Wiesen Environmental Science

17.1: Climate and Its Causes

Introduction

Although almost anything can happen with the weather, climate is more predictable. The weather on a particular winter day in San Diego may be colder than on the same day in Lake Tahoe, but, on average, Tahoe's winter climate is significantly colder than San Diego's (**Figure** below). Climate then is the long-term average of weather. Good climate is why we choose to vacation in Hawaii in February, even though the weather is not guaranteed to be good!

Lake Tahoe's climate makes it easy to predict that there will be snow in the winter.

What is Climate?

Climate is the average of weather in that location over a long period of time, usually for at least 30 years. A location's climate can be described by its air temperature, humidity, wind speed and direction, and the type, quantity, and frequency of precipitation. Climate can change, but only over long periods of time.

The climate of a region depends on its position relative to many things. These factors are described in the next sections.

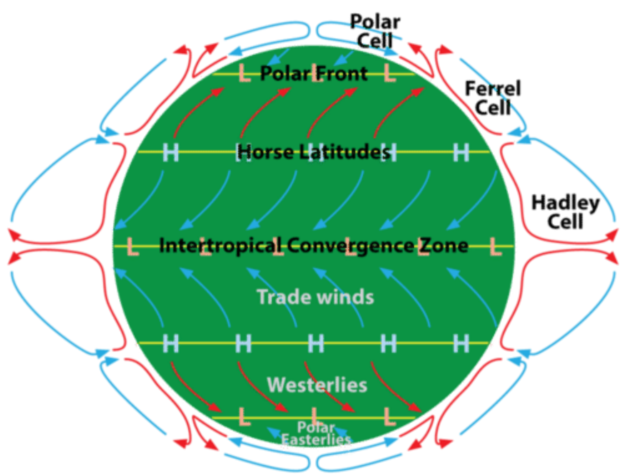
Latitude

The main factor influencing the climate of a region is latitude because different latitudes receive different amounts of solar radiation. To review from the Earth's Atmosphere chapter:

- The equator receives the most solar radiation. Days are equally long year-round and the sun is just about directly overhead at midday.
- The polar regions receive the least solar radiation. The night lasts six months during the winter. Even in summer, the sun never rises very high in the sky. Sunlight filters through a thick wedge of atmosphere, making the sunlight much less intense. The high albedo, because of ice and snow, reflects a good portion of the sun's light.

Atmospheric Circulation Cells

Recall from the Earth's Atmosphere chapter the circulation cells and global wind belts (**Figure** below):



The atmospheric circulation cells and their relationships to air movement on the ground.

The position of a region relative to the circulation cells and wind belts has a great effect on its climate. In an area where the air is mostly rising or sinking, there is not much wind.

The ITCZ

The **Intertropical Convergence Zone (ITCZ)** is the low pressure area near the equator in the boundary between the two Hadley Cells. The air rises so that it cools and condenses to create clouds and rain (**Figure** below). Climate along the ITCZ is therefore warm and wet. Early mariners called this region the doldrums because their ships were often unable to sail because there were no steady winds

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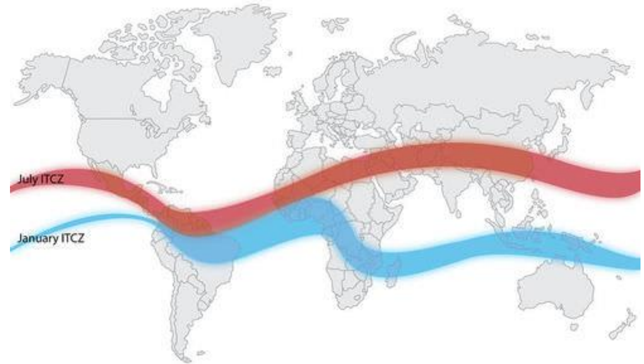
The ITCZ can easily be seen where thunderstorms are lined up north of the equator.

