Investigation 1A

Earth's Ocean

All Manual figures can be enlarged or printed by clicking on the figure.

Objectives

This course is an innovative study of the global ocean, delivering new understandings and insights into the role of the ocean in the Earth system.

After completing this investigation, you should be able to:

- Describe the importance of the ocean as part of the Earth system.
- Describe the central role of the ocean in the global water cycle.
- Interpret satellite imagery showing the atmospheric transport of clouds and water vapor originating above the ocean that impacts weather and climate worldwide.

An Earth System Approach

The Earth system consists of four major subsystems that interact in orderly ways described by natural laws. The subsystems can be defined as:

- **Atmosphere**: Free-flowing, well-mixed (below 80 km) envelope of gases at the interface of Earth and space.
- **Hydrosphere**: Includes all water, in all its forms, on, under, and over Earth's surface, from Earth's liquid water to gaseous water (water vapor). The hydrosphere includes the cryosphere, all frozen water (ice).
- **Lithosphere**: The crust of our planet and the uppermost solid mantle region.
- **Biosphere**: All of the plants, animals, and microbes within the atmosphere, hydrosphere and lithosphere.

The ocean is the largest reservoir of the hydrosphere, accounting for 97% of the water on Earth, and covers 71% of Earth's surface. In this course, we will explore how the ocean fits into the Earth system, how the subsystem interactions affect the ocean and are affected by it, how energy and materials flow through and are conserved within the ocean, and how our activities impact and are impacted by the ocean.

We employ an Earth system approach as we focus on ocean components and properties, internal and external processes involving the ocean, and the ocean's role in biogeochemical cycles (e.g., the carbon cycle). This Earth system perspective is guided and unified by the *AMS Ocean Paradigm*.

The AMS Ocean Paradigm

Earth is a complex and dynamic system with a surface that is more ocean than land. The ocean is a major component of the Earth System as it interacts physically and chemically with the other components of the hydrosphere (including the cryosphere), atmosphere, geosphere (including the lithosphere), and biosphere by exchanging, storing, and transporting matter and energy.

By far the largest reservoir of water on the planet, the ocean anchors the global hydrological cycle—the ceaseless flow of both water and energy within the Earth system. As a major component of all other biogeochemical cycles, the ocean is the final destination of water-borne and air-borne materials.

The ocean's range of physical properties and supply of essential nutrients provide a wide variety of marine habitats for a vast array of living organisms.

The ocean's great thermal capacity and inertia, radiative properties, and surface and deep-water circulations make it a primary player in Earth's climate system. Climate, inherently variable, is currently changing at unprecedented rates largely due to human actions that are altering the environment. This positions climate change as part of a complex, coupled human/natural system in which society impacts and is impacted by the ocean.

Humans rely on the ocean for food, livelihood, commerce, natural resources, security, and dispersal of waste. Humankind's intimate relationship with the sea calls for continued scientific assessment, prediction, and stewardship to achieve and maintain environmental quality and sustainability.

1. The Earth system's subsystems interact in ______ ways as described by natural laws.

   a. chaotic
   b. random
   c. orderly

2. The ocean is the largest reservoir of the ______.

   a. lithosphere
   b. hydrosphere
   c. atmosphere
   d. biosphere

3. The ocean is a main player in Earth's climate system due to its ______.

   a. surface and deep-water circulation
   b. thermal capacity and thermal inertia
   c. radiative properties

d. all of the above properties

There are many reasons to study Earth's ocean. We have crossed the ocean for ages in search of food and home but also for commerce, recreation, and security. Many of us call the coasts home. The ocean is a source of energy generation through tides, ocean currents, and offshore wind farms. We also exploit the ocean floor, establishing outposts, like oil platforms, for resource extraction as well as scientific investigations.

The Ocean within Earth's Climate System

The ocean plays an integral role in Earth's climate system. The planet has warmed over the past century (about 1°C since 1880) and the ocean is the major reservoir for the additional heat in Earth's climate system. By monitoring temperature changes and heat transport in and between the layers of the ocean, we are forewarned of the changing climate.

Figure 1A-1 shows the change in heat content since 1955 of the upper layer (0–700 m or 0–1.2 mi.) of the ocean, where most of the warming has occurred. The red line is the three-month average, the black line is the annual average, and the blue line is the five-year average. About 93% of the heat added to Earth's climate system in recent decades resides in the ocean, which has considerable implications for climate.

All figures can be enlarged by clicking on the image.

