Investigation 1B

OCEAN IN THE GLOBAL WATER CYCLE

Objectives

The world ocean covers almost 71% of Earth's surface to an average depth of about 4300 m (14,000 ft.). With the commanding presence of the ocean and the large expanses of terrestrial ice and snow cover, lakes, groundwater, and atmospheric moisture, Earth is truly a water planet. Central to the functioning of the Earth system is the global water cycle, the ceaseless flow of water, energy, and water-borne materials among the oceanic, terrestrial, and atmospheric reservoirs, and their interactions with life on Earth.

In this course, we employ an Earth system approach as we focus on (a) ocean components and properties, (b) internal and external processes involving the ocean, and (c) the ocean's role in biogeochemical cycles (e.g., the carbon cycle).

After completing this investigation, you should be able to:

- Describe the central role of the world ocean in the global water cycle.
- Interpret satellite imagery showing the atmospheric transport of clouds and water vapor originating above ocean surfaces that impact weather and climate worldwide.
- Name and delineate the five major subdivisions of the world ocean.

The Global Water Cycle

Figure 1B-1 schematically illustrates the reservoirs, movements, and transformations of water in the Earth system. For a NASA animation of the water cycle, click Link 1B-1.

Figure 1B-1 also helps explain why water cycles through its reservoirs, namely, to move energy from place to place. The mass flow of water as portrayed in the figure is in response to the non-uniform distribution of energy in the Earth system. Note that whereas Earth is a closed system for cycling matter, as in the case of water, Earth is an open system or "flow-through" system for energy. Energy is absorbed and converted as it comes from space as sunlight and is eventually lost back to space as infrared radiation. Water's coexistence in all three phases (solid, liquid, and vapor) and the relative ease at which it changes phase within the temperature and pressure ranges on Earth makes water the primary working fluid that absorbs, transports, and releases heat energy within the Earth system.

