MATERIALS PACKET

The Dynamics of Climate
A Teacher Professional Development Toolkit for Climate Science

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Introduction

The *Materials Packet* contains the originals for printing the handouts, data sets, activity materials, and assessment instruments for use in the professional development workshop. The *Presenter Guide* provides a detailed description of the workshop and PowerPoint program, highlighting the main points of each slide and providing an outline for each activity. It is designed to assist the presenter (facilitator) in implementing the workshop. The workshop activities engage participants in analyzing and interpreting climatic data sets and visualizations. Pedagogically, the workshop promotes active learning and collaboration. The manual, *The Dynamics of Climate: A Teacher Professional Development Toolkit for Climate Science,* provides an overview of the toolkit, guidelines for conducting effective workshops, and a listing of available resources and background readings.

Workshop Materials Checklist

✓Sign-in sheet

✓Statements about climate change, “Why Care about Climate Change?”

✓ Masking tape, chart paper and markers for “Draw a Climate System” activity

✓Carbon Cycle activity materials

✓Light meter and color construction paper (white = snow/ice/clouds, green = vegetation, blue = water/oceans, brown = land) for albedo activity

✓Changes in the Climate System data handouts and response sheets

✓Wedge Game handouts and materials

✓Case study handouts and materials

✓Climate education resources handouts

✓Climate glossary handout

✓Assessment

I care about climate change because of its impact on the hundreds of millions of people – **climate refugees** – who will likely be uprooted as a result of sea level rise and an increase in extreme weather events, droughts and desertification.

I care about climate change because of the negative ecological consequences of biodiversity loss.

It is important to conserve the diversity of life for medical and economic reasons. Plants and animals could provide us with additional foods, medicines, and other products that will save lives and benefit society.

I care about climate change and know I can do something to help solve it!

"Everybody talks about the weather, but nobody does anything about it."

~ Mark Twain, 1897

I care about climate change because of the rising temperatures, changing rainfall and an increase in the frequency and intensity of extreme weather events already being felt in many parts of the world.

I care about climate change because I like having electricity powering lights and air conditioning. But increasingly hot days increase the demand on electricity often leading to blackouts. Blackouts can lead to hotter dwellings that are not built for optimal air flow and people can overheat and die.

I don’t believe that climate change is real.

The Carbon Cycle, Then and Now

Lesson Summary

Students learn about the carbon cycle by becoming carbon atoms and experiencing different journeys. They travel through the carbon cycle before and after the industrial revolution to understand the changes that humans have made to this cycle.

Time Allotment
50 minutes

Materials
- 12 Pre and Post-1700 dice (see Advance Preparation)
- 8 station signs (see Advance Preparation)

Per student
- How Carbon Moves data sheet (see Advance Preparation)
- Forms of Carbon data sheet (see Advance Preparation)
- Graph paper

Advance Preparation
Make copies of the station signs and cut them out. Place each sign and its Pre-1700 die at 8 different stations in the room, using desks, chairs, etc. Allow space for each die to be tossed. Save the Post-1700 dice for use after the Pre-1700 dice.

Make double-sided copies of the Forms of Carbon and How Carbon Moves data sheets for each student.

Arrange students in cooperative groups.

Make copies of all the dice patterns. Cut and paste them into dice. The codes are:

Dice Code	Meaning
A: <1700	Atmosphere Pre-1700
P/A: <1700	Plant/Animal Pre-1700
OS: <1700	Ocean Sediment Pre -1700
FF: <1700	Fossil Fuels Pre-1700
DO	Deep Ocean Pre & Post-1700
ML	Marine Life Pre & Post-1700
S	Soil Pre & Post-1700
SO	Surface Ocean Pre & Post-1700
A: >1700	Atmosphere Post-1700
P/A: <1700	Plant/Animal Post-1700
OS: <1700	Ocean Sediment Post-1700
FF: >1700	Fossil Fuels Post-1700

Lesson Objectives
- Learn the carbon cycle as carbon moves through different forms in an ecosystem (atmosphere, life, ocean, and fossil fuels).
- Identify human roles in impacting the carbon cycle.
- Understand that changes in the Earth's atmospheric composition impact climate and life on Earth.

Illinois Goals and Standards for Middle/Junior High School
Science:
Goal 11: A.3c, A.3e, A.3f
Goal 12: C.3b, E.3a

The Carbon Cycle, Then and Now

Math:
Goal 10: A.3a

Language Arts:
Goal 3: B.3a

Vocabulary

Carbon
Carbon cycle
Carbon dioxide (CO_2)
Fossil fuels
Greenhouse gas
Non-renewable resource
Sink
Source

Background Information

Carbon is an atom, or element, that is essential to life on Earth. It can form up to four bonds with other atoms to form a wide variety of molecules and substances from gases like **carbon dioxide (CO_2)** and methane (natural gas) to liquids like gasoline and vegetable oil to solids like wood or coal. All living things contain carbon. It is also found in the air, in soda, in the shells of snails and clams, and in many rocks that are used for building. Things that aren't made of carbon are usually metals, glass, and water.

Like water, carbon moves from place to place through an ecosystem and throughout the globe. This movement is called the **carbon cycle**. Some places and organisms act as carbon **sinks**, which means that they take in and store carbon. Others act as carbon **sources** because they release carbon. Most places and organisms act as both.

In the atmosphere, carbon can be found mostly in the form of carbon dioxide (CO_2). Carbon dioxide is absorbed by plants for use in photosynthesis, a process that combines CO_2 with water and light to form sugars, starches, and cellulose. Through the food chain, this carbon moves into all other living things. At the same time, burning anything with carbon in it causes carbon to combine with oxygen and return to the atmosphere in the form of CO_2. This happens when dead plants and animals are burned, when animals' bodies burn food for energy, or when dead plants and animal decompose. These processes cause carbon to move quickly through the carbon cycle.

Other processes can take millions of years. Long ago some plant and animal materials did not decay because they got buried under layers of sand and silt. Over time the sugars, starches, cellulose, fats, and proteins in the materials came under high pressure and heat as they got buried deeper and deeper. At the same time they were exposed to various chemical reactions that slowly changed them into the form of **fossil fuels** such as crude oil, natural gas, and coal. Over millions of years, this process drew enormous amounts of carbon out of the atmosphere and stored it deep inside the Earth's crust. Fossil fuels are called **non-renewable resources** because they can be used up faster than they are made.

During the Industrial Revolution humans began removing and burning fossil fuels for power. This process, which started in the 1700s, has moved a large part of the carbon that was in long-term storage back into our atmosphere. This is a problem because carbon dioxide acts as a **greenhouse gas**. Greenhouse gases absorb some of the sun's energy close to the earth. This process is what keeps our planet at a livable temperature. As the amount of carbon dioxide in the atmosphere increases, the average temperature of the globe increases.

The Carbon Cycle, Then and Now

While this happens naturally, humans are increasing the concentration of carbon dioxide faster than the planet has ever experienced. This could drastically alter the Earth's climate in unexpected ways.

Initial Discussion

1. Review with students what carbon is (see Background Information). Ask students to touch something that is made of carbon and then something that isn't. Discuss students' responses.

2. Discuss what a cycle is with students (a course or series of events that usually eventually leads back to the starting point). Introduce the concept of the carbon cycle (see Background Information).

3. Explain to students that carbon is never created nor destroyed, but that it moves between different forms. Pass out the data sheet to each student.

4. Referring to the Forms of Carbon page on the back of the data sheet, review with students the forms of carbon and how it may move from one form to another.

Hands-On Activity

5. Explain to students that they will be playing a game in which they will become an atom of carbon. Since carbon atoms move according to chance, they will be using dice to determine the random way they may move throughout the carbon cycle.

6. Discuss with students that they will get to play the game twice. Have students turn over their data sheets. The first time they play they will represent the carbon cycle Pre-1700, before the Industrial Revolution (see Background Information). The second time they play, they will use dice representative of Post-1700.

7. Explain the rules of the game:
   a. Place each station sign with its corresponding Pre-1700 die.
   b. Assign each student to start from various stations. Have students label their starting stations on their data sheets. *Note: Only have a few students start at the Fossil Fuels Station and do not have any students start at the Ocean Sediments station.*
   c. Explain to the students that at each station there is a die. The students will line up single file behind the die at each station. Each student will gently roll the die and record the next station on their data sheet. Students may roll a "Stay at _____." If this is the case, then they must still record this station's name as a turn on their data sheets, move to the back of the line, and wait to roll the same die again.
   d. When a student arrives at the next station, they get in line. When it is their turn, they roll the die, record the next station, and proceed onward. Students should repeat the steps until they have completed their journey on the tenth line.
   e. Students should sit down when they are done and tally up how many times they visited each station.

Relate Activity to Concept

8. When everyone has finished playing the Pre-1700 game, have each student share how many times he or she visited the Atmosphere and Fossil Fuels stations in a chart like the one below:

The Carbon Cycle, Then and Now

	Pre-1700	Post-1700
Atmosphere	Sum of students' visits to atmosphere station	Wait to play the game a second time
Fossil Fuels	Sum of students' visits to fossil fuels station	Wait to play the game a second time

9. After creating a class chart with the sums of visits to the Pre-1700 Atmosphere and Fossil Fuel stations, switch out the following four dice so that all dice are now Post-1700: Atmosphere, Plant/Animal, Soil, and Fossil Fuels.

10. Repeat the activity. Students must start at the same exact station as the first round. Have students record how many times they visited all stations. When all students are finished, complete the class chart using the Post-1700 data.

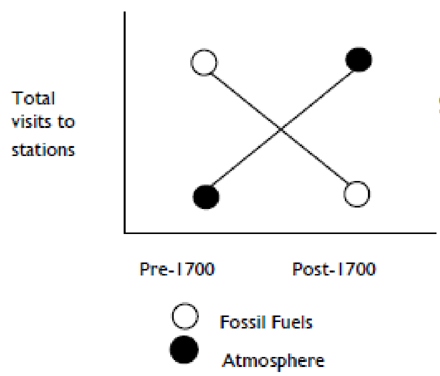
	Pre-1700	Post-1700
Atmosphere	Sum of students' visits to atmosphere station	Sum of students' visits to atmosphere station
Fossil Fuels	Sum of students' visits to fossil fuels station	Sum of students' visits to fossil fuels station

11. Ask students what it was like being a carbon atom, having a few students tell their stories. Discuss how each station represented one of the forms that carbon may take in the carbon cycle.

12. Ask students why some of them may have gotten "stuck" as carbon atoms in the Pre-1700 Fossil Fuels station and not in Post-1700 (Prior to the Industrial Revolution in the 1700s, fossil fuels were being created and the carbon was immobile. Post-1700, fossil fuels were mainly burned and released into the atmosphere).

13. Ask students how looking at the Atmosphere and Fossil Fuels data can be an indicator of significant change to the carbon cycle. Why should we concentrate on looking at the data from student visits to only the Atmosphere and Fossil Fuels stations?

14. Pass out graph paper to each student. Have students create a simple line graph to represent this data.



Sample Graph

15. Post-1700, why didn't anyone who visited the Ocean Sediments Station end up in the Fossil Fuels Station? (Since fossil fuels take millions of years to form, they couldn't be formed in the few hundred years from 1700 to the present).

16. Why did more students visit the Atmosphere station than the Fossil Fuel station during the post-1700 round (Humans are burning fossil fuels as an energy source)? What are humans specifically doing to decrease the usage of carbon found in fossil fuels and move it to the atmosphere (Driving cars,

cutting down forests, increased paving, using high amounts of electricity, increased industrial activities, etc.)?

17. Discuss with students what happens as more carbon is released into the atmosphere, reviewing the effects of greenhouse gases (see Background Information). Ask students how carbon dioxide, which is now acting as an intensified greenhouse gas, will affect the climate of the Earth. What does this mean for its future? Our future?

Global Expressions Journal Prompt

Make an entry in the form of a mandala. Compile class data according to the tables described in the 'relate activity to concept' section of this lesson. Students can record this data on a sheet of paper, cut it out, and use it as the "square" portion of the mandala they create for this carbon cycle (circle portion of the mandala) activity.

Assessment

Have students write a story of their adventures as carbon atom, explaining the similarities and differences of the class' Pre- and Post-1700 data. Have students explore the effects that the differences have on the climate of the Earth.

Extension Activity

Have students design a third set of dice reflecting what they believe will represent a carbon atom's journey Post-2000, knowing how humans have further impacted the carbon cycle in the last three hundred years. Play the game a third time with the newly designed dice. Note changes and have students explain the reasoning behind their results.

The Carbon Cycle, Then and Now

Forms of Carbon

Atmosphere
Carbon is paired with two atoms of oxygen in the form of carbon dioxide. It can remain in the atmosphere, become part of plants through photosynthesis, or dissolve in the ocean waters.

Plant/Animal
Carbon is part of a chain, in a tree trunk, sugar in a fruit, or in the muscle of an animal. It can be respired by a plant or animal into the atmosphere or become part of the soil as the organism decays.

Soil
Carbon enters soil as part of a chain, in plant material such as a fallen leaf. It can remain in the soil, be carried downstream to the ocean, develop into a fossil fuel or be released into the atmosphere as part of the decaying process.

Surface Ocean
Carbon is dissolved in the surface of the ocean. It can remain in the ocean, be released into the atmosphere, be carried deeper into the ocean by currents, or become part of marine life through photosynthesis.

Deep Ocean
Carbon is dissolved in the deeper waters of the ocean. It can remain in the deep ocean, settle to the bottom of the ocean as sediment, or move to the ocean's surface by currents.

Marine Life
Carbon is part of a chain in algae or a marine animal. It can be exhaled by marine life and return to the surface of the ocean or become part of the deep ocean when the marine life dies.

Ocean Sediment
Carbon is part of the material that settles to the bottom of the ocean and will become sedimentary rock. It can either become a fossil fuel after ten million years or be released into the atmosphere when a volcano erupts, releasing carbon dioxide.

Fossil Fuels
Carbon is part of a chain in oil, coal, or natural gas. It can remain as a fossil fuel or be released into the atmosphere after it's been burned for human use.

The Carbon Cycle, Then and Now

How Carbon Moves

Name: ____________________

Pre-1700 Stations

1. ____________________
(Start)
2. ____________________
3. ____________________
4. ____________________
5. ____________________
6. ____________________
7. ____________________
8. ____________________
9. ____________________
10. ____________________
(Finish)

Station	Times Visited
Atmosphere	
Plants/Animals	
Soil	
Surface Ocean	
Deep Ocean	
Marine Life	
Ocean Sediment	
Fossil Fuels	

Post-1700 Stations

1. ____________________
(Start)
2. ____________________
3. ____________________
4. ____________________
5. ____________________
6. ____________________
7. ____________________
8. ____________________
9. ____________________
10. ____________________
(Finish)

Station	Times Visited
Atmosphere	
Plants/Animals	
Soil	
Surface Ocean	
Deep Ocean	
Marine Life	
Ocean Sediment	
Fossil Fuels	

