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NOAA National Ocean Service Education: Motion in the Ocean

Ocean Currents and Waves / Grades 9-12 / Physical Science, Earth Science

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Focus Question

What causes ocean currents and waves?

Learning Objectives

- Students will identify the primary causes for ocean currents and waves.
- Students will explain how and why ocean currents vary with increasing latitude.
- Students will explain the cause of the Coriolis effect, and how this effect influences ocean currents.
- Students will calculate the magnitude of ocean currents, given data from drifter studies.

Links to Overview Essays and Resources Useful for Student Research

- http://oceanservice.noaa.gov/education/tutorial_currents/ - Tutorial on tidal, coastal, and ocean currents.
- http://oceanservice.noaa.gov/topics/navops/ports/ - Introductory essay and links on NOAA's efforts in monitoring tides and currents.

Materials

- Copies of "Problems on Winds, Waves, and Currents" worksheet, one copy for each student or student group. Click here for a printable copy of the worksheet.
- Copies of the Currents Subject Review. Click here for a printable copy of the Subject Review.
- (Optional) Computers with Internet access; if students do not have access to the internet, download copies of materials cited under "Learning Procedure" and provide copies of these materials to each student or student group

Audio/Visual Materials

None

Teaching Time

One 45-minute class period, plus time for student research

Seating Arrangement

Classroom style or groups of 3-4 students

Maximum Number of Students

30

Key Words

Ocean current
Ocean wave
Coriolis effect

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Background Information

More than 98% of cargo shipped to and from the United States is transported by water. In addition to accurate information on the geography of coastal areas, safe and efficient navigation of coastal waters requires up-to-the minute information on weather and sea conditions. Since these conditions can vary significantly from place to place and can change dramatically in a short period of time, mariners need accurate real-time information to avoid groundings and collisions. NOAA’s Center for Operational Oceanographic Products and Services (CO-OPS) collects and distributes oceanographic observations and predictions to ensure safe, efficient and environmentally sound maritime transportation. The Center:

- provides information on water levels, coastal currents, and tides;
- establishes standards for collecting and processing these data;
- conducts research into new or improved oceanographic observing systems;
- designs software to improve data processing capabilities;
- performs regular data analysis and quality control of data; and
- disseminates this information to the public.

CO-OPS also manages a national network of Physical Oceanographic Real-Time Systems (PORTS®) located in major U.S. harbors. The PORTS® network provides real-time information such as water levels, currents, air gap (the clearance between the water surface and the bottom of a bridge), weather data, and other oceanographic information to help mariners avoid groundings and collisions. Visit http://tidesandcurrents.noaa.gov/products for more information on CO-OPS, PORTS®, other CO-OPS programs and their data products.

While CO-OPS deals mostly with currents along the coast and inside estuaries, other NOAA Program Offices are involved with measuring and understanding currents and circulation patterns in the open ocean. NOAA's National Oceanographic Data Center (NODC) compiles information from the latest ocean current measurement programs that use current meters and drifters. Through the NODC Web site (http://www.nodc.noaa.gov/General/getdata.html*)*, you can access a variety of data sets containing information on currents and other oceanographic measurements, such as beach temperatures, coastal buoy data, global temperature and salinity data, and photograph collections. For global current data obtained through satellite remote sensing systems visit NOAA's Ocean Surface Current Analyses - Real Time Web site at http://www.oscar.noaa.gov/.

In this lesson, students will explore the relationships between currents, winds, and ocean waves.

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Learning Procedure

1. To prepare for this lesson, review:

- Introductory information on tides and currents at http://oceanservice.noaa.gov/topics/navops/ports/ and http://oceanservice.noaa.gov/education/tutorial_currents/;
- The Currents Subject Review (Click here for a printable copy of the Subject Review), and
- The "Problems on Winds, Waves, and Currents" worksheet (Click here for a printable copy of the worksheet).
- You may also want to review the "Tides and Water Levels" tutorial (http://oceanservice.noaa.gov/education/kits/tides/), which offers a tutorial on the complex systems that govern the movement of tides and water levels, a "Roadmap to Resources" that directs you to specific tidal and current data, and lesson plans for students in grades 9–12.