The ITCZ migrates slightly with the season. Land areas heat more quickly than the oceans. Because there are more land areas in the Northern Hemisphere, the ITCZ is influenced by the heating effect of the land. In Northern Hemisphere summer, it is approximately 5° north of the equator while in the winter it shifts back and is approximately at the equator. As the ITCZ shifts, the major wind belts also shift slightly north in summer and south in winter, which causes the wet and dry seasons in this area (**Figure** below).



Seasonal differences in the location of the ITCZ are shown on this map.

Hadley Cell and Ferrell Cell Boundary

At about 30°N and 30°S, the air is fairly warm and dry because much of it came from the equator where it lost most of its moisture at the ITCZ. At this location the air is descending, and sinking air warms and causes evaporation

Mariners named this region the horse latitudes. Sailing ships were sometimes delayed for so long by the lack of wind that they would run out of water and food for their livestock. Sailors tossed horses and other animals over the side after they died. Sailors sometimes didn't make it either.

Ferrell Cell and Polar Cell Boundary

The polar front is around 50° to 60°, where cold air from the poles meets warmer air from the tropics. The meeting of the two different air masses causes the polar jet stream, which is known for its stormy weather. As the Earth orbits the Sun, the shift in the angle of incoming sunlight causes the polar jet stream to move. Cities to the south of the polar jet stream will be under warmer, moister air than cities to its north. Directly beneath the jet stream, the weather is often stormy and there may be thunderstorms and tornadoes.

Prevailing Winds

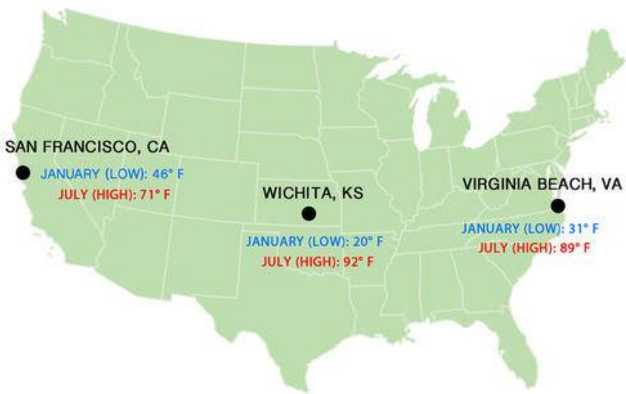
The prevailing winds are the bases of the Hadley, Ferrell, and Polar Cells. These winds greatly influence the climate of a region because they bring the weather from the locations they come from. For example, in California, the predominant winds are the westerlies blowing in from the Pacific Ocean, which bring in relatively cool air in summer and relatively warm air in winter. Local winds also influence local climate. For example, land breezes and sea breezes moderate coastal temperatures.

Continental Position

When a particular location is near an ocean or large lake, the body of water plays an extremely important role in affecting the region's climate.

- A **maritime climate** is strongly influenced by the nearby sea. Temperatures vary a relatively small amount seasonally and daily. For a location to have a true maritime climate, the winds must most frequently come off the sea.
- A **continental climate** is more extreme, with greater temperature differences between day and night and between summer and winter.

The ocean’s influence in moderating climate can be seen in the following temperature comparisons. Each of these cities is located at 37°N latitude, within the westerly winds (**Figure** below).



How does the ocean influence the climate of these three cities?

Ocean Currents

The temperature of the water offshore influences the temperature of a coastal location, particularly if the winds come off the sea. The cool waters of the California Current bring cooler temperatures to the California coastal region. Coastal upwelling also brings cold, deep water up to the ocean surface off of California, which contributes to the cool coastal temperatures. Further north, in southern Alaska, the upwelling actually raises the temperature of the surrounding land because the ocean water is much warmer than the land. The important effect of the Gulf Stream on the climate of northern Europe is described in the chapter, Earth's Oceans.

Review Questions

1. Describe the weather of the location where you are right now. How is the weather today typical or atypical of your usual climate for today’s date?

