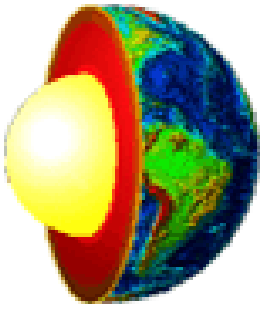
Earth System Science

In the phrase "Earth System Science (ESS)," the key term is "system." A system is a collection of interdependent parts enclosed within a defined boundary. Within the boundary of the earth is a collection of four interdependent parts called "spheres." Earth's spheres include:

Geosphere

The geosphere (also often referred to as the lithosphere*) contains all of the cold, hard solid land of the planet's crust (surface), the semi-solid land underneath the crust, and the liquid land near the center of the planet. The surface of the geosphere is very uneven (see image on right). There are high mountain ranges like the Rockies and Andes (shown in red), huge plains or flat areas like those in Texas, Iowa, and Brazil (shown in green), and deep valleys along the ocean floor (shown in blue).

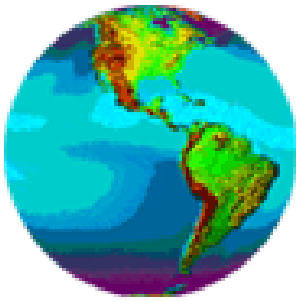


The solid, semi-solid, and liquid land of the geosphere form layers that are physically and chemically different. If someone were to cut through Earth to its

center, these layers would be revealed like the layers of an onion (see right image above). The outermost layer of the geosphere consists of loose soil rich in nutrients, oxygen, and silicon. Beneath that layer lies a very thin, solid crust of oxygen and silicon. Next is a thick, semi-solid mantle of oxygen, silicon, iron, and magnesium. Below that is a liquid outer core of nickel and iron. At the center of Earth is a solid inner core of nickel and iron.

* Note: The word "lithosphere" can take on different meanings depending on the speaker and the audience. For example, many geologists--scientists who study the geologic formations of Earth--reserve the word "lithosphere" to mean only the cold, hard surface of Earth, and the upper portion of the mantle, not the entire inside of the planet. I will try to be consistent and use the more inclusive term "geosphere". However, there will be times when I use other sites or information from other authors who will use the term "lithosphere" as I do geosphere.

Hydrosphere



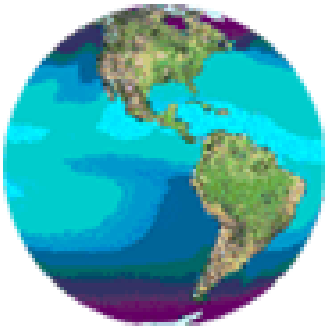
The hydrosphere contains all the solid, liquid, and gaseous water of the planet.** It ranges from 10 to 20 kilometers in thickness. The hydrosphere extends from Earth's surface downward several kilometers into the geosphere and upward about 12 kilometers into the atmosphere.

A small portion of the water in the hydrosphere is fresh (non-salty). This water flows as precipitation from the atmosphere down to Earth's surface, as rivers and streams along Earth's surface, and as groundwater beneath Earth's surface. Most of Earth's fresh water, however, is frozen.

Ninety-seven percent of Earth's water is salty. The salty water collects in deep valleys along Earth's surface. These large collections of salty water are referred to as oceans. The image above depicts the different temperatures one would find on oceans' surfaces. Water near the poles is very cold (shown in dark purple), while water near the equator is very warm (shown in light blue). The differences in temperature cause water to change physical states. Extremely low temperatures like those found at the poles cause water to freeze into a solid such as a polar icecap, a glacier, or an iceberg. Extremely high temperatures like those found at the equator cause water to evaporate into a gas.

** Note: Some scientists place frozen water--snow, glaciers, icecaps, and icebergs--in its own sphere called the "cryosphere." In our class, however, frozen water will be included as part of the hydrosphere. The word "hydrosphere" will be used in reference to all water in Earth's system.