2. Ask students to comment on the present-day importance of marine navigation. Students should realize that despite the prevalence of air travel and advances in aerospace technology, Earth's oceans are still vital to freight transportation, energy production, and recreation. Discuss the importance of real-time information for safe navigation, and have students brainstorm the types of information that would be useful to a present-day mariner. Tell students that their assignment is to learn some basic facts about "ocean motion," and use this information to solve problems dealing with winds, ocean waves, and currents.
3. If they have not already done so, have students complete the Currents Subject Review. If you choose to have students work in groups, you may want to assign different tutorial sections to each student. Have each student or student group answer questions in the

Currents Subject Review. If students will not have access to the internet, makes enough copies of the Currents Tutorial for each student or student group. To save class time, you may want to assign this portion of the lesson as homework. Lead a discussion of students' answers to the questions, highlighting ways in which knowledge of tides can be useful and important.

4. Provide a copy of the "Problems on Winds, Waves, and Currents" worksheet to each student or student group, and have students answer worksheet questions.
5. Lead a discussion of students' answers to worksheet questions. Be sure students understand the relationship between winds, ocean waves, and currents.

The correct answers are:

1. 3 feet
2. Increasing the wind speed by 60 knots would increase the wave height to approximately 12 feet, while increasing the fetch length by 60 nautical miles (nm) would increase the wave height to less than 6 feet.
3. A 60 knot wind would have to blow over a fetch of about 9 miles to produce a wave 10 feet high.
4. The distance between the points is 524.6 nautical miles. The total time elapsed is 6 days, 10.25 hours = 154.25 hours. So the estimated current speed is:
   524.6 nm ÷ 154.25 hr = 3.40 nm/hr = 3.40 knots
   The estimated direction of the current is northeast.
5. The distance between the points is 1,443.68 kilometers = 1.444 x 108 centimeters. The total time elapsed is 14 days, 2.92 hours = 338.92 hours = 1.220 x 106 seconds. So the estimated current speed is
   1.444 x 108 cm ÷ 1.220 x 106 sec = 118.4 cm/sec
   The estimated direction of the current is slightly east of due south.
6. Since the latitude at the equator is zero, the formula for Coriolis acceleration suggests that the magnitude of this acceleration at the equator is zero.
7. The latitude of Tijuana is about 32.5° N. A velocity of 10 meters/second is equal to 1,000 centimeters/second. So, the magnitude of the Coriolis acceleration is
   (sin 32.5° • 1.5 x 10-4 • 1,000) cm/sec2
   = 0.537 • 1.5 x 10-4 • 1,000 = 0.081 cm/sec2
   The effect is very small.
8. Even though the effect of Coriolis acceleration on soccer balls, walking humans, etc. is practically negligible, when it acts on very large masses over very long distances, the acceleration becomes significant.

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The Bridge Connection

The Bridge is a growing collection online marine education resources. It provides educators with a convenient source of useful information on global, national, and regional marine science topics. Educators and scientists review sites selected for the Bridge to insure that they are accurate and current.

www.vims.edu/bridge - In the “Site Navigation” menu on the left, click on “Ocean Science Topics,” then “Physics,” then one of the headings at the top of the page for links and resources about tides, waves, and currents.

The “Me” Connection

Have students write a short essay on how the Coriolis force affects them personally, even though it only is significant at very large scales.

Extensions

1. Visit the “Tides and Water Levels” Discovery Kit (http://oceanservice.noaa.gov/education/kits/tides/) for additional resources and lesson plans.
2. Visit http://www.usm.maine.edu/maps/lessons/nr10.htm and http://www.usm.maine.edu/maps/lessons/nr11.htm for additional lesson plans and activities about currents from the University of Southern Maine’s Osher Map Library.
3. Visit Multimedia Learning Objects at http://www.learningdemo.com/noaa/. Click on the links to Lessons 8 and 9 for interactive multimedia presentations and Learning Activities on Ocean Currents and Ocean Waves, including an activity involving landing safely on an aircraft carrier by allowing for the Coriolis Effect.

