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 of interconnected ideas concerning Earth's ocean that 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 imagery from *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 1A-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 1A-1 shows the long-term pentadal (running 5-year) average from l955–1960 through 2013–2017.

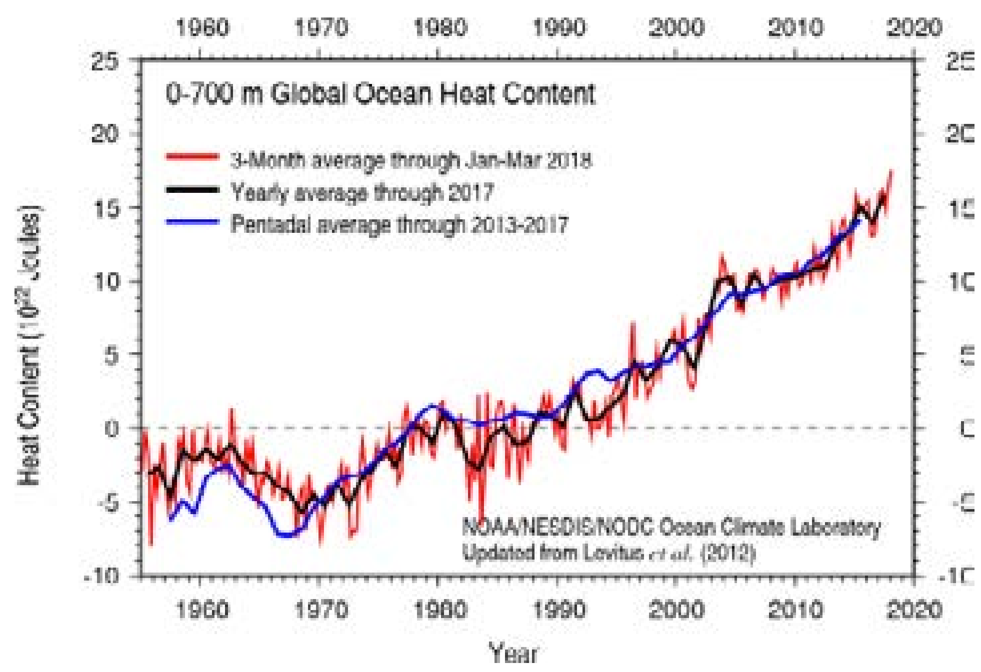

Figure 1A-1. Changes in heat content (in Joules) of top 2000 m (1.2 mi.) of global ocean from 1955 to March 2018. [NOAA National Oceanographic Data Center]

1. In Figure 1A-1, 3-month, yearly, and pentadal average curves are presented. The red line shows the 3-month average in recent years through January to 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 an 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 ______ the pentadal trend.

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

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 atmosphere-ocean 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 and has already impacted 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, the 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 ocean 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. orderely
   b. chaotic
   c. random

4. The ocean is a ______ component of biogeochemical cycles (e.g., the water cycle) operating as part

of the Earth system.

a. major
b. minor
c. insignificant

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**, 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 on 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 1A-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.

