AMERICAN METEOROLOGICAL SOCIETY

The Maury Project

OCEAN SOUND

TEACHER'S GUIDE

NSF

The Maury Project

This guide is one of a series produced by The Maury Project, an initiative of the American Meteorological Society and the United States Naval Academy. The Maury Project has created and trained a network of selected master teachers who provide peer training sessions in precollege physical oceanographic education. To support these teachers in their teacher training, The Maury Project develops and produces teacher's guides, slide sets, and other educational materials.

For further information, and the names of the trained master teachers in your state or region, please contact:

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Forward

This guide has been prepared to introduce fundamental understandings about the guide topic. This guide is organized as follows:

Introduction

This is a narrative summary of background information to introduce the topic.

Basic Understandings

Basic understandings are statements of principles, concepts, and information. The basic understandings represent material to be mastered by the learner, and can be especially helpful in devising learning activities and in writing learning objectives and test items. They are numbered so they can be keyed with activities, objectives and test items.

Activities

These are related investigations. Each activity typically provides learning objectives, directions useful for presenting and completing the activity and questions designed to reinforce the learning objectives.

Information Sources

A brief list of references related to the guide topic is given for further reading.

If we except the tides, and ... those that may be created by the wind, we may lay it down as a rule that all the currents of the ocean owe their origin to difference of specific gravity between sea water at one place and sea water at another; for wherever there is such a difference, whether it be owing to difference of temperature or to difference of saltiness, etc., it is a difference that disturbs equilibrium, and currents are the consequence.

Matthew Fontaine Maury
from The Physical Geography of the Sea. 1855.

Introduction: Ocean Sound

Marine scientists and many marine animals make extensive use of underwater sound because it can be extremely effective for sensing the ocean environment and communicating. Underwater sounds can travel long distances with relatively little loss in intensity, or loudness. This is especially true for low frequency sounds such as those made by whales, underwater earthquakes, ships, and submarines.

Sound travels rapidly through water, on average more than four times faster than through air. The ocean has physical properties which affect the speed of sound through water. The speed increases as temperature increases and as pressure increases. These properties vary with depth. Temperatures are greatest at the surface while pressures are greatest at the bottom. Since the speed of sound increases with increasing water temperature and pressure, underwater sound tends to travel faster near the surface and near the bottom. In between, there is a horizontal zone centered about 1000 meters below the surface, through which sound travels relatively slowly, but with especially small losses in intensity.

The reason for this is that sound waves tend to be guided into the slow speed zone and trapped within it. So sound waves are confined within the zone instead of spreading through the entire depth of the ocean. This means that sounds traveling within this zone can cross entire ocean basins and still be clearly detected. The guiding, or channeling, properties of this zone give it its name, the **Deep Sound Channel** (DSC), also called the **Sound Fixing and Ranging** (SOFAR) Channel.

The channeling occurs because a sound wave turns, or is refracted, when one part of the wave travels slower than another. Specifically, the wave turns toward the slower speed region. This wave turning is analogous to what happens when one side of a fast moving car runs off a smooth paved road onto a soft, sandy, or snowy, road shoulder. The car, like a wave, tends to turn itself toward the region in which it travels slower. This means toward the road shoulder for the car and toward the DSC for an ocean sound wave. This wave bending process confines sound waves to the DSC, guides them across the ocean, and makes the DSC a very effective zone of long distance sound transmissions. Obstacles such as land and underwater mountains, however, may block sounds traveling in the DSC.

Underwater microphones, called hydrophones, placed in the DSC to detect sound sources such as ships and submarines, are now being used to study natural noise sources including whales and underwater earthquakes. Some marine scientists are using sound transmitted in the DSC to investigate deep ocean currents and other features of ocean circulation. Other scientists are attempting to employ decade-long sound experiments in the DSC to determine if the temperature of the ocean is changing in response to variations in global climate.

Basic Understandings

Sound and Seawater

1. All sounds result from vibrations which are transmitted through a substance. In order for sound waves to be produced, there must be a **source** that initiates a mechanical disturbance and a **medium** through which it passes.

2. Sound is a form of energy transmitted through a substance by a regular alternation of pressure, consisting of successive compressions and decompressions of the medium. The more rapid the alterations, the higher the sound **frequency**.

3. Seawater transmits sound as waves of energy passed along by water particles vibrating back and forth in the direction of propagation.

4. Sounds of different frequencies travel through seawater with identical speeds. Lower frequency sounds travel farther because higher frequency sounds are more readily converted to heat and chemical energy by seawater.

