INTRODUCTION

In this activity, you will explore one of the most iconic data sets in all of science: the historic record of **carbon dioxide (CO_2)** in our atmosphere. You will explore processes that add and remove CO_2 from the atmosphere. You'll also manipulate a model to test different inputs and outputs and find out how your predictions match observations. By the end of the activity, you should be able to explain the processes and causes of the patterns in the data set.

PART 1: Carbon in the Atmosphere

For more than a century, scientists have warned that burning fossil fuels releases CO_2, a greenhouse gas that affects Earth's climate. However, no one was able to continuously measure CO_2 in the atmosphere until scientist Charles Keeling.

In 1958, Keeling began measuring atmospheric CO_2 levels at the Mauna Loa Observatory in Hawaii. He chose this location because it is far away from large numbers of cars, factories, and other sources of possible contamination. The ongoing record of CO_2 measurements at Mauna Loa is known as the **Keeling Curve** (Figure 1).

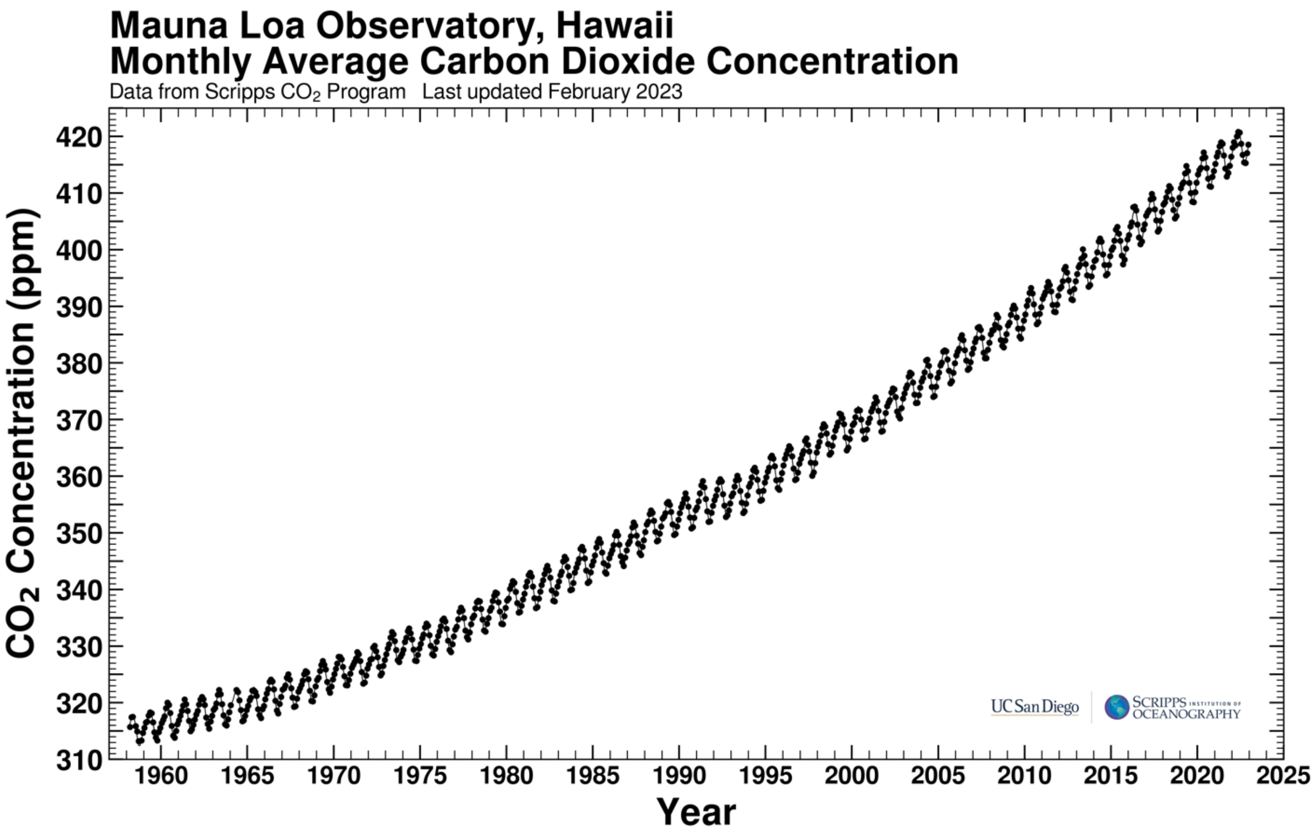


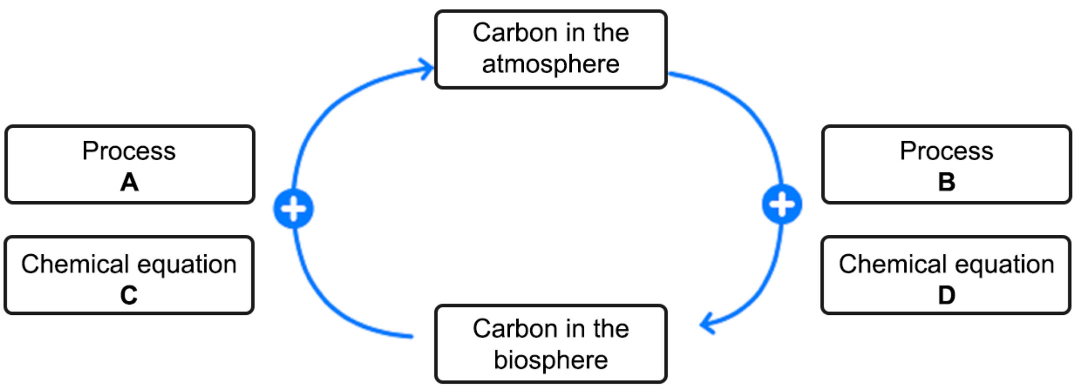
Figure 1. The monthly average concentrations of CO_2 in the atmosphere, measured in parts per million (ppm), at the Mauna Loa Observatory from 1958 through February 2023.