The Carbon Cycle, Then and Now

Atmosphere Station Pre-1700

Cut ———
Fold - - -

Plant/Animal

A: <1700

Stay at Atmosphere

A: <1700

Plant/Animal

A: <1700

Surface Ocean

A: <1700

Stay at Atmosphere

A: <1700

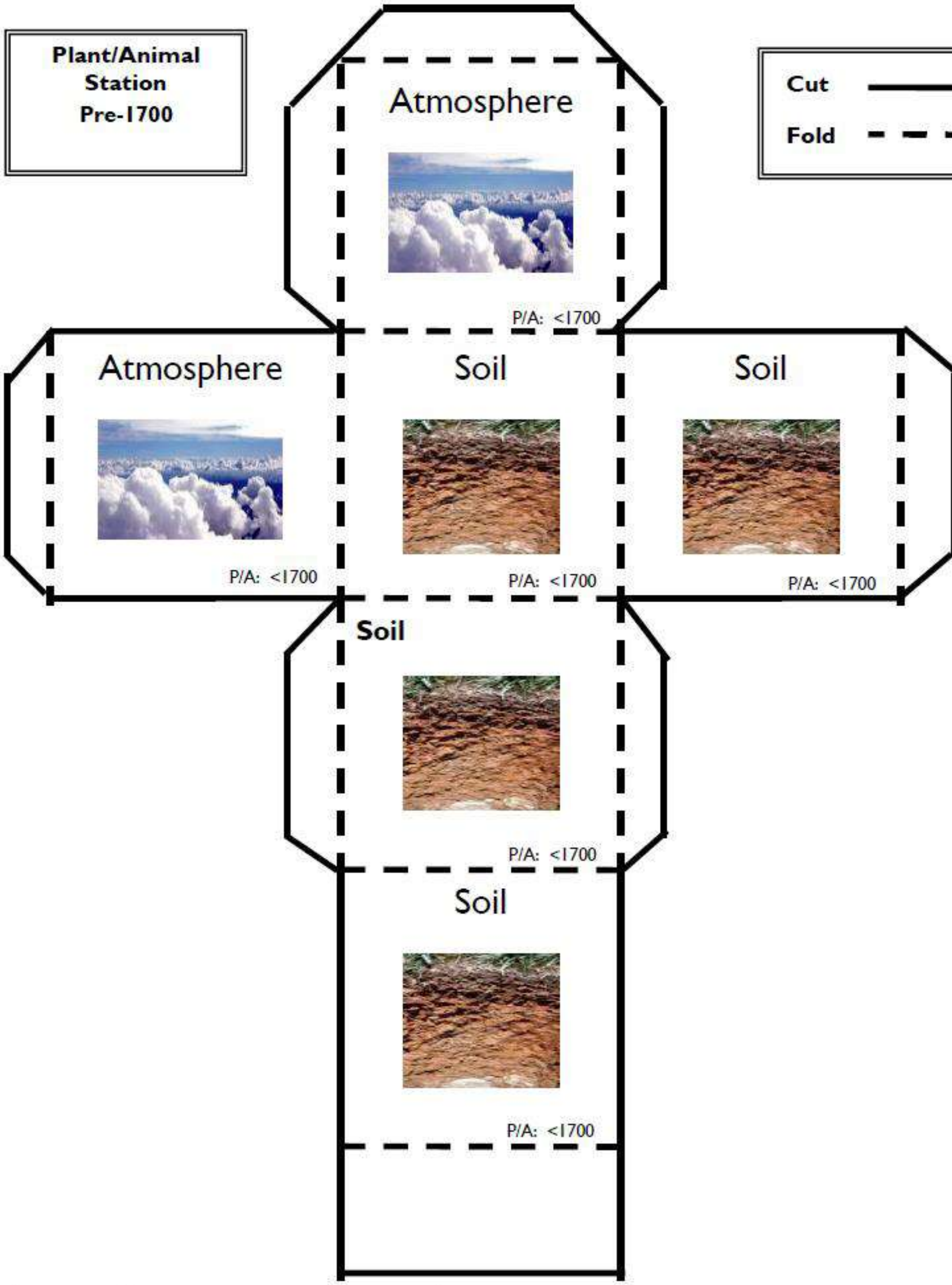
Surface Ocean

A: <1700

The Carbon Cycle, Then and Now

Plant/Animal Station
Pre-1700

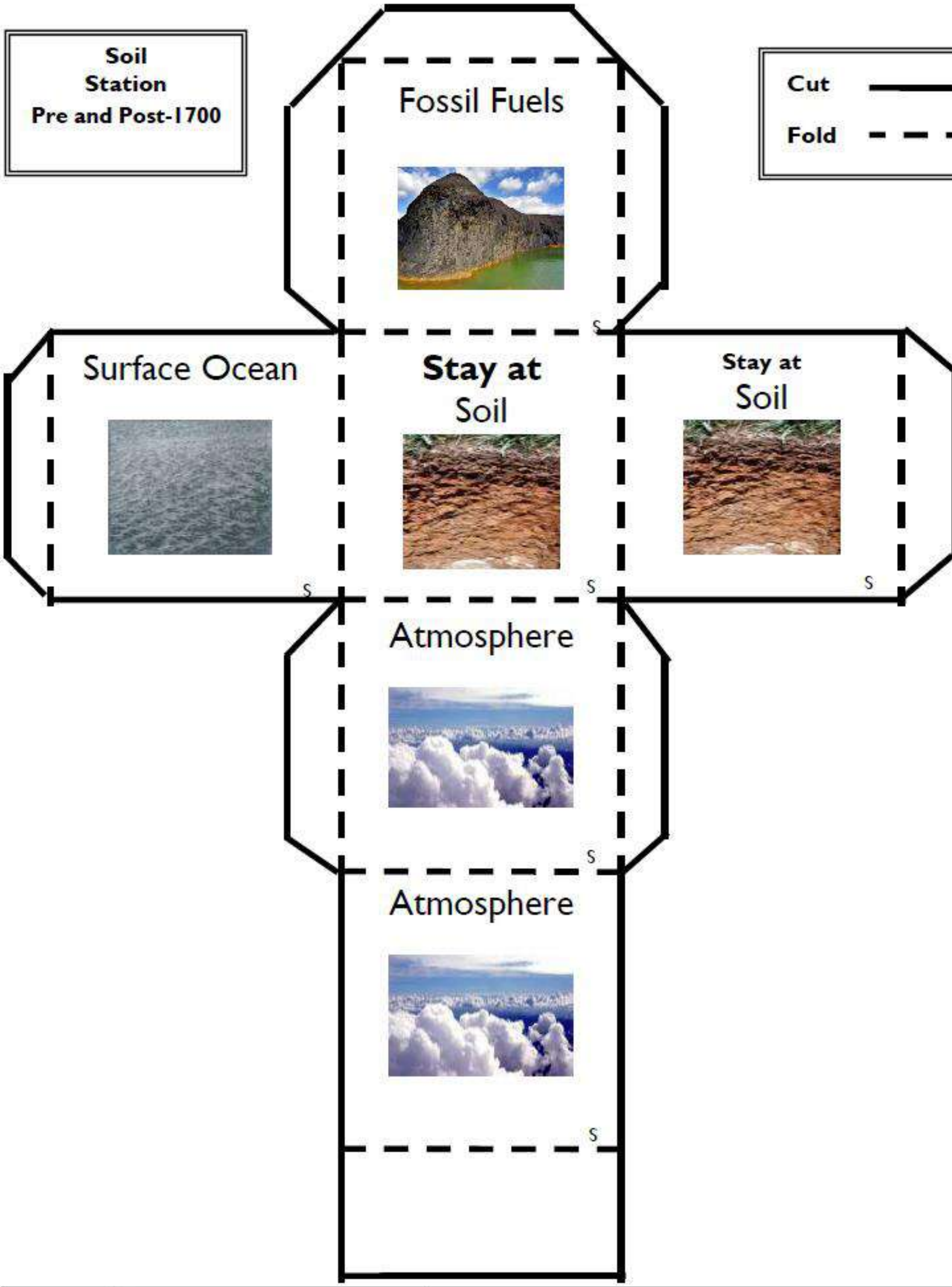
Cut ———
Fold – – –



The Carbon Cycle, Then and Now

Soil Station
Pre and Post-1700

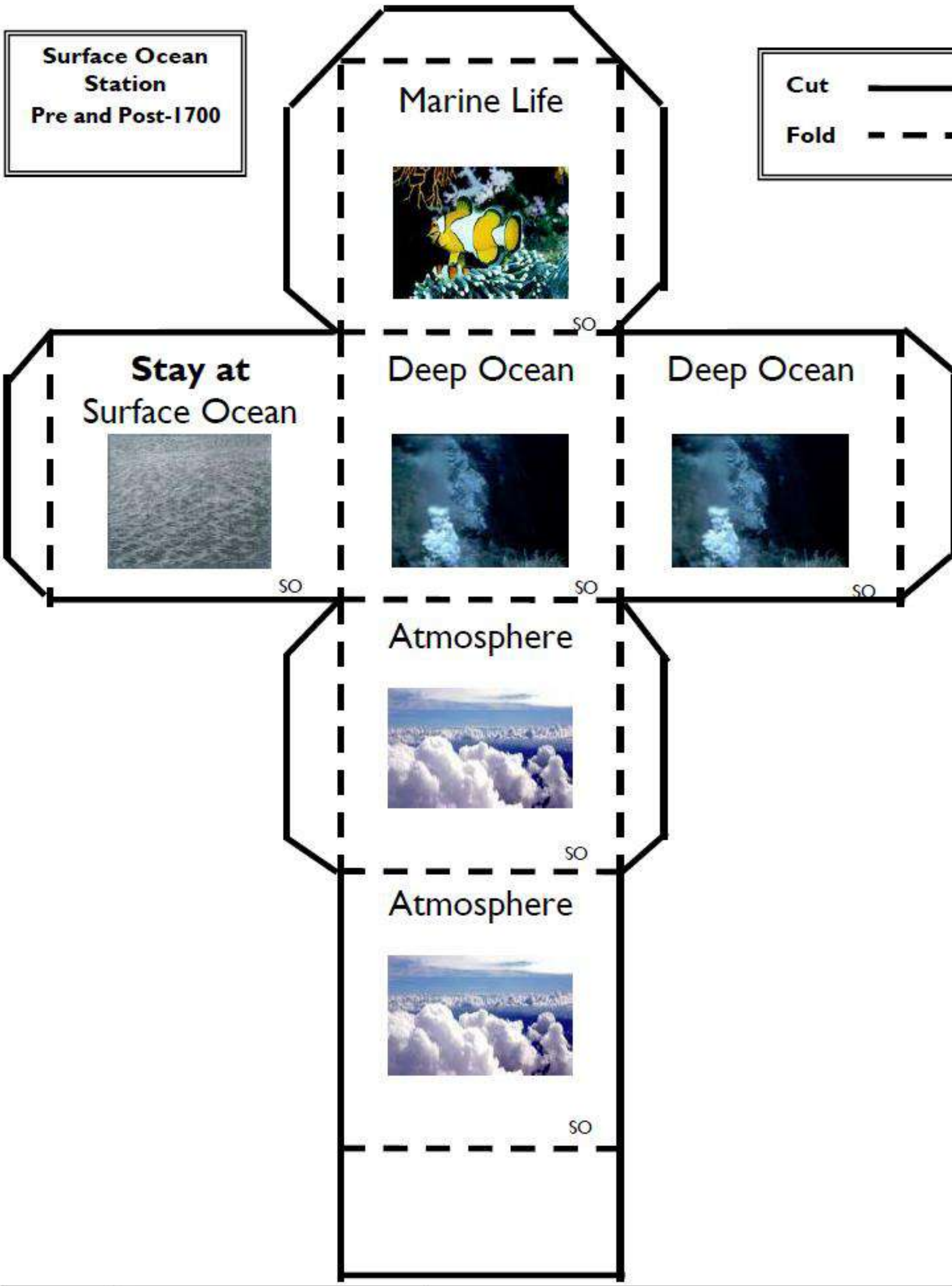
Cut ——
Fold - - -



The Carbon Cycle, Then and Now

Surface Ocean Station
Pre and Post-1700

Cut ———
Fold - - -



The Carbon Cycle, Then and Now

Deep Ocean Station
Pre and Post-1700

Cut ———
Fold - - -

Ocean Sediment

DO

Stay at
Deep Ocean

DO

Stay at
Deep Ocean

DO

Stay at
Deep Ocean

DO

Surface Ocean

DO

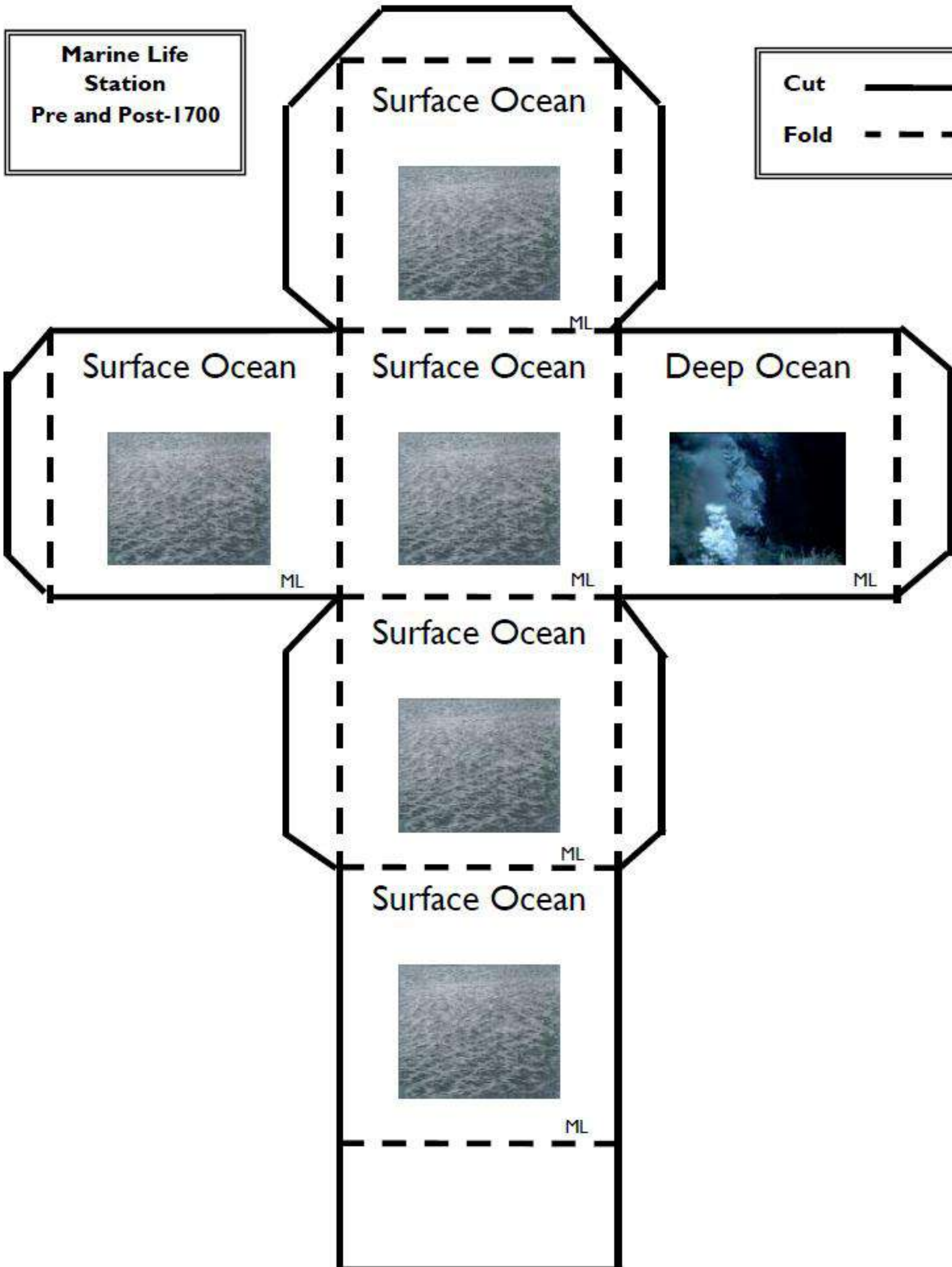
Surface Ocean

DO

The Carbon Cycle, Then and Now

Marine Life Station
Pre and Post-1700

Cut ——
Fold - - -

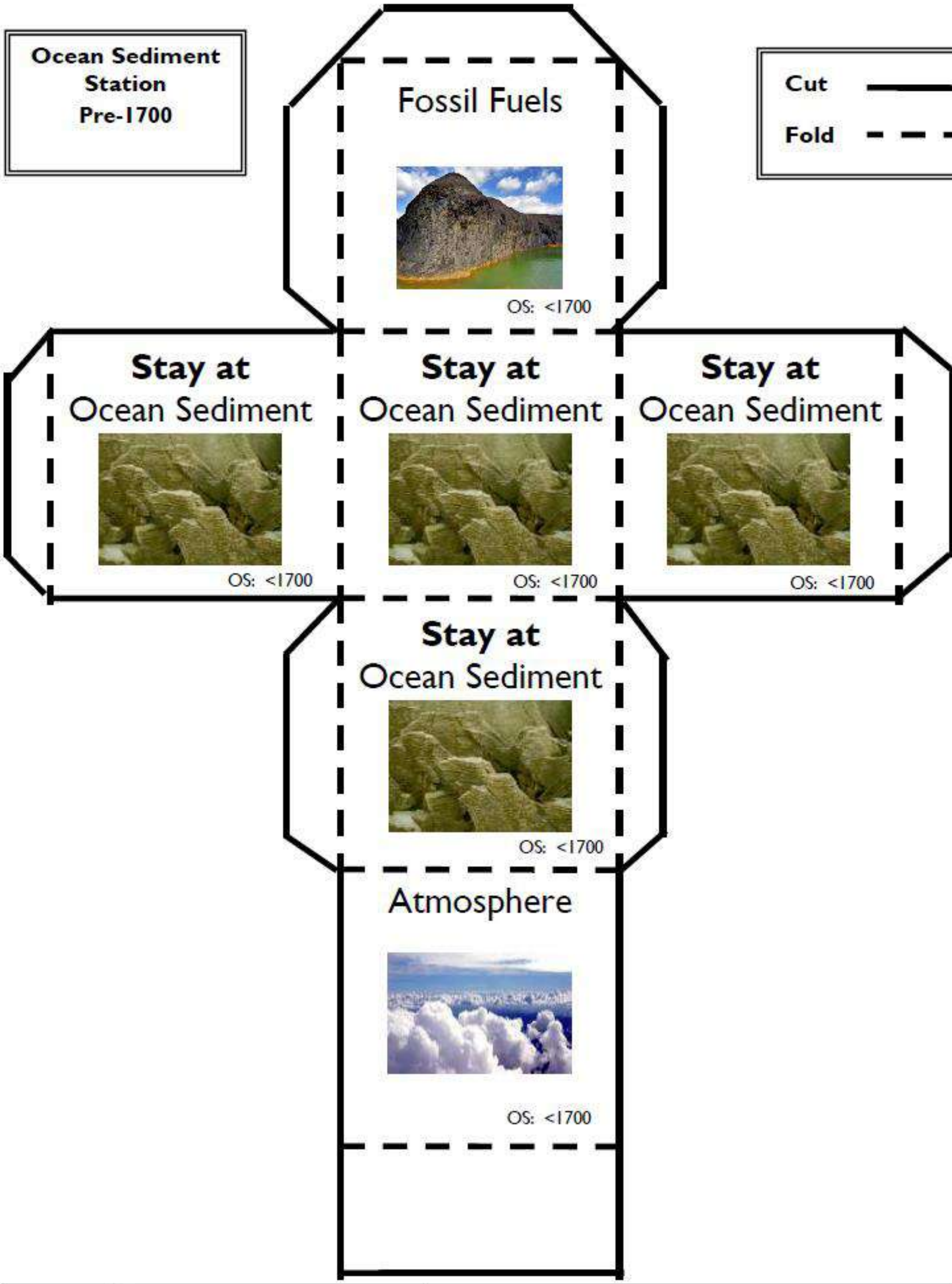


The Carbon Cycle, Then and Now

Ocean Sediment Station
Pre-1700

Cut ———

Fold – – –



The Carbon Cycle, Then and Now

Fossil Fuels Station Pre-1700

Cut

Fold

Stay at
Fossil Fuels

FF: <1700

Stay at
Fossil Fuels

FF: <1700

Stay at
Fossil Fuels

FF: <1700

Stay at
Fossil Fuels

FF: <1700

Stay at
Fossil Fuels

FF: <1700

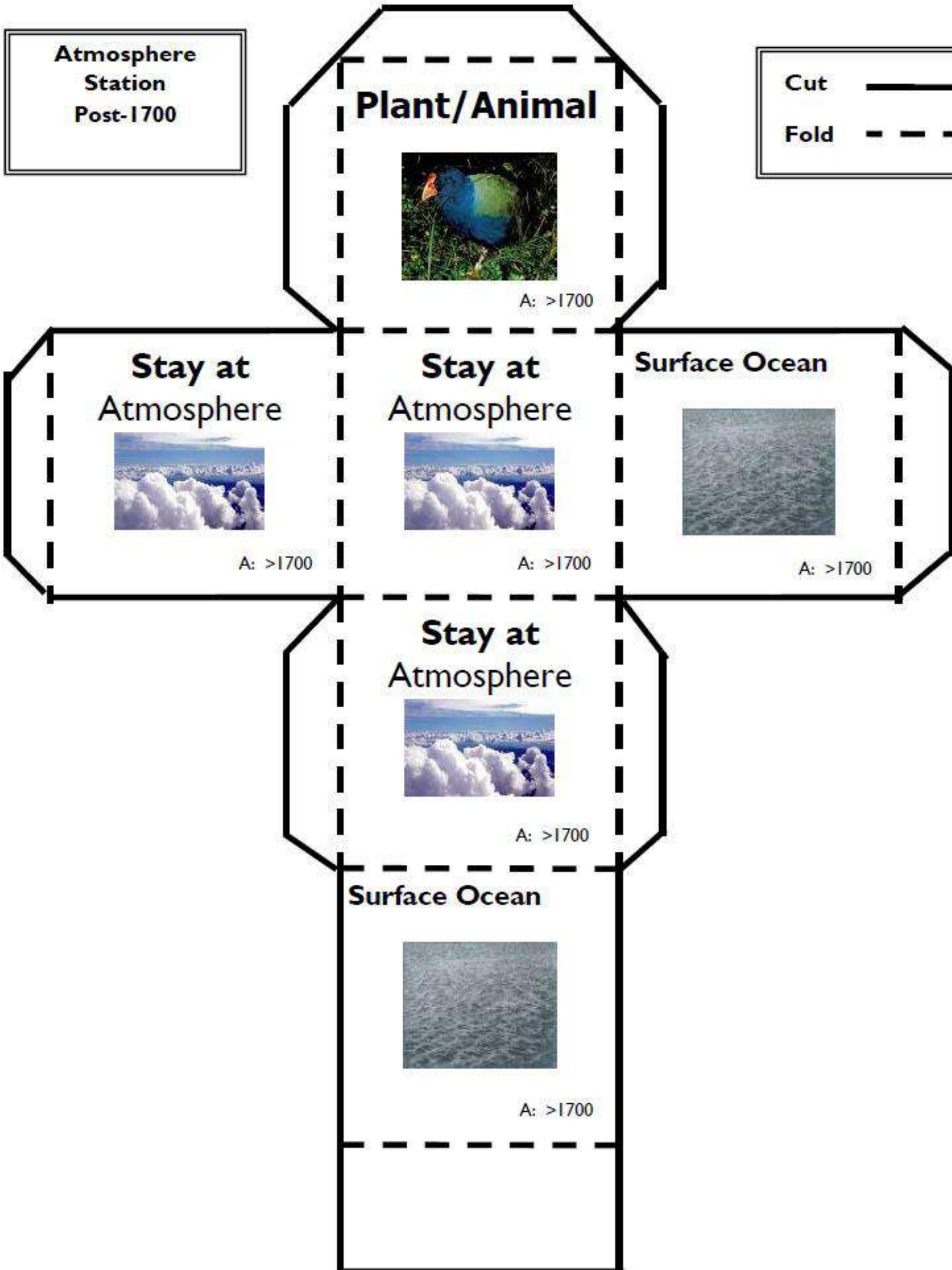
Stay at
Fossil Fuels

FF: <1700

The Carbon Cycle, Then and Now

Atmosphere Station Post-1700

Cut ———
Fold – – –



The Carbon Cycle, Then and Now

Soil Station Post-1700

Cut ———
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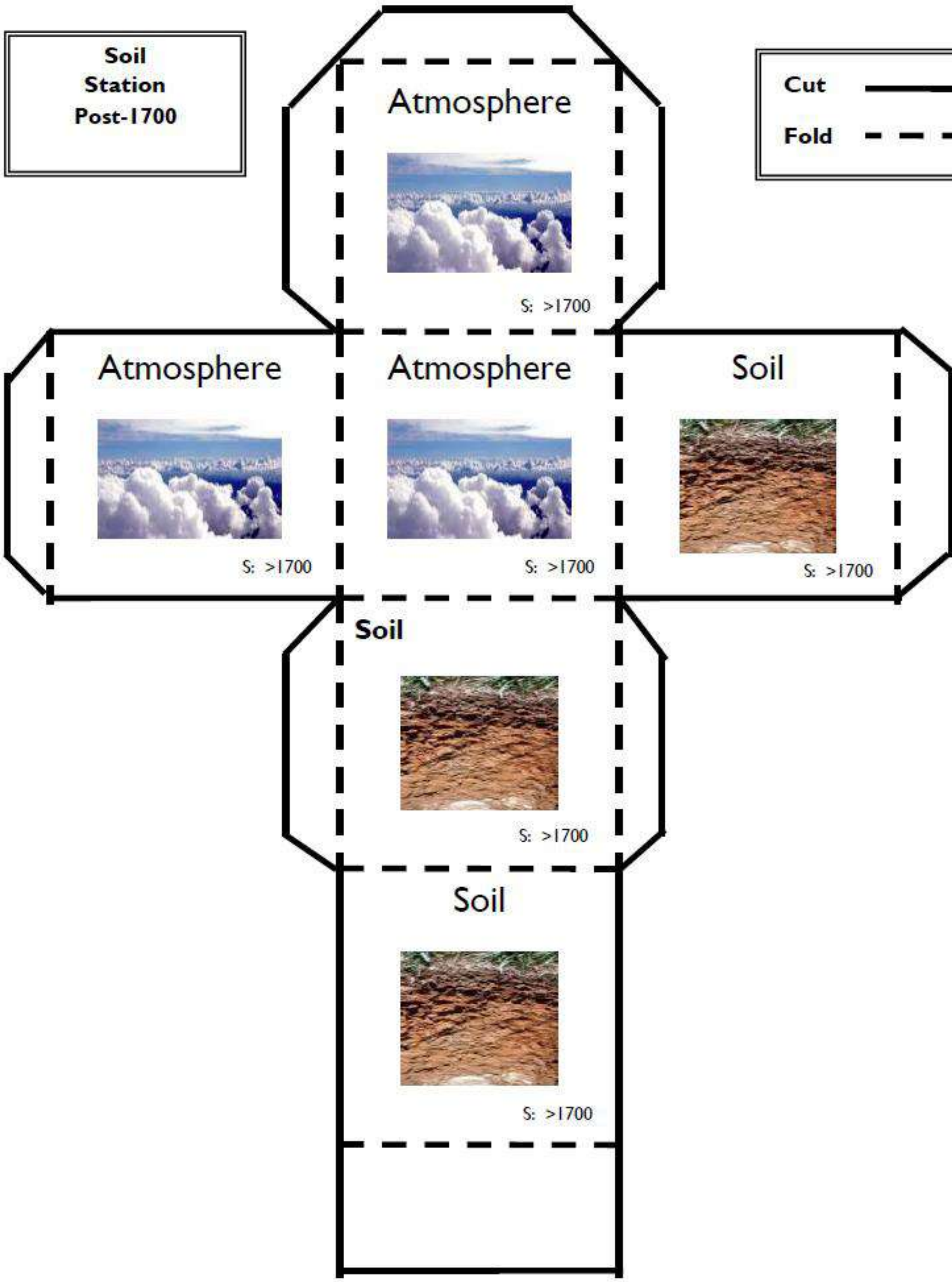
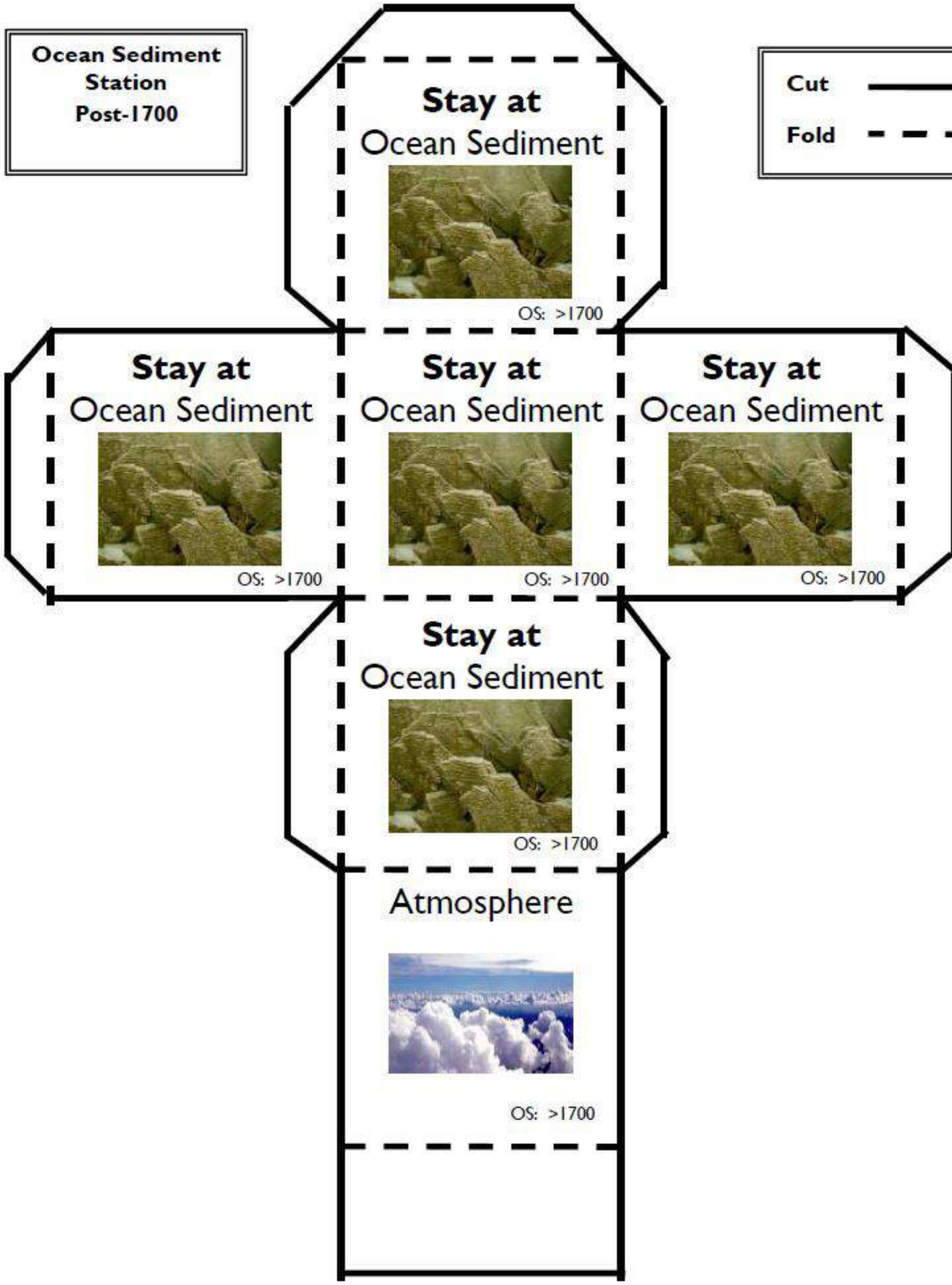


The Carbon Cycle, Then and Now

Ocean Sediment Station Post-1700

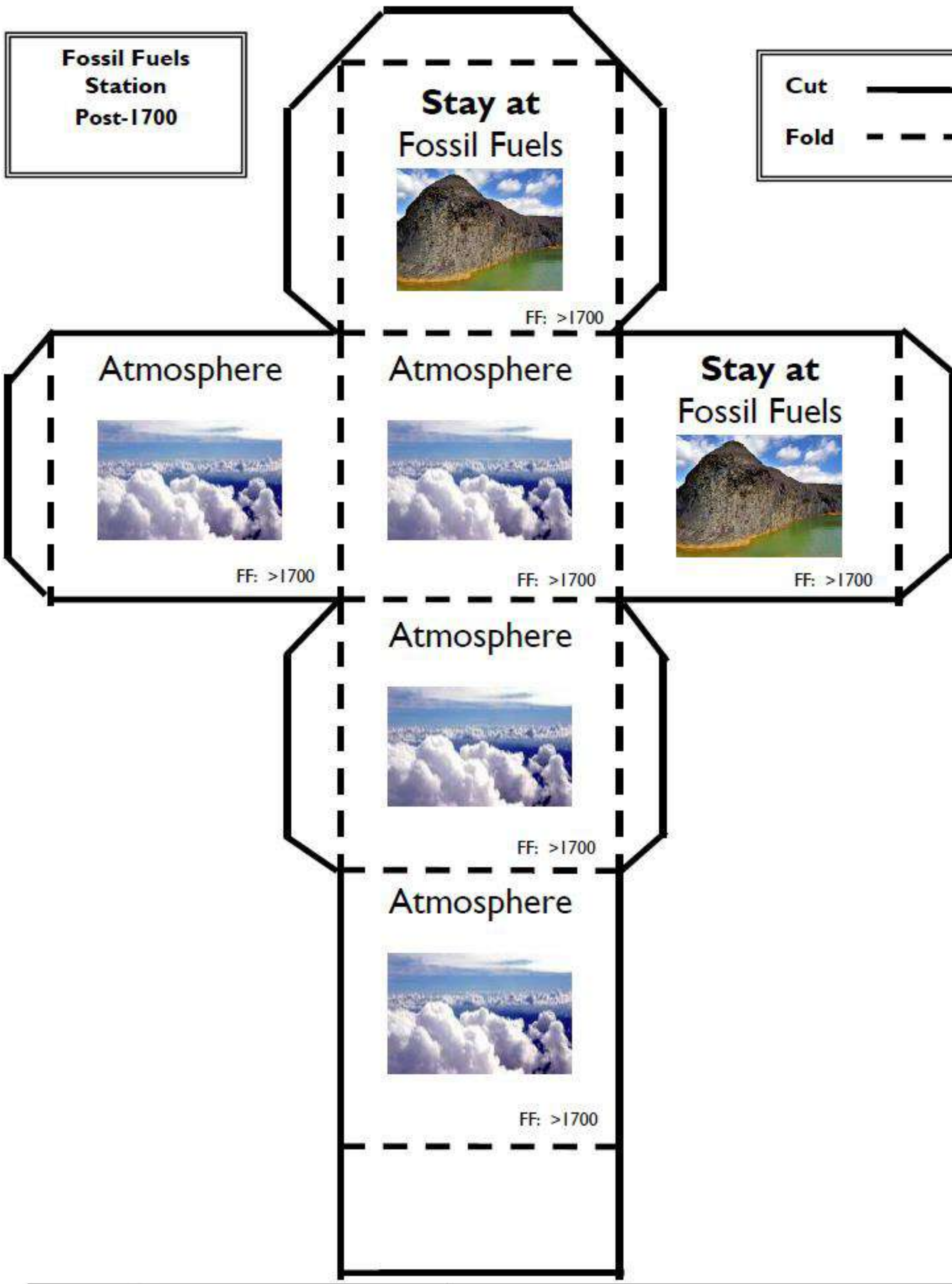
Cut ———
Fold - - -



The Carbon Cycle, Then and Now

Fossil Fuels Station Post-1700

Cut
Fold



Atmosphere

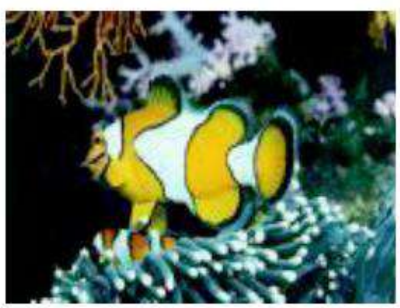
Plant/Animal

Soil

Surface Ocean

Deep Ocean

Marine Life



Ocean Sediment

Fossil Fuels

Changes to the Climate System:
ICE

How has the component changed?

What is the evidence of this change?

What relationship might this have with global warming?

Describe how the other components of the climate system impact the component:

Land→

Vegetation→

Atmosphere→

Ocean→

Describe how changes to the component might impact the other components of the climate system:

→Land

→Vegetation

→Atmosphere

→Ocean

How might these changes impact climate?

Changes to the Climate System:
Ocean

How has the component changed?

What is the evidence of this change?

What relationship might this have with global warming?

Describe how the other components of the climate system impact the component:

Land→

Vegetation→

Atmosphere→

Ice→

Describe how changes to the component might impact the other components of the climate system:

→Land

→Vegetation

→Atmosphere

→Ice

How might these changes impact climate?

Changes to the Climate System:
Land

How has the component changed?

What is the evidence of this change?

What relationship might this have with global warming?

Describe how the other components of the climate system impact the component:

Ice→

Vegetation→

Atmosphere→

Ocean→

Describe how changes to the component might impact the other components of the climate system:

→Ice

→Vegetation

→Atmosphere

→Ocean

How might these changes impact climate?

Changes to the Climate System:
Vegetation

How has the component changed?

What is the evidence of this change?

What relationship might this have with global warming?

Describe how the other components of the climate system impact the component:

Land→

Ice→

Atmosphere→

Ocean→

Describe how changes to the component might impact the other components of the climate system:

→Land

→Ice

→Atmosphere

→Ocean

How might these changes impact climate?

Changes to the Climate System:
Atmosphere

How has the component changed?

What is the evidence of this change?

What relationship might this have with global warming?

Describe how the other components of the climate system impact the component:

Land→

Vegetation→

Ice→

Ocean→

Describe how changes to the component might impact the other components of the climate system:

→Land

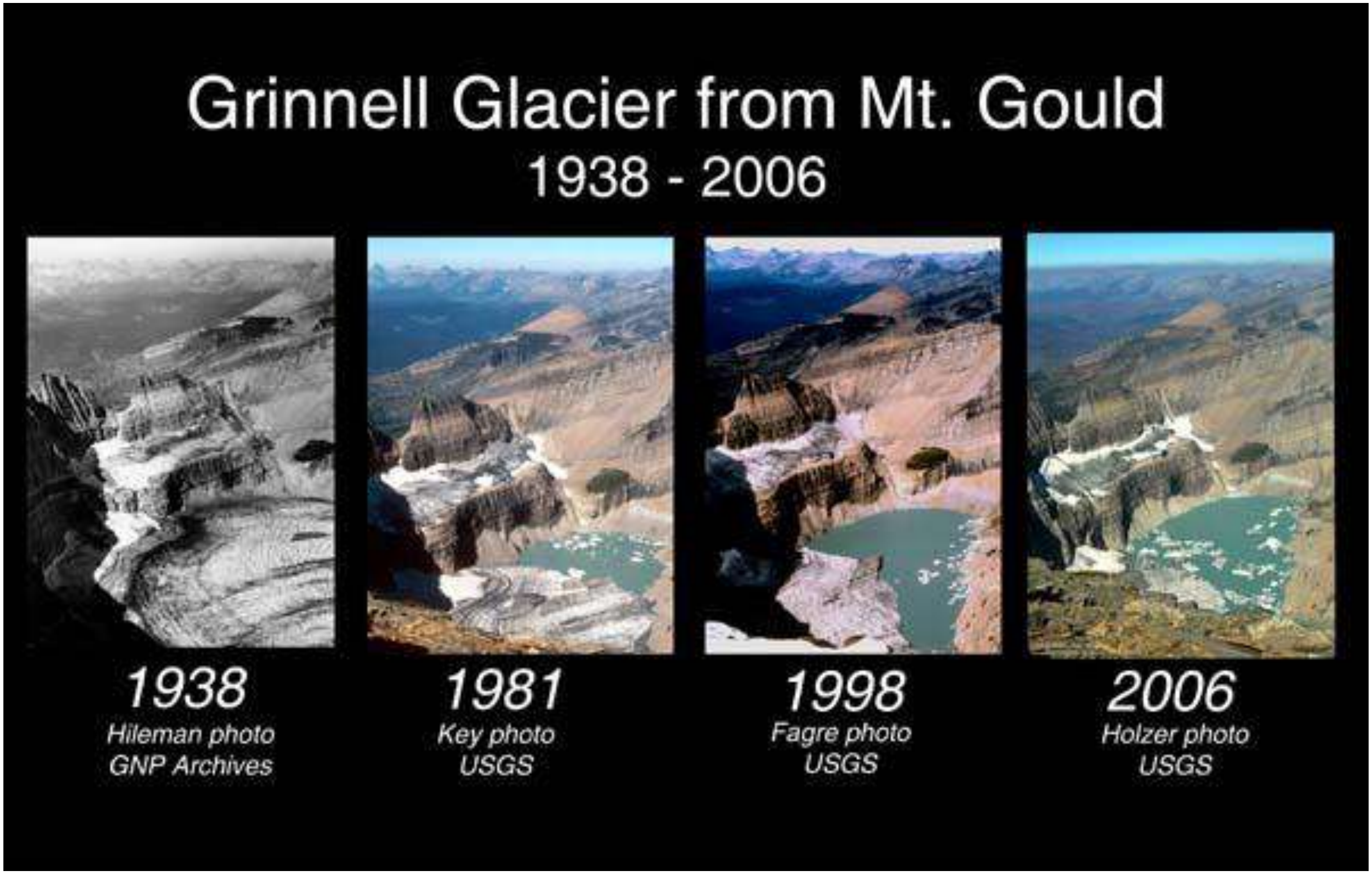
→Vegetation

→Ice

→Ocean

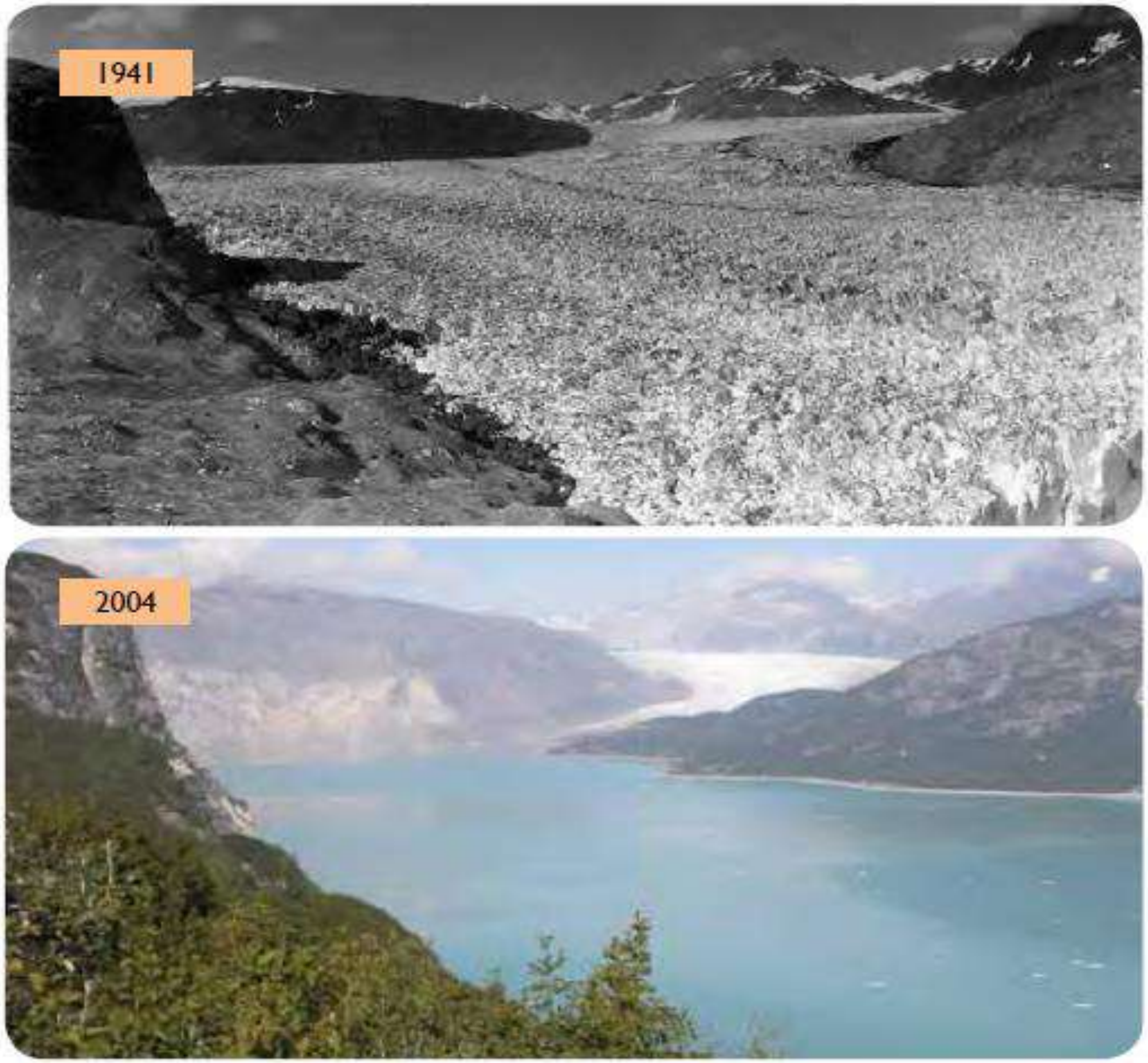
How might these changes impact climate?

Ice

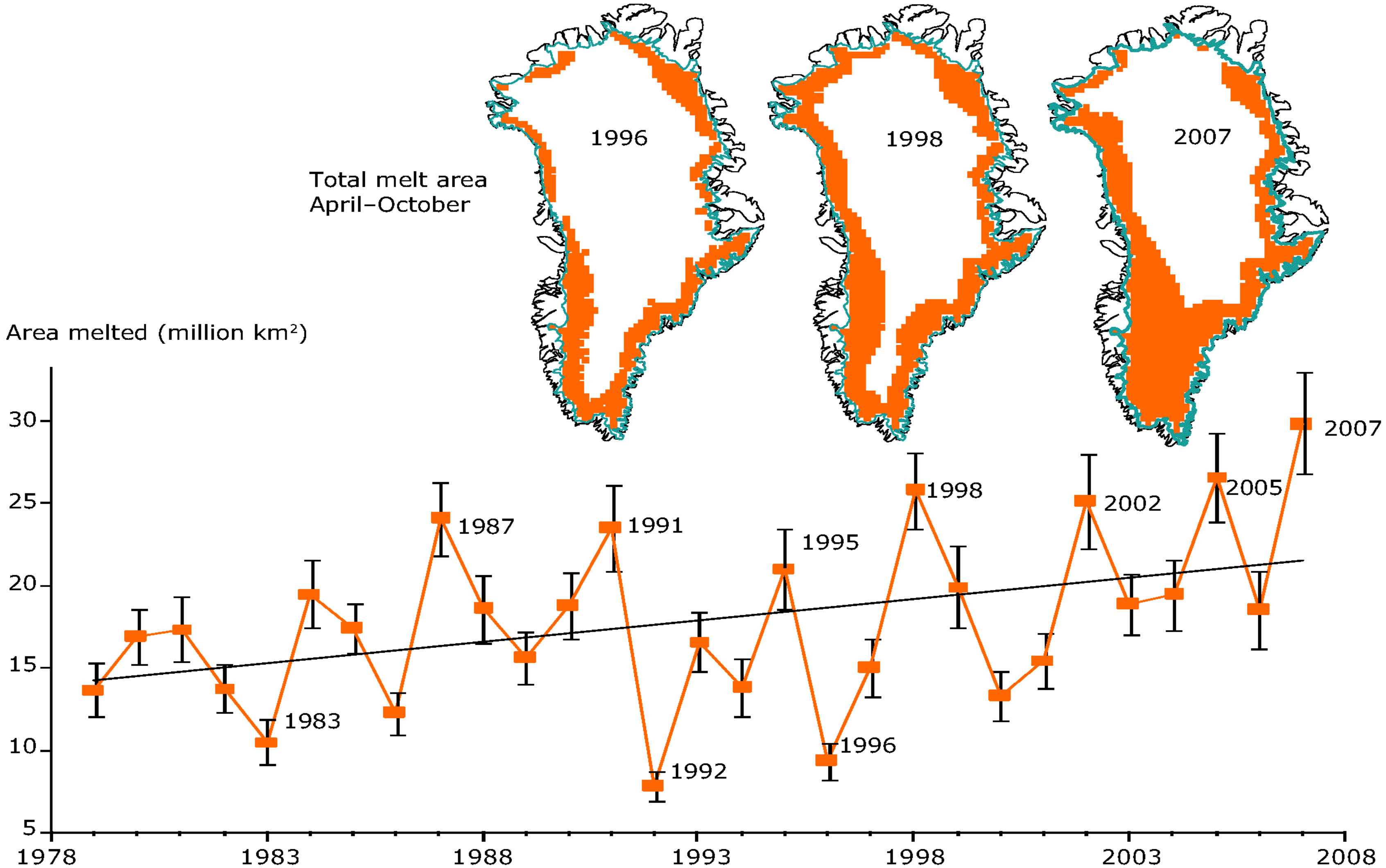


http://www.nat-park.com/grinnell-glacier-glacier-national-park/

Photographs of Muir Glacier, Alaska, 1941 and 2004



Sources: Field, 1941;[5] Molnia, 2004[6]



http://www.eea.europa.eu/data-and-maps/indicators/greenland-ice-sheet/greenland-ice-sheet-assessment-published

Figure 1. Change in Volume of Glaciers Worldwide, 1960–2006

This figure shows the cumulative change in volume of glaciers worldwide beginning in 1960. Negative values in later years indicate a net loss of ice and snow compared with the base year of 1960. For consistency, measurements are in cubic miles of water equivalent, which means the total amount of ice or snow lost has been converted to the equivalent volume of liquid water.

Data source: Dyurgerov, in press[7]

Figure 2. Mass Balance of Three Typical U.S. Glaciers, 1958–2008

This figure shows the cumulative mass balance of the three U.S. Geological Survey "benchmark" glaciers since measurements began in the 1950s or 1960s. For each glacier, the mass balance is set at zero for the base year of 1965. Negative values in later years indicate a net loss of ice and snow compared with the base year. For consistency, measurements are in meters of water equivalent, which means the amount of ice or snow has been converted to the equivalent amount of liquid water.

Data source: USGS, 2009[a]

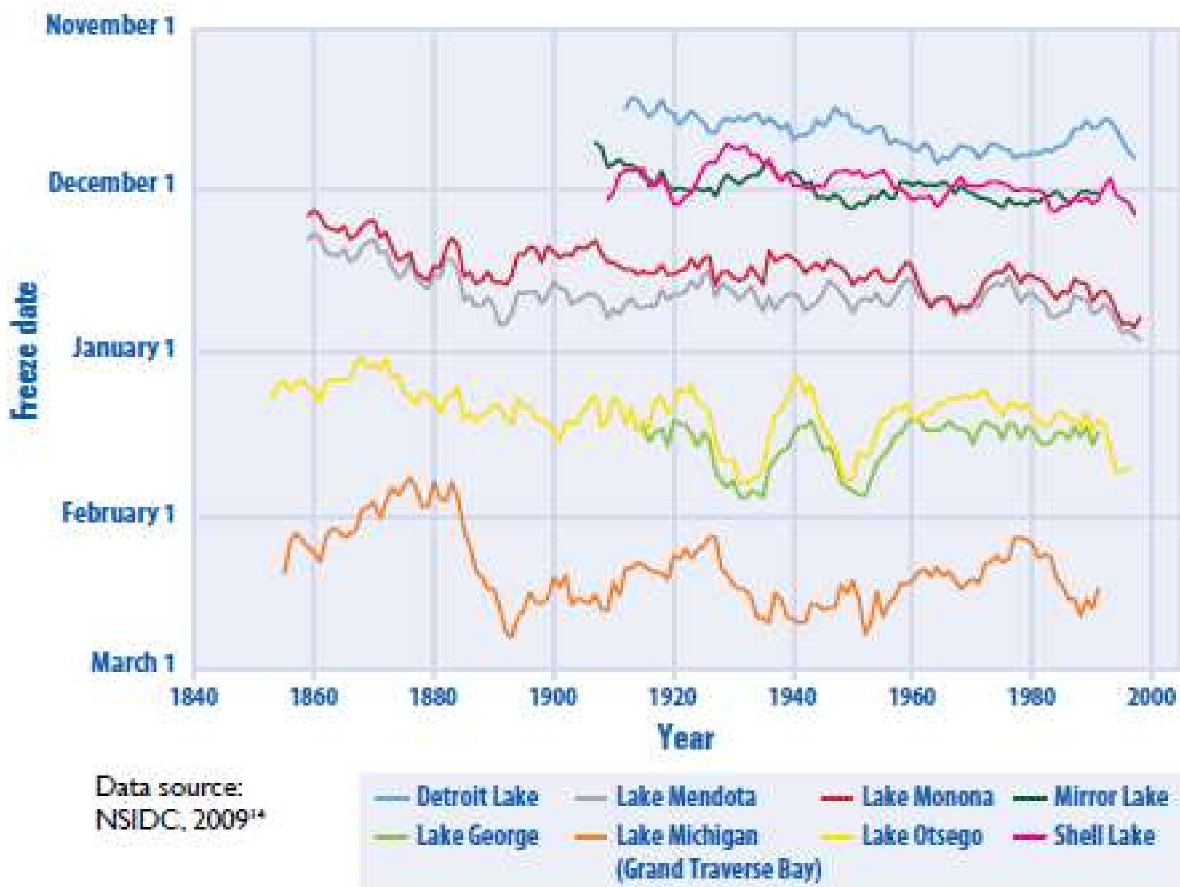
Figure 1. Duration of Ice Cover for Selected U.S. Lakes, 1850–2000

This figure displays the duration (in days) of ice cover for eight U.S. lakes. The data are available from approximately 1850 to 2000, depending on the lake, and have been smoothed using a nine-year moving average.

Data source: NSIDC, 2009[12]

Figure 2. Ice Freeze Dates for Selected U.S. Lakes, 1850–2000

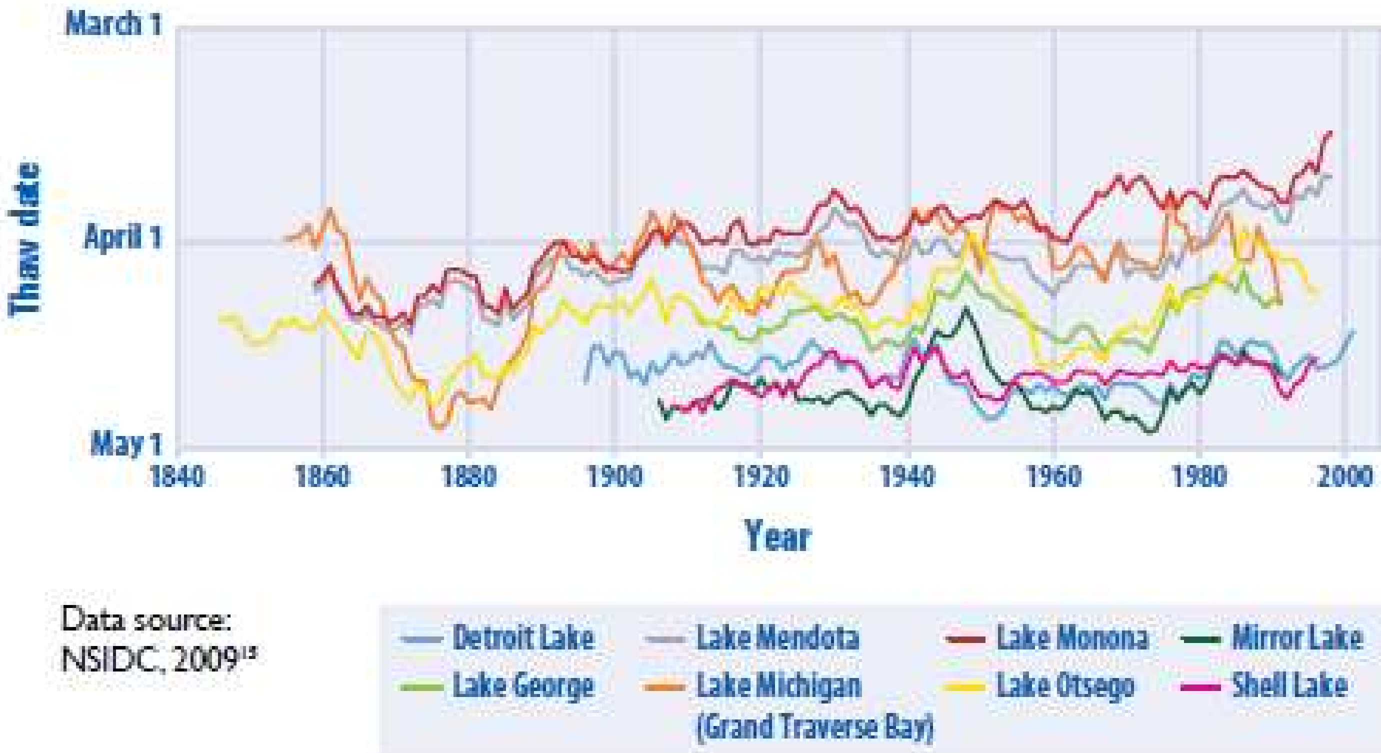
This figure shows the "ice-on" date, or date of first freeze, for eight U.S. lakes. The data are available from approximately 1850 to 2000, depending on the lake, and have been smoothed using a nine-year moving average.



