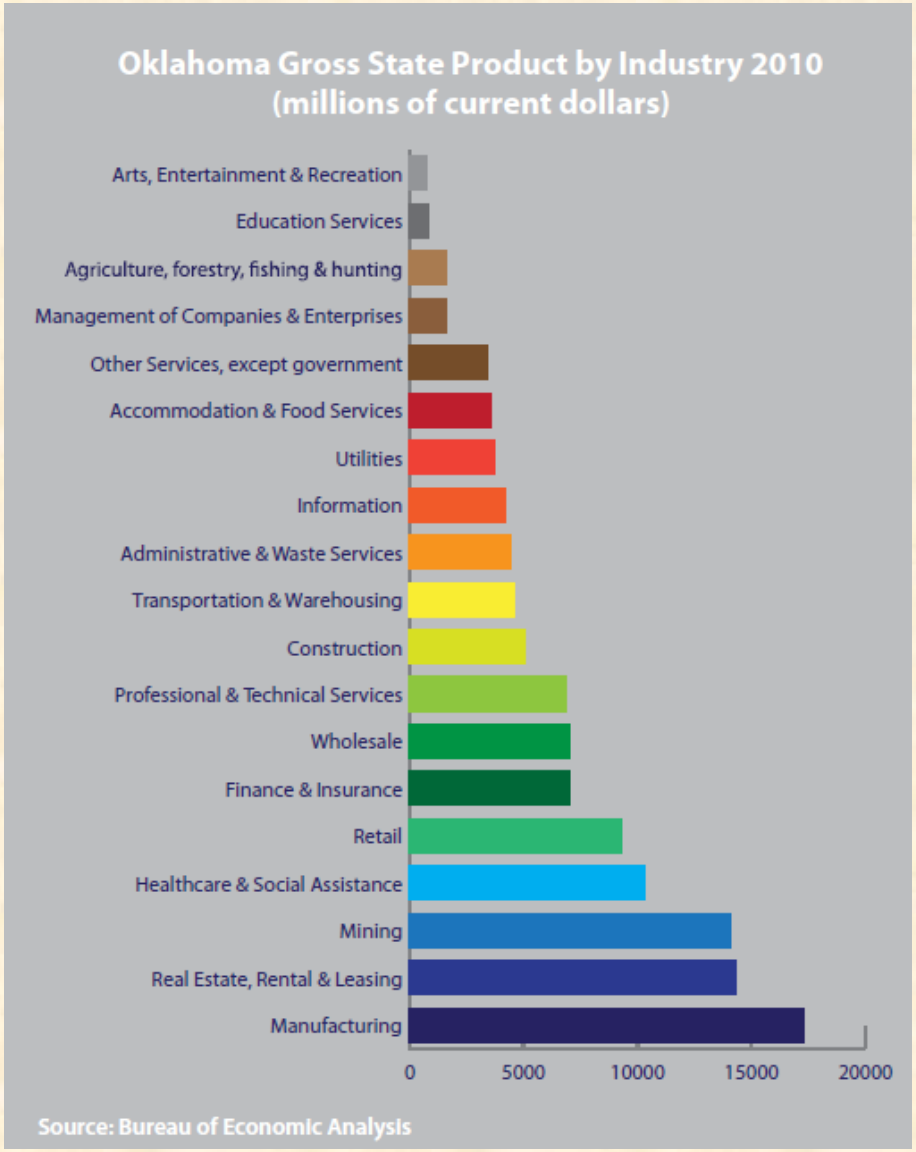
- In 2011 groundwater levels decreased by 6 or more feet in south-central Oklahoma, while only decreasing by about a foot in the panhandle.
- Part of these variations have to do with patterns of precipitation. The northeast, which has relatively large streamflows, was relatively wet. Rain falling mostly through convective thunderstorms is more likely to runoff than gentler rain of widespread stratiform fronts.





Climate effects on the economy

- The economy of Oklahoma is based on manufacturing, services, mining, utilities, and agriculture.
- Many categories on the graph to the right are concentrated in cities and may not be strongly affected by climate (except for severe storms and ice).
- In rural Oklahoma, agriculture is a large part of the economy. ODAFF estimated $5.6 billion of agricultural production in the state in 2010.
- Agriculture is most likely to be affected by climate of any of these economic sectors.



Climate effects on the economy

- Several hundred million to several billion dollars are spent every year in Oklahoma to clean up and repair damage from storms. Insurance availability and rates increase in areas with large and/or repeated disaster claims.
- Several hundred homes and several hundred thousand acres are burnt in wildfires during dry seasons, costing tens of millions of dollars per year.
- Floods or drought can cause millions to more than 1 billion dollars of losses per year in the agricultural sector. The 2011 drought caused crop and livestock losses greater than $1.6 billion. State cattle counts are the smallest that they've been since the 1960s.
- Agricultural losses from floods, droughts, and freezes in rural areas can cost city dwellers millions to billions of dollars per year through increased costs of food, clothing, and fuel.

Associated Press images

Climate effects on the economy

- Municipal water shortages and watering bans can reduce water-utility cashflows and hydroelectric-power generation, leading to higher taxes and more carbon emissions.
- Floods and drought affect aquatic and terrestrial wildlife, decreasing economic activity from hunting and fishing, costing at least tens of millions of dollars per year.
- Dry hot weather can degrade visible water quality from blue-green algae growth and other problems, decreasing recreational water activities, and costing tens of millions of dollars per year in tourism and related sectors.

Grand River Dam Authority, okiefish.com, and newson6.com images

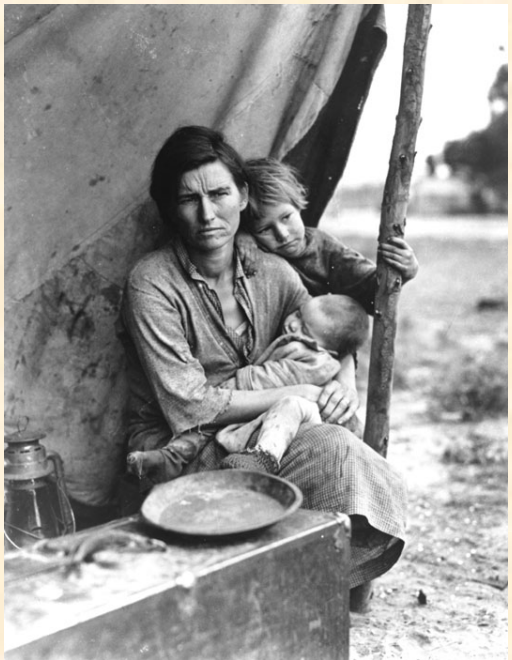
Climate effects on the economy

- Long-term droughts and groundwater mining can dry up private wells or shallow municipal wells, costing rural homeowners, irrigators, and cities thousands to hundreds of thousands of dollars to drill each new well.
- Alternation between wet and dry periods can cause structural damage to buildings in clay-soil areas, costing several thousand dollars or more per structure.

