

OCEAN IN THE GLOBAL WATER CYCLE

Objectives:

The world ocean covers almost 71% of Earth's surface to an average depth of about 3700 m (12,100 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 impacting weather and climate worldwide.
- Name and delineate the five major subdivisions of the world ocean.

The Global Water Cycle:

Figure 1 schematically illustrates the reservoirs, movements, and transformations of water in the Earth system. The figure was developed by the Global Water Cycle program element of the U.S. Global Change Research Program. [For a NASA animation of the water cycle, go to http://www.nasa.gov/mpeg/136230main_EnergyUncompNotex.mpeg.]

Figure 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 whereby it changes phase within the temperature and pressure ranges on Earth makes water the working fluid that absorbs, transports, and releases heat energy within the Earth system.

Water is the primary mover of energy in the Earth system from where there is relatively more 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, including the highest mountain peaks.

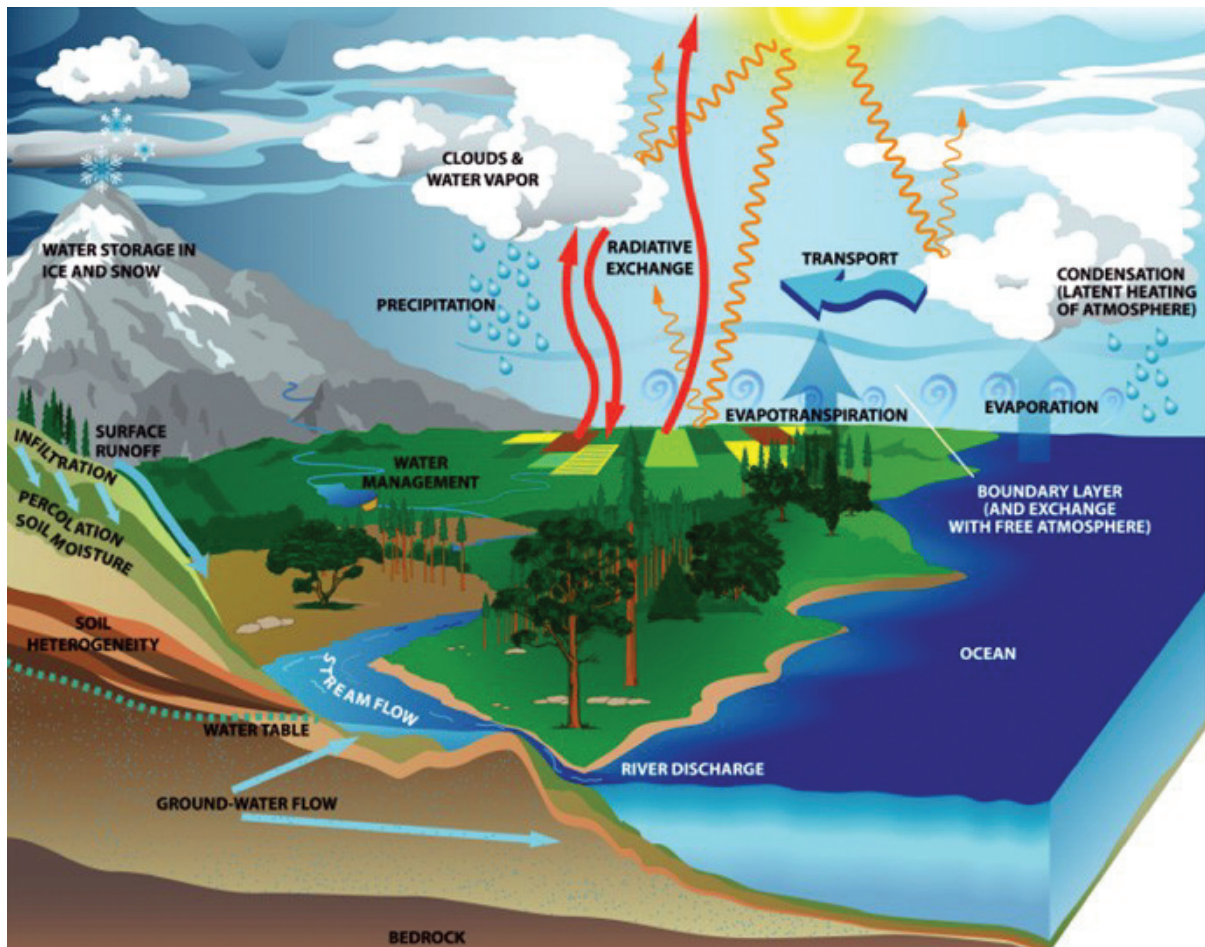


Figure 1.
Schematic conceptualization of the global water cycle. [USGCRP]

