Investigation 1A

EARTH’S OCEAN

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

Objectives

This course is an innovative study of the world ocean, delivering new understandings and insights into the role of the ocean in the Earth system. Collectively, the course components are directed toward helping you build your own learning progression in which webs of interconnected ideas concerning Earth’s ocean grow and deepen over time.

After completing this investigation, you should be able to:

• Describe the importance of the ocean as part of the Earth system.
• Compare flat-map and global depictions of Earth’s surface.
• Investigate the ocean as part of the Earth system via the Google Earth 3-D Viewer.

Why Study the Ocean?

There are many reasons for studying Earth’s ocean. People have traversed the ocean for millennia, many rely on it as a major food source, and it is plied for commerce, recreation, and national security. The coastal zone has always attracted human habitation. Energy generation via tides, ocean currents, and offshore wind farms have emerging potential. In the future, the ocean bottom will become a greater source of minerals and fuels. We maintain ocean outposts, such as oil platforms, for resource extraction and scientific investigations, and are now installing regional cabled ocean observatories off our coasts.

The importance of the ocean as a prime component of Earth’s climate system has become strikingly clear. This is of special significance because the environmental observational record unequivocally shows warming of the global climate over the past half-century. Whether we live along the coast or thousands of miles inland, the climate variations and more frequent extremes in weather events that we experience and hear about reveal strong ocean connections. It is through the search for the causes of these energy-driven changes and extremes that the role of the ocean as the driver of global climate comes into focus. Continuing rises in sea level impact the inhabitants of the coastal zone, and increased evaporation from a warmer ocean into a warmer atmosphere drives an enhanced hydrologic cycle.

Figure 1 shows the change in heat content from 1955 to March 2018 of the 0–2000 m (0–1.2 mi.) layer of the global ocean, where most of the warming has occurred. It is estimated that about 93% of the heat added to Earth’s climate system in recent decades resides in the ocean. The implications of this change for weather and climate are considerable, as well as other impacts, including much of the observed sea-level rise because of the expansion of ocean water as it warms. The blue line in Figure 1 shows the long-term pentadal (running 5-year) average from 1955-1960 through 2013-2017.
Figure 1. Changes in heat content (in Joules) of top 2000 m (1.2 mi.) of global ocean from 1955 to March 2018. [NOAA National Oceanographic Data Center]

1. In Figure 1, 3-month, yearly, and pentadal average curves are presented. The red line shows the 3-month average in recent years through Jan-March 2018. The black curve identifies the change in yearly averages through 2017. The overall trend of the pentadal average heat content since the late 1960s shows a generally upward trend. Although the 3-month average curve (red) shows more variability over those tri-monthly averages after about 2006, its overall trend to March 2018 is generally

a. unchanging compared to
b. opposite to
c. consistent with

The ocean also plays a key role in the global carbon cycle. In its *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$_2$ of anthropogenic origin since pre-industrial times has been absorbed by the world ocean. At the air-sea interface, the rising concentration of atmospheric CO$_2$ drives the net flux of carbon dioxide into the water.

By absorbing significant quantities of the CO$_2$ released into the atmosphere due to anthropogenic activity, the world ocean has lowered the rate at which global warming would otherwise have occurred. But this absorption is changing the chemical state of the ocean, which will also produce dire consequences, including the acidification (lowering the pH) of ocean water that already impacts marine ecosystems.
2. As described in the *Why Study the Ocean?* section above, the ocean’s central role in Earth’s climate system and climate change is evidenced by its absorption of ________.

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

**An Earth System Approach**

This course employs an Earth system perspective and is guided and unified by the *AMS Ocean Paradigm*. The Earth system consists of subsystems—hydrosphere (of which the ocean is the major component), atmosphere, geosphere, and biosphere—that interact in orderly ways, described by natural laws. In this course, we will explore subsystem interactions, the flow and conversion of energy and materials, and how human activity impacts and is impacted by the ocean.

**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, cryosphere, atmosphere, geosphere, 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.
3. Components of the Earth system (e.g., hydrosphere, geosphere) interact in ________ ways as described by natural laws.
   a. chaotic
   b. orderly
   c. random

4. The ocean is a ________ component of biogeochemical cycles (e.g., the water cycle) operating as part of the Earth system.
   a. insignificant
   b. minor
   c. major

5. The ocean has ________ influence on Earth’s weather and climate.
   a. no observable
   b. very little
   c. a major

Exploring Locations on Earth

Exploring the ocean in the Earth system relies on various methods for displaying scientific information, including map projections.