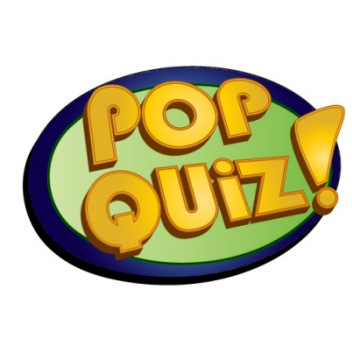
Oklahomahistory.net and foundationrepairoklahoma.com images

Climate effects on human culture

- Repeated floods or long-term droughts can cause people to leave the affected area, disrupting family and community bonds.
- Climate affects sense of economic well-being, causing increased or decreased spending.
- Economic and other effects of weather can improve or worsen moods, affecting rates of depression and suicide.
- Medical problems, such as respiratory illnesses, coronary stress, blood pressure, and heat stroke are affected by weather.



Class Exercise



Wordpress.rowan.edu image

- Let's divide into groups according to Geography: NE Oklahoma, S Oklahoma, W Oklahoma, and New Mexico.

Please develop answers for the following questions for the next 15 minutes:

1) *How has climate affected you personally in the past 10 years?*
2) *Can you estimate financial and other losses incurred by you during that period?*
3) *Has climate affected your Tribe as a group, in addition to the personal effects that you've experienced?*

- Please designate a spokesperson to summarize your group's thoughts for the class.
- Did groups from different areas mention different climate effects?

Let’s take a break!

Drought in Oklahoma

Koco.com image

- Before the early 1900s, most of Oklahoma was covered with short- or mixed-grass prairies, the only vegetation that could grow with low and variable precipitation, high evaporation, and a regular natural fire cycle.
- Given the importance of drought in Oklahoma's climate, let's talk more about drought.

Drought categories

Drought is caused by a long-term deficiency in precipitation.

There are four drought categories--

- Meteorologic—a deficit of precipitation from normal for a given time period (daily, weekly, monthly, seasonal, annual).
- Agricultural—the effects of drought on agriculture based on precipitation deficit, evapotranspiration, and soil-water deficits.
- Hydrologic—the effects of precipitation shortfalls on surface or groundwater, specified as departure from normal streamflow, reservoir levels, and groundwater levels, expressed on a watershed or aquifer scale. Typically a hydrologic drought takes longer to develop than the other types of drought.
- Socioeconomic—when demand for a good exceeds supply due to shortages of water. The most common sign is rising food or fiber prices.

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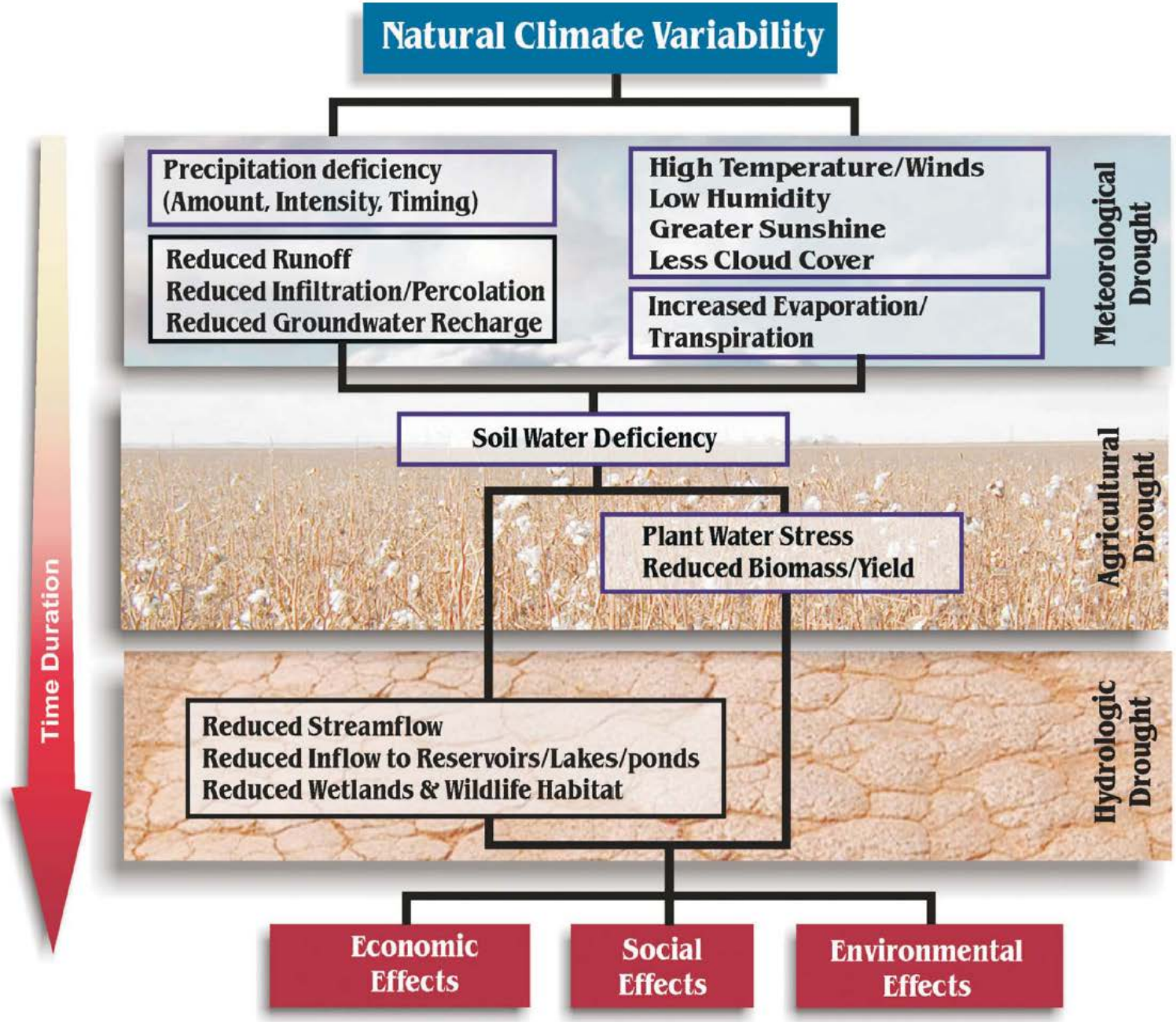
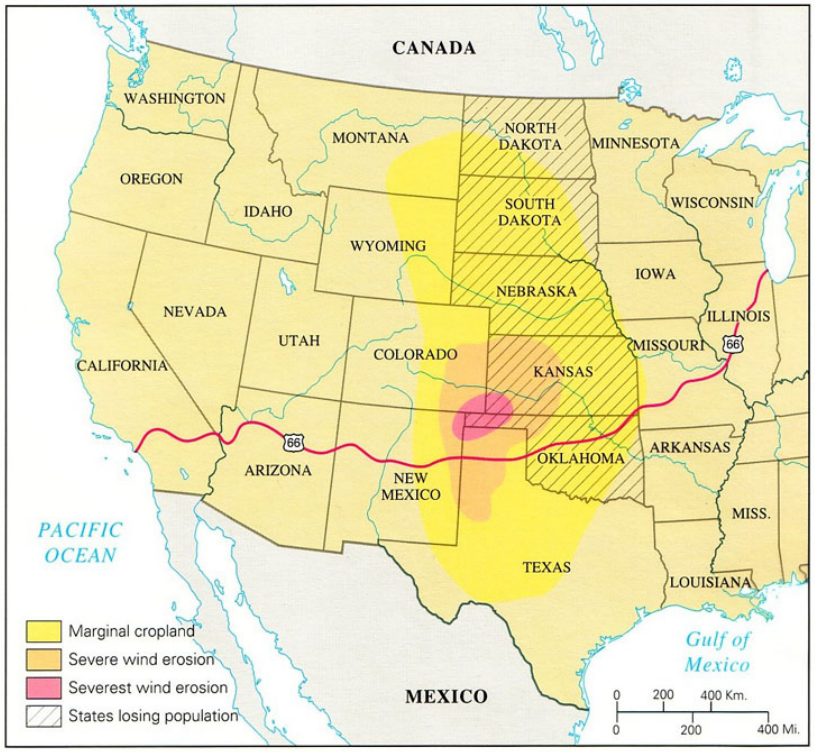