2. Why is there so little wind in the locations where the atmospheric circulation cells meet?

3. If it is windy at 30°N where there is normally little wind, does that mean the model of the atmospheric circulation cells is wrong?

4. What is the ITCZ? What winds do you expect to find there?

5. How does the polar jet stream move from summer to winter? How does this affect the climate of the locations where it moves?

6. Imagine two cities in North America. How does the climate of a city at 45°N near the Pacific Ocean differ from one at the same latitude near the Atlantic Coast?

7. Why does the ocean water off California cool the western portion of the state, while the water off the southeastern United States warms that region?

17.3: Climate Change

For the past two centuries, climate has been relatively stable. People placed their farms and cities in locations that were in a favorable climate without thinking that the climate could change. But climate has changed throughout Earth history, and a stable climate is not the norm. In recent years, Earth’s climate has begun to change again. Most of this change is warming because of human activities that release greenhouse gases into the atmosphere. The effects of warming are already being seen and will become more extreme as temperature rise.

Climate Change in Earth History

Climate has changed throughout Earth history. Much of the time Earth's climate was hotter and more humid than it is today, but climate has also been colder, as when glaciers covered much more of the planet. The most recent ice ages were in the Pleistocene Epoch, between 1.8 million and 10,000 years ago (**Figure** below). Glaciers advanced and retreated in cycles, known as glacial and interglacial periods. With so much of the world’s water bound into the ice, sea level was about 125 meters (395 feet) lower than it is today. Many scientists think that we are now in a warm, interglacial period that has lasted about 10,000 years.

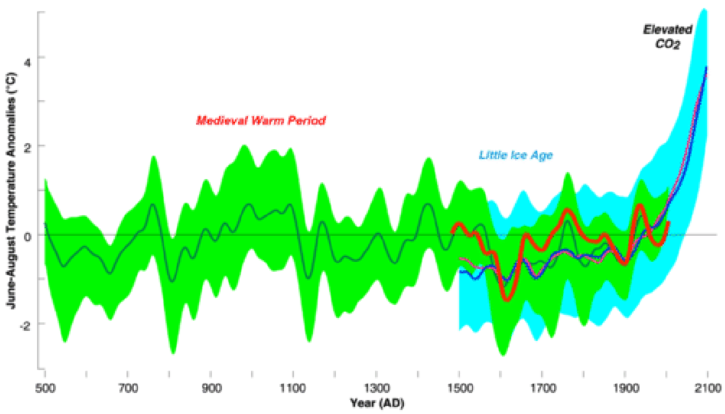
The maximum extent of Northern Hemisphere glaciers during the Pleistocene epoch.

For the past 1500 years, climate has been relatively mild and stable when compared with much of Earth's history. Why has climate stability been beneficial for human civilization? Stability has allowed the expansion of agriculture and the development of towns and cities.

Fairly small temperature changes can have major effects on global climate. The average global temperature during glacial periods was only about 5.5°C (10°F) less than Earth's current average temperature. Temperatures during the interglacial periods were about 1.1°C (2.0°F) higher than today (**Figure** below).

Since the end of the Pleistocene, the global average temperature has risen about 4°C (7°F). Glaciers are retreating and sea level is rising. While climate is getting steadily warmer, there have been a few more extreme warm and cool times in the last 10,000 years. Changes in climate have had effects on human civilization.

- The Medieval Warm Period from 900 to 1300 A.D. allowed Vikings to colonize Greenland and Great Britain to grow wine grapes.
- The Little Ice Age, from the 14th to 19th centuries, the Vikings were forced out of Greenland and humans had to plant crops further south.



The graph is a compilation of 5 reconstructions (the green line is the mean of the five records) of mean temperature changes. This illustrates the high temperatures of the Medieval Warm Period, the lows of the Little Ice Age, and the very high (and climbing) temperature of this decade.