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Resources

http://oceanexplorer.noaa.gov/explorations/03edge/background/edu/media/coriolis.pdf – Lesson on the Coriolis force from NOAA’s Ocean Explorer program, including “the Dishpan Analogy” explanation for this effect.

http://oceanservice.noaa.gov/education/tutorial_currents/ - Tutorial on tidal, coastal, and ocean currents.

http://oceanservice.noaa.gov/education/tutorial_tides/ – NOAA’s “Tides and Water Levels” Tutorial.

http://tidesandcurrents.noaa.gov – NOAA’s Center for Operational Oceanographic Products and Services (CO-OPS) Web page, with links to data and information about tides, water levels, currents, predictions, weather observations, forecasts, and harmonic constituents.

http://www.usm.maine.edu/maps/lessons/nr10.htm and http://www.usm.maine.edu/maps/lessons/nr11.htm – Lesson plans and activities about currents from the University of Southern Maine’s Osher Map Library.

http://www.eeb.ucla.edu/test/faculty/nezlin/PhysicalOceanography.htm — Online tutorial with additional details about ocean currents

National Science Education Standards

Content Standard A: Science as Inquiry

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Content Standard B: Physical Science

- Motions and forces

Content Standard D: Earth and Space Science

- Energy in the earth system

Content Standard E: Science and Technology

- Abilities of technological design
- Understandings about science and technology

Content Standard F: Science in Personal and Social Perspectives

- Natural resources
- Environmental quality
- Natural and human-induced hazards
- Science and technology in local, national, and global challenges

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Ocean Literacy Essential Principles and Fundamental Concepts

Essential Principle 1. The Earth has one big ocean with many features.

- Fundamental Concept c. Throughout the ocean there is one interconnected circulation system powered by wind, tides, the force of the Earth's rotation (Coriolis effect), the Sun, and water density differences. The shape of ocean basins and adjacent land masses influence the path of circulation.

Essential Principle 3. The ocean is a major influence on weather and climate.

- Fundamental Concept a. The ocean controls weather and climate by dominating the Earth’s energy, water and carbon systems.
- Fundamental Concept b. The ocean absorbs much of the solar radiation reaching Earth. The ocean loses heat by evaporation. This heat loss drives atmospheric circulation when, after it is released into the atmosphere as water vapor, it condenses and forms rain. Condensation of water evaporated from warm seas provides the energy for hurricanes and cyclones.
- Fundamental Concept c. The El Niño Southern Oscillation causes important changes in global weather patterns because it changes the way heat is released to the atmosphere in the Pacific.
- Fundamental Concept g. Changes in the ocean’s circulation have produced large, abrupt changes in climate during the last 50,000 years.

Essential Principle 7. The ocean is largely unexplored.

- Fundamental Concept b. Understanding the ocean is more than a matter of curiosity. Exploration, inquiry and study are required to better understand ocean systems and processes.