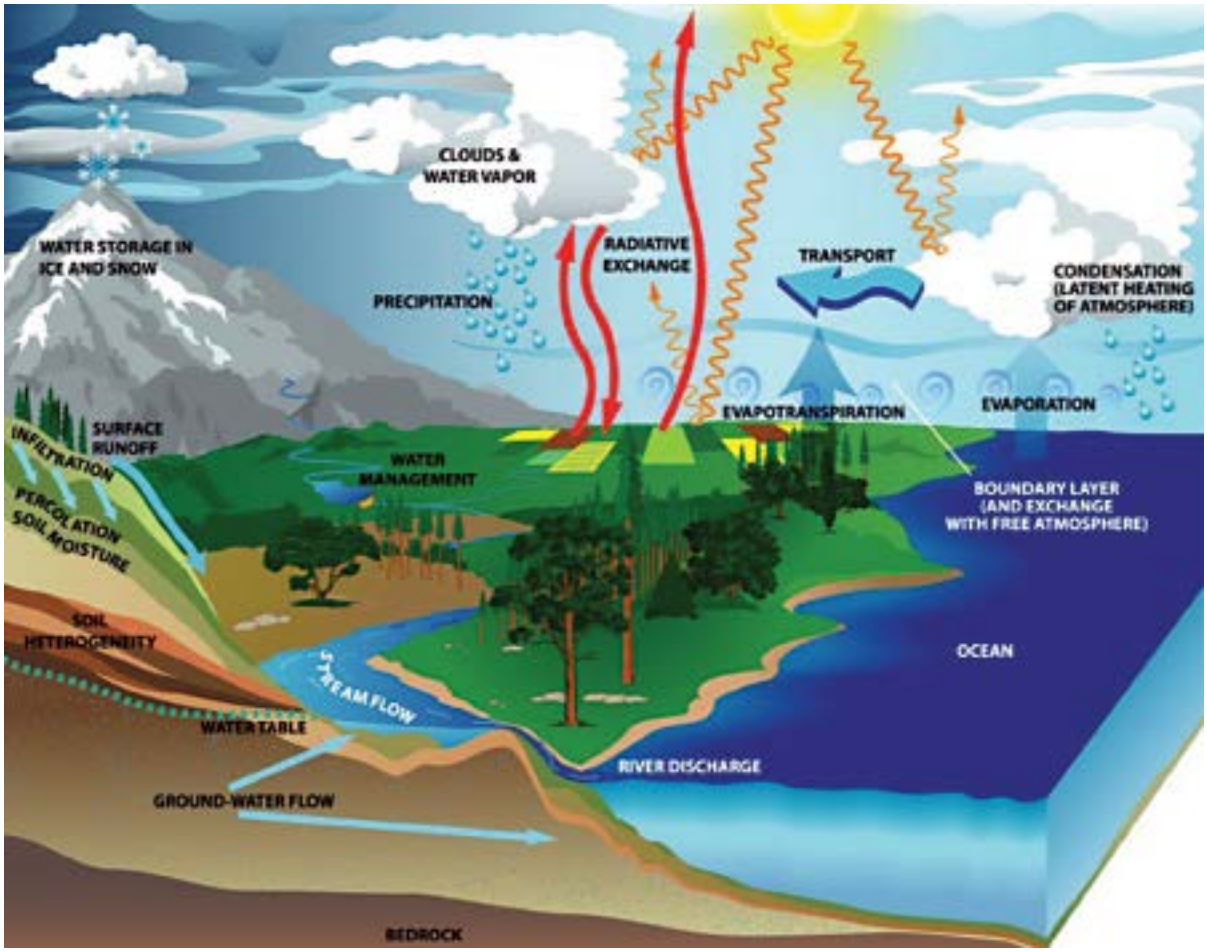

Figure 1B-1. Schematic conceptualization of the global water cycle. [USGCRP]

Water is the primary mover of energy in the Earth system from where there is relatively more energy to where there is relatively less. Ocean currents transport enormous quantities of heat energy poleward, and the ocean is the primary source of atmospheric moisture, accounting for about 85% of all evaporation worldwide. Winds transport water vapor and the latent heat absorbed during evaporation to every location on Earth, no matter how remote from the ocean or how high. Changing back to liquid or solid within the atmosphere, water begins its gravity-driven return trip as rain or snow to Earth's surface and, ultimately, to the ocean. An integral part of this course is the development of this more complete and authentic learning progression about the global water cycle in terms of both mass and energy flows.

1. The view of the global water cycle in Figure 1B-1 shows the ocean to the right. Water is transported to the ocean via _____.

   a. groundwater flow
   b. stream flow
   c. both processes

2. Precipitation also occurs over the ocean, adding fresh water directly to the ocean surface. Meanwhile, water is lost from the ocean via _____. Not shown in Figure 1B-1 are ocean losses by infiltration into the sediments and rocks beneath the ocean or the addition of water to the ocean via volcanic activity.

a. evaporation
b. surface runoff
c. precipitation

Figure 1B-2 provides evidence of global-scale mass and energy flows. The figure is a composite of weather-satellite images capable of sensing water vapor and clouds in Earth's atmosphere. Bright white areas portray clouds. The light to medium gray regions depict mainly water vapor in the atmosphere at altitudes between about 3000 and 7000 m (10,000 and 23,000 ft.) above sea level. These regions would likely appear clear on visible and ordinary infrared satellite images. Dark areas delineate relatively dry (low humidity) regions where air is sinking. This composite image is derived from computer processing of the invisible infrared radiation emitted by Earth's surface that interacts with water in the portion of the atmosphere described above. This particular image was acquired on 10 December 2018 at 1800 UTC.