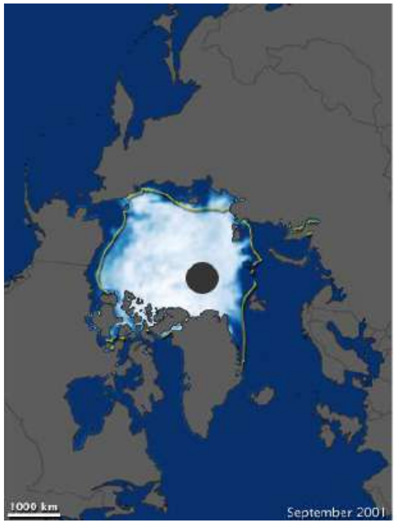
Data source: NSIDC, 2009[14]

Figure 3. Ice Thaw Dates for Selected U.S. Lakes, 1850–2000

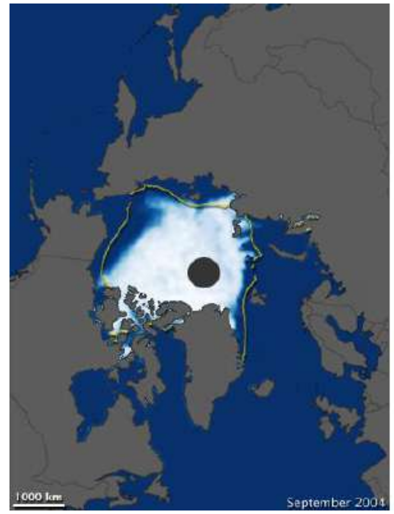
This figure shows the "ice-off" date, or date of ice thawing and breakup, for eight U.S. lakes. The data are available from approximately 1850 to 2000, depending on the lake, and have been smoothed using a nine-year moving average.



Data source: NSIDC, 2009[15]

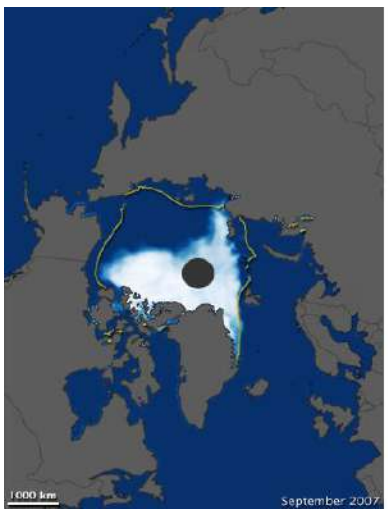


September 2001 March 2002

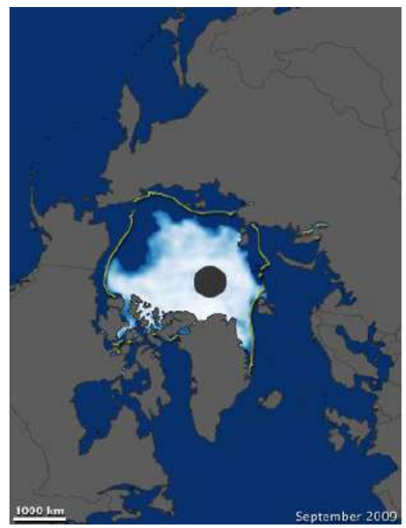


September 2004 March 2005

Black dot = North Pole Yellow lines indicate normal extent of ice



September 2007 March 2008

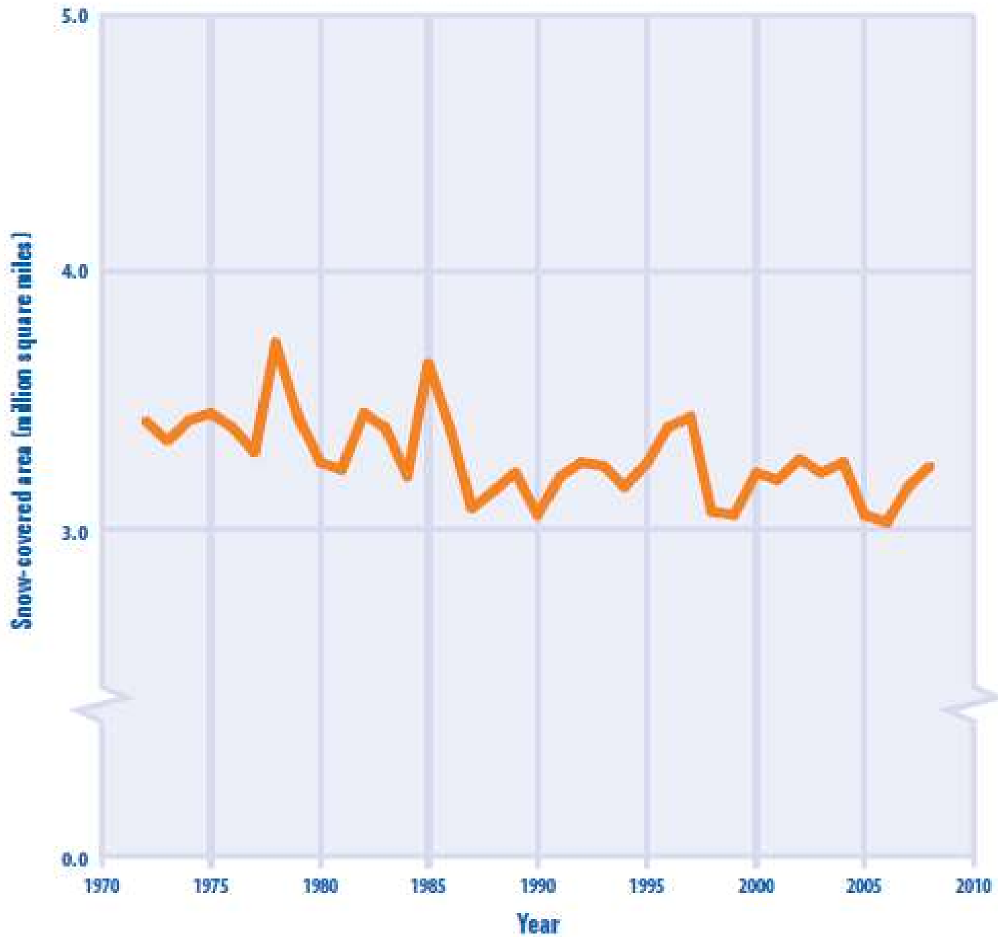


September 2009 March 2010

NASA Earth Observatory

Figure 1. Snow-Covered Area in North America, 1972–2008

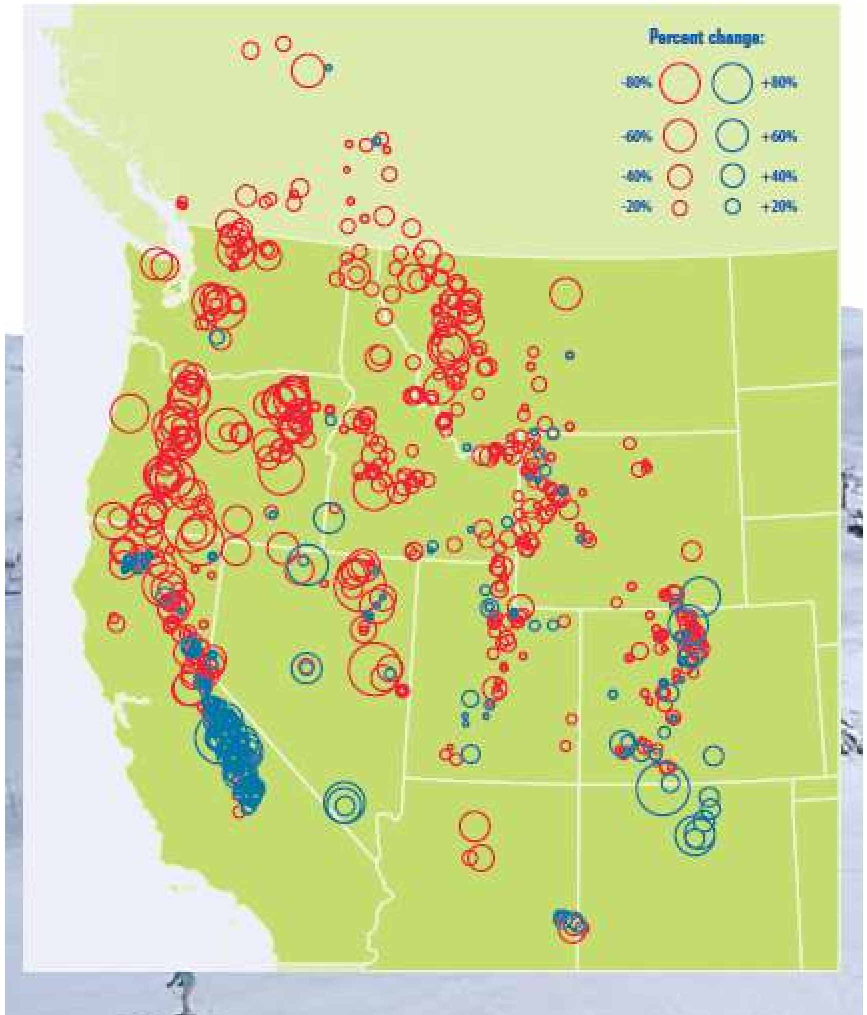
This graph shows the average area covered by snow in a given year, based on an analysis of weekly maps. The area is measured in square miles. These data cover all of North America.



Data source: Rutgers University Global Snow Lab, 2009[14]

Figure 1. Trends in April Snowpack in the Western United States and Canada, 1950–2000

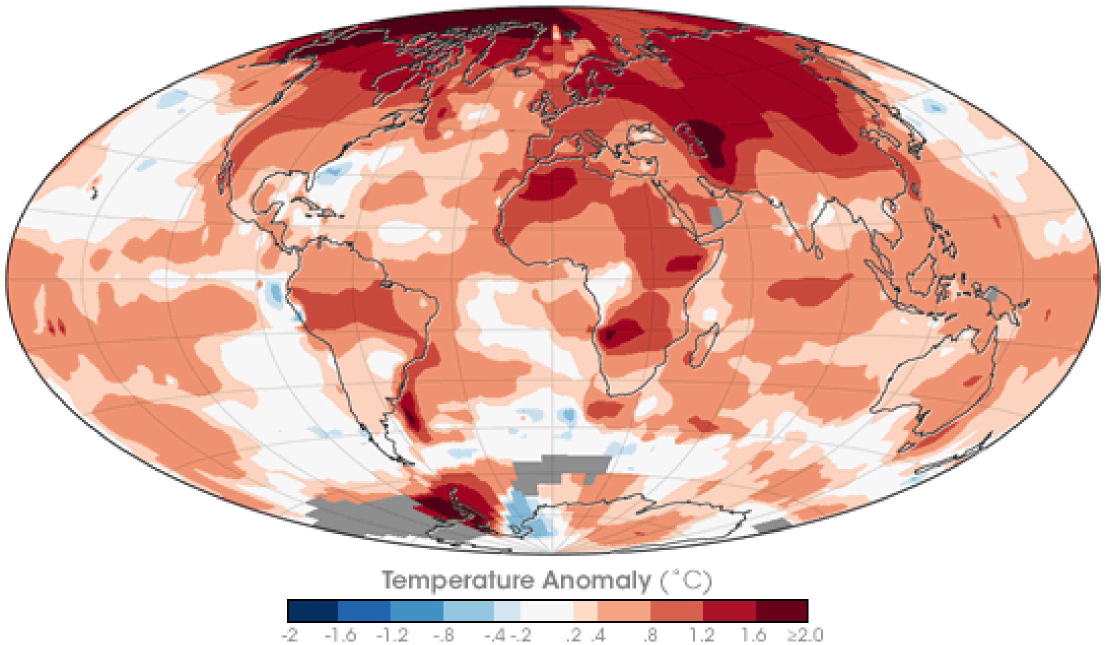
This map shows trends in snow water equivalent in the western United States and part of Canada. Negative trends are shown by red circles and positive trends by blue.



Data source: Mote, 2009[14]

Oceans

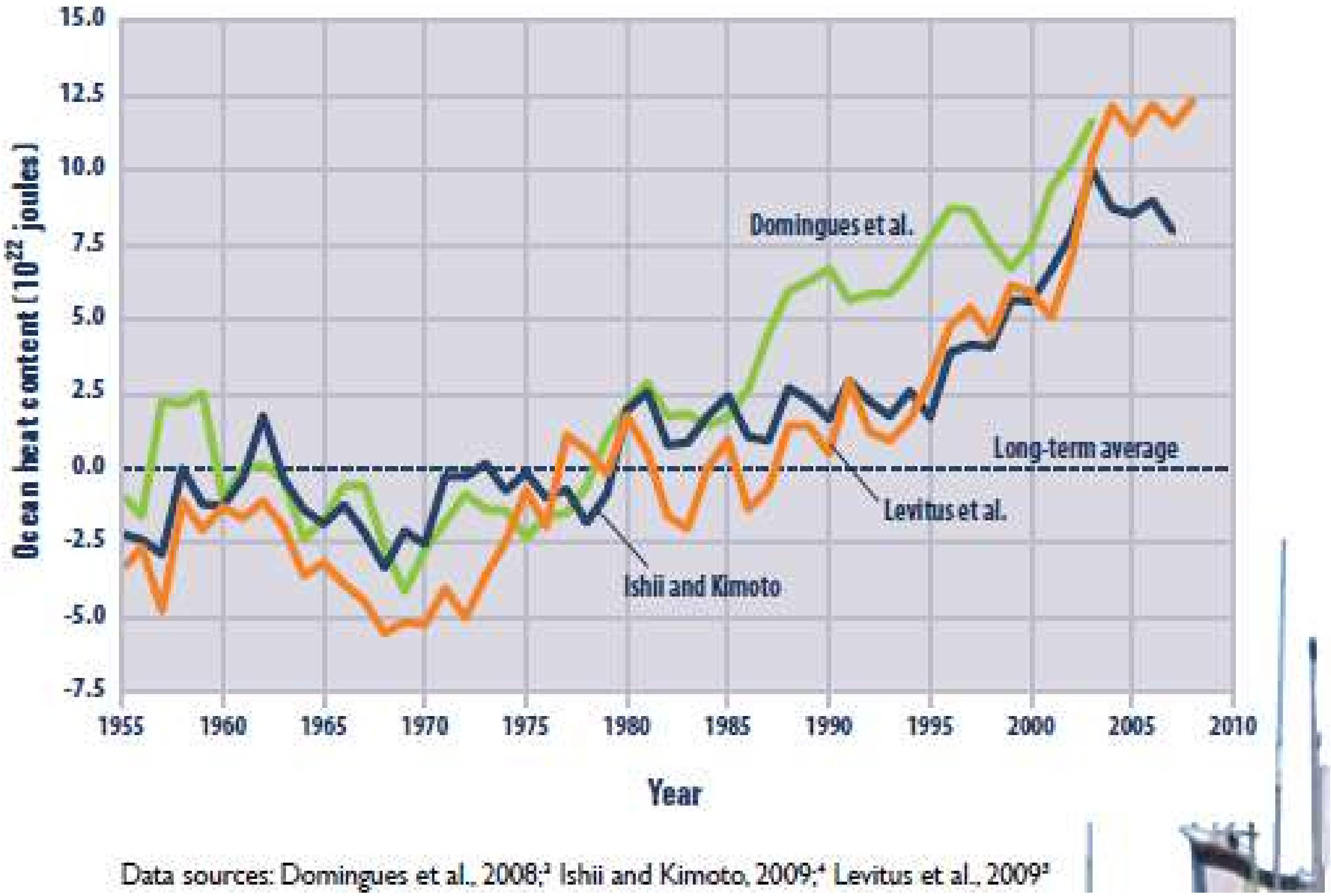
Temperature Change



Global temperature change, 1951 to 2006 (NASA)

Figure 1. Ocean Heat Content, 1955–2008

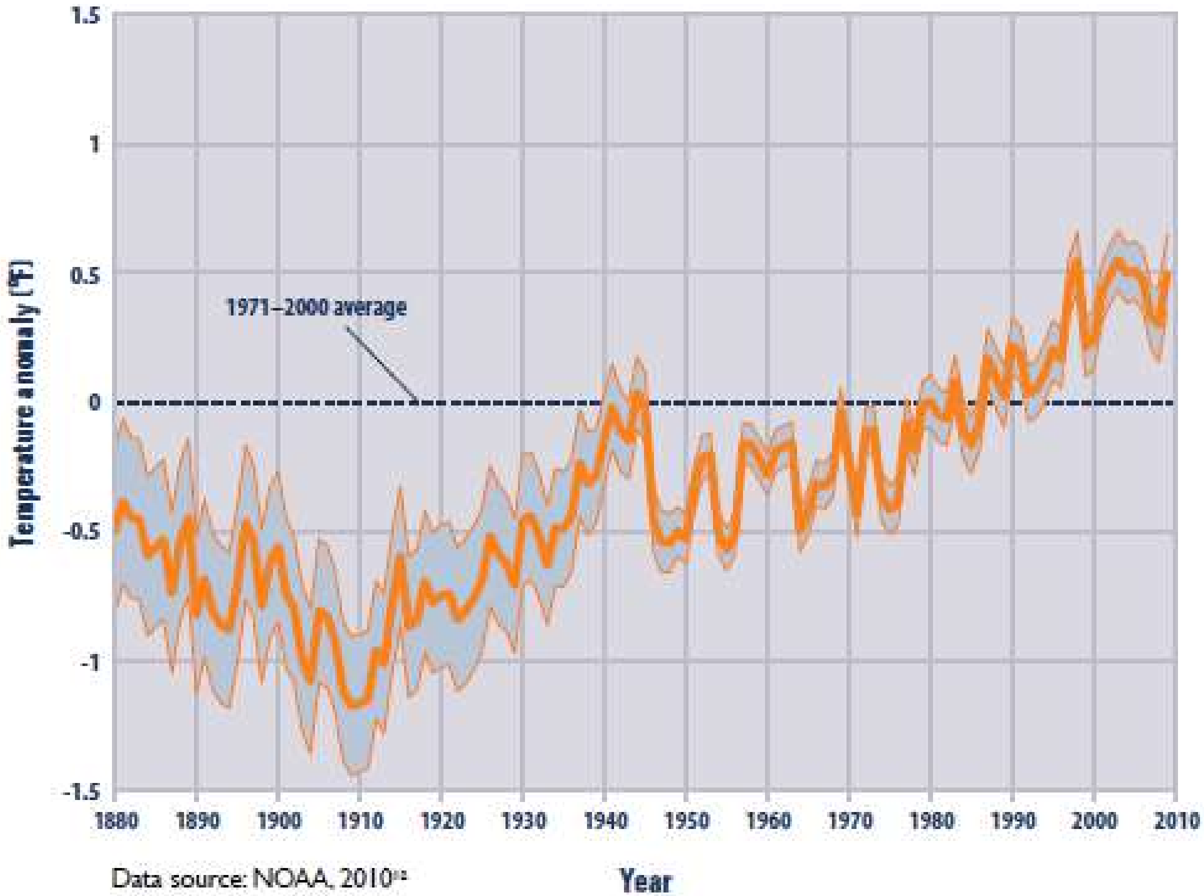
This figure shows changes in ocean heat content between 1955 and 2008. Ocean heat content is measured in joules, a unit of energy, and compared against the long-term average, which is set at zero.



Data sources: Domingues et al., 2008;[3] Ishii and Kimoto, 2009;[4] Levitus et al., 2009[5]

Figure 1. Average Global Sea Surface Temperature, 1880–2009

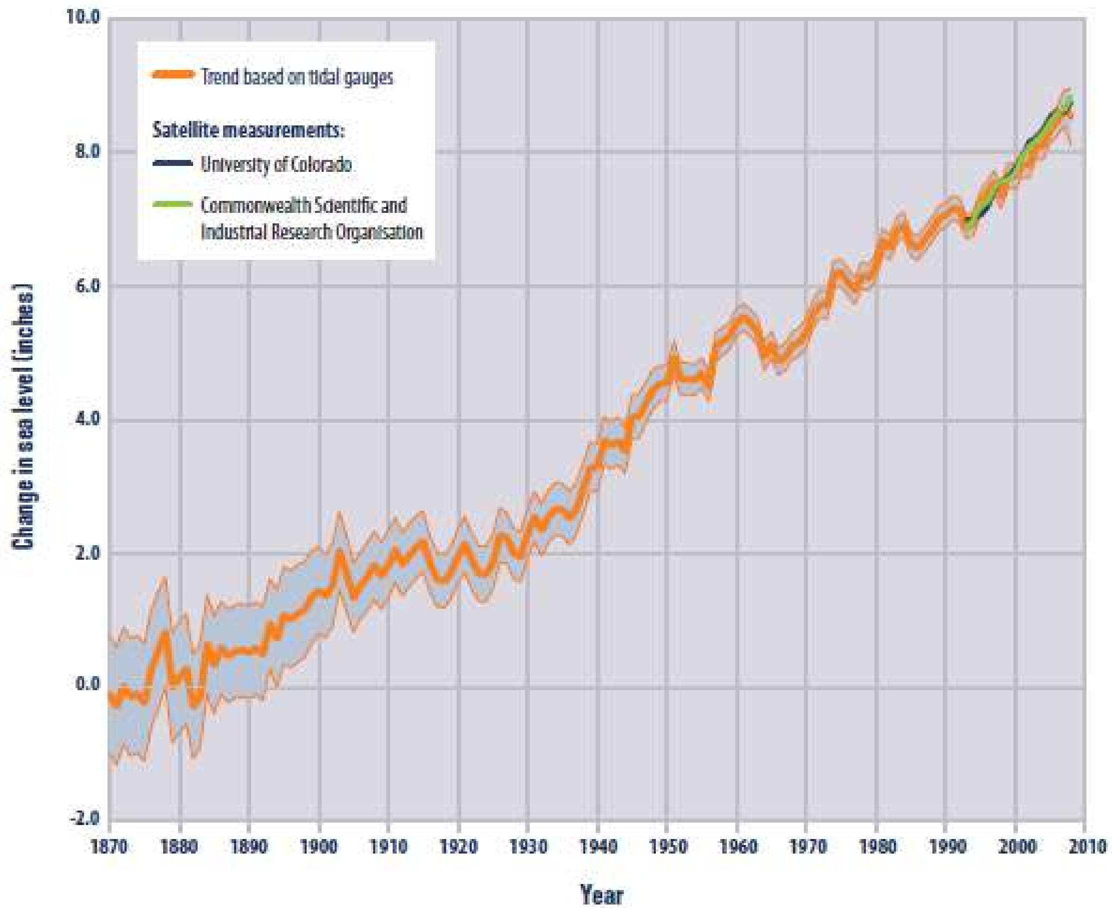
This graph shows how the average surface temperature of the world's oceans has changed since 1880. This graph uses the 1971 to 2000 average as a baseline for depicting change. Choosing a different baseline period would not change the shape of the trend. The shaded band shows the likely range of values, based on the number of measurements collected and the precision of the methods used.



Data source: NOAA, 2010[12]

Figure 1. Trends in Global Average Absolute Sea Level, 1870–2008

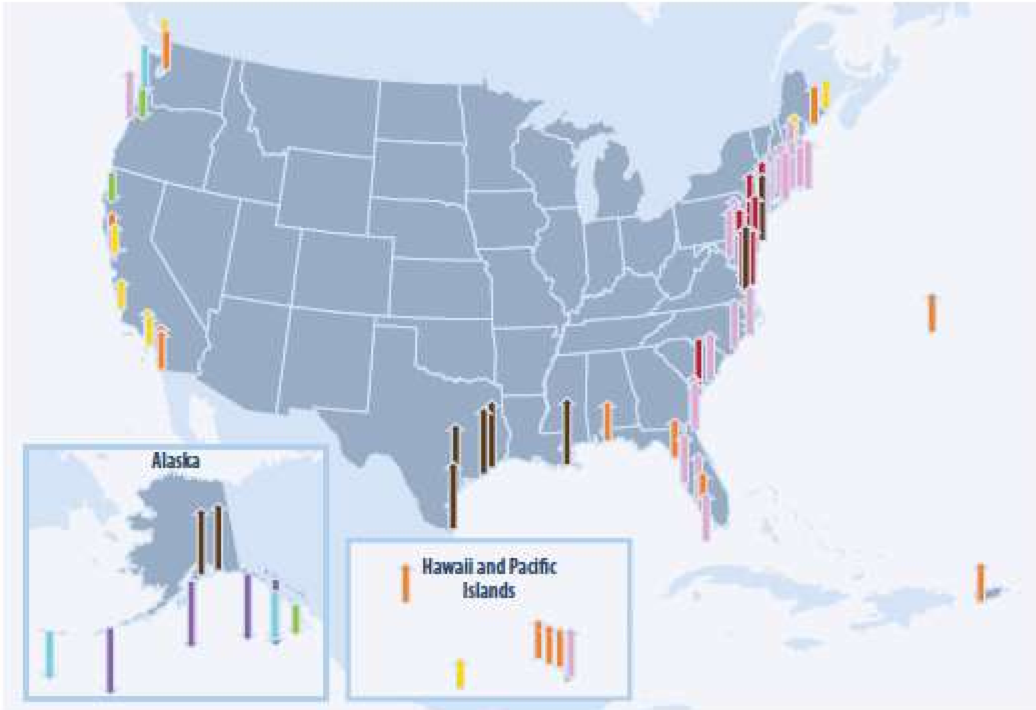
This graph shows how the average absolute sea level of the world's oceans has changed since 1870, based on a combination of long-term tidal gauge measurements and recent satellite measurements. Absolute sea level does not account for changes in land elevation. The shaded band shows the likely range of values, based on the number of measurements collected and the precision of the methods used.



Data sources: CSIRO, 2009;[14] University of Colorado at Boulder, 2009[15]

Figure 2. Trends in Relative Sea Level Along U.S. Coasts, 1958–2008

This map shows changes in relative sea level from 1958 to 2008 at tidal gauge stations along U.S. coasts. Relative sea level accounts for changes in sea level as well as land elevation.



Data source: NOAA, 2009[16]

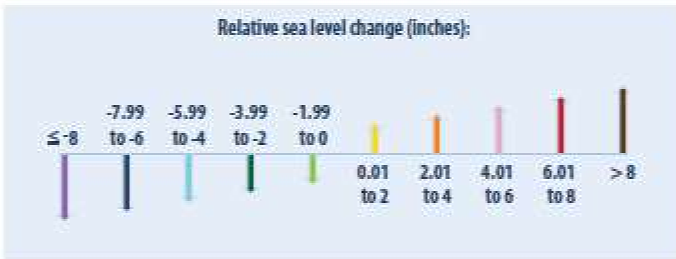
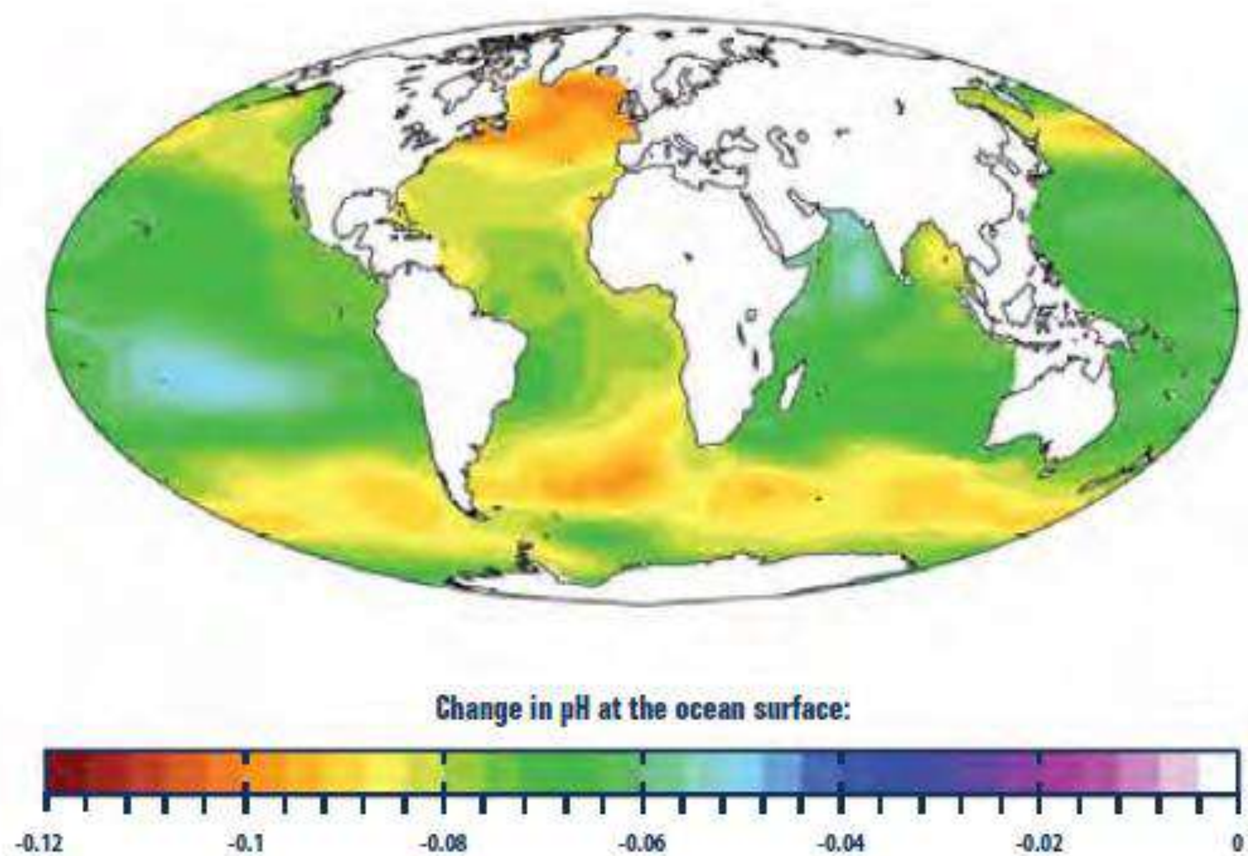


Figure 2. Historical Changes in Ocean Acidity, 1700s–1990s

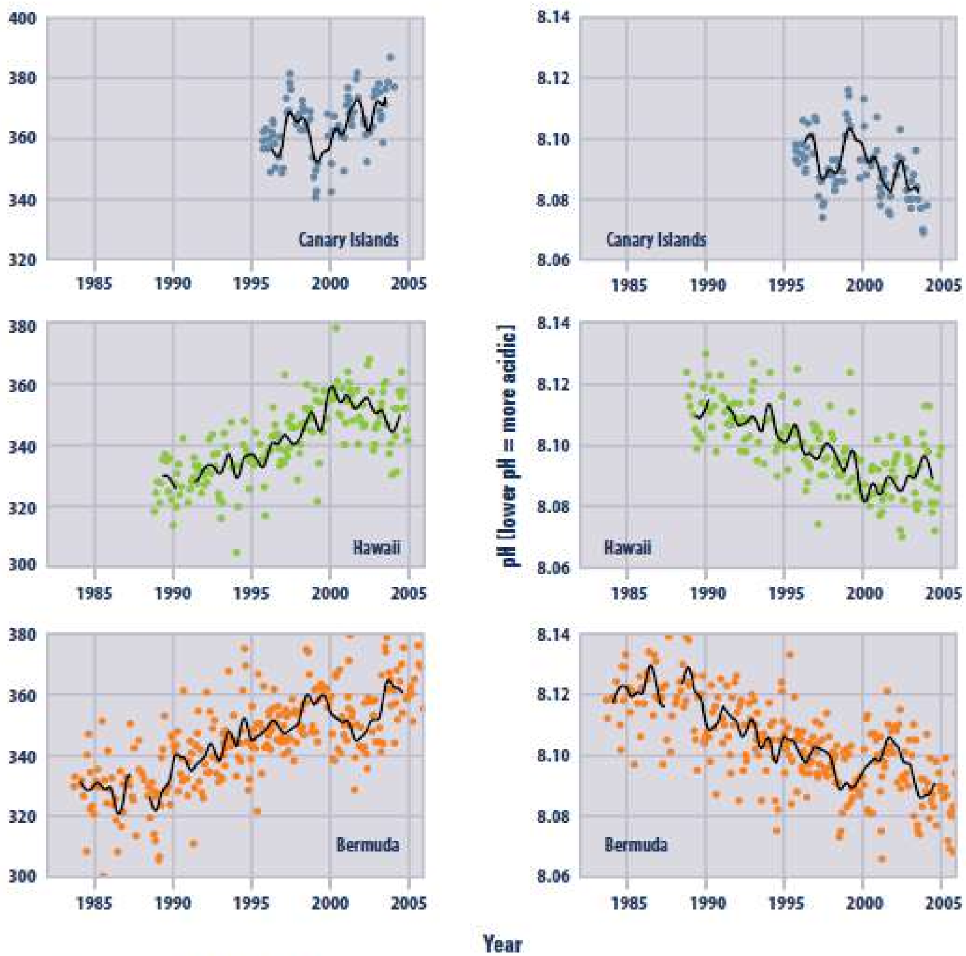
This figure shows changes in ocean pH levels around the world from pre-industrial times to the present based on modeled data.