(Oklahoma Water Resources Board, 2007a)

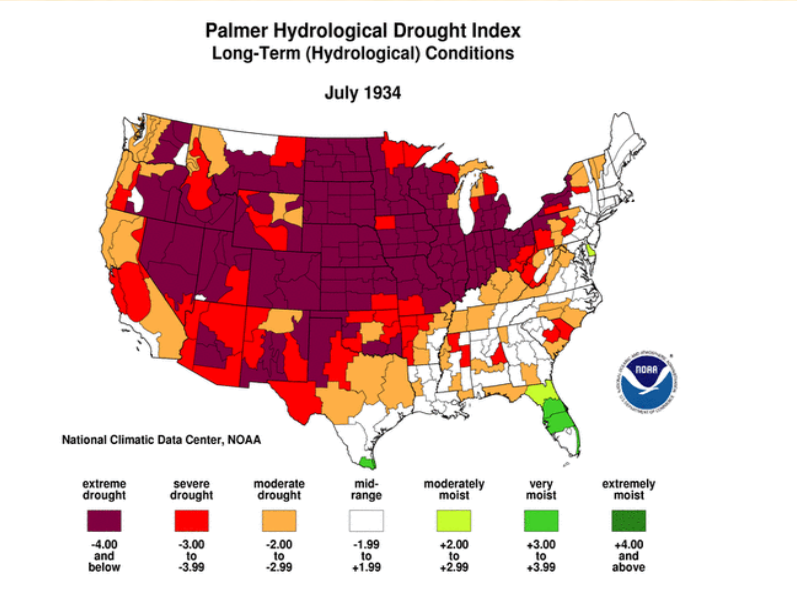
The Dust Bowl in Oklahoma

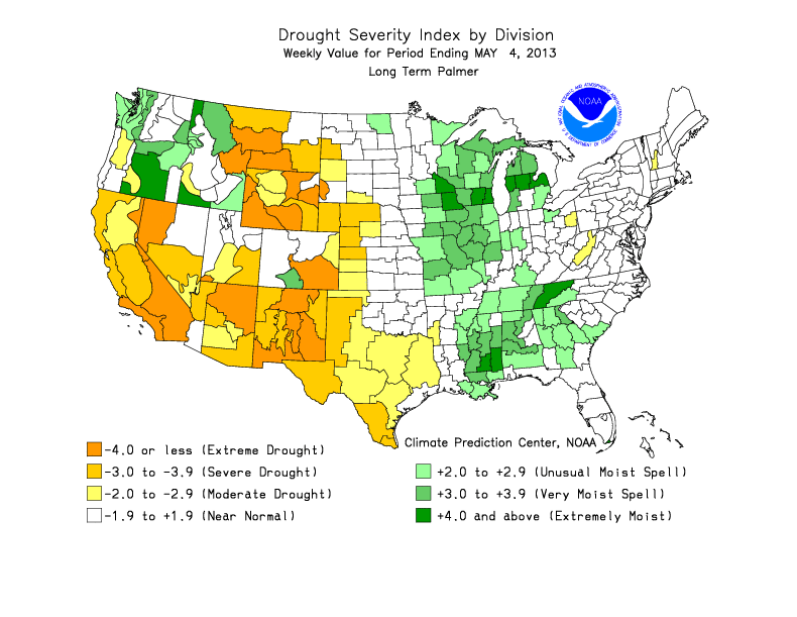
- Any discussion of drought in Oklahoma has to begin with the Dust Bowl and lessons learned from the “dirty thirties”.
- The greatest natural disaster in U.S. history, the dust bowl was a consequence of climate variability and unwise farming practices that disrupted millions of lives and exacerbated the effects and extended the length of the Great Depression.
- Climate—Cooler-than-normal Pacific Ocean temperatures and warmer-than normal tropical Atlantic Ocean temperatures caused dry air and high temperatures to persist in the Central Great Plains from 1931-39.