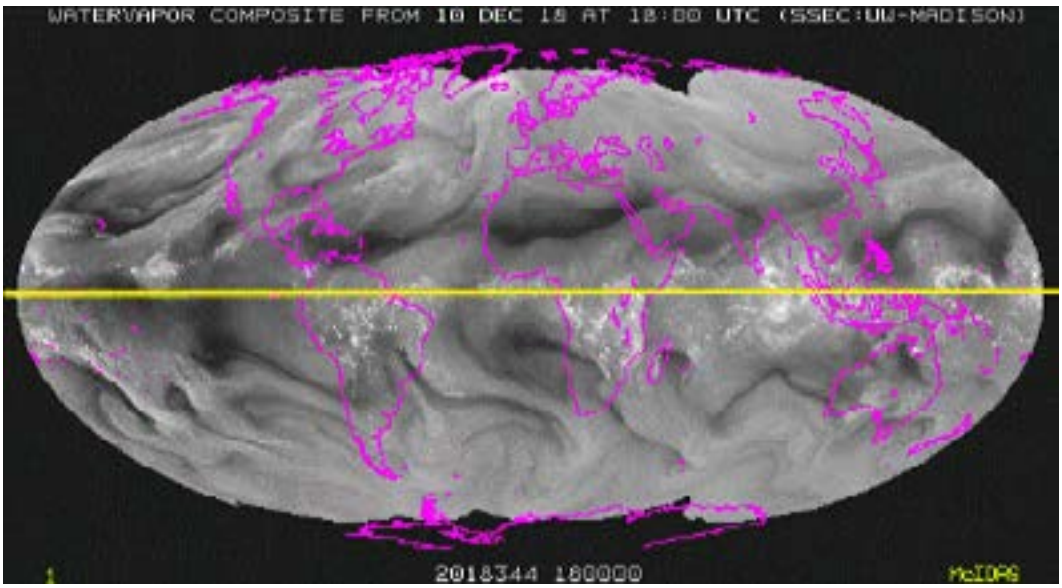

Figure 1B-2. Satellite image showing water vapor and clouds in the middle region of the atmosphere, 10 December 2018. [SSEC, University of Wisconsin – Madison]

To view a sample animation of global water vapor composite imagery, click Link 1B-2. The animation puts into motion the atmospheric component of the global water cycle (and simultaneously presents an Earth system perspective) by showing patterns of white clouds and gray (non-cloud) swirls of water vapor. Streaks of clouds and curls of gray in the middle latitudes are part of the general eastward flow of air at those latitudes. The circulation of clouds and vapor in the atmosphere is part of the heat-driven *uphill* (upward vertical motion) component of the water cycle that lifts water to higher altitudes while winds move it great distances horizontally. The rest of the cycle is the gravity-driven *downhill* journey to the ocean, which begins as precipitation. Once returned to the ocean, surface winds and variations in water density resulting from temperature and salinity differences drive the ocean water circulation.

3. A horizontal yellow line divides the Earth view in half to locate the equator for reference. The bright white cloud patches forming an irregular band roughly aligned with the equator mark areas of thunderstorm activity where huge quantities of water vapor enter the atmosphere from the underlying warm ocean and moist land surfaces. These thunderstorms imply _____ is/are entering the atmosphere from the underlying surface.

a. energy
b. water vapor
c. both water vapor and energy

4. In the image, the bright blotches in the lower latitudes are generally centered to the south of the equator. This is because in this early December view, just a few weeks prior to the Northern Hemisphere's winter solstice, the _____ Hemisphere is warmer. The Sun is higher in the Southern Hemisphere's late spring sky, providing more incoming solar radiation to warm surfaces and fuel evaporation.

   a. Northern
   b. Southern

5. Darker regions form two discontinuous latitude bands north and south of the equator indicate _____ humidity air. These are regions of sinking air, which suggest areas of little or no precipitation. The result is greater surface evaporation than receipt of precipitation in those areas, causing underlying ocean water to become saltier (have higher surface salinity).

   a. low
   b. high

6. When viewing the global composite water vapor imagery animation, we can often see atmospheric water vapor plumes and clouds in the tropics, embedded in the trade wind circulation, and migrating _____ in the Northern Hemisphere.

