Carbon Dioxide and Global Warming Case Study

Key Concepts:

- Carbon dioxide
- El Niño
- Global warming
- Greenhouse effect
- Greenhouse gas
- La Niña
- Land use
- Methane
- Nitrous oxide
- Radiative forcing
- Temperature
- Urban heat island
- Water vapor

WHAT YOU WILL LEARN

1. You will learn about greenhouse gases and the greenhouse effect.
2. You will analyze global carbon dioxide and temperature data as evidence for global warming.
3. You will learn about human activities and natural processes that cause climate change.
4. You will learn about how climate change is likely to affect geographic regions of the U.S.

Engage Your Thinking

Global warming and climate change are international concerns. Scientists from around the world are working hard to determine how human activities, in particular the burning of fossil fuels, are impacting the Earth's temperature and climate. The learning activity below has three parts, and will help you understand how fossil fuel use effects our environment. Part I consists of a series of questions that will help you to clarify what you currently know and think about global warming and climate change. Part II involves a case study of global warming and climate change. Reading this case study will provide you with the actual scientific data often used as evidence to support global warming. The case study will add to what you already know about the problem of global warming and the questions in this section will help you think about and analyze the data and evidence used to support global warming. Part III will promote your reflection on your initial ideas and thinking about global warming and allow you to develop answers to problems and questions concerning global warming and climate change.

1. What evidence suggests that the Earth's temperature is warming?

2. How might an increase in atmospheric carbon dioxide impact the Earth's temperature?

3. What are some human activities that might cause the Earth's temperature to increase?

4. What are some natural processes that might cause the Earth's temperature to increase?

5. How might climate change impact our environment?

Case Study

A case study is a story about an issue or problem. The case presents the information, facts, and data needed to analyze the problem and to consider the possible consequences and solutions. The purpose of this case study is to help you connect what you already know about global warming and climate change with the knowledge scientists have about the way that global warming and climate change affect the Earth. As you work through the case study, answer the questions and complete the global warming issue analysis worksheet. Think about the causes of global warming and its effects on the environment, where global warming is located, and how the problem of global warming might be solved.

Does the Earth's Temperature Vary Over Time?

Geologists and climatologists are scientists who study global warming and climate change. These specialists who study the Earth's climate have concluded that the Earth's temperature has varied over the past four million years, and that at least 30 glacial periods have occurred. These glacial periods can be described as time periods when the Earth's temperature was cooler than it is today, and many continental glaciers occurred. These glacial periods were separated by time periods when the Earth's temperature became warmer, known as interglacial periods. During these cooler time periods, the polar ice caps expanded, ocean levels fell, and glaciers advanced over the continents. The last glacial period in North America started about 18,000 years ago and extended from Canada south to St. Louis, Missouri. As the Earth entered a warming period (about 15,000 years ago), this glacier began to melt and retreat. The advancing, melting, and retreating resulted in the formation of the Great Lakes. With the glacial periods, the Earth's temperature was cooler, and with the melting periods, the Earth's temperature was warmer.

One way scientists estimate the changes in the Earth's temperature is through the physical and chemical analysis of ice core samples taken from the polar ice caps in the Arctic and Antarctic regions. Based on ice core samples, scientists have been able to estimate the Earth's temperature as far back as 160,000 years. The variations in the Earth's temperature for the past 140 years and the past 1,000 years are shown below in Figure 1.

