The Earth's Dynamic Cryosphere and the Earth System

The Earth System

By Richard S. Williams, Jr.[1]

The Earth System (fig. 1) has two primary components: the geosphere and the biosphere. The geosphere has four subcomponents: lithosphere (solid Earth), atmosphere (gaseous envelope), hydrosphere (liquid water), and cryosphere (frozen water) (fig. 2). Each of these subcomponents can be further subdivided into elements: for example, the oceans are an element of the hydrosphere. The biosphere (living organisms) contains about 100 phyla organized into five kingdoms of life forms. Human beings belong to the Kingdom Animalia and are but one species of the estimated 20 million to 100 million species in the biosphere.

Our species—nearly 7 billion human beings—interacts with the entire Earth System, the components and subcomponents of which follow the fundamental principles of physics, chemistry, biology, and geology. These principles function in terms of processes, including climate processes, and of cycles, including biogeochemical cycles and the global hydrologic cycle. In 2009, human beings numbered 6.8 billion, currently increasing annually by approximately 75 million and projected to reach a total of approximately 9 billion by 2050, according to the U.S. Census Bureau (http://www.census.gov/ipc/www/idb/).

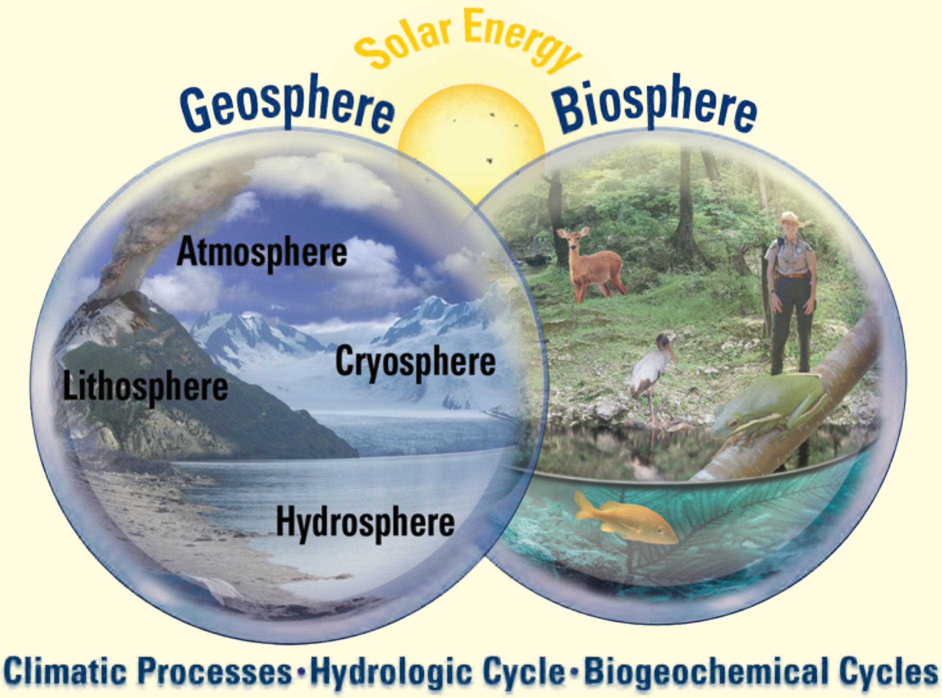

Figure 1. The Earth System. Its two primary components are the geosphere (the collective name for the lithosphere, hydrosphere, cryosphere, and atmosphere) and the biosphere; climatic processes, the hydrologic cycle, and the multiple biogeochemical cycles are interactive in the Earth System; the Sun is the primary source of energy. Graphic design by James A. Tomberlin, USGS

Figure 2. The Earth's cryosphere is comprised of four elements: glaciers, snow cover, floating ice, and permafrost. Graphic design by James A. Tomberlin, USGS

Our technological capabilities for altering all aspects of the Earth System directly or indirectly, and our use of renewable and nonrenewable resources place human beings in seemingly inevitable competition with all other organisms that the Earth System sustains. Consequences of this competition emerge in Earth's climatic processes (global warming), in its biogeochemical cycles (perturbation of the nitrogen cycle), and in the hydrologic cycle (regional changes in quality and quantity of fresh water).

All parts of the Earth System interact and are interrelated. A change in one will likely result in change in one or more others. Many environmental scientists suspect that some of these interrelationships in the Earth System are metastable; that is, they are in dynamic equilibrium, an equilibrium that can easily change to a less stable state of dynamic equilibrium once a threshold is exceeded. Environmental scientists are concerned that present-day global climate warming is caused, in part, by the continuing increase in carbon dioxide (CO_2) in the Earth's atmosphere. Scientists discern the

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range of natural variability of CO_2 (in parts per million, by volume (ppmv)) using data obtained from ice cores spanning six glacial and interglacial intervals during the last 650,000 years. A glacial interval has a minimum CO_2 content of approximately 180 ppm; an interglacial interval has a maximum CO_2 content of approximately 280 ppm. This range of natural variability is based on analyses of glacier ice cores from Antarctica (for example, the ice core from the European Project for Ice Coring in Antarctica (EPICA) extracted from Dome C) (fig. 3) and on instrumental records, beginning in 1958, on Mauna Loa, Hawaii, by the atmospheric chemist C. David Keeling. The Earth's atmosphere in 2009 contained 390 ppm, 39 percent more than the maximum range of natural variability.