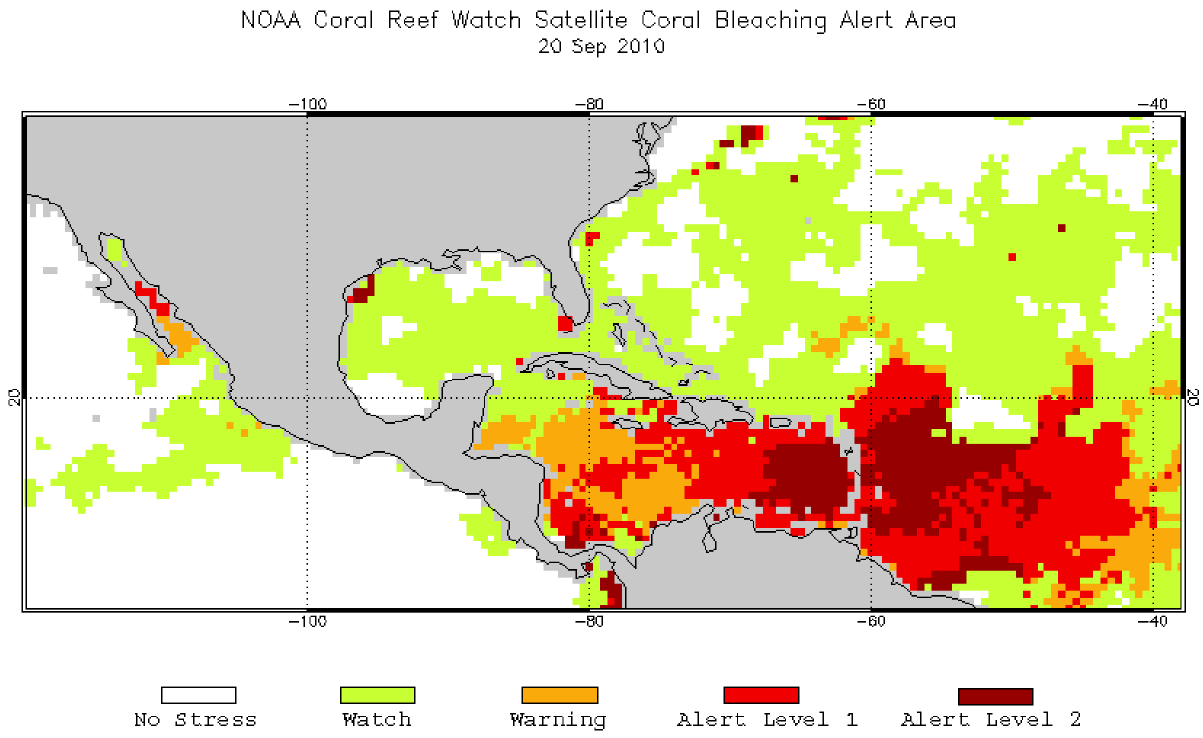
Data source: Yool, 2007[23]

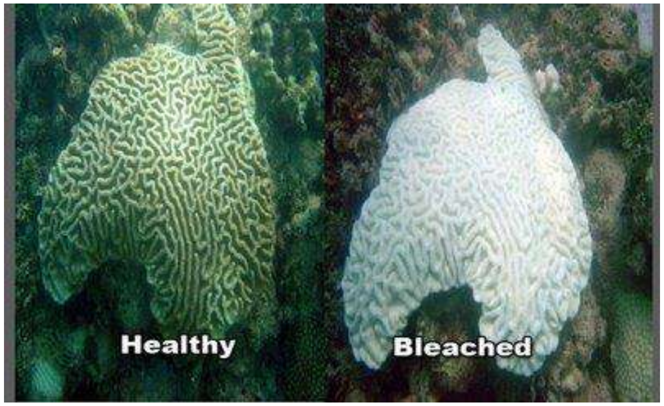
Figure 1. Ocean Carbon Dioxide Levels and Acidity, 1983–2005

This figure shows changes in ocean carbon dioxide levels (measured as a partial pressure) and acidity (measured as pH). The data come from two observation stations in the North Atlantic Ocean (Canary Islands and Bermuda) and one in the Pacific (Hawaii). Dots represent individual measurements, while the lines represent smoothed trends.

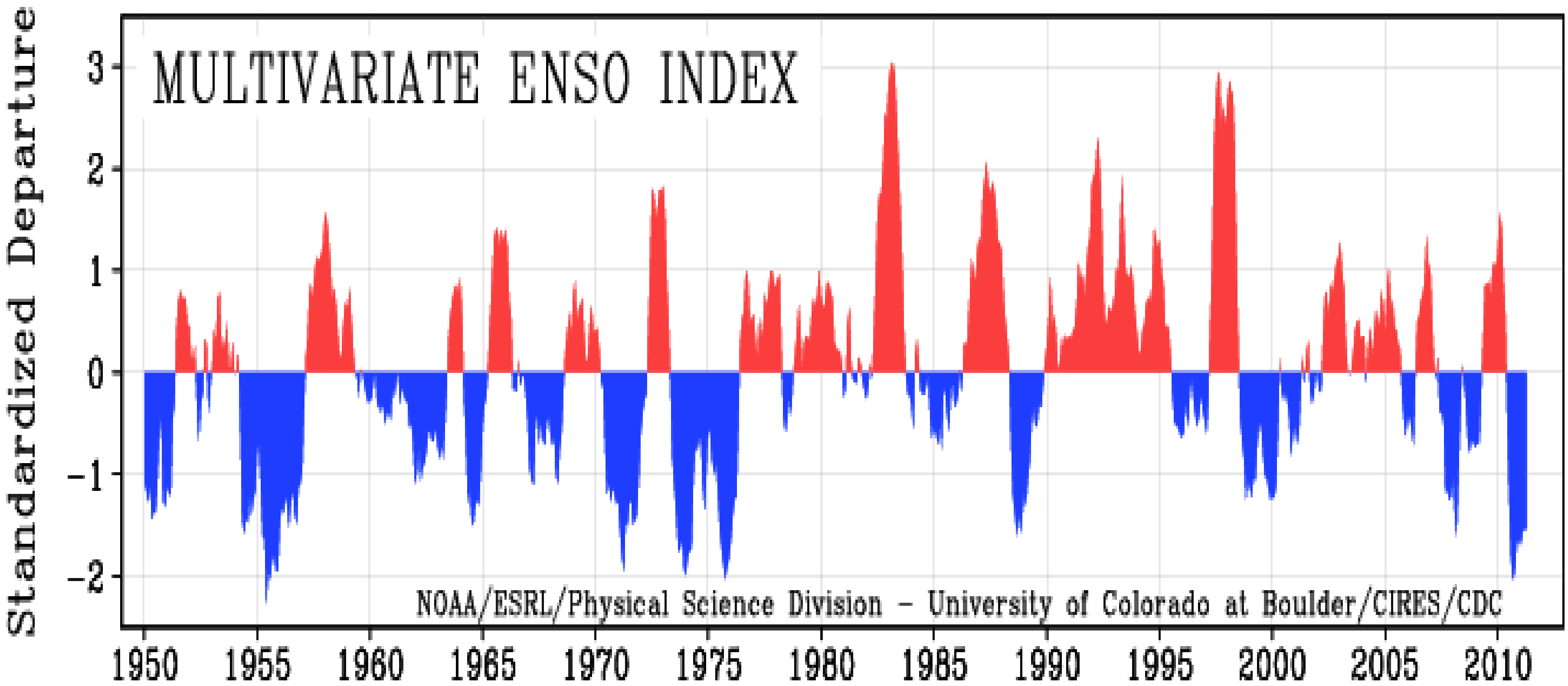


Data source: Bindoff et al., 2007[21]


NOAA Coral Reef Watch Satellite Coral Bleaching Alert Area
20 Sep 2010
−100
−80
−60
−40
20
No Stress
Watch
Warning
Alert Level 1
Alert Level 2

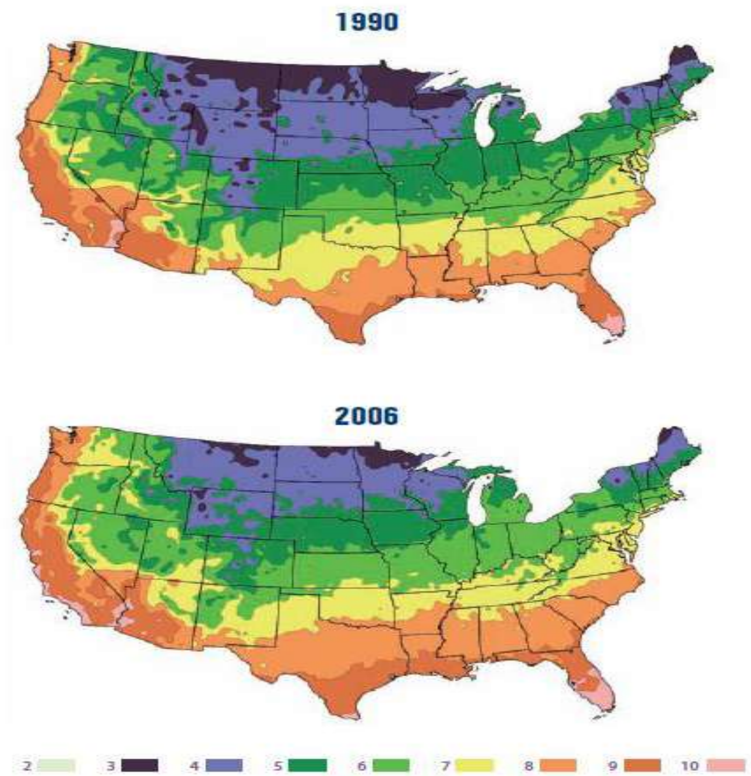

Healthy
Bleached

The chart below shows temperature changes in the Pacific Ocean waters off of the coast of Peru from 1950 to 2006. The red areas of the chart above the normal line record El Niño events.



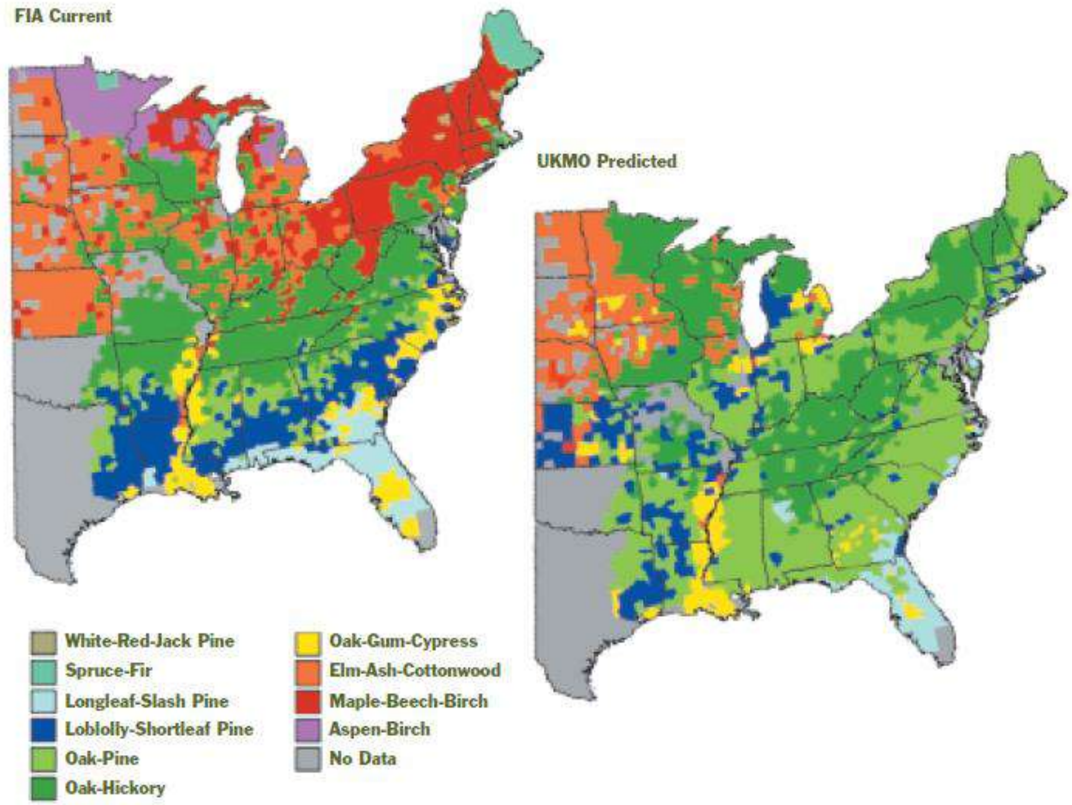
Vegetation

Change in Plant Hardiness Zones, 1990 to 2006



Source: Arbor Day Foundation. 2006. www.arborday.org/media/map_change.cfm

Plant hardiness zones are regional designations that help farmers and gardeners determine which plant species are expected to survive a typical winter. Locations are assigned a numbered plant hardiness zone based on an average of the lowest temperatures recorded each winter. This figure depicts plant hardiness zones in the lower 48 states in 1990 and 2006.

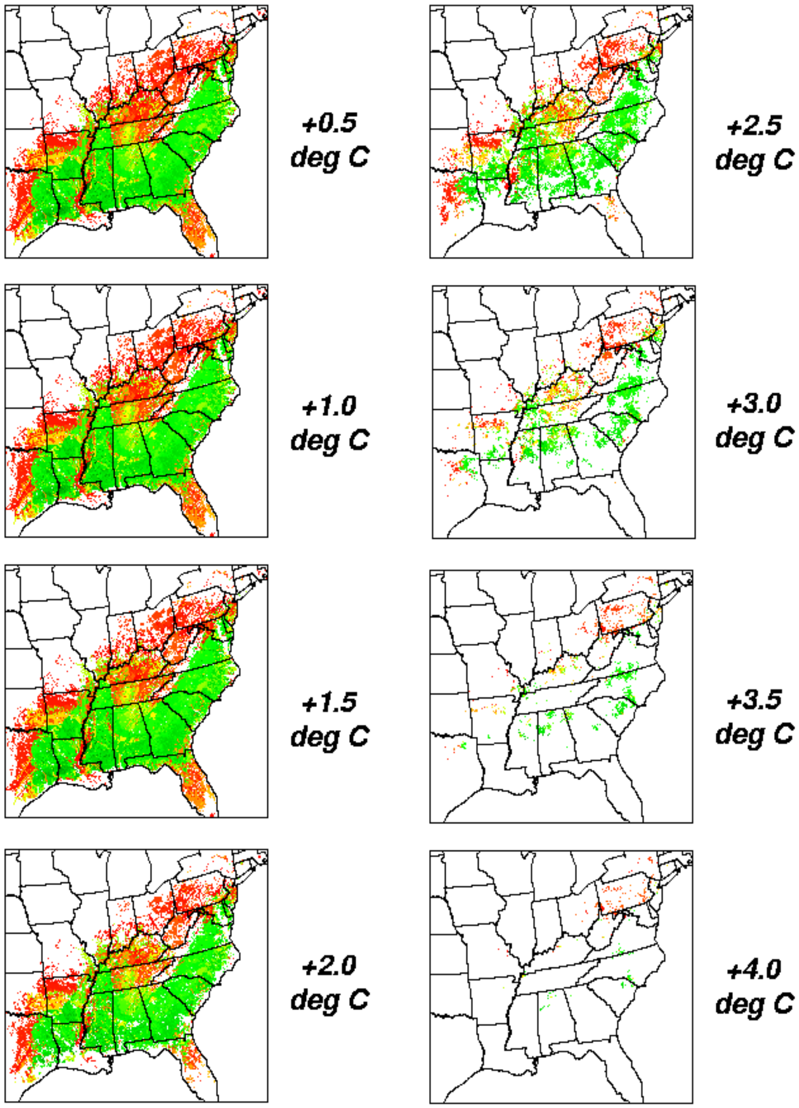


The above maps depict changes in the geographic distribution of major forest types in the eastern United States in response to climate change. Forest type categories were based upon the work of Iverson (1999). Left: Present distribution of forest types from the current USDA/Forest Service inventory (FIA) data. Right: Analogous forest type map generated under the climate conditions predicted by the United Kingdom Meteorological Office (UKMO) for a doubling of atmospheric CO_2.

Source: Iverson et al., 1999.


Canada
United States
Current range
Canada
United States
GFDL scenario

BEECH TREES



Loblolly Pine predicted range with temperature increases.

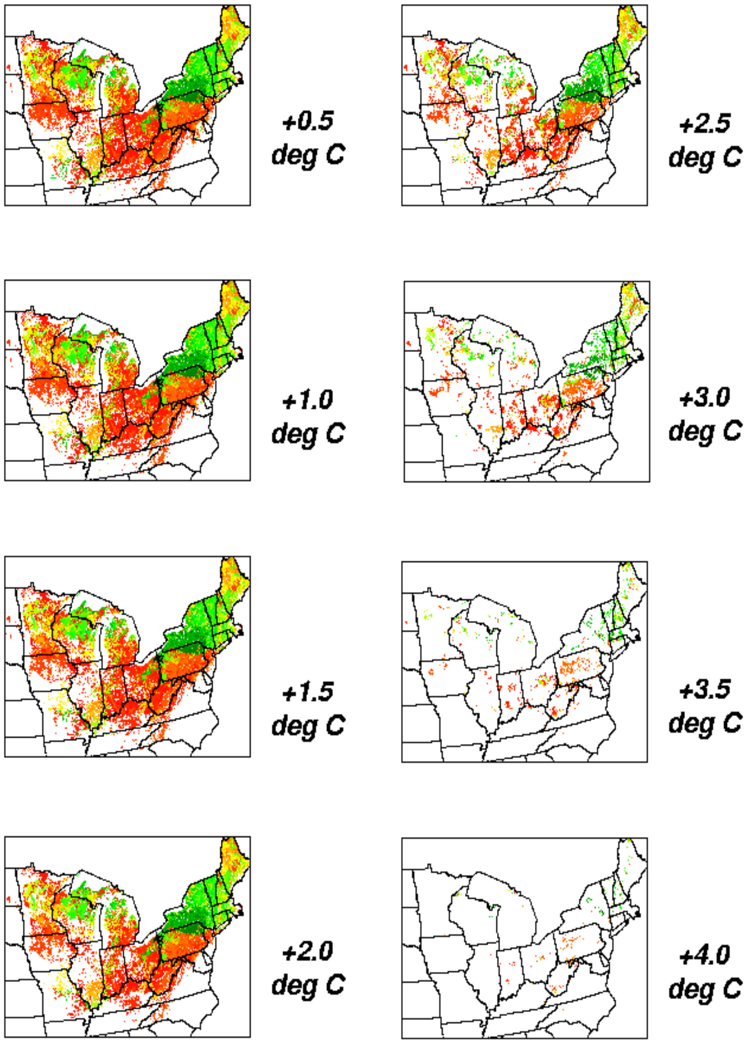
Green: High productive areas

Yellow: Average productive areas

Red: Low productive areas

Niche model geographic range prediction sequence for loblolly pine under a climate scenario of geographically uniform increase in mean, maximum, and minimum annual temperature, by half degree increments.

http://www.colorado.edu/research/cires/banff/pubpapers/104/



Sugar Maple predicted range with temperature increases.

Green: High productive areas

Yellow: Average productive areas

Red: Low productive areas

Niche model geographic range prediction sequence for sugar maple under a climate scenario of geographically uniform increase in mean, maximum, and minimum annual temperature, by half degree increments.

http://www.colorado.edu/research/cires/banff/pubpapers/104/

Figure 1. Length of Growing Season in the Lower 48 States, 1900–2002

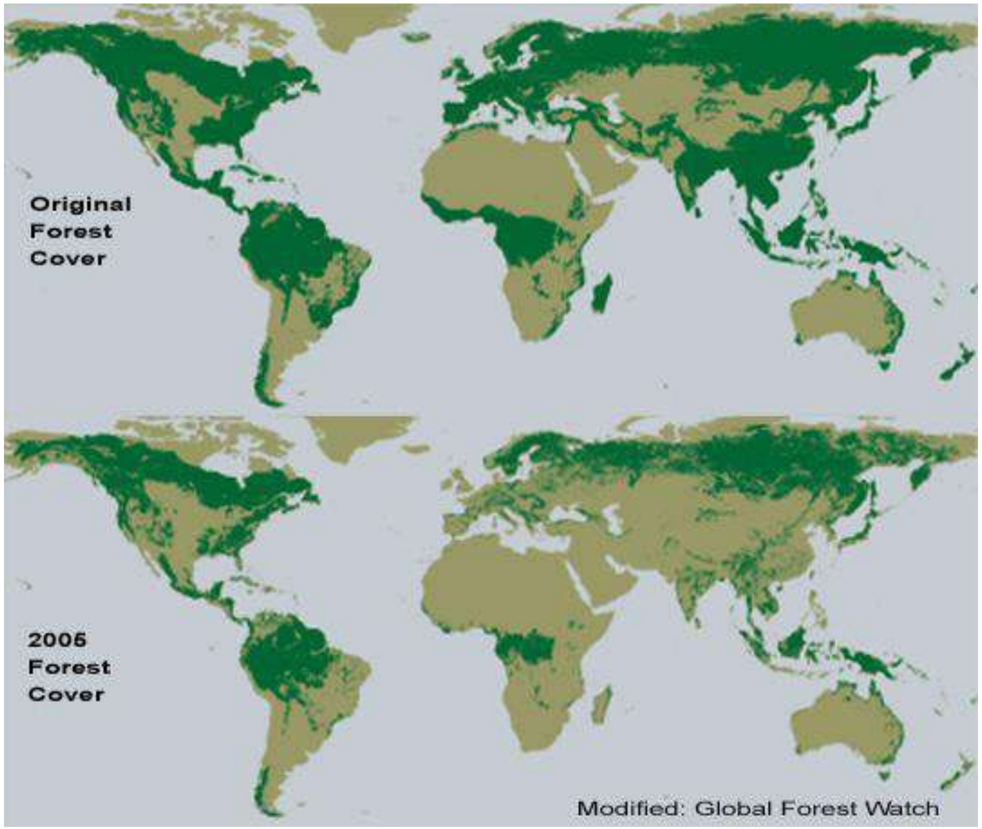
This figure shows the length of the growing season in the lower 48 states compared with a long-term average. For each year, the line represents the number of days shorter or longer than average. The trend line was smoothed using an 11-year moving average. Choosing a different long-term average for comparison would not change the shape of the trend.

Data source: Kunkel, 2009[a]

Figure 2. Length of Growing Season in the Lower 48 States, 1900–2002: West Versus East

This figure shows the length of the growing season in the western and eastern United States compared with a long-term average. The trend line was smoothed using an 11-year moving average. Choosing a different long-term average for comparison would not change the shape of the trends.

Data source: Kunkel, 2009*


Original
Forest
Cover
2005
Forest
Cover
Modified: Global Forest Watch

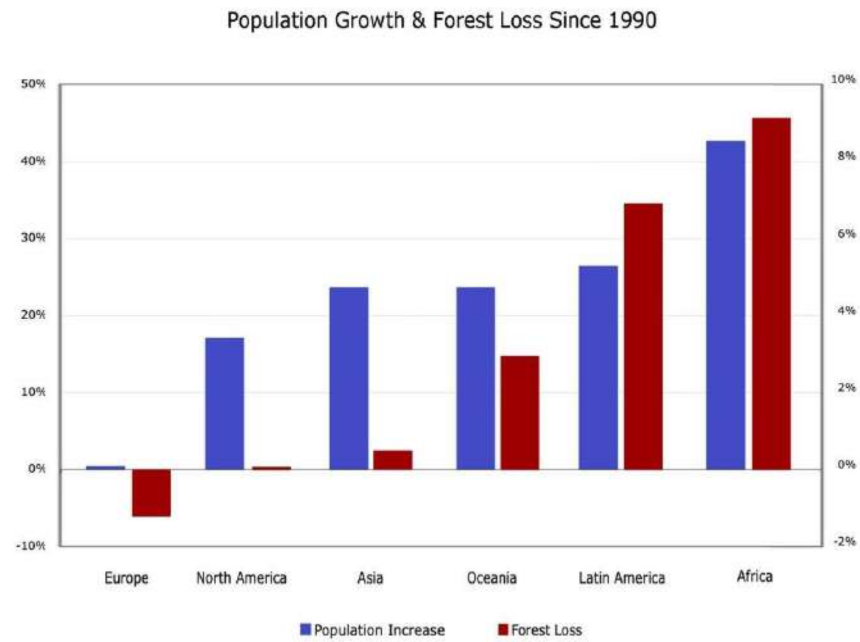
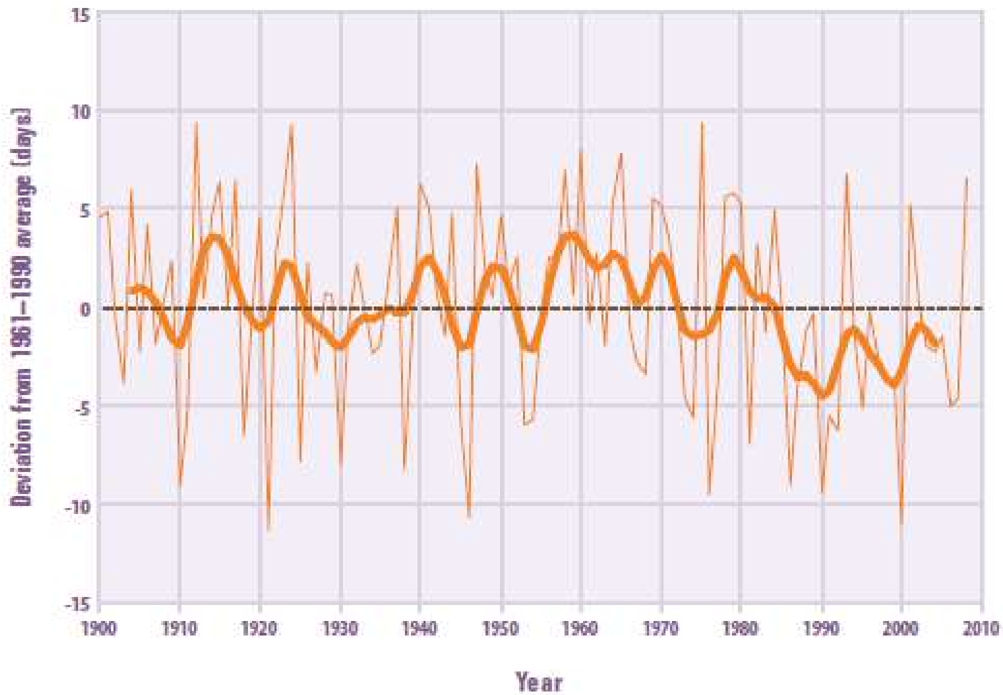

Population Growth & Forest Loss Since 1990
50%
40%
30%
20%
10%
0%
-10%
10%
8%
6%
4%
2%
0%
-2%
Europe
North America
Asia
Oceania
Latin America
Africa
Population Increase
Forest Loss

Figure 1. First Leaf Dates in the Lower 48 States, 1900–2008

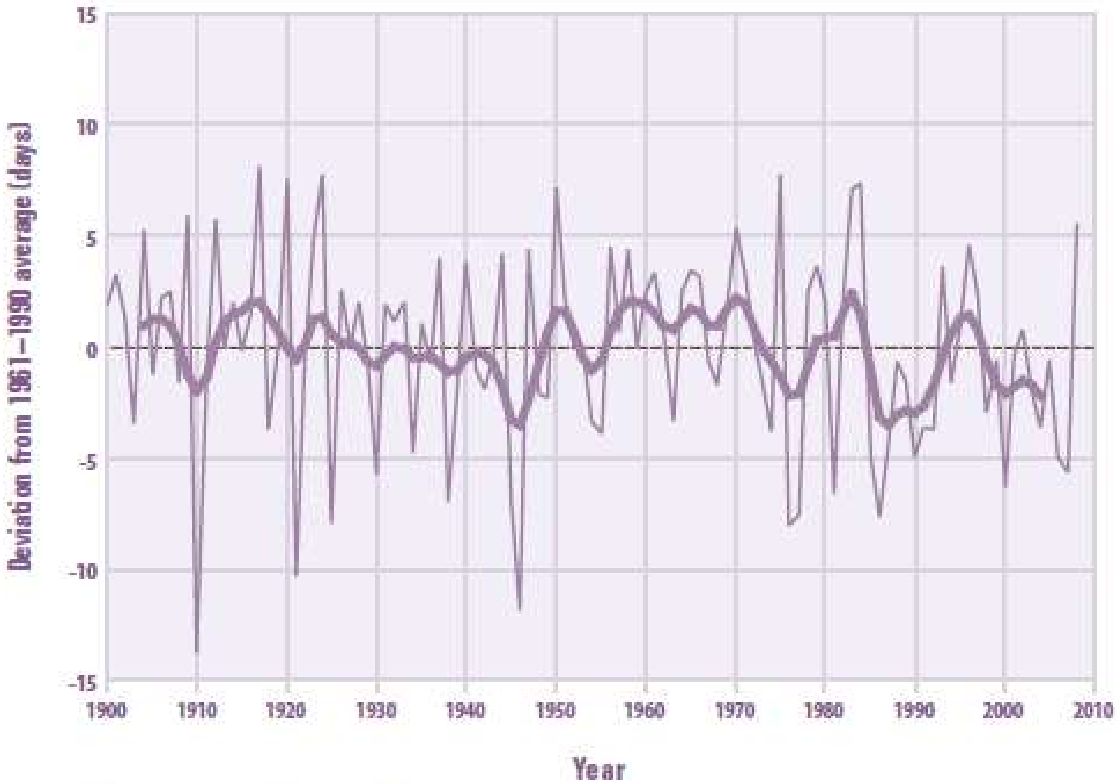
This figure shows modeled trends in lilac and honeysuckle first leaf dates across the lower 48 states, using the 1961 to 1990 average as a baseline. Positive values indicate that leaf growth began later in the year, and negative values indicate that leafing occurred earlier. The thicker line was smoothed using a nine-year weighted average. Choosing a different long-term average for comparison would not change the shape of the trend.



Data source: Schwartz, 2009[12]

Figure 2. First Bloom Dates in the Lower 48 States, 1900–2008

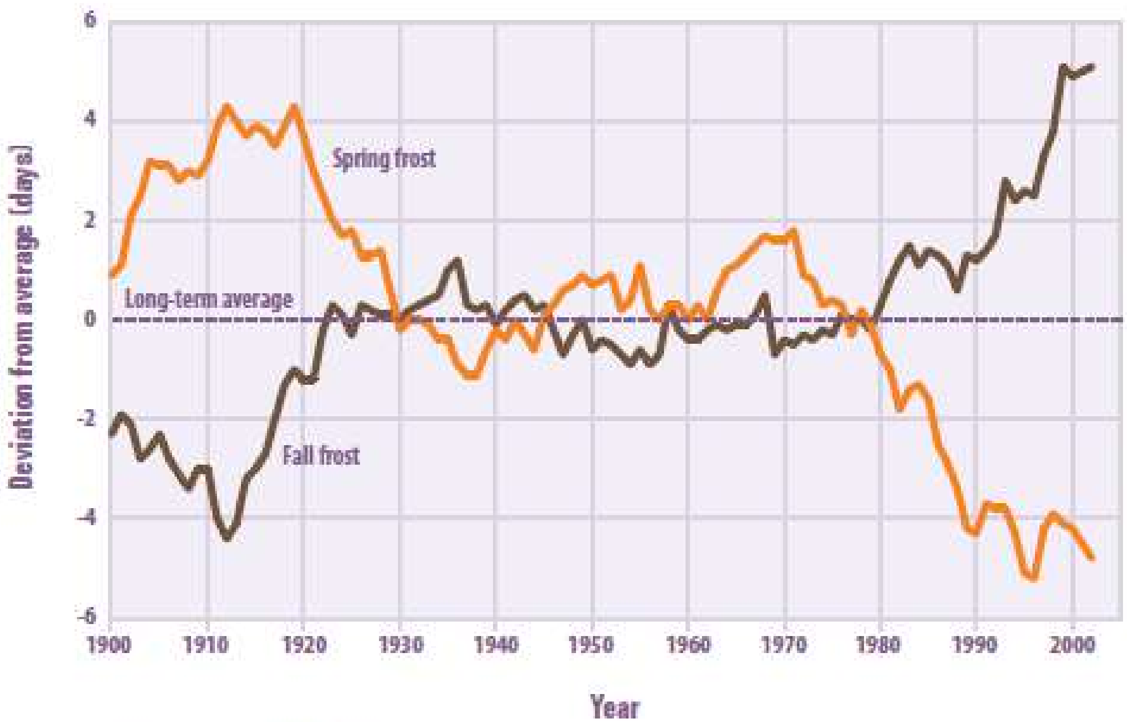
This figure shows modeled trends in lilac and honeysuckle bloom dates across the lower 48 states, using the 1961 to 1990 average as a baseline. Positive values indicate that blooming occurred later in the year, and negative values indicate that blooming occurred earlier. The thicker line was smoothed using a nine-year weighted average. Choosing a different long-term average for comparison would not change the shape of the trend.



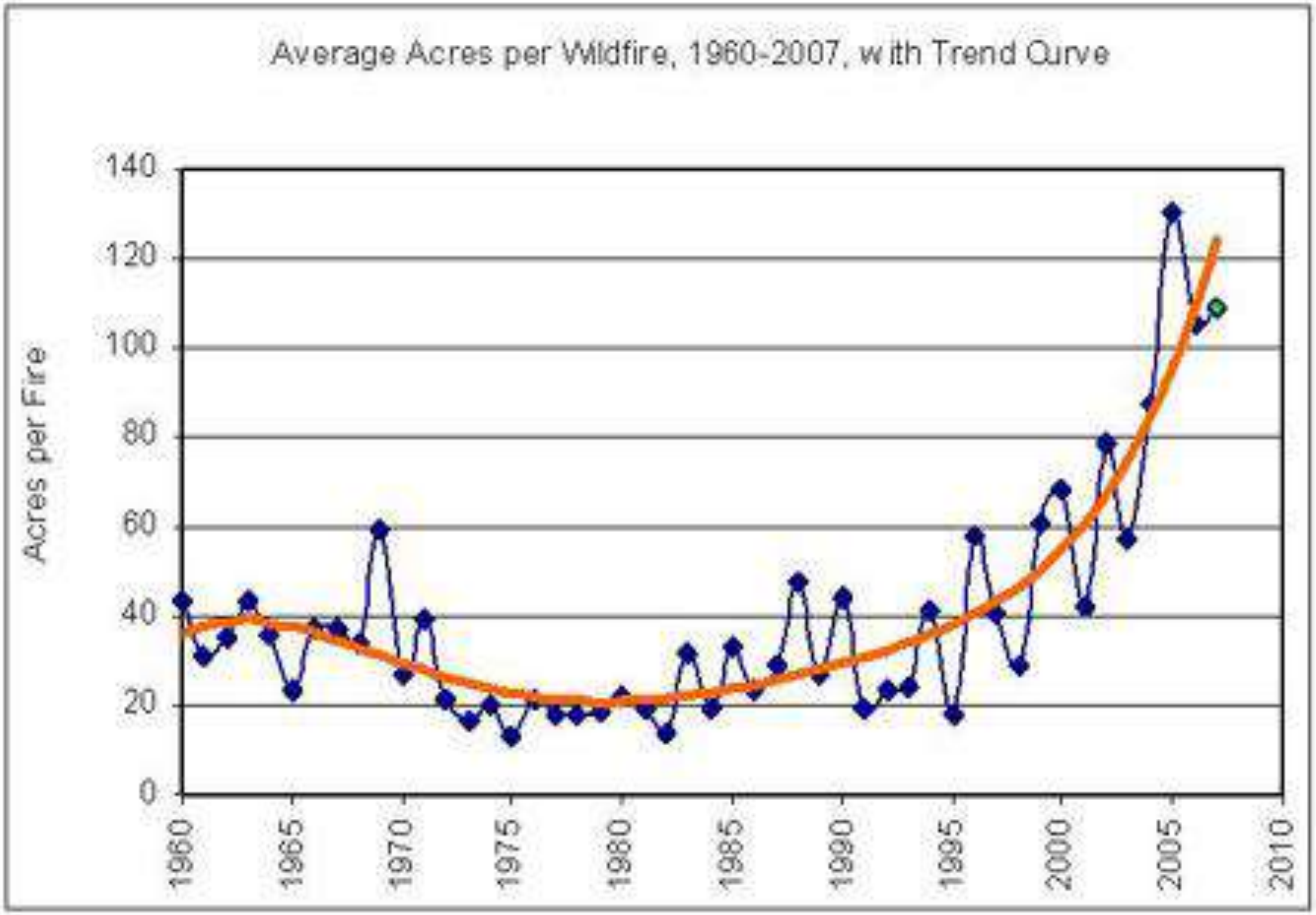
Data source: Schwartz, 2009[14]

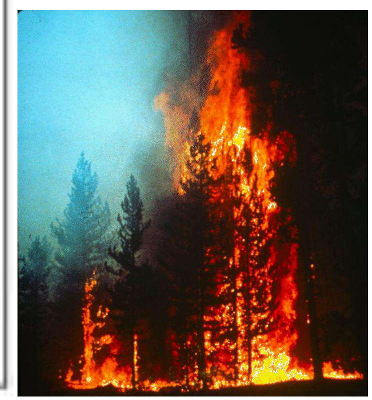
Figure 3. Timing of Last Spring Frost and First Fall Frost in the Lower 48 States, 1900–2002

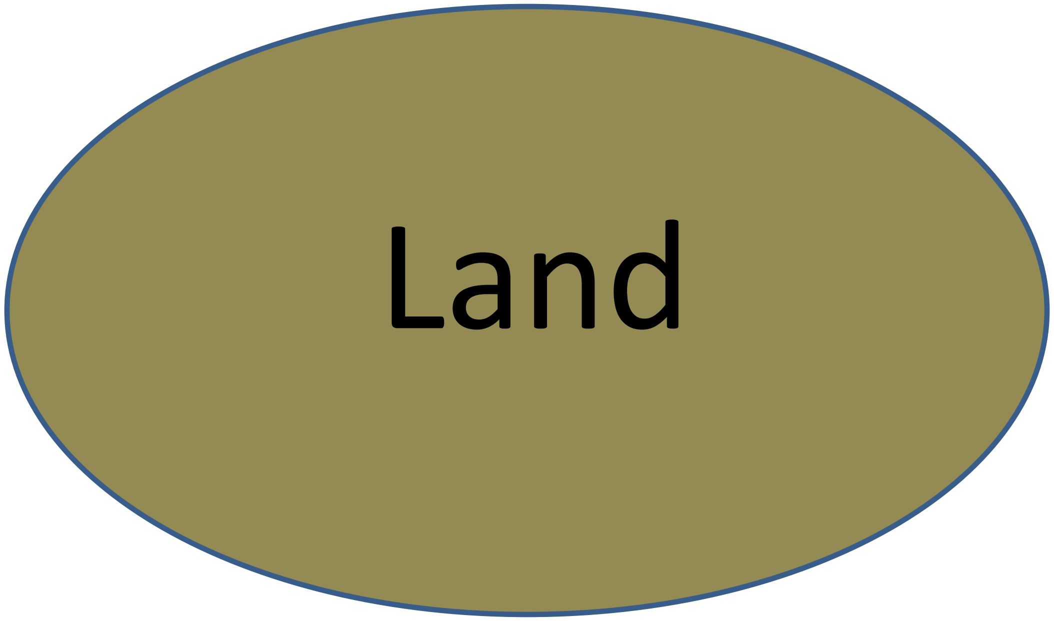
This figure shows the timing of the last spring frost and the first fall frost in the lower 48 states compared with a long-term average. Positive values indicate that the frost occurred later in the year, and negative values indicate that the frost occurred earlier in the year. The trend lines were smoothed using an 11-year moving average. Choosing a different long-term average for comparison would not change the shape of the trends.