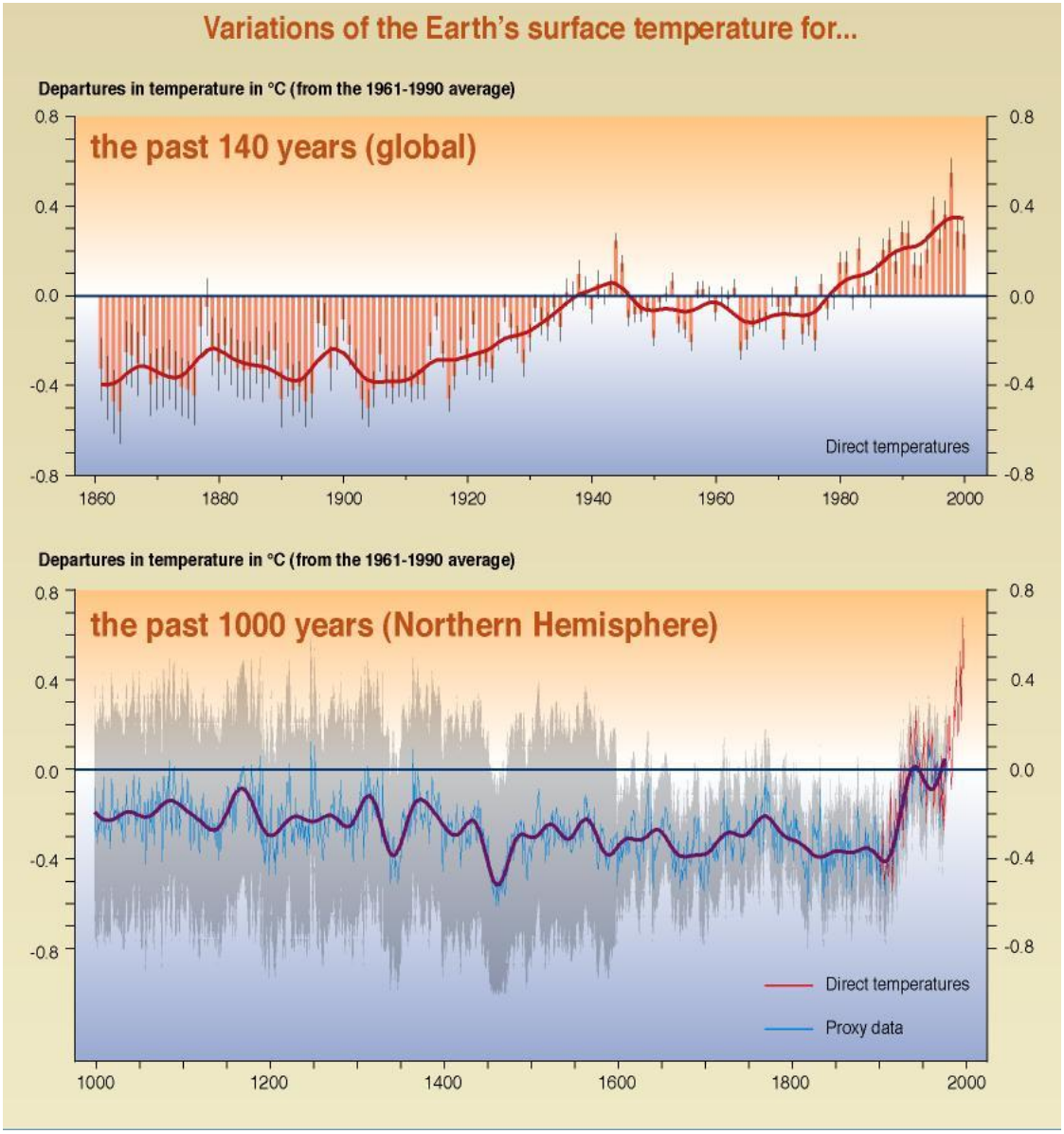

Figure 1. The Earth's Past Temperature.
Source: IPCC

6. Based on the data in Figure 1, what can you say about the Earth's temperature during the past 1,000 years?

7. Based on the data in Figure 1, what can you say about the Earth's temperature during the past 100 years?

8. Based on the data in Figure 1 is the Earth entering a cool or warm period? What evidence supports your view?

Has the Earth's Temperature Increased?

Today, scientists are able to measure the Earth's actual temperature from over 2,000 meteorological stations around the world. In 1995, this data was analyzed by the *United Nations Intergovernmental Panel on Climate Change* (IPCC). The IPCC scientists concluded that the Earth's temperature had increased during the last century. The average temperatures from 1880 and on are shown in Figure 2.