By the beginning of the 21st century, the overwhelming scientific consensus is that burning of fossil fuels and deforestation, both of which are human activities, are the dominant factors in the Earth's observed warming: warming of the atmosphere, warming of the upper layers of the oceans (hydrosphere), accelerated melting of glacier ice (cryosphere), and rise in global sea level (from interactions among the hydrosphere, cryosphere, and hydrologic cycle). How much of this warming is caused by this increase in CO_2 (from interactions between the atmosphere and biogeochemical cycles) and how much is a natural variability (from rebound of the Earth's climate since the end of the Little Ice Age in the late 1800s)? Will the global warming that causes changes in one or more components and subcomponents of the Earth System be a linear change, an exponential change, or a step-function change?

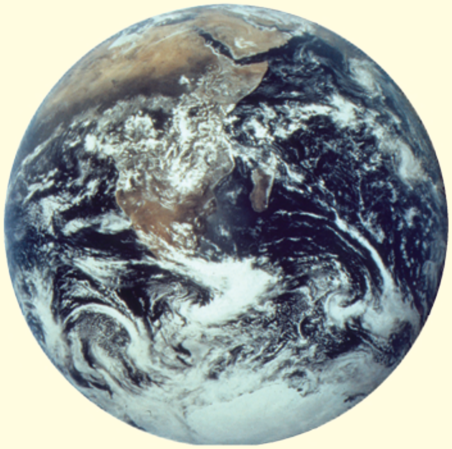

Figure 4. The Earth. Photograph taken during the Apollo 17 Mission to the Moon in December 1972, the last of the Apollo missions, by the geologist-astronaut Harrison H. (Jack) Schmitt. NASA photograph No. 72-HC-928, courtesy of the NASA Public Information Office, Washington, D.C.

The most negative effect from global warming is likely to be an alteration in the hydrologic cycle, including changes in regional patterns of precipitation and in evapotranspiration. The resulting reduction in volume of glacier ice (cryosphere), the meltwater from which will be added to the ocean (hydrosphere), will intensify the already rapid rise in sea level (currently rising at 3 to 4 millimeters per year).

The four subcomponents of the geosphere and the biosphere appear in silent clarity in the world-famous color photograph of the Earth (fig. 4) taken during the Apollo 17 mission to the Moon in December 1972 by the geologist-astronaut, Harrison H. "Jack" Schmitt. We see deserts in northern and southern Africa and in the Middle East and two diverging plates along the Red Sea (lithosphere); oceans and lakes (hydrosphere); clouds, (atmosphere); and Antarctica and its continent-wide cover of glacier ice, the largest of the two remaining ice sheets on Earth (cryosphere). And we see tropical rainforest in central Africa around the Congo River basin (biosphere).

Water on the Earth exists as water vapor in the atmosphere: as liquid water in the oceans (97 percent), in lakes, rivers, groundwater aquifers, soil of the lithosphere, and in organisms of the biosphere (1 percent), and as frozen water in glaciers of the cryosphere (2 percent). The dynamic hydrologic cycle, in which water exists in its three phases, and the biosphere that has such a diversity of life forms, make the Earth unique among the other planets in the Solar System. Because 70 percent of the Earth's surface is covered by water, perhaps the Earth would more accurately be called "Water."

URL Addresses:

http://www.essc.psu.edu/

http://nasascience.nasa.gov/earth-science/focus-areas/

http://earthobservatory.nasa.gov/

http://visibleearth.nasa.gov/

http://www.realclimate.org/index.php?p=221

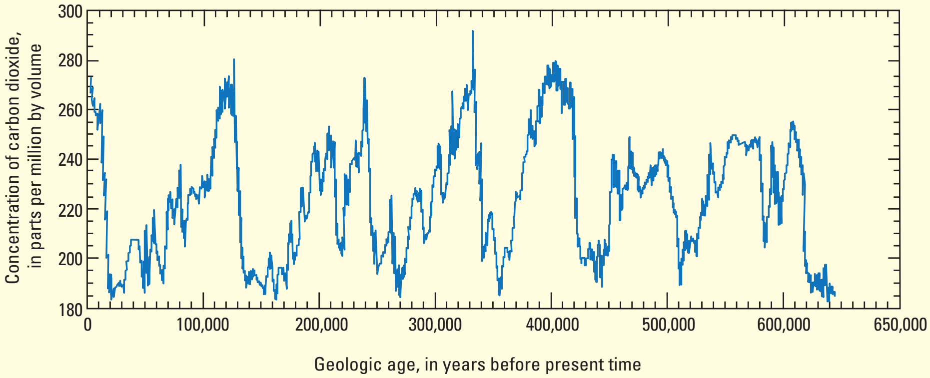

Figure 3. Variation in concentration of carbon dioxide in the Earth's atmosphere for the previous six glacial/interglacial cycles (past 650,000 years), from analyses of the ice core taken by the European Project for Ice Coring in Antarctica (EPICA) from Dome C, Antarctica. The concentration of carbon dioxide in the atmosphere in 2009 was 390 ppmv.

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