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 1 shows the ocean to the right. Water is transported to the ocean via [*(stream flow)(groundwater flow)(both processes)*].
2. Precipitation also occurs over the ocean adding fresh water directly to the ocean surface. Meanwhile, water substance is lost from the ocean as [*(precipitation)(evaporation)*]. Not shown in Figure 1 are oceanic losses by infiltration into the sediments and rocks beneath the ocean or the additions of water to the ocean via volcanic activity.

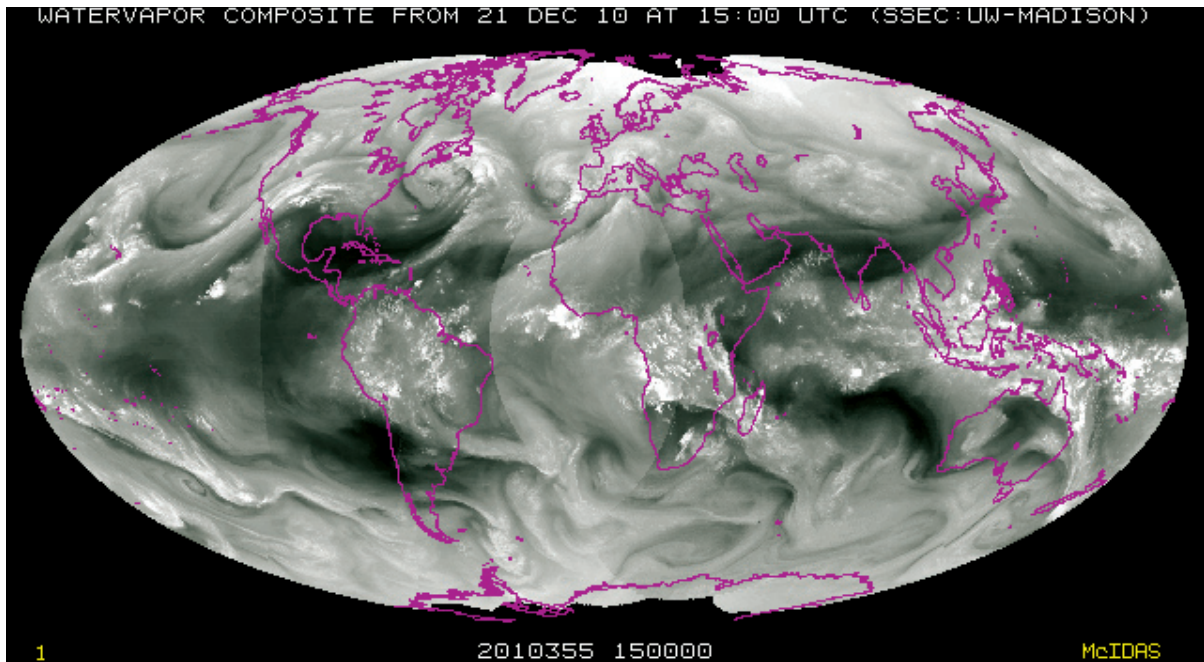


Figure 2.

Satellite image displaying the distribution of water vapor and clouds in the middle region of the atmosphere. [SSEC, University of Wisconsin – Madison]

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 21 December 2010.

Figure 2 depicts 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* (movement vertically upward) component of the water cycle which can lift water to high altitudes while moving it great distances horizontally. The rest of the cycle is the gravity-driven *downhill* journey to the ocean which begins as rain or snow. Once returned to the ocean, the seawater circulation is driven by surface winds and variations in water density resulting from differences in temperature and salinity.