   a. eastward
   b. westward

7. Such animations also confirm that cloud and water vapor swirls in the mid-latitudes of the Northern and Southern Hemispheres migrate generally _____.

   a. eastward
   b. westward

8. The curving swirls of water vapor in the middle latitudes of the Northern and Southern Hemispheres of the animation show that atmospheric motions _____ transporting water vapor north and south as well.

   a. are
   b. are not

9. Middle latitude swirls are storm systems that transport humid warm air poleward to be replaced by colder and drier polar air moving equatorward. Storm motions transfer _____ within the Earth system.

   a. heat energy
   b. water particles and vapor
   c. heat energy, water particles, and vapor

To view the latest global composite water vapor image, click Link 1B-3. The latest global composite water vapor imagery can be animated, click Link 1B-4.

Evaporation of ocean water, a natural distillation process, is the principal source of fresh water in the global water cycle. When ocean water evaporates, dissolved salts and suspended particles are left behind. Incorporated into the air, water vapor is carried both horizontally and vertically. Rising air expands and cools, bringing about condensation (or deposition) of water vapor into tiny water droplets (or ice crystals) forming clouds, some of which produce rain or snow that falls back to Earth's surface.

Ocean water becoming saltier because of evaporation and its salinity decreasing when freshened by precipitation are major processes causing variations in the salinity of ocean water.

10. Annually, the Atlantic Ocean basin loses more water to the atmosphere by evaporation than it receives by precipitation and other sources. This causes Atlantic surface water to become saltier. At lower latitudes, there is a net flow of atmospheric water vapor evaporated from the Atlantic Ocean across Central America to the Pacific Ocean. There, rain freshens Pacific surface water and _____ salt concentration and water density. This transport mechanism, referred to as a *freshwater bridge*, enhances the thermohaline circulation of the world ocean.

    a. decreases
    b. increases

Figure 1B-3 is a NOAA satellite image portraying moisture conditions in the middle portion of the atmosphere as viewed from the U.S. GOES East satellite's water vapor channel at 1515 UTC on 8 December 2018, just two days earlier from Figure 1B-2. On this day, a large atmospheric winter storm was making its way up the east coast and would end up dumping inches of snow from Georgia and the Carolinas up through the southern parts of Virginia and West Virginia. Link 1B-5.

