The Galápagos Rift Expedition 2011

Inside *Okeanos Explorer*: Doppler Speed Log

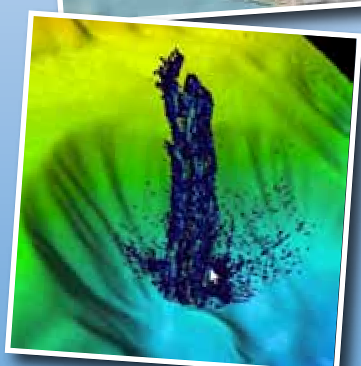


Image captions/credits on Page 2.

lesson plan

Focus
Doppler effect and speed estimation

Grade Level
9-12 (Physical Science/Physics)

Focus Question
How can ocean explorers use the Doppler effect to estimate a ship's speed?

Learning Objectives
- Students will explain the Doppler effect.
- Students will describe how a Doppler speed log is used to estimate *Okeanos Explorer's* speed while underway.

Materials
- ❑ Copies of *Doppler Speed Log Worksheet,* one for each student group

Audio-Visual Materials
- ❑ None

Teaching Time
One or two 45-minute class periods

Seating Arrangement
Classroom style or groups of 3-4 students

Maximum Number of Students
32

Key Words
Doppler effect
Doppler speed log
Okeanos Explorer

Background Information
Explanations and procedures in this lesson are written at a level appropriate to professional educators. In presenting and discussing this material with students, educators may need to adapt the language and instructional approach to styles that are best suited to specific student groups.

Note: This lesson is focused on how a physical phenomenon—the Doppler effect—is used in navigation systems aboard the *Okeanos Explorer*. In the summer of 2011, the ship's state-of-the-art exploration capabilities were applied to a search for undiscovered hydrothermal vent ecosystems around the Galápagos Spreading Center. Because hydrothermal vents provide an interesting context for instruction, the following section provides background information about these systems that educators may wish to include in addition to information about the Doppler effect and Doppler speed logs.

Port view of the *Okeanos Explorer*.
http://oceanexplorer.noaa.gov/okeanos/media/slideshow/gallery/ex2010/hires/port_view_hires.jpg

On August 13, 2008, the NOAA Ship *Okeanos Explorer* was commissioned as "America's Ship for Ocean Exploration;" the only U.S. ship whose sole assignment is to systematically explore our largely unknown ocean for the purposes of discovery and the advancement of knowledge. To fulfill its mission, *Okeanos Explorer* uses an exploration strategy that involves three major activities:

- Underway reconnaissance;
- Water column exploration; and
- Site characterization.

Underway reconnaissance involves mapping the ocean floor and water column while the ship is underway, and using other sensors to measure chemical and physical properties of seawater. Water column exploration involves making measurements of chemical and physical properties "from top to bottom" while the ship is stopped. In some cases these measurements may be made routinely at pre-selected locations, while in other cases they may be made to decide whether an area with suspected anomalies should be more thoroughly investigated. Site characterization involves more detailed exploration of a specific region, including obtaining high quality imagery, making measurements of chemical and physical seawater properties, and obtaining appropriate samples.

Key technologies involved with this strategy include:

- Multibeam sonar mapping system;
- CTD and other electronic sensors to measure chemical and physical seawater properties; and
- A Remotely Operated Vehicle (ROV) capable of obtaining high-quality imagery and samples in depths as great as 6,000 meters.

A fourth technological capability that is essential to the *Okeanos Explorer* exploration strategy is advanced broadband satellite communication. This capability provides the foundation for "telepresence;" technologies that allow people to observe and interact with events at a remote location. Telepresence allows live images to be transmitted from the seafloor to scientists ashore, classrooms, newsrooms and living rooms, and opens new educational opportunities that are a major part of *Okeanos Explorer's* mission for advancement of

Images from Page 1 top to bottom:
An overview of the Galápagos Islands. They are produced by volcanic activity caused by magma upwelling at the Galápagos hotspot. Green to white indicates the coastline, outside this is below sea level. Image produced by Ken Macdonald using GeoMapApp courtesy of Lamont Doherty Earth Observatory.
http://oceanexplorer.noaa.gov/explorations/05galapagos/background/hotspots/media/Galapagos_IS_Topo_600.html

Multibeam image of Mendocino Ridge Plume taken with the Kongsberg EM302 multibeam bathymetric mapping system. Image courtesy INDEX-SATAL 2010 Expedition.
http://oceanexplorer.noaa.gov/okeanos/media/movies/mendocino_ridge_plume_video.html

Close-up imagery showing a type of gooseneck barnacle, shrimp and a scaleworm on Kawio Barat submarine volcano. Image captured more than 1,850 meters deep by the *Little Hercules* ROV on August 3, 2010. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.
http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/slideshow/ex_july_highlights/gallery/hires/barnacle_zoom_hires.jpg

Doug Jongeward, a highly skilled IT Specialist, works in the control room of the *Okeanos Explorer* managing the enormous amounts of video and data that is collected each day on board the ship. Image courtesy of NOAA *Okeanos Explorer* Program.
http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/hires/8_doug_jongeward_hires.jpg

The Sperry SRD 500 Doppler marine speed log on board the *Okeanos Explorer*. Image credit, Mel Goodwin, NOAA.

The NOAA Ship *Okeanos Explorer*

Formerly: USNS *Capable*
Launched: October 28, 1988
Transferred to NOAA: September 10, 2004
Commissioned: August 13, 2008
Class: T-AGOS
Length: 224 feet
Breadth: 43 feet
Draft: 15 feet
Displacement: 2,298.3 metric tons
Berthing: 46 (19 Mission/science)
Speed: 10 knots
Range: 9600 nm
Endurance: 40 days

Systems and Instrumentation:

Kongsberg EM302 Multibeam rated to 7,000 m
SBE 911plus CTD
ROVs -
- *Little Hercules* - 4,000 m depth rating; USBL tracking; depth, altitude, attitude/heading sensors; Seabird SBE 49 FastCat CTD; HD camera and HMI lights
- Camera platform with depth/altitude/heading sensors, HD camera and HMI lights.

