Investigation 1B

Earth's Climate System

Objectives

Fundamentally, climate is formed by the Sun's energy as it is received on Earth and is reflected, absorbed, transformed, and eventually emitted back to space. The atmosphere, hydrosphere, lithosphere, and biosphere further define the interactions and changes that shape *Earth's climate system*. Earth's climate system results from the movement of energy through the subsystems, their interactions and feedbacks.

In this investigation, we will:

- Describe Earth's climate system and its subsystems.
- Examine components that change subsystems within Earth's climate system.
- Understand the carbon cycle and how carbon changes through the subsystems.

Earth's Climate System

Earth's climate system is inherently variable. No single, simple explanation can account for the variability and changes inherent in it across geologic ages. The complex spectrum of climate variability and climate change is a response to the interactions of many forces and mechanisms operating both within and external to Earth's climate system.

How systems interact, physically and chemically, with their surroundings defines them as either open or closed. An **open system** exchanges both energy and mass with its environment, while a **closed system** only exchanges energy with the environment. Earth's climate system is considered a closed system because there is practically no exchange of mass between Earth and space.

The subsystems of Earth's climate system are open systems, with both mass and energy exchanged between them. As a mass, liquid water moves from the ocean into the atmosphere via evaporation, becoming water vapor. Transfer of matter or energy across a system boundary will cause fluctuations inside the system, leading to a change in the physical state of the system.

Earth's climate system is comprised of four major subsystems:

- **Atmosphere**: Free-flowing, well-mixed (below 80 km) envelope of gases at the interface of Earth and space.
- **Hydrosphere**: Includes all water, in all its forms, on, under, and over Earth's surface, from Earth's liquid water to gaseous water (water vapor). The hydrosphere includes the cryosphere, all frozen water (ice).
- **Lithosphere**: The atmosphere, hydrosphere, and cryosphere are all underlain by the lithosphere, which includes the crust of our planet and the uppermost solid mantle region.
- **Biosphere**: The entire collection of Earth's ecosystems worldwide. An ecosystem is a communal system of plants, animals, and microbes within their physical environment.

Figure 1B-1 depicts components of Earth's climate system (atmosphere, ocean, cryosphere, land surface, and biosphere) that must be considered when understanding the interaction of Earth's climate as a whole. These components interact with each other through flows of energy in various forms, such as exchanges of water, the transfer of greenhouse gases (e.g., carbon dioxide, methane), and the cycling of nutrients.