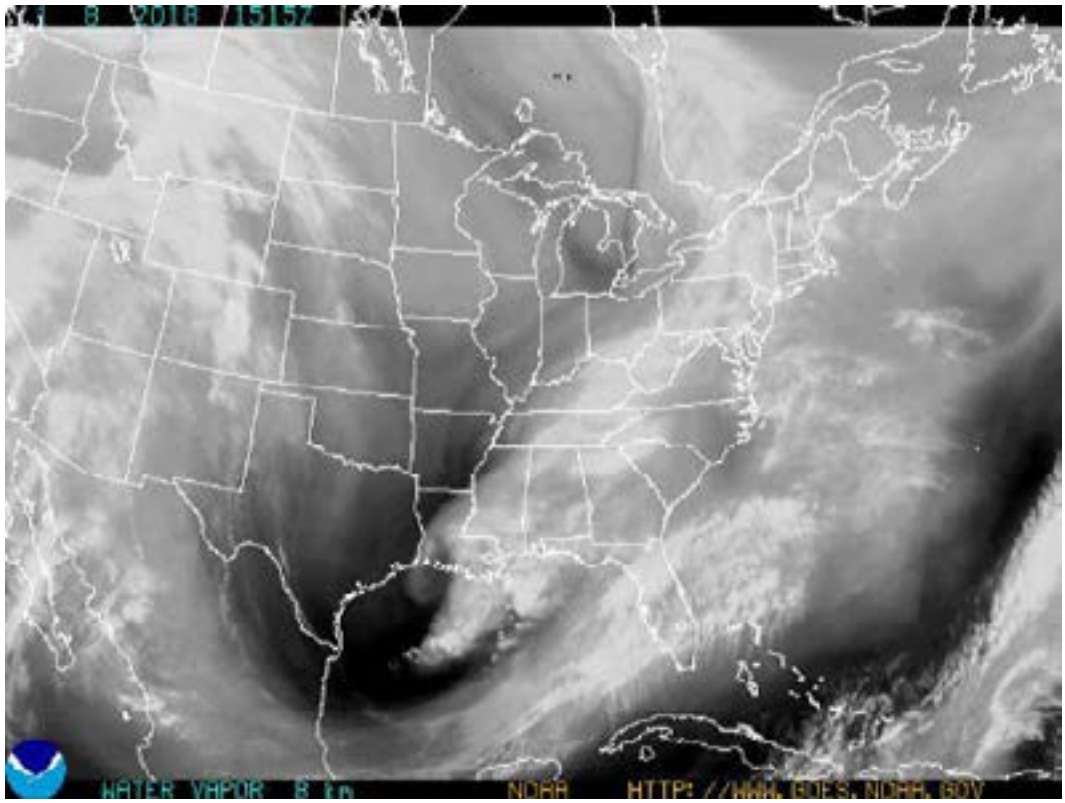

Figure 1B-3. Water vapor image at 1515 UTC 8 December 2018. [NOAA]

In Figure 1B-3, you can locate an atmospheric plume (or "river") of humid air (bright white) flowing in the Gulf of Mexico. This plume quickly made its assault on the East Coast as you can see by comparing Figures 1B-2 and 1B-3 that the storm had by December 10th, exited the East Coast and was off in the Atlantic Ocean. The plume itself actually originated along the California coast a few days earlier, as what would be named Winterstorm *Diego.* A coast to coast recap had records of 4–5 in. of rain and 1 ft. of snow in the "SoCal" higher elevation regions. Eastward progression brought 10 in. of snow in Lubbock, TX and appoximately 8 in. of rain near Houston. In northeast Arkansas it dropped 0.5 in. of freezing rain and upward of 1–3 ft. of snow in the southern Appalachians, ending with 60+ mph wind gusts on the Outer Banks. Quite the system!

11. In Figure 1B-3, the moisture plume crossing the Louisiana coasts was delivering significant quantities of water via atmospheric motions from the _____ areas. Additional vapor can be seen curving from the ocean off Mississippi and Alabama.

    a. land toward ocean
    b. ocean toward land

12. Much of the water vapor in the moisture plume condensed into clouds that produced precipitation and replenished fresh water at Earth's surface. The ultimate source of energy that lifts and transports the atmospheric water (vapor and cloud) to its highest elevations is _____.

    a. gravity
    b. solar energy
    c. Earth's rotation

13. From the time rain and snow begin to fall toward Earth's surface until the water is returned to the ocean directly or by streams and groundwater flows, _____ drives the water's movement.

    a. gravity
    b. solar energy
    c. Earth's rotation

Ocean Basins

The ocean is by far the largest reservoir in the global water cycle, containing about 97% of all water on the planet. Although the ocean is continuous, continents and other land barriers separate it into three expansive deep-water basins that extend northward from the ocean-dominated area surrounding Antarctica. This geographical confinement is among the reasons why the world ocean is divided into the Arctic, Atlantic, Indian, Pacific, and Southern Oceans.

To locate the boundaries of major ocean basins, click Link 1B-6. This U.S. Central Intelligence Agency (CIA) publication is generally recognized as the most up-to-date source of information on geographical and geopolitical information, including maps delineating major world regions.