5. On average, sound travels through seawater at about 1,500 meters per second. Sound travels through seawater more than four times faster than through air.

6. The speed of sound in seawater varies with differences in water temperature, pressure, and salinity. The speed of sound increases as temperature or pressure or salinity increases.

Sound Speed in the Ocean

1. Variations in the speed of sound in seawater are primarily determined by the combined or net effects of differences in temperature and water pressure. Salinity variations have a comparatively smaller, although measurable, effect.

2. Except at the high latitudes, the uppermost 1,000 meters of the ocean are generally characterized by warmest water at the surface and coldest below. Throughout this depth zone, temperature effects on the speed of sound are greater than those pro-duced by pressure. Consequently, highest sound speeds are found in the warmer water above and speeds decrease with increasing depths as the temperature drops.

3. Below the uppermost 1,000 meters of the ocean, there is little temperature variation with increasing depth. Here, the steadily increasing pressure has the dominating effect on the speed of sound. Consequently, the speed of sound increases with increasing depth from about 1,000 meters downward.

4. The plotting of sound speeds with depth produces a vertical **sound speed profile** which shows the combined effects of temperature and pressure on sound speed. Sound speed profiles can be used to predict the path of sound travel in the ocean.

Sound Paths

1. Sound travels outward in all directions from a source, unless reflected or refracted.

2. Sound waves striking surfaces such as the sea bottom or ocean surface can be reflected. Those returning directly to the source are called **echoes**.

3. Sound waves that pass at angles other than perpendicular to the boundary between regions in which sound speeds are different are bent, or refracted. Refraction occurs when the speeds of different parts of the same sound wave are slightly dif-ferent, thereby producing a change in the sound wave's direction. Refracted sound waves will always turn or bend towards the region exhibiting lower sound speeds.

4. When the vertical sound speed profile indicates that sound speed is decreasing with depth, all sound waves except those traveling vertically will curve downward.

5. When the vertical sound speed profile indicates that sound speed is increasing with depth, all sound waves except those traveling vertically will curve upward.

Deep Sound Channel

1. Sound speeds tend to increase upward from the 1,000 meter depth due to the higher water temperatures above this level and increase downward from the 1,000 meter depth due to the increase in pressure below this level in water exhibiting little temperature variation.

2. The depth zone centered at about 1,000 meters at which minimum sound speeds occur is called the **Deep Sound Channel (DSC)**.

3. Sound waves encountering the DSC at an angle other than vertical are refracted towards the region of slower sound speed.

4. Within the DSC, a downward moving sound wave approaching the lower boundary of the sound channel at an angle other than vertical is bent back upward because of increasing sound speed caused by increasing pressure. An upward moving sound wave approaching the upper boundary at an angle other than vertical is bent back downward because of increasing sound speed caused by increasing temperature.

5. Sound waves crossing through the DSC's minimum sound-speed level at an angle other than vertical can become trapped in the DSC as they curve in alternating upward and downward directions while spreading horizontally.

6. Because of its sound-wave guiding or channeling characteristics, the DSC transmits sounds great distances, sometimes for thousands of kilometers if not blocked by land or underwater obstacles.

Deep Sound Channel Research

1. Hydrophones placed in the DSC, which is also known as the **SOFAR** (sound fixing and ranging) **Channel**, have been used to detect and locate ships and submarines as well as natural noise sources including underwater earthquakes and whales.

2. By directing research ships to the site of sounds that accompany the eruption of submarine volcanoes, scientists can make detailed measurements of these eruptions and their effects on the sea floor and ocean waters.

3. Hydrophones in the DSC allow whales of some species to be tracked by listening to their distinctive voices. Such listening makes it possible to describe the distribution, abundance, and seasonal migration of these whale species throughout the ocean basins and to predict responses of whales to human activities.

4. The DSC is being used by scientists to study the slow flow of deep ocean currents by the long-term acoustical tracking of floats that are designed to be neutrally buoyant at prescribed depths.

5. Computer analysis of the changes in sound velocity between acoustic transmitters and receivers in the DSC enable scientists to obtain a three-dimensional image of the structure and movement of physical oceanographic features including water masses, fronts, and eddies. This process, in which sound pulses traveling through the water are timed to detect differences in water temperature and salinity, is called **acoustic tomography**.

6. Scientists are attempting to employ the DSC to determine if the temperature of the ocean is changing in response to variations in global climate. This is accomplished by initiating a loud sound into the DSC and measuring the time required for the sound wave to reach various remote listening stations. If the ocean is warming, an increase in the speed of sound in the DSC is expected to be detectable over a period of a decade or so.