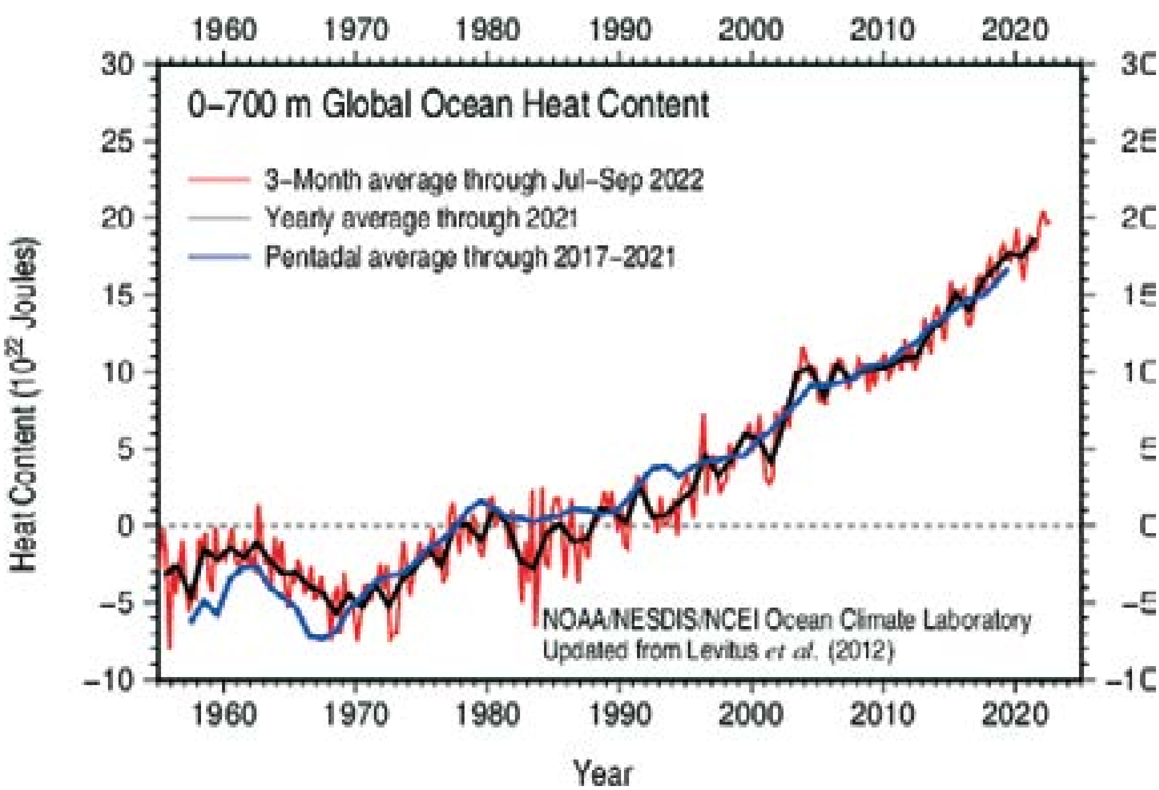

Figure 1A-1. Changes in heat content (in Joules) of the top 700 m (1.2 mi.) of the ocean from 1955 until July to September 2022 for the three-month average, 2021 for the annual average, and 2017–2021 for the five-year average. [NOAA National Oceanographic Data Center, Link 1A-1]

4. Despite some variability, the overall trend in Figure 1A-1 is a(n) ______ temperature in the top layer

of the ocean since 1965.

a. decreased
b. not changed
c. increased

The ocean also plays a key role in the global carbon cycle. At the atmosphere-ocean interface, the rising concentration of atmospheric carbon dioxide (CO_2) drives the net flux of carbon dioxide into the water. In the *Climate Change 2013: The Physical Science Basis* (AR5 WG1) report, the Intergovernmental Panel on Climate Change (IPCC) estimated that about 30% of the total atmospheric CO_2 produced by humans since the 1800s has been absorbed by the ocean.

5. The ocean's central role in Earth's climate system and climate change is evidenced by its absorption of ______.

   a. heat
   b. carbon dioxide
   c. both heat and carbon dioxide
   d. neither heat nor carbon dioxide

As the ocean absorbs carbon dioxide, the chemical state of the water changes. With more CO_2 absorbed, water pH decreases, becoming more acidic. Ocean acidification is already impacting marine ecosystems.

The Global Water Cycle

The 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 as well as terrestrial ice and snow cover, lakes, groundwater, and atmospheric moisture, Earth is truly a water planet. Central to 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.

Because water exists in all three phases, solid, liquid, and vapor, and can change between phases within the temperature and pressure ranges on Earth, it is the primary working fluid that absorbs, transports, and releases heat energy within the Earth system. It moves energy from where there is more to where there is less. **Figure 1A-2** illustrates the reservoirs, movements, and transformations of water in the Earth system. For a NASA animation of the water cycle, visit Link 1A-2.