Dust Bowl causes and effects

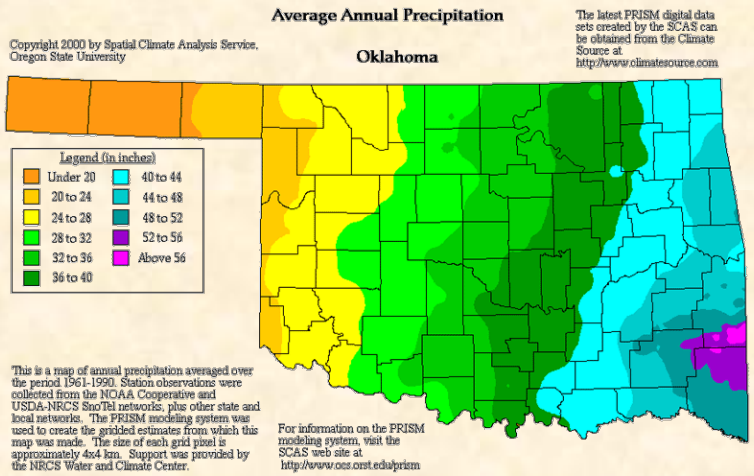
- In the 1930s, the jet stream was weakened and low-level winds reduced northward movement of moist air from the Gulf of Mexico.
- Bumper wheat crops of 1930-31 led to extensive plowing and planting which removed native grasses on millions of acres.
- In March 1932, there were 22 days of dust storms. In 1933 there were 139 days of dust storms that destroyed the wheat crop. In May 1934, notable quantities of dust were blown to the east coast.
- Heat waves lasting for months with temperatures up to 120 degrees killed hundreds of people. Thousands more died of respiratory illnesses.
- 100 million acres were turned into a wasteland and more than 2.5 million people were bankrupted and displaced.





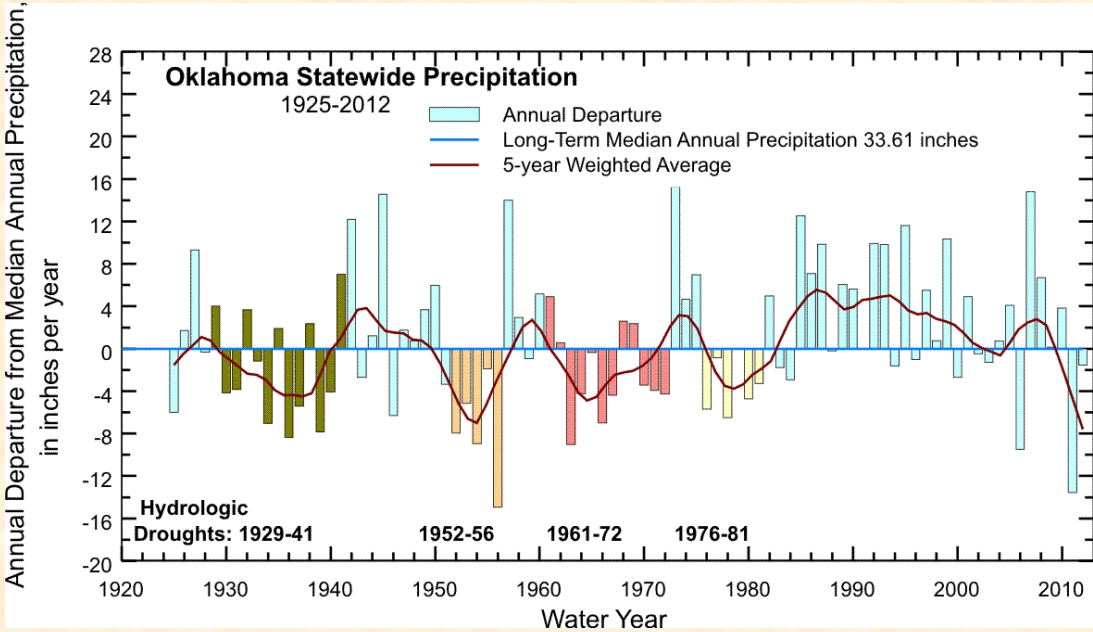
Preventing another dust bowl

- 140 million acres of the High Plains was purchased by the government and replanted as grasslands, now leased for grazing.
- The Soil Conservation Service (now NRCS) was formed and soil conservation practices, including windbreaks, contour plowing, terracing, and rotation to fallow land were subsidized. Such measures reduced the dust by 65 percent by 1938.
- Government subsidies reduced the amount of cultivated private land.
- Thousands of small reservoirs were constructed.
- Center-pivot irrigation greatly increased irrigated acreages starting in the 1940s, but in some parts of the High Plains water table elevations have declined by >100 ft.



Moving right along…

- Though not as long-lasting, the drought of the mid-1950s was the most severe recorded since the dustbowl.
- The drought of the 1960s was nearly as long and severe as that of the 1930s.
- Another shorter and less severe drought followed in the late 1970s.
- The 20 year period from 1980 to the early 2000s was anomalously wet.
- Are we headed into another severe drought period? 2006 and 2011 had severe droughts, but 2007 was one of the wettest years on record. 2013 has been wetter than normal.
- *Did we have Dust-Bowl-style droughts in the 50s, 60s, and late 70s?*



Recent droughts--2006

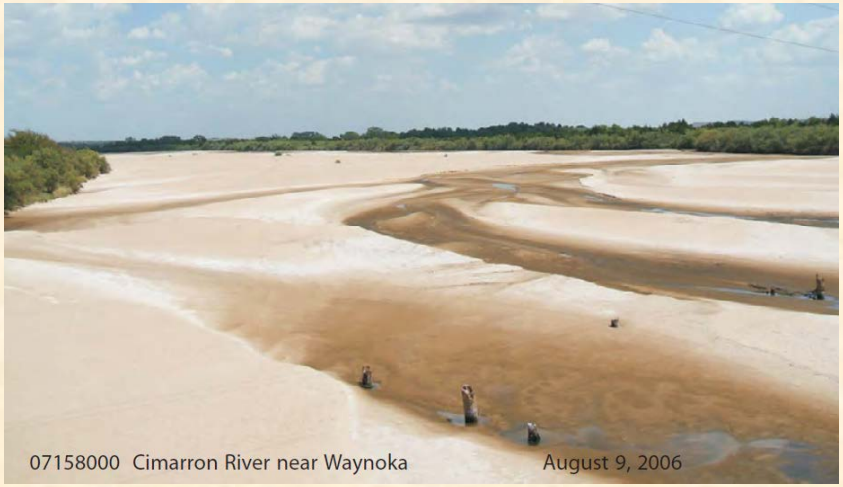
- Statewide annual precipitation in Water Year 2006 was the 3rd driest since 1925, at 72 % of normal.
- Statewide annual runoff (related to storm flows) was the 6th smallest since 1930.
- 80-85 percent of long-term stream gages in Oklahoma measured below-normal streamflow in August and November.
- Groundwater levels in the Arbuckle-Simpson aquifer near Ada ranged from near normal to 17 ft below normal.