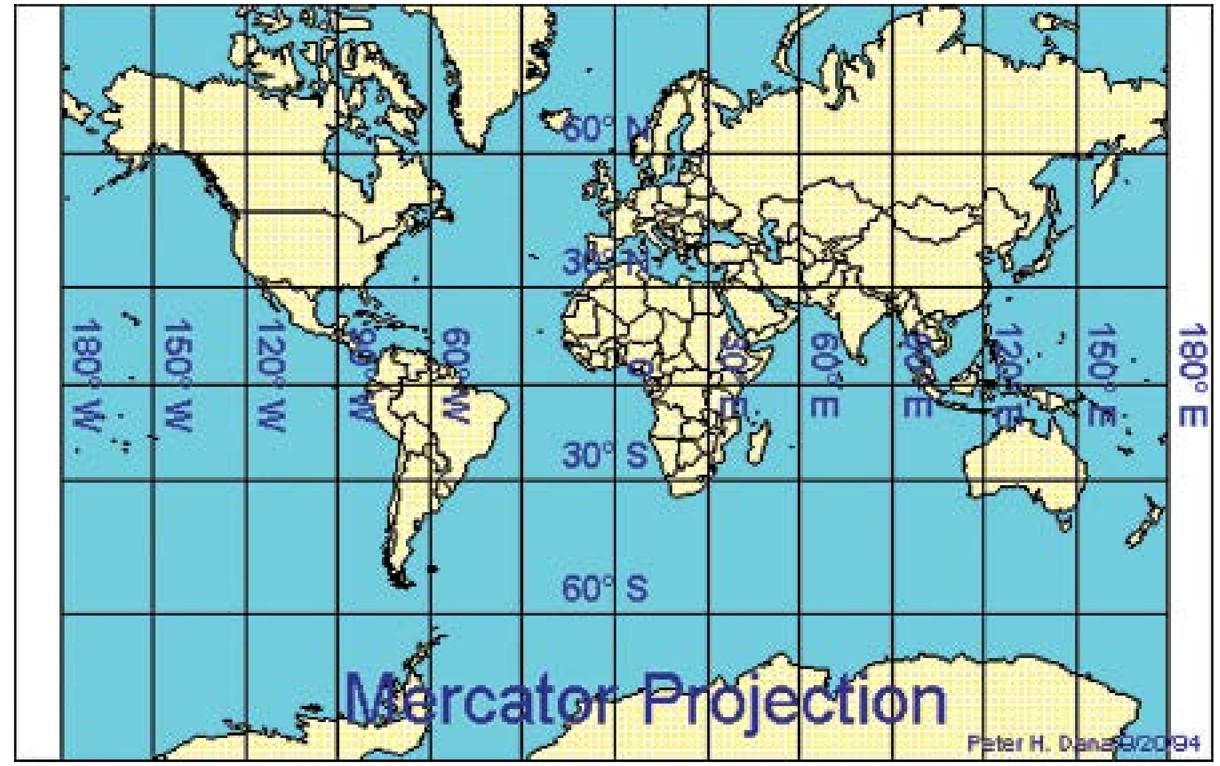

Figure 1A-2. Sample Conformal Map. [Used with permission of the author, Peter H. Dana, The Geographer's Craft Project, Department of Geography, The University of Colorado at Boulder, © 1999 Peter H. Dana]

6. Figure 1A-2 is a Mercator flat map. An important property of such conformal maps is that lines of latitude and longitude are ______.

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

7. Because distortion increases away from the equator, the map in Figure 1A-2 shows another common feature of Mercator projections. The distance between adjacent lines of latitude ______ as latitude increases from the equator toward the poles.

a. increases
b. decreases
c. remains the same

Equal-area maps maintain a constant scale of areas. **Figure 1A-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.

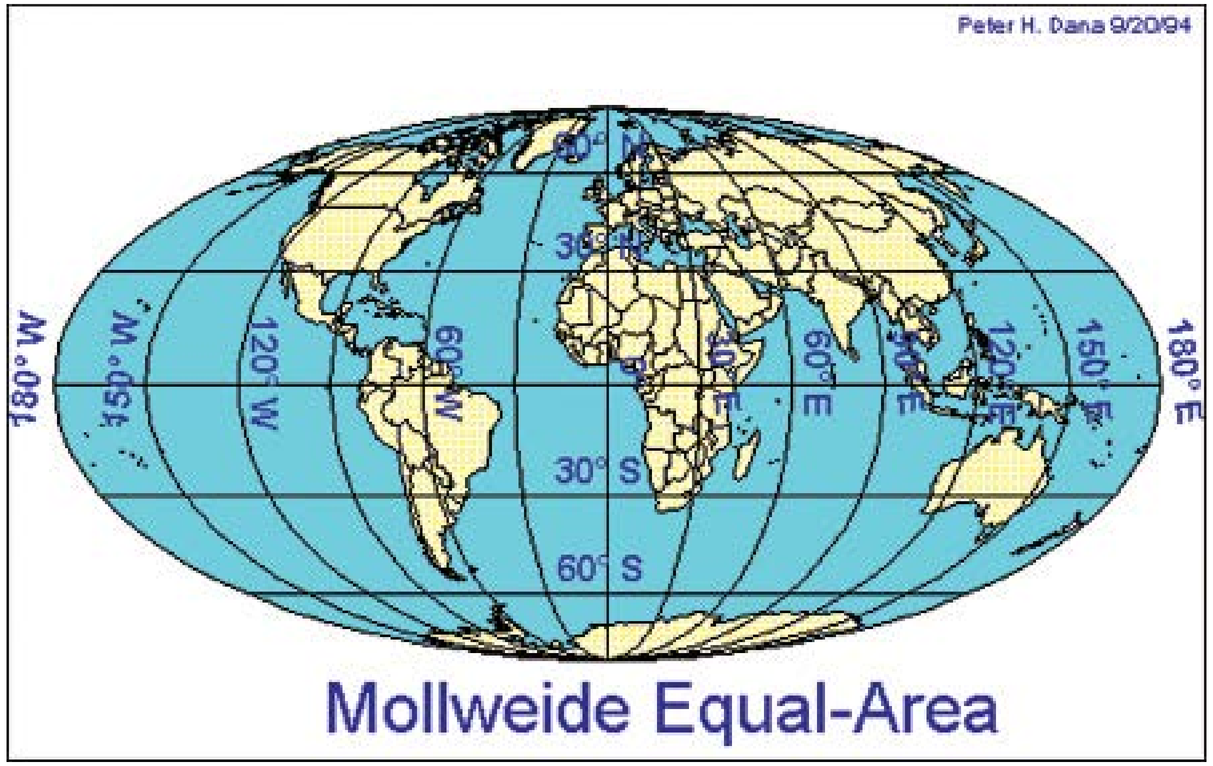

Figure 1A-3. Sample Equal-Area Map. [Used with permission of the author, Peter H. Dana, The Geographer's Craft Project, Department of Geography, The University of Colorado at Boulder, © 1999 Peter H. Dana]

8. Figure 1A-3 is an equal-area map. Compare the apparent sizes of Greenland and South America in Figures 1A-2 and 1A-3. The Figure 1A-2 Mercator map depiction suggests that they are about the same size whereas on the Figure 1A-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, 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, and they are difficult to carry with you. 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 1A-4**.