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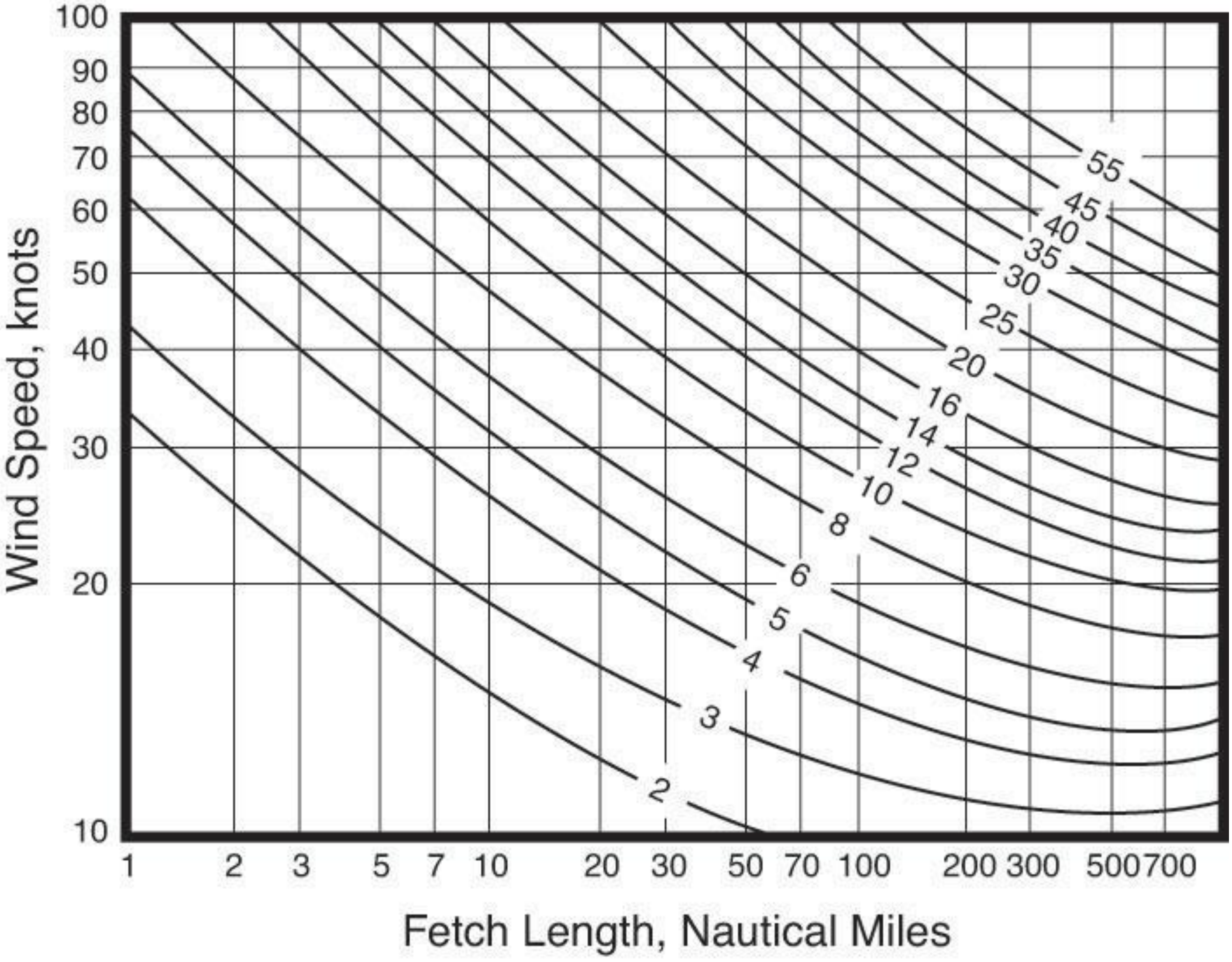
Student Worksheet - Problems on Winds, Waves, and Currents

Surface ocean waves are produced by winds. The height of these waves depends upon wind speed, the length of time the wind blows (duration) and the distance over which the wind blows (fetch). In 1952, Charles Bretschneider created a diagram that describes the relationship between these parameters and provides an easy way to predict the height of a wave produced by specific wind conditions. Figure 1 is an example of this kind of diagram (usually called a “Sverdrup-Munk-Bretschneider nomogram”). The y-axis describes Wind Speed; the x-axis describes Fetch Length; solid curved lines in the middle of the diagram show the Wave Height in feet (most Sverdrup-Munk-Bretschneider nomograms also include lines showing wave period and wind duration; these have been omitted from Figure 1 for clarity). When using the nomogram, be sure to match these lines with the correct labels!