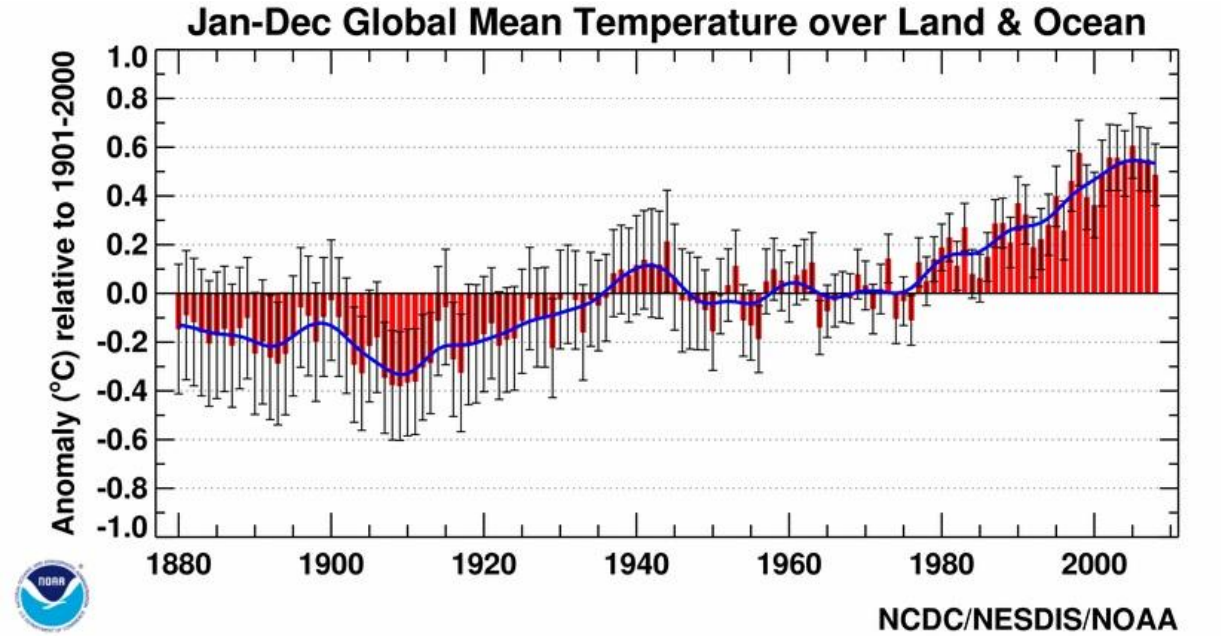

Figure 2. Changes in the Earth's Temperature. Source: NOAA

9. How does the data in Figure 2 support the idea that the Earth's temperature is increasing? Why?

Based on the ice core data and the actual temperature data, scientists have concluded that:

- Global temperatures have varied over time with cool (glacial) periods and warm periods.
- Over the past 100 years, global temperatures have tended to increase and now appear to be continuing to increase.
- The Earth's temperature is warmer today than at any other time in the past 1,000 years.

Could an Increase in Atmospheric Carbon Dioxide Be the Cause of Global Warming?

Atmospheric **carbon dioxide** levels have mostly been measured at the Mauna Loa Observatory in Hawaii. The data collected since 1958 shows a trend toward increasing atmospheric carbon dioxide levels, as well as seasonal variation—peaks during the winter, and valleys or troughs during the summer (Figure 3). Scientists have also measured air bubbles in the Vostok ice core in order to estimate the level of atmospheric carbon dioxide before 1958 (Figure 4). Scientists call ice core data **proxy data** because it is not a direct measure of carbon dioxide levels or temperature (see box). The analysis of this data shows that carbon dioxide levels have increased from about 220 parts per million (ppm) to about 380 ppm today.

Proxy Data

Scientists collect proxy data from natural sources such as tree rings, ice cores, fossil pollen, ocean sediments, and corals. By analyzing these proxy sources, scientists can construct a picture of the Earth's climate beyond the years of actual measurement.

Scientists generally mark the beginning of the Industrial Revolution in 1750 with the first burning of coal (a fossil fuel) as an energy source. The burning of coal releases carbon dioxide into the atmosphere. Most scientists agree that the burning of **fossil fuels** (coal, petroleum, and natural gas) is the primary cause for the increase in atmospheric **carbon dioxide** levels. Today about 85% of the total energy used in the United States is derived from fossil fuels, and this use contributes about 97% of the carbon dioxide released by the US into the Earth's atmosphere. Utilities emit about 35% of the total carbon dioxide released into the atmosphere followed by the transportation (about 31%), industrial (about 21%), commercial (5%), and residential (7%) sectors. The average annual increase in atmospheric carbon dioxide levels from fossil fuel use in the United States is about 1%. Since the Industrial Revolution global atmospheric carbon dioxide levels have increased about 30%.