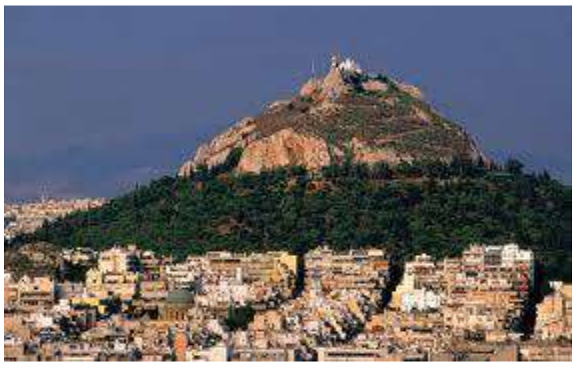
Data source: Kunkel, 2009[7]


Average Acres per Wildfire, 1960-2007, with Trend Curve
Acres per Fire
140
120
100
80
60
40
20
0
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010

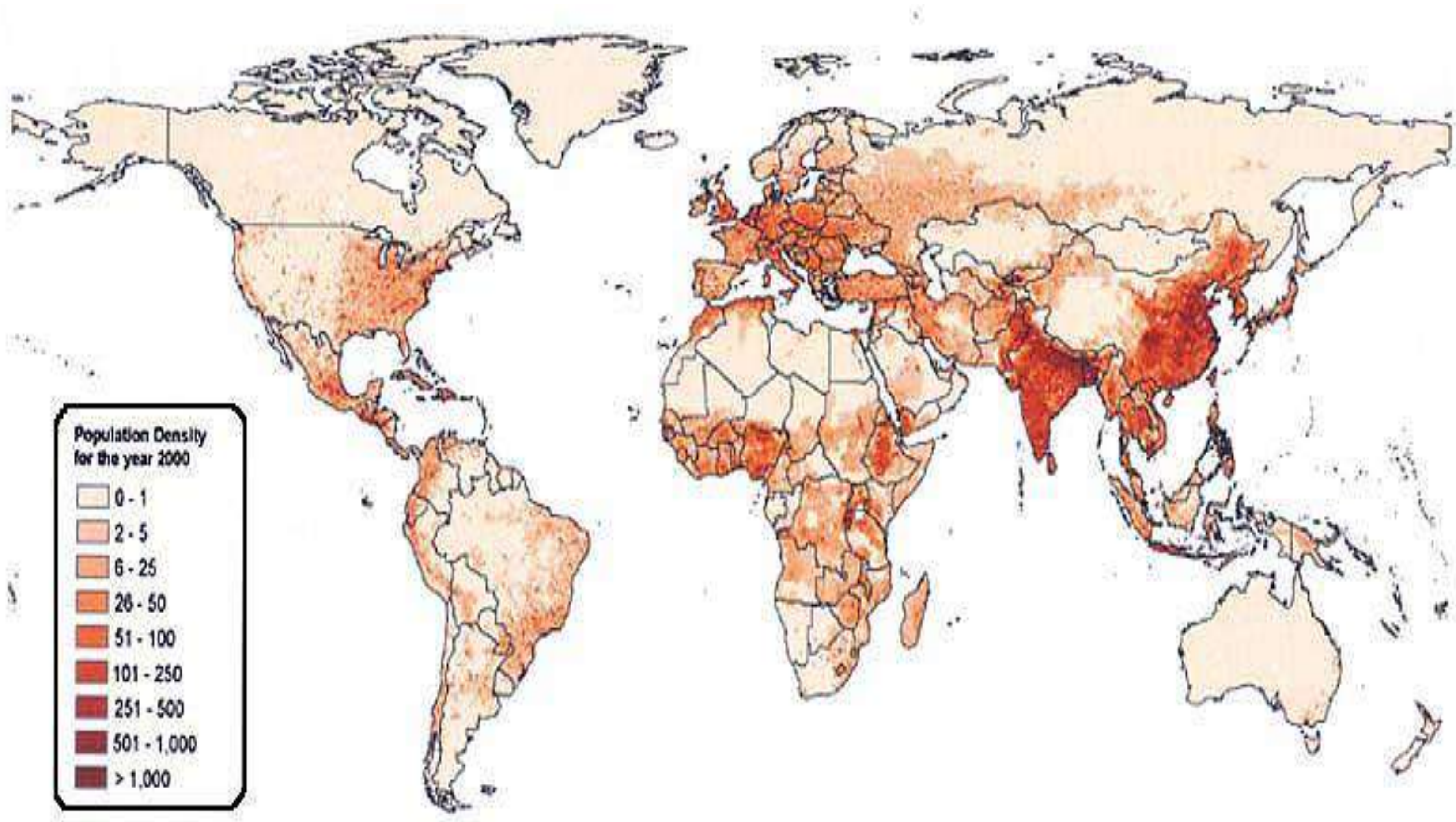



Land

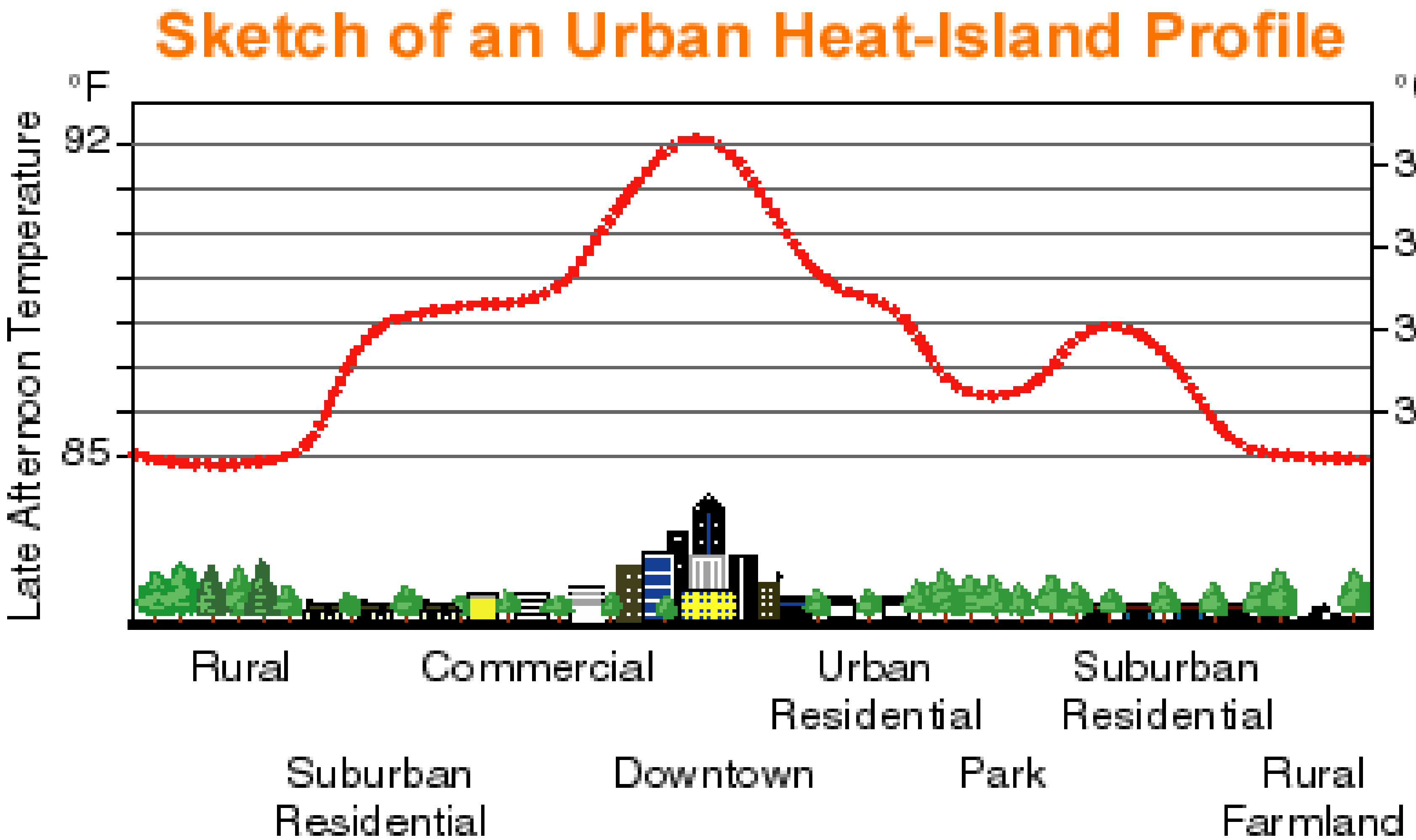



"We're waiting for the city to come to us..."

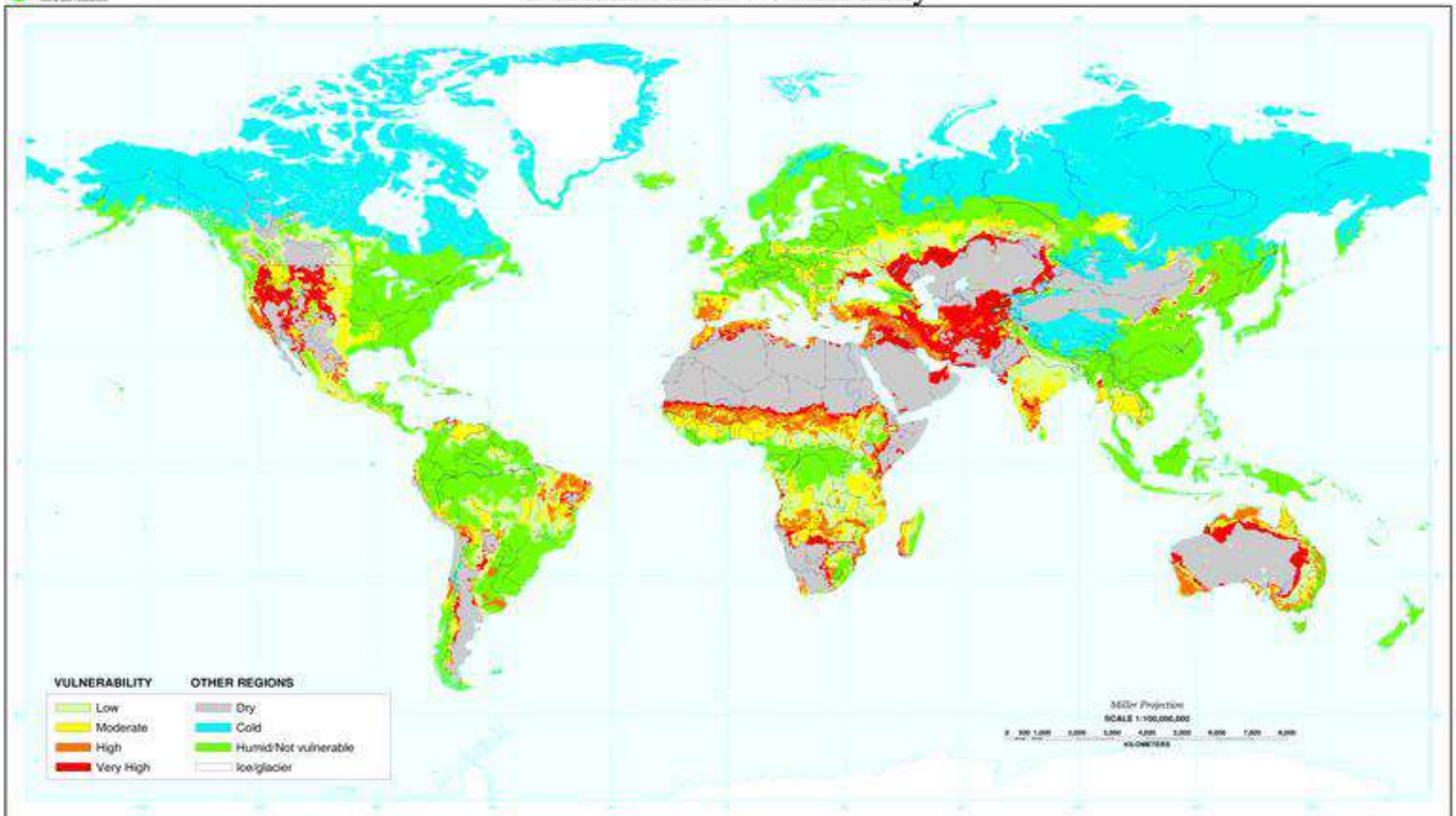
Source: Center for International Earth Science Information Network (CIESIN), Columbia University and Centro International de Agriculture Tropical (CIAT)


Sketch of an Urban Heat-Island Profile
°F
92
85
Late Afternoon Temperature
°C
33
32
31
30
Rural
Commercial
Urban Residential
Suburban Residential
Suburban Residential
Downtown
Park
Rural Farmland

Urban Environments and Climate

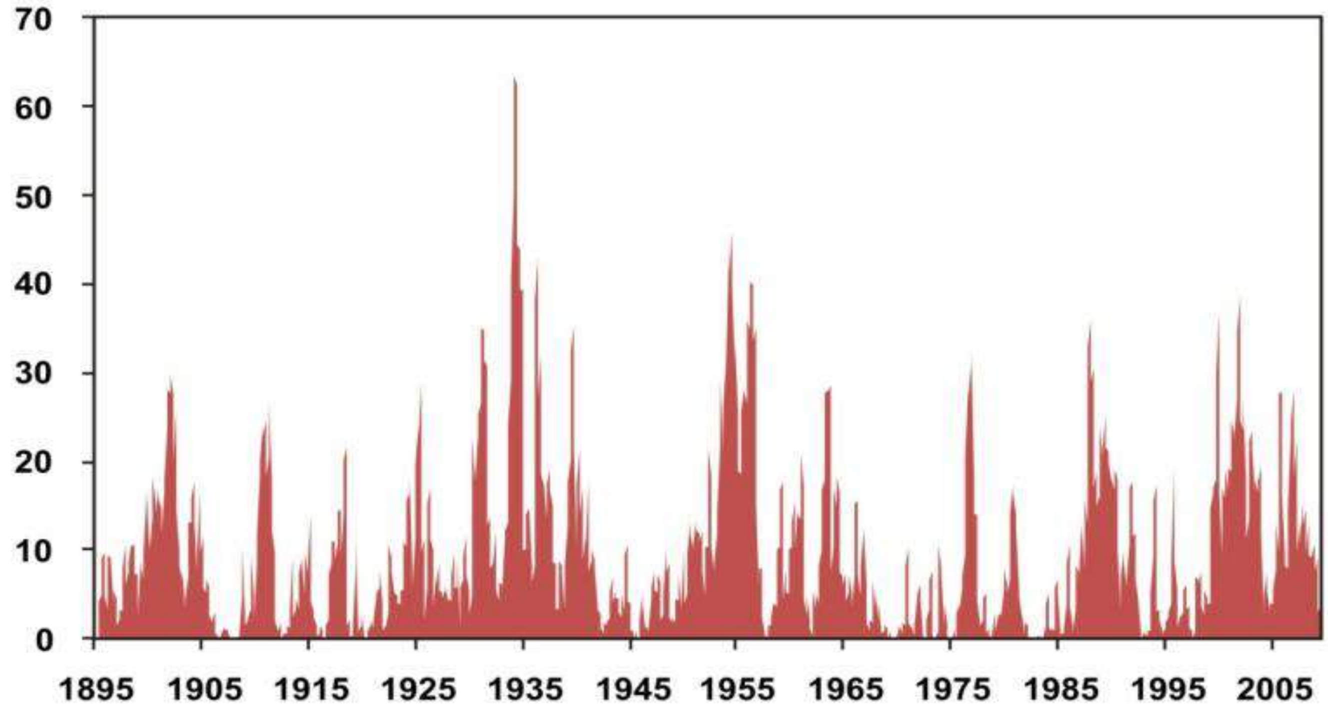
Environmental Parameter	**Impact**
Temperature	+2-8^{o}F annual mean +2-3 week freeze-free season
Wind	+5-20% calm days
Relative Humidity	-2% winter, -8% summer
Cloudiness	+5-10% cloud cover
Precipitation	+5-10% amount

Desertification Vulnerability



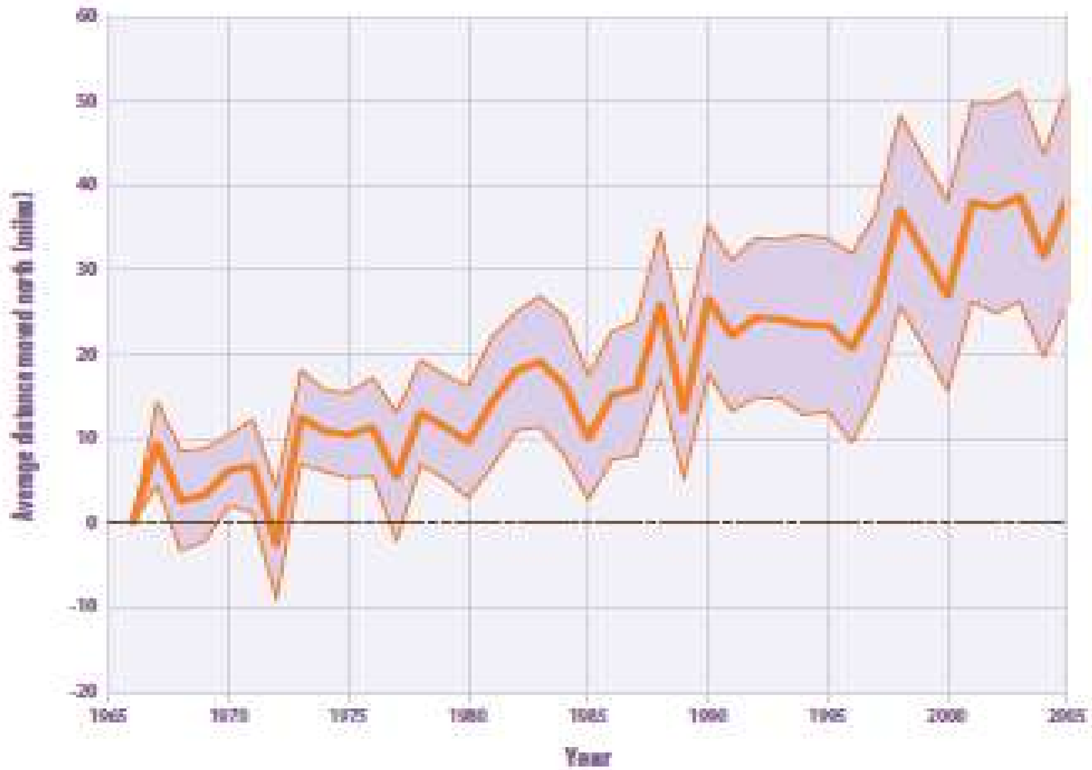
Percent Area of the United States in Severe and Extreme Drought

January 1895–February 2010



Based on data from the National Climatic Data Center/NOAA

Northward Shift of Bird Migrations, 1966–2005



Source: National Audubon Society. 2009. www.audubon.org/bird/bacc/techreport.html

Hundreds of species of birds in North America are wintering farther north in recent years.

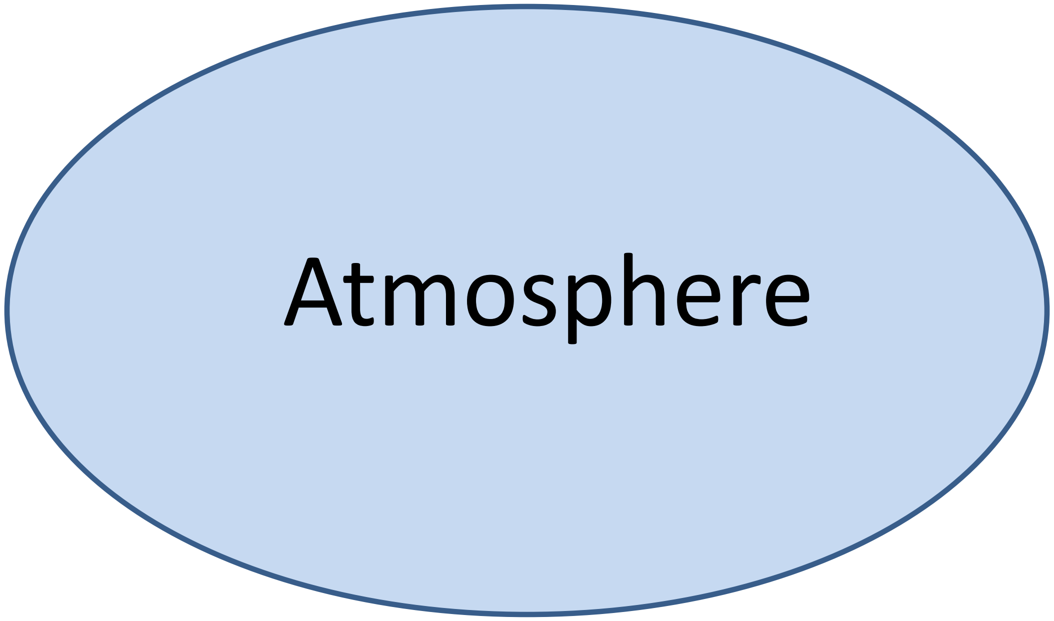
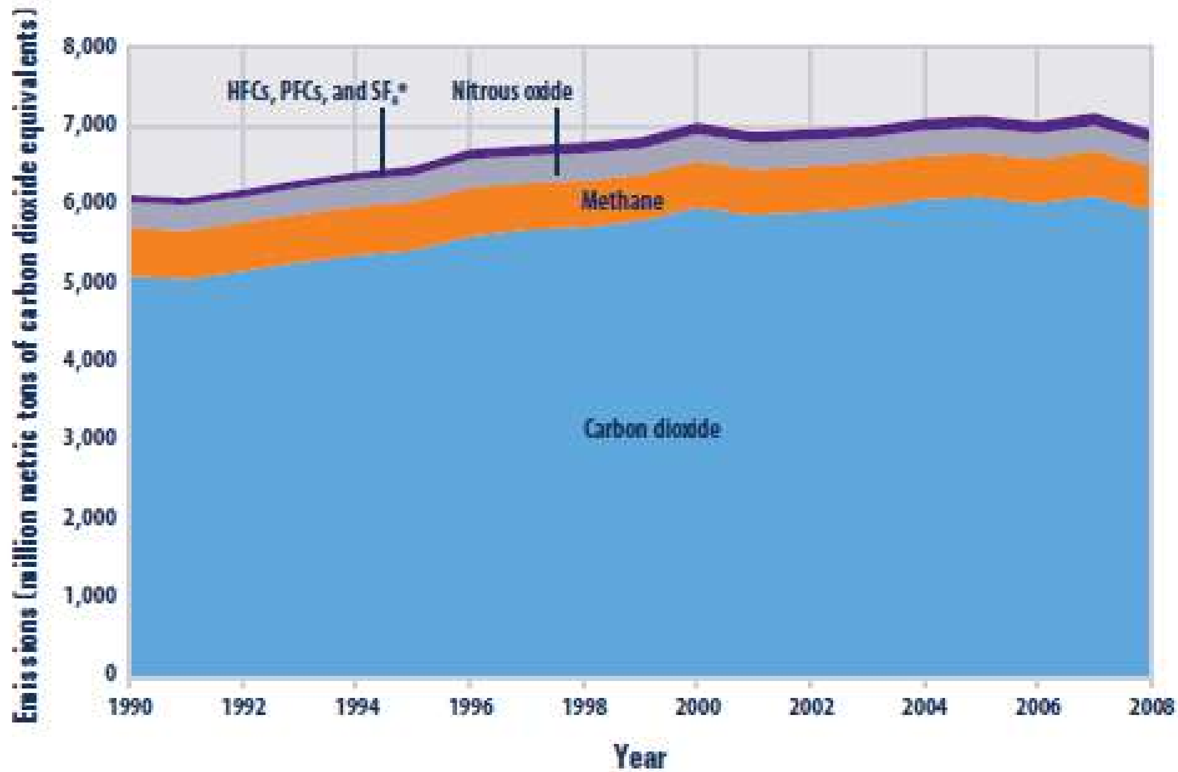

Atmosphere

Figure 1. U.S. Greenhouse Gas Emissions by Gas, 1990–2008

This figure shows emissions of carbon dioxide, methane, nitrous oxide, and several fluorinated compounds in the United States from 1990 to 2008. For consistency, emissions are expressed in million metric tons of carbon dioxide equivalents.

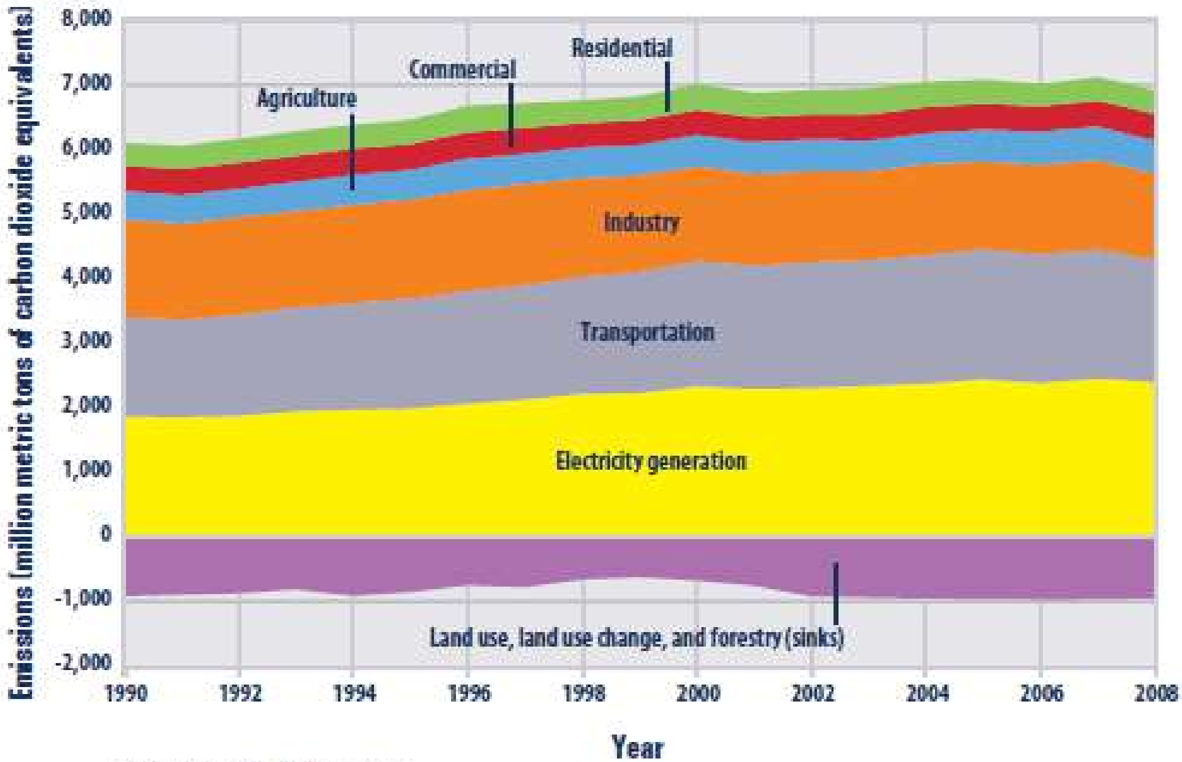


* HFCs are hydrofluorocarbons, PFCs are perfluorocarbons, and SF_6 is sulfur hexafluoride.

Data source: U.S. EPA, 2010[2]

Figure 2. U.S. Greenhouse Gas Emissions and Sinks by Economic Sector, 1990–2008

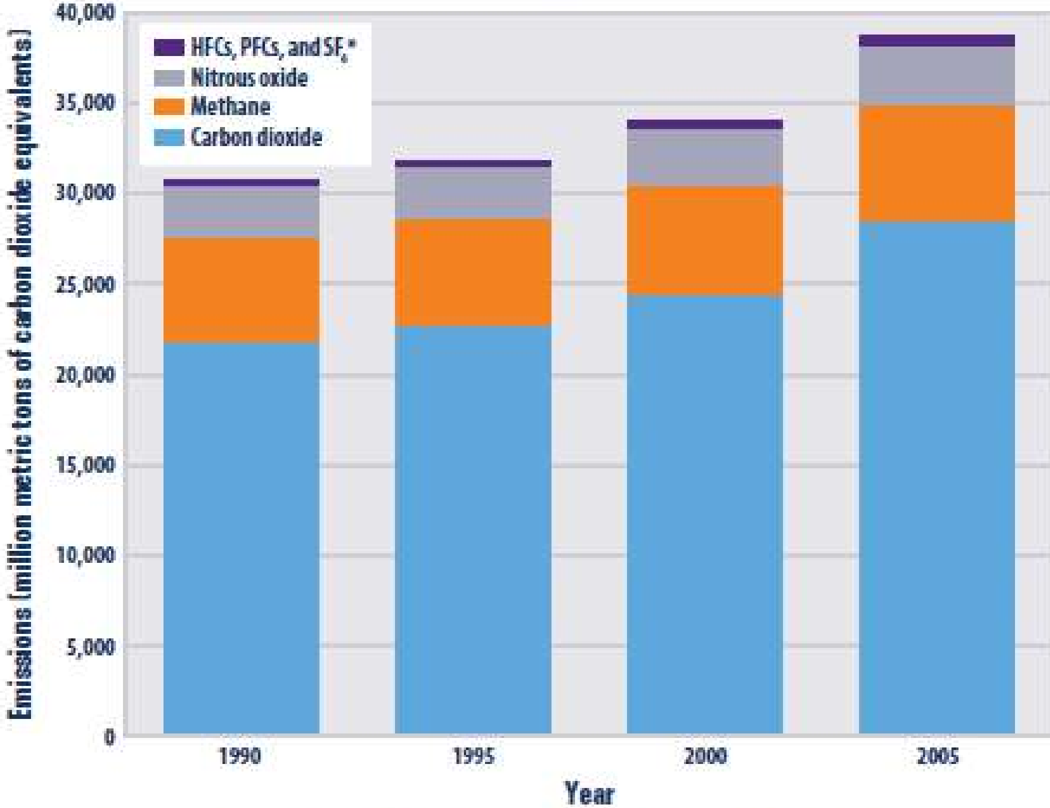
This figure shows greenhouse gas sinks and emissions by source in the United States from 1990 to 2008. For consistency, emissions are expressed in million metric tons of carbon dioxide equivalents. Totals do not match Figure 1 exactly because the economic sectors shown here do not include emissions from U.S. territories.



Data source: U.S. EPA, 2010[3]

Figure 1. Global Greenhouse Gas Emissions by Gas, 1990–2005

This figure shows worldwide emissions of carbon dioxide, methane, nitrous oxide, and several fluorinated compounds from 1990 to 2005. For consistency, emissions are expressed in million metric tons of carbon dioxide equivalents. These totals do not include emissions due to land use change or forestry because estimates are not available for the most recent years.

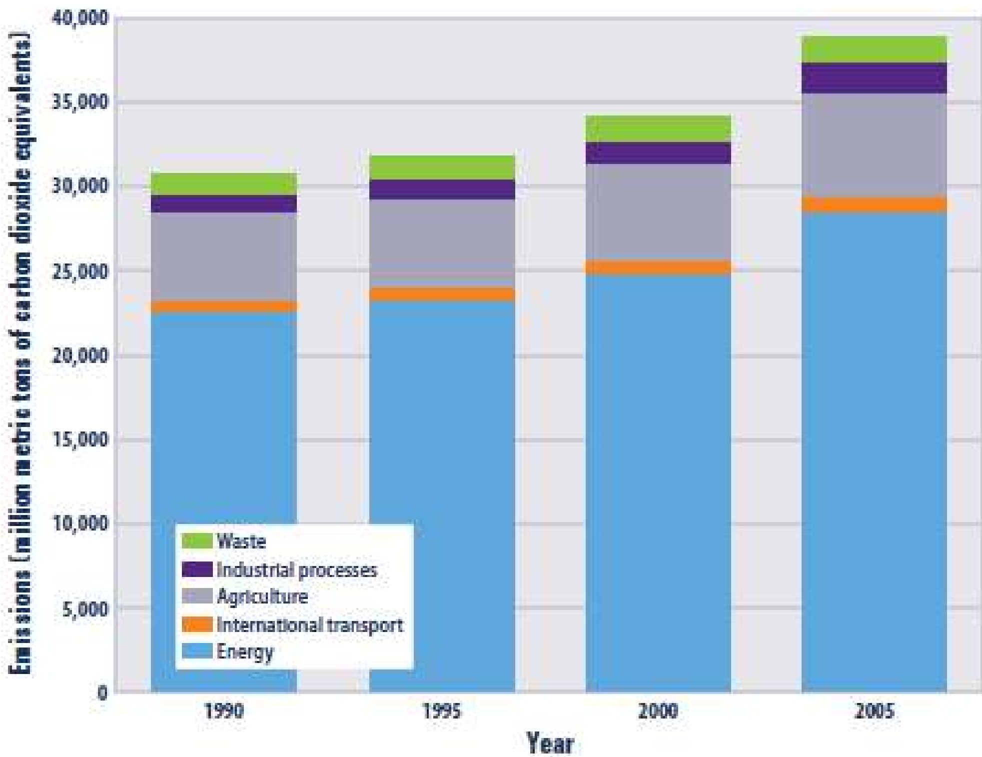


* HFCs are hydrofluorocarbons, PFCs are perfluorocarbons, and SF_6 is sulfur hexafluoride.