Telepresence

Operations:

Ship crewed by NOAA Commissioned Officer Corps and civilians through NOAA's Office of Marine and Aviation Operations; Mission equipment operated by NOAA's Office of Ocean Exploration and Research

For more information, visit http://oceanexplorer.noaa.gov/okeanos/welcome.html.

knowledge. In addition, telepresence makes it possible for shipboard equipment to be controlled by scientists in shore-based Exploration Command Centers (ECCs). In this way, scientific expertise can be brought to the exploration team as soon as discoveries are made, and at a fraction of the cost of traditional oceanographic expeditions.

In addition to these exploration technologies, the *Okeanos Explorer* is equipped with numerous other devices that contribute to the precise navigation of the ship. One such device is the Sperry SRD 500 Doppler marine speed log. In this lesson, students investigate the Doppler Effect, and how it is used aboard *Okeanos Explorer* to determine the ship's speed.

About Hydrothermal Vent Ecosystems and Ocean Explorer Expeditions to the Galapagos Rift

On Feb. 17, 1977, scientists exploring the seafloor near the Galápagos Islands made one of the most significant discoveries in modern science: large numbers of animals that had never been seen before were clustered around underwater hot springs flowing from cracks in the lava seafloor. Similar hot springs, known as hydrothermal vents, have since been discovered in many other locations where underwater volcanic processes are active.

These processes are often associated with movement of the tectonic plates, which are portions of the Earth's outer crust (the lithosphere) about 5 km thick, as well as the upper 60 - 75 km of the underlying mantle. These plates move on a hot flowing mantle layer called the asthenosphere, which is several hundred kilometers thick. Heat within the asthenosphere creates convection currents (similar to the currents that can be seen if food coloring is added to a heated container of water). Movement of convection currents causes tectonic plates to move several centimeters per year relative to each other.

Where tectonic plates slide horizontally past each other, the boundary between the plates is known as a transform plate boundary. A well-known example of a transform plate boundary is the San Andreas Fault in California. View animations of different types of plate boundaries at: http://www.seed.slb.com/flash/science/features/earth/livingplanet/plate_boundaries/en/index.html.

When tectonic plates collide more or less head-on, the boundary between the plates is known as a convergent plate boundary. When two continental plates collide, they may cause rock to be thrust upward at the point of collision, resulting in mountain-building (the Himalayas were formed by the collision of the Indo-Australian Plate with the Eurasian Plate). When an oceanic plate and a continental plate collide, the oceanic plate moves beneath the continental plate in a process known as subduction. Deep trenches are often formed where tectonic plates are being subducted, and earthquakes are common. As the sinking plate moves deeper into the mantle, fluids are released from the rock causing the overlying mantle to partially melt. The new magma (molten rock) rises and may erupt violently to form volcanoes, often forming arcs of islands along the convergent boundary. These island arcs are always landward of the neighboring trenches. View the three-dimensional structure of a subduction zone at: http://oceanexplorer.noaa.gov/explorations/03fire/logs/subduction.html.

Where tectonic plates are moving apart, they form a divergent plate boundary. At divergent plate boundaries, magma rises from deep within the Earth and erupts to form new crust on the lithosphere. Most divergent plate boundaries are underwater (Iceland is an exception), and form submarine mountain ranges called oceanic spreading ridges. While the process is volcanic, volcanoes and earthquakes along oceanic spreading ridges are not as violent as they are at convergent plate boundaries. View the three-dimensional structure of a mid-ocean ridge at: http://oceanexplorer.noaa.gov/explorations/03fire/logs/ridge.html.

Volcanic activity can also occur in the middle of a tectonic plate, at areas known as hotspots, which are thought to be natural pipelines to reservoirs of magma in the upper portion of the Earth's mantle. The volcanic features at Yellowstone National Park are the result of hotspots, as are the Hawaiian Islands.

The Galápagos region is geologically complex (see Figure 1 on page 5). The Galápagos Islands were formed by a hotspot called the Galápagos Mantle Plume (GMP), which continues to produce active volcanoes (the Sierra Negra volcano erupted on October 22, 2005). These islands are formed on the Nazca Plate, which is moving east-southeast. On the western side of the Nazca Plate, this motion produces a divergent plate boundary with the Pacific Plate. This boundary is called the East Pacific Rise. On the northern side of the Nazca Plate, just north of the Galápagos archipelago, another divergent plate boundary exists with the Cocos Plate. This boundary is known as the Galápagos Spreading Center (GSC). A convergent boundary exists on the eastern side of the Nazca Plate, which is being subducted beneath the South American and Caribbean Plates. This subduction has caused some of the oldest seamounts formed by the GMP to disappear beneath the South American and Caribbean Plates, so it is not certain exactly how long the GMP has been active in its present position (for additional discussion and illustrations about these processes, see "This Dynamic Earth" available online from the U.S. Geological Survey at http://pubs.usgs.gov/publications/text/dynamic.pdf).