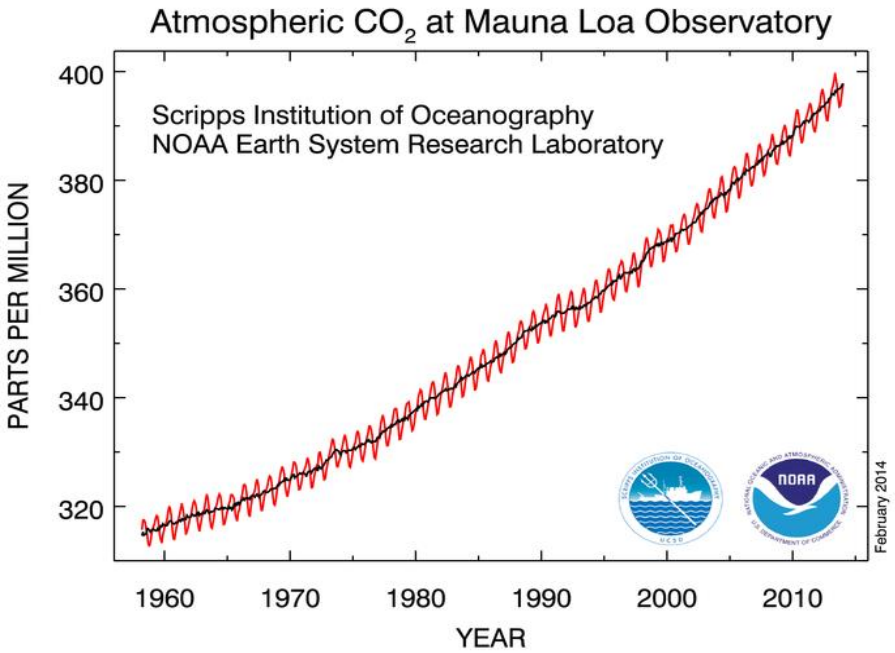

Figure 3: Carbon Dioxide Levels, Mauna Loa Observatory, Hawaii

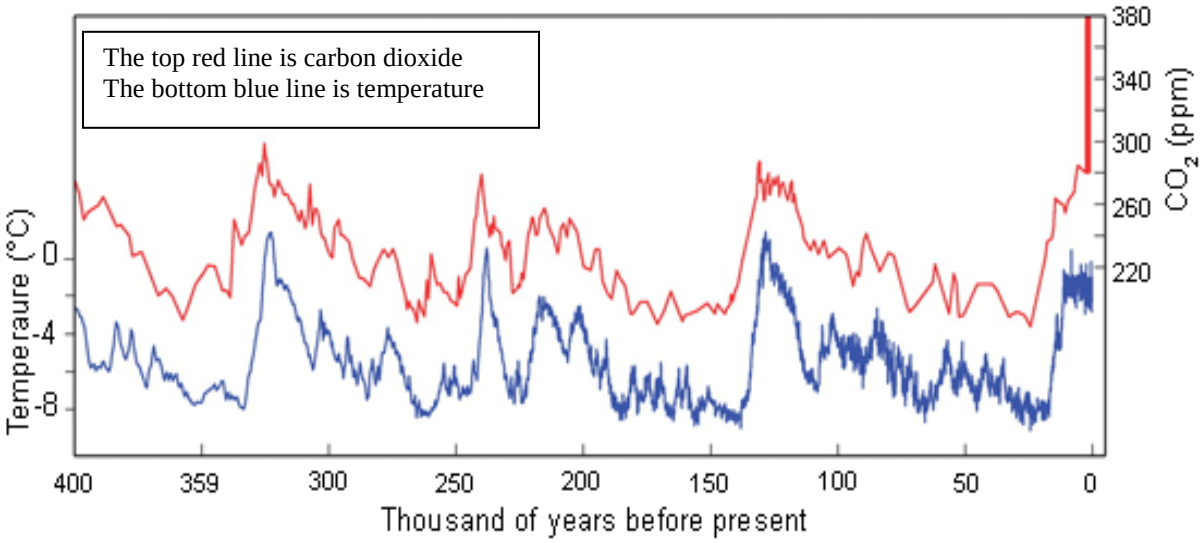

Figure 4. Vostok CO_2 and Temperature Data

10. Based on the data in Figure 4, how would you explain the relationship between the Earth's temperature and the level of atmospheric carbon dioxide?

IPCC scientists and others, using computer models and different world population growth rates and economic development scenarios projected an increase in atmospheric carbon dioxide levels (Figure 5). The high-emission scenario assumes current rates of population growth, high economic growth, and the continued use of fossil fuels. The mid-range scenario assumes that world population growth will slow, economic activity will increase, and the use of fossil fuels will continue. The low-emission scenario assumes that the world population and economic development will stabilize and that fossil fuel use will decline. All three scenarios project an increase in atmospheric carbon dioxide levels, ranging from about 470 ppm for the low-emission scenario to almost 900 ppm for the high-emission scenario.