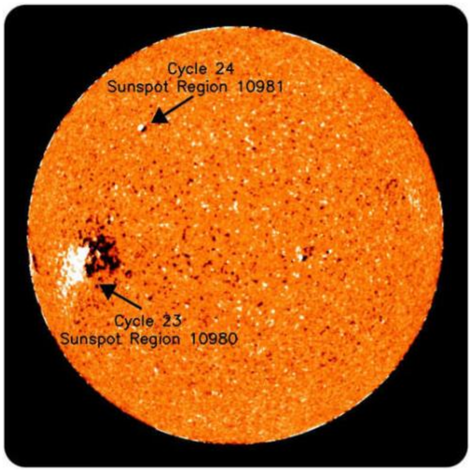
Causes of Long-term Climate Change

Many processes can cause climate to change. These include changes:

- in the amount of energy the Sun produces over years.
- in the positions of the continents over millions of years.
- in the tilt of Earth's axis and orbit over thousands of years.
- that are sudden and dramatic because of random catastrophic events, such as a large asteroid impact.
- in greenhouse gases in the atmosphere, caused naturally or by human activities.

Solar Variation

The amount of energy the Sun radiates is variable. **Sunspots** are magnetic storms on the Sun's surface that increase and decrease over an 11-year cycle (**Figure** below). When the number of sunspots is high, solar radiation is also relatively high. But the entire variation in solar radiation is tiny relative to the total amount of solar radiation that there is and there is no known 11-year cycle in climate variability. The Little Ice Age corresponded to a time when there were no sunspots on the Sun.



Sunspots on the face of the Sun.

Plate Tectonics

Plate tectonic movements can alter climate. Over millions of years as seas open and close, ocean currents may distribute heat differently. For example, when all the continents are joined into one supercontinent (such as Pangaea), nearly all locations experience a continental climate. When the continents separate, heat is more evenly distributed.

Plate tectonic movements may help start an ice age. When continents are located near the poles, ice can accumulate, which may increase albedo and lower global temperature. Low enough temperatures may start a global ice age.

Plate motions trigger volcanic eruptions, which release dust and CO_2 into the atmosphere. Ordinary eruptions, even large ones, have only a short-term effect on weather (**Figure** below). Massive eruptions of the fluid lavas that create lava plateaus release much more gas and dust, and can change climate for many years. This type of eruption is exceedingly rare; none has occurred since humans have lived on Earth.

An eruption like Sarychev Volcano (Kuril Islands, northeast of Japan) in 2009 would have very little impact on weather.

Milankovitch Cycles

The most extreme climate of recent Earth history was the Pleistocene. Scientists attribute a series of ice ages to variation in the Earth's position relative to the Sun, known as **Milankovitch cycles**.

The Earth goes through regular variations in its position relative to the Sun:

1. The shape of the Earth's orbit changes slightly as it goes around the Sun. The orbit varies from more circular to more elliptical in a cycle lasting between 90,000 and 100,000 years. When the orbit is more elliptical, there is a greater difference in solar radiation between winter and summer.

2. The planet wobbles on its axis of rotation. At one extreme of this 27,000 year cycle, the Northern Hemisphere points toward the Sun when the Earth is closest to the Sun. Summers are much warmer and winters are much colder than now. At the opposite extreme, the Northern Hemisphere points toward the Sun when it is farthest from the Sun. This results in chilly summers and warmer winters.