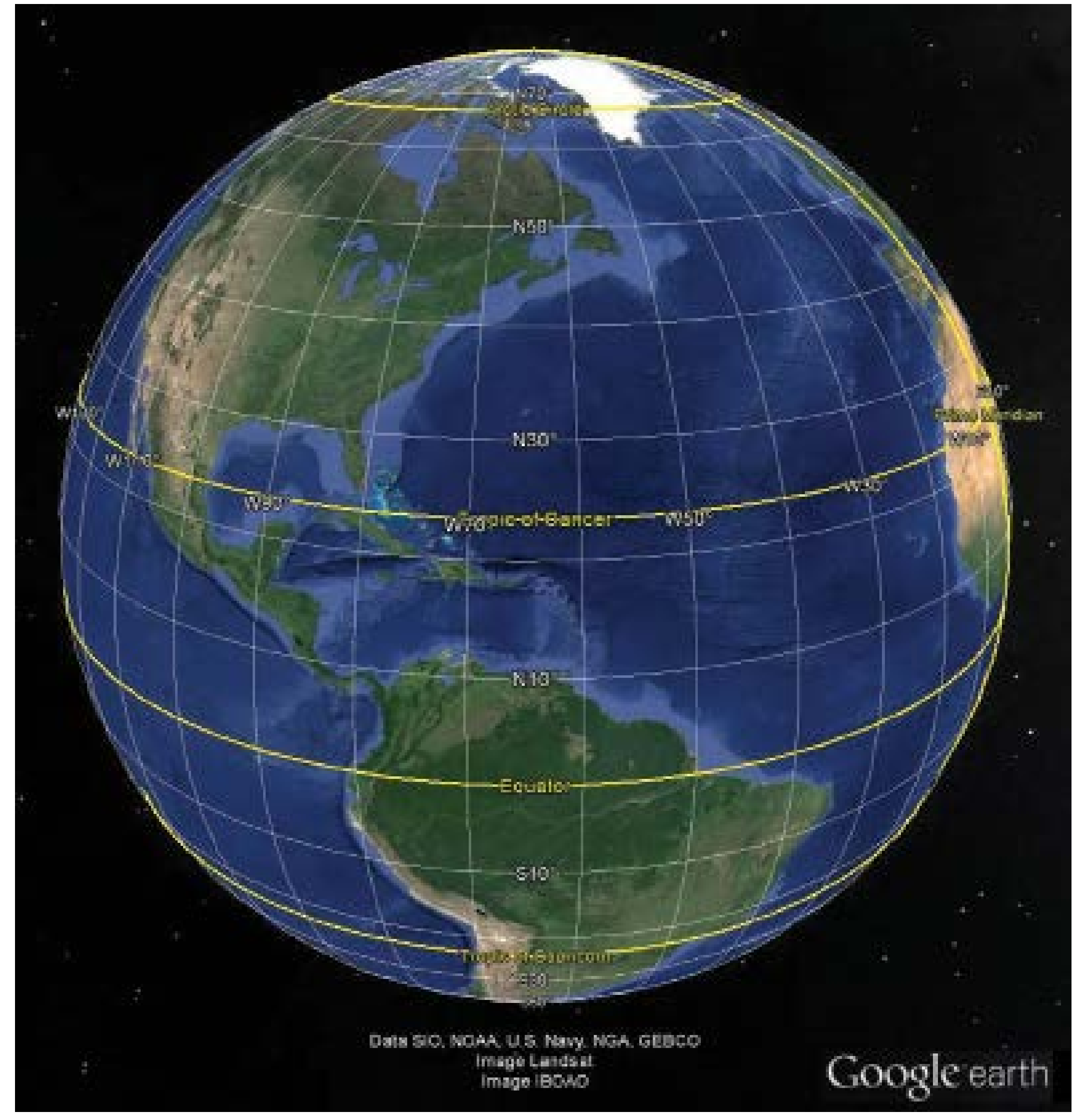

Figure 1A-4. Sample *Google Earth* 3-D viewer image demonstrating a field of view. [Google Earth]

Optional: Follow *Google Earth* on your desktop via Link 1A-2, and click *Launch Earth*. 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 with navigation controls, the size of Earth can be changed by adjusting the vertical slider. Adjust the slider until Earth 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.

9. Note the positions of Greenland and South America in Figure 1A-4. Appearing as though viewed on an actual globe, the depictions of these locations can be assumed to be ______.

   a. equal-area
   b. conformal
   c. both conformal and equal area
   d. neither conformal nor equal area

10. As seen in the *Google Earth* view, Greenland is ______ South America. This is consistent with the depictions on the Figure 1A-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. 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-3.

The video positions you high above Earth's equator at an altitude of about 32,000 km (20,000 mi.), high enough to 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 move towardsthe east ______.

   a. while curving to the right
   b. in a straight line
   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. lockwise
   b. counterclockwise

The video then maneuvera your viewing position southward, passing over the equator until you 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. clockwise
   b. counterclockwise

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.