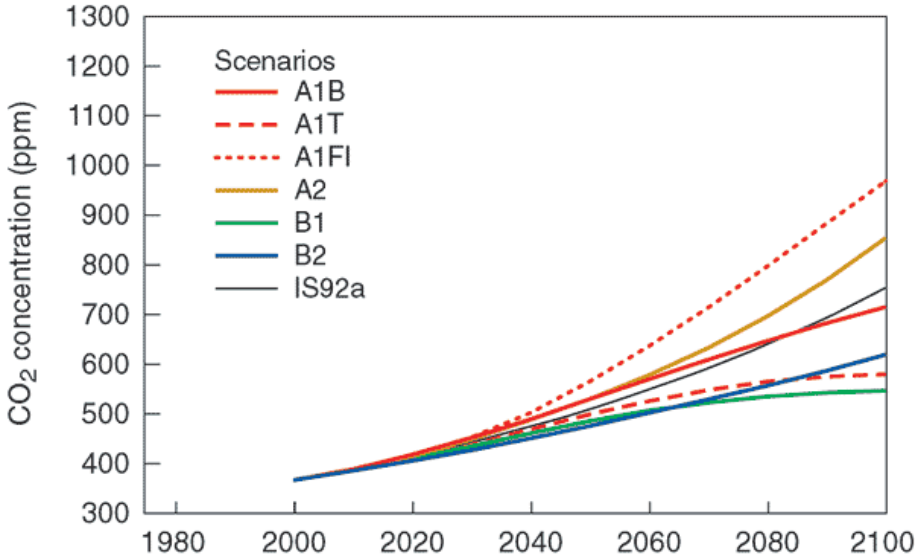

Figure 5. CO_2 Projections. Source: IPCC

11. Why was it important for the IPCC to include world population growth and economic development in their model for projecting carbon dioxide levels?

12. Based on these projections what might happen to the Earth's temperature in the future?

How is the Increase in Atmospheric Carbon Dioxide Linked to Global Warming?

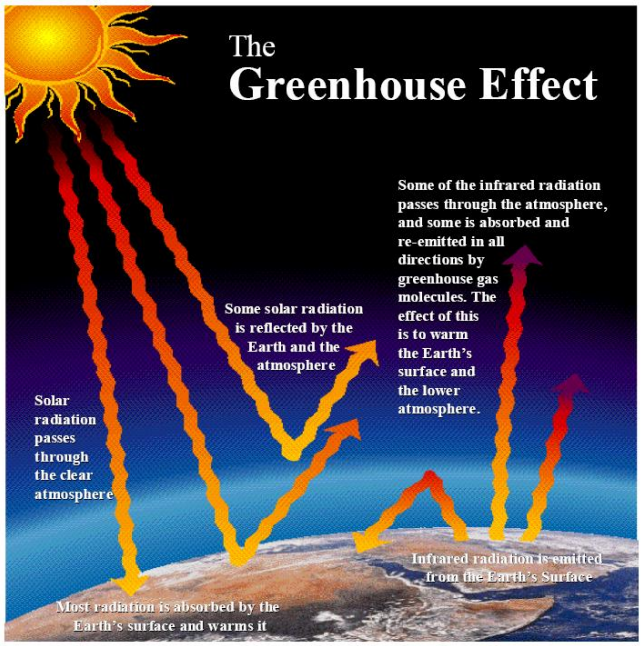

Figure 6. The Greenhouse Effect. Source: EPA

Carbon dioxide, **water vapor**, **nitrous oxide**, and **methane** are naturally occurring gases in the Earth's atmosphere. These gases work together as a type of filter that lets some of the sun's energy (visible light) pass through the atmosphere and reach the Earth's surface where the light is absorbed and changed into heat (infrared radiation). This heat then radiates back upwards into the Earth's atmosphere. The carbon dioxide, water vapor, nitrous oxide, and methane in the atmosphere work again as a filter and trap some of this heat, and re-radiate it back towards the Earth's surface, warming the Earth with the earth's own heat (Figure 6). This natural process is known as **radiative forcing** and is similar to the way the glass walls and ceilings of a greenhouse work to let light in, but to prevent heat loss. Since carbon dioxide, water vapor, nitrous oxide, and methane work like the glass ceilings of a greenhouse, letting the light through and keeping the Earth's reflected heat in, these gasses are known as **greenhouse gases**, and this natural heating process is called the **greenhouse effect**. Naturally occurring levels of carbon dioxide, water vapor, nitrous oxide, and methane are essential to life on earth. Without these greenhouse gases to hold in the warmth of the sun, the Earth's temperature would be much cooler.