When the movement of tectonic plates causes deep cracks to form in the ocean floor, seawater can flow into these cracks. As the seawater

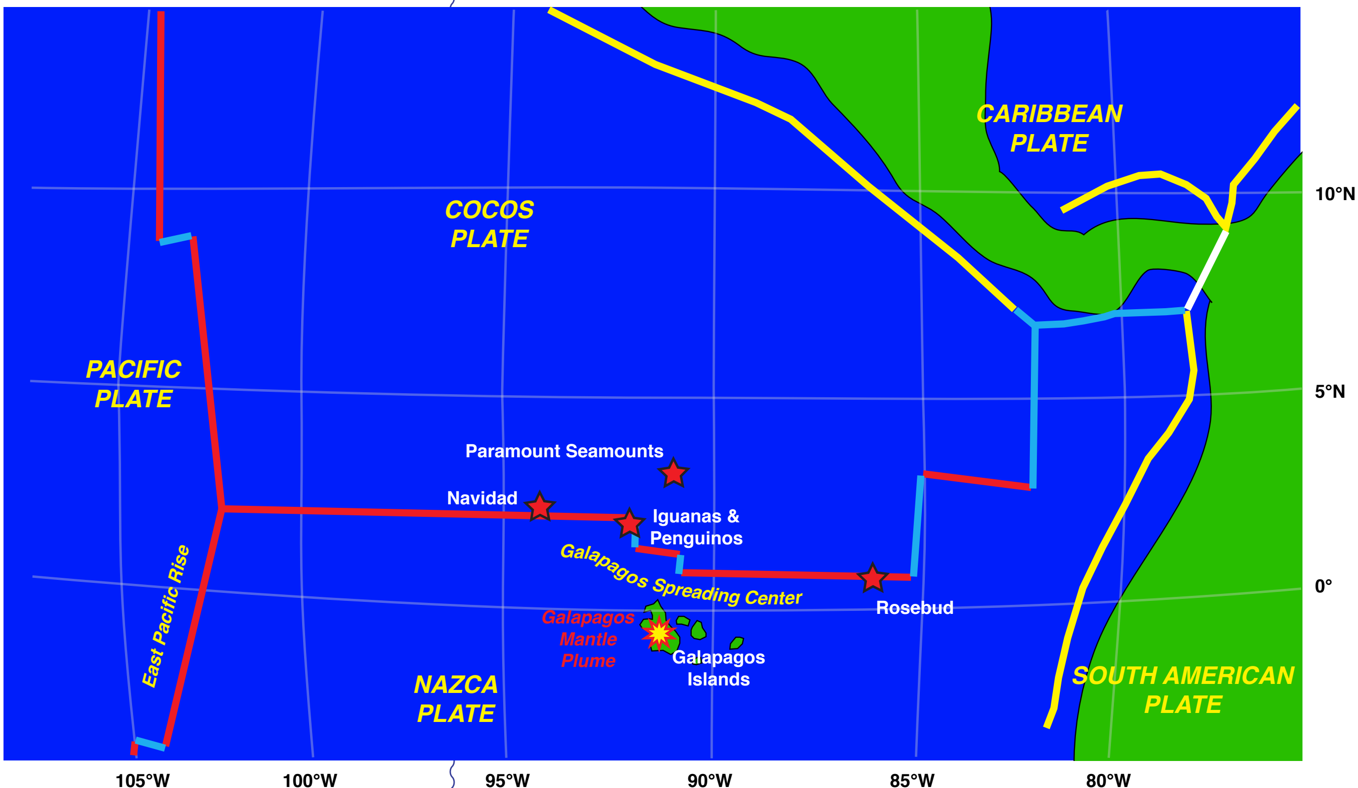
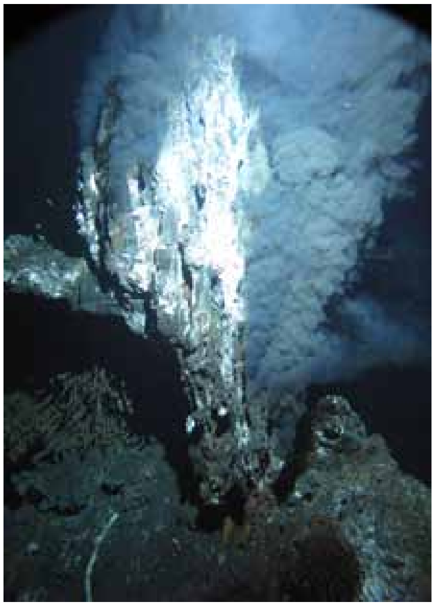


Figure 1. Galápagos Tectonic Setting. Red plate boundaries are divergent; yellow plate boundaries are convergent; blue plate boundaries are transform; white plate boundaries are undetermined. Navidad, Iguanas and Penguinos are locations where black smokers were discovered in 2005. Paramount Seamounts are an exploration target for Galápagos Rift Expedition 2011. For more information see the Galapagos Rift Expedition 2011 Expedition Education Module (http://oceanexplorer.noaa.gov/okeanos/explorations/ex1103/background/edu/edu.html. Credit: UNAVCO (tectonic boundaries); NOAA (hydrothermal sites)

moves deeper into the crust, it is heated by molten rock. As the temperature increases, sulfur and metals such as copper, zinc, and iron dissolve from the surrounding rock into the hot fluid. Eventually, the mineral-rich fluid rises again and erupts from openings in the seafloor. The temperature of the erupting fluid may be as high as 400°C, and contains hydrogen sulfide, which is toxic to many species. When the hot hydrothermal fluid meets cold (nearly freezing) seawater, minerals in the fluid precipitate. The precipitated mineral particles give the fluid a smoke-like appearance, so these vents are often called black smokers or white smokers, depending upon the types of minerals in the fluid. Precipitated minerals may also form chimneys that can be several meters high.