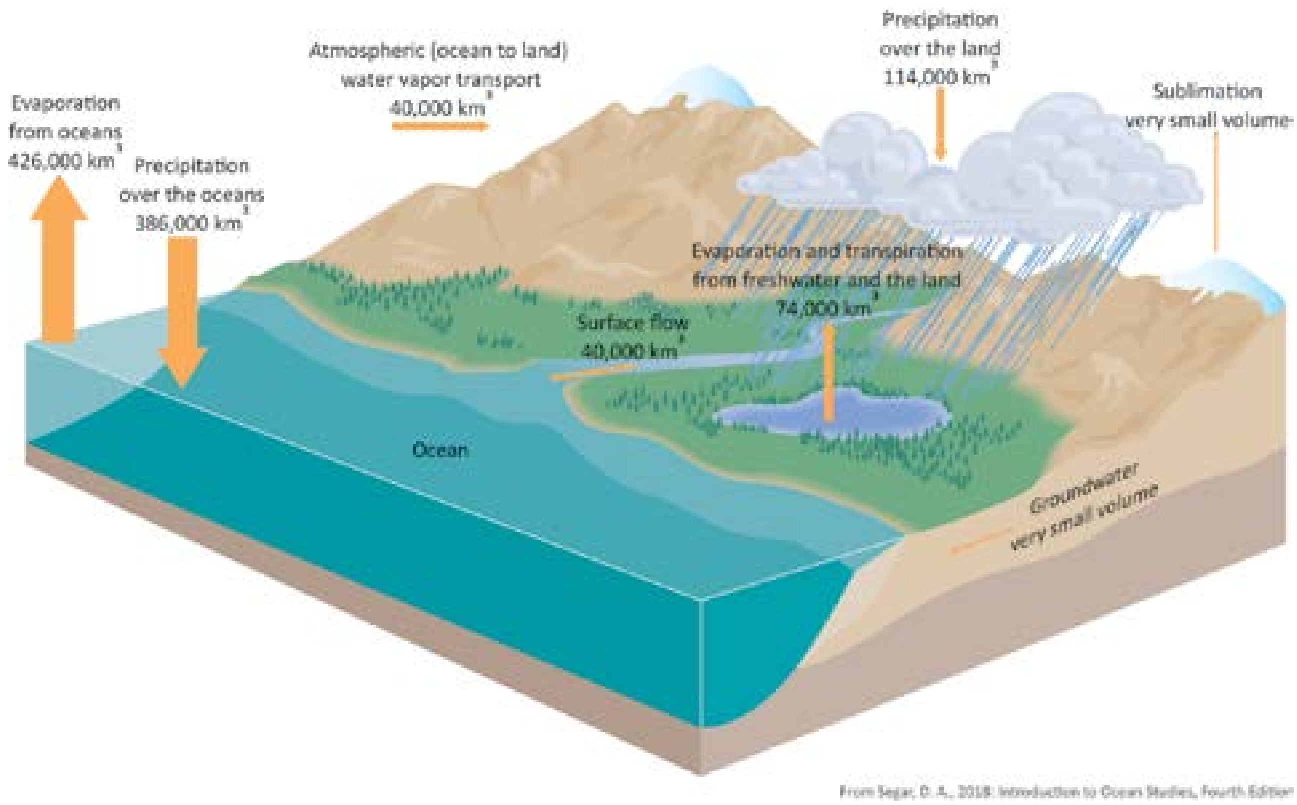

Figure 1A-2. The volumes of water moving through the global water cycle. [Segar, 2017]

Figure 1A-2 also shows how water cycles through its reservoirs, moving energy from place to place. The flow of water is in response to the nonuniform distribution of energy in the Earth system. While 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. Much of that energy is transported as heat through the global water cycle.

Winds transport water vapor and the latent heat absorbed during evaporation to every location on Earth. Changing back to a liquid or solid within the atmosphere, water begins its gravity-driven return trip as rain and snow to Earth's surface and, ultimately, to the ocean. Ocean currents also transport heat energy poleward, and the ocean is the primary source of atmospheric moisture, accounting for about 85% of all evaporation worldwide. An integral part of this course is developing an understanding of the global water cycle in terms of both mass and energy flows.

6. The view of the global water cycle in Figure 1A-2 shows the ocean to the left. Water is transported to the ocean via ______. Precipitation also occurs over the ocean, adding fresh water directly to the ocean surface.

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

7. Meanwhile, water is lost from the ocean via ______. Not shown in Figure 1A-2 are ocean losses via infiltration into the sediments and rocks beneath the ocean or the addition of water to the ocean via

volcanic activity.

a. precipitation
b. evaporation
c. surface runoff

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 becomes saltier because of evaporation and its salinity decreases when freshened by precipitation, causing variations in ocean salinity.