1. Describe two main patterns in Figure 1.

2. Figure 1 shows that the amount of CO_2 in the atmosphere changes over time.
   a. Based on what you already know, what are some processes that *add* CO_2 to the atmosphere?

   b. What are some processes that *remove* CO_2 from the atmosphere?

Below is a simplified model of how carbon (which may be in the form of CO_2 or organic matter) moves between the atmosphere and the **biosphere**, the part of the Earth system occupied by life. This model includes two processes (A and B) that move carbon, and each process has a chemical equation (C and D).

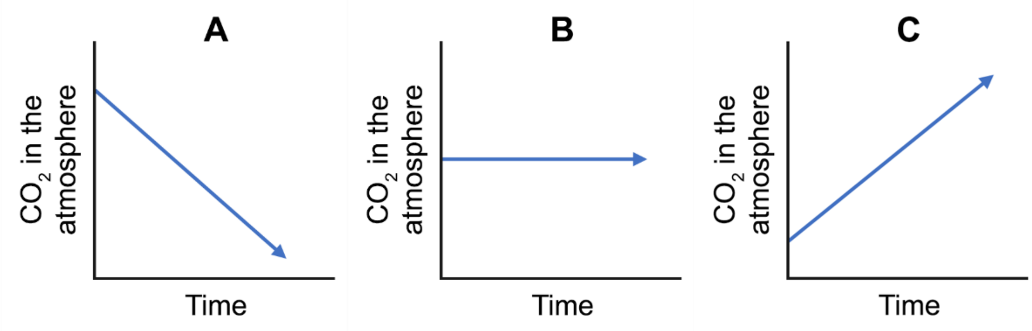


3. Match the following processes and equations to the letters in the model. Record the matching letters in the table.

Process or Equation	**Letter**
$6CO_2 + 6H_2O$ + light energy → $C_6H_{12}O_6 + 6O_2$	
$C_6H_{12}O_6 + 6O_2$ → $6CO_2 + 6H_2O$ + chemical energy	
Photosynthesis	
Respiration	

Respiration and photosynthesis are natural processes that "mirror" each other. One process adds CO_2 to the atmosphere, and the other removes it. Think about how the balance between these two processes might affect CO_2 levels in the atmosphere.