Hydrothermal vent communities and other deepwater chemosynthetic ecosystems are fundamentally different from other biological systems on Earth, and there are plenty of unanswered questions about the individual species and interactions between species found in these communities. Many of these species are new to science, and include primitive living organisms (Archaea) that some scientists believe may have been the first life forms on Earth. Although much remains to be learned, useful products have already been discovered in hydrothermal vent organisms. At present, almost all drugs produced from natural sources come from terrestrial plants, but marine animals produce more drug-like substances than any group of organisms that live on land. Some chemicals from microorganisms found around hydrothermal vents (the exopolysaccharide HE 800 from *Vibrio diabolicus*) are



A black smoker chimney named 'Boardwalk' emitting 644°F (340°C) hydrothermal fluids in the northeastern Pacific Ocean at a depth of 7,260 feet (2,200 m). Microbes grow within and on the surface of such mineral formations. Image courtesy of James F. Holden, University of Massachusetts, Amherst.
http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/hires/boardwalk_black_smoker_hires.jpg

Hydrothermal vents on Kawio Barat submarine volcano spew white smoke. Image captured more than 1,850 meters deep by the *Little Hercules* ROV on August 3, 2010. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.
http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/slideshow/ex_july_highlights/gallery/hires/white_plumes_hires.jpg

promising for the treatment of bone injuries and diseases, while similar chemicals may be useful for treating cardiovascular disease. Other examples of useful products include a protein from *Thermus thermophylus,* which is a microorganism that is adapted to live under extremely high temperature conditions near hydrothermal vents. One of these adaptations is the protein Tth DNA polymerase that can be used to make billions of copies of DNA for scientific studies and crime scene investigations. Another microorganism (genus *Thermococcus*) produces a type of protein (an enzyme called pullulanase) that can be used to make sweeteners for food additives.

In 2002 and 2005, NOAA's Office of Ocean Exploration and Research sponsored expeditions to the Galápagos Rift (see http://oceanexplorer.noaa.gov/explorations/02galapagos/welcome.html and http://oceanexplorer.noaa.gov/explorations/05galapagos/welcome.html for more information about these expeditions). A major objective of the 2002 expedition was to revisit a hydrothermal vent site named Rose Garden to investigate changes that might have occurred in the community of living organisms around the vent since it was discovered in 1977. Scientists found that significant changes had indeed taken place: Rose Garden had completely disappeared! In its place was a fresh sheet of lava that had apparently buried the vent and all of the surrounding organisms. About 300 meters away, a new vent field (which the scientists named Rosebud) was discovered with typical hydrothermal vent species beginning to colonize cracks in recently-formed lava. These discoveries underscored a growing awareness that the deep ocean environment can change much more quickly than was previously believed. The 2005 expedition focused on a portion of the GSC that had never been explored for hydrothermal vents. Scientists hoped that they would find black smokers, because at that time high temperature (several hundred degrees C) vents had not been found in the Galápagos region; only vents whose temperatures were less than 50°C. Using chemical and physical clues, explorers eventually made the first discovery of black smokers on the Galápagos Rift!

These discoveries set the stage for the Galápagos Rift Expedition 2011, which will use the state-of-the-art exploration capabilities of the NOAA Ship *Okeanos Explorer* to obtain detailed information about the biology and geology of Galápagos hydrothermal ecosystems, and determine whether different ecosystems are found at different vent fields within the Galápagos region.

Learning Procedure

1. To prepare for this lesson:
   (a) Review the *Doppler Speed Log Worksheet*.
   (b) You may also want to review this applet illustrating the Doppler effect:
   http://lectureonline.cl.msu.edu/~mmp/applist/doppler/d.htm

(c) If you want to include information about hydrothermal vent communities and the Galapagos Rift Expedition 2011, review introductory essays for the expedition at http://oceanexplorer.noaa.gov/okeanos/explorations/ex1103/welcome.html. You may also want to review the *Hydrothermal Vent Plume Inquiry Guide* (http://oceanexplorer.noaa.gov/explorations/10chile/background/edu/media/plume.pdf) which provides additional information and guides student inquiries about hydrothermal vents and plumes.

2. Briefly introduce the NOAA Ship *Okeanos Explorer*, which is the only U.S. ship whose sole assignment is to systematically explore Earth's largely unknown ocean for the purposes of discovery and the advancement of knowledge. If you want to include information about hydrothermal vents in this lesson, also introduce the Galapagos Rift Expedition 2011. Be sure students understand that discoveries of deep-sea chemosynthetic communities during the last 30 years are major scientific events that have changed many assumptions about life in the ocean and have opened up many new fields of scientific investigation. Present additional information about hydrothermal vents as desired.

3. Point out that in addition to specialized equipment needed for ocean exploration (CTD, multibeam sonar, remotely operated vehicle, telepresence capability), a modern ocean research vessel carries a variety of other instruments and equipment needed to navigate the vessel on Earth's ocean.

   Provide each student group with a copy of Part A of the *Doppler Speed Log Worksheet*, which is a review of basic concepts related to a ship log and to waves. When students have completed Part A of the *Worksheet*, lead a discussion of their answers, which should include:

   - The spacing between knots on a ship log needs to be 47 ft, 3 in. Knowing that one nautical mile is about 6,076 ft, and that there are 3,600 seconds in an hour, a speed of one nautical mile per hour is equal to 6,076 ft ÷ 3,600 sec = 1.687 ft/sec. So, at a speed of one nautical mile per hour, in 28 seconds a ship would move 28 sec • 1.687 ft/sec = 47.236 ft, which is about 47 ft, 3 in.

   - Waves are energy transport phenomena. When a wave appears to move, we are seeing a disturbance moving through a solid, liquid, or gaseous medium. The only thing that is actually transported from one place to another is the energy of the wave.

   - A sound wave is an example of a mechanical wave, which requires a medium through which energy can be transferred. You may want to point out that electromagnetic waves do not require a medium, because their energy is transferred as electric and magnetic fields. Electromagnetic waves can also be thought of as the motion of massless packets of energy called photons which move at the speed of light.

- Crest and trough are terms that identify the extremes of displacement experienced by a particle moving in a wave. The crest is maximum upward or positive displacement of a particle compared to its resting position. The trough is the maximum downward or negative displacement of a particle compared to its resting position.

- The frequency of a wave is the number of complete waves that pass a given point in a certain amount of time, usually one second. Counting the number of crests that pass a certain point in a measured amount of time is one way to find the frequency of the waves.

- The wavelength of a wave is the distance over which a wave's shape repeats. That is, the distance between two adjacent crests.

- The speed of a series of waves is equal to the frequency of the waves multiplied by their wavelength:

  $$C = W \bullet F$$

  where C is the speed of the wave, W is wavelength in meters per wave, and F is frequency in hertz (waves per second). The speed of sound waves depends upon the density of the medium through which the waves travel. Notice that at a constant speed, wavelength decreases as frequency increases.