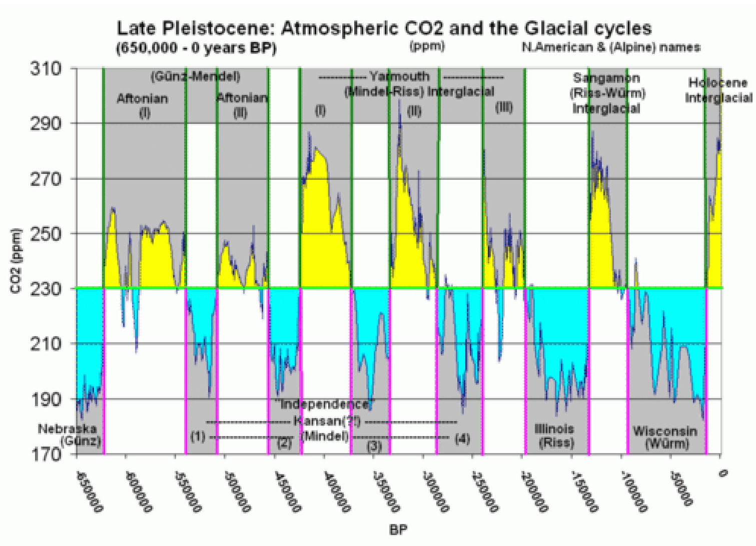
3. The planet's tilt on its axis varies between 22.1° and 24.5°. Seasons are caused by the tilt of Earth's axis of rotation, which is at a 23.5° angle now. When the tilt angle is smaller, summers and winters differ less in temperature. This cycle lasts 41,000 years.

When these three variations are charted out, a climate pattern of about 100,000 years emerges. Ice ages correspond closely with Milankovitch cycles. Since glaciers can form only over land, ice ages only occur when landmasses cover the polar regions. Therefore, Milankovitch cycles are also connected to plate tectonics.

Changes in Atmospheric Greenhouse Gas Levels

Since greenhouse gases trap the heat that radiates off the planet's surfaces what would happen to global temperatures if atmospheric greenhouse gas levels decreased? What if greenhouse gases increased? A decrease in greenhouse gas levels decreases global temperature and an increase raises air temperature.

Greenhouse gas levels have varied throughout Earth history. For example, CO_2 has been present at concentrations less than 200 parts per million (ppm) and more than 5,000 ppm. But for at least 650,000 years, CO_2 has never risen above 300 ppm, during either glacial or interglacial periods (**Figure** below).



CO_2 levels during glacial (blue) and interglacial (yellow) periods. Are CO_2 levels relatively high or relatively low during interglacial periods? Current carbon dioxide levels are at 392 ppm, the highest level for the last 650,000 years. BP means years before present.

Natural processes add and remove CO_2 from the atmosphere

- Processes that add CO_2
  - volcanic eruptions
  - decay or burning of organic matter.
- Processes that remove CO_2
  - absorption by plant and animal tissue.

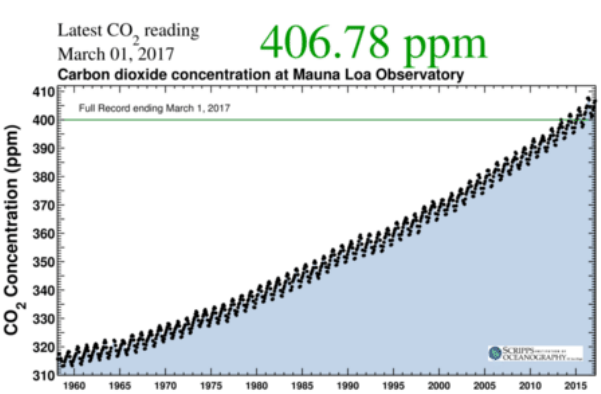
When plants are turned into fossil fuels the CO_2 in their tissue is stored with them. So, CO_2 is removed from the atmosphere. What does this do to Earth's average temperature?

What happens to atmospheric CO_2 when the fossil fuels are burned? What happens to global temperatures?

Fossil fuel use has skyrocketed in the past few decades more people want more cars and industrial products. This has released CO_2 into the atmosphere.

Burning tropical rainforests, to clear land for agriculture, a practice called **slash-and-burn agriculture**, also increases atmospheric CO_2. By cutting down trees, they can no longer remove CO_2 from the atmosphere. Burning the trees releases all the CO_2 stored in the trees into the atmosphere.

There is now nearly 40% more CO_2 in the atmosphere than there was 200 years ago, before the Industrial Revolution. About 65% of that increase has occurred since the first CO_2 measurements were made on Mauna Loa Volcano, Hawaii, in 1958 (**Figure** below).