Figure 1: Sverdrup-Munk-Bretschneider Nomogram



1. If a wind blows over a 10 nautical mile fetch at 21 knots, what would the resulting wave height be?
2. What would cause the larger increase in wave height for conditions in the preceding question: increasing the wind speed by 60 knots or increasing the fetch length by 60 nautical miles?
3. What would be the minimum fetch over which a 60 knot wind would have to blow to produce a wave 10 feet high?
4. There are a variety of ways to measure the velocity of a current. One of the oldest and simplest methods is to use a “drifter,” which can be any floating object (an ideal drifter is one that is not affected by wind; glass bottles partially filled with sand are a traditional type of drifter). To measure current velocity, an observer places the drifter into the water, measures the amount of time the drifter takes to move a known distance, and notes the direction of the drifter’s motion (since velocity is a vector quantity, and has dimensions of direction as well as speed). Next, the observer finds the speed of the current by dividing the distance the drifter traveled by the time it took to travel that distance. The

speed of the drifter combined with the direction in which it moved is the current’s velocity.

Suppose a drifter is released near Charleston, SC from a research vessel whose position is 32°23’15” North latitude, 79°12’33”West longitude, at 0915 eastern standard time (EST) on May 11, 2004. A sailing yacht recovers the drifter at 1930 EST on May 17, 2004 in position 39°56’23” North latitude, 73°44’35” West longitude. What is the estimated velocity of the current that transported this drifter? In this case, it is sufficient to describe the direction component of the velocity vector as north, northeast, east, southeast, south, southwest, west, or northwest. State the speed component of the vector in knots (nautical miles per hour). [Hint: You can use the calculator at http://www.chemical-ecology.net/java/lat-long.htm to find the distance between two points whose latitude and longitude are known.]

If you would like to have a map of the area covered by the drifter, visit the Marine Geoscience Data System Web site (http://www.marine-geo.org/tools/maps_grids.php). Enter the latitude and longitude boundaries for the area you want the map to cover, then click on the “Map” button. In this case you would enter 40° as the northern boundary; -80° as the western boundary (note that longitudes west of the prime meridian are assigned a negative value, while longitudes east of the prime meridian are positive); -73° as the eastern boundary; and 32° as the southern boundary. The map will show the elevation (or depth) of Earth’s surface in the included area. You can download the map using the “Save Image As . . ” function of your Web browser.

5. Suppose an amateur oceanographer in Oregon releases a drift bottle from position 46°13’56” North latitude, 125°47’12” West longitude, at 1140 Pacific standard time (PST) on August 6, 2005. At 1435 PST on August 20, 2005, the bottle is found floating between the islands of Santa Cruz and Santa Rosa in Channel Islands National Park at 34°00’23” North latitude, 120°00’10” West longitude. Estimate the velocity of the current that transported this drifter. Describe the direction component of the velocity vector as north, northeast, east, southeast, south, southwest, west, or northwest, and state the speed component of the vector in centimeters per second.

   You can use the Marine Geoscience Data System Web site (http://www.marine-geo.org/tools/maps_grids.php) to generate a map as described above. Enter 47° as the northern boundary; -126° as the western boundary; -120° as the eastern boundary; and 34° as the southern boundary.

6. The deflection of moving objects caused by Earth’s rotation is called the Coriolis effect. Acceleration due to the Coriolis effect always acts at right angles to the direction of the velocity vector, and has a magnitude of

$$(2 \bullet w \bullet v \bullet \sin f) \text{ cm/sec2}$$

where w is the angular velocity of Earth, v is the velocity of the moving object, and f is the latitude in degrees. Since the angular velocity of Earth is about 7.29 x 10-5 radians/sec, acceleration due to the Coriolis effect is about

(1.5 x 10-4 • v • sin f) cm/sec2

(note that radians have no units). What does this equation suggest about the magnitude of the Coriolis acceleration at the equator?

7. Suppose a soccer player in Tijuana, Mexico kicks a soccer ball with a velocity of 10 meters per second. What is the effect of the Coriolis acceleration on the ball?
8. Given the results of the preceding question, why is Coriolis acceleration significant to the circulation is the atmosphere and ocean?

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