Data source: World Resources Institute, 2009[4]

Figure 2. Global Greenhouse Gas Emissions by Sector, 1990–2005

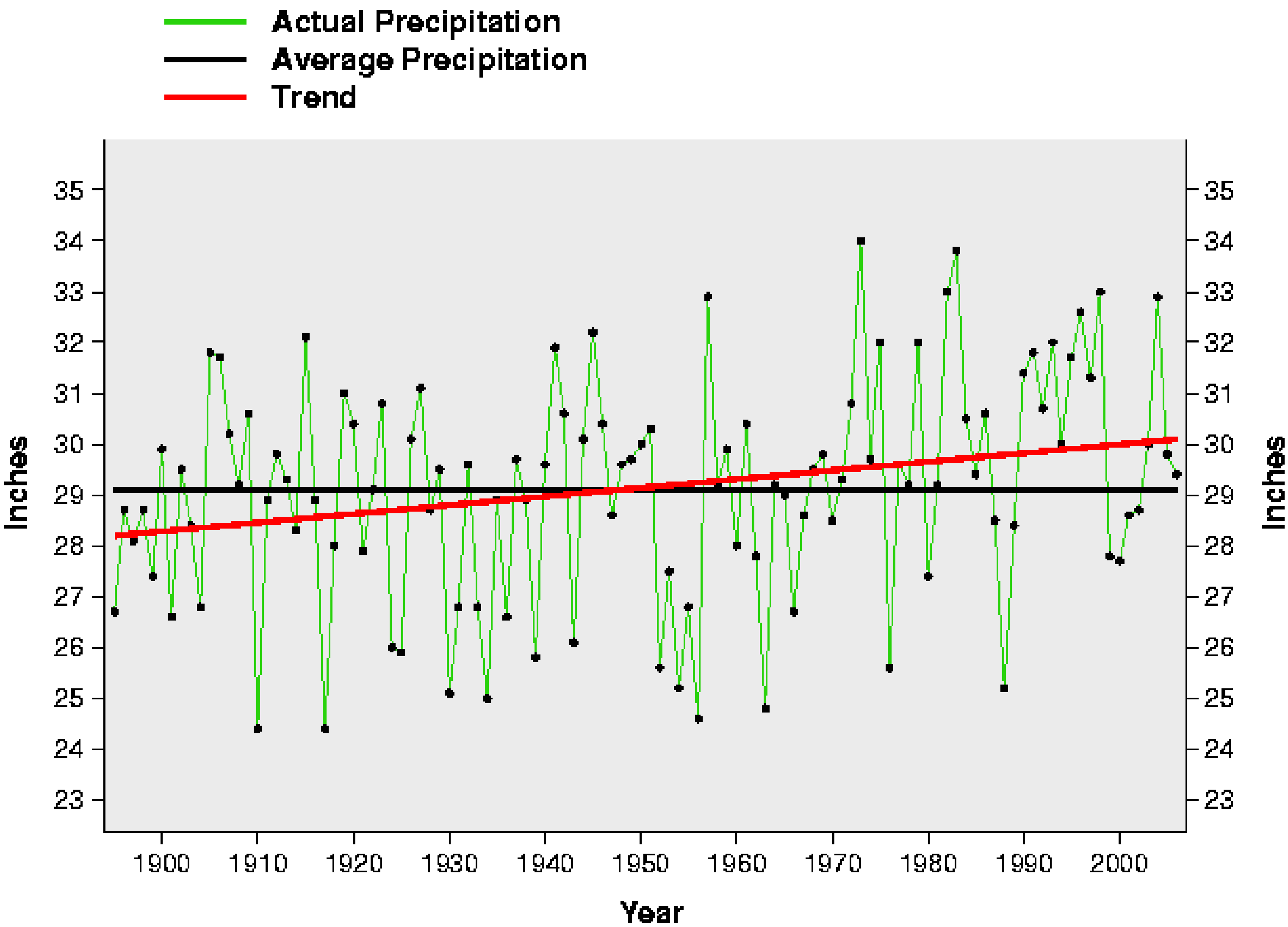
This figure shows worldwide greenhouse gas emissions by sector from 1990 to 2005. For consistency, emissions are expressed in million metric tons of carbon dioxide equivalents. These totals do not include emissions due to land use change or forestry because estimates are not available for the most recent years.*



* Note that the sectors shown here are different from the economic sectors used in U.S. emissions accounting (see the U.S. Greenhouse Gas Emissions indicator). Emissions from international transport (aviation and marine) are separate from the energy sector because they are not part of individual countries' emission inventories.

Data source: World Resources Institute, 2009[7]

Annual Precipitation, US



Indiana Annual Precipitation

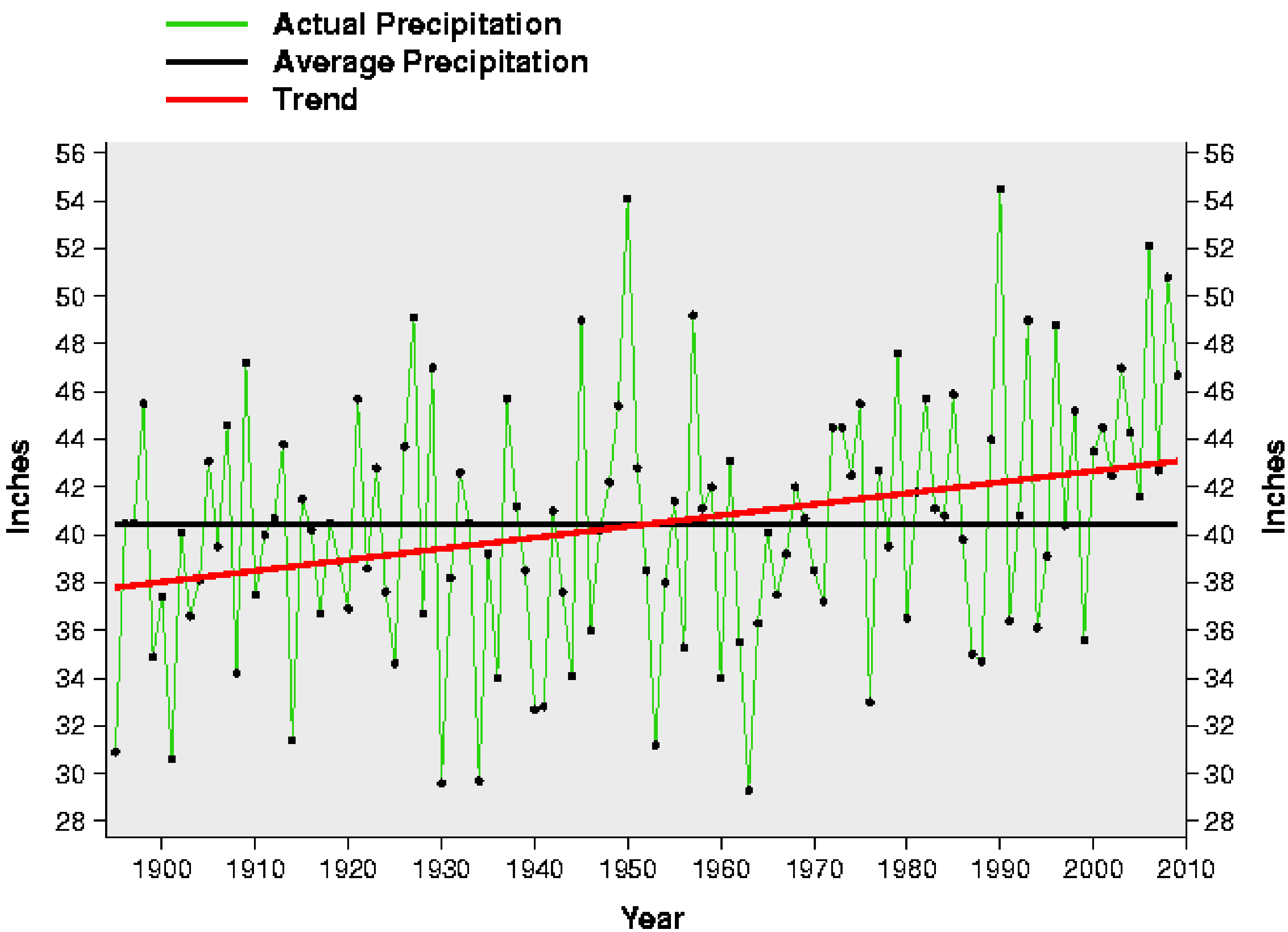
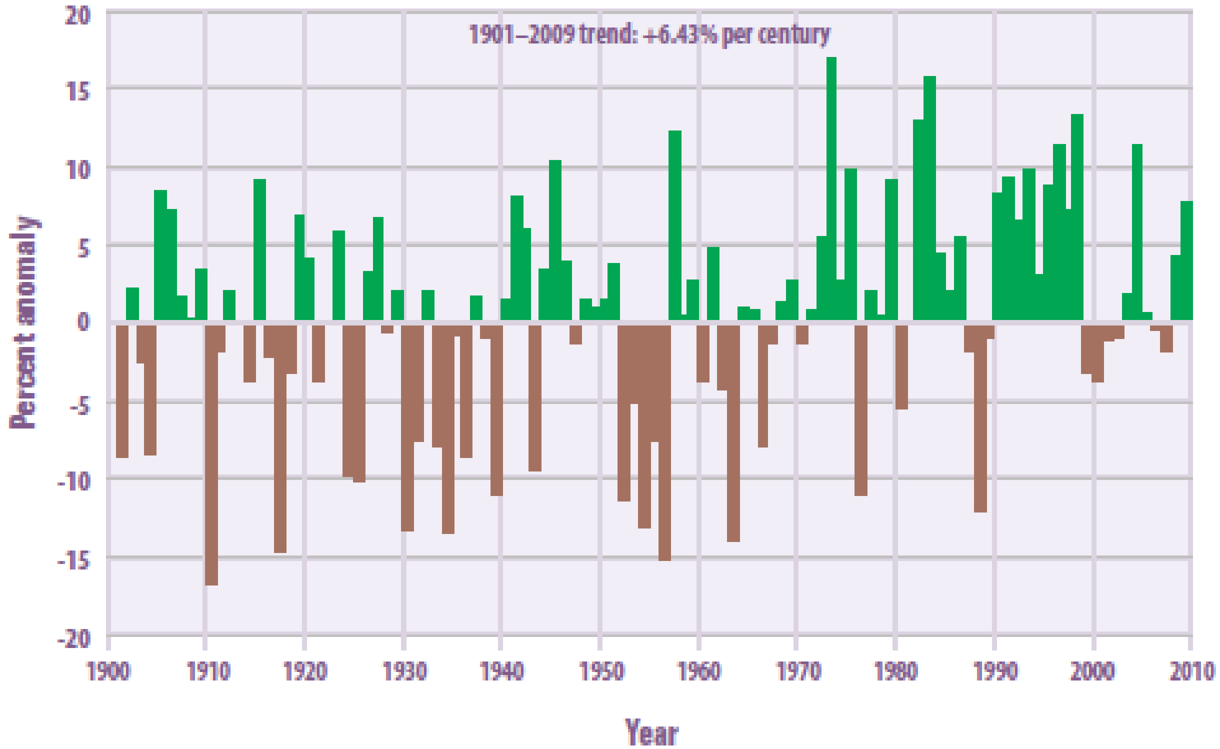


Figure 1. Precipitation in the Lower 48 States, 1901–2009

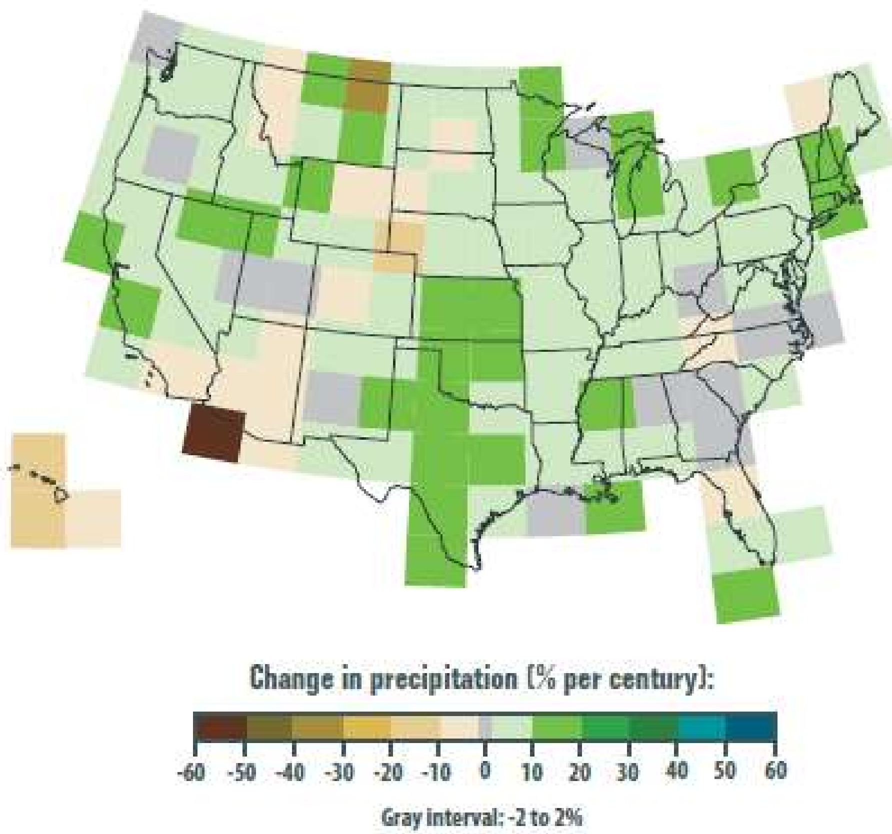
This figure shows how the amount of precipitation in the lower 48 states has changed since 1901. This graph uses the 1901 to 2000 average as a baseline for depicting change. Choosing a different baseline period would not change the shape of the trend.



Data source: NOAA, 2010[15]

Figure 3. Rate of Precipitation Change in the United States, 1901–2008

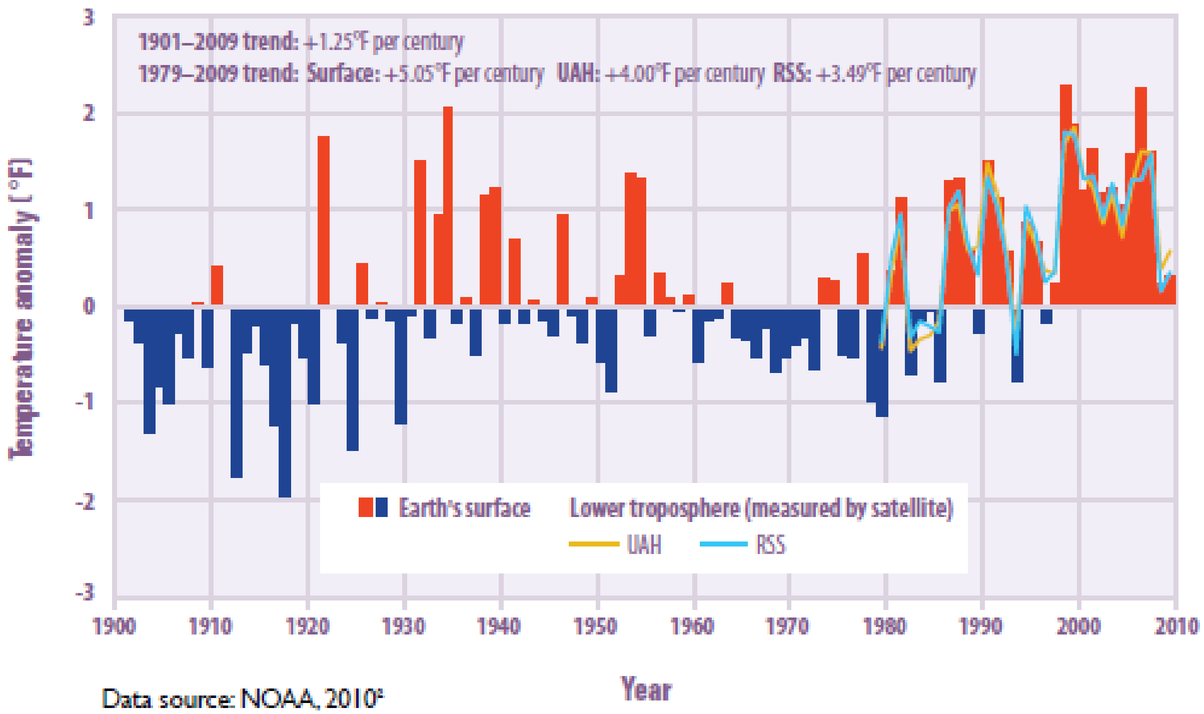
This figure shows how the amount of precipitation has changed in different parts of the United States since the early 20th century (since 1901 for the lower 48 states; since 1905 for Hawaii). Alaska is not shown because of limited data coverage.



Data source: NOAA, 2009[17]

Figure 1. Temperatures in the Lower 48 States, 1901–2009

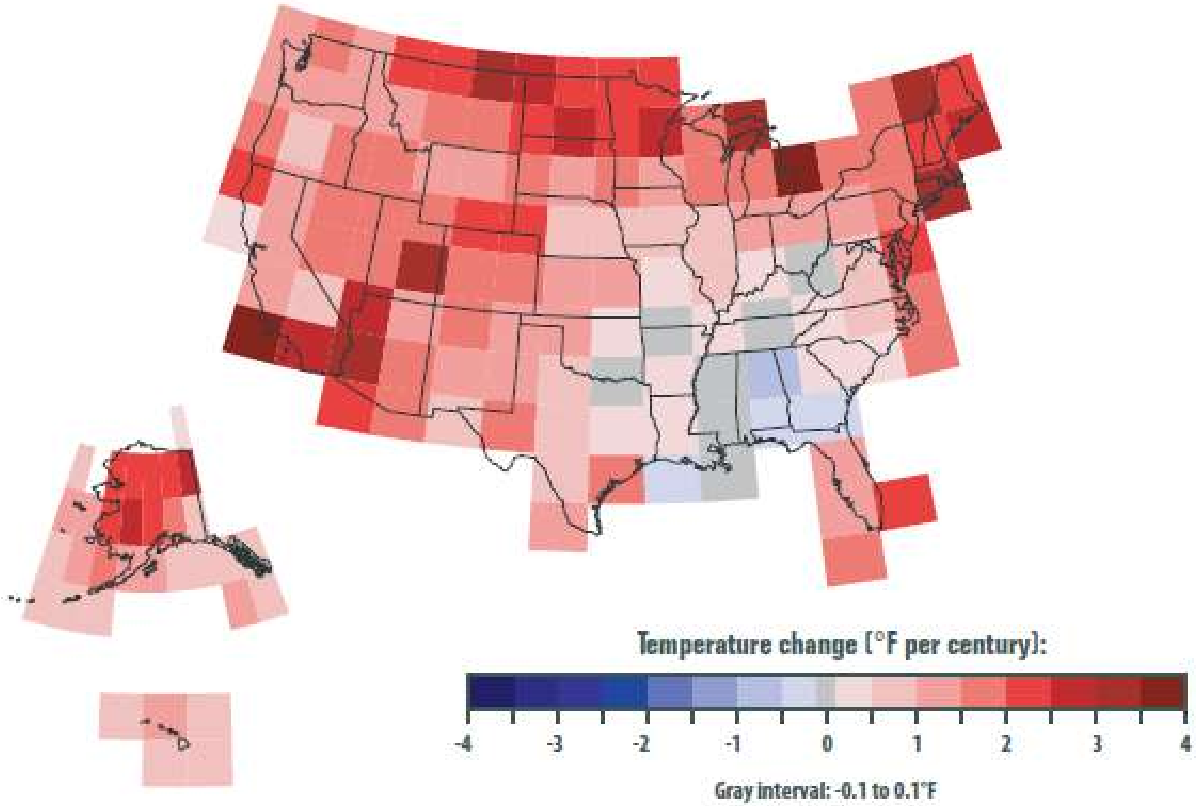
This figure shows how average temperatures in the lower 48 states have changed since 1901. Surface data come from land-based weather stations, while satellite measurements cover the lower troposphere, which is the lowest level of the Earth's atmosphere (see diagram on p. 20). "UAH" and "RSS" represent two different methods of analyzing the original satellite measurements. This graph uses the 1901 to 2000 average as a baseline for depicting change. Choosing a different baseline period would not change the shape of the trend.



Data source: NOAA, 2010[2]

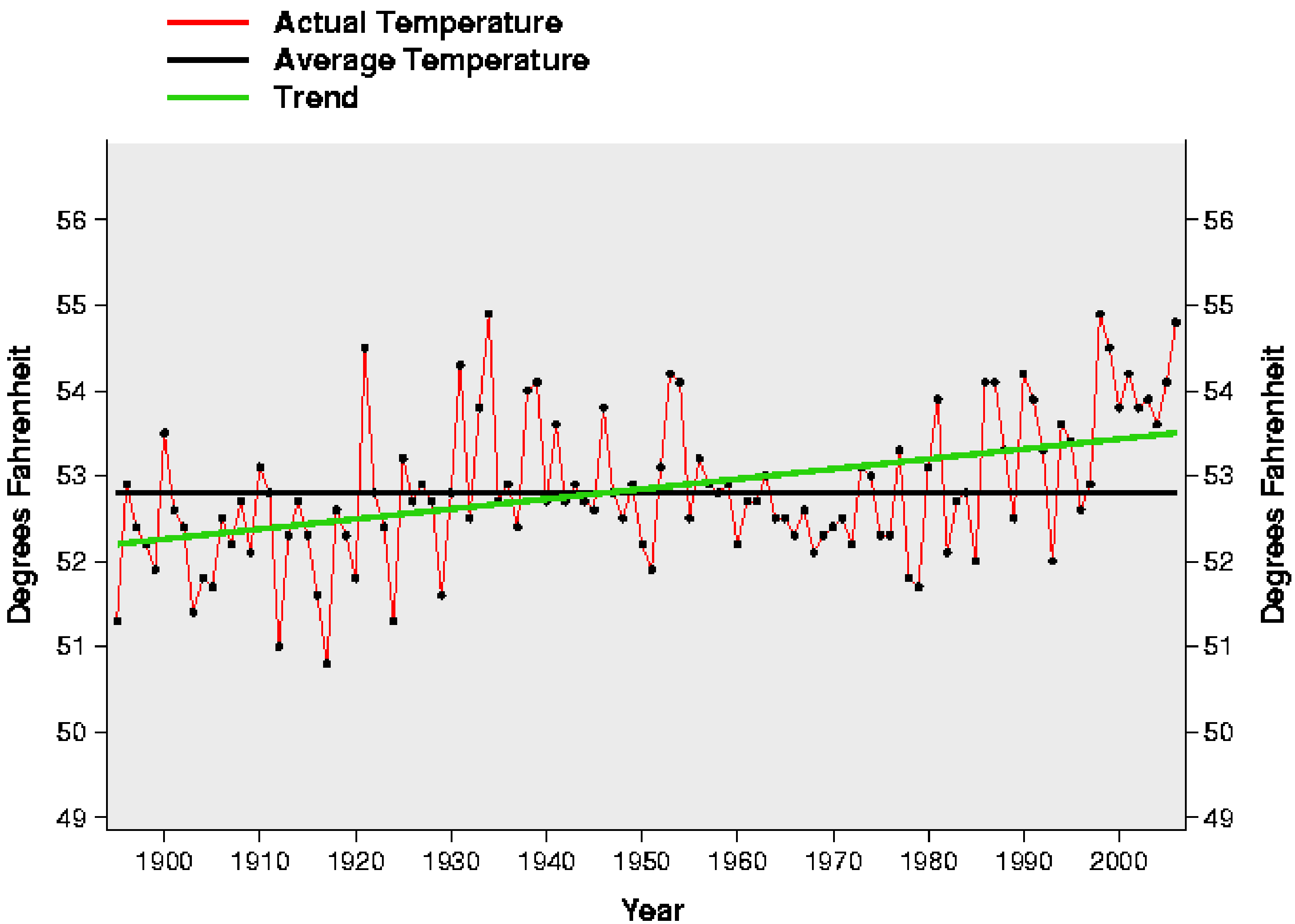
Figure 3. Rate of Temperature Change in the United States, 1901–2008

This figure shows how average air temperatures have changed in different parts of the United States since the early 20th century (since 1901 for the lower 48 states, 1905 for Hawaii, and 1918 for Alaska).

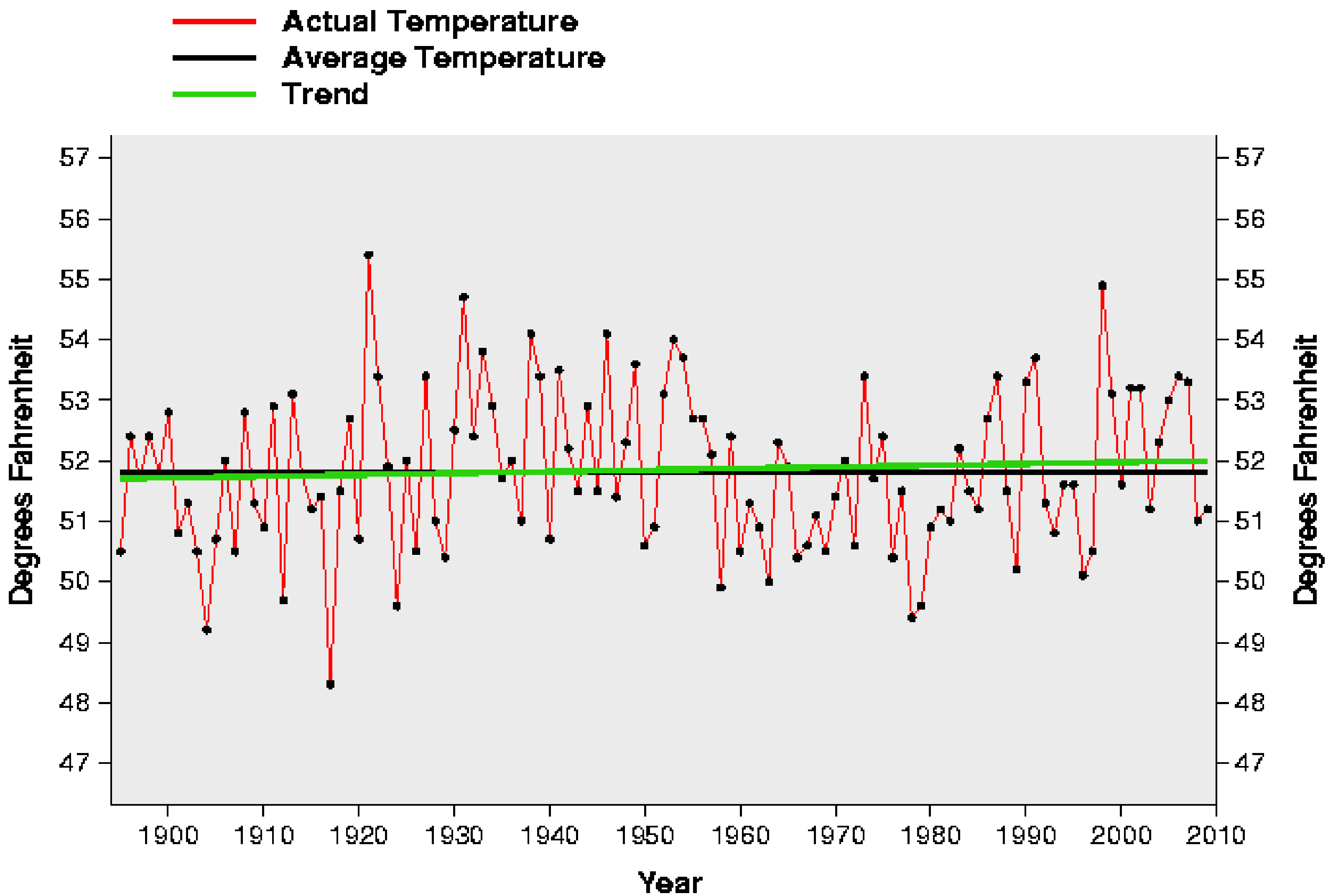


Data source: NOAA, 2009[4]

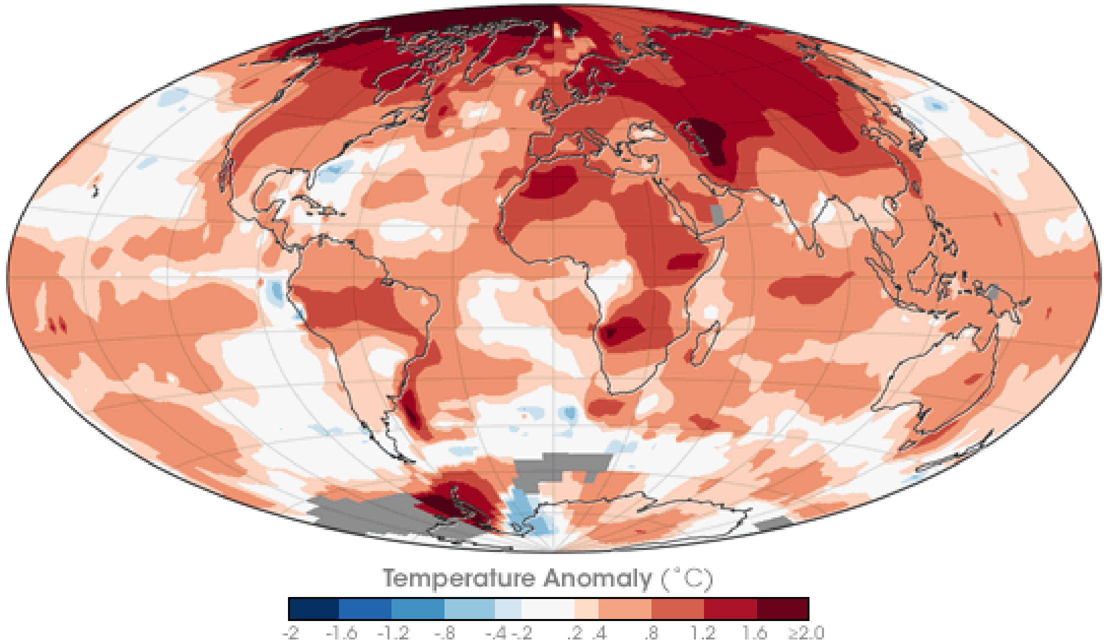
Annual Temperature, US



Indiana Annual Temperature



Temperature Change



Global temp change, 1951 to 2006 (NASA)

Author: Roberta Hotinski
Last updated September 2011

Stabilization Wedges:
A Concept & Game

The **Carbon Mitigation Initiative** is a joint project of Princeton University, BP, and Ford Motor Company to find solutions to the greenhouse gas problem. To emphasize the need for early action, Co-Directors Robert Socolow and Stephen Pacala created the concept of stabilization wedges: 25-billion-ton "wedges" that need to be cut out of predicted future carbon emissions in the next 50 years to avoid a doubling of atmospheric carbon dioxide over pre-industrial levels.

The following pages contain:

- An introduction to the carbon and climate problem and the stabilization wedge concept (pp. 1-3)
- Descriptions of currently available mitigation tools that have the capacity to reduce future emissions by at least one wedge (pp. 4-8)
- Materials and instructions for carrying out the "Stabilization Wedges Game," an activity that drives home the scale of the carbon mitigation challenge and the tradeoffs involved in planning climate policy (pp. 9-16)

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You can download a free up-to-date copy of this guide and view additional resources at our wedge website:

http://cmi.princeton.edu/wedges/

We hope to revise these materials with your input! If you have questions or feedback, please contact Dr. Roberta Hotinski, Consultant to CMI, at **hotinski@princeton.edu**

The Carbon and Climate Problem

Evidence continues to accumulate that carbon dioxide, or CO_2, from fossil fuel burning is causing dangerous interference in the climate. . Nine of the ten warmest years on record have occurred since 2001 and the ten warmest years have occurred since 1998. Tropical glaciers with ice thousands and tens of thousands years old are disappearing, offering graphic rebuttal to claims that the recent warming is part of a natural cycle. Models predict that, without action to curb the growth of greenhouse gases in the atmosphere, we risk triggering catastrophe -- cessation of the dominant pattern of ocean circulation, loss of the West Antarctic ice sheet, or a several-fold increase in category-five hurricanes.

CO_2 and some other gases in the atmosphere change the climate by letting sunlight pass through the atmosphere and warm the planet, but hindering the escape of heat to outer space (a phenomenon popularly known as "the greenhouse effect"). By burning fossil fuels, which are composed mainly of hydrogen and carbon, we add CO_2 to the atmosphere.

The Earth's atmosphere currently contains about **800 billion tons** of carbon as CO_2, and combustion of fossil fuels currently adds about **8 billion tons of carbon** every year. If we think of the atmosphere as a bathtub, these carbon emissions are like water coming out of the tap to fill the tub (**Figure 1**). The ocean and land biosphere act as two drains for this bathtub – carbon can be taken out of the atmosphere by being dissolved in the surface ocean or being taken up by growing forests. However, these two "drains" only take out about half the carbon we emit to the atmosphere every year. The remainder accumulates in the atmosphere (currently at a rate of roughly 4 billion tons per year), so the level of carbon in the tub is rising.

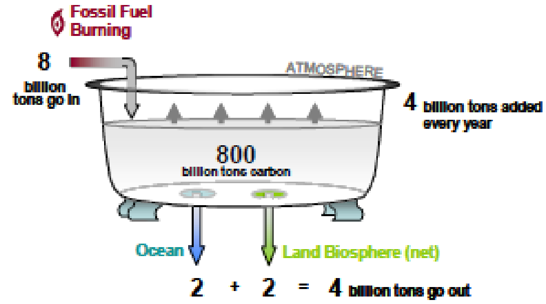

Figure 1. The atmosphere as a bathtub, with current annual inputs and outputs of carbon. The level in the tub is rising by about 4 billion tons per year.

The fossil fuel tap was "opened" with the Industrial Revolution. In pre-industrial times, the atmosphere contained only about 600 billion tons of carbon, 200 billion tons less than today (Figure 2). As an illustration of the importance of CO_2 to the Earth's climate, ice core records show that past atmospheric carbon changes of a similar magnitude have meant the difference between Ice Ages and the familiar warmer conditions of the past 10,000 years.

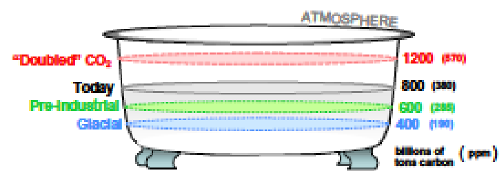

Figure 2. Past, present, and potential future levels of carbon in the atmosphere in two units. 2.1 billions of tons of carbon = 1 part per million (ppm).

Observations indicate that the carbon already added to the atmosphere has raised the global average temperature by around 1º Fahrenheit since the 19th century, and almost every year the fossil fuel tap is opened wider. An average of many forecasts predicts that we'll be adding **16 billion tons** of carbon per year to the "bathtub" in 50 years, twice today's rate, unless action is taken to control carbon emissions. If we follow this path, the amount of carbon in the atmosphere will reach 1200 billion tons -- **double its pre-industrial value** – well before the end of this century, **and will continue to increase** into the future. As a result, the Earth's temperature is expected to rise at a rate unprecedented in the last 10,000 years. **How can we get off this path?**

An Introduction to Stabilization Wedges

The "stabilization wedges" concept is a simple tool for conveying the emissions cuts that can be made to avoid dramatic climate change.

We consider two futures - **allowing emissions to double versus keeping emissions at current levels** for the next 50 years (Figure 3). The emissions-doubling path (black dotted line) falls in the middle of the field of most estimates of future carbon emissions. The climb approximately extends the climb for the past 50 years, during which the world's economy grew much faster than its carbon emissions. Emissions could be higher or lower in 50 years, but this path is a reasonable reference scenario.

The emissions-doubling path is predicted to lead to significant global warming by the end of this century. This warming is expected be accompanied by decreased crop yields, increased threats to human health, and more frequent extreme weather events. The planet could also face rising sea-level from melting of the West Antarctic Ice Sheet and Greenland glaciers and destabilization of the ocean's thermohaline circulation that helps redistribute the planet's heat and warm Western Europe.