8. Annually, the Atlantic 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 that evaporates from the Atlantic Ocean across Central America to the Pacific Ocean. There, rain freshens the 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. increases
   b. decreases

Evidence of global-scale mass and energy flows is seen in **Figure 1A-3**, a composite of weather-satellite images capable of sensing water vapor and clouds in Earth's atmosphere. This composite image is derived from computer processing of the infrared radiation emitted by Earth's surface that interacts with water in the atmosphere. This particular image was acquired on 23 November 2022 at 9 UTC.

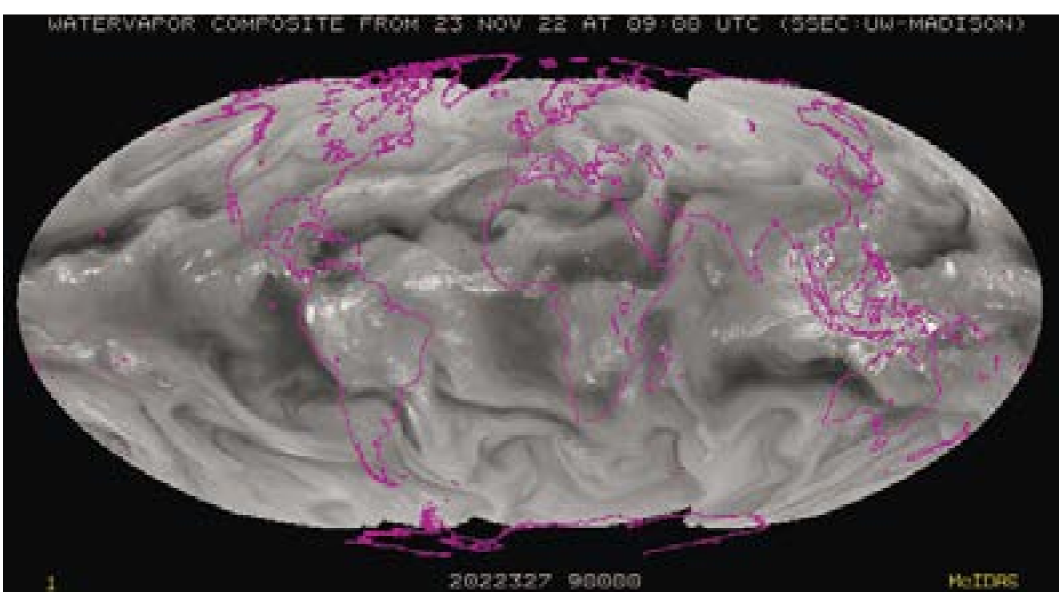

Figure 1A-3. Satellite image showing water vapor and clouds in the middle region of the atmosphere for 23 NOV 2022. [SSEC, University of Wisconsin - Madison, Link 1A-3]

In Figure 1A-3, 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 dry (low humidity) regions where air is sinking.

9. In Figure 1A-3, note the bright white cloud patches that form in an irregular band roughly near the equator. This area roughly aligns with 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

10. 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 precipitation, causing underlying ocean water to become saltier (higher surface salinity).

    a. high
    b. low

To view a sample animation of global water vapor composite imagery, click Link 1A-4. The animation puts into motion the atmospheric component of the global water cycle (and simultaneously presents the 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 water greater 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.

11. When viewing the water vapor animation, you see atmospheric water vapor plumes and clouds in the *tropics*, embedded in the trade wind circulation, and migrating ______ in the Northern Hemisphere.

    a. westward
    b. eastward

12. Also, when viewing the global composite water vapor imagery animation, you can see that cloud and water vapor swirls in the *middle latitudes* of the Northern and Southern Hemispheres migrate generally ______.

    a. westward
    b. eastward

13. 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

Mid-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 particles, and vapor within the Earth system.

To view the latest global composite water vapor image, click Link 1A-5. You can also view the latest global composite water vapor imagery animated at Link 1A-6.

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. Just as the ocean impacts other components of the Earth system, these other components impact the ocean.

Summary

The *AMS Ocean Paradigm* describes the role of the ocean as a major component of the Earth system. The ocean is an extremely valuable natural resource that provides food, transportation, minerals and energy, as well as invites commerce and recreation. It is also a primary component and driver of Earth's climate system. Its role in climate change is especially significant because of the strong absorption of heat and carbon dioxide by ocean water. The ocean also plays a central role in the Earth system and is the anchor of the global water cycle, including both mass and energy flows.

References

IPCC, 2013: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, Stocker, T. F., and Coauthors, Eds., Cambridge University Press, 1535 pp, https://www.ipcc.ch/report/ar5/wg1/.

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