- Using a straight edge and pen or colored pencil, draw a horizontal line that divides the image in half to approximate the location of the equator. The bright white cloud patches forming an irregular band roughly near 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 [(water vapor)(energy)] (water vapor and energy) is/are entering the atmosphere from the underlying surface. If we viewed a series of similar satellite images in rapid succession, we would see that atmospheric water vapor and clouds flow more or less steadily from east to west in the tropics. This flow is embedded in the trade winds of the low latitudes.

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4. Large clusters of low-latitude thunderstorm clouds mark source regions of water vapor, some of which flow to higher latitudes (shown as broad gray plumes and swirls on the satellite image). Darker regions forming two discontinuous latitude bands located north and south of the equator indicate [~~humid~~dry] air. These are regions of sinking air which suggest areas of meager precipitation. The result is net surface evaporation of ocean water causing it to become saltier (salinity increases).
5. In the image, the bright blotches in the lower latitudes mark the presence of thunderstorms and clouds resulting from intense evaporation from warm underlying water and vegetative surfaces. These areas in the image are generally located to the south of the equator. This is because in this December view, the [~~Northern~~Southern] Hemisphere is warmer. The Sun is higher in the Southern Hemisphere sky in December, providing more incoming solar radiation to warm surfaces and fuel evaporation.

To view animated global composite water vapor imagery ending with the latest composite available, go to: <http://www.ssec.wisc.edu/data/composites.html>. Scroll down to **Global Satellite Composites** and, after the **Water vapor global composite** bullet, click on either “QuickTime Movie” or “MPEG Movie”. Allow time for it to load. After it is fully loaded, click on the play button (▶). Use the control buttons to return the animation to its start position and then step through the images, being sure you are going from earlier to later time.

6. The animation shows that the cloud/water vapor band near the equator (and especially over ocean surfaces), being embedded in the trade wind circulation, generally migrates [~~eastward~~westward].
7. The animation also confirms that cloud/water vapor swirls in the mid-latitudes of the Northern and Southern Hemispheres migrate generally [~~eastward~~westward].
8. The curving swirls of water vapor in the middle latitudes of the Northern and Southern Hemisphere portions of the image imply that atmospheric motions [~~do~~do not] transport water vapor north and south as well.
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 [~~heat energy~~water mass]heat energy and water mass within the Earth system.

Evaporation of ocean water, a natural distillation process, is the principal source of fresh water in the global water cycle. When seawater evaporates, dissolved salts and suspended particles are left behind in the ocean. Incorporated into the air, water vapor is carried both horizontally and vertically by the winds. 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.

The freshening of seawater by evaporation and subsequent downwind precipitation of the fresh water is the major cause of variations in the salinity of seawater.

10. Over the period of a year, the Atlantic Ocean basin loses more water to the atmosphere by evaporation than it receives by precipitation and other sources. This water loss causes Atlantic surface water to become saltier. At lower latitudes, there is a net flow of atmospheric water vapor evaporated from the Atlantic Ocean westward across Central America to the Pacific Ocean. There, precipitation freshens Pacific surface water and thereby [~~(decreases)~~~~(increases)~~] salt concentration and water density. This transport mechanism is referred to as a *freshwater bridge*. We will see later that this atmospheric flow of water vapor enhances the thermohaline circulation of the world ocean. The thermohaline circulation contributes to the large-scale, north-south overturning of the world ocean, known as the meridional overturning circulation (MOC).

Figure 3 is a NOAA satellite image portraying moisture conditions in the middle portion of the troposphere over a Northern Hemisphere composite section centered on North America on 21 December 2010 at 1700 UTC. Depicted is a huge arc, or plume, of water vapor (milky white to bright white) flowing from the Pacific Ocean in a broad region including the Hawaiian Islands across southern California and onward. It is dubbed the “Pineapple Express” by the media or, generally, as an “atmospheric river” by scientists. The plume was delivering record-breaking rain and snowfalls over California. Another giant swirl extends northward over the western North Atlantic into Atlantic Canada and curling through New England. A sequential series of imagery ending with this view showed rotation of each swirl in a counterclockwise direction as viewed from above. The eastern swirl was the remains of a major winter storm impacting the Northeastern U.S.