Sound in the Slow Lane

Introduction

Underwater sounds are used by scientists and many marine animals to sense the environment and to communicate. Temperature, pressure, and salinity affect the transmission of sound in the ocean. The variations in these properties typically combine to produce a minimum sound speed at a depth of about 1,000 meters throughout a large part of the world ocean. At this depth, sound travels relatively slowly compared to the speed of sound through water at greater and lesser depths. The depth zone centered around this level of minimum sound speed is called the **Deep Sound Channel**. Sound traveling in this layer tends to be trapped and channeled, making this layer extremely effective in transmitting sound for thousands of kilometers throughout the ocean.

The following activity models the paths of sound waves in the Deep Sound Channel by the movement of playing pieces across a board divided into slow and fast lanes.

Materials

Photocopy of the *Playing Board* page, scissors, pencil.

Objectives

After completing this activity, you should be able to:

- Describe the effect of temperature, pressure, and salinity on the speed of sound in seawater.
- Describe the long range transmission of sound in the Deep Sound Channel.

Investigations

1. With scissors, cut off the lower portion of the *Playing Board* page along the dashed line. Carefully cut out the Playing Pieces A, B and C. The *Playing Board* depicts a vertical cross-section of the ocean with the middle unshaded Slow Lane approximating the zone of minimum sound speed in the Deep Sound Channel.

2. Place Playing Piece A in the starting position outlined on the *Playing Board*. The dashed arrows on the playing piece represent the distances sound travels in one unit of time. The longer sound arrow represents a (***faster***) (***slower***) speed and is positioned on the board in a (***slow***) (***fast***) lane. The shorter arrow denotes a (***faster***) (***slower***) speed and is located in a (***slow***) (***fast***) lane.

3. At the tip of each sound arrow, pencil a dot on the *Playing Board*. Draw a straight solid line connecting the two dots. Do <u>not</u> extend the line beyond the dots. Label the line with the move number (1). This line represents the position of the sound wave, which started on the Start Line, after one interval of time. For the next move, place the back edge of the same playing piece on the line you just drew on the board. Be sure the tails of the sound arrows are lined up with the penciled dots at the ends of the line you drew. Again pencil new dots on the board at the arrow tips. Draw a line connecting the two new dots and label it with the move number (2). Compare its orientation to the starting line and the line drawn after the first move. They demonstrate that the sound wave is turning (***<u>towards</u>***) (***<u>away from</u>***) the slow lane.

4. Repeat the procedure of moving the playing piece forward, marking dots, drawing lines and labeling with the move numbers. **When either sound arrow on the playing piece extends half or more across a lane boundary into a lower or higher speed lane, change to the other playing piece with two arrows to maintain the correct lane speeds for the sound arrows.**

5. Being sure to switch the moving pieces when necessary to maintain the correct lane speeds, move the appropriate playing piece and mark and label until the Finish Line is crossed.

6. The sequence of lines represents the path of a sound wave across the *Playing Board*. The path shows that as the playing piece moved, the sound it represented had a general tendency to turn (***<u>towards</u>***) (***<u>away from</u>***) the slow speed lane.

7. Place *Playing Piece B* in the starting position outlined on the playing board. Note that the positions of the sound arrows are the inverse of those on *Playing Piece A*. Based on what you have learned so far in this activity, your prediction is that as *Playing Piece B* is moved across the board, the sound it represents has a general tendency to turn (***<u>towards</u>***) (***<u>away from</u>***) the slow lane.

8. Check your prediction by moving *Playing Piece B* across the board from start to finish, marking dots, drawing lines, and labeling lines with move numbers.

9. Does sound starting from the Start Line reach the Finish Line in the shortest possible time by traveling along a straight line? To find out, place *Playing Piece C* in the slow-lane starting position marked “C” on the playing board. *Playing Piece C* represents a horizontally transmitted sound that undergoes no refraction. Move it across the board, marking and labeling dot positions with move numbers, until it crosses the finish line. Your investigation shows that the sound wave traveling in a straight line in the slow lane arrived at the finish line (***<u>before</u>***) (***<u>after</u>***) the sound waves that followed the longer paths you determined with *Playing Pieces A* and *B.*

Questions

1. On average, sound travels through seawater at about 1,500 meters per second, or more than four times faster than through air. The speed of sound is not constant throughout the ocean, but varies with differences in water temperature, pressure, and salinity. The speed of sound increases with increasing temperature, pressure, or salinity. The speed of sound decreases as temperature, pressure, or salinity (***increases***) (***decreases***).