- When we hear sound waves, changes in pitch are the result of changes in frequency; when the frequency of sound waves increases, we perceive this change as a higher pitch. Sound waves that we perceive as having a higher pitch have a shorter wavelength than sound waves with a lower pitch.

4. Perform a demonstration to illustrate the Doppler effect. Two common demonstrations are to tie a small buzzer onto a string approximately 2 m long, stand in the center of the classroom, and whirl it over your head. An alternative is to put the buzzer inside a soft ball (such as a tennis ball or nerf ball), and then toss it to various students. In both demonstrations, students should observe that the pitch of the buzzer appears to increase as it moves toward them, and decrease as it moves away.

Ask students what they think is happening to cause this effect. Students should recognize that the effect is observed when the source of sound is moving toward or away from the observer. Ask students to recall what happens to the frequency of the sound when the source is moving toward the observer. Remind them about the relationship between frequency and wavelength, and ask what happens to wavelength as the frequency increases. Since increased frequency means decreased wavelength, what could be happening to cause shorter wavelength? At this point, you may want the show the applet referenced in Step 1(c). Students should eventually infer that the sound waves are being compressed as the source of sound moves toward an observer, and that the waves are being extended as the source of sound moves away. Be sure students understand that the frequency of sound produced by the buzzer does not change, and that we perceive a different frequency because the position of the buzzer is changing relative to the observer. Tell students that this perceived change is called Doppler shift, or the Doppler effect, and remind them once again that this is a shift in the OBSERVED frequency and not a shift in the ACTUAL frequency at which the source vibrates. The Doppler shift is the difference between the frequency you hear when the sound source is stationary and what you hear when the sound source moves. If the sound source is stationary and you hear a frequency of 5 kHz, and then the sound source starts moving and you hear a frequency of 5.1 kHz, then the Doppler shift is 0.1 kHz.

5. Ask students to think of examples in which some environmental characteristic is measured by observing some effect of this characteristic, rather than directly measuring the characteristic itself. For example, temperature is a characteristic that results from the energy contained in materials. We rarely measure this energy directly. Instead, we measure some effect of this energy such as the expansion of a liquid in a thermometer. This is an example of a proxy, which is a person or thing that substitutes for another person or thing. Proxies are often used in scientific investigations when there is a known relationship between two things that makes it possible to measure one to predict the measurement of the other. Tree rings are another example: the number of tree rings is a proxy for the age of the tree, and the distance between rings can be a proxy for climatic conditions during the year when the rings were formed.

   Ask students to brainstorm ways that the Doppler effect might be used as a proxy to estimate the speed of a ship through the water. This activity may be done as a class discussion, or in groups of two to four students. For purposes of this assignment, students may assume that the ratio of the Doppler shift to the frequency of the sound source is equal to the ratio of the velocity between the sound source and the observer to the speed of sound in water:

$$Fd / Fs = V / C$$

where Fd is the Doppler shift frequency, Fs is the frequency of the sound source when nothing is moving, V is the relative velocity between the sound source and the observer (m/sec), and C is the speed of sound (m/sec). So, if the observer is stationary, the ship's speed could be determined as:

$$V = (Fd / Fs) \bullet C$$

After brainstorming, discuss students' ideas. Guide this discussion as necessary to establish the idea that if we have:

- A sound source on a ship whose frequency is known;
- Something in the water that can reflect sound from this source;
- A way to listen to echoes from the sound reflector; and
- A way to measure the frequency of the echoes

then we can measure the Doppler effect as the difference between the frequency of the source sound and the frequency of the echoes, and use this measurement to estimate the ship's speed.

Students should realize that this situation is different from the buzzer demonstration. In the demonstration, sound travelled from the source to the observer, and the Doppler shift is

$$Fd = Fs \bullet (V / C)$$

(from the first equation above).

But in case of ship speed measurements, sound travels from the source on the ship to a reflector, and then back to the ship. So the Doppler shift happens as the sound is travelling away from the ship, and then again as the echo travels to the ship. So the Doppler shift is doubled, and the equation must be changed to:

$$Fd = 2 \bullet Fs \bullet (V/C)$$

and

$$V = [Fd / (2 \bullet Fs)] \bullet C$$

6. Provide each student group with a copy of Part B of the *Doppler Designs Worksheet*. If time permits, you may want to have students create and present their projects to explain the Doppler effect. Prior to these presentations, discuss students' answers to questions in Part B:
   - In the ocean, the reflectors for our hypothetical instrument may be particles suspended in the water or the ocean floor. The Sperry SRD-500 Doppler Speed Log aboard the *Okeanos Explorer* is able to use the ocean floor as a reflector at depths of 200 meters or less.
   - If the sound source is oriented at an angle A to the horizontal as shown in Figure 1, then the vector component that is parallel to the ship's motion and the vector component parallel to the sound direction form two sides of a right triangle. Using trigonometry, the vector component parallel to the ship's motion is equal to

$$(\cos A) \bullet (\text{sound direction vector})$$

so
$$Fd = 2 \cdot Fs \cdot (V/C) \cdot \cos A$$
and
$$V = [Fd / (2 \cdot Fs \cdot \cos A)] \cdot C$$

- One way to compensate for the effect of vessel pitch would be to have a separate instrument that measured the angle of pitch, the use this information to apply a correction to the Doppler shift. Since the degree of pitch changes constantly, this could get pretty complicated. In practice, Doppler speed logs use two sound beams, one transmitted ahead of the ship and the other transmitted astern. This is called a Janus configuration after the Roman god who had two faces that were able to see into the future as well as the past. When the ship pitches, the angle of pitch affects both beams, but in opposite directions (see Figure 2). So when the Doppler shift estimates from the two beams are combined, the effect of pitch is cancelled out. The Sperry SRD-500 Doppler Speed Log aboard the *Okeanos Explorer* uses four sound beams, and is capable of measuring forward and backward speed, as well as side-to-side speed.

