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The Earth's Dynamic Cryosphere and the Earth System

Global Hydrologic Cycle

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Of all the cycles and processes that operate on Earth, the most important is the hydrologic cycle (fig. 1), the complex process through which water, in its three phases—solid, liquid and vapor—moves through all components and subcomponents of the geosphere and the biosphere.

The physical and chemical properties of the water molecule make water unique as a substance. Physically, it has a high specific heat, meaning that much more energy is required to increase the temperature of water (4.186 joule/gram degrees Celsius (°C) than that of most common substances. Chemically, it is a universal solvent that varies with respect to its pH value (negative logarithm of the concentration of the hydrogen ion: less than 7, acidic; 7, neutral; more than 7, basic). Acid rain, for example, dissolves the surface of limestone blocks in buildings and of marble in sculptures, and it can lower the pH of lakes to render them devoid of aquatic organisms. The movement of water through the Earth System also transports and releases energy. As water changes its phase from solid to liquid, from liquid to gas, and from solid to gas (sublimates), thermal energy is absorbed (endothermic change); changes in phase in the opposite direction release energy (exothermic change). Another unusual physical property of water is that it is most dense (liquid) at 4°C and less dense as a solid (ice). This is critical to the survival of the aquatic organisms (in the biosphere) in marine and terrestrial environments of the hydrosphere when floating ice forms. In lakes, water freezes from the surface down; deeper lakes and the oceans therefore retain liquid water having temperatures below that of the ice cover, which is at or higher than 0°C. Under certain circumstances, however, frazil ice (special forms of ice crystals) can form in the water column in fast-flowing rivers and streams; if such ice adheres to the bottom, it forms anchor ice that can grow (from the bottom up) to many centimeters in thickness. Anchor ice can affect the accuracy of measurements of a river's winter discharge by altering the cross section of the river. In temperate and high-latitude regions, a convective circulation ("turnover") occurs in lakes twice each year (spring and fall) as the water warms (or cools) to 4° C, thereby oxygenating (adding oxygen to) the entire water column.

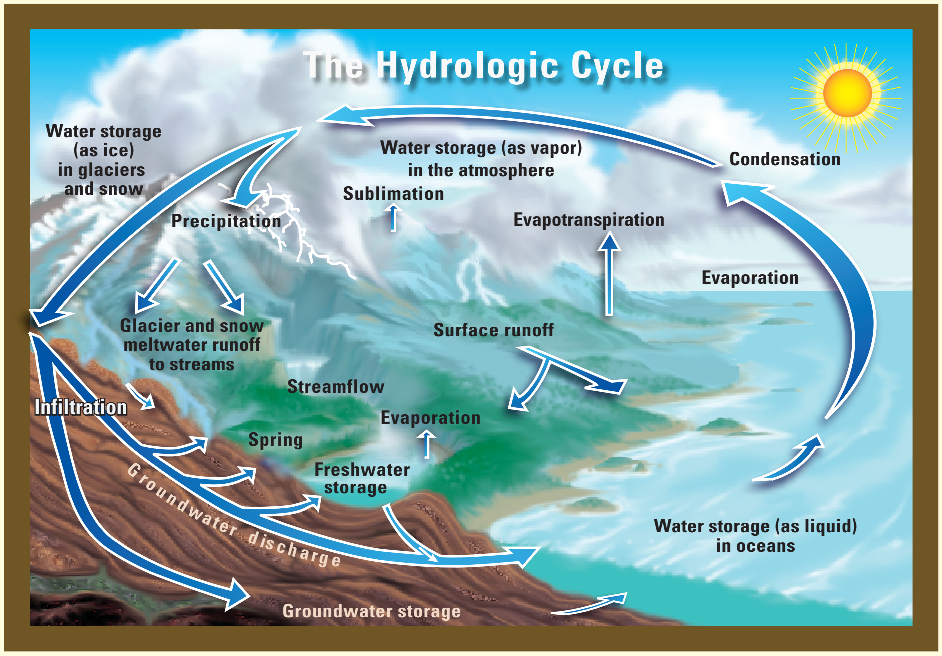

Figure 1. The global hydrological cycle. Water evaporates from oceans and lakes and precipitates on land as rain or snow. The cycle transports runoff from rivers and streams, by subsurface movement through aquifers, through animals, plants, and other organisms, through the soil, and stores water in oceans, lakes, and glaciers. Modified from U.S. Geological Survey, 2009, Water science for schools: The water cycle: accessed 23 February 2010, at http://ga.water.usgs.gov/edu/watercycle.html

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As water evaporates from oceans and lakes and precipitates on land as rain or snow, the hydrologic cycle transports liquid water by runoff of surface water (rivers and streams); by subsurface movement of groundwater (aquifers); through animals (by respiration), plants (by evapotranspiration), and other organisms; through the soil; and stores water in oceans, lakes, and glaciers (cryosphere). The oceans (hydrosphere) contain 97 percent of Earth's water, and glaciers store 2 percent. Therefore, less than 1 percent of Earth's water remains as surface water, groundwater, and soil moisture to sustain most life forms in terrestrial ecosystems.

The long-term exchange between glacier ice (cryosphere) and the oceans (hydrosphere) determines global (eustatic) sea level (fig. 2). In response to variations in the volume of glacier ice on the continents, sea level has repeatedly fallen and risen between glacials and interglacials. Approximately 20,000 years ago, for example, sea level was about 125 meters (m) lower than at present (2009). If all of the present glacier ice on land were to melt, sea level would rise an additional 75 m. At present, eustatic sea level is rising at the rate of about 0.4 m per century (about 3 to 4 millimeters per year) from a combination of glacial meltwater and an increase in volume (a steric rise) from warming of the oceans. Under conditions of global warming, the melting of glaciers is expected to accelerate. If this expectation is borne out, global sea level will rise rapidly.

A warmer climate will likely result in increased evaporation and evapotranspiration that will intensify or accelerate the hydrologic cycle. The rate of exchange of water among its various phases is expected to increase as it circulates through the atmosphere, cryosphere, hydrosphere, and through the terrestrial biosphere. Climate projections based on global circulation models (GCMs) indicate that wet regions are likely to become wetter and dry regions may become drier. Although increases in precipitation are typically expressed as increases in rainfall intensity (amount per unit time), periods between precipitation events are likely to lengthen, even in areas that receive more total precipitation. Drought is therefore likely to become more frequent.

Figure 2. Ground photograph of glacial meltwater plunging over the 60-m-high Skógafoss waterfall, southern Iceland. The glacial meltwater originates from the Eyjafjallajökull ice cap and flows south into the North Atlantic Ocean. Photograph by Richard S. Williams, Jr., U.S. Geological Survey.

Percent by volume of the earth's water supply

[Modified from table in U.S. Geological Survey in U.S. Geological Survey Circular 536 (http://pubs.usgs.gov/circ/1967/0536/report.pdf)]

Reservoir	Percentage by Volume
Oceans	97.200
Freshwater:	
Glacier ice	2.150
Subsurface water	0.625
Surface water	0.017
Atmosphere	0.001
Subtotal (fresh water)	2.793
Total	**~100.00**

URL Addresses:

http://ga.water.usgs.gov/edu/watercycle.html

http://www.iwr.msu.edu/edmodule/water/cycle.htm

http://earthobservatory.nasa.gov

http://nasascience.nasa.gov/earth-science/oceanography/ocean-earth-system/ocean-water-cycle

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