These three graphs show how CO_2 levels in the atmosphere could change over time.



4. Match the following scenarios to each of the graphs. Record the letters for the matching graphs in the table.

Scenario	**Graph**
Respiration = Photosynthesis	
Respiration > Photosynthesis	
Respiration < Photosynthesis	

PART 2: Seasonal Variations in Natural Processes

Rates of respiration and photosynthesis change with the seasons. In some months, respiration is greater than photosynthesis. In other months, respiration is less than photosynthesis. These seasonal differences result in the **sawtooth**, or zigzag, pattern in the Keeling Curve (Figure 1), where CO_2 levels rise and fall throughout each year.

You'll now use a simulator to recreate this pattern with a model of respiration and photosynthesis. To access the simulator, open the BioInteractive Click & Learn *The Breathing Biosphere and Human Contribution*. Go to the **"Natural Processes"** tab and read the information at the top. Select the blue underlined "Read More" link to show more details.

Adjust the settings in the simulator to make the model levels (blue dots) fit the observed levels (black triangles) as closely as you can. The **"Fit Score"** displayed next to the graph will be closer to 1 for better fits. Here are some tips for getting started:

- The Mauna Loa Observatory is in Hawaii, which is in the northern hemisphere. Think about which month might have the peak (highest) rate of photosynthesis and respiration there.
- Annual estimates for photosynthesis and respiration rates are around 60 ppm/*year*. You can use this as a starting point to estimate the rates in ppm/*month* for the simulator.
- Increase the peak rate of photosynthesis to your estimated value. The model levels should fall below the observed levels. Next, increase the peak rate of respiration to balance photosynthesis.
- Note that photosynthesis varies more with the seasons and drops to near zero in the winter. (Respiration also has a peak but is spread more evenly throughout the year.)

5. Once you find your best possible fit, record your settings and fit score in the following table.

Setting/Score	**Value**
Photosynthesis Peak Rate	
Photosynthesis Peak Month	

Respiration Peak Rate	
Respiration Peak Month	
Fit Score	

6. The observed data in the simulator come from the Mauna Loa Observatory in Hawaii, which is in the northern hemisphere. Would you expect the same pattern from an observatory in Antarctica? Explain your answer.

PART 3: The Human Contribution

In Part 2, you simulated natural processes (respiration and photosynthesis) to model seasonal variations in CO_2 levels. Globally, respiration and photosynthesis each move about 120 billion tons of carbon per year.

7. In addition to seasonal variations, the Keeling Curve (Figure 1) also shows an overall increase in CO_2 since 1958. Based on what you've learned from the previous questions, can the natural balance of respiration and photosynthesis account for this increase? Explain your answer.

Figure 2 (at the end of this worksheet) shows the **carbon cycle:** a series of processes that move carbon between the atmosphere, biosphere, and other parts of Earth.

8. Which process in Figure 2 is the most likely to be responsible for the increase in atmospheric CO_2? (*Hint*: Look for the biggest *unbalanced* movement of carbon to the atmosphere.)

Return to the Click & Learn. Go to the **"Human Contribution"** tab and read the information at the top. Use the slider to adjust the human contribution in the model and fit the observed data the best that you can.

9. Once you find your best possible fit, record your settings and fit score in the following table.

Setting/Score	**Value**
Annual Human Contribution	
Fit Score	

10. Human activity releases excess CO_2 to the atmosphere, which is causing global climate change. What are some actions that individuals and society can take to reduce CO_2 emissions?