The BRIDGE Connection

www.vims.edu/bridge/ – Click on "Ocean Science Topics" in the menu on the left side of the page, then "Habitats" then select "Deep Ocean" for activities and links about deep ocean ecosystems.

The "Me" Connection

Have students write a brief essay describing at least three ways in which they make personal use of proxies to obtain information about their environment.

Connections to Other Subjects

Mathematics, Earth Science

Assessment

Students answers to *Worksheet* questions and class discussions provide opportunities for assessment.

Extensions

1. Visit the *Okeanos Explorer* Digital Atlas (http://www.ncddc.noaa.gov/website/google_maps/OkeanosExplorer/mapsOkeanos.htm) and Web page (http://oceanexplorer.noaa.gov/okeanos/welcome.html) for reports, images, and other products from *Okeanos Explorer* cruises.
2. See http://www.astrocappella.com/doppler.shtml for a musical explanation of the Doppler effect in astronomy, and a great example of using fine arts to explain science!

Multimedia Discovery Missions

http://oceanexplorer.noaa.gov/edu/learning/welcome.html – Click on the links to Lessons 1, 5, and 6 for interactive multimedia presentations and Learning Activities on Plate Tectonics, Chemosynthesis and Hydrothermal Vent Life, and Deep-Sea Benthos.

Other Relevant Lesson Plans from NOAA's Ocean Exploration Program

Tools of Exploration – Remotely Operated Vehicles
(from the INDEX-SATAL 2010 Expedition)
http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/edu/media/multibeam.pdf

Focus: Technology for deep ocean exploration: Remotely Operated Vehicles (Earth Science/Physical Science)

Students describe systems and capabilities of science-class remotely operated vehicles, typical applications and limitations of imagery obtained with ROVs, and use ROV imagery to make inferences about deep ocean habitats.

To Explore Strange New Worlds
(Grades 7-8; adaptations for Grades 5-6 & 9-12) (from the *Okeanos Explorer Education Materials Collection, Volume 2: How Do We Explore?*)
http://oceanexplorer.noaa.gov/okeanos/edu/lessonplans/media/hdwe_78_toexplore.pdf

Focus: Strategies for exploring unknown areas on Earth (Life Science/Physical Science/Earth Science)

Students describe requirements for explorations of unknown areas on Earth; discuss factors that influenced exploration strategies of the Lewis and Clark and *Challenger* Expeditions; describe the overall exploration strategy used aboard the NOAA Ship *Okeanos Explorer*; and describe how fractal geometry models natural systems, and how scale influences exploration strategy and results.

Through Robot Eyes
(from the *Okeanos Explorer Education Materials Collection, Volume 2: How Do We Explore?*)
http://oceanexplorer.noaa.gov/okeanos/edu/lessonplans/media/hdwe_912_roboteyes.pdf

Focus: Image analysis (Physical Science/Technology)

Students describe typical applications and limitations of imagery obtained with remotely operated vehicles (ROVs); demonstrate how lasers may be used to calibrate images for size and distance measurements; and analyze ROV imagery from the *Okeanos Explorer* to make inferences about deep ocean habitats.

The Ridge Exploring Robot
(from the INSPIRE: Chile Margin 2010 Expedition)
http://oceanexplorer.noaa.gov/explorations/10chile/background/edu/media/robot.pdf

Focus: Autonomous Underwater Vehicles/Marine Navigation (Earth Science/Mathematics)

Students explain a three-phase strategy that uses an autonomous underwater vehicle (AUV) to locate, map, and photograph previously undiscovered hydrothermal vents, design a survey program to provide a photomosaic of a hypothetical hydrothermal vent field, and calculate the expected position of the AUV based on speed and direction of travel.

Reduced Fare
(from the INSPIRE: Chile Margin 2010 Expedition)
http://oceanexplorer.noaa.gov/explorations/10chile/background/edu/media/reducedfare.pdf

Focus: Deep-Sea Reducing Environments (Life Science)

Students describe oxidation and reduction, explain the meaning of "reducing environment," give at least three examples of deep-sea reducing environments, demonstrate a flow of electric current produced by a redox reaction.

The Chemosynthetic Cafe
(from the INSPIRE: Chile Margin 2010 Expedition)
http://oceanexplorer.noaa.gov/explorations/10chile/background/edu/media/cafe.pdf

Focus: Biochemistry of hydrothermal vents (Life Science)

Students compare and contrast food web energy sources in hydrothermal vent and aerobic environments, and will use models to explain the overall chemistry of autotrophic nutrition.

The Big Balancing Act
(from the New Zealand American Submarine Ring of Fire 2005 Expedition)
http://oceanexplorer.noaa.gov/explorations/05fire/background/edu/media/rof05_balancing.pdf

Focus: Hydrothermal vent chemistry at subduction volcanoes (Chemistry/Earth Science)

Students define and describe hydrothermal circulation systems, explain the overall sequence of chemical reactions that occur in hydrothermal circulation systems, compare and contrast "black smokers" and "white smokers" and make inferences about the relative significance of these systems to ocean chemical balance compared to terrestrial runoff from data on chemical enrichment in hydrothermal circulation systems.

Hydrothermal Vent Challenge
(from the Submarine Ring of Fire 2006 Expedition)
http://oceanexplorer.noaa.gov/explorations/06fire/background/edu/media/ROF06.VentChallenge.pdf

Focus: Chemistry of hydrothermal vents (Chemistry)

Students define hydrothermal vents and explain the overall processes that lead to their formation; explain the origin of mineral-rich fluids associated with hydrothermal vents; explain how "black smokers" and "white smokers" are formed; and hypothesize how properties of hydrothermal fluids might be used to locate undiscovered hydrothermal vents.