2. Below the warm mixed surface layer of the ocean, there is a layer called the thermocline where the temperature decreases rapidly with depth. This layer extends down to about 1,000 m. In the thermocline, vertical temperature changes can be relatively large and variations in the speed of sound are dominated by temperature effects. Because this region has warmer water above and cooler water below, sound speeds (***decrease***) (***increase***) with increasing depth.

3. Below the uppermost 1,000 m of the ocean, there is less variation of temperature or salinity with depth. Pressure changes become the prime cause of sound speed variability. Because of the steadily increasing pressures as depth increases, sound speeds at depths below 1,000 m (***increase***) (***decrease***) with increasing depth.

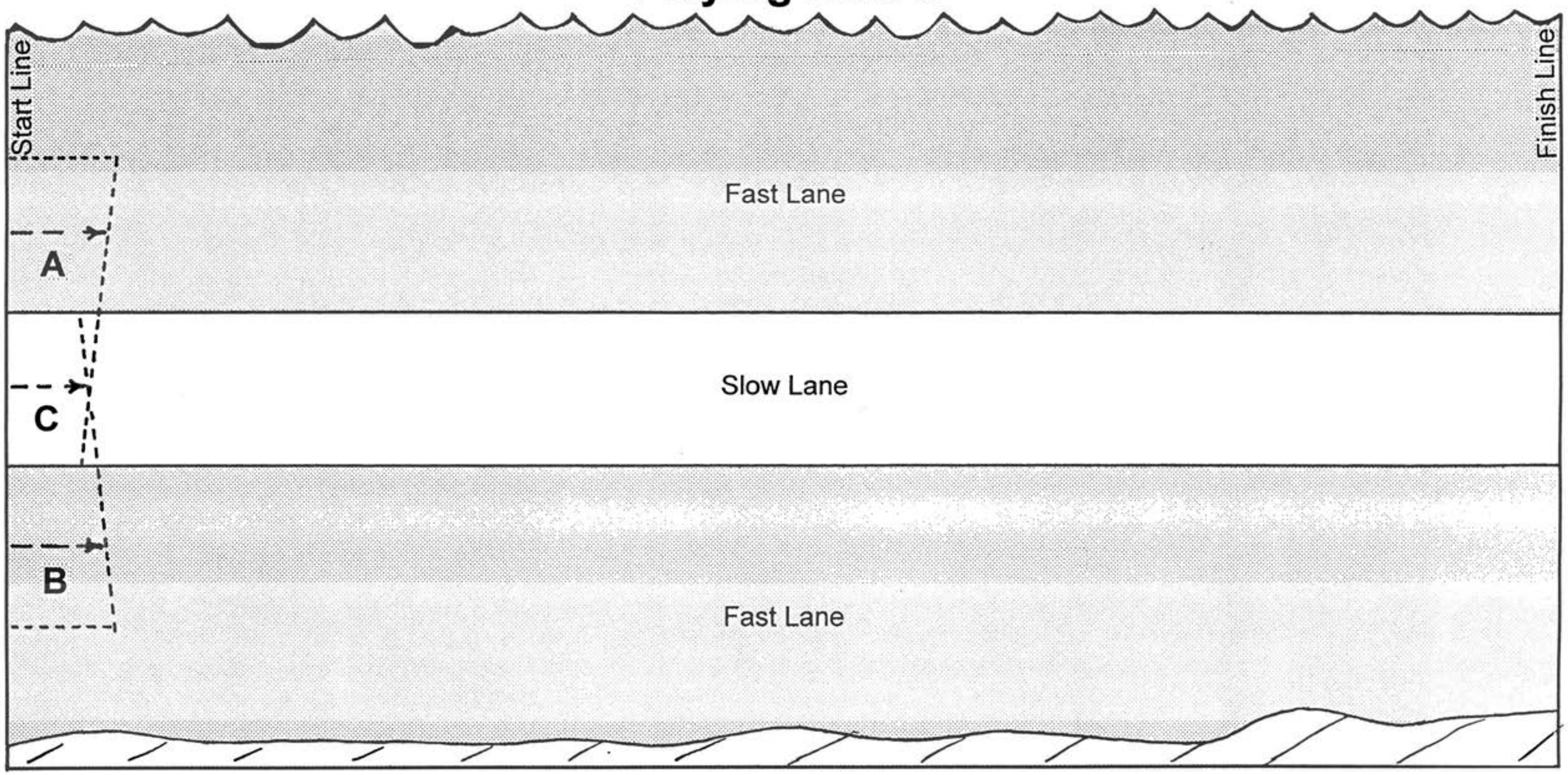
4. Sound speeds typically increase upward from the 1,000 m depth due to the warmer water above this level and increase downward from the 1,000 m depth due to increasing water pressure. Consequently, there is a layer of minimum sound speed, called the Deep Sound Channel (DSC), whose center is found in most ocean basins at about (***0 m***) (***1,000 m***) (***4,000 m***).