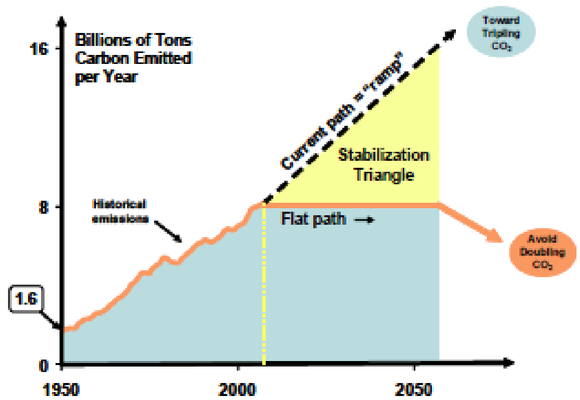

Figure 3. Two possible emissions scenarios define the "stabilization triangle."

In contrast, we can prevent a doubling of CO_2 if we can keep emissions flat for the next 50 years, then work to reduce emissions in the second half of the century (Figure 3, orange line). This path is predicted to keep atmospheric carbon under 1200 billion tons (which corresponds to about 570 parts per million (ppm)), allowing us to skirt the worst predicted consequences of climate change.

Keeping emissions flat will require cutting projected carbon output by about 8 billion tons per year by 2060, keeping a total of ~200 billion tons of carbon from entering the atmosphere (see yellow triangle in Figure 3). This carbon savings is what we call the **"stabilization triangle."**

The conventional wisdom has been that only revolutionary new technologies like nuclear fusion could enable such large emissions cuts. There is no reason, however, why one tool should have to solve the whole problem. CMI set out to quantify the impact that could be made by **a portfolio of existing technologies** deployed on a massive scale.

To make the problem more tractable, we divided the stabilization triangle into **eight "wedges."** (Figure 4) A wedge represents a carbon-cutting strategy that has the potential to grow from zero today to avoiding 1 billion tons of carbon emissions per year by 2060, or one-eighth of the stabilization triangle. The wedges can represent ways of either making energy with no or reduced carbon emissions (like nuclear or wind-produced electricity), or storing carbon dioxide to prevent it from building up as rapidly in the atmosphere (either through underground storage or biostorage).

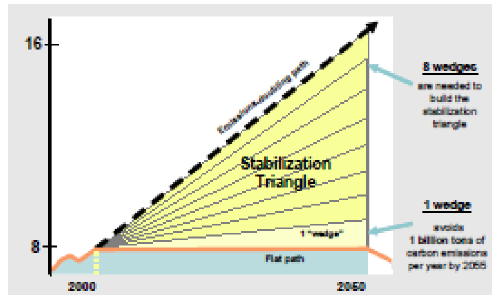

Figure 4. The eight "wedges" of the stabilization triangle.

Keeping emissions flat will require the world's societies to "fill in" the eight wedges of the stabilization triangle. In CMI's analysis, **at least 15 strategies are available <u>now</u>** that, with scaling up, could each take care of at least one wedge of emissions reduction. No one strategy can take care of the whole triangle -- new strategies will be needed to address both fuel and electricity needs, and some wedge strategies compete with others to replace emissions from the same source -- but there is already a more than adequate portfolio of tools available to control carbon emissions for the next 50 years.

Wedge Strategies Currently Available

The following pages contain descriptions of 15 strategies already available that could be scaled up over the next 50 years to reduce global carbon emissions by 1 billion tons per year, or **one wedge.** They are grouped into four major color-coded categories:

Efficiency & Conservation

- Increased transport efficiency
- Reducing miles traveled
- Increased building efficiency
- Increased efficiency of electricity production

Fossil-Fuel-Based Strategies

- Fuel switching (coal to gas)
- Fossil-based electricity with carbon capture & storage (CCS)
- Coal synfuels with CCS
- Fossil-based hydrogen fuel with CCS

Nuclear Energy

- Nuclear electricity

Renewables and Biostorage

- Wind-generated electricity
- Solar electricity
- Wind-generated hydrogen fuel
- Biofuels
- Forest storage
- Soil storage

Each strategy can be applied to one or more sectors, indicated by the following symbols:

= Electricity Production, =Heating and Direct Fuel Use, =Transportation, = Biostorage

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Increased Efficiency & Conservation

1. Transport Efficiency

A typical 30 miles per gallon (30 mpg) car driving 10,000 miles per year emits a ton of carbon into the air annually. Today there are about about 600 million cars in the world, and it's predicted that there will be about 2 billion passenger vehicles on the road in 50 years. **A wedge of emissions savings would be achieved if the fuel efficiency of all the cars projected for 2060 were doubled from 30 mpg to 60 mpg.** Efficiency improvements could come from using hybrid and diesel engine technologies, as well as making vehicles out of strong but lighter materials.

Cutting carbon emissions from trucks and planes by making these engines more efficient can also help with this wedge. Aviation is the fastest growing component of transportation.

2. Transport Conservation

A wedge would be achieved if the number of miles traveled by the world's cars were cut in half. Such a reduction in driving could be achieved if urban planning leads to more use of mass transit and if electronic communication becomes a good substitute for face-to-face meetings.

3. Building Efficiency

Today carbon emissions arise about equally from providing electricity, transportation, and heat for industry and buildings. The largest potential savings in the buildings sector are in space heating and cooling, water heating, lighting, and electric appliances.

It's been projected that the buildings sector as a whole has the technological and economic potential to cut emissions in half. **Cutting emissions by 25% in all new and existing residential and commercial buildings would achieve a wedge worth of emissions reduction.** Carbon savings from space and water heating will come from both end-use efficiency strategies, like wall and roof insulation, and renewable energy strategies, like solar water heating and passive solar design.

4. Efficiency in Electricity Production

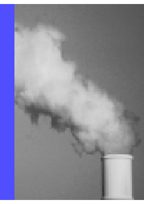
Today's coal-burning power plants produce about one-fourth of the world's carbon emissions, so increases in efficiency at these plants offer an important opportunity to reduce emissions. **Producing the world's current coal-based electricity with doubled efficiency would save a wedge worth of carbon emissions.**

More efficient conversion results at the plant level from better turbines, from using high-temperature fuel cells, and from combining fuel cells and turbines. At the system level, more efficient conversion results from more even distribution of electricity demand, from cogeneration (the co-production of electricity and useful heat), and from polygeneration (the co-production of chemicals and electricity).

Due to large contributions by hydropower and nuclear energy, the electricity sector already gets about 35% of its energy from non-carbon sources. Wedges can only come from the remaining 65%.

Suggested Link:
IPCC Working Group III Report "Mitigation of Climate Change", Chapters 4, 5 & 6
http://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_wg3_report_mitigation_of_climate_change.htm

Carbon Capture & Storage (CCS)



If the CO_2 emissions from fossil fuels can be captured and stored, rather than vented to the atmosphere, then the world could continue to use coal, oil, and natural gas to meet energy demands without harmful climate consequences. The most economical way to pursue this is to capture CO_2 at large electricity or fuels plants, then store it underground. This strategy, called carbon capture and storage, or **CCS**, is already being tested in pilot projects around the world.

5. CCS Electricity

Today's coal-burning power plants produce about one fourth of the world's carbon emissions and are large point-sources of CO_2 to the atmosphere. **A wedge would be achieved by applying CCS to 800 large (1 billion watt) baseload coal power plants or 1600 large baseload natural gas power plants in 50 years. As with all CCS strategies, to provide low-carbon energy the captured CO_2 would need to be stored for centuries.**

There are currently 3 pilot storage projects in the world, which each store about 1 million tons of carbon underground per year. Storing a wedge worth of emissions will require 3500 times the capacity of one of these projects.

6. CCS Hydrogen

Hydrogen is a desirable fuel for a low-carbon society because when it's burned the only emission product is water vapor. Because fossil fuels are composed mainly of carbon and hydrogen they are potential sources of hydrogen, but to have a climate benefit the excess carbon must be captured and stored.

Pure hydrogen is now produced mainly in two industries: ammonia fertilizer production and petroleum refining. Today these hydrogen production plants generate about 100 million tons of capturable carbon. Now this CO_2 is vented, but only small changes would be needed to implement carbon capture. **The scale of hydrogen production today is only ten times smaller than the scale of a wedge of carbon capture.**

Distributing CCS hydrogen, however, requires building infrastructure to connect large hydrogen-producing plants with smaller-scale users.

7. CCS Synfuels

In 50 years a significant fraction of the fuels used in vehicles and buildings may not come from conventional oil, but from coal. When coal is heated and combined with steam and air or oxygen, carbon monoxide and hydrogen are released and can be processed to make a liquid fuel called a "synfuel."

Coal-based synfuels result in nearly twice the carbon emissions of petroleum-derived fuels, since large amounts of excess carbon are released during the conversion of coal into liquid fuel. The world's largest synfuels facility, located in South Africa, is the largest point source of atmospheric CO_2 emissions in the world. **A wedge is an activity that, over 50 years, can capture the CO_2 emissions from 180 such coal-to-synfuels facilities.**

Suggested link:
IPCC Special Report on Carbon dioxide Capture and Storage, SPM
http://www.ipcc.ch/pdf/specialreports/srccs/srccs_summaryforpolicymakers.pdf

5

Fuel Switching

8. Fuel-Switching for Electricity

Because of the lower carbon content of natural gas and higher efficiencies of natural gas plants, producing electricity with natural gas results in only about half the emissions of coal. **A wedge would require 1400 large (1 billion watt) natural gas plants displacing similar coal-electric plants.**

This wedge would require generating approximately four times the Year 2000 global production of electricity from natural gas. In 2060, 1 billion tons of carbon per year would be emitted from natural gas power plants instead of 2 billion tons per year from coal-based power plants.

Materials flows equivalent to one billion tons of carbon per year are huge: a wedge of flowing natural gas is equivalent to 50 large liquefied natural gas (LNG) tankers docking and discharging every day. Current LNG shipments world-wide are about one-tenth as large.

Suggested link:
U.S. Environmental Protection Agency: Electricity from Natural Gas
http://www.epa.gov/RDEE/energy-and-you/affect/natural-gas.html

Nuclear Energy

9. Nuclear Electricity

Nuclear fission currently provides about 17% of the world's electricity, and produces no CO_2. **Adding new nuclear electric plants to triple the world's current nuclear capacity would cut emissions by one wedge if coal plants were displaced.**

In the 1960s, when nuclear power's promise as a substitute for coal was most highly regarded, a global installed nuclear capacity of about 2000 billion watts was projected for the year 2000. The world now has about one-sixth of that envisioned capacity. If the remainder were to be built over the next 50 years to displace coal-based electricity, roughly two wedges could be achieved.

In contrast, phasing out the worlds' current capacity of nuclear power would require adding an additional half wedge of emissions cuts to keep emissions at today's levels.

Nuclear fission power generates plutonium, a fuel for nuclear weapons. These new reactors would add several thousand tons of plutonium to the world's current stock of reactor plutonium (roughly 1000 tons).

IPCC Working Group III Report "Mitigation of Climate Change", Chapter 4 - Energy Supply
http://www.ipcc.ch/pdf/assessment-report/ar4/wg3/ar4-wg3-chapter4.pdf

Renewable Energy & Biostorage

10. <u>Wind Electricity</u>

Wind currently produces less than 1% of total global electricity, but wind electricity is growing at a rate of about 30% per year. **To gain a wedge of emissions savings from wind displacing coal-based electricity, current wind capacity would need to be scaled up by a factor of 10.**

This increase in capacity would require deployment of about 1 million large windmills. Based on current turbine spacing on wind farms, a wedge of wind power would require a combined area roughly the size of Germany. However, land from which wind is harvested can be used for many other purposes, notably for crops or pasture.

11. <u>Solar Electricity</u>

Photovoltaic (PV) cells convert sunlight to electricity, providing a source of CO_2-free and renewable energy. The land demand for solar is less than with other renewables, but **installing a wedge worth of PV would still require arrays with an area of two million hectares, or 20,000 km^2.** The arrays could be located on either dedicated land or on multiple-use surfaces such as the roofs and walls of buildings. The combined area of the arrays would cover an area the size of the U.S. state of New Jersey, or about 12 times the size of the London metropolitan area.

Since PV currently provides less than a tenth of one percent of global electricity, achieving a wedge of emissions reduction would require increasing the deployment of PV by a factor of 100 in 50 years, or installing PV at about 2.5 times the 2009 rate for 50 years.

A current drawback for PV electricity is its price, which is declining but is still 2-5 times higher than fossil-fuel-based electricity. Also, PV can not be collected at night and, like wind, is an intermittent energy source.

12. <u>Wind Hydrogen</u>

Hydrogen is a desirable fuel for a low-carbon society because when it's burned the only emission product is water vapor. To produce hydrogen with wind energy, electricity generated by wind turbines is used in electrolysis, a process that liberates hydrogen from water. **Wind hydrogen displacing vehicle fuel is only about half as efficient at reducing carbon emissions as wind electricity displacing coal electricity, and 2 million (rather than 1 million) windmills would be needed for one wedge of emissions reduction.** That increase would require scaling up current wind capacity by about 20 times, requiring a land area roughly the size of France.

Unlike hydrogen produced from fossil fuels with CCS, wind hydrogen could be produced at small scales where it is needed. Wind hydrogen thus would require less investment in infrastructure for fuel distribution to homes and vehicles.

Renewables & Biostorage (cont'd)

13. Biofuels

Because plants take up carbon dioxide from the atmosphere, combustion of biofuels made from plants like corn and sugar cane simply returns "borrowed" carbon to the atmosphere. Thus burning biofuels for transportation and heating will not raise the atmosphere's net CO_2 concentration.

The land constraints for biofuels, however, are more severe than for wind and solar electricity. Using current practices, just one wedge worth of carbon-neutral biofuels would require 1/6th of the world's cropland and an area roughly the size of India. Bioengineering to increase the efficiency of plant photosynthesis and use of crop residues could reduce that land demand, but large-scale production of plant-based biofuels will always be a land-intensive proposition.

Ethanol programs in the U.S. and Brazil currently produce about 20 billion gallons of biofuel per year from corn and sugarcane. **One wedge of biofuels savings would require increasing today's global ethanol production by about 12 times, and making it sustainable.**

14. Forest Storage

Land plants and soils contain large amounts of carbon. Today, there is a net *removal* of carbon from the atmosphere by these "natural sinks," in spite of deliberate deforestation by people that *adds* between 1 and 2 billion tons of carbon to the atmosphere. Evidently, the carbon in forests is increasing elsewhere on the planet.

Land plant biomass can be increased by both reducing deforestation and planting new forests. **Halting global deforestation in 50 years would provide one wedge of emissions savings.** To achieve a wedge through forest planting alone, new forests would have to be established over an area the size of the contiguous United States.

15. Soil Storage

Conversion of natural vegetation to cropland reduces soil carbon content by one-half to one-third. However, soil carbon loss can be reversed by agricultural practices that build up the carbon in soils, such as reducing the period of bare fallow, planting cover crops, and reducing aeration of the soil (such as by no till, ridge till, or chisel plow planting). **A wedge of emissions savings could be achieved by applying carbon management strategies to all of the world's existing agricultural soils.**

Suggested links:
U.S. DOE, Energy Efficiency & Renewable Energy
http://www.eere.energy.gov/

IPCC Working Group III Report "Mitigation of Climate Change", Chapters 8 & 9
http://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_wg3_report_mitigation_of_climate_change.htm

The Stabilization Wedges Game – Lesson Plan

Goals

The core purpose of this game is to convey the scale of effort needed to address the carbon and climate situation and the necessity of developing a portfolio of options. By the end of the exercise, students should understand the magnitude of human-sourced carbon emissions and feel comfortable comparing the effectiveness, benefits, and drawbacks of a variety of carbon-cutting strategies. The students should appreciate that **there is no easy or "right" solution to the carbon and climate problem.**

Objectives

Students will learn about the technologies currently available that can substantially cut carbon emissions, develop critical reasoning skills as they create their own portfolio of strategies to cut emissions, and verbally communicate the rationale for their selections. Working in teams, students will develop the skills to negotiate a solution that is both physically plausible and politically acceptable, and defend their solution to a larger group.

National Science Content Standards

- Systems, Order and Organization
- Science as Inquiry
- Science in Personal and Social Perspectives
  Natural and Human Induced Hazards
  Environmental Quality

Materials (see **Student Game Materials** at end of packet)

- 1 copy of Instructions and Wedge Table **per student (print single-sided to allow use of gameboard pieces!)**
- 1 Wedge Worksheet and 1 Gameboard with multi-colored wedge pieces **per group**, plus scissors for cutting out game pieces and glue sticks or tape to secure pieces to gameboard
- Optional - overhead transparencies, posters, or other materials for group presentations

Time Required

We suggest using 2-3 standard (40-50 minute) class periods to prepare for and play the Stabilization Wedges game. In the first period, the Stabilization Triangle and the concept of wedges are discussed and the technologies introduced. Students can further research the technologies as homework. In the second period, students play the game and present their results. Depending on the number of groups in the class, an additional period may be needed for the presentation of results. Assessment and application questions are included and may be assigned as homework after the game has been played, or discussed as a group as part of an additional class period/assignment.

Lesson Procedure/Methodology

I. **<u>Introduction</u> (40 minutes)**

a. **Motivation.** Review the urgency of the carbon and climate problem and potential ways it may impact the students' futures.

b. **Present the Concepts.** Introduce the ideas of the Stabilization Triangle and its eight "wedges".

c. **Introduce the Technologies.** Briefly describe the 15 wedge strategies identified by CMI, then have students familiarize themselves with the strategies as homework. Participants are free to critique any of the wedge strategies that CMI has identified, and teams should feel free to use strategies not on our list.

d. **Form Teams.** Teams of 3 to 6 players are best, and it is particularly helpful to have each student be an appointed "expert" in a few of the technologies to promote good discussions. You may want to identify a recorder and reporter in each group.

e. **Explain the Rules.** See instructions in **Student Game Materials** at back of packet

II. **Playing the Game (40 minutes)**

a. **Filling in the Stabilization Triangle.** Teammates should work together to build a team stabilization triangle using 8 color-coded wedges labeled with specific strategies. Many strategies can be used more than once.

b. **Wedge Worksheet.** Each team should fill in one **stabilization wedge worksheet** to make sure players haven't violated the constraints of the game, to tally costs, and to predict judges' ratings of their solution. NOTE: Costs are for guidance only – they are not meant to be used to produce a numerical score that wins or loses the game!

c. **Reviewing the Triangle.** Each team should review the strengths and weaknesses of its strategies in preparation for reporting and defending its solutions to the class.

III. **Reports (depending on the number of groups this may require an additional class period)**

a. Representatives from each team will defend their solutions to the class in a 5-minute report. The presentation can be a simple verbal discussion by the group or a reporter designated by the group. If additional time is available, the presentations could include visual aids, such as a poster, PowerPoint presentation, etc.

b. Students should address not only the technical viability of their wedges, but also the economic, social, environmental and political implications of implementing their chosen strategies on a massive scale.

IV. **Judging**

In CMI workshops, the teams' triangles have been judged by experts from various global stakeholder groups, such as an environmental advocacy organization, the auto industry, a developing country, or the U.S. Judging ensures that economic and political impacts are considered and emphasizes the need for consensus among a broad coalition of stakeholders. For a classroom, judges can be recruited from local government, colleges, businesses, and non-profit organizations, or a teacher/facilitator can probe each team about the viability of its strategies.

V. **Closure/Assessment of Student Learning**

In addition to addressing the game and lessons learned, discussion questions are provided below that give opportunity to develop and assess the students' understanding of the wedges concept and its applications.

1) Given physical challenges and risks, how many wedges do you think each wedge strategy can each realistically provide?

2) In choosing wedge strategies, it's important to avoid double counting – removing the same emissions with two different strategies. For example, there are 6 strategies for cutting emissions from electricity, but we project only 5 wedges worth of carbon produced from the electric sector 50 years from now. Can you think of reasons, other than the adoption of alternative or nuclear energy, that emissions from electricity would be lower or higher than we predict? Examples: increased use of carbon-intensive coal versus natural gas (higher), slower population growth (lower), substitution of electricity for fuel, as via plug-in electric cars (higher).

3) Industrialized countries and developing countries now each contribute about half the world's emissions, although the poorer countries have about 85% of the world's population. (The U.S. alone emits one fourth of the world's CO_2.) If we agree to freeze global emissions at current levels, that means if **emissions in one region of the world go up as a result of economic/industrial development, then emissions must be cut elsewhere.** Should the richer countries reduce their emissions 50 years from now so that extra carbon emissions can be available to developing countries? If so, by how much?

4) Nuclear energy is already providing one-half wedge of emissions savings – what do you think the future of these plants should be?

5) Automobile emissions are a popular target for greenhouse gas cuts. What percent of greenhouse gases do you think come from the world's passenger vehicles? (answer: about 18%)

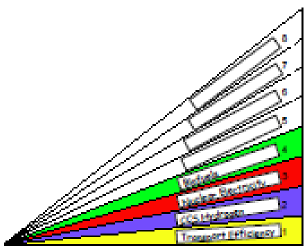
Resources & Feedback
More stabilization wedge resources, including background articles and slides, are available at
http://cmi.princeton.edu/wedges

Student Game Instructions & Materials

The goal of this game is to **construct a stabilization triangle using eight wedge strategies**, with only a few constraints to guide you. From the 15 potential strategies, choose 8 wedges that your team considers the best global solutions. Keep costs and impacts in mind.

1) **Find the Wedge Gameboard** in the back of this packet and cut apart the red, green, yellow, and blue wedge pieces supplied (if not already done for you).

2) **Read the information** on each of the 15 strategies in the **Wedge Table** below. Costs ($, $$, $$$) are indicated on a relative basis, and are intended only to provide guidance, not a numerical score. Feel free to argue against any information presented and include alternative wedge strategies if you can support them.



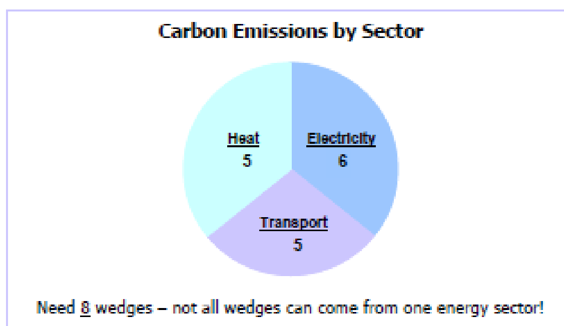
3) Each team should **choose one wedge strategy at a time** to fill the 8 spots on the wedge gameboard (see illustration of gameboard with 4 wedges filled in at left – this is only an example!).

4) **The four colors of the wedge pieces indicate the major category** (fossil fuel-based (blue), efficiency and conservation (yellow), nuclear (red), and renewables and biostorage (green)). Choose a red, yellow, blue, or green wedge for your strategy, then **label the wedge to indicate the specific strategy** (examples shown in illustration at left).

5) **Most strategies may be used more than once, but not all cuts can come from one energy sector.**

Of the 16 billion tons of carbon emitted in the 2060 baseline scenario, we assume electricity production accounts for 6 wedges, transportation fuels accounts for 5 wedges, and direct fuel use for heat and other purposes accounts for 5 wedges (see pie chart right).

Because biostorage takes carbon from all sources out of the atmosphere, biostorage wedges do not count toward an energy sector.



6) **Cost and impacts must be considered.** Each wedge should be viewed in terms of both technical and political viability.

7) For each of the 8 strategies chosen, each team should **fill out one line in the Wedge Worksheet.** After all 8 wedges have been chosen, tally total cuts from each energy sector (Electricity, Transport, and Heat) and costs. Use the scoring table to predict how different interest groups would rate your wedge on a scale from 1 to 5.

8) Each team should **give a 5-minute oral report** on the reasoning behind its triangle. The report should justify your choice of wedges to the judge(s) and to the other teams. **Note: There is no "right" answer** – the team that makes the best case wins, not necessarily the team with the cheapest or least challenging solution

Stabilization Wedges – 15 Ways to Cut Carbon

= Electricity Production, =Heating and Direct Fuel Use, =Transportation, = Biostorage

Strategy	Sector	Description	1 wedge could come from…	Cost	Challenges
1. **Efficiency – Transport**	Transportation	Increase automobile fuel efficiency (2 billion cars projected in 2050)	**… doubling the efficiency of all world's cars from 30 to 60 mpg**	$	Car size & power
2. **Conservation - Transport**	Transportation	Reduce miles traveled by passenger and/or freight vehicles	**… cutting miles traveled by all passenger vehicles in half**	$	Increased public transport, urban design
3. **Efficiency - Buildings**	Electricity Production, Heating and Direct Fuel Use	Increase insulation, furnace and lighting efficiency	**… using best available technology in all new and existing buildings**	$	House size, consumer demand for appliances
4. **Efficiency – Electricity**	Electricity Production	Increase efficiency of power generation	**… raising plant efficiency from 40% to 60%**	$	Increased plant costs
5. **CCS Electricity**	Electricity Production	90% of CO_2 from fossil fuel power plants captured, then stored underground (800 large coal plants or 1600 natural gas plants)	**… injecting a volume of CO_2 every year equal to the volume of oil extracted**	$$	Possibility of CO_2 leakage
6. **CCS Hydrogen**	Transportation, Heating and Direct Fuel Use	Hydrogen fuel from fossil sources with CCS displaces hydrocarbon fuels	**… producing hydrogen at 10 times the current rate**	$$$	New infrastructure needed, hydrogen safety issues
7. **CCS Synfuels**	Transportation, Heating and Direct Fuel Use	Capture and store CO_2 emitted during synfuels production from coal	**… using CCS at 180 large synfuels plants**	$$	Emissions still only break even with gasoline
8. **Fuel Switching – Electricity**	Electricity Production	Replacing coal-burning electric plants with natural gas plants (1400 1 GW coal plants)	**… using an amount of natural gas equal to that used for all purposes today**	$	Natural gas availability
9. **Nuclear Electricity**	Electricity Production	Displace coal-burning electric plants with nuclear plants (Add double current capacity)	**… ~3 times the effort France put into expanding nuclear power in the 1980's, sustained for 50 years**	$$	Weapons proliferation, nuclear waste, local opposition
10. **Wind Electricity**	Electricity Production	Wind displaces coal-based electricity (10 x current capacity)	**… using area equal to ~3% of U.S. land area for wind farms**	$$	Not In My Back Yard (NIMBY)
11. **Solar Electricity**	Electricity Production	Solar PV displaces coal-based electricity (100 x current capacity)	**.. using the equivalent of a 100 x 200 km PV array**	$$$	PV cell materials
12. **Wind Hydrogen**	Transportation, Heating and Direct Fuel Use	Produce hydrogen with wind electricity	**… powering half the world's cars predicted for 2050 with hydrogen**	$$$	NIMBY, Hydrogen infrastructure, safety
13. **Biofuels**	Transportation, Heating and Direct Fuel Use	Biomass fuels from plantations replace petroleum fuels	**… scaling up world ethanol production by a factor of 12**	$$	Biodiversity, competing land use
14. **Forest Storage**	Biostorage	Carbon stored in new forests	**… halting deforestation in 50 years**	$	Biodiversity, competing land use
15. **Soil Storage**	Biostorage	Farming techniques increase carbon retention or storage in soils	**… practicing carbon management on all the world's agricultural soils**	$	Reversed if land is deep-plowed later

For more information, visit our website at http://cmi.princeton.edu/wedges.

Wedge Worksheet

1. Record your strategies to reduce total fossil fuel emissions by 8 wedges by 2060.
(1 "wedge" = 1 billion tons carbon per year)

- You may use a strategy more than once
- Use only whole numbers of wedges
- You may use a maximum of
  - 6 electricity wedges (E)
  - 5 transportation wedges(T)
  - 5 heat or direct fuel use wedges (H)

	Strategy	Sector (E,T,H or B)	Cost ($)	Challenges
1				
2				
3				
4				
5				
6				
7				
8				
	TOTALS	E = ___ (6 max) T = ___ (5 max) H = ___ (5 max) B = ___	______	

2. Guess the score each stakeholder group would give your team's triangle on a scale of 1 to 5 (5 = best).

Judge:	Taxpayers/ Consumers	Energy Companies	Environmental Groups	Manufacturers	Industrialized country governments	Developing country governments
Score:						

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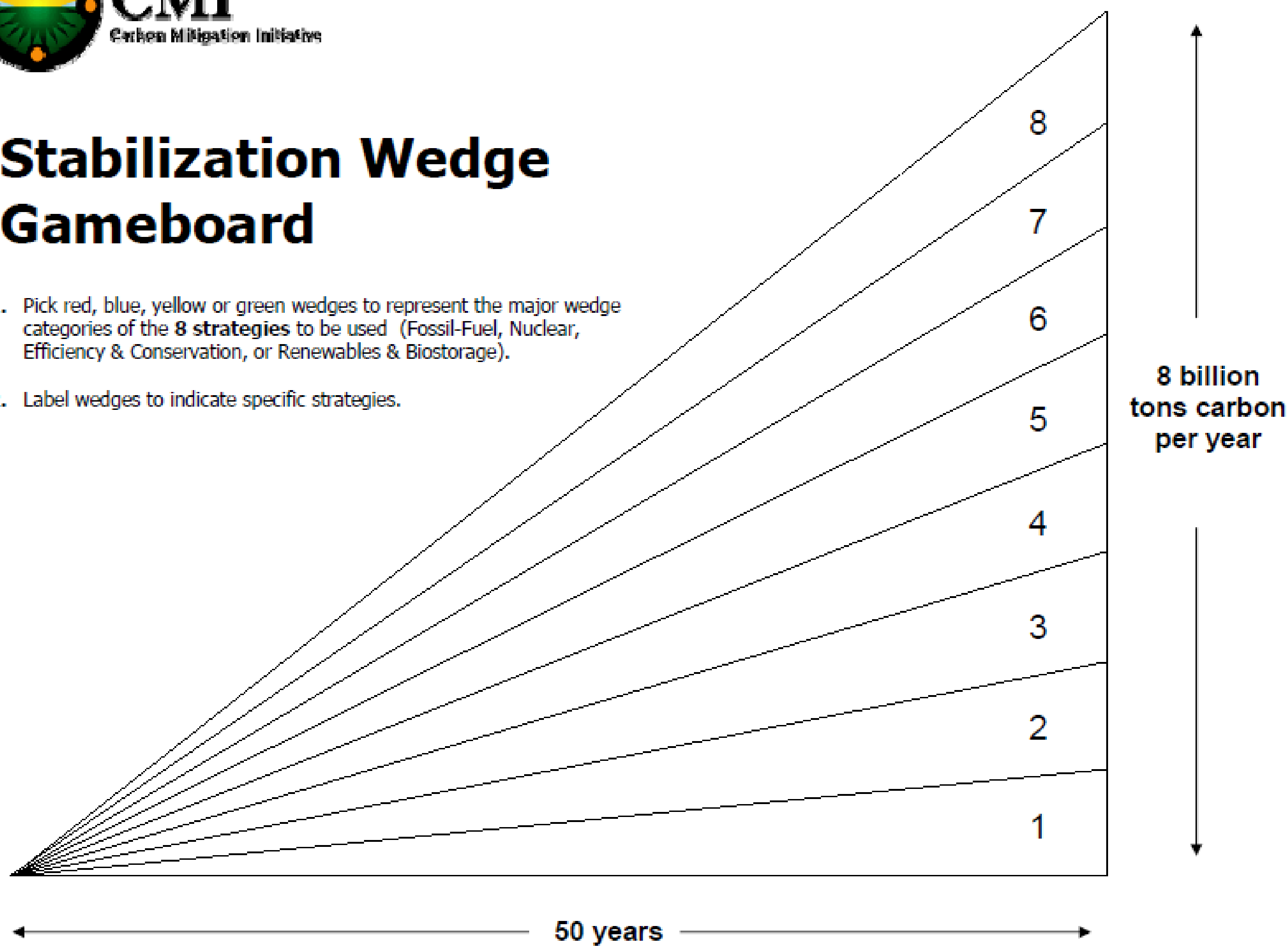
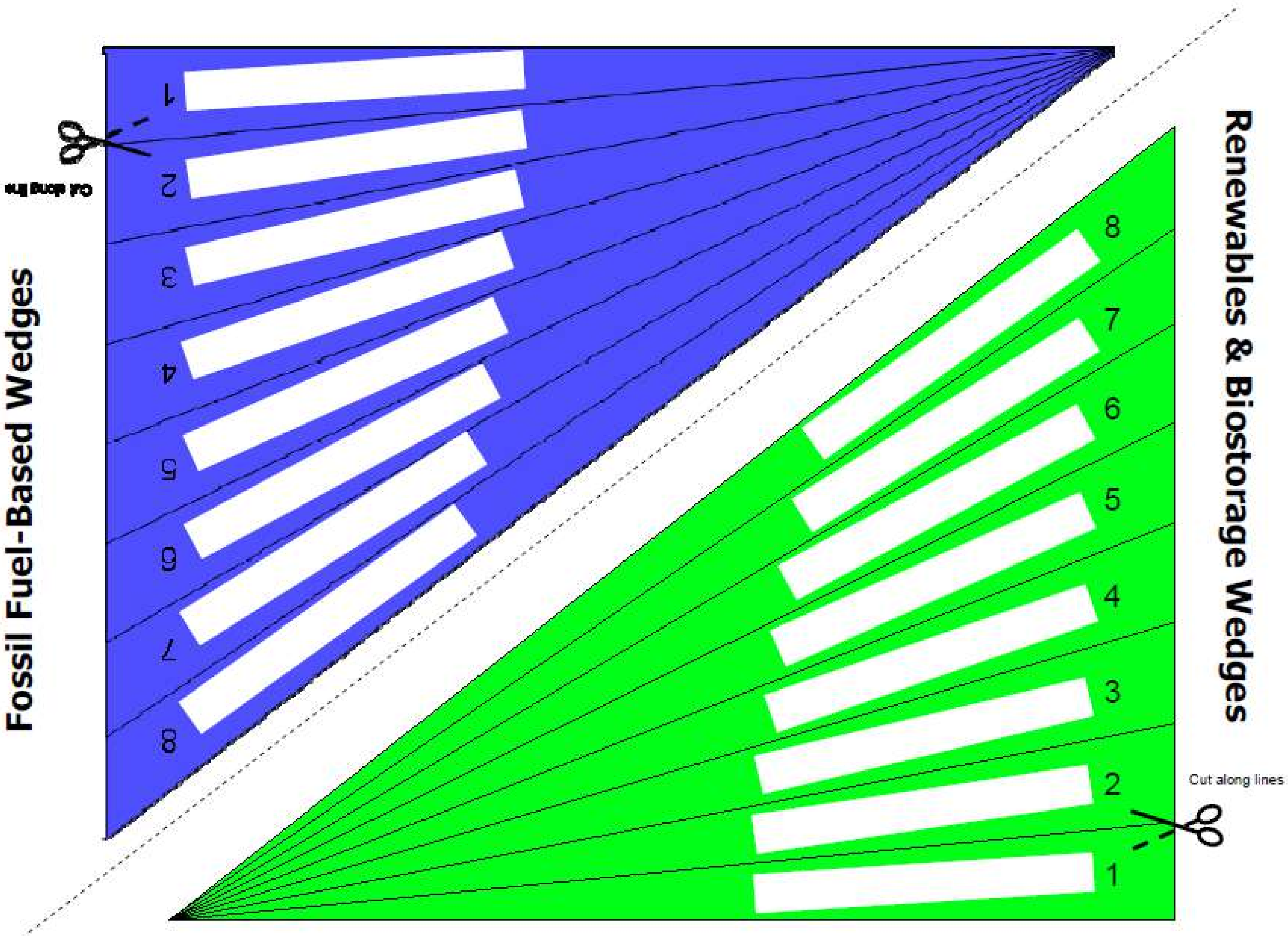
CMI
Carbon Mitigation Initiative

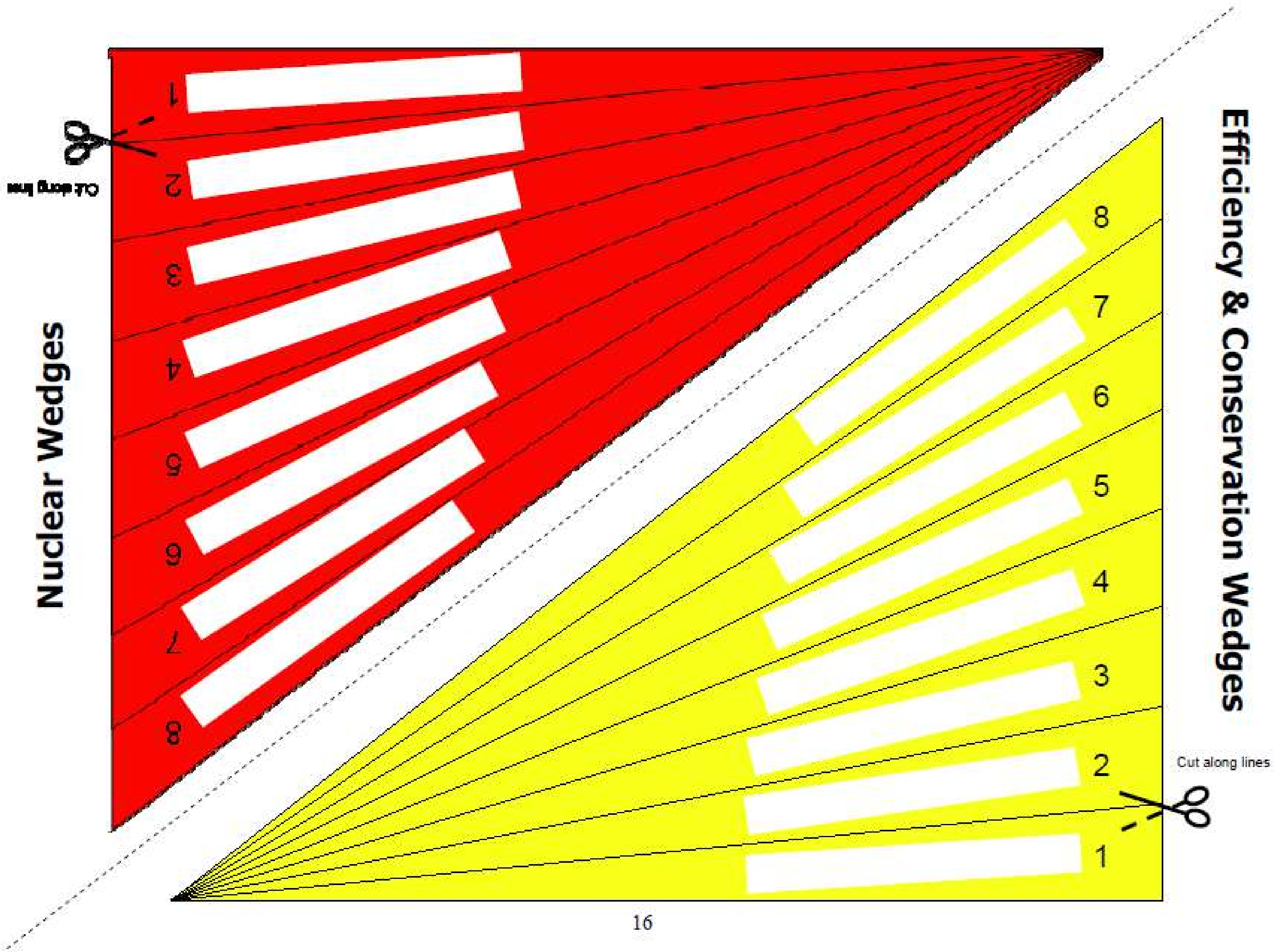
Stabilization Wedge Gameboard

1. Pick red, blue, yellow or green wedges to represent the major wedge categories of the **8 strategies** to be used (Fossil-Fuel, Nuclear, Efficiency & Conservation, or Renewables & Biostorage).