Survivors on the Ocean Ridge
(from the 2002 Galapagos Rift Expedition)
http://oceanexplorer.noaa.gov/explorations/02galapagos/background/education/media/gal_gr9_12_l5.pdf

Focus: Inheritance of genetic traits and the effect of environmental pressures on the expressed traits (Life Science)

Students investigate the history of explorations of the hydrothermal vent systems; design a new shrimp species based on the introduction of a new gene form from migrating shrimp populations along the rift systems; assess the viability of the new shrimp species; and develop a model for the establishment of a population of a new species of shrimp.

Other Resources

The Web links below are provided for informational purposes only. Links outside of Ocean Explorer have been checked at the time of this page's publication, but the linking sites may become outdated or non-operational over time.

http://oceanexplorer.noaa.gov/okeanos/explorations/ex1103/welcome.html – Web site for Galápagos Rift Expedition 2011, with links to lesson plans, career connections, and other resources http://oceanexplorer.noaa.gov/okeanos/edu/welcome.html – Web page for the NOAA Ship *Okeanos Explorer* Education Materials Collection

http://celebrating200years.noaa.gov/edufun/book/welcome.html#book - A free printable book for home and school use introduced in 2004 to celebrate the 200th anniversary of NOAA; nearly 200 pages of lessons focusing on the exploration, understanding, and protection of Earth as a whole system

http://oceanexplorer.noaa.gov/explorations/02galapagos/welcome.html – Web site for the 2002 Galápagos Rift Expedition

http://oceanexplorer.noaa.gov/explorations/05galapagos/welcome.html – Web site for the 2005 GalAPAGoS: Where Ridge Meets Hotspot Expedition

Gordon, R. L. 1996. Acoustic Doppler Current Profiler Principles of Operation A Practical Primer. RD Instruments. San Diego, California; available online at http://comm-tec.com/Library/Technical_Papers/RDI/Broadband%20Primer.pdf

http://oceanexplorer.noaa.gov/explorations/02fire/logs/magicmountain/welcome.html – Links to virtual fly-throughs and panoramas of the Magic Mountain hydrothermal vent site on Explorer Ridge in the NE Pacific Ocean, where two tectonic plates are spreading apart and there is active eruption of submarine volcanoes

http://www.pmel.noaa.gov/vents/nemo/index.html – Web site for NOAA's New Millennium Observatory (NeMO), a seafloor observatory at an active underwater volcano near the spreading center between the Juan de Fuca and Pacific tectonic plates

http://www.nationalgeographic.com/xpeditions/lessons/07/g35/seasvents.html – National Geographic Xpeditions lesson plan, *We're in Hot Water Now: Hydrothermal Vents*, includes links to *National Geographic* magazine articles and video with an emphasis on geography and geographic skills

http://www.divediscover.whoi.edu/vents/index.html – Woods Hole Oceanographic Institution's Dive and Discover Web site about hydrothermal vents includes details about vent formation, education resources, and the story of the discovery of the first hydrothermal vent in 1977.

http://seawifs.gsfc.nasa.gov/OCEAN_PLANET/HTML/ps_vents.html – Article, *Creatures of the Thermal Vents* by Dawn Stover

http://www.courseworld.com/ocean/smokers.html – *Black Smokers and Giant Worms*, article on hydrothermal vent organisms

Corliss, J. B., J. Dymond, L.I. Gordon, J. M. Edmond, R. P. von Herzen, R. D. Ballard, K. Green, D. Williams, A. Bainbridge, K. Crane, and T. H. Andel, 1979. Submarine thermal springs on the Galapagos Rift. *Science* 203:1073-1083. – Scientific journal article describing the first submersible visit to a hydrothermal vent community

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
- Structure and properties of matter
- Motions and forces
- Interactions of energy and matter

Content Standard E: Science and Technology
- Abilities of technological design

Ocean Literacy Essential Principles and Fundamental Concepts

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

Fundamental Concept b. An ocean basin's size, shape and features (such as islands, trenches, mid-ocean ridges, rift valleys) vary due to the movement of Earth's lithospheric plates. Earth's highest peaks, deepest valleys and flattest vast plains are all in the ocean.

Essential Principle 2.
The ocean and life in the ocean shape the features of the Earth.

Fundamental Concept a. Many earth materials and geochemical cycles originate in the ocean. Many of the sedimentary rocks now exposed on land were formed in the ocean. Ocean life laid down the vast volume of siliceous and carbonate rocks.

Fundamental Concept e. Tectonic activity, sea level changes, and force of waves influence the physical structure and landforms of the coast.

Essential Principle 5.
The ocean supports a great diversity of life and ecosystems.

Fundamental Concept g. There are deep ocean ecosystems that are independent of energy from sunlight and photosynthetic organisms. Hydrothermal vents, submarine hot springs, and methane cold seeps rely only on chemical energy and chemosynthetic organisms to support life.

Essential Principle 7.
The ocean is largely unexplored.
Fundamental Concept a. The ocean is the last and largest unexplored place on Earth—less than 5% of it has been explored. This is the great frontier for the next generation's explorers and researchers, where they will find great opportunities for inquiry and investigation.
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.
Fundamental Concept d. New technologies, sensors and tools are expanding our ability to explore the ocean. Ocean scientists are relying more and more on satellites, drifters, buoys, subsea observatories and unmanned submersibles.
Fundamental Concept f. Ocean exploration is truly interdisciplinary. It requires close collaboration among biologists, chemists, climatologists, computer programmers, engineers, geologists, meteorologists, and physicists, and new ways of thinking.

Send Us Your Feedback

In addition to consultation with expedition scientists, the development of lesson plans and other education products is guided by comments and suggestions from educators and others who use these materials. Please send questions and comments about these materials to: oceanexeducation@noaa.gov.