Canadian River downstream from State Highway 99 near Ada August 16, 2006

Canadian River near Thomas August 11, 2006

Additional effects of the 2006 drought

- Hundreds of homes were destroyed and 600,000 acres were burned by wildfires in January and outdoor burning bans continued through most of the year.
- Hundreds of farm ponds had dried up by mid-January.
- Hydroelectric power generation ranged from 7-47% of normal.
- 86.3% of conservation storage was available at the end of the year.
- Similar or worse drought conditions extended southwest of Oklahoma.



Recent droughts--2011

- Statewide annual precipitation in Water Year 2006 was the 2nd driest since 1925, at 60 % of normal.
- Statewide annual streamflow was the 16th lowest and statewide annual runoff (related to storm flows) was the 42nd smallest since 1930, due in part to wetter conditions in the northeast part of the state.
- The all-time monthly temperature record for all states (89.1 deg F) was broken in Oklahoma in July 2011.
- Groundwater levels in the Arbuckle-Simpson aquifer were several feet below normal and continued a long-term decline in the High Plains aquifer near Texhoma.

High and dry sailboats at Lake Hefner and the North Canadian River near Calumet, OK, Sept. 2011.

Additional effects of the 2011 drought

- Hundreds of homes were destroyed and 300,000 acres were burned by wildfires in January and outdoor watering and burning bans continued through most of the year.
- Hundreds of farm ponds dried up.
- Agriculture losses were more than $1 billion, with 50% loss of many crops, high hay and feed prices, and sell offs of state cattle herds to 1968 levels.
- Blue-green algae blooms were abundant on major lakes in the summer, with recreational tourism being decreased. Many species of aquatic and terrestrial wildlife had die-offs, lowered reproduction, and poorer condition.
- Hydroelectric power generation ranged from 23-112% of normal.
- 83.3% of conservation storage was available at the end of the year.

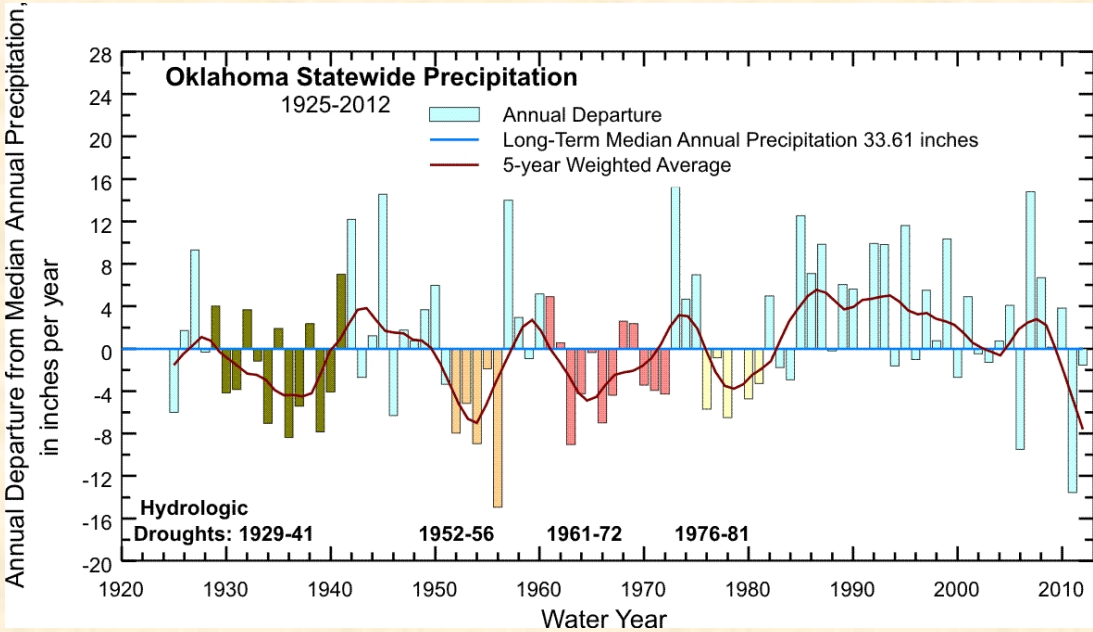
NOAA and Oklahoma Farm Report images

Let’s take a break.

“Enough with the drought already!”

Projected future climate

- As we've discussed, Oklahoma climate is highly variable and is punctuated by severe weather events that can levy great economic and societal costs.
- Projected future climate may be even more variable.



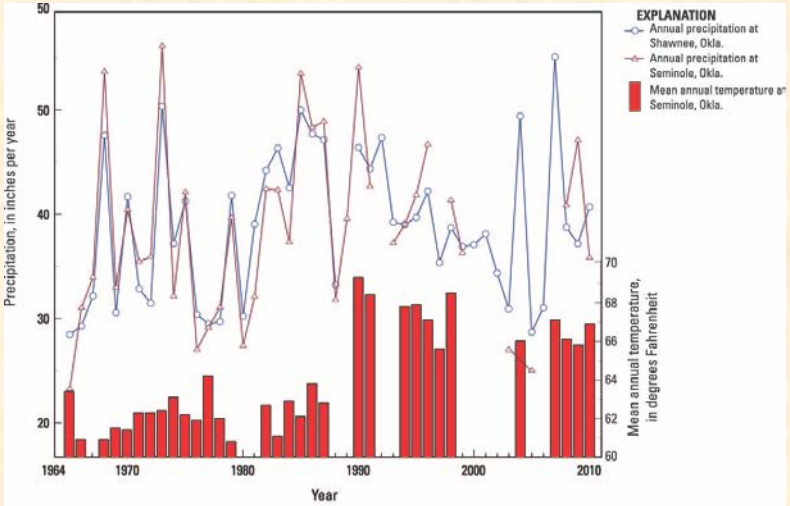


Figure 3. Annual precipitation and mean annual temperature at selected weather stations in or near the Citizen Potawatomi Nation Tribal Jurisdictional Area, Oklahoma, 1965 through 2010.

