SAMPLE

Earth's Dynamic Systems: The Water Cycle

From Ocean to Cloud to Rain

Aira Astralis

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Conclusion

This free sample contains the Introduction and Chapter 1. The complete book contains the full contents above.

Introduction

The water cycle (or hydrologic cycle or hydrological cycle) is a biogeochemical cycle that involves the continuous change in form of water on, above and below the surface of the Earth across different reservoirs. The mass of water on Earth remains fairly constant over time. However, the partitioning of the water into the major reservoirs of ice, fresh water, salt water and atmospheric water is variable and depends on climatic variables.

The water moves from one reservoir to another, such as from river to ocean, or from the ocean to the atmosphere due to a variety of physical and chemical processes. The processes that drive these movements, or fluxes, are evaporation, transpiration, condensation, precipitation, sublimation, infiltration, surface runoff, and subsurface flow. In doing so, the water goes through different phases: liquid, solid (ice) and vapor.

The ocean plays a key role in the water cycle as it is the source of 86% of global evaporation.

The water cycle is driven by energy exchanges in the form of heat transfers between different phases. The energy released or absorbed during a phase change can result in temperature changes. Heat is absorbed as water transitions from the liquid to the vapor phase through evaporation. This heat is also known as the latent heat of vaporization. Conversely, when water condenses or melts from solid ice it releases energy and heat.

On a global scale, water plays a critical role in transferring heat from the tropics to the poles via ocean circulation. The evaporative phase of the cycle also acts as a purification process by separating water molecules from salts and other particles that are present in its liquid phase. The condensation phase in the atmosphere replenishes the land with freshwater. The flow of liquid water transports minerals across the globe.

It also reshapes the geological features of the Earth, through processes of weathering, erosion, and deposition. The water cycle is also essential for the maintenance of most life and ecosystems on the planet. Human actions are greatly affecting the water cycle. Activities such as deforestation, urbanization, and the extraction of groundwater are altering natural landscapes (land use changes) all have an effect on the water cycle.

On top of this, climate change is leading to an intensification of the water cycle.

Two further loops complete the picture. Beneath the visible cycle, a deep

geological one carries water into the mantle at subduction zones and returns it through volcanoes, on timescales that make the ocean's own age look brief; and around the visible cycle, a human one has grown up, drawing rivers into canals and aquifers into fields and re-forging, in a few centuries, the distribution the planet spent billions of years arranging. The chapters that follow take each of these loops in turn: how the cycle was discovered and how it works, what it carries and what it moves, how it is measured, how it intensifies, and what it finally asks of the civilizations that depend on it. It is a story with a cast of everything, from the Sun and the deep mantle to the leaf of a tree.

Chapter 1: The Discovery of The Water Cycle

The cycle's discovery is itself a story of watching water. Ancient observers knew the sky was involved long before they could explain it: it was observed that when the clouds were full, they emptied rain on the earth (Ecclesiastes 11:3), and in the Adityahridayam, a devotional hymn to the Sun God in the Hindu epic Ramayana dated to the 4th century BCE, the 22nd verse says that the Sun heats up water and sends it down as rain. By roughly 500 BCE, Greek scholars were speculating that much of the water in rivers can be attributed to rain.

The origin of rain was also known by then. These scholars maintained the belief, however, that water rising up through the earth contributed a great deal to rivers. Examples of this thinking included Anaximander (570 BCE) (who also speculated about the evolution of land animals from fish) and Xenophanes of Colophon (530 BCE). Warring States period Chinese scholars such as Chi Ni Tzu (320 BCE) and Lu Shih Ch'un Ch'iu (239 BCE) had similar thoughts. The idea that the water cycle is a closed cycle can be found in the works of Anaxagoras of Clazomenae (460 BCE) and Diogenes of Apollonia (460 BCE).

Both Plato (390 BCE) and Aristotle (350 BCE) speculated about percolation as part of the water cycle. The modern science arrived by measurement rather than philosophy. In 1674 the French physicist Edme Mariotte weighed the rainfall falling on a patch of the Seine's catchment and showed that the river carried far less water than the sky delivered, settling that rivers are fed by rain and not by deep upwelling; in 1711 Edmond Halley measured evaporation from a pan of heated water and scaled it up to the Mediterranean, showing the sea could easily supply the rivers' return flow.

When Bernard Palissy had earlier argued for rainfall as the sole source of springs, the quantitative case had not existed to back him; by the close of the eighteenth century, with Pierre

Perrault's careful accounting of rainfall and runoff on the Upper Seine, it did.

What the ancients had guessed and the seventeenth century had measured, the twentieth could finally assemble whole: Robert Horton's work on infiltration and the physics of runoff in the 1930s turned the old cycle of rain into the quantitative, modelable system that hydrology studies today.

Research has shown that global warming is causing shifts in precipitation patterns, increased frequency of extreme weather events, and changes in the timing and intensity of rainfall. These water cycle changes affect ecosystems, water availability, agriculture, and human societies. The water cycle is

powered by the energy emitted from the sun.