The atmospheric content, or concentration, of greenhouse gases has naturally varied over time. Since the Industrial Revolution, human activities such as burning fossil fuels (oil, natural gas, and coal) and cutting down trees have added greenhouse gases, especially carbon dioxide, to the atmosphere.

Carbon dioxide (CO_2) enters the atmosphere through the burning of fossil fuels, solid waste, trees and wood products. Atmospheric concentrations have increased from about 280 ppm prior to the Industrial Revolution to about 380 ppm today. Carbon dioxide is increasing at about 1.8 ppm/year and concentrations are now higher than they have been at any other time. One of the greenhouse gasses, **methane** (CH_4), is emitted during the production and transport of coal, natural gas, and oil. Methane emissions also result from livestock and other agricultural practices and by the decay of organic waste in municipal solid waste landfills. Atmospheric methane is more abundant today than at any other time. Atmospheric concentrations of methane have increased

by 151% since the Industrial Revolution. **Nitrous oxides** (NO_x) are emitted during agricultural and industrial activities, as well as during the combustion of fossil fuels and solid waste. Atmospheric concentrations of nitrous oxide have increased by 18% over the past 200 years.

15. Given that carbon dioxide is released when fossil fuels are burned, how might the increased use of fossil fuels affect the level of carbon dioxide in the Earth's atmosphere?

16. Given that carbon dioxide is a greenhouse gas, how might increases in atmospheric carbon dioxide levels affect the greenhouse effect and the Earth's temperature?

Since 1990 the Environmental Protection Agency (EPA) has been responsible for determining the amount of greenhouse gases emitted to the atmosphere each year in the U.S. (Figure 7).

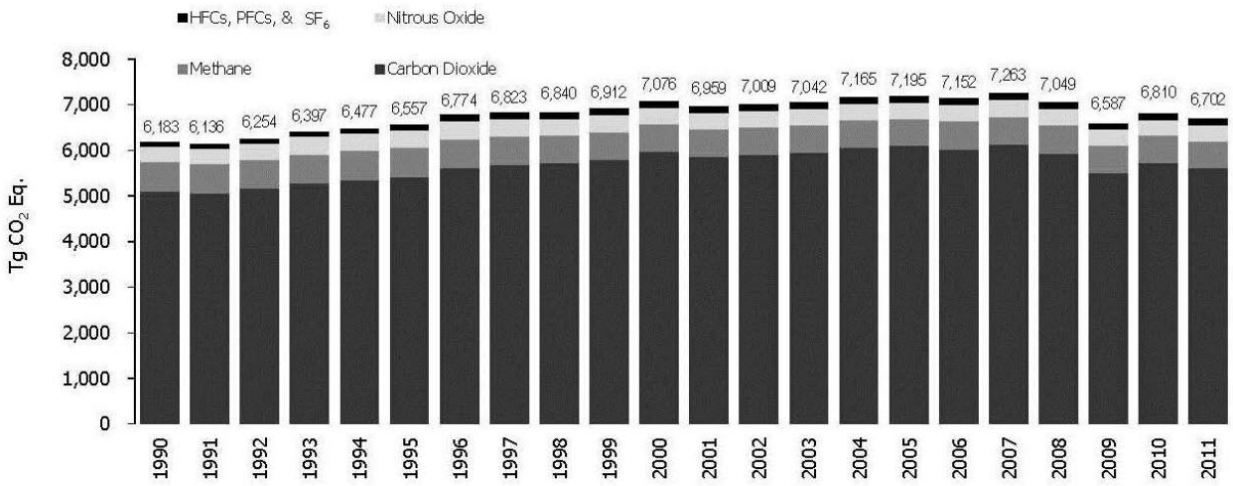

Figure 7. U.S. Greenhouse Gas Emissions. Source: EPA
Units: Tg = One million metric tons

17. Based on Figure 7, which gas is the major greenhouse gas?

The Earth's natural process of storing and releasing carbon dioxide is called the **carbon cycle**. Natural processes remove, absorb, and store carbon dioxide from the atmosphere. Although burning fossil fuels releases carbon dioxide into the atmosphere (a **carbon source**), not all of this carbon dioxide remains in the atmosphere. Two important processes remove and store carbon dioxide from the atmosphere; these are known as **carbon sinks**; the Earth has two main carbon sinks:

- Photosynthesis, the process where plants use carbon dioxide to make food (Recall the seasonal variation in carbon dioxide levels at the Mauna Loa Observatory, Hawaii).

- Ocean uptake, the process where carbon dioxide dissolves in ocean water to form carbonates and bicarbonates.