Climate variability and Tribes

- Native American Tribes are likely to be one of groups most affected by climate variability in North America due to their:

A) Long-standing relationship with the land and environment,

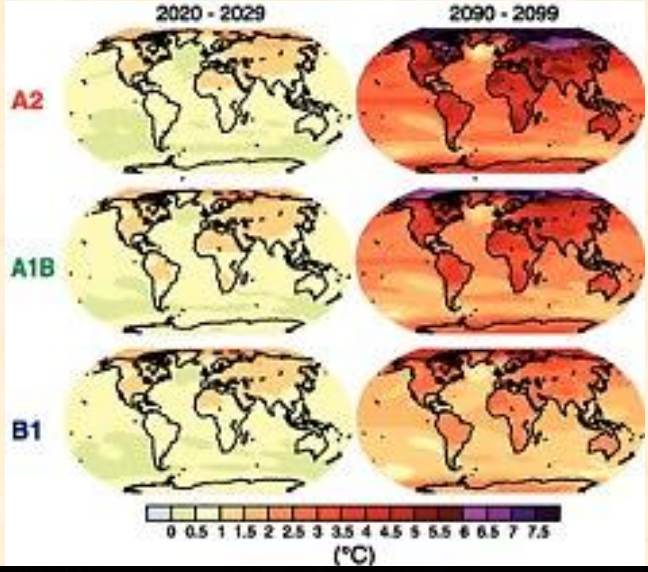
B) Agricultural economic bases, and

C) Practice of subsistence activities by many communities.

- These thoughts came from several documents about Tribal adaptation to climate change.
- *Do you think that these ideas are correct? Are they outdated?*
- *Has your Tribe been in your area long enough to have built up traditional ecological knowledge of your area?*
- *What additional thoughts do you have about the susceptibility of Tribes to climate variability?*

Projected changes in Oklahoma's climate

- For the period 2020-2029, air temperatures may increase from 1 to 1.5 ^{o}C compared to 1980-99.
- For the period 2090-2099, air temperatures may increase from 3.5-4.5 ^{o}C compared to 1980-99.
- Extremely hot weather, heat waves, and heavy precipitation events are likely to become more frequent.
- Hurricanes are likely to become more intense with storm tracks moving north in the northern hemisphere (e.g. Hurricane Sandy).
- Precipitation may decrease in the summer by several percent.



IPPC and Weather Underground images

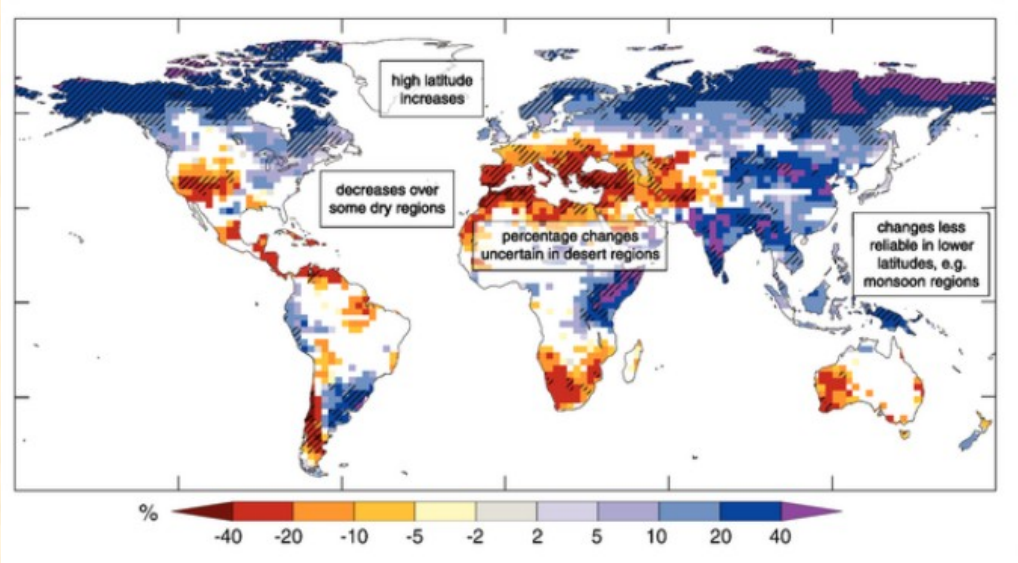
Some projected effects of climate change in the south central U.S.

- Changes in land use and climate are likely to disrupt many ecosystems by 2099.
- 20-30% of plant and animal species face greater risk of extinction.
- Species' geographic ranges are likely to change, decreasing biodiversity and ecosystem goods and services.
- Crop productivity may decrease, increasing food costs and hunger.
- Flooding and drought may increase as precipitation becomes more variable seasonally and with location.

USGS and Oklahoma Farm Report images

Some projected effects of climate change in the south central U.S.

- Deaths, diseases, and injury may increase from extreme weather events, cardio-respiratory disease incidence may increase, and spatial distribution of infectious diseases may change (e.g. West Nile virus).
- Changes in precipitation and temperature will lead to decreases in runoff and water availability.
- Areas in which runoff declines will have a reduction in the value of the services provided by water resources.
- Drought-affected areas will increase in extent as will demand for irrigation water.



Projected changes in annual runoff, in percent, in 2090-99 relative to 1980-1999 (IPCC Fourth Assessment Report)

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Mitigation of and adaptation to climate change

- Global atmospheric composition is changing and climate is becoming more variable, tending towards hotter weather and greater drought frequency.
- If the human population is going to continue to grow and have standards of living close to those to which we've been accustomed, a wide range of mitigation or adaptation measures have been suggested.
- I'll list a few of these measures, but please be thinking about additional measures or strategies to live in a changing climate.

Sustainable living

A few rhetorical questions…

- *Can 7, 10, or 15 billion people live the idealized upper-middle-class American lifestyle without noticeable consequences to the Earth's resources and environment?*
- *Does the earth contain infinite energy, mineral, agricultural, and potable water resources?*
- *Does what we do/how we live affect others far beyond ourselves?*
- *Are the prices of energy, food, clothing, and major purchases likely to decrease?*
- Everyone here knows the answers to these questions, but let's invest a few minutes discussing these general issues and potential solutions to these issues.

People+cars+industry=smog
Does smog only affect people?