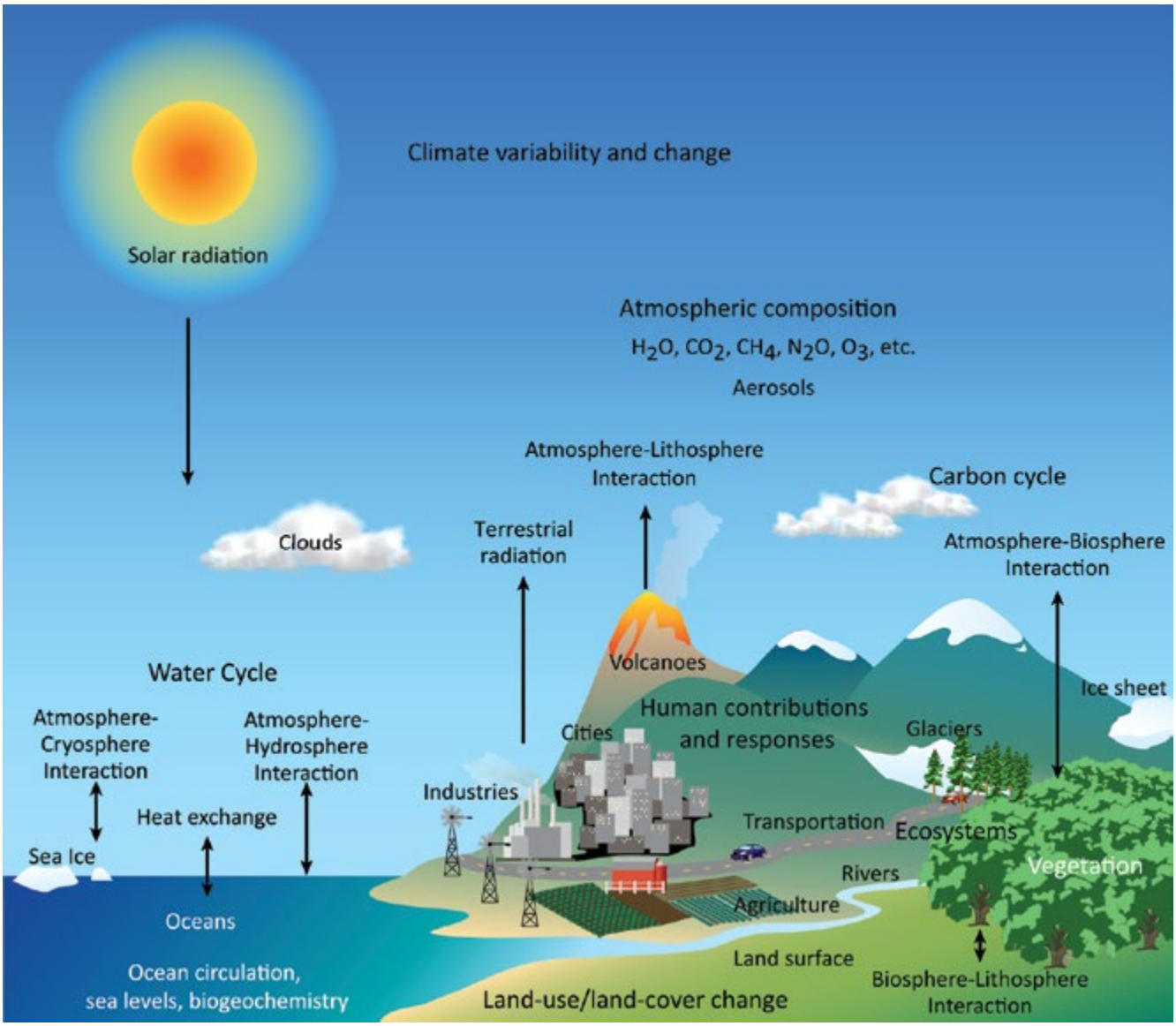


Figure 1B-1. Components of Earth's climate system, their processes, and their interactions. [Adopted from NOAA GFDL]

1. Figure 1B-1 shows _____ is(are) the origin of energy and the driving force for the motion of the atmosphere and ocean, as well as heat transport, cycling of water, and biological activity.

   a. the Sun
   b. the wind
   c. volcanoes
   d. all of these

2. The various components in Figure 1B-1 can be thought of as scenarios of emissions and drivers that impact climate change. It can be inferred from the diagram that climate is impacted by _____.

    a. naturally changes
    b. human contributions and responses
    c. both of these

3. Which of these is an example of a human-caused emission?

    a. Burning coal
    b. Evaporation of water
    c. Irrigation
    d. Volcanic eruptions

4. The arrows in the figure identify the processes and interactions with and between the major components of Earth's climate system. The *double-headed* arrows show that _____ of the interactions between the components (such as between atmosphere-hydrosphere or atmosphere-biosphere) involve bidirectional (upward and downward) flows.

    a. none
    b. few
    c. most

5. While the human impact that most affects global climate is changes to the *atmospheric composition*, the human impact that most likely directly alters local and regional climate is changes in the _____.

    a. cryosphere
    b. water cycle
    c. land surface
    d. ocean

6. Which of these is *not* an example of a human-caused change in the land surface?

    a. Burning a forest for farmland
    b. Adding a highway
    c. A heavy rainstorm
    d. Planting trees

7. The atmosphere is composed of many gases, such as nitrogen, oxygen, and water vapor. A gas that contributes to global warming is known as a **greenhouse gas**. When these gases interact with outside influences, aerosols or heat-trapping greenhouse gases can form or be enhanced in concentration. Since these gases are part of the atmosphere, they will interact with the _____.

    a. biosphere
    b. hydrosphere
    c. cryosphere
    d. lithosphere
    e. all of the above

Moreover, various cycles move through the subsystems of Earth's climate system, carrying and exchanging mass and energy with them. In the carbon cycle, carbon is physically and chemically transformed within and between the biosphere, lithosphere, hydrosphere, and atmosphere, existing in many different forms in this process.