18. If the Earth has natural carbon sinks, why then do you think carbon dioxide levels are increasing?

19. If photosynthesis is a natural carbon sink, how might planting more trees help lower atmospheric carbon dioxide levels?

The greenhouse effect is not the only process that affects the Earth's temperature. Sulfate aerosols, very small particulate matter (particles) reflect a small portion of the incoming solar energy back towards outer space, cooling the Earth's atmosphere. The cooling, however, does not last long as the sulfate aerosols do not remain in the atmosphere for long periods of time. They fall to the Earth's surface or are deposited on the ground with rain and snow. The sources of sulfate aerosols include volcanoes and the burning of high sulfur coal to produce electricity.

The way people use or alter land may also impact the Earth's temperature, moisture, and climate. **Land use** change, such as, urbanization (building towns and cities) deforestation (removing large areas of trees), and desertification (the formation of deserts), affects radiative forcing. Urbanization, deforestation, and desertification changes the land's surface, which changes the reflectivity of the land or how much of the sun's energy is absorbed and changed into heat (infrared radiation) and radiated back toward the atmosphere. For example, bare ground can absorb more radiation than forests, therefore, deforestation would increase surface heating and have a slight warming effect as more heat would be absorbed and radiated. A similar impact is seen

with urbanization. Cement and asphalt reflect less of the sun's energy and thus absorb and radiate more heat than bare ground, forming an **urban heat island**. Urban heat islands are formed because the air and surface temperatures in urban areas are higher than in surrounding rural areas (Figure 8). Most urban areas have air temperatures that are up to 10° F (5.6° C) warmer.

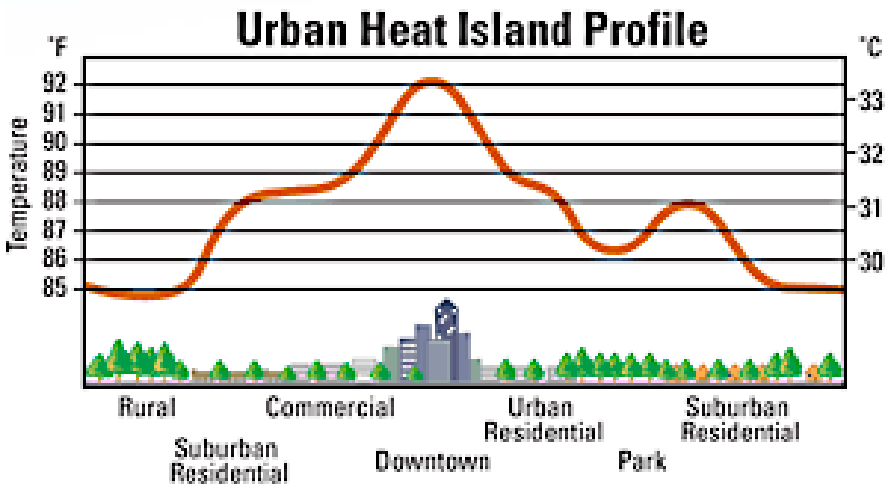

Figure 8. The Urban Heat Island. Source: EPA

Is the Earth's Temperature Naturally Warming?

Although many scientists are in agreement that the Earth's temperature is increasing and that human activity is contributing to this increase in temperature, some controversy exists about the exact cause of this increase known as global warming. As you have seen, the data shows unquestionably that atmospheric carbon dioxide levels have increased and that the Earth's temperature has also increased over the past century. The uncertainty lies in the cause of this increase. Is global warming a result of human activity, or the outcome of natural processes, or a combination of the two? Scientists who do not agree that global warming is occurring often identify two natural processes that cause the Earth's temperature and climate to vary: the **El Nino** and **La Nina** effects (ocean circulation patterns) and the **Milankovitch cycles**.

The El Nino effect is the movement of warm ocean water in the central Pacific toward the east, raising the water temperatures off the coasts of Central and South America. This rise in water temperatures causes heavy spring rains in California. The La Nina effect is the upwelling of deep, cold Pacific Ocean water near South America. The La Nina effect cools the air and causes more snow than normal to fall in the Midwestern and Eastern United States. The natural variation in the Earth's rotation and orbit are known as Milankovitch cycles. These orbital variations could cause periods of global cooling and warming which appear to repeat over thousands of years. If these natural processes are causing the climate to warm, then scientists cannot be sure how much human activity can influence global warming.

How Might Climate Change Impact Our Environment?