2. Label wedges to indicate specific strategies.




Fossil Fuel-Based Wedges
Cut along line
1
2
3
4
5
6
7
8
Renewables & Biostorage Wedges
Cut along lines
8
7
6
5
4
3
2
1


Nuclear Wedges
1
2
3
4
5
6
7
8
Cut along lines
Efficiency & Conservation Wedges
8
7
6
5
4
3
2
1
Cut along lines

16

Community Action Scenario

Denver Neighborhood Climate Prosperity Project
Denver, Colorado

Climate Showcase Communities
Local Climate and Energy Program

The goal of Denver's Neighborhood Climate Prosperity Project is to reduce greenhouse gas (GHG) emissions at the neighborhood level. The project consists of four elements:

- Greening small businesses
- Expanding neighborhood sustainable mobility options
- Providing incentives to support clean energy
- Engaging residents to reduce GHG emissions

To support the greening of local small businesses, the City of Denver provided workshops and education resources, developed energy action plans across business districts, and assisted small businesses through a "start-to-finish" energy-assistance package. The City also worked with businesses to expand sustainable mobility options in neighborhoods. To achieve this goal, the project promoted local non-auto routes, helped businesses provide incentives to reduce vehicle travel, and promoted alternative fuels.

In addition, the project promoted the voluntary purchases of renewable energy and travel GHG emission offsets through a community "Energy Makeover" program. Neighborhoods that met targets for purchasing renewable energy or travel offsets received funding for energy efficiency upgrades or a renewable energy system at a local school or community building.

Finally, the city engaged residents to reduce GHG emissions from their homes. Through Denver's Neighborhood Energy Action Partnership, residents in high-need neighborhoods gained access to programs including: free curbside recycling, free tree planting, free CFL porch bulbs, energy audits, home weatherization for low-income families, and utility rebates.

The benefits of the Climate Prosperity Project included a reduction in GHG emissions by improving residential energy efficiency, reducing commercial energy use, promoting green power, and reducing transportation GHG emissions. The project realized social benefits by supporting green jobs and by educating residents, students, and small business owners while influencing behavioral changes necessary for the long-term achievement of environmental objectives.

<u>Program Results:</u>

Expected GHG Reductions:	28,745 metric tons CO_2 annually
GHG Reductions (as of 6/11):	11,302 metric tons CO_2 annually
Expected Electricity Savings:	325 MWh annually
Businesses Reached (as of 6/11):	245
Residences Reached (as of 6/11):	26,927 visits, 6,716 program sign-ups

LATEST UPDATE

The Denver Neighborhood Climate Prosperity Project, now known as the Denver Energy Challenge, reached over 25,000 households in 16 neighborhoods through outreach efforts as of June 2011. Nearly 20% of households (4,958 households) have pledged to take climate action. Approximately 500 households have signed up for Xcel Energy's Windsource program, a voluntary renewable energy program where customers can specify which part of their electricity should be generated by wind energy. This increase in Windsource participation will result in approximately $12,000 in additional funding from Xcel Energy for Denver Public Schools' (DPS) energy initiatives. The project team has also fully launched their energy outreach efforts for small businesses. As of June 2011, 245 businesses have signed up to participate in the Denver Energy Challenge. Thanks to the outreach and education efforts support by this grant coupled with the financial incentives offered through the DOE Better Buildings grant, more than 80 businesses have completed energy efficient projects which are expected to eliminate nearly one million kilowatt hours of energy consumption per year.

Questions for Discussion

1. Which activity/activities could you engage in and why?
2. Which activity/activities would be difficult for you to do and why?
3. Which activities could your community implement and why?

Source: EPA http://www.epa.gov/statelocalclimate/local/showcase/index.html

Forestry and Agricultural Scenario

Laura owns about 400 acres of forest and agricultural lands in the Midwest. She has been investigating forestry and agricultural practices that are recognized as potential greenhouse gas (GHG) mitigation options (Tables 1 and 2). These recognized forestry and agriculture practices reduce and/or avoid emitting the three most important GHG to the atmosphere: carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O).

Laura has found that the removal of atmospheric CO_2 through sequestration in carbon "sinks" is a mitigation option in forestry and agriculture. Sequestration is defined as the process of increasing the carbon content of a carbon pool other than the atmosphere. Carbon pools in forestry and agriculture include tree biomass (roughly 50% carbon), soils, and wood products. A carbon pool is a sink if, over time, more carbon flows into the pool than is flowing out of the pool. Likewise, a carbon pool can be a net source of CO_2 emissions if less carbon flows into the pool than is flowing out of the pool. Individual carbon sequestration and GHG mitigation options in forestry and agriculture include:

- tree planting
- forest management activities that enhance tree growth over time
- forest preservation
- conservation tillage practices on agricultural lands
- agricultural livestock and nutrient management

In croplands, carbon pools in soils and increases or decreases depending on inputs from plant-fixed carbon in leaves, stems and roots; human-related inputs (e.g., fertilizer); and type of management practice (e.g., conventional vs. conservation tillage). In agricultural soils, carbon may be sequestered for 15 years or longer, depending on the type of soil and on the type of management practice.

Table 1.Agricultural Practices that Sequester/Reduce Greenhouse Gas Emissions

Key Agricultural Practices	**Typical definition and some examples**	**Effect on greenhouse gases**
Conservation or riparian buffers	Grasses or trees planted along streams and croplands to prevent soil erosion and nutrient runoff into waterways.	Increases carbon storage through sequestration.
Conservation tillage on croplands	Defined as any tillage and planting system in which 30% or more of the crop residue remains on the soil after planting. This disturbs the soil less, allowing soil carbon to accumulate.	Increases carbon storage through enhanced soil sequestration, may reduce energy-related CO_2 emissions from farm equipment.
Grazing land management	Modification to grazing practices that produce beef and dairy products that leads to net greenhouse gas reductions (e.g., rotational grazing).	Increases carbon storage through enhanced soil sequestration and may affect emissions of CH_4 and N_2O.

In forests, carbon may be sequestered over decades, until mature ecosystems reach carbon saturation; however, natural decay and disturbances such as fire or harvesting may release carbon into the atmosphere. Carbon from forests may be stored in wood products like furniture and housing lumber for decades. When the carbon in wood products decays, it is released as CO_2 back to the atmosphere.

Nationally, forests and croplands sequester over 600 teragrams (Tg) of CO_2 equivalent per year. This current sequestration offsets about 12% of the total U.S. CO_2 emissions from the energy, transportation, and industrial sectors. Internationally, 20% of the world's annual CO_2 emissions result from land use change, primarily deforestation in Central and South America, Africa, and Asia. This change in land use shifts naturally high-carbon sink forests to generally lower-carbon sink crop and grazing lands or urban areas.

Table 2. Forestry Practices that Sequester/Reduce Greenhouse Gas Emissions

Key Forestry Practices	**Typical definition and some examples**	**Effect on greenhouse gases**
Afforestation	Tree planting on lands previously not in forestry (e.g., conversion of marginal cropland to trees).	Increases carbon storage through sequestration.
Reforestation	Tree planting on lands that in the more recent past were in forestry, excluding the planting of trees immediately after harvest.	Increases carbon storage through sequestration.
Forest preservation or avoided deforestation	Protection of forests that are threatened by logging or clearing.	Avoids CO_2 emissions via conservation of existing carbon stocks.
Forest management	Modification to forestry practices that produce wood products to enhance sequestration over time (e.g., lengthening the harvest-regeneration cycle, adopting low-impact logging).	Increases carbon storage by sequestration and may also avoid CO_2 emissions by altering management. May generate some N_2O emissions due to fertilization practices.

Questions for Discussion

1. Which practices could you implement to reduce your greenhouse gas emissions and why?
2. Which practices would be difficult for you to implement and why?
3. Which practices could your community implement to reduce its greenhouse gas emissions and why?

Source:

EPA, http://www.epa.gov/sequestration/overview.html

Human Health and Global Warming Scenario

Dr. Julie Andrews is the epidemiologist for the county health department. She has become concerned about how well the county is prepared for local health issues associated with global warming and climate change. She is one of the few, for only five states have prepared public health response plans related to global warming and climate change. Her concerns center on increased temperatures and extreme weather events, specifically flooding. She recalls the July 1995 Chicago heat wave where the heat index peaked at 119 degrees Fahrenheit. Thousands of Chicagoans developed severe heat-related illnesses, and paramedics and hospitals were unable to keep up with emergencies. As a result, 465 people died from heat-related illnesses. Many of these individuals were elderly, in poor health, lived in poverty, lived alone, and lacked air conditioning. In 1999 Chicago once again experienced extreme heat conditions. This time they issued heat warnings, opened cooling centers and provided free transportation to them, and went door-to-door contacting the elderly that lived alone. This action reduced the number of heat-related deaths to 110.

As shown in Chicago, human health is closely related to local climatic conditions; however, few individuals are aware of this link. For example, warmer temperatures may result in:

- the direct loss of life from heat exhaustion.
- changes in the range and distribution of parasites, increasing infectious diseases.
- increases in air and water pollution, which may impact human health.

Global warming may lead to more extreme summer heat waves. Chicago is projected to experience 25 percent more frequent heat waves and Los Angeles a four-to-eight-fold increase in heat wave days. Heat exposure has a range of health effects, from mild heat rashes to deadly heat stroke. Heat exposure can aggravate chronic cardiovascular and respiratory disease. The results can be severe and result in increased illness and death. In these communities, and others, individuals with heart problems and asthma, the elderly and very young, and the homeless may be especially vulnerable to extreme heat. Other extreme weather events, such as floods and thunderstorms, may also impact human health, causing more human deaths and injuries, as well as property damage. Over a longer time period, increased temperatures may cause droughts. Long term drought conditions may strain agricultural productivity, resulting in increased food prices and food shortages.

Global warming is likely to cause air quality problems, exacerbating respiratory disorders as a result of more frequent smog (ground-level ozone) events and particulate air pollution. Higher temperatures and heat waves increase demand for electricity and thus the combustion of fossil fuels, generating more airborne particulates and indirectly increasing respiratory disease. Higher temperatures also result in an increase in ground-level ozone concentrations, causing direct lung injury and increasing the severity of respiratory diseases such as asthma and chronic obstructive pulmonary disease.

There is some concern that warmer temperatures will increase the risk and spread of infectious diseases transmitted by mosquitoes and other insects, including malaria, dengue fever, yellow fever, and encephalitis. In locations where these diseases already exist, there is the possibility that warmer temperatures, in combination with increased rainfall, could prolong the transmission season. Lyme disease, which is transmitted by ticks, may increase in regions where temperature and humidity levels are optimized, and may expand northward into Canada. The dynamics of disease migration are complex, and temperature is just one factor affecting the distribution of these diseases.

Table 1: Health Effects of Climate Change in the United States

Weather Event	Health Effects	Populations Most Affected
Heat waves	■ Premature death ■ Heat-related illnesses such as heat stroke, heat exhaustion, and kidney stones	■ The elderly ■ Children ■ Diabetics ■ Poor, urban residents ■ People with respiratory diseases ■ Those active outdoors (workers, athletes, etc.)
Poor air quality	■ Increased asthma[18] ■ Increased chronic obstructive pulmonary disease (COPD) and other respiratory diseases[19,20]	■ Children ■ Those active outdoors (workers, athletes, etc.) ■ The elderly ■ People with respiratory diseases ■ The poor
Hurricanes	■ Death from drowning ■ Injuries ■ Mental health impacts such as depression and post-traumatic stress disorder ■ Increased carbon monoxide poisoning ■ Increased gastrointestinal illness ■ Population displacement/homelessness	■ Coastal residents ■ The poor ■ The elderly ■ Children
Extreme rainfall and floods	■ Death from drowning ■ Injuries ■ Increased water-borne diseases from pathogens and water contamination from sewage overflows ■ Increased food-borne disease[21]	■ Residents in low-lying areas ■ The elderly ■ Children ■ The poor ■ Residents in the Southwestern U.S.
Wildfires	■ Death from burns and smoke inhalation ■ Injuries ■ Eye and respiratory illness due to fire-related air pollution	■ People with respiratory diseases
Droughts	■ Disruption in food supply ■ Changing patterns of crops, pests and weed species ■ Water shortages ■ Malnutrition[22] ■ Food- and water-borne disease ■ Emergence of new vector-borne and zoonotic disease	■ The poor ■ The elderly ■ Children
Increased average temperature	■ Increased food-borne disease, such as Salmonella poisoning ■ Increased vector-borne disease such as West Nile virus, equine encephalitis, Lyme disease, Rocky Mountain spotted fever, and hantavirus ■ Increased strain on regional drinking water supplies ■ Increased vulnerability to wildfires and associated air pollution	■ Children ■ Those active outdoors (workers, athletes, etc.)
Increased temperature and rising carbon dioxide levels	■ Increased allergies caused by pollen ■ Increased cases of rashes and allergic reactions from toxic plants such as poison ivy, stinging nettle, and other weeds	■ People with respiratory disease ■ People with acute allergies ■ Children ■ Those active outdoors (workers, athletes, etc.)

Source: Except where noted, the information above is from Karl, T.R., J.M. Melillo, and T.C. Peterson, eds. *Global Climate Change Impacts in the United States*. New York, NY: Cambridge University Press, 2009, p. 89-98.

The severity of human health problems caused by global warming and climate change will likely depend on the effectiveness and preparedness of local, public health systems.

Questions for Discussion

1. What actions could you take to reduce human health issues related to global warming?
2. What actions could you take to prepare for human health issues related to global warming?
3. What actions could your community take to prepare for human health issues related to global warming?

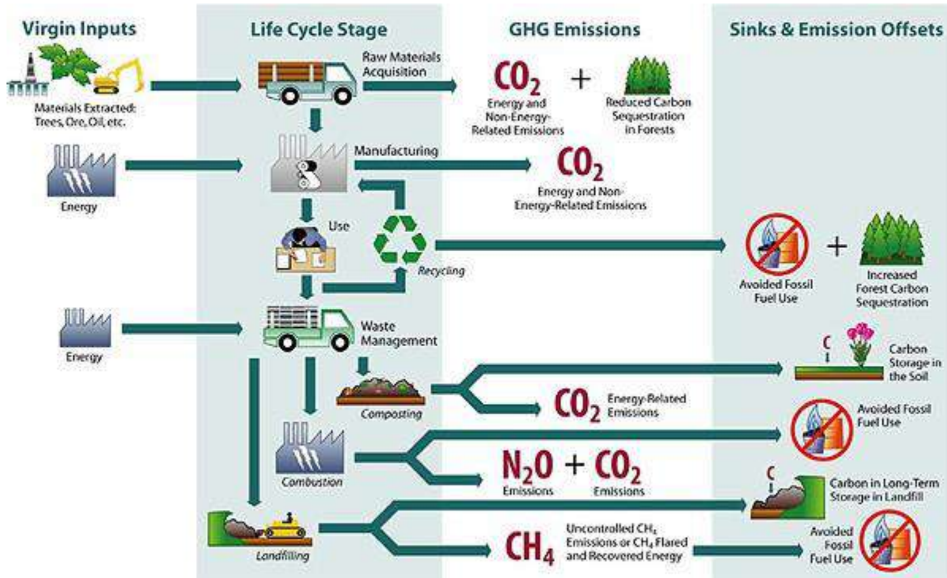
Sources:

EPA. http://www.epa.gov/climatechange/effects/health.html

IPCC (2007). Climate Change 2007: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom.

CDC. http://www.cdc.gov/climatechange/

Solid Waste, Greenhouse Gases, and Global Warming Scenario



Allen, like most people, was surprised to learn that solid waste reduction and recycling helps address global warming. He knew, as an informed consumer, that the manufacturing, distribution, and use of products resulted in the emission of greenhouse gases. What he did not know was that the disposal of solid waste also results in the emission of greenhouse gases. Allen wanted to know more about how solid waste produces greenhouse gases. What he found was that the disposal of solid waste produces greenhouse gases from the:

- anaerobic decomposition of solid waste in landfills, which produces methane, a greenhouse gas 21 times more potent than carbon dioxide.
- incineration of solid waste, which produces carbon dioxide as a by-product
- transportation of solid waste to disposal sites, which produces greenhouse gas emissions from the combustion of the fuel used in the equipment.
- replacement of disposed waste material by new products, which requires the use of fossil fuels to obtain raw materials and to manufacture the new items, thus producing greenhouse gas emissions from the combustion of the fuel.

As a responsible consumer, Allen wanted to know what practical solid waste management strategies he could implement that would reduce his personal greenhouse gas emissions. What he learned was that waste prevention and recycling—referred to as waste reduction—is the best way to manage the solid waste he generates, reducing his greenhouse gas emissions:

- Waste reduction diverts solid wastes from landfills, reducing the methane released when these materials decompose.
- Recycling and waste prevention decreases the amount of waste being incinerated and thus reduces greenhouse gas emissions from the combustion of solid waste.
- Recycling saves energy. Manufacturing goods from recycled materials uses less energy than producing goods from virgin materials. Waste prevention is even more effective at saving energy. When people reuse products less energy is needed to extract, transport,

and process raw materials and to manufacture products. When less energy is used, fewer fossil fuels are burned and less carbon dioxide is emitted to the atmosphere.

- Waste prevention and recycling of paper products allow more trees to remain standing in the forest, where they continue to remove carbon dioxide from the atmosphere and store it as wood, called "carbon sequestration."

To reduce, reuse, and recycle, Allen identified the following waste reduction strategies he could implement at home and work:

- Reduce food waste by using up food before buying more food.
- Donate little used or slightly worn clothing to charities and shelters.
- Reuse items around the house such as rags and wipes, empty jars and mugs, party decorations, and gift wrap.
- Buy products in concentrate, bulk, and in refillable containers, reducing packaging waste
- Check product labels to determine an item's recyclability and whether it was made from recycled materials. Buying recycled encourages manufacturers to make more recycled-content products.
- Recycle paper, newspapers, magazines, beverage containers and glass jars.
- Use canvas/cloth tote bags when shopping instead of a store’s plastic bag.
- Stop buying bottled water; use a reusable thermos.
- Compost grass clippings and yard waste.
- Reduce waste by using two-sided printing and copying, and recycle used printer cartridges.

As a result of implementing these strategies, Allen greatly reduced his greenhouse gas emissions. He pondered the idea of forming a neighborhood coalition for reducing solid waste.

Questions for Discussion

1. Which activity/activities could you engage in and why?
2. Which activity/activities would be difficult for you to do and why?
3. Which activities could your community or neighborhood implement and why?
4. What strategies could you implement to involve your neighbors in reducing their solid waste?

Source:

EPA http://www.epa.gov/climatechange/wycd/waste/generalinfo.html

Handout: Climate Education Websites

The websites listed provide both classroom-based instructional activities and materials and climate science content background. In addition, the following websites provide information on climate literacy and climate change:

Climate Literacy: The Essential Principles of Climate Science
http://www.climatescience.gov/Library/Literacy/

Intergovernmental Panel on Climate Change (IPCC)
http://www.ipcc.ch/

Website	Link
Activities for Conceptualizing Climate and Climate Change	http://climate.agry.purdue.edu/climate/ccc/
CoCoRaHS observing network for precipitation reports (rain, hail, snow, drought, significant weather)	www.cocorahs.org
NOAA Education	http://www.education.noaa.gov/index.html
NOAA Climate Education Resources	http://www.education.noaa.gov/Climate/
The USGS and Science Education	http://education.usgs.gov/
NASA Education	http://www.nasa.gov/offices/education/about/index.html
US Environmental Protection Agency	http://www.epa.gov/climatechange/index.html
Digital Library for Earth System Education	http://dlese.org/library/index.jsp
Climate Change at the National Academies	http://dels.nas.edu/climatechange/ecological-impacts.shtml
NASA Earth Observatory	http://earthobservatory.nasa.gov/
PBS	http://www.pbs.org/now/classroom/globalwarming.html
Center for Integrated Study of the Human Dimensions of Global Change	http://hdgc.epp.cmu.edu/teachersguide/teachersguide.htm
Global Warming: Understanding the Forecast	http://geoflop.uchicago.edu/forecast/docs/lectures.html
Climate Literacy Catalog	http://serc.carleton.edu/climatechange/climate_literacy_search.html
Smithsonian Institution-Climate Change	http://www.smithsonianconference.org/climate/teachers/
The Globe Program	http://classic.globe.gov/
Earth Watch Institute	http://www.earthwatch.org/aboutus/education/lessonideas/
Global Climate Change-Climate kids	http://climate.nasa.gov/kids/index.cfm
The Ultimate Guide to Weather and Climate Resources Online	http://www.guidetoonlineschools.com/library/weather-resources
Climate Prediction Center, Educational Materials	http://www.cpc.ncep.noaa.gov/products/outreach/education.shtml

Handout: Climate and Climate Change Resources

The following websites provide: 1) answers to the most often asked questions about climate and climate change, 2) links to short video casts and other media resources, and 3) access to climate data for individual analysis or classroom use.

Answers to Frequently Asked Questions about Climate and Climate Change

- Climate FAQs (NCDC): http://www.ncdc.noaa.gov/faqs/index.html
- UCAR (University Corporation for Atmospheric Research) Global Warming and Climate Change FAQs: http://www2.ucar.edu/climate/faq
- Climate glossary: http://www.cpc.ncep.noaa.gov/products/outreach/glossary.shtml

Multimedia Resources

- UCAR Podcasts (brief 3-5 min general descriptions by experts on main questions): http://www.ucar.edu/webcasts/voices/#
- Additional UCAR multimedia: http://www2.ucar.edu/news/understanding-climate-change-multimedia-gallery
- NOAA Climate Services (videos and articles of updated topics): http://www.climate.gov/#climateWatch

Access to Climate Data

- National Climatic Data Center (NCDC). National station specific temperature and precipitation data: http://www.ncdc.noaa.gov/oa/ncdc.html
- NCDC Climate Program Office data and products (quick access to NCDC data and climatological normals, i.e. Climate-At-A-Glance): http://www.climate.noaa.gov/index.jsp?pg=./data_products/data_index.jsp&data=catalog
- Climate Prediction Center (CPC):
  - monitoring and data index: http://www.cpc.ncep.noaa.gov/products/MD_index.shtml
  - weather and climate data: http://www.cpc.ncep.noaa.gov/products/precip/CWlink/
  - global regional climate maps (temp and precipitation): http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/regional_monitoring/
  - monthly atmospheric and SST indices: http://www.cpc.ncep.noaa.gov/data/indices/
  - regional climate maps: http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/regional_monitoring/usa.shtml
  - U.S. temp and precip trends: http://www.cpc.ncep.noaa.gov/charts.shtml
  - Northern hemisphere snow cover: http://www.cpc.ncep.noaa.gov/data/snow/
- Southern Climate Impacts Planning Program (SCIPP):
  - data tools: http://www.southernclimate.org/data.php
  - annual monthly graphs: http://www.southernclimate.org/products/temp_precip.php
  - graphs by season: http://www.southernclimate.org/products/trends.php
  - graphs by station: http://www.southernclimate.org/products/climo_graph.php

Handout: Background Readings on Climate and Climate Change

The following NASA Earth Observatory articles provide excellent background reading on climate and climate change:

- Climate and Earth's Energy Budget :
  http://earthobservatory.nasa.gov/Features/EnergyBalance/

- Global Warming:
  http://earthobservatory.nasa.gov/Features/GlobalWarming/global_warming_2007.pdf

- The Carbon Cycle:
  http://earthobservatory.nasa.gov/Features/CarbonCycle/carbon_cycle2001.pdf

- The Greenhouse Effect:
  http://earthobservatory.nasa.gov/Experiments/PlanetEarthScience/GlobalWarming/GW_Movie3.php

- Oceans and Climate:
  http://earthobservatory.nasa.gov/Features/OceanClimate/

Glossary of Common Climate Terms

(from CPC, IPCC, EPA, and NWS)

Adaptation – A change in the way one lives due to the influence of the environment. Moreover, how we cope with changes in climate.

Aerosol – A system of colloidal particles dispersed in a gas, such as smoke or fog.

Albedo – Reflectivity; the fraction of radiation striking a surface that is reflected by that surface (calculated by dividing reflective light by the incident (incoming) light).

Anomaly - The deviation of a measurable unit, (e.g., temperature or precipitation) in a given region over a specified period from the long-term average, often the thirty year mean, for the same region.

Carbon sink - A carbon pool is a sink if, over time, more carbon flows into the pool than is flowing out of the pool.

Carbon source - A carbon pool can be a net source of CO_2 emissions if less carbon flows into the pool than is flowing out of the pool.

Chlorofluorocarbons (CFCs) - Manufactured substances used as coolants and computer chip cleaners. When these products break down they destroy stratospheric ozone, creating the Antarctic Ozone Hole in the Southern Hemisphere spring (Northern Hemisphere fall). While no longer in use, their long lifetime will lead to a very slow removal from the atmosphere.

Climate - The average of weather over at least a 30-year period. Note that the climate taken over different periods of time (30 years, 1000 years) may be different. The old saying is climate is what we expect and weather is what we get.

Climate Change - A non-random change in climate that is measured over several decades or longer. The change may be due to natural or human-induced causes.

Climate Model - Mathematical model for quantitatively describing, simulating, and analyzing the interactions between the atmosphere and underlying surface (e.g., ocean, land, and ice).

Climate Outlook - A climate outlook gives probabilities that conditions, averaged over a specified period, will be below-normal, normal, or above-normal.

Climate System - The system consisting of the atmosphere (gases), hydrosphere (water), lithosphere (solid rocky part of the Earth), and biosphere (living) that determine the Earth's climate.

Climate Variability – Fluctuations of conditions in the Earth’s climate over various time scales, commonly observed from season to season with abnormally wet/dry or warm/cool periods. The ENSO cycle is also an example of climate variability.

Climatology - (1) The description and scientific study of climate. (2) A quantitative description of climate showing the characteristic values of climate variables over a region.

Convection - In meteorology, the term is used specifically to describe vertical transport of heat and moisture in the atmosphere, especially by updrafts and downdrafts in an unstable atmosphere. The terms "convection" and "thunderstorms" often are used interchangeably, although thunderstorms are only one form of convection.

CPC – Climate Prediction Center

Drought - Drought is a deficiency of moisture that results in adverse impacts on people, animals, or vegetation over a sizeable area. NOAA together with its partners provides short- and long-term Drought Assessments.

El Niño - El Niño, a phase of ENSO, is a periodic warming of surface ocean waters in the eastern tropical Pacific along with a shift in convection in the western Pacific further east than the climatological average. These conditions affect weather patterns around the world. El Niño episodes occur roughly every four-to-five years and can last up to 12-to-18 months. The preliminary CPC definition of El Niño is a phenomenon in the equatorial Pacific Ocean characterized by a *positive* sea surface temperature departure from normal, averaged over three months, greater than or equal in magnitude to 0.5^{o}C in a region defined by the Niño 3.4 dataset.

Ensemble Forecast - Multiple predictions from an ensemble of slightly different initial conditions and/or various versions of models. The objective is to improve the accuracy of the forecast through averaging the various forecasts, which eliminates non-predictable components, and to provide reliable information on forecast uncertainties from the diversity amongst ensemble members. Forecasters use this tool to measure the likelihood of a forecast.

ENSO (El Niño-Southern Oscillation) - Originally, ENSO referred to El Niño/ Southern Oscillation, or the combined atmosphere/ocean system during an El Niño warm event. The ENSO cycle includes La Niña and El Niño phases as well as neutral phases, or ENSO cycle, of the coupled atmosphere/ocean system though sometimes it is still used as originally defined. The Southern Oscillation is quantified by the Southern Oscillation Index (SOI).

Evaporation - The physical process by which a liquid or solid is changed to a gas; the opposite of condensation.

Forecasts - A weather forecast, or prediction, is an estimation based on special knowledge of the future state of the atmosphere with respect to temperature, precipitation, and wind. Weather forecasts are now routinely provided for up to 14 days in advance and outlooks for seasonal and longer timescales.

Global Warming - Certain natural and human-produced gases prevent the sun's energy from escaping back to space leading to an overall rise in the temperature of the Earth's atmosphere.

Greenhouse Effect (GHE) - The atmosphere allows solar radiation to reach the earth relatively easily. The atmosphere absorbs the infrared radiation emitted by the Earth's surface and radiates it back to the Earth in much the same way a greenhouse traps heat as the sun's rays pass through the glass, and the heat generated does not pass back through the glass. The "greenhouse effect" causes the surface of the Earth to be much warmer that it would be without the atmosphere 60°F). Without the greenhouse effect, life as we know it might not exist on Earth.

Greenhouse Gas (GHG) - Certain gases, such as water vapor, carbon dioxide, and methane, that more effectively trap heat affecting the Earth's surface temperature.

IPCC – Intergovernmental Panel on Climate Change

Jet Stream - Strong winds concentrated within a narrow zone in the atmosphere in the upper troposphere, about 30,000 feet aloft that generally move in an easterly direction that drive weather systems around the globe. In North America jet streams are more pronounced in winter.

Keeling Curve – The trend of atmospheric carbon dioxide levels over time.

La Niña - La Niña, a phase of ENSO, is a periodic cooling of surface ocean waters in the eastern tropical Pacific along with a shift in convection in the western Pacific further west than the climatological average. These conditions affect weather patterns around the world. The preliminary CPC definition of La Niña is a phenomenon in the equatorial Pacific Ocean characterized by a *negative* sea surface temperature departure from normal (for the 1971-2000 base period), averaged over three months, greater than or equal in magnitude to 0.5°C in a region defined by the Niño 4 dataset.

Meteorology - The scientific study of the physics, chemistry, and dynamics of the Earth's atmosphere, especially weather and climate.

Mitigation – A human intervention to reduce the sources or enhance the sinks of greenhouse gases.

NCAR –National Center for Atmospheric Research

NOAA – National Oceanic and Atmospheric Administration

Normal - To understand whether precipitation and temperature is above or below normal for seasons and longer timescales, normal is defined as the average weather over 30 years. These averages are recalculated every ten years. The National Weather Service has just recalculated the baseline period for normal from 1971 to 2000 to 1981 to 2010.

NWS – National Weather Service

Ozone - A molecule consisting of three oxygen atoms that is formed by a reaction of oxygen and ultraviolet radiation. In the stratosphere, ozone has beneficial properties where it forms an ozone shield that prevents dangerous radiation from reaching the Earth's surface. Closer to the planet's surface, ozone is considered an air pollutant that adversely affects humans, plants and animals as well as a greenhouse gas.

Ozone Hole - A severe depletion of stratospheric ozone over Antarctica that occurs each spring. The possibility exists that a hole could form over the Arctic as well. The depletion is caused by a chemical reaction involving ozone and chlorine, primarily from human produced sources, cloud particles, and low temperatures.

Sea Surface Temperatures (SSTs) - The term refers to the mean temperature of the ocean in the upper few meters.

Stratosphere - The region of the atmosphere extending from the top of the troposphere to the base of the mesosphere, an important area for monitoring stratospheric ozone.

Teleconnection - A strong statistical relationship between weather in different parts of the globe. For example, there appears to be a teleconnection between the tropics and North America during El Niño.

Thermocline - As one descends from the surface of the ocean, the temperature remains nearly the same as it was at the surface, but at a certain depth temperature starts decreasing rapidly with depth. This boundary is called the thermocline. In studying the tropical Pacific Ocean, the depth of 20°C water ("the 20°C isotherm") is often used as a proxy for the depth of the thermocline. Along the equator, the 20°C isotherm is typically located at about 50m depth in the eastern Pacific, sloping downwards to about 150 m in the western Pacific.

Troposphere - The lowest portion of the atmosphere which lies next to the earth's surface where most weather occurs.

Ultraviolet (UV) (or Ultraviolet Radiation) - Ultraviolet radiation from the sun plays a role in the formation of the ozone layer by acting as a catalyst for a chemical reaction that breaks apart oxygen molecules which then recombine to form ozone. The absorption of UV by stratospheric ozone and atmospheric oxygen prevents very little ultraviolet radiation to reach earth's surfaces where it can detrimental effects on human health and property.

Weather-The present condition of the atmosphere, including temperature, humidity, wind, precipitation, among other meteorological elements and their variations over relatively short time periods (hours and days).