11. Compare Figure 3 with Figure 2. Both are 21 December 2010 images acquired at nearly the same time. Although the scales and perspectives of the two images are quite different, their North American cloud and water vapor views [~~(are)~~~~(are not)~~] similar.
12. In Figure 3, the moisture plume flowing eastward as it was crossing the California coast was delivering water via atmospheric motions from [~~(land to ocean)~~~~(ocean to land)~~] areas.
13. The air in the Figure 3 cloud and moisture swirl over Atlantic Canada and New England entered the swirl from the east and southeast. Based on area covered and brightness, the source of the greatest part of the water vapor plume “feeding” the swirl at the time of the image probably was the [~~(Atlantic Ocean)~~~~(Gulf of Mexico)~~].
14. Much of the water vapor in the moisture plumes seen in the images condensed into clouds which produced precipitation that 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 [~~(solar energy)~~~~(gravity)~~~~(Earth’s rotation)~~].
15. From the fall of rain and snow until the water is returned to the sea by streams and groundwater flows, [~~(solar energy)~~~~(gravity)~~~~(Earth’s rotation)~~] drives the movement of the water.

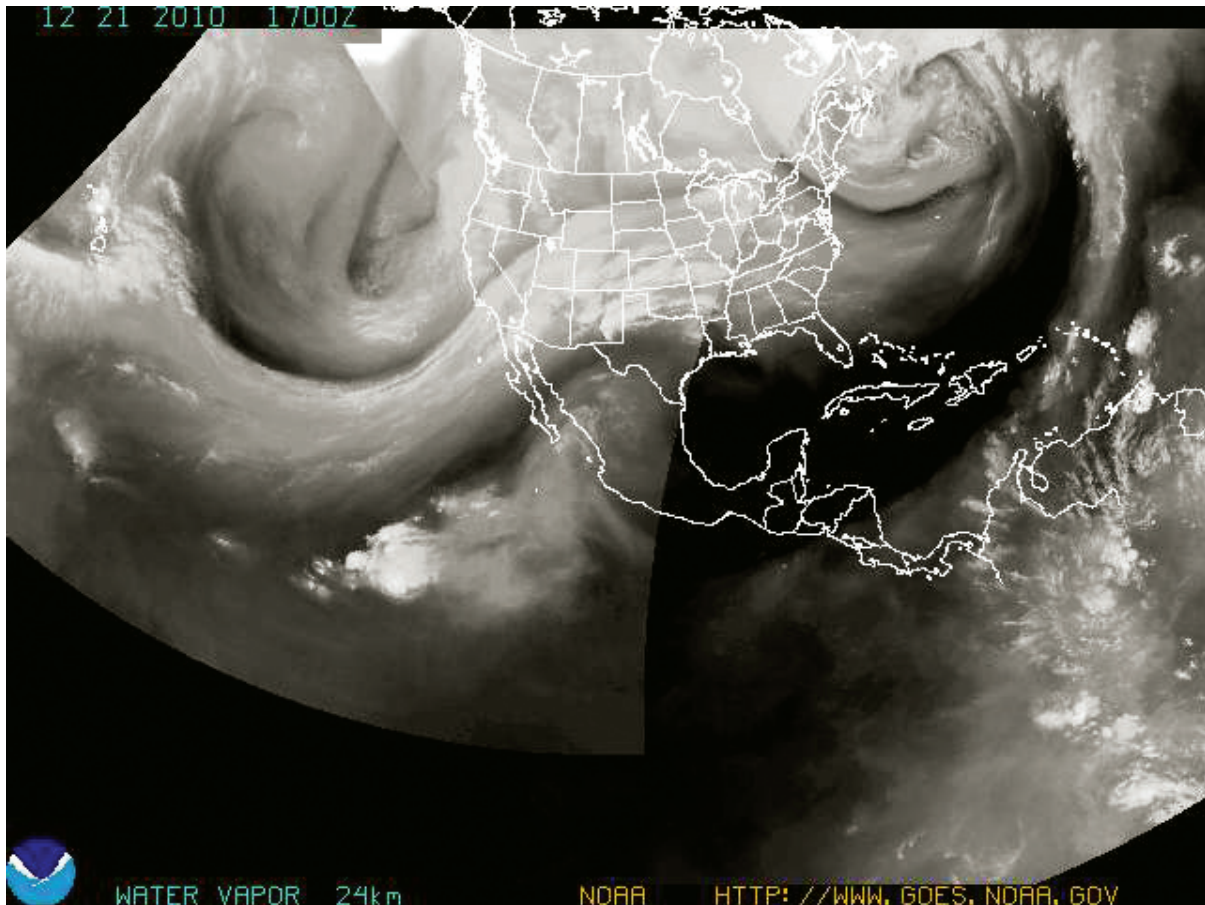


Figure 3.
Northern Hemisphere composite water vapor image at 17 UTC 21 December 2010. [NOAA]