14. In the World Factbook's Please select a country to view drop box (to the upper right), click on "Arctic Ocean." On the map that appears, the lighter blue shading for water and the white representing ice indicates the area of the Arctic Ocean. The map shows that Greenland and Iceland are _____ surrounded by the Arctic Ocean.

a. not
b. partly
c. completely

15. Below the map, click on the "Introduction" bar. The Background paragraph indicates that the Arctic Ocean is the _____ of the ocean basins in terms of surface area.

a. smallest
b. second smallest
c. middle sized
d. second largest
e. largest

16. Click on the "Geography" bar to show Terrain information. This indicates that the Arctic Ocean's central surface is covered year-round by polar ice pack that more than _____ in area between summer minimum and winter maximum. Note in the Geography section as well as on the map that the Arctic Ocean includes peripheral water bodies including Hudson Bay, Beaufort Sea, and other tributary water bodies.

a. doubles
b. triples
c. quadruples

17. Return to the Please select a country to view drop box and click on "Atlantic Ocean." Then, click on "Introduction" to confirm that the Atlantic Ocean is the _____ of the ocean basins by surface area. Straddling the equator, this ocean is divided into the North Atlantic and South Atlantic.

a. smallest
b. second smallest
c. middle sized
d. second largest
e. largest

18. Click on the "Geography" bar. According to the Area section, the Norwegian Sea and Mediterranean Sea _____ considered to be part of the Atlantic Ocean.

a. are
b. are not

19. Now visit the "Indian Ocean" via the Please select a country drop box. Click on the "Introduction" bar. The Background paragraph states that the Indian Ocean ranks as the _____ ocean basin.

a. largest
b. second largest
c. third largest
d. fourth largest

20. The map presented shows that most of the Indian Ocean is located in the _____ Hemisphere.

    a. Southern
    b. Northern

21. Next, visit the "Pacific Ocean" via the Please select a country to view drop box. Again, click on the "Introduction" bar and read the background paragraph. The Pacific Ocean ranks as the _____ ocean basin. By clicking on the "Geography" bar, it is stated in the Area-comparative section that the Pacific (North and South) covers 28% of Earth's surface, essentially equal to our planet's total land surface area.

    a. smallest
    b. second smallest
    c. second largest
    d. largest

22. Finally, visit the "Southern Ocean" via the "Please select a country to view" window. The Southern Ocean, ranging from Antarctica to 60°S latitude, ranks as the _____ largest of the five ocean basins (see the background paragraph in the "Introduction"). Note that the northern boundary of the Southern Ocean is also the southern boundaries of the Atlantic, Indian, and Pacific Oceans.

    a. first
    b. second
    c. third
    d. fourth

The Southern Ocean is not universally recognized but this course considers it as an ocean because it is a distinctly bounded body by land to the south and a well-defined current of water to the north, and has a unique ecological region. The U.S. Board on Geographic Names, the official standardizing body of geographic names for the U.S. and Federal use, adopted the name "Southern Ocean" in 1999 to describe this body of water. Its boundaries were defined by the International Hydrographic Organization in 2000 and coincides with the Antarctic Treaty Limit. NOAA and other Federal agencies comply with the decisions of the U.S. Board in the usage of the term Southern Ocean.

23. According to the "Geography" section, Terrain description, the Southern Ocean is characterized by the _____ Current, which flows ceaselessly eastward around the globe and is the world's largest ocean current.

    a. Agulhas
    b. Humboldt
    c. Weddell
    d. Antarctic Circumpolar

Summary

The ocean plays a central role in the Earth system and is the anchor of the global water cycle, including both mass and energy flows. The ocean is a reservoir for much of the energy that drives Earth's climate

system. The flow of mass and energy between the ocean and atmosphere expands the ocean's impact on weather, climate, and climate change worldwide. And, just as the ocean impacts other components of the Earth system, these other components impact the ocean.

The world ocean can be divided into five major basins, identified as the Atlantic, Pacific, Indian, Arctic, and Southern Oceans. Knowledge of their locations, expanses, and boundaries is helpful in ocean studies, particularly when interpreting conformal, equal-area, and 3-D representations of their existence.