The Keeling Curve shows the increase in atmospheric CO_2 on Mauna Loa volcano since measurements began in 1958. The blue line shows yearly averaged CO_2. The red line shows seasonal variations in CO_2.

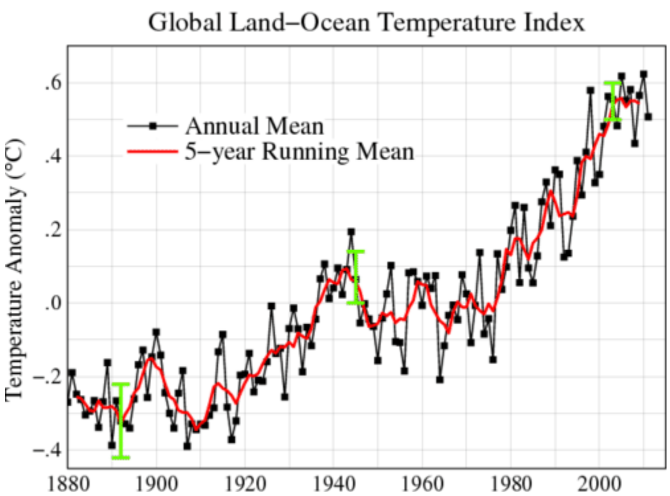
• Methane: released from raising livestock, rice production, and the incomplete burning of rainforest plants.
• Chlorofluorocarbons (CFCs): human-made chemicals that were invented and used widely in the 20th century.
• Tropospheric ozone: from vehicle exhaust, it has more than doubled since 1976.

Global Warming

With more greenhouse gases trapping heat, average annual global temperatures are rising. This is known as **global warming**.

Temperatures are Increasing

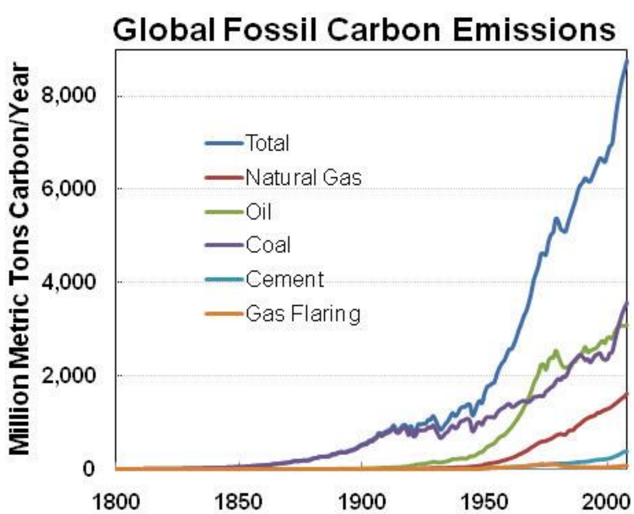
While temperatures have risen since the end of the Pleistocene, 10,000 years ago, this rate of increase has been more rapid in the past century, and has risen even faster since 1990. The nine warmest years on record have all occurred since 1998, and 16 of the 17 hottest years have occurred since 2001. The warmest year on record was 2016, with 2015 and 2014 being the second and third warmest (through 2016) (**Figure** below). People who are younger than 30, have never experienced a month in which Earth's average surface temperature was below average for that month during the 20th century. The last time global temperatures were below that average was in February 1985.



Recent temperature increases show how much temperature has risen since the Industrial Revolution began.

Annual variations aside, the average global temperature increased about 1.0°C (1.8°F) between 1880 and 2015, according to the Goddard Institute for Space Studies, NASA. This number doesn't seem very large. Why is it important?

The United States has long been the largest emitter of greenhouse gases, with about 20% of total emissions in 2004 (**Figure** below). As a result of China's rapid economic growth, its emissions surpassed those of the United States in 2008. However, it's also important to keep in mind that the United States has only about one-fifth the population of China. What's the significance of this? The average United States citizen produces far more greenhouse gases than the average Chinese person.