The Carbon Cycle

The building block of life on Earth, carbon is the backbone of the biosphere. By mass, it is the second most abundant element in the human body and is also found in large quantities as coal, peat, and oil, the transformed remains of once living organisms. As an inorganic compound, it can be found dissolved throughout the ocean in the hydrosphere, in sedimentary rocks of the lithosphere, and as carbon dioxide in the atmosphere. The **carbon cycle**, in which carbon changes locations throughout all the subsystems, is shown in **Figure 1B-2**.

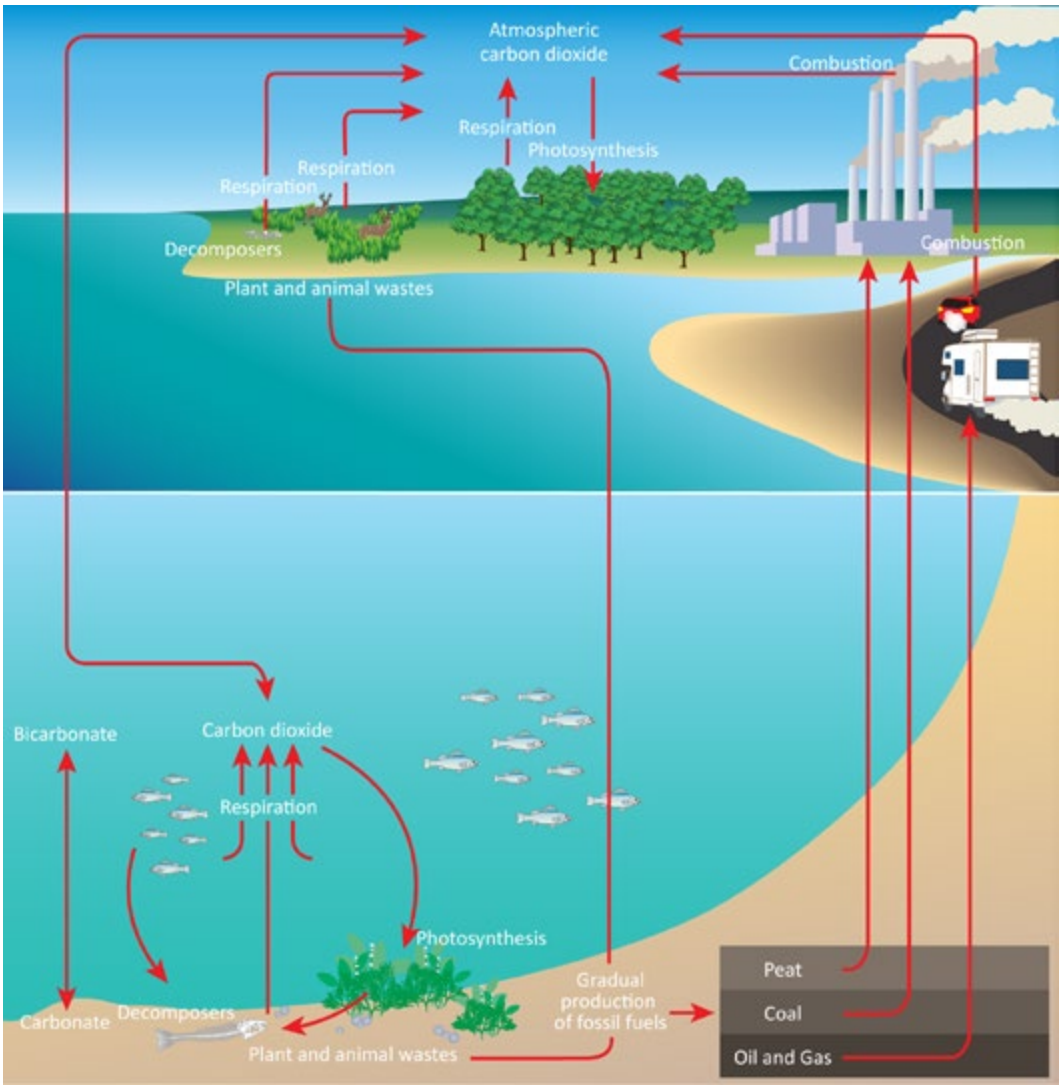


Figure 1B-2. Schematic representation of the global carbon cycle. [Segar, Kish, and Mills, 2018]

If a component of the carbon cycle stores more carbon than it releases, it is considered a reservoir or a **carbon sink**. When carbon enters a carbon sink, the carbon is integrated into molecules, often changing which type of molecule it was part of. If the carbon is released from those sinks, especially if too much is released too quickly, it can change how energy moves through Earth's climate systems.