Where we live?—give and take session

- ***<u>Distance</u>****-how far do you live from where you work, shop, go to school? Does distance affect your time, finances, family life, and environmental impact (carbon footprint)?*
- *Have you changed your distance, increased or decreased, in the past 5 years? Why did you make that change?*
- *Are Native Americans less likely to "pick up stakes" than other groups? If so, what are the pros and cons of that stability?*
- *Does living in rural areas inherently increase distance, or not?*
- *How can greater distances be managed to be more sustainable?*

Where we live?—give and take

- **<u>Size and *features*</u>**—*Does square footage, or more appropriately cubic footage, of your residence affect your environmental footprint?*
- *How many are familiar with the term "Life cycle assessment"? What does it mean?*
- *Do the materials with which your house is made affect your environmental footprint?*
- *Does the age of your residence affect your energy and materials usage?*
- *Is building a new house better for the environment?*
- *What things can you do to minimize the effects of your residence on the environment?*

How we get there?—give and take

- *Do we need 3 tons of metal, glass, plastic, and rubber to get to the grocery store?*
- *Is the internal-combustion engine efficient? Are the alternatives affordable and useful?*
- *What are the benefits and drawbacks of alternative fuels?*
- *Are the benefits of world travel outweighed by the environmental costs?*
- *Do we need a major cultural change to maximize public transportation for the trips that we need to make?*

How many of us?—give and take

- *Does the size of our families affect our distance, housing, and transportation decisions?*
- *Do larger families have greater environmental impacts?*
- *What are the cultural, historical, and economic reasons for having larger or smaller families?*
- *What are the pros and cons of larger or smaller families?*
- *Should everyone make their own choices about family size, or should family groups or governments pressure/prescribe limits?*

Sustainable choices

- Sustainable—a system that maintains itself by using techniques that allow for minimal resource use and reuse of resources.
- Clearly, we are faced with a large number of choices in how we live.
- Many of those choices are informed by our culture and beliefs (religious, ethical, etc.).
- Economic limits also affect our choices, e.g. if our family income is $50,000, can we spend $100,000 per year on a long-term basis?
- Let's discuss some of our lifestyle options in a bit more detail in the following few slides.

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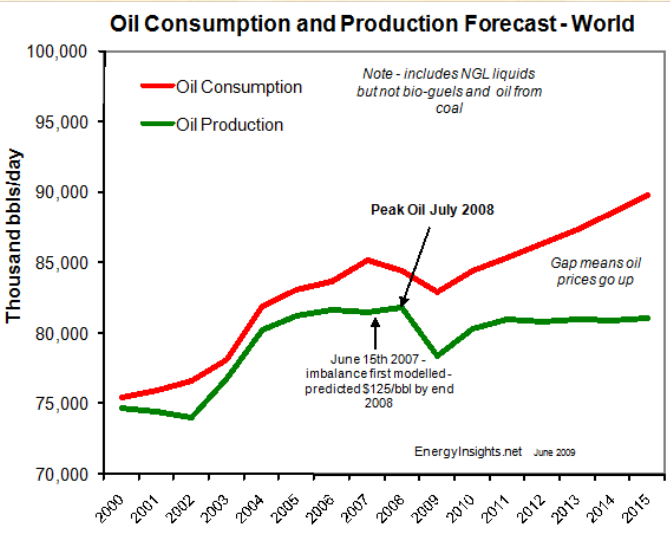
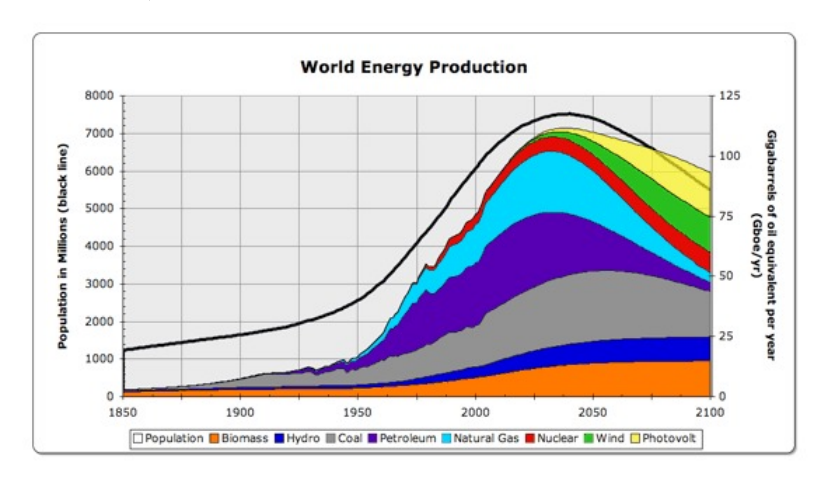
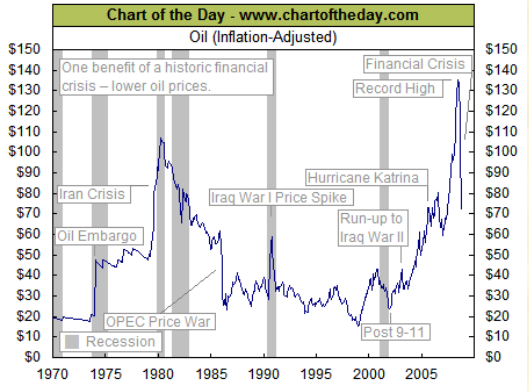
Energy sustainability

- The large increase in U.S. living standards in the 20th century was based primarily on cheap and abundant energy.
- Peak oil production was reached in July 2008.
- Peak energy production may be reached ca. 2040.
- Oil prices are near all-time highs.
- World population may increase by another billion people by 2050.
- Residents of formerly 3rd world nations want to enjoy the idealized western lifestyle.







Managing energy demands and rising populations

Rising energy demands have effects on climate change and the way that we live. *How can we mitigate this problem?*

I. Conservation—making energy by saving energy

a) Use more efficient appliances/bulbs/cars, etc.

b) Using those things less

c) Buying less "stuff" (remember life cycle assessment and reduce-reuse-recycle?)

Are these measures consistent with economic growth?

Can you have economic growth in the conventional sense when the resource base is shrinking and resource costs are rising?

Should you spend it as fast as you make it?

Do we have an obligation to future generations and the surrounding environment to conserve resources and reduce pollution emissions?

Managing energy demands and rising populations

II. <u>Alternative energy</u>

Two major categories—modifying current power consumption and developing renewable power sources.

a) Modifying current power consumption--electric vehicles, hybrid vehicles, natural-gas powered vehicles…*what are the advantages and disadvantages?*

b) Renewable power sources—ethanol, biodiesel, algae, biogas, solar, wind, geothermal, hydroelectric…*what are the advantages and disadvantages?*

Should we hope that creativity and engineering will provide the "magic bullets" needed to keep global energy supplies from peaking. Is a peak in energy production useful or debilitating?