Biosphere



The biosphere contains all the planet's living things. This sphere includes all of the microorganisms, plants, and animals of Earth.***

Within the biosphere, living things form ecological communities based on the physical surroundings of an area. These communities are referred to as biomes. Deserts, grasslands, and tropical rainforests are three of the many types of biomes that exist within the biosphere.

It is impossible to detect from space each individual organism within the biosphere. However, biomes can be seen from space. For example, the image above distinguishes between lands covered with plants (shown in shades of green) and those that are not (shown in brown).

***Note: Some scientists place humans in their own sphere called the "anthrosphere". In our class, however, humans will be included as part of the biosphere. The word "biosphere" will be used in reference to all living things in Earth's system.

Atmosphere

The atmosphere contains all the air in Earth's system.**** It extends from less than 1 m below the planet's surface to more than 10,000 km above the planet's surface. The upper portion of the atmosphere protects the organisms of the biosphere from the sun's ultraviolet radiation. It also traps heat. When air temperature in the lower portion of this sphere changes, weather occurs. As air in the lower atmosphere is heated or cooled, it moves around the planet. The result can be as simple as a breeze or as complex as a tornado.

****Note: The atmosphere is made up of many layers that differ in chemical composition and temperature. The word "atmosphere" will be used in reference to all of the layers.

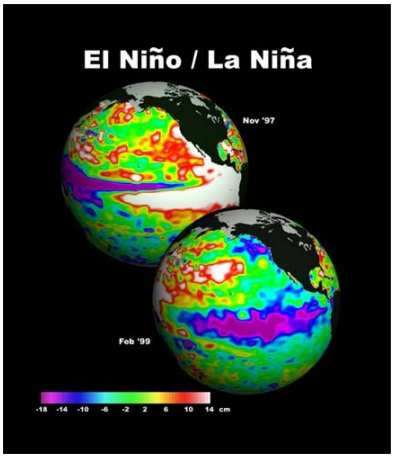
Interaction of Earth's Spheres

These spheres are closely connected. For example, many birds (biosphere) fly through the air (atmosphere), while water (hydrosphere) often flows through the soil (geosphere). In fact, the spheres are so closely connected that a change in one sphere often results in a change in one or more of the other spheres. Such changes that take place within an ecosystem are referred to as **events**.

Events can occur naturally, such as an earthquake or a hurricane, or they can be caused by humans, such as oil spill or air pollution. An event can **cause** changes to occur in one or more of the spheres, and/or an event can be the **effect** of changes in one or more of Earth's four spheres. This two-way cause and effect

relationship between an event and a sphere is called an **interaction**. Interactions also occur among the spheres; for example, a change in the atmosphere can cause a change in the hydrosphere, and vice versa.

Interactions that occur as the result of events such as floods and small forest fires may impact only a local region, meaning the flood waters can only travel so many miles from the original stream, and only the trees that lie within the area on fire will be burned. On the other hand, the effects of events such as El Nino or ozone depletion may cause interactions that can be observed worldwide.



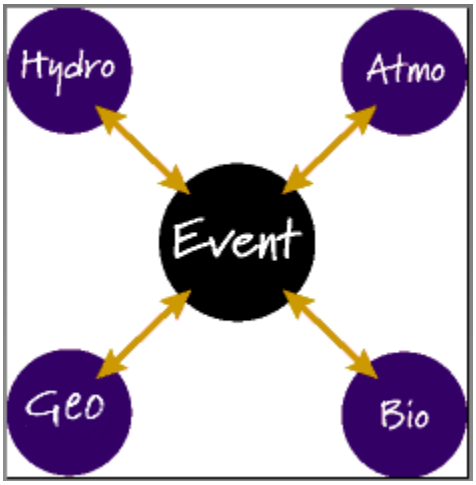
For example, the El Nino event--a change in the ocean temperature off the coast of Peru-- can cause changes in weather patterns all the way across North America, while ozone depletion above Antarctica may result in increased levels of ultra-violet B radiation around the world.