The ocean acts as a significant carbon sink, absorbing large amounts of carbon dioxide (CO_2) from the atmosphere. This process, known as **carbon sequestration**, helps regulate the concentration of CO_2 in the atmosphere.

However, the increase in CO_2 in the ocean changes its chemistry, and leads to ocean acidification. Not all organisms can survive this change, which we discuss in a later investigation.

Taken together, living organisms that make up the biosphere can be considered a carbon sink. Many organisms, such as plants and phytoplankton, absorb CO_2 from the air and convert it into organic compounds through photosynthesis.

8. When growing new leaves or adding another layer of bark, a tree absorbs carbon from the _____ for photosynthesis. The carbon from carbon dioxide is broken from the oxygen and helps build the tree's structure, DNA, chlorophyll, and everything else the tree needs to thrive.

    a. hydrosphere
    b. atmosphere
    c. lithosphere
    d. biosphere

When a giraffe eats a leaf, the carbon that formed the leaf is broken down and reformed to support the giraffe. While some carbon is released as CO_2 when the giraffe exhales, the rest remains, forming everything from fur to bones and muscles. It is the same with all living organisms, and the carbon remains in the biosphere so long as another creature, from lion to mosquito, eats the giraffe. Even when the giraffe dies, the process of decomposition includes numerous microorganisms that are nourished and they add that carbon, from the dead giraffe, into the soil as organic carbon.

That is one reason why changing the land surface can release carbon into the atmosphere. Conservation agriculture, cover cropping, and crop rotation can enhance carbon sequestration in the soil.

The carbon cycle also involves long-term geological processes. Carbon dioxide in the atmosphere can dissolve in rainwater, which is part of the hydrosphere, to form carbonic acid that reacts with rocks and minerals, which are part of the lithosphere. Over time, this leads to the storage of carbon in the form of sedimentary carbonate rocks, such as limestone.

9. Carbon moves through all the subsystems and interacts with the components within. Which of the following is *not* a component of the carbon cycle?

    a. Combustion of fossil fuels
    b. Absorption of carbon dioxide by oceans
    c. Conversion of sunlight into heat
    d. Formation of sedimentary rocks

10. _____ involves the breakdown of carbon from dead organisms into the soil. Organic carbon in the soil is a sequestered carbon from the atmosphere.

    a. Respiration
    b. Decomposition
    c. Fossil fuel formation
    d. Photosynthesis

11. How does deforestation, the clear-cutting of forests for lumber, agriculture, or development, impact the carbon cycle?

    a. It reduces the amount of carbon in the atmosphere.
    b. It increases carbon sequestration in sedimentary rocks.
    c. It decreases the amount of carbon absorbed by trees and vegetation.
    d. It promotes the growth of plant life and enhances photosynthesis.

12. The carbon cycle has been a constant for tens of thousands of years. More recently, _____ has released carbon from the carbon sinks into the atmosphere as carbon dioxide.

    a. volcanic activity
    b. ocean absorption
    c. human activity
    d. geological process

The carbon cycle is intricately linked to all the subsystems of Earth's climate system, and these subsystems interact with and influence one another. It is essential to recognize the interconnectedness of these components and the feedback loops that exist within the Earth's climate system. These interactions highlight the complexity of the Earth's climate system and the need to consider the interdependencies between various subsystems when studying climate change.

Summary

While Earth's climate system is a closed system that only exchanges energy with surrounding space, its subsystems are open, with both energy and mass cycling and interacting among them. The four major subsystems are the biosphere, hydrosphere, lithosphere, and atmosphere. Carbon journeys freely through these subsystems in the carbon cycle, impacting and interacting with their components. As carbon changes form, it travels through the spheres at different speeds. When carbon is sequestered, it has a minimal immediate impact on Earth's climate system, but when too much is released from a sink, Earth's climate can be affected. During the next chapter, we will cover how scientists describe climate empirically.

References

Figure 1B-1 – GFDL, 2014: Major natural and anthropogenic processes and influences on the climate system addressed in scenarios. Earth systems models. Accessed 6 November 2015, https://www.gfdl.noaa.gov/earth-system-model/.

Figure 1B-2 – Segar, D. A., S. W. Kish, and E. W. Mills, 2018: *Ocean Studies: Introduction to Oceanography 4th Edition*. American Meteorological Society, 774 pp.