Map projections (two-dimensional representations) printed on flat sheets of paper or viewed on screens are common and convenient ways to portray features of Earth’s surface. But, like all graphical models, maps have their limitations. Over great distances, flat maps do not faithfully represent Earth’s surface because our planet is not flat.

Maps covering major portions of Earth’s surface are typically constructed for either conformality, where all small features on Earth’s surface retain their original shapes on the map, or to preserve equal areas, that is, map portions of the same size everywhere on the map represent equal areas. Flat maps cannot be both conformal and equal-area at the same time. For a detailed discussion of map projections, click [Link 1A-1](#).

Global-scale map projections exhibit considerable distortion because the entire surface of the planet, which is essentially a sphere, is projected onto a flat surface. Nonetheless, such depictions can be extremely useful—although the user should be aware of their strengths and limitations. Conformal maps are often adequate for depicting the configuration of some property. Figure 2 is an example of a conformal map. It is a Mercator-type conformal projection that maintains the shapes of small regions and has lines of latitude and longitude forming a rectangular grid. Its major strength is that it preserves angles, so any straight line drawn on a Mercator map is a line of constant bearing (same direction). This attribute is of immense significance in ocean navigation.
6. Figure 2 is a Mercator flat map. An important property of such conformal maps is that lines of latitude and longitude are ________.

a. curved  
b. straight and perpendicular to each other  
c. circular

7. Because distortion increases away from the equator, the map in Figure 2 shows another common feature of Mercator projections, that is, the distance between adjacent lines of latitude ________ as latitude increases from the equator toward the poles.

a. decreases  
b. remains the same  
c. increases

**Figure 2.** Sample Conformal Map. [Used with permission of the author, Peter H. Dana, The Geographer’s Craft Project, Department of Geography, The University of Colorado at Boulder, © 1999 Peter H. Dana]

**Equal-area maps** maintain a constant scale of areas. **Figure 3** is one type of equal-area world map. Equal-area maps are limited by the curvature of longitude and/or latitude lines that distorts shapes.
8. Figure 3 is an equal-area projection. Compare the apparent sizes of Greenland and South America in Figures 2 and 3. The Figure 2 Mercator map depiction suggests that they are about the same size whereas on the Figure 3 equal-area map, it is clear that Greenland is ________ South America.

a. much smaller than
b. about the same size as
c. much larger than

Adding the Third Dimension - A Global View

While flat maps are essential and useful tools in ocean studies, the true relations of properties and locations can only be displayed on a map that approximates the real shape of our very nearly spherical planet — a globe. A globe is both conformal and equal area in its representation of Earth’s surface and its features, thereby eliminating the distortions introduced by flat map projections. It also provides an authentic representation of spatial relationships in three dimensions. This 3-D attribute is particularly useful in making models relating Earth to the Sun and the Moon, investigating the effects of Earth’s rotation, and exploring the impacts of external forcings (radiational and gravitational) on the Earth system.

Physical globes are not without their limitations, however. Globes display features with relatively little detail. No more than half of a globe’s surface can be viewed at the same time. Fortunately, computers enable users to visualize global views in a 3-D perspective. In addition, these visualizations are often designed to zoom seamlessly between expansive global views and detailed local depictions.
In this course, we utilize both flat maps and global perspectives to investigate the world ocean and coastal areas. We employ *Google Earth* imagery to emulate the physical aspects of globes, including 3-D visual perspectives, as seen in **Figure 4**.

**Figure 4.** Sample *Google Earth* 3-D viewer image demonstrating a field of view. [Google Earth]

9. Note the positions of Greenland and South America in Figure 4 as seen via the *Google Earth* 3-D Viewer. Appearing as though viewed on an actual globe, the depictions of these locations can be assumed to be ________.

   a. equal-area  
   b. conformal  
   c. neither conformal nor equal area  
   d. both conformal and equal area
10. As seen in the Google Earth view, Greenland is ________ South America. This is consistent with the depictions on the Figure 3 equal-area map.

   a. much smaller than  
   b. about the same size as  
   c. much larger than  

**Earth Rotation**

In addition to enabling the user to manipulate the Earth view in terms of size, resolution, and perspective, 3-D viewers often enable animation capabilities. Especially important for the Earth system sciences, is the ability to observe Earth’s rotation in 3-D visualizations. Here, we will examine how Earth’s rotation impacts the sense of motion at different Earth latitudes as portrayed via ESRI ArcGlobe 3-D visualization animations.