If nothing is done to decrease the rate of CO_2 emissions, by 2030, CO_2 emissions are projected to be 63% greater than they were in 2002.

Global CO_2 emissions are rising rapidly. The industrial revolution began about 1850 and industrialization has been accelerating.

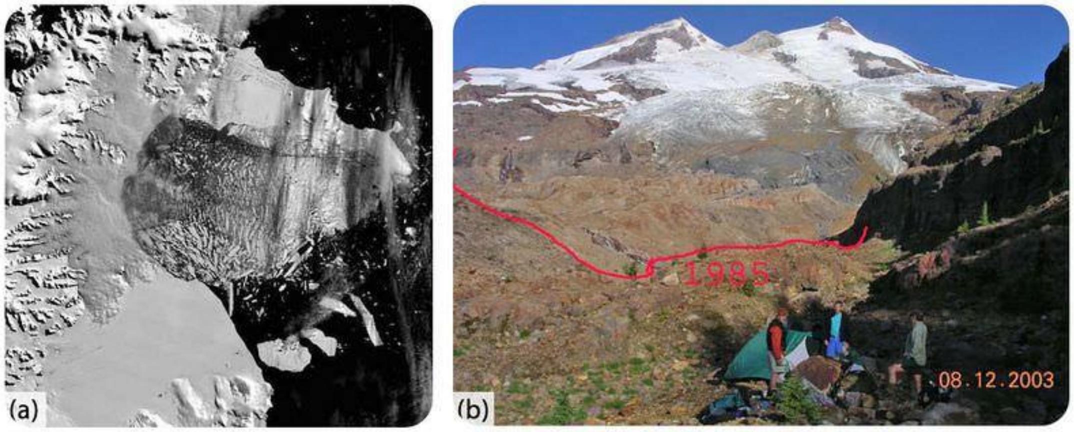
Future Warming

The amount CO_2 levels will rise in the next decades is unknown. What will this number depend on in the developed nations? What will it depend on in the developing nations? In the developed nations it will depend on technological advances or lifestyle changes that decrease emissions. In the developing nations, it will depend on how much their lifestyles improve and how these improvements are made.

Computer models are used to predict the effects of greenhouse gas increases on climate for the planet as a whole and also for specific regions. If nothing is done to control greenhouse gas emissions and they continue to increase at current rates, the surface temperature of the Earth can be expected to increase between 0.5°C and 2.0°C (0.9°F and 3.6°F) by 2050 and between 2° and 4.5°C (3.5° and 8°F) by 2100, with CO_2 levels over 800 parts per million (ppm). On the other hand, if severe limits on CO_2 emissions begin soon, temperatures could rise less than 1.1°C (2°F) by 2100.

Whatever the temperature increase, it will not be uniform around the globe. A rise of 2.8°C (5°F) would result in 0.6° to 1.2°C (1° to 2°F) at the equator, but up to 6.7°C (12°F) at the poles. So far, global warming has affected the North Pole more than the South Pole, but temperatures are still increasing at Antarctica.

The following images show changes in the earth and organisms as a result of global warming:



(a) Breakup of the Larsen Ice Shelf in Antarctica in 2002 was related to climate warming in the region. (b) The Boulder Glacier has melted back tremendously since 1985. Other mountain glaciers around the world are also melting.