Sustainable Housing Questions

- *How many square or cubic feet do we need per person to be comfortable/happy?*
- *Should we all build LEED (Leadership in Energy and Environmental Design)-certified houses?*
- *Should we retrofit old houses to be more energy and space-efficient?*
- *Should we live in micro-houses or micro-apartments in urban centers?*
- *Should we regulate or mandate where and how people live?*
- *If we taper down our wants and expectations for housing now, will that change benefit future generations or our current situation?*

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Sustainable Food Questions

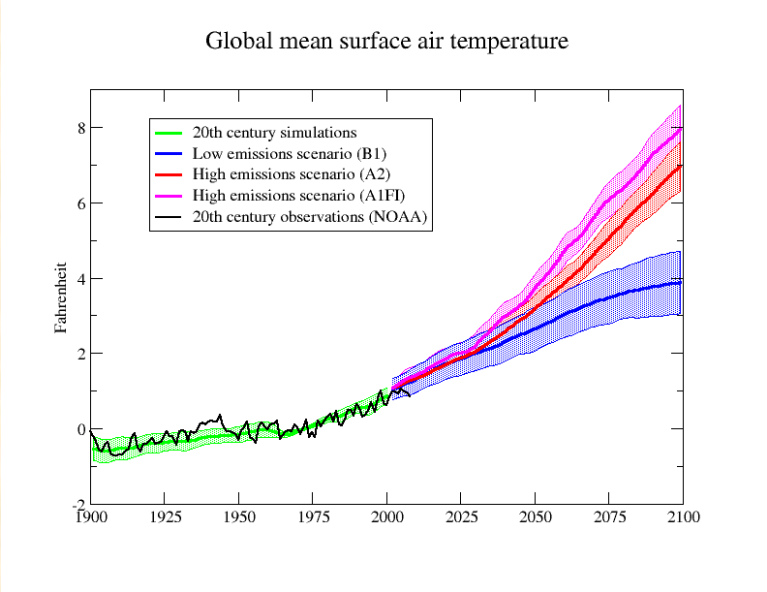
- Food miles are the distance that food travels from a farm to your table. Average food miles in the U.S. are 1,500. Almost 250,000 tons of greenhouse gases are emitted from importing food to the U.S.—about the same as used by 40,000 cars.
- How much energy is used in food production? …tomatoes grown in Mexico may take much less energy to produce than tomatoes grown in a heated greenhouse in Michigan for instance.
- A lifecycle assessment of food production would include food miles, energy of production, other inputs and wastes to develop a full cost of any food (or other) item.
- *Should we shop locally? Is all of the food in a farmer's market grown locally? Are there environmental and health benefits to organic food? Is organic food affordable? Should we raise as much of our own food as we can?*

Sustainable stuff

- Resources used and miles transported apply to virtually anything else that we buy…clothes, appliances, cars, cosmetics, furniture, etc.
- An important way to conserve energy and other resources and limit environmental disruption is to buy less stuff…have fewer things and don't replace them until they're truly worn out. Put a little more money into savings and spend somewhat less at the store. *Are there drawbacks to that approach?*
- Living more sustainably can mitigate climate change, reduce air and water pollution (improve health), conserve resources for future generations, and save money.

Adaptation to climate change

- We've talked about mitigating climate change, let's talk about adapting to it.
- Even if we sharply curtailed emissions of greenhouse gases, climate change is likely to continue for many decades.
- If we wish to continue to have reasonably comfortable lives, we and wildlife will have to adapt to climate change.
- Some adaptation strategies can include migration, adjustments to changing seasons, and substitution of foods and other materials.



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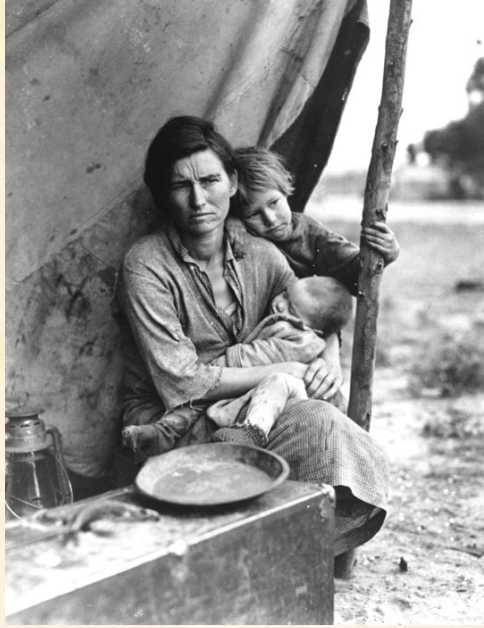
Migration

- Climate change has prompted migration away from some areas…by people escaping sea-level rise, droughts, and icepack melting; and by migratory birds and fish seeking cooler climates. Crop-growing areas are moving too.
- Movement of wildlife as well as direct climate changes have caused hardships and migrations of human populations, e.g. away from coasts, from rural areas to cities.
- Many thousands of people have had to quit their livelihoods, leave their societies and ways of life, and change food sources. Many more people are likely to have to move in the future when their current locations and livelihoods become unsustainable (e.g. as major coastal cities are flooded).
- Wildlife species with narrow ecological niches, such as polar bears, are likely to go extinct, except in captivity.



Adjustments to changing seasons

- When I grew up (a long, long time ago), many houses in the southern half of the U.S. had no air conditioners or perhaps one window unit. Homes in the northern half of the country typically had no air conditioners of any kind. Now less than 25 percent of U.S. homes have no air conditioning.
- Central air conditioning now is in the majority of houses in the U.S., with people spending much more sedentary time indoors during the summer. *Has that change had health consequences?*
- Swimming pools are much more common.
- Built-in lawn irrigation systems are more common.
- *What effects do these adjustments have on climate change, and other resources such as energy and water?*
- *Do increased efficiencies of air conditioners completely make up for this change?*

Substitution of foods and crops

- Increasing drought has led to smaller yields of common crops (-4 to -6% for corn and wheat) and efforts to substitute crops with smaller water requirements, such as grain sorghum and Sudan grass, instead of corn.
- Areas that have historically relied on fish or molluscs as major sources of food and livelihoods are having smaller catches. Mediterranean fish species such as red mullet are replacing Atlantic cod in the North Sea.
- Constrained quantities and higher prices for livestock feed have caused sell-offs of herds, increasing prices for meat and dairy products.
- Using grains for biofuels has increased food shortages.
- Constrained food supplies and increasing human populations have caused large price increases for food, affecting the poor the most.

Mitigating and adapting to climate change—a few last words

- A great deal of creativity and self-denial is likely to be needed to minimize the effects of climate change on human society.
- If we choose to keep going as we are, we're likely to hit a wall of unsustainable climate conditions, and costs for food and energy that will cause a crisis in the next several decades.
- *Is it better to practice some self-denial now and set a gentler glide path for future generations and our surrounding ecosystems to the post fossil-fuel age?*

Thank you for your time!

- We hope that this class has been useful and interesting for you.
- We'll hand out course-completion certificates and take a class photo in a few minutes.
- Please fill out the course evaluation form that you will be receiving by email in the next several weeks.

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