**Viewing Earth’s Continuous Rotation From Space**

To view Earth as seen from high above the equator, the North Pole, or the South Pole, click [Link 1A-2](#).

The video begins with the viewer (you) being positioned high above Earth’s equator. You are at an altitude of about 32,000 km (20,000 mi.), high enough so you can see about 40% of the rotating Earth’s total surface area. At the start, you are positioned so the point directly beneath you is on the white line that represents the equator. The other white lines appearing on the globe at the start of the video are the Tropic of Cancer at 23.5°N and the Tropic of Capricorn at 23.5°S. Later, you will also be able to see the Arctic Circle (67.5°N) and the Antarctic Circle (67.5°S). You can start, stop, and re-start the video by using the control panel that appears on the screen when you scroll over the video.

11. From your position above the equator, you see that Earth’s rotation is causing objects attached to Earth at the equator to be moving towards the east ________.

   a. in a straight line  
   b. while curving to the right  
   c. while curving to the left  

After observing the Earth from above the equator, the video will maneuver your viewing position until you are directly above the North Pole. From this vantage point, you can see the Arctic Circle represented by a concentric circle with the North Pole at its center.

12. As viewed from above the North Pole, all points on Earth’s surface (except directly at the North Pole) are following a ________ path as Earth rotates.

   a. circular  
   b. straight  

13. The sense of Earth’s rotation as seen from this vantage point is ________ around the North Pole as seen from above.

   a. counterclockwise  
   b. clockwise
The video will then maneuver your viewing position southward, passing over the equator to finally arrive at a point directly above the South Pole. The South Pole is positioned in the center of the circle representing the Antarctic Circle shown in yellow.

14. As viewed from above the South Pole, all points on Earth’s surface (except directly at the pole) show ________ motion due to Earth’s rotation.

   a. circular
   b. straight

15. The sense of Earth’s rotation from this vantage point is ________.

   a. counterclockwise
   b. clockwise

As your ocean study proceeds, you will learn that Earth’s rotation has an immense impact on the circulation of the ocean (and the overlying atmosphere).

**Summary**

There are many reasons for studying Earth’s ocean. The *AMS Ocean Paradigm* describes the role of the ocean as a major component of the Earth System. The world ocean is an extremely valuable natural resource that provides food, is used for transportation and commerce, invites recreational use, and is a source of minerals and energy. It is 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 in ocean water. This is the result of increased concentrations of atmospheric carbon dioxide due to the burning of fossil fuels.

Exploring the ocean relies on various methods for displaying scientific information, including the use of flat-map and global map projections. *Google Earth* 3-D depictions have the added value of providing authentic representations of spatial relationships in three dimensions while enabling us to seamlessly zoom between nearly hemispherical to local scale views.

Earth’s rotation appears quite different when seen from different vantage points. Viewed from high above the equator, fixed locations on Earth’s surface are seen to move eastward, with those on the equator moving along straight paths. Seen from above the North Pole, Earth surface locations move counterclockwise in concentric circles about the planet’s rotational axis. Viewed from above the South Pole, the sense of Earth’s rotation is clockwise.

Optional: This and other investigations in this course employ imagery and data acquired via the *Google Earth* 3-D Viewer. It is strongly recommended that you become a direct user of *Google Earth* via its *Google Earth Pro* version as it is a powerful solution for treating many forms of geospatial data. *Google Earth* software is available for use, free of charge, on most computer systems. *Google Earth Pro* is designed for use on desktop systems.

To acquire *Google Earth* software, click [Link 1A-3](#). Click on the “EARTH PRO ON DESKTOP” in the top menu line towards the upper right. On the new page that appears, click on “DOWNLOAD,” and proceed with installation as directed. When your installation is complete, a 3-D view of Earth will appear on your screen. [It is recommended that, if no coordinate system gridding is on the image you see, search your menu bar for this option. For PC platform users, click on “View” in the uppermost menu bar and click on “Grid”.]
The 3-D *Google Earth* image can be easily manipulated. Once the Earth image appears on the screen, navigation controls will appear when you move your cursor to the upper right of the 3-D viewer (or other navigation means will be displayed, particularly on tablet platforms). On devices where the navigation controls appear, the size of the Earth image can be changed by adjusting the vertical slider. Adjust the slider until the Earth image has a diameter about half the width of the 3-D viewer. You can turn the image by dragging your cursor across the screen, by using the keyboard arrows, or adjusting the other navigation tools at the upper right. Among useful keyboard controls is to press the “N” key so the longitude line passing through the center of the image aligns vertically with north towards the top of the image.