For More Information

Paula Keener, Director, Education Programs
NOAA Office of Ocean Exploration and Research
Hollings Marine Laboratory
331 Fort Johnson Road, Charleston SC 29412
843.762.8818
843.762.8737 (fax)
paula.keener-chavis@noaa.gov

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Credit

Inside *Okeanos Explorer*: Doppler Speed Log
Doppler Speed Log Worksheet

Part A

1. A Little History

A fundamental piece of information needed to navigate any ship is how fast the ship is moving through the water. For several centuries, a ship's speed was determined with a device called a ship log (also called a Dutchman's log or chip log). This device consisted of a wedge-shaped piece of wood, weighted along one side and attached to a spool of rope so that when the wedge was thrown into the water it would orient at right angles to the rope. Knots were tied into the rope at regular intervals. To measure a ship's speed, the wedge was thrown into the water from the stern of the ship. The resistance of the wedge to water flow caused the rope to pull off of the spool as the ship moved forward. One sailor would hold the spool of rope, another sailor would start a sandglass filled with 28 seconds of sand; and a third man would count the knots as they passed over the stern. When the 28 seconds of sand expired, the time keeper would call out and the counting of knots would stop. The number of knots in the rope that were counted in 28 seconds was equal to the speed of the ship in nautical miles per hour. The speed of ships is usually stated in knots, which is equivalent to nautical miles per hour.

A nautical mile is based on the circumference of the earth at the equator, and is defined as one minute of longitude at the equator. There are 60 minutes in one degree, and 360 degrees around the entire Earth. Which means that there are 21,600 minutes of longitude around the equator. So, Earth's circumference at the equator is 21,600 nautical miles. One nautical mile is equal to about 6076 feet.

In order for the ship log to work as described above, the knots had to be spaced so that the number of knots that passed over the vessel's stern in 28 seconds was equal to the ship's speed in nautical miles per hour. What is the space between knots that would give this result? Hint: How much rope would run out in 28 seconds at a speed of one nautical mile per hour?

2. Some Basic Concepts About Waves

a. When we see a wave, something appears to be moving. Does this motion involve transporting something from one place to another?

b. Sound waves require a medium through which the wave can move. What is the name for this type of wave?

c. What do the terms crest and trough mean?

d. What is the frequency of a wave?

e. What is the wavelength of a wave?

f. What is the relationship between wavelength, frequency, and the speed of a series of waves?

g. When we hear sound waves, what causes changes in the pitch of the sound we hear?

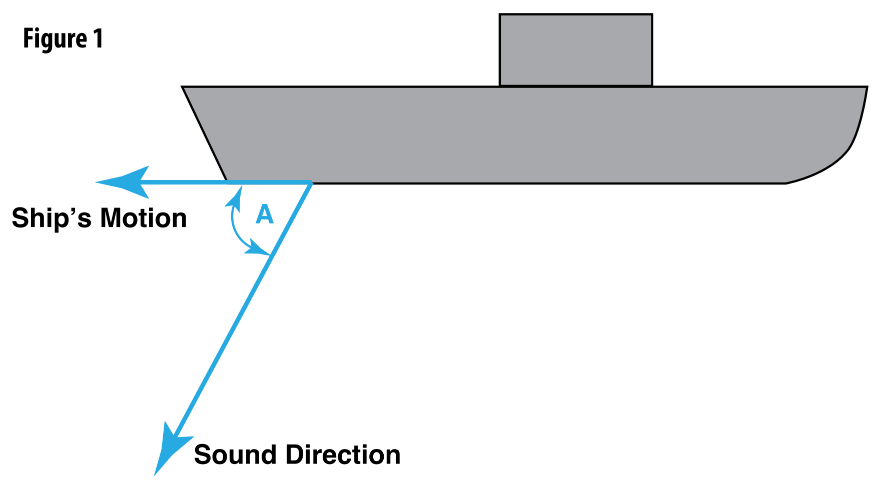
Inside *Okeanos Explorer*: Doppler Speed Log

Doppler Speed Log Worksheet

Part B

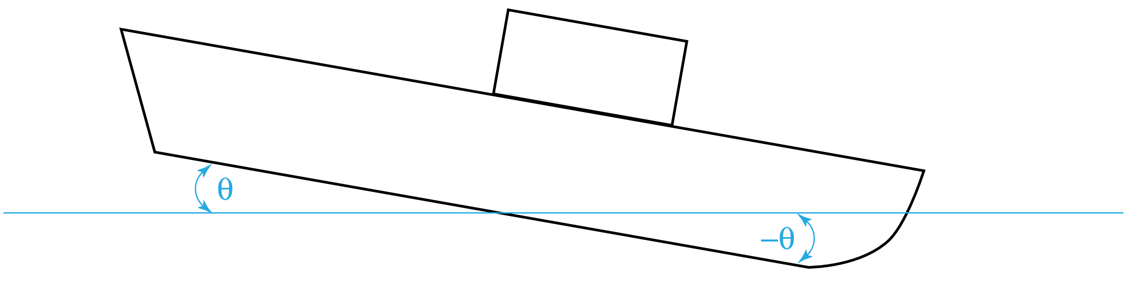
1. What objects in the ocean could be the reflectors for our instrument to measure ship speed using the Doppler effect?

Figure 1



2. Our formula that relates Doppler shift to a ship's speed is Fd = 2 • Fs • (V/C) But this formula will only work if surface that reflects the transmitted sound is directly ahead of the ship. Since this arrangement is not practical, the sound transmitter aboard the ship will have to point at an angle to the horizontal as shown in Figure 1. How could you modify the formula to account for the angular direction of the transmitted sound?

Figure 2



3. In heavy weather, ships tend to move up and down around an axis that passes from side to side through the middle of the ship. In other words, the bow goes up as the stern moves down, then the bow goes down as the stern moves up. This motion is called pitch or heave. This motion would change the angle shown in Figure 2, and would cause an incorrect estimate of the ship's speed. How could you compensate for this motion?

4. Design a project to explain how the Doppler effect works. This may be a physical demonstration, cartoon, musical product, or any other format suitable for presentation in your classroom.