There are several ways in which this is accomplished, one of the first ways is through evaporation where the energy from the sun heats the water in oceans, lakes, streams, rivers, seas, ponds, etc.

Two other ways that water gets into the atmosphere is through snow and ice sublimating into water vapor and through evapotranspiration which is water transpired from plants and evaporated from the soil.

Clouds form because water molecules have a smaller molecular mass than the major gas components of the atmosphere (oxygen, O2; and nitrogen, N2); this smaller molecular mass leads to water having a lower density which drives the water molecules higher up in the atmosphere due to buoyancy. However, as altitude increases, air pressure decreases which causes a drop in temperature.

The lower temperature forces the water vapor to go through another phase change, this time it forces it to condense into liquid water droplets which are supported by an updraft; if there is enough of these water droplets over a large area, it is considered a cloud. Condensation of the water vapour closer to the ground level is referred to as fog.

Atmospheric circulation moves water vapor around the globe; cloud particles collide, grow, and fall out of the upper atmospheric layers as precipitation.

Some precipitation falls as snow, hail, or sleet, and can accumulate in ice caps and glaciers, which can store frozen water for thousands of years. Most water falls as rain back into the ocean or onto land, where the water flows over the ground as surface runoff. A portion of this runoff enters rivers, with streamflow moving water towards the oceans. Runoff and water emerging from the ground (groundwater) may be stored as freshwater in lakes.

Not all runoff flows into rivers; much of it soaks into the ground as infiltration. Some water infiltrates deep into the ground and replenishes aquifers, which can store freshwater for long periods of time. Some infiltration stays close to the land surface and can seep back into surface-water bodies (and the ocean)

as groundwater discharge or be taken up by plants and transferred back to the atmosphere as water vapor by transpiration.

Some groundwater finds openings in the land surface and emerges as freshwater springs.

In river valleys and floodplains, there is often continuous water exchange between surface water and ground water in the hyporheic zone. Over time, the water returns to the ocean, to continue the water cycle. The ocean dominates

the accounting: it holds nearly all of the planet's water, receives most of the world's rain, and supplies most of the vapour that keeps the whole system turning.

Important physical processes within the water cycle include (in alphabetical order): Advection: The movement of water through the atmosphere. Without advection, water that evaporated over the oceans could not precipitate over land. Atmospheric rivers that move large volumes of water vapor over long distances are an example of advection. Condensation: The transformation of water vapor to liquid water droplets in the air, creating clouds and fog.

Evaporation: The transformation of water from liquid to gas phases as it moves from the ground or bodies of water into the overlying atmosphere. The source of energy for evaporation is primarily solar radiation. Evaporation often implicitly includes transpiration from plants, though together they are specifically referred to as evapotranspiration. Total annual evapotranspiration amounts to about 505,000 km3, roughly 121,000 cubic miles of water, of which some 434,000 km3 (104,000 cu mi) evaporates from the oceans.

Infiltration: The flow of water from the ground surface into the ground. Once infiltrated, the water becomes soil moisture or groundwater. A recent global study using water stable isotopes, however, shows that not all soil moisture is equally available for groundwater recharge or for plant transpiration. Percolation: Water flows vertically through the soil and rocks under the influence of gravity. Precipitation: Condensed water vapor that falls to the

Earth's surface.

Most precipitation occurs as rain, but also includes snow, hail, fog drip, graupel, and sleet.

Approximately 505,000 km3 (121,000 cu mi) of water falls as precipitation each year, 398,000 km3 (95,000 cu mi) of it over the oceans. The rain on land contains 107,000 km3 (26,000 cu mi) of water per year and a snowing only 1,000 km3 (240 cu mi). 78% of global precipitation occurs over the ocean. Runoff: The variety of ways by which water moves across the land. This includes both surface runoff and channel runoff.

As it flows, the water may seep into the ground, evaporate into the air, become stored in lakes or reservoirs, or be extracted for agricultural or other human uses. Subsurface flow: The flow of water underground, in the vadose zone and aquifers. Subsurface water may return to the surface (e.g. Water returns to the land surface at lower elevation than where it infiltrated, under the force of gravity or gravity induced pressures.

The deep water cycle, or geologic water cycle, involves exchange of water with the mantle, with water carried down by subducting oceanic plates and returning through volcanic activity, distinct from the water cycle process that occurs above and on the surface of Earth.

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ABOUT THE AUTHOR

Aira Astralis is a science writer specializing in astronomy and space exploration. Her work spans the full breadth of humanity's relationship with the cosmos -- from the earliest naked-eye observations to the engineering marvels of modern space missions.

Her books are built on a foundation of primary sources: peer-reviewed research, mission archives, and direct engagement with the scientific community. She writes for readers who want to understand not just what we know about the universe, but how we came to know it.

She believes that the most important frontier is not out there but in the gap between what scientists discover and what the public understands. Her books exist to close that gap.