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, go to the course website and in the “Earth System” section click on “The World Factbook”. Using your *AMS Ocean Studies* globe and a permanent marking pen, complete the following to delineate the major ocean basins.

16. In The World Factbook’s “Select a Country or Location” window (near the top), click on “Arctic Ocean”. The darker blue shading for water and the white representing ice indicates the area of the Arctic Ocean. The map shows that Greenland is [(*partly*) (*completely*)] surrounded by the Arctic Ocean.

17. Below the map, click on the “Introduction” bar. The “Background” paragraph indicates that the Arctic Ocean is the [***(smallest)(second smallest)(second largest)(largest)***] of the ocean basins in terms of surface area.
18. Click on the “Geography” bar to show “Terrain” information. This indicates that the pack ice cover of the Arctic Ocean [***(does)(does not)***] completely melt during the summer. Referring to the map, and using a permanent marker draw dashed (- - -) lines to mark the water boundaries of the Arctic Ocean on your globe.
19. Scroll up to the “Select a Country or Location” window and click on “Atlantic Ocean”. Then, click on “Introduction” to confirm that the Atlantic Ocean is the [***(smallest)(second smallest)(second largest)(largest)***] of the ocean basins in terms of surface area. Straddling the equator, this ocean is divided into the North Atlantic and South Atlantic.
20. Click on the “Geography” bar. According to the “Area” section, the Norwegian Sea and Mediterranean Sea [***(are)(are not)***] considered to be part of the Atlantic Ocean. Mark the southern water boundaries of the Atlantic Ocean (which extend to 60 degrees S latitude) on your globe by drawing dashed (- - -) lines.
21. Now visit the “Indian Ocean” via the “Select a Country or Location” window. Click on the “Introduction” bar. The Background paragraph states that the Indian Ocean ranks as the [***(smallest)(largest)(second largest)(third largest)***] ocean basin.
22. The map presented shows that most of the Indian Ocean is located in the [***(Northern)(Southern)***] Hemisphere. Mark the water boundaries of the Indian Ocean on your globe by drawing dashed (- - -) lines.
23. Next, visit the “Pacific Ocean” via the “Select a Country or Location” window. Again, click on the “Introduction” bar and read the background paragraph. The Pacific Ocean ranks as the [***(smallest)(second smallest)(second largest)(largest)***] 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, making it essentially equal to our planet’s total land surface area. Mark the water boundaries of the Pacific Ocean on your globe by drawing dashed (- - -) lines.
24. Finally, visit the “Southern Ocean” via the “Select a Country or Location” window. The Southern Ocean, ranging from Antarctica to 60 degrees S latitude, ranks as the [***(second)(third)(fourth)***] largest of the five ocean basins (see the background paragraph in the “Introduction”).

Note: 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 is a unique ecological region. The U.S. Board on Geographic Names, the official standardizing body of geographic names for the U.S.

and for 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”.

25. According to the “Geography” section, “Terrain” description, the Southern Ocean is characterized by the [(*Humboldt*)(*Weddell*)(*South Pacific*)(*Antarctic Circumpolar*)] Current, which flows ceaselessly eastward around the globe and is the world’s largest ocean current.

Surprise! You have already marked the northern boundary of the Southern Ocean if you correctly drew the southern boundaries of the Atlantic, Indian, and Pacific Oceans. With the different ocean basins clearly marked, your globe is now an even more useful reference.

Summary:

The ocean plays a central role as the anchor of the global water cycle. The global water cycle includes 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.

The world ocean can be divided into major basins which, in turn, are divided into the Atlantic, Pacific, Indian, Arctic and Southern Oceans. Locating the boundaries of these oceans on the *AMS Ocean Studies* globe helps to provide a three-dimensional conformal and equal-area representation of their existence.