Due to the complexity of climate systems, scientists are unsure about how much the Earth's temperature will be affected by the emission of greenhouse gases into the atmosphere. Projections about future warming are tentative and subject to adjustments (either upward or downward) as scientists learn more about the Earth's climate. IPCC temperature projections indicate that the Earth's temperature is likely to increase by 2.5 to 10.4°F (1.4-5.8°C) by the end of the century (Figure 9). The IPCC also projects that this warming will not be distributed equally around the globe. For example:

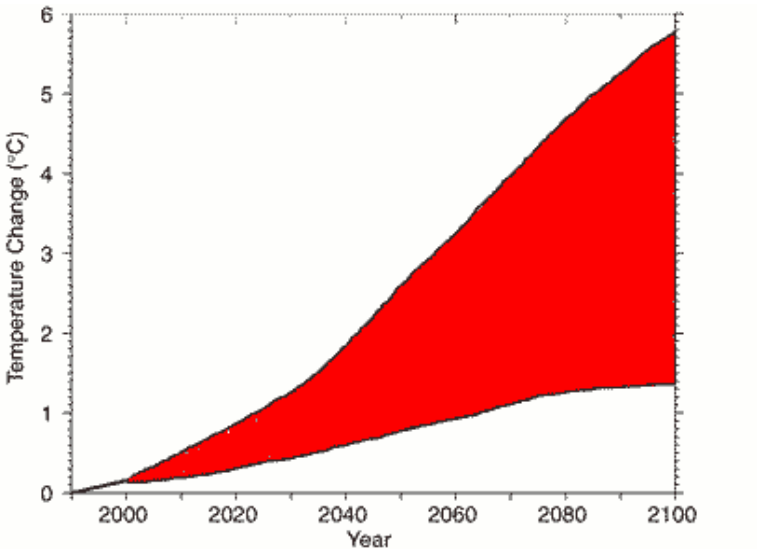

Figure 9. The Range in Temperature Projections. Source IPCC

- Land areas will warm more than oceans because of water's ability to store heat.
- High latitudes will warm more than low latitudes due to melting polar ice.
- The northernmost regions of North America could warm more than the global average.
- Warming will vary by season with winters warming more than summers.

Climate change is likely to affect geographic regions of the United States differently. The IPCC, for example, has predicted the following scenarios:

- In the Northeast plant and animal species will move northward because of warmer temperatures, coastal erosion will increase because of increased storm surges and sea level rises, and summer temperatures will be higher.

- The Southeast and Gulf Coast will experience increased loss of barrier islands and wetlands and coastal flooding because of sea level rise and severe storms, and fire and insect outbreaks because of changes in forest characteristics; also, summer temperatures will be higher.

- In the Midwest and Great Lakes region, lake and river levels will be lower because of warmer temperatures and increased evaporation; agricultural productivity may increase because of warmer temperatures and higher carbon dioxide levels, and summers will be hotter.

- In the Great Plains droughts will increase and agricultural productivity will shifts northward; more springtime flooding and summertime drought cycles will occur, and summer temperatures will be higher.

- In the West, changes in ecosystems will occur because of higher temperatures and more winter precipitation; earlier snowmelt may cause water shortages during the summer, drier summers may result in increased wildfires, and summer temperatures will be higher.

- Alaska sea ice will be reduced affecting the polar bear and other wildlife species' survival; more permafrost will melt, Forests will be disturbed by increased pest outbreaks, and retreating sea ice and earlier snowmelt will impact native peoples' life styles.

Conclusion

Many scientists believe that human activity, especially the burning of fossil fuels, is increasing global atmospheric carbon dioxide levels and contributing to global warming. The scientific uncertainties are: How much warming will occur? How fast will this warming happen? What are the climatic and environmental impacts of this warming? What are the other potential adverse and beneficial effects of climate change? Because it will take scientists some time, perhaps decades, to answer these questions with certainty, governments and the people of the world will need to make decisions based on the current and best scientific evidence available. So, in reflecting back on this case study, re-think your answers to the initial questions.

Reflect on What You Have Learned

Now that you have read the case study, re-formulate your knowledge and thinking about global warming and climate change. The following questions will allow you to develop answers to the problems and questions concerning global warming based on the information you learned in the case study.

20. What evidence suggests that the Earth's temperature is warming?

21. How might an increase in atmospheric carbon dioxide impact the Earth's temperature?

22. What are some human activities that might cause the Earth's temperature to increase?

23. What are some natural processes that might cause the Earth's temperature to increase?

24. How might climate change impact our environment?