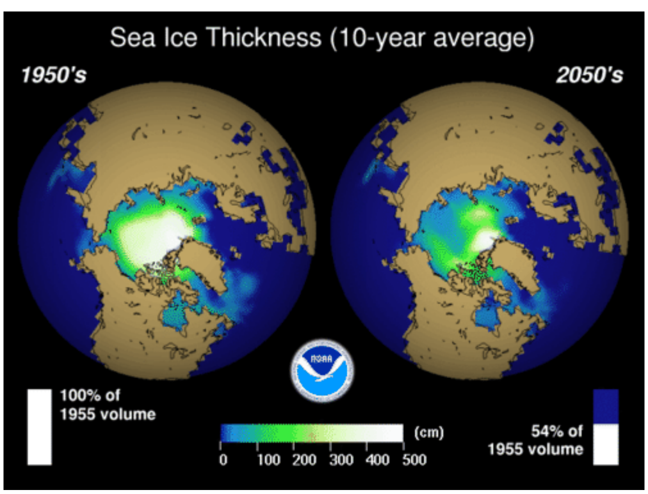
The timing of events for species is changing. Mating and migrations take place earlier in the spring months. Species that can are moving their ranges uphill. Some regions that were already marginal for agriculture are no longer farmable because they have become too warm or dry.

What are the two major effects being seen in this animation? Glaciers are melting and vegetation zones are moving uphill. If fossil fuel use exploded in the 1950s, why do these changes begin early in the animation? Does this mean that the climate change we are seeing is caused by natural processes and not by fossil fuel use?

As greenhouse gases increase, changes will be more extreme. Oceans will become slightly more acidic, making it more difficult for creatures with carbonate shells to grow, and that includes coral reefs. A study monitoring ocean acidity in the Pacific Northwest found ocean acidity increasing ten times faster than expected and 10% to 20% of shellfish (mussels) being replaced by acid tolerant algae.

Plant and animal species seeking cooler temperatures will need to move poleward 100 to 150 km (60 to 90 miles) or upward 150 m (500 feet) for each 1.0°C (8°F) rise in global temperature. There will be a tremendous loss of biodiversity because forest species can't migrate that rapidly. Biologists have already documented the extinction of high-altitude species that have nowhere higher to go.

Decreased snowpacks, shrinking glaciers, and the earlier arrival of spring will all lessen the amount of water available in some regions of the world, including the western United States and much of Asia. Ice will continue to melt and sea level is predicted to rise 18 to 97 cm (7 to 38 inches) by 2100 (**Figure** below). An increase this large will gradually flood coastal regions where about one-third of the world's population lives, forcing billions of people to move inland.



Sea ice thickness around the North Pole has been decreasing in recent decades and will continue to decrease in the coming decades.

Weather will become more extreme with heat waves and droughts. Some modelers predict that the Midwestern United States will become too dry to support agriculture and that Canada will become the new breadbasket. In all, about 10% to 50% of current cropland worldwide may become unusable if CO_2 doubles.

Although scientists do not all agree, hurricanes are likely to become more severe and possibly more frequent. Tropical and subtropical insects will expand their ranges, resulting in the spread of tropical diseases such as malaria, encephalitis, yellow fever, and dengue fever.

You may notice that the numerical predictions above contain wide ranges. Sea level, for example, is expected to rise somewhere between 18 and 97 cm — quite a wide range. What is the reason for this uncertainty? It is partly because scientists cannot predict exactly how the Earth will respond to increased levels of greenhouses gases. How quickly greenhouse gases continue to build up in the atmosphere depends in part on the choices we make.

An important question people ask is this: Are the increases in global temperature natural? In other words, can natural variations in temperature account for the increase in temperature that we see? The answer is no. Changes in the Sun's irradiance, El Niño and La Niña cycles, natural changes in greenhouse gas, and other atmospheric gases cannot account for the increase in temperature that has already happened in the past decades.

Review Questions

1. Why is the climate currently warming?

2. How can the human history of Greenland be related to climate cycles?

3. If climate has been much warmer in Earth history, why do we need to worry about global warming now?

4. What two events must occur for there to be an ice age?

5. What human activities increase greenhouse gases in the atmosphere? Explain.

6. Why are CO_2 emissions projected to increase during the next few decades?

7. What role will the developed nations play in increasing CO_2 emissions in the next few decades?

8. Why do storms increase in frequency and intensity as global temperatures increase?

9. Earth is undergoing some important changes, some of which are known about because of and monitored by satellites. Describe the sort of global change that satellites can monitor.

10. What can be done to reduce greenhouse gas emissions?