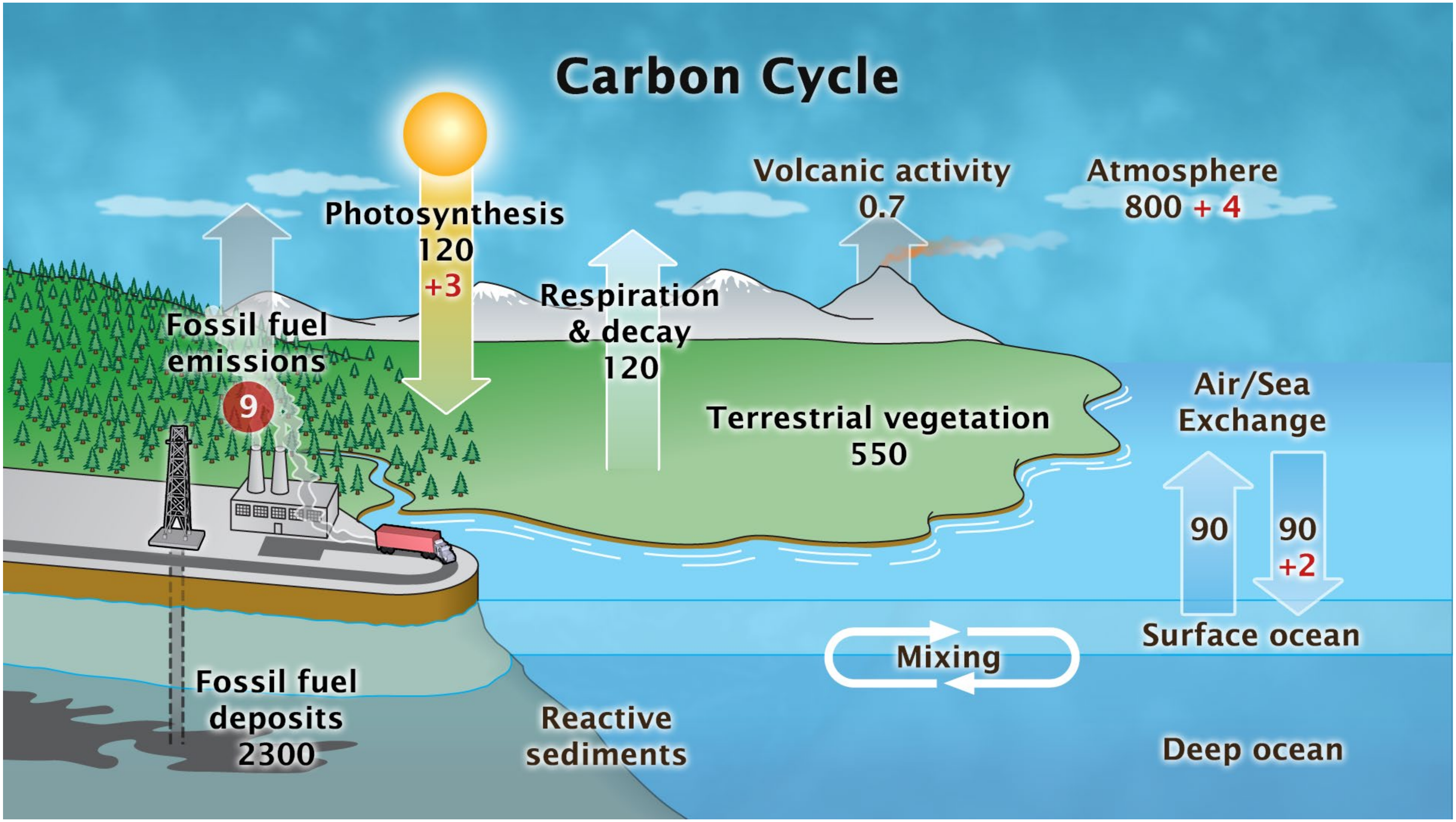


Figure 2. Simplified diagram of the "short-term" carbon cycle. (Longer-term processes, such as the cycling of carbon in the deep ocean, are not included.) Units are in terms of "billion tons of carbon." The arrows show annual movement of carbon (billion tons per year). Red numbers show changes to the amount of carbon transferred or stored as a result of human activity.