5. Sound waves that enter the DSC pass from a layer of faster sound speed into one of lower sound speed. If they enter the DSC at an angle other than vertical, the sound waves will be bent, or refracted, because the part of the waves in water with a faster sound speed moves more quickly than the part of the waves in water with a slower sound speed. Sound waves will bend, or refract, towards the layer exhibiting (***faster***) (***slower***) sound speed.

6. A downward moving sound wave approaching the lower boundary of the DSC at an angle other than vertical is bent back upward as the result of the increasing sound speed caused by increasing pressure. An upward moving sound wave approaching the upper boundary of the DSC at an angle other than vertical is bent back downward because of the increasing sound speed caused by increasing (***temperature***) (***pressure***).

7. Because of its sound wave guiding or channeling characteristics, the DSC is extremely effective in transmitting sound, sometimes for thousands of kilometers. Thus, it may be used to listen to the sounds of distant earthquakes, whales, ships, and submarines. The transmission of these sounds in the DSC may be blocked by obstacles such as continents and underwater (***mountains***) (***trenches***).

Playing Board

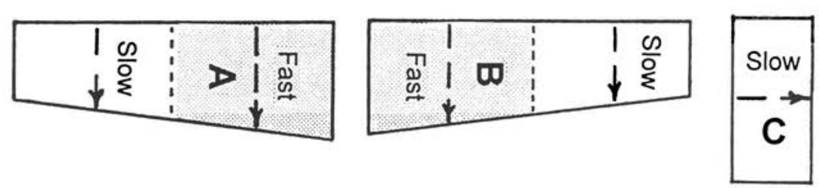


- - - - - - cut here - - - - - - cut here - - - - - - cut here - - - - - - cut here - - - - - -

Directions:

1. Using scissors, cut along dashed line above
2. Cut out playing pieces A, B, and C. Be careful to cut along the solid lines.

Playing Pieces



Extensions

A. Geometric Losses:

1. The loudness, or intensity, of an underwater sound decreases as the distance traveled increases. Under ideal conditions, sound energy from a point source spreads out uniformly in all directions in the shape of an expanding sphere. As the sphere expands, its surface area increases in direct proportion to the square of its radius. Thus, the spreading of sound energy follows the same "inverse square law" as does light from a point source. That is, its intensity is inversely proportional to the square of the distance traveled. What does doubling the distance traveled do to the sound intensity?

2. In the DSC, the top and bottom of the expanding sphere of sound are constrained by refractions, so the sound spreads out horizontally in the shape of an expanding cylindrical surface. The area of the cylindrical surface is directly proportional to its radius. Thus, the spreading loss for the emitted sound energy is directly proportional to the distance traveled. What does doubling the distance traveled do to the intensity?

3. Use what you have just learned about spreading losses to explain why sound can travel for great distances with limited loss in the DSC.

B. Where It was Heard:

1. In the early 1990's, an experiment was successfully conducted using the DSC to send a sound from a single source through all three major ocean basins. Assuming only straight-line sound travel without reflection, use a globe to find the land location where this sound had to originate to be "heard" in the North Atlantic, North Pacific, and North Indian Ocean.

2. If the sound in the previous question traveled at the average speed of sound (about 1500 m/sec) in seawater, how long did it take to reach detecting hydrophones near coastal Oregon, a distance of about 20,000 kilometers, or half the circumference of the Earth away?

C. Global Sense:

1. Scientists are attempting to employ the DSC to determine if the temperature of the ocean is changing over time and, if so, whether or not it is in response to variations in global climate. Data will be collected by periodically creating a loud sound in the DSC and measuring the time required for the sound wave to reach various remote listening stations. Assuming everything else remains the same

or has been accounted for, what is happening to the temperature of the ocean if the travel time decreases?

2. These ocean temperature studies were delayed due to concern that the sound signals might interfere with marine animals. If there are little data available on the effects of this sound on marine animals, what might be the next step in this investigation?

D. Echo First:

1. In Investigation number 9 about sound waves traveling in the DSC, you found that sound waves traveling horizontally along the central axis of the DSC travel the least distance but at the slowest speed. They arrive later than sound waves taking longer weaving paths at generally faster speeds. Since the loudness of the sound decreases as the distance traveled increases, would the loudest sounds arrive first or last?

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