Understanding the interactions among the earth's spheres and the events that occur within the ecosystem allows people to predict the outcomes of events. Being able to predict outcomes is useful when, for example, developers wish to know the environmental effects of a project such as building an airport before they begin construction.

Understanding the interactions that occur in the earth system also helps people to prepare for the effects of natural disasters such as volcanic eruptions; this understanding allows people to predict things like how far and in what direction the lava will flow. This relatively new field of studying the interactions between and among events and the earth's spheres is called **Earth System Science** (ESS). There are ten possible types of interactions that could occur within the earth system. Four of these interactions are between the event and each of the earth's spheres:

event ⟷ geosphere
event ⟷ hydrosphere
event ⟷ biosphere
event ⟷ atmosphere

The double-headed arrows (⟷) indicate that the cause and effect relationships of these interactions go in both directions; for example, "event ⟷ hydrosphere" refers to the effects of the event on the hydrosphere, as well as the effects of the hydrosphere on the event. These four types of interactions can be illustrated in the **Earth System Diagram** below:

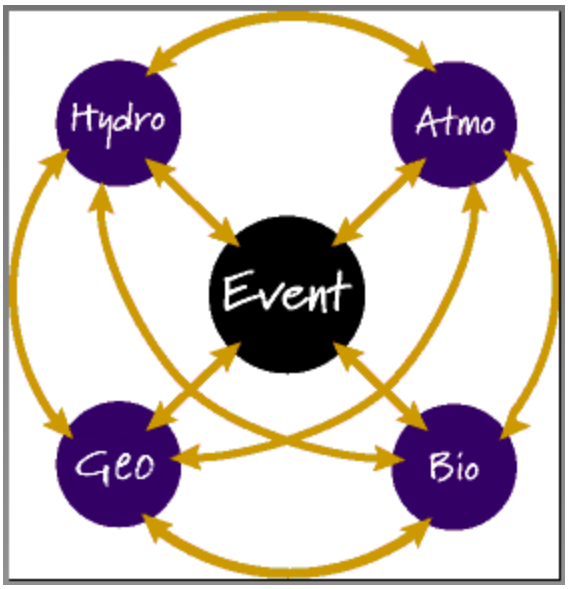


In addition to the above four event ⟷ sphere interactions, there are six interactions that occur among the earth's spheres:

geosphere ⟷ hydrosphere
geosphere ⟷ biosphere
geosphere ⟷ atmosphere
hydrosphere ⟷ biosphere
hydrosphere ⟷ atmosphere
biosphere ⟷ atmosphere

Again, the double-headed arrows (⟷) indicate that the cause and effect relationships of the interactions go in both directions; for example, "geosphere hydrosphere" refers to the effects of the geosphere on the hydrosphere, as well as the effects of the hydrosphere on the geosphere.

These six types of interactions can be illustrated in the **Earth System Diagram** below (note the four event ⟷ sphere interactions are also included in this diagram):



The ten types of interactions that can occur within the earth system often occur as a series of chain reactions. This means one interaction leads to another interaction, which leads to yet another interaction--it is a ripple effect through the earth's spheres. For example, a forest fire may destroy all the plants in an area (event ⟷ biosphere). The absence of plants could lead to an increase in erosion--washing away--of soil (biosphere ⟷ geosphere). Increased amounts of soil entering streams can lead to increased turbidity, or muddiness, of the water (geosphere ⟷ hydrosphere). Increased turbidity of stream water can have negative impacts on the plants and animals that live in it (hydrosphere ⟷ biosphere).

How Is Earth System Science Conducted?
Earth system science is conducted by examining each event ⟷ sphere and sphere ⟷ sphere interaction; this approach is referred to as an "Earth System Science analysis" or an "ESS analysis." The examination of the interactions is accomplished by asking oneself the following questions:

1. How may each of the earth's four spheres (hydrosphere, atmosphere, geosphere, and biosphere) have caused the event to occur? (The answers to this question are the sphere ⟷ event impacts.)

2. What are the effects of the event on each of the earth's four spheres (hydrosphere, atmosphere, geosphere, and biosphere)? (The answers to this question are the event ⟷ sphere impacts.)

Note: When you do an ESS analysis, you will list the answers to Questions 1 and 2 together under event ⟷ sphere interactions.

3. What are the effects of changes in one of earth's four spheres (hydrosphere, atmosphere, geosphere, or biosphere) on each of the other spheres

(hydrosphere, atmosphere, geosphere, or biosphere)? (The answers to this question are the sphere ⟷ sphere interactions.)

This approach of answering the questions above is performed during every ESS analysis; simply replace the term "event" with the event you wish to investigate.

An Example of an Earth System Science Analysis.
An ESS analysis was performed on the forest fires event that occurred in Yellowstone National Park, Wyoming. This forest fires event occurred in 1988 and destroyed tremendous areas of the park.

Below are some of the event ⟷ sphere interactions discovered during an ESS analysis of the Yellowstone forest fires event:

Event ⟷ Hydrosphere

A lack of moisture in the soil and in vegetation may have provided a dry environment in which the fires, once burning, could continue to burn.

Heat from the fire may have further removed moisture from the air, soil, and vegetation through the process of evaporation.

Event ⟷ Atmosphere

A lightning strike from the air may have started the fires by igniting the dry vegetation.

Gaseous pollutants such as carbon dioxide (CO_2) may have been produced during the burning of the vegetation and carried into the air by the wind.

Event ⟷ Geosphere

The intense heat from the fires may have caused some rocks to break apart.

Event ⟷ Biosphere

Dead branches and pine needles on the ground may have provided fuel for the fires.

The seeds of some plants may have required that their outer shells be burned before they could germinate; therefore they benefited from the forest fires.

Below are some of the sphere ⟷ sphere interactions discovered during the ESS analysis of the Yellowstone forest fires event:

Geosphere ⟷ Hydrosphere

Increased erosion of loose soil (see "Geosphere ⟷ Biosphere," below) may have led to increased sediments (i.e. soil particles) in stream water, making the water "muddier."

Geosphere ⟷ Biosphere

A decrease in vegetation may have resulted in increased soil erosion because there were fewer roots to hold the soil in place.

Geosphere ⟷ Atmosphere

Ash particles in the air may have been carried by the wind and dropped on the ground miles away from the forest fires; the ash particles--which have a high pH--may have changed the pH of the soil. .

Hydrosphere ⟷ Biosphere

Ash particles in the water may have clogged the gills of fish and other aquatic organisms and choked them.

Hydrosphere ⟷ Atmosphere

There may have been more precipitation in neighboring areas because ash particles in the air may have become condensation centers upon which raindrops could form.

Very dry, windy air may have drawn moisture out of the living grasses and trees through the process of evaporation.

Biosphere ⟷ Atmosphere

Smoke in the air may have coated the lungs of animals--including people--and affected their ability to breathe.

Remember, these are NOT all the possible event ⟷ sphere and sphere ⟷ sphere interactions that could have occurred as a result of the Yellowstone forest fires. These are merely a few examples of what seem to be some reasonable causes and effects. There are many other possibilities.

Also keep in mind that as you list event ⟷ sphere and sphere ⟷ sphere interactions, it is important that you be able to explain why or how the interactions occur. For example, the above geosphere ⟷ biosphere interaction does not merely state "a decrease in vegetation may have resulted in increased erodibility of soil." It gives the reason "because there were fewer roots to hold it in place." Such explanations display your understanding of the science behind the interactions. These explanations are valuable for you and others because they make your "Why?" or "How?" thinking visible and they often